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The State of Florida's Estuaries and Future Needs in Estuarine Research

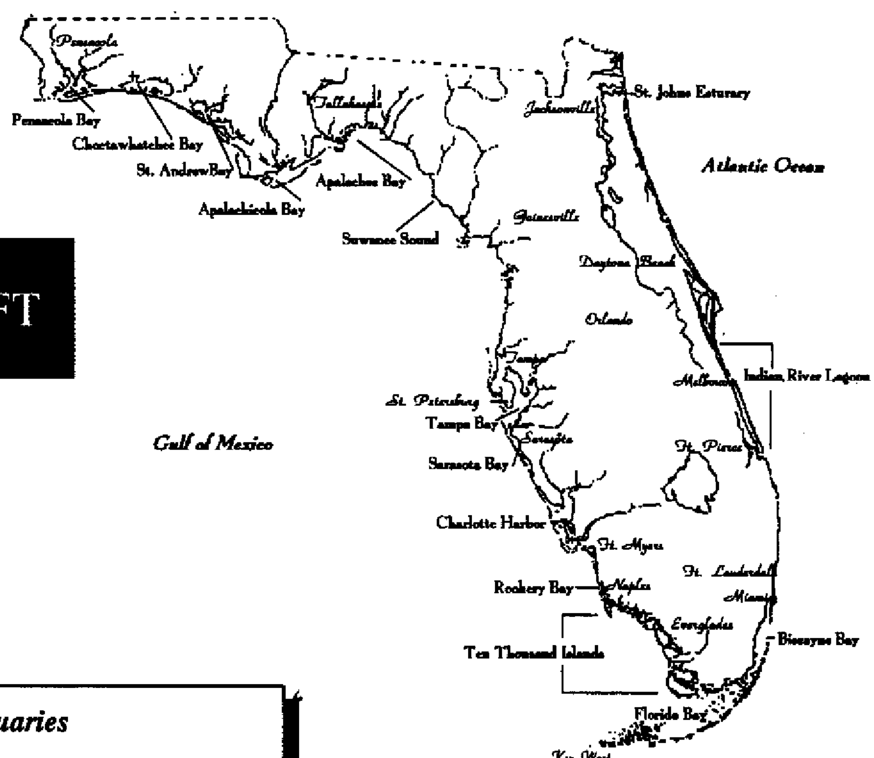
Part 1. A Synopsis of Florida's Estuarine Resources with Recommendations for their Conservation and Management

Prepared by

G.S. Kleppel

and

The Estuarine Theme Panel



REVIEW DRAFT

Featured Estuaries

St. Johns River	Charlotte Harbor
Indian River Lagoon	Tampa Bay
Biscayne Bay	Suwannee River
Florida Bay	Apalachicola Bay
Rookery Bay	Pensacola Bay

Sea Grant Florida

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The State of Florida's Estuaries and Future Needs in Estuarine Research

Part 1. A Synopsis of Florida's Estuarine Resources with Recommendations for their Conservation and Management

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Executive Summary

This report is the result of a project to describe the current status or condition of Florida's estuaries. It will be used to develop a research agenda, aimed principally at academe, for the Florida Sea Grant Program. The goal is to contribute to the understanding and management of the state's estuarine resources. In the fall of 1994, Drs. J. Cato and W. Seaman of the University of Florida Sea Grant College Program began discussions with Dr. Kleppel of Nova Southeastern University on the elements of such a project. It was decided that development of a research theme area on estuaries would require interdisciplinary expertise, the insight of academic scientists from around the state, and a retrospective analysis that would describe what is currently known about estuaries within Florida. The simultaneous request for proposals from the Florida Coastal Management Program to develop a report on the current state of Florida's estuaries provided the opportunity to combine the Sea Grant and Coastal Management Project objectives into a single project that through mutual funding would be capable of addressing the needs of both agencies and of identifying and seeking solutions to mutual problems.

It was clear that a project of this scope could not be pursued by a single individual trained in a single discipline. To address the need for interdisciplinary insight, an Estuary Theme Area (ETA) Panel was convened. The ETA Panel is composed of academicians (Sea Grant is a program aimed at academics) who have made significant contributions to estuarine and environmental research in Florida. The purpose of the ETA Panel was to provide guidance and expertise on the multi-dimensional aspects of describing, studying and managing estuaries. The ETA Panel met in Gainesville in July 1995 to discuss the central issues involved in developing a research theme area focused on generating data and theoretical products to facilitate the development of resource management strategies.

The results of this project will be disseminated in two volumes. This document is the first volume. It provides a retrospective examination of Florida's estuaries. In the early planning of this project, we considered developing a data matrix that described "what we know" about the estuaries. The locations in the matrix where data were needed would be considered research needs. This approach proved unsuccessful due to the variety of ways that data were collected, the issues that were described and the immensity and complexity of the data set. Further, Florida's estuaries are composed of numerous unique microcosms. For instance, the Indian River Lagoon is divisible into 6 segments. Each segment is divisible into as many as 70 sub-basins. Although one can describe, in a general way, the characteristics of the six segments, attempts to quantify and tabulate data on most parameters, would result in a gross oversimplification of the system and would trivialize the efforts of the researchers and managers. Short of an effort to accumulate data for a GIS type matrix, the original concept of a data matrix was clearly beyond the scope of this project.

There was, however, a different problem that emerged as data were collected, compressed, synthesized and interpreted. It was evident that no overarching conceptual framework existed to guide either research or management in Florida, with respect to the estuaries. Thus, goals existed at the local level as a result of regulations at higher levels. No effort had been made, however, to ascertain a reasonable or logical answer to the question, "What should Florida's estuaries look like?" The implications of this question, are enormous. At present, a systematic strategy for addressing it does not exist. The development of a framework to understand and address this question has become an important theme of this project.

Thus, this report provides a retrospective analysis of Florida's estuaries, and attempts to formulate both the ideological and practical context to deal with future impacts and challenges to estuarine resources. Although our aim is ultimately to develop a decidedly academic research product, the intended audience of this volume of the report (Part 1) is very broad. We have consciously minimized jargon and technical detail to encourage non-scientists and non-academics to examine our work.

The second volume of this report, the describes a research program that, through the guidance of Florida Sea Grant, in coordination with other agencies and programs in the state, will be focused on the question of how to balance the frequently inconsistent concepts of estuary structure and function with resource utilization. The ideas presented in this volume will be debated both by researchers and non-researchers. Ultimately, the research theme area that is generated from this debate will guide policy development aimed at stimulating productive and sustainable use of Florida's estuarine resources.

"The only constant is change..."

Heraclitus
circa 500 BC

I. Project Summary

This report, the result of a year-long examination of the literature and other sources of information on Florida's estuaries, seeks to describe the current status of these systems from natural, historical and socio-demographic perspectives. The study focused on ten estuaries on the Atlantic and Gulf coasts of Florida with the intent of characterizing the diversity and breadth of natural and anthropogenic influences on these systems. This report was prepared to identify patterns and generalities in the data base from which a more comprehensive understanding of estuarine function, that is, of how natural and anthropogenic processes influence estuaries and estuarine resources, can be developed to guide research and policy.

This report was compiled primarily by reviewing major summary documents prepared by the research and management communities on specific estuaries. Information from research articles, data bases on specific topics (e.g., compilations of salinity data), and the results of interviews, discussions and meetings with managers, scientists and academicians were also incorporated. Emphasis was placed on identifying a set of estuaries that would reflect the range of variability in the physical, biological, socioeconomic and demographic conditions. The literature on each estuary was reviewed and briefly summarized. In each case, we sought to identify some of the principal factors or processes that have brought the system to its current condition. From this series of individual analyses, an effort was made to identify common attributes, forcing functions and trends characteristic of all, or groups of estuaries. These points of common ground form the basis of an integrated analysis from which arise the principal findings and recommendations for research, management and outreach.

A. Study Results

1. Estuaries are of enormous value as economic and aesthetic resources.

2. Florida's estuaries tend to be small to moderate in size, while the watersheds upon which they are dependent tend to be relatively large. As a result, land use practices and hydrological manipulations within the watersheds (i.e., over large areas, often far from the coast) can have substantial impacts on the estuaries.

3. Most estuaries in the state are currently experiencing some degree of anthropogenic stress. During the coming decades, this stress will increase. In some cases pressure will be applied within the estuary itself. More often, however, stress will be applied from upland sources, within the watershed. Factors associated

with population growth, changing demography, and the growing need for water will affect the habitats and resources of most of the state's estuaries over the next few decades.

4. Modifications of estuarine hydrology and annual salinity cycles has already resulted in significant degradation of estuarine habitats. Continued unconsidered hydrological modifications may be the most significant threat to the integrity and functionality of Florida's estuaries in the coming decades.

5. Point-source control of eutrophication and contamination has met with considerable success.

6. Non-point sources of contamination, including agricultural and urban runoff, septic system failure and dredging, are recognized as the principal source terms for many of the contaminants in Florida's estuaries.

7. Management of estuarine resources will be augmented by understanding long term biological and hydrological cyclic variability.

8. New approaches to management may be required. They will depend upon:

- **a**. Efficient academic-government research interactions,
- **b**. Multidisciplinary approaches to estuarine research,
- **c**. Incentive rather than regulatory basis for management,
- **d**. An educated public.

Ultimately, two factors -- hydrology and cyclic variation -- seem key to the integrity of the estuaries that were studied. These factors underlie the physical and socioeconomic functioning of each estuary. They provide a framework for research and management.

1. **Hydrology**. Not simply in the sense of the mass balance, but within the context of the significance of water, flow, and the salinity cycle to the integrity and functioning of the ecosystem, hydrology links the land, the watershed, the coastal ocean and the estuary. All of the areas of key concern to estuarine management derive from the hydrology and can be viewed from a hydrological perspective.

2. **Cyclic variation.** Though less obvious in the literature as an underlying influence on the estuaries, variability, especially that which is pulsed, emerges as a key attribute in determining estuarine function. Estuaries are pulsed, constantly changing (both randomly and non-randomly) systems. Many of the cycles that are significant to managers (e.g., fish population dynamics) have scarcely been investigated. The concept of cyclic variation is poorly understood in estuarine science and its impact is under appreciated in the management community.

Finally, a general conclusion that can be drawn from this study is that the only way that Florida's estuaries can be managed is to affect a convergence of science, society and management. No estuary in Florida is unaffected by man. Nor is there an estuary that is independent of natural forcing. Both natural and social scientific questions must be addressed in a manner that permits exchange between disciplines in order to account for the variability in living and non-living resources in the estuaries. Management of estuarine resources requires an understanding of how the two forces (nature and society) are related.

II. Recommendations

The following are recommendations for management, technical development and research.

A. Recommendations for management:

1. Efforts to document non-point contaminant sources, to reduce their loads and to mitigate their impacts should remain priorities of estuary management.
2. Residential septic systems and combined municipal storm and sanitary sewer systems are inappropriate in areas such as Florida, which are characterized by high rates of population growth. Current designs should be eliminated from planning in all new development. Methods for improving septic systems and for separating existing combined sewer systems should be sought.
3. Florida's participation in the National Estuarine Program and similar federal and regional programs that promote data acquisition, planning, management and education should increase.
4. Habitat destruction is a priority environmental problem. Efforts to recover estuarine habitat need to couple traditional and novel approaches with research and education on habitat and microhabitat structure and function.
5. Investigate approaches for incentive-based management of estuarine water quality and resources. Public education and outreach efforts should focus on (a) new residents, (b) elected and appointed officials and (c) developers, and (d) long time residents.
6. Incorporate the management of estuaries and estuarine/watershed hydrology into Florida's water policy.

B. Recommendations for the Development of Tools and Protocols

7. Mechanisms for enlarging the state's GIS data base and for sharing GIS products should be sought.
8. Standardization of data collection protocols, and quality assurance and control must be mandatory for laboratories making measurements on the state's estuaries. Teams composed of representatives from the management, private and academic sectors need to develop standards and methods for ensuring adherence to these accepted protocols and conventions.
9. Expand the use and study of restoration technologies to recover habitat and to provide buffer zones against contaminants.

C. Recommendations for Research

10. The effective management of estuaries requires an understanding of hydrology and hydrological cycles. These should be resolved for all estuaries in the state. Emphasis should not simply be on water mass balance but on the relationships between that balance, the annual salinity cycle and the ecological integrity and function of the estuaries. The minimal and maximal flows required to maintain ecosystem integrity must be established.

11. Focus scientific research on identifying major environmental and biological patterns and cycles that occur on the time scales of variation of the most important indicator species (e.g., fish), communities (e.g., seagrasses) and phenomena (e.g., bloom and salinity cycles).

12. Research collaborations aimed at selected estuaries should be sought between state agencies and academe. Research should focus on updating old information on resource distributions, on documenting essential processes and rates (e.g., trophic dynamics, productivity, ecological efficiencies) and on identifying ecological stress. These investigations should permit greater understanding of estuarine function within the context of variability in the hydrological environment. They should seek to understand the "present" system within the context of continuous, pulsed change resultant from natural and anthropogenically forcing. Finally, the scientific research must be design to identify the policy that will be generated to guide development of watershed management strategies by relating ecosystem function to demographic trends and associated land uses.

III. Introduction

The length of the Florida coastline is greater than the combined coastline lengths of all other states on the eastern seaboard. Florida's many estuaries form a boundary between the terrestrial and freshwater systems of the state and the coastal ocean. These brackish border-waters, however, represent more than the confluence of freshwater with the sea. They are unique natural resources that provide numerous benefits to the inhabitants of the state. The estuaries are critical habitats for wildlife, including numerous threatened and endangered species. They are habitats and nursery grounds for approximately 70% of the fish species in the tropics and subtropics (Lugo and Snedaker 1974). They provide shoreline stabilization and they represent some of the most biologically diverse and productive ecosystems on earth (Odum 1974). Estuaries are also key locations for commerce and industry, and major points of human immigration and embarkation. And they are prime locations for recreation and leisure activities that not only speak to the quality of life in Florida, but are worth billions of dollars annually to recreation-based industries.

For any estuary/watershed system, there is a variety of users. Often, the activities of these user groups are incompatible. For example, estuaries serve as receiving waters for toxic wastes as well as recreational waters for swimmers and boaters. The designation of an estuary for one purpose may obviate its use for others, and conflict over resources has been common in estuaries everywhere. Both natural processes and human activities, especially land use practices resulting in hydrological manipulations, affect estuarine sediment and water quality and associated living and abiotic resources, thereby determining from outside of the system, the functioning of the estuary, its habitats and resource-base.

The varied physiographies, climatologies, and the natural history of Florida, resulting from a geography that extends over 6 degrees of latitude, give rise to a diversity of estuary types. These range from barrier beach lagoons to cuspate riverine systems, and from sub-tropical, mangrove-seagrass estuaries to Carolinian-temperate, salt marsh systems. A characterization of Florida's estuaries cannot, therefore, be achieved by the same set of processes as would be used if a single system (such as Chesapeake Bay) dominated the region.

Florida's estuaries tend to be relatively small to moderate in size by comparison with estuaries in the northeastern U.S. Many, however, have large watersheds. On average, the ratio of watershed to estuary surface area is approximately 10:1. Often the drainage basins of different estuaries overlap and it is difficult to determine where one estuary ends and another begins. Yet, if estuarine resources are to be conserved and managed for sustainable consumption, if conflicts over competing uses of land and water in the drainage basins are to be resolved in ways that maximize value and minimize exclusivity, then some overriding set of principals must be devised to guide the development of sound, basin-specific and inter-basin research, planning and management.

This document is intended for use by a diverse readership that includes scientists, resource managers, policy makers and the public. It is not a technical report. It is, rather, an effort to accomplish two goals. First, to bring together a considerable amount of summary material on the natural and socioeconomic systems associated with a representative sample of Florida's many estuaries and diverse estuarine resources. Second, to glean from this compilation of information, a set of generalities that allows one to organize that information and to think about Florida's estuaries in a uniform way. It is an attempt to identify attributes and problems common to the estuaries of this state and to merge these into what might be defined as an "Estuarine Theme Area" from which debate, research and policy might emerge. This report should not be considered conclusive, in the sense that it provides specific research projects or policy agendas. It states neither unshakable truths nor a rigid doctrine regarding the state of the estuaries. Rather, this document should be considered a point of departure, a starting point from which a dialogue can emerge.

Within the range of ideas that have been examined there are two ultimate generalities. The first is that hydrology, the distribution and movement of water, ultimately determines estuarine function physically, biologically and socioeconomically. Second, estuaries are governed by cycles, they are pulsed systems. Certain cycles need to be understood in order to manage any estuary and this, according to Blum (1995) and Odum et al. (1995), represents the new paradigm in estuarine research. Finally, it is proposed that no estuary in Florida is unaffected by human activity. There is a discontinuity between what is perceived as a functional estuary in the natural sense, what is required or feasible through management, and what happens to the estuary as a result of forcing by socioeconomic factors. The purpose of research in the natural sciences is to resolve and explain the natural variability of the system. Natural forcing, however, may appear unrelated to changes that actually occur within an estuary, or with the way the estuary is managed. Conversely, the human activity that occurs within an estuary and its watershed and the impact of such activities upon the integrity, functionality and sustainable productivity of the system are strongly affected by natural variability. Unless natural scientists, social scientists and managers can consider the three components of the estuary (nature, society, management) in a holistic way, it is impossible to control the output (i.e., the management strategy).

Presently, the conceptual framework that defines what an estuary is differs between scientific disciplines, and management may appear to some to be a random process. What is needed is more than simple recognition that different conceptual models exist. Rather, the disciplines must learn each others' "languages" such that researchers and policy makers not only recognize that estuaries are affected by a multi-variate environment but that they begin thinking and working within this framework. It is with this concept in mind that the present report has been produced.

This document is a status report on the current condition of Florida's diverse estuarine resources. It is presented in a format that is purposely not geared to a certain discipline or type of technical expertise. It is hoped, that this report will encourage dialogue between academics, state and federal researchers and those in the management and policy sectors.

IV. Methods

No single method of collecting and processing information can provide the understanding needed to characterize the state of Florida's estuaries. These are complex ecological systems with additional complexity imposed by socioeconomic, demographic and political factors. An effort to characterize the estuaries must apply a multidisciplinary strategy and utilize a variety of approaches for compiling, reviewing and interpreting information. Therefore, the Estuarine Theme Area Panel, an interdisciplinary group of academicians with expertise in estuarine and environmental studies, was convened to consult on the preparation of this report. Information was obtained by: (1) literature review; (2) interviews and conversations with managers, representatives from university outreach programs, researchers and other appropriate individuals; (3) meetings and conversations with scholarly groups.

A. Selection of Estuaries

The estuaries studied for this report are listed in Table 1. Their locations along the Florida coast are shown in Figure 1. Taken together, these estuaries represent a range of environmental conditions, demographies and human impacts found within the state. These estuaries also represent systems for which sufficient data are available to permit evaluation of the desired parameters, though systems differ in the extent to which various attributes have been described in the literature. A criterion for inclusion in this study is that an estuary must have a sufficient data base to provide a contribution to the development of the synthesis or set of generalizations that it was our goal to produce.

Two types of analyses are presented. The first is an integrated interpretation of the general status and trends in Florida estuaries (Section V.A). This is followed by a series of recommendations for estuarine research and management (Section V.B). The second type of analysis is a brief description of each estuary that was studied (Section V.C.). We document the physical setting and climatology, living resources and habitats associated with each estuary and its watershed, and we describe some of the demographic patterns and socioeconomic trends that characterize the region. Water and sediment quality are described in a separate section in each estuary summary, and finally aspects of governance, planning and management of each system are presented. These system-specific summaries represent the raw data from which the integrated synthesis was developed.

Table 1. The estuaries considered in this report with information about the region in Florida that they occupy, the size of the estuary and its drainage basin and the designation of all or part of the estuary within a federal program, i.e., the National Estuary Program, the National Estuarine Research Reserves or the National Marine Sanctuary or National Park System.

No.	Name	Fig.	Location	Size (mi^2)		Federal
				Estuary	Basin	Protection[1]
1	Lower St. Johns River Estuary	4	Northeast Peninsula	2,777	9,562	1
2	Indian River Lagoon	5	Central East Peninsula	360	2,234	1
3	Biscayne Bay	6	Southeast Peninsula	99	938	3
4	Florida Bay	7	South	850	NA	2
5	Rookery Bay	8	Southwest Peninsula	3	15	2
6	Charlotte Harbor	9	Southwest Peninsula	270	4,500	1
7	Tampa Bay	10	Central West Peninsula	400	2,300	1
8	Suwannee River	11	Northwest Peninsula		9,950	
9	Apalachicola Bay	12	East Panhandle	212	19,600	1,2
10	Pensacola Bay	13	West Panhandle	414	7,000	

[1] Federal Siting Codes: 1 -- National Estuary Program Site; 2 -- National Estuarine Research Reserve or National Marine Sanctuary; 3 -- National Park. Note: one NEP site, Sarasota Bay, was not included in this report.

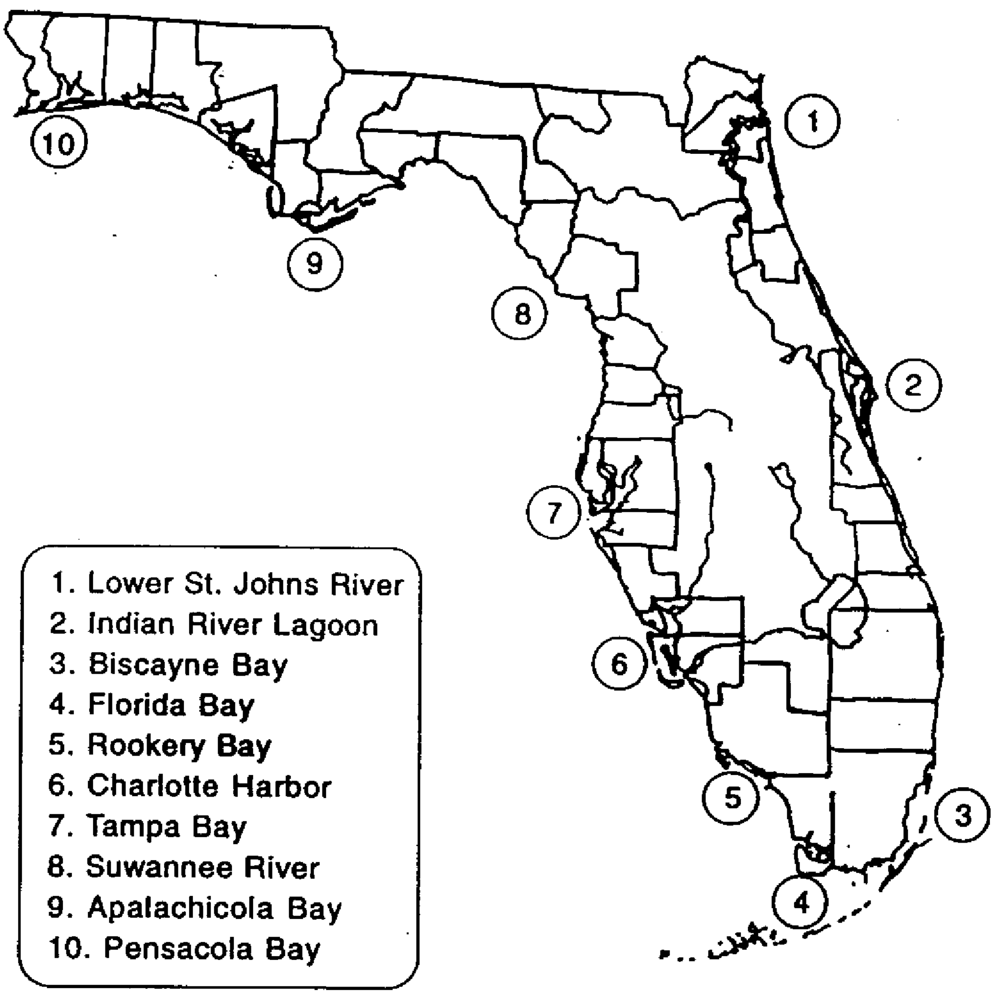

Figure 1. Locations of the estuaries described in this report.

The reader will note that this report does not contain large tables of data. While such tables are useful as reference material, they are purposely avoided in this report for two reasons. First, this report is intended to provide a strategy, a conceptual approach around which to develop research and planning. It is not intended as a reference document from which individual numerical data can be extracted. The reader is directed to numerous SWIM, NEP and Status and Trends documents listed in the bibliography for that sort of summary (in short, that work has been done; this product is different). Second, we rather frown at the idea of comparing isolated data, such as the concentration of some metal, between estuaries. In some cases this can be useful, but a consensus seems to be developing in the research and management communities that this practice may be less than useful as a comparative tool, without supporting environmental data. The influence of a contaminant on a system, for example, depends not solely on the concentration of the contaminant, but on the hydrodynamic and geologic environments to which it is delivered, the biota that are exposed and potentially, on numerous other factors. Further, in many cases, estuaries consist of large numbers of sub-basins, each with a different hydrology, biology and contaminant history. In such systems, averages are meaningless and ranges are not much of an improvement. To list the mean values for each sub-basin would be an enormous undertaking of questionable value and is beyond the scope and context of this report.

B. Literature Review

Retrospective analysis implies an examination of existing data. It was impossible to acquire and manipulate the raw data sets on a sufficient number of variables, from a large enough number of estuaries to produce, within the time allotted for this project, a realistic evaluation of the general condition of Florida's estuaries. It was, however, feasible to use major summary documents dealing with specific estuaries and watersheds to compile a general review (Table 2).

Summary literature on Florida's estuaries was obtained in the form of large reports or management plans from various agencies and organizations. Contributing organizations include Florida's water management districts (SWIM plans), the National Estuary Program (NEP) sites, the National Estuarine Research Reserves (NERR) program, the Florida Department of Environmental Protection (FDEP), the Offices of Ocean Resources Conservation and Assessment (ORCA) of NOAA, the US Environmental Protection Agency (EPA) and the Florida Department of Community Affairs (DCA). Major technical reports, surface water improvement and management (SWIM) plans and similar documents were obtained from the appropriate agencies, usually by simple telephone requests. It is noted that agency cooperation,

Table 2. Principal sources of summary material used to produce this report.

Estuary	NEP Repts[1]	WMD/ SWIM Docs[2]	NERR Sum-maries[3]	Mono-graphs	Primary Lit.[4]	Data & Status/ Trends Repts.
SJR	+	+			+	
IRL	+	+		+	+	
BB		+			+	+
FB		+			+	+
RB			+			
CH		+			+	+
TB	+	+			+	+
SRE		+			+	
AB	+	+			+	+
PB		+			+	+

Estuary Codes: SJR=St. Johns River, IRL=Indian River Lagoon, BB=Biscayne Bay, FB=Florida Bay, RB=Rookery Bay, CH=Charlotte Harbor, TB=Tampa Bay, SRE=Suwannee River Estuary, AB=Apalachicola Bay, PB=Pensacola Bay

[1] National Estuary Program. Includes reports by consultants as well as NEP staff.

[2] Water Management Districts. Includes SWIM and other documents.

[3] National Estuarine Research Reserves

[4] Includes articles in peer reviewed journals and books as well as some reports for specific contractors.

complicity and support in filling requests, in sharing information and in recommending additional resources was excellent.

Additionally, specific research products were identified in the published literature, from electronic abstract services and by examining published bibliographies such as those prepared for the NEP reports, SWIM plans and the Florida Sea Grant Program. In some cases, authors were contacted for further discussion of specific findings.

C. Interviews and Conversations with Individuals

Discussions were conducted with personnel from a variety of state research and resource management agencies, and academic outreach programs (Table 3). The literature review was supplemented with these personal interviews for several reasons.

First, the interview process may lead to a better appreciation of how resource managers actually perceive the systems they manage. Second, discussions frequently resulted in new insights and levels of understanding not obtainable from official documents. Third, most of the summary documents that were reviewed were submitted or published between 1988 and 1994. In a state where the demographics and socioeconomic structures are changing rapidly, certain aspects of these reports may already be obsolete. Researchers and resource managers helped to identify recent sources of information. Fourth, interviewees were often aware of additional resources. Fifth, in certain cases, the description of a process was aided by a visit to a facility and discussions with its operators. Visits were made to examine the geographical information systems (GIS) of the Florida Marine Research Institute (FMRI), Department of Environmental Protection (FDEP), and to the laboratory of Professor Gustavo Antonini of the Department of Geography, University of Florida, Gainesville. NOAA/ORCA headquarters in Silver Spring, Maryland were also visited to identify source materials from the National Status and Trends Program and other data bases. On each occasion, discussions were conducted with on-site staff who explained both the electronic archiving system and provided information about the data sources that are collected and supplied to users.

D. Group Meetings

Meetings were arranged with academic researchers and faculty throughout the state to help identify research topics and information needs and by considering novel suggestions and approaches to research. Meetings were held with faculties from the University of Florida, Florida State University, Florida Institute of Technology, and with members of the faculty and staff of the University of South Florida and the Florida Institute of Oceanography. These meetings helped to develop a sense of the general questions and problems that are relevant both to the way Florida's estuaries are perceived and the way they are managed.

Table 3. Agencies and other organizations from source data, documents and information were obtained through interviews and conversations with staff.

	Estuary[1] or Topic										
Org.[2]	SJR	IRL	BB	FB	RB	CH	TB	SRE	AB	PB	Technol. & Other[3]
WMDs	++	+	++	+		++	+	++	++	++	
NEPs	+	++					++		+		
NERRs					+						
SG				++				+	+		++
SGES	++	++				++	+		+		
RPCs	+										
FDEP				++							++
DERMs				++							
Univs	++	++	++					++			++
NOAA/ ORCA											++

[1] Estuary codes are as in Table 2.

[2] Org. = Organization. Codes are as in Table 2. Codes not given in Table 2 are as follows: SG= Sea Grant, including Florida SG, National SG Office, Rhode Island SG; SGES= Sea Grant (Florida) Extension Service; RPC= Regional Planning Councils; FDEP= Florida Department of Environmental Protection; DERMs= Departments of Environmental Resource Management (County); Univs=Universities; NOAA/ORCA= National Oceanic and Atmospheric Administration, Office of Ocean Resources Conservation and Assessment.

[3] Technol. & Other refers to provision of information on technologies such as GIS and conversations with individuals regarding general concepts and ideas, as well as information on status and trends issues.

V. The State of Florida's Estuaries

A. Status and Trends: A Synthesis

1. Introduction to this section

Estuaries are dominant features of Florida's coastal topography, accounting for approximately three quarters of Florida's 1350 mile coastline. Most of the residences, businesses, industries and recreational facilities in the state are located within estuarine basins or watersheds. As a result, estuaries are among the most widely used and valuable natural resources in Florida. They provide diverse biological habitats, as well as locations for residential development, sheltered harbors that support multi-billion dollar seaports and commerce, and they are prime locations for recreational and retirement activities. Estuaries are complex systems ecologically and socioeconomically. Their management for sustainable resource utilization requires an understanding of both the natural and the socioeconomic forcing functions that act upon them.

The findings of this study are summarized in this section. The focus here is on issues that are either susceptible to immediate action by the management community, or to the goal of identifying general principles that can lead to research which will improve the capability to manage the estuaries. Thus, the topics addressed in the Status and Trends section (V.A.) lay the foundation for the discussion in the Recommendations section (V.B.). Section V.C. System-Specific Summaries, provides a description of each estuary considered in this report. The individual summaries were placed after the Status and Trends and Recommendations sections to emphasize the focus on generalization and synthesis rather than on the individual component systems.

2. Physical setting and climatology

Most of Florida's estuaries are lagoonal or cuspate-lagoonal systems. Estuaries on the east coast, particularly in the south, tend to drain small tributaries, man-made canals or diffuse, non-point sources. On the west coast and particularly as one moves north, drainage tends to be provided by 2-4 major rivers per estuary (Table 4). In general, the lagoons are shallow embayments, <15 feet deep (though often dredged), separated from the ocean by barrier beach islands. The lagoons tend to parallel the coast and are often composed of numerous sub-basins (Woodward-Clyde 1994; South Florida Water Management District 1995).

Table 4. Some of Florida's estuaries and their tributaries.

Estuary	Location	Tributaries/Drainage System
Lower St. Johns River	North East	St. Johns River
Indian River Lagoon	Central East	Canals & Ditches
Biscayne Bay	South East	Canals & Ditches
Florida Bay	South	Everglades
Rookery Bay	South West	Henderson Creek
Charlotte Harbor	South West	Peace, Myakka & Caloosahatchee Rivers
Tampa Bay	Central West	Hillsborough, Alafia, Little Manatee & Manatee Rivers
Suwannee River Estuary	North West	Suwannee, Santa Fe, Alapaha & Withlacoochee Rivers
Apalachicola Bay	Panhandle	Apalachicola, Flint, Chattahoochee & Chipola Rivers
Pensacola Bay	Panhandle	Escambia, Blackwater, East Bay & Yellow Rivers

Much of Florida is characterized by well drained soils, permeable (calcium carbonate) bed rock and a shallow water table. Groundwater provides important contributions to most of Florida's estuaries. Soil and groundwater characteristics affect land uses enormously and influence the susceptibility of estuaries to runoff and various waste disposal practices. For example, in six of the ten estuaries studied (lower St. Johns River, Indian River, Charlotte Harbor, Florida, Apalachicola and Pensacola Bays) septic system failure coupled with soil and hydrological characteristics was cited as a significant contributor to estuarine water quality deterioration. In one additional estuary, the Suwannee, septic system problems were reported to have occurred and to have been corrected to a significant extent.

The Florida peninsula occupies a transition between two climatic zones, the Carolinian temperate (also called the humid continental zone) and the subtropical. Two distinct seasons, dry and wet, occur. The wet season, which extends from June to October or November, is hot and humid. Between 60 and 75% of the annual precipitation occurs during this time of year. The dry season, from November or December through May is cooler, with the temperate, northern portion of the state being cooler on average than in the subtropical south.

3. Living resources and ecosystems

Two modalities -- bottom dominated and water-column dominated -- can be distinguished among the submerged biological communities of Florida's estuaries, especially south of ca. 28° N latitude. The principal primary producer in bottom dominated communities is seagrass. *Thalassia testudinum*, turtle grass, is frequently identified as the climax species. Shoal grasses, *Halodule* spp., and other grasses are the principal subdominants. However, considerable system-specific variability in seagrass community composition exists (see section V.C.). Seagrasses provide habitat for a diverse assemblage of benthic invertebrates and several recreational and commercially important fish, including spotted sea trout, red drum and snook. Seagrasses tend to be light (and sometimes nutrient) limited (see Fourqurean et al. 1992; 1995). At depths exceeding approximately 6 feet, attenuation by water reduces the photosynthetically available radiation (i.e., the amount of light available for photosynthesis) to levels insufficient to sustain a net positive primary production. Resuspension of sediments from dredging and other activities, either within the estuary or in the watershed, as well as phytoplankton blooms associated with the delivery of dissolved inorganic nutrients from point and non-point sources, reduce water clarity by absorbing or scattering light (see Tampa Bay NEP 1995). The result is a reduction in seagrass production or, at best, succession to species tolerant of low-light and eutrophic conditions. A healthy seagrass community is typically associated with clear water which, in turn, is frequently assumed to be an analog for environmental quality. During the period between ca. 1950 and 1970, unregulated development throughout the state, resulted in the loss of 20-100% of the seagrass biomass in various estuaries and portions of estuaries. Recovery of seagrass beds has become a standard against which the recovery of water quality has been judged in Tampa Bay and the Indian River Lagoon (Table 5). The use of a of a "seagrass standard" has been proposed as a measure of the recovry of water quality in Florida Bay as well (Boesch et al. 1995).

Table 5. An example of habitat restoration as a function of improvements in water quality. Losses and recovery of seagrasses[1] (in thousands of acres) in Tampa Bay and the Hillsborough Bay segment of Tampa Bay.

	Year				
Location	1950	1982	1988	1992	2010[2]
Tampa Bay	40.0	21.6	23.9	25.1	39.0
Hillsborough Bay	2.7	0	--	--	--

[1] In 1950, the principal seagrass was *Thalassia testudinum*. The dominant species recovering is *Halodule wrightii* which is more tolerant than T.testudinum of turbidity and eutrophic conditions.

[2] Projected"seagrass standard" has been proposed as a measure of the recovery of water quality in Florida Bay as well (Boesch et al. 1995).

Water column dominated estuaries (or portions of estuaries) tend to be turbid. Phytoplankton are the dominant non-emergent primary producers. The major grazers are protozoans, copepods and meroplanktonic crustaceans. Planktivores, such as anchovy and mullet, consume the grazers.

At latitudes higher than approximately 28° N, estuaries tend to be turbid (saltmarsh types) where phytoplankton and epiphytes contribute an important portion of the submerged primary production. A few types of seagrasses may characterize the shoals. Estuaries to the south tend to exhibit seagrass dominance in shallow areas and phytoplankton dominance in turbid and deep areas. Efforts to measure the combined production of bottom and water column communities have been infrequent. However, available data indicate that, on average, primary production is similar (though variable) in both (Table 6; see also Zieman et al. 1995). We diverge here to consider, in some detail, the implications of Table 6, and the relationship between energy flow and composition in the ecosystem. Observations from Florida Bay are used to suggest that shifts in the composition of the dominant producer and subsequent trophic structure do not necessarily result in major changes in the amount of energy that reaches the apex predator. Thus, if the composition of primary producers varies, but areal primary production is relatively stable (i.e., order of magnitude) then differences in trophic structure may be compositional rather than energetic. This scenario has socioeconomic implications which are discussed below. Evidence to support this hypothesis is found in raptorial bird distributions in Florida Bay (Robertson 1995). Robertson (1995) suggested that raptor populations (specifically fishing birds) have been relatively constant in the bay for the past 32 years. If, indeed, the upper and lower trophic levels (Table 6) are relatively stable energetically, then one might hypothesize that the ecological carrying capacity of an estuary may be relatively constant given climatic and hydrological stability (Fig. 2a). Paleoecological data from Florida Bay suggest that cyclic environmental variability in hydrological phenomena occurs on several time scales (Wingard 1995; Halley 1995). Variability in submerged primary producer community structure and associated fauna is likely to be associated with cyclic (deterministic) environmental variability on decadal timescales (Fourqurean et al. 1995) (Fig. 2b). Such changes in producer communities may have socioeconomic effects because, while water column dominance tends to support commercial fisheries (forage fish, shrimps), bottom dominance supports production of certain game fish (bone fish, snook) (Fig. 2a).

Table 6. Primary production (g C/m^{-2}/y) in submerged and emergent vegetation in representative estuaries in Florida.

Producer	Florida Bay	Tampa Bay	Indian River Lagoon
Phytoplankton	350	340	0.05-442
Seagrasses	376	730	182.5-3650
Benthic Microalgae	nd	150	nd
Macroalgae	nd	70	175.2
Mangroves	nd	1132	1200
Marshes	nd	300	
High Marshes			130 - 700
Impoundments			2000 - 2500
Low Marshes			1300 - 2200

Data sources: For Florida Bay phytoplankton: C. Tomas (pers. comm.), for sea grasses: Fourqurean et al. (1992); For Tampa Bay phytoplankton, benthic microalgae and macroalgae: Tampa Bay NEP (1995), for mangroves: Estavez and Mosura (1985), for marshes and seagrasses: Lewis (1985); For Indian River Lagoon: Woodward-Clyde (1994e).

nd: no data

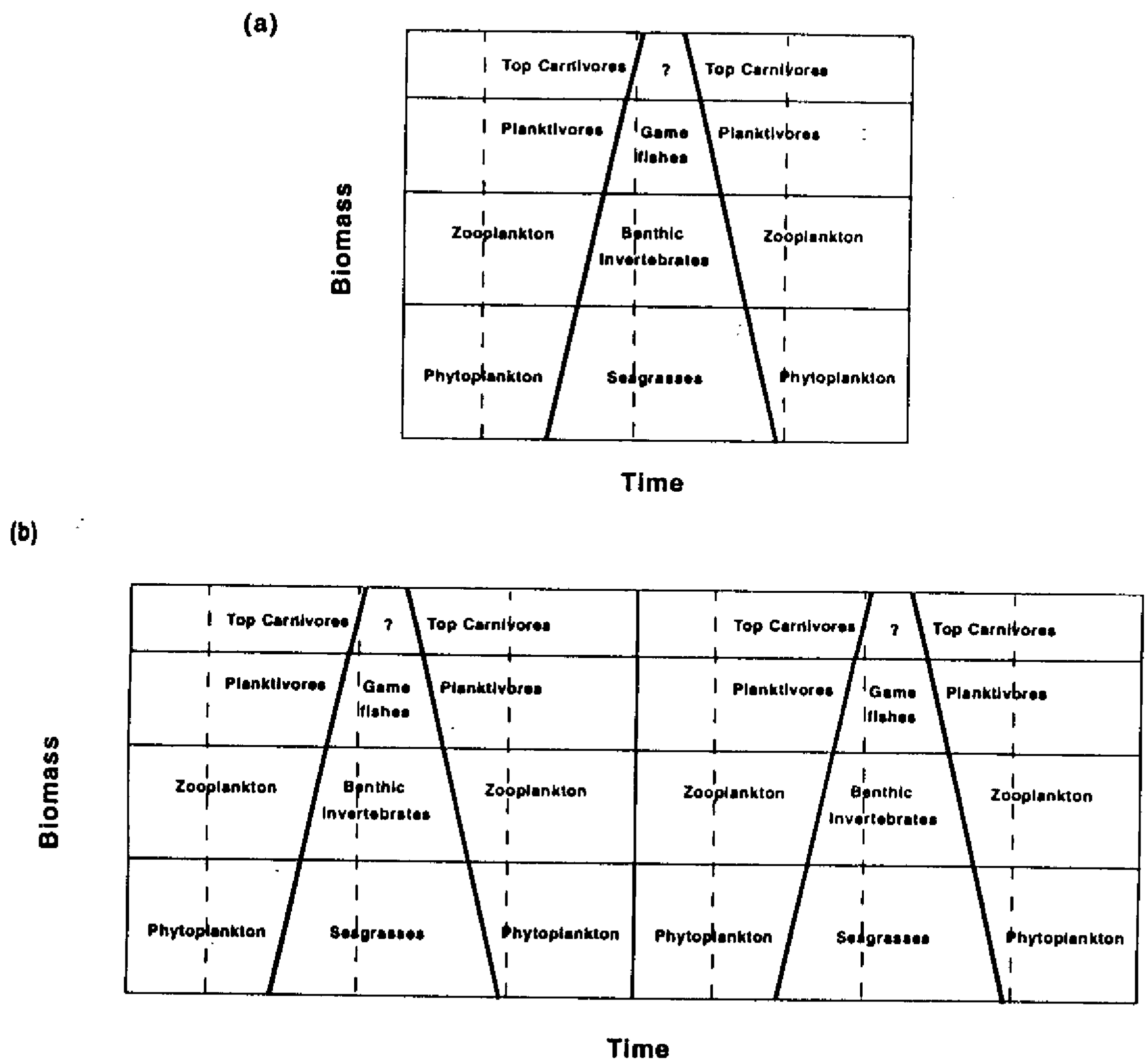

Figure 2. A conceptual model of trophic structure in Florida estuaries. In this model (a) total biomass (i.e. carrying capacity) is relatively stable and variations occur as changes in primary producer and resultant consumer communities. (b) The system is seen to cycle between phytoplankton (water column) and seagrass (bottom) dominated communities through time.

Major ecosystem alterations (e.g., very long term or quasi-permanent modification in hydrology) would likely result in changes in energetics. At present, it is not known how much perturbation or modification an estuary can accommodate before its carrying capacity is changed. Determination of this critical stress level represents an aspect of a larger set of questions for research, that is discussed in the Recommendations section (V.B.).

Recent data from Florida Bay suggest that the relationships between water clarity, seagrass production and water quality are complex and that reduced water clarity may not necessarily connote environmental degradation (Zieman et al. 1995). Seagrass coverage in Florida Bay was higher during the early 1980s than at present. Primary production, however, was relatively low with respect to current rates. High seagrass density and low productivity may result in approximately the same area-specific production as low seagrass density and high production (Zieman et al. 1995). And a reduction in primary production in the bottom seems to be compensated for by increased water column production.

The fringes of Florida's estuaries are populated by mangrove forests, saltmarshes or both depending upon latitude. The northern limit of mangrove forestation is approximately 28° limit of mangrove forestation is approximately 28° N. On the east coast, there is a gradual decline in mangrove concentration until, at approximately Melbourne, mangroves are replaced by salt marshes as the dominant emergent vegetation (Woodward-Clyde 1994e). Mangrove and saltmarsh tidal wetlands are among the most productive components of Florida's estuaries (Table 6) and they represent crucial wildlife habitats and nursery areas (Odum 1953; Tampa Bay NEP 1995; Roberts 1995). They also serve as buffer zones, filtering contaminants from the estuary. Invasions by exotic species (e.g., *Casurina*, the Australian pine), removal of wetlands for development (including residences, ports, marinas and resorts) and dredging and filling activities for commerce and other purposes have reduced or completely eliminated many of the wetlands surrounding Florida's estuaries (e.g., Tampa Bay NEP 1995). Habitat restoration is a management priority in Florida and successful restoration projects have been undertaken in Biscayne Bay (SFWMD 1994a), Tampa Bay (Tampa Bay NEP 1995) and the Indian River Lagoon (Woodward-Clyde 1994f,g). A major restoration effort is currently planned for Florida Bay (SFWMD 1994b).

Upland ecosystems, pine and salt barrens, hammocks and freshwater wetlands are frequently not thought of as being part of an estuarine system. Watershed managers realize, however, that activities in the watershed, impinge directly on the estuary (e.g., Charlotte Harbor, see SWFWMD 1993). Florida's estuaries and watersheds support important, frequently threatened or endangered habitats. SWIM planning documents typically list as many as 30 threatened or endangered species in estuarine and watershed habitats. Careful management has helped to restore some populations of fish (Tampa Bay NEP 1995) and reptiles (Mazzotti and Brandt 1995) and is having a positive effect on bird populations in several of the state's estuaries (e.g., Tampa Bay, Indian River Lagoon). Protection and management of upstream habitats and ecosystems may be among the most difficult jobs in estuarine management in the coming decades when growth in many watersheds will occur at an accelerated rate and the direct link to the estuary may not be apparent to the public or to policy makers.

4. Demographic patterns and socioeconomic trends

The population growth rate in Florida, particularly in the southern portion of the state, has been among the highest in the nation. For example, the change in population density in the Indian River Lagoon (IRL) watershed between 1940 and 1990 was exponential (Fig. 3). Rates of population growth averaging around 60%, but approaching or exceeding 100% have been common in some basins (Table 7).

Only a few of Florida's estuaries have not experienced large increases in population during the past 50 years. However, planners are concerned that population growth in the urban watersheds will divert resources from less developed systems to support burgeoning population centers (SRWMD 1991). This could stress the few relatively pristine estuaries in the state. Unfortunately, some of these estuaries (e.g., the Suwannee River estuary) have not been well studied; others have not been examined in 20 or 30 years and need to be re-studied.

Historically, estuaries in Florida were associated with several principal economic activities. Until the 19th century, Florida's estuaries were primarily transportation routes, supporting the shipment of agricultural products to market (e.g., citrus in the south and forestry in the north) and trade. Fisheries (particularly mollusks and shrimps) became important in the 19th century. The military presence around the estuaries increased substantially during World War II as bases and training facilities became established. These activities remain important throughout the state, though population growth, development and the growth of tourism during the past four decades have had marked effects on the socioeconomic character and demographic profile of most of the estuaries in Florida. The growth of ports has had an enormous impact upon the economies of several estuaries. Some examples of the distribution of economic resources are provided in Table 8, which is not intended as an exhaustive economic analysis. Rather, it expresses the diversity of economic activities that occur in Florida's estuaries. The socioeconomic diversity of Florida's estuaries and watersheds, both in terms of population structure (Table 7) and distinct economic composition (Table 8), argues for a basin-specific approach to management.

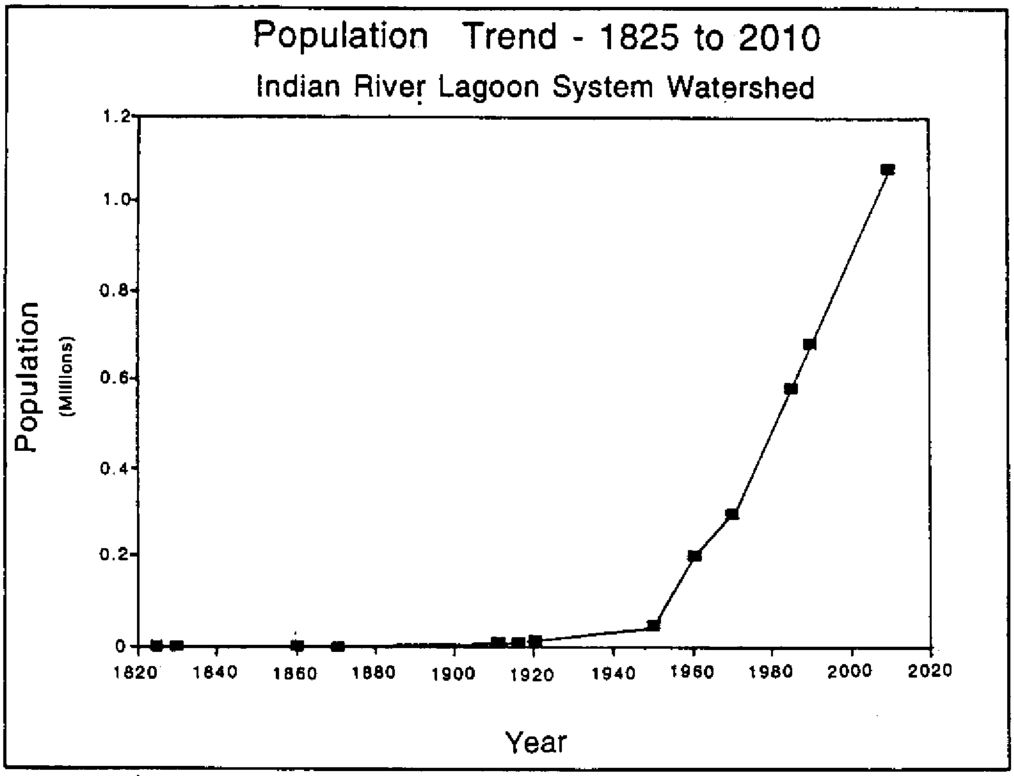

Figure 3. Population changes in the Indian River Lagoon system projected to the year 2010. (Figure redrawn from Woodward-Clyde 1994a.)

Table 7. Population growth in some representative estuarine watersheds.

Estuary	Section or Unit	Population (in thousands)			
Lower St. John River					
		Year	1993	2010	
	Jacksonville		640	880	
Indian River Lagoon					
		Year	1970	1990	2010
	Basin		302	679	1,082
Charlotte Harbor					
		Year	1980	1990	2020
	Basin		407	547	847
Tampa Bay					
		Year	1993	2010	
	Watershed		1,700	2,250	
Suwannee River					
		Year	1980	1995	2000
	Basin		91	125	133
Pensacola Bay					
		Year	1988	2010	
	Escambia Co.		283	376	
	Okaloosa Co.		154	239	
	Santa Rosa & Walton Cos.		< 100	< 100	

Table 8. Some examples of socioeconomic impacts of Florida's estuaries. Values in millions of 1990 dollars.

	Estuary		
	Lower St. Johns River Estuary	Indian River Lagoon	Tampa Bay
Activity			
Fishing	120.0		
Commercial		114.0	19.5
Recreational		54.3	197.0
Agriculture	128.5	1.7	ND
Industry	ND	0.012	ND
Ports	33.7	369.0	>5,000.0
Tourism	450.0	ND	ND
Military	1,800.0	NS	ND

ND: data not available

NS: not significant

While this report seeks to identify attributes common to Florida's estuaries and their functional integrity, ultimately management must respond to the unique set of conditions that occurs in each basin. However, the general principles identified are intended to guide efforts to develop solutions to estuary-specific problems.

5. Water and sediment quality

By comparison with estuaries and coastal waters in other states, the water and sediment qualities of Florida's estuaries are quite good. Many of the state's estuaries are classified as Class III (supporting healthy fish and wildlife populations) and several are graded as Class II waters (safe for consumable shellfish production). Efforts to protect Florida's estuaries from contamination have been conscientious over the past 15-20 years and amelioration of impacts from point source contamination by reducing domestic and industrial loads has been, and continues to be, successful (Tampa Bay NEP 1995; Woodward-Clyde 1994a,b). Nonetheless, both point source and non-point sources of contamination affect the estuaries. Closures of fisheries have occurred in many areas, including portions of the Indian River Lagoon, Biscayne and Apalachicola Bays.

Most of the estuaries considered in this report exhibited locally elevated levels of certain metals or synthetic contaminants (though some metals occur naturally at levels that exceed standards), and a few estuaries (e.g., Lower St. Johns River) have been sited for US EPA Superfund activity. Among the principal industrial point sources are the chemical and citrus processing industries. Agriculture and horticulture are important non-point source contributors of toxic chemicals. Although less toxic contaminant loading appears to occur in Florida than in many other parts of the country, Florida's geology and hydrology facilitate seepage and the entry of contaminants into the shallow water table. Thus, Florida's estuaries are more susceptible to the impacts of contamination than are estuaries in other regions of the country.

Eutrophication, i.e., nutrient enrichment, is a major problem in Florida. Both predominantly nitrogen (e.g., Tampa Bay) and predominantly phosphorus (e.g., Biscayne Bay) limited estuaries occur. Both nutrients may limit phytoplankton production at different times (Tomas and Bendis 1995).

Dredging and filling for navigation and development (e.g., Tampa Bay), and erosion due to logging and removal of shoreline vegetation (e.g., Suwannee River) have had major impacts on water quality in Florida's estuaries. In some systems, reduction of suspended particulate loads is considered among the chief challenges to water quality management.

The identification and control of non-point source loading terms have proven to be among the most intractable problems in water quality management and are currently rated among the highest priority challenges to estuary management. Nutrients and toxic chemicals are loaded to the state's waters by runoff, septic tank failure and other (e.g., airborne; see Paerl 1993) diffuse mechanisms. It has been estimated that more than 50% of the nutrient load and 90% of the total particulate load to the estuaries arises from non-point sources (Livingston 1984). The consensus among water quality managers is that in estuaries and watersheds with large numbers of septic systems: (1) septic system failure is a significant problem; (2) at high population density, septic systems contribute a substantial load to receiving waters; and (3) alternatives or improvements to septic systems and combined sewer systems should be sought in places where the population growth rate is likely to be high.

New approaches to runoff control and management are needed to deal with the problem of non-point source contamination of estuaries and their tributaries in Florida and neighboring states (see individual summaries V.C. 8., 9. and 10. for the Suwannee River, Apalachicola Bay and Pensacola Bay). We will return to this topic in section V.B.6. Governance, Management and Planning.

Virtually every problem in water and sediment quality management is determined by hydrology. While several hydrological models were described in the literature that was reviewed and by managers who were interviewed, it is abundantly clear that the regulation of freshwater in Florida is a complex issue which is likely to become more complex in the coming years. And although it was not stated in the literature, it was evident from interviews and discussions that decisions regarding the flow of water into and away from the state's estuaries are not always based on the needs of the estuaries. Possibly the best example of this problem is found in Charlotte Harbor, where groundwater reductions resulted in a 70% loss of freshwater input to the Peace River by 1960 (see section V.C.6.). Since that time, freshwater input to the Peace River has continued to decline such that the ecological integrity of the estuary may now be in jeopardy.

The impacts of hydrological manipulation are often insidious, but severe. For example, development in the watershed during the past decade has led to increasing diversion of freshwater to Rookery Bay. This has had a subtle but significant impact on the ecosystem. Monument Point in the inner bay was a continuously brackish habitat. That is, the salinity of this area never fell below 10 ppt. During the past decade, the summertime salinity at Monument Point has declined to 0. Because estuaries are key nursery habitats for marine organisms, which find food and refuge from predators in the brackish habitats, the change in the annual salinity cycle of Monument Point may be ecologically significant. Changes in salinity-dependent benthic macrofaunal communities may affect recruitment patterns of economically valuable invertebrate species, such as the Florida spiny lobster (Herrnkind 1995). Thus, while changing the salinity cycle is probably not perceived in the same way as synthetic hydrocarbon loading, its impact may be dramatic. Most significant, however, is that the Florida's water policy does not consider the estuaries. This is a gross oversight that leaves some of the state's most valuable resources vulnerable to degradation and mismanagement.

6. Aspects of governance, management and planning

In Florida there is an enormous layering of management by federal, state, regional and local agencies. An ordering of objectives and priorities in management, however, was not evident in our review. There seems to be no clearly overarching philosophy to management within the state, while on the other hand, there is also not yet a completely localized approach to management. And to reiterate a most important concern, the state of Florida does not presently consider the estuaries in its water management policy. It is apparent that the development of some framework, beyond simple adherence to regulations or the search to meet sets of generic criteria and standards, needs to be in place to guide the process of setting goals (i.e., developing plans) in order for management to have meaning in an increasingly challenged environment.

Nonetheless, considerable evidence of intrastate and interagency cooperation was found in the literature and dialogues. For example, cooperative efforts at modeling demographic and water quality trends have been pursued by the Southwest Florida Water Management District and the Tampa Bay NEP. Cooperation in time series data collection and analysis and in restoration projects has occurred in Biscayne Bay between the Dade County Department of Environmental Resource Management and the South Florida Water Management District. It appeared, from the documents examined for this report, that interstate cooperation in watershed management, particularly in the Suwannee River and Pensacola Basins, needs to be improved. Florida would likely benefit by taking the initiative to developing methods to enhance mutual planning and governance.

7. Summary of Key Environmental Quality Issues

The goal of this report is to develop a set of generalizations about the factors that govern estuary function in Florida. As part of the effort to achieve this goal a set of 14 environmental problems that are consistently rated by managers (in the literature and during interviews) as matters of concern has been identified (Table 9). Many of these problems are related and no attempt was made to seek mutual exclusivity among the categories of problems. Each problem has been ranked (0 to 3) according to its apparent priority in each estuary and watershed for which the literature was reviewed (see Section V.C.). The overall importance of each issue, relative to the others in Table 9 can be ascertained by summing the rows of estuary-specific ranks for each problem category.

Table 9. Environmental quality issues (problems) identified in the literature and the priority of each issue in each of the estuaries studied. Values in () are the ranks of each issue relative to the others.

Estuary Problem	SJR	IRL	BB	FB	RB	CH	TB	SRE	AB	PB
Non-Point Sources (1)	3	3	3	3	0	3	3*	0	3	3
Habitat Loss (2)	2	3*	3*	3	3	3	3*	0	0	3
Flow Mods (3)	0	3	3	3	3	3	3	0	0	2
Septic Syst. (4)	3	3	0	2	0	3	0	2	3	2
Eutroph-ication (5)	1	3*	3	3	0	3	3*	0	0	2*
Turbid-ity (6)	0	2	1	3	2	2	3*	0	0	2
Welands Loss (6)	2*	3	3*	0	0	3	3	3*	0	0
Fisheries Biodiv. (7)	0	2*	2*	3	0	2	2	0	0	3
Toxics (7)	1	1	2	1	0	2	2	0	2	3
Point 2 Srcs/STP's[1] (8)	2*	2	0	0	1	2*	0	0	3*	
DO/BOD[2] (9)	3	2	2	0	0	0	0	0	1	3*
Dredg-ing (10)	2	2	1	0	0	0	3*	0	0	2
Bact/ 3 Pathogens (10)	2	0	0	0	2	0	0	1	2	
Industr. Wastes (11)	1	0	2	0	0	3	0	0	0	3*

Priority: 0=minimal or not mentioned; 1=localized problem or low priority; 2= moderate priority or of general concern; 3=significant problem, great concern
[1]STP's = sewage treatment plants
[2]DO/BOD = dissolved oxygen/biological oxygen demand
Asterisk (*) indicates that program or planning is in place to address problem

Obviously, this exercise can easily become counterproductive if too much is made of the analysis. The approach taken here is admittedly coarse and the rating system is subjective. The approach seems, however, adequate to identify, in a broad sense, relationships between categories, or more precisely, an attribute or attributes common to several problem categories. Most important, however, is that it be emphasized that this approach is not a suitable method for developing a statewide agenda for management and this is definitely not an attempt to do so. Each estuary must be managed on the basis of its own problems, priorities and management strategies.

Nonetheless the approach is simple and useful as a tool for identifying certain broad areas of consensus within the management community. It is seen that, in other than Rookery Bay, Suwannee River and Apalachicola Bay, between 8 and 13 problems (out of 14 possible) are identified. The mean (excluding the three estuaries noted above) is 11; the mode is 13. The three highest priority problems (highest sum of rows) were: non-point source contamination, habitat loss and hydrological modification. (Diversion of water was cited as a problem in significantly more estuaries than was the addition of freshwater). Problems associated with septic system failure, eutrophication, turbidity and wetlands loss were in the next priority group (ranked 4-6).

The real value of Table 9 is that it permits one to ask how issues of similar priority might be related. When Table 9 is studied carefully, a common thread, water flow, begins to emerge. Freshwater flow affects the salinity cycle, the turbidity, trophic state, dissolved oxygen (DO), and contaminant levels in estuaries. Ultimately, it determines the distribution and structure of the variables that constitute the physico-chemical environment. These, in turn, determine ecosystem structure and the level at which each estuary functions.

Hydrology is, thus, a common denominator, a source of linkage among factors currently perceived as priority concerns in Florida's estuaries. Additional generalizations, not as obvious from simple tabular analyses, also exist. These are identified below.

B. Recommended responses to observed scientific, policy and management needs

A summary of the recommendations for estuarine research, policy development and management was presented in Section II. These are discussed in greater detail here. Ultimately, these recommendations address a fundamental question that must be answered in a unique way for each estuary. That question is, What should the managed system "look like"? Or how is the understanding gained from research on the natural system, and societal pressures on estuarine resources related to the "managed" system? This section is divided into three parts: V.B.1. Recommendations for management, policy development and planning ; V.B.2. Recommendations for development of new tools and protocols; V.B.3. Recommendations for research.

1. Recommendations for management, policy development and planning

a. Non-point sources of contamination provide the greatest challenge to water and sediment quality in the state. These sources result from land uses within the watersheds. Efforts must be made to understand, to a greater extent, the sources that various land uses represent, to document them, to reduce their loads and to mitigate their impacts. This may require novel approaches to water quality management, including increased use of existing bioremediative techniques and improvements in these technologies (e.g., restorations of shoreline vegetation and wetlands, use of biofilters), as well as increased application of incentive-based approaches to management (discussed below) through education and outreach programs. In parts of northern Florida increased interstate cooperation is needed to mitigate contaminant loading within the watershed.

b. Residential septic systems represent a special case of non-point source loading. The evidence obtained in this review leads to the conclusion, that at the current level of technical development, individual domestic sanitation systems are inappropriate for waste water management in densely populated parts of Florida. Septic system malfunction is a problem in six of the ten estuaries studied (see System-Specific Summaries, section V.C). The problem is two fold: (1) the porous soils and shallow water table in Florida make it difficult to maintain septic systems, especially during storms; (2) as the population continues to surge, septic systems become increasingly difficult to control. It is suggested that, first, the use of septic systems be discouraged, and perhaps on the basis of population growth projections, banned in most areas. Second, initial sewering of new development may be cost effective relative to the cost of later conversion from septic to sewer systems (Citizens' Advisory Committee 1995). Thus, it is recommended that Florida commit to a program of septic system phase out or of research into better septic system design and begin developing cost effective sewer conversion programs for existing systems.

A related issue is the coupling or combining of sanitary and storm sewers. It has been clearly demonstrated that in areas of high population density and substantial rainfall, combined sewer systems are significant source terms for contaminants and bacteria. Growth projections are available for all water management districts in the state of Florida. It is obvious that the projected population densities in most parts of the state obviate the feasibility of either septic or combined sewer systems.

c. Several estuaries in Florida are involved in federal programs that assist in information gathering, planning and/or managing resources. Notable among these are the National Estuarine Program (NEP) sites. NEP's are presently located in the Lower St. John's River, Indian River Lagoon, Sarasota Bay, Tampa Bay and Apalachicola Bay. Many other estuaries in the state may qualify for the program and additional NEP siting should be encouraged.

d. Habitat destruction has been repeatedly identified by the management community as a priority environmental problem in Florida's estuaries. Concern even exists within pristine systems. Efforts need to be made to (1) restore habitats by traditional methods, (2) develop new approaches to restoration (see below) which may also facilitate amelioration of certain non-point source impacts and (3) increase the current understanding of habitat and microhabitat structure and function in Florida's estuaries.

e. Scholars have begun to question the wisdom of the "control by regulation" approach to management. Trends in government and politics during the past decade have been toward deregulation. The perception is that such trends are accelerating. The challenge to management may be to find ways of overcoming the "tragedy of the commons" by incentive based approaches to management. Such approaches are anchored on the concepts of education and public stewardship. Implementation of this approach will require considerable research and will not be immediate. It will need to reach policy makers, developers, existing residents and especially new residents in the state. Programs currently in place, such as the Florida Sea Grant Extension Program, and outreach programs associated with the water management districts, the NEP's and the State University System, seem ready and capable of providing a portion of the education and of promoting the philosophy needed to form the foundation of an incentive based management strategy. Most important will be the willingness of the state to provide financial incentives that favor sustainable development of estuarine resources.

f. Currently, Florida's water policy does not include the estuaries. Given the ratio of watershed to estuary surface area and the importance of freshwater to the estuaries, the failure to consider the estuaries within the state's water policy is a serious oversight. The task of developing an estuary policy that can be merged with the current water policy should be considered among the highest priority environmental policy needs in the state.

2. Recommendations for the development of new tools and protocols

a. There is currently a massive amount of data on Florida's estuaries. Use of such a large data set for identifying and solving problems is greatly enhanced by the data management and manipulation capabilities afforded by geographical information systems (GIS). Originally developed as the COMPAS system in conjunction with the Office of Ocean Resources Conservation and Assessment within NOAA, the Florida Department of Environmental Protection has been creating a new GIS that will address the needs described above. We strongly support this effort and make the following recommendations:

i. Several GIS's exist or are being developed simultaneously within the state and efforts should be made to coordinate them (this is not to suggest that cooperation does not exist at present). Funding for GIS by the state should be tied, in part, to a demonstration of cooperation to minimize unnecessary redundancy and maximize standardization.

ii. DEP, other agencies (e.g., water management districts) and the state universities should coordinate data collection and input, as well as documentation, standardization and quality assurance for all GIS's.

iii. Access to the state GIS should be available to public and private users through the internet. Nodes can be established to pass information in various forms to users (e.g., Florida Sea Grant for the universities, water management districts for local government users and consulting firms) and to fill requests for hard copy and other data products.

b. Standardization and documentation of data collection protocols, and quality assurance and control seem absolutely crucial for laboratories making measurements on the state's estuaries. Failure to document techniques or to utilize standard procedures has severely limited the ability to use and combine historical data sets and has created difficulties in developing GIS tools. Teams of experts from the management, private and academic sectors need to collaborate in the development of standards and protocols. And efforts must be made to ensure that accepted procedures are followed.

c. Restoration ecology is a young science but significant success has been achieved in restoring mangrove habitat in certain estuaries in Florida. Success at recovering seagrass communities by encouraging recruitment through improvement of water clarity and by controlling eutrophication has also been impressive. Experience in freshwater ecosystems suggests that wetlands restoration can be used, not only to improve habitat, but to filter contaminants as well. Such approaches should be considered for estuaries. Restoration engineering may ultimately prove useful for reclaiming habitat, for providing aesthetics and for buffering estuarine resources against contamination.

3. Recommendations for research

Recommendations for research are described further in Part 2 (Technical Paper-86) of this report which is provided to the Florida Sea Grant Program. Certain major themes in estuarine research are considered here and a particular research philosophy that considers estuarine environmental variability and its implications to management is put forth.

a. The hydrological environment represents the most crucial component of the equation that relates understanding to management of Florida's estuaries. In this study, the existence of several hydrological models became apparent. We suggest that while such models are useful, hydrological management involves not simply turning the flow to each estuary on and off. It involves an awareness of both the flow terms and of the relationship between water and land use upstream. (This is not a new idea.) Continued efforts to quantify the hydrology of Florida's estuaries need to be supported. More importantly, the relationships between water policy, land use and demography, and estuarine resources need to become a central focus of estuarine research. In particular, the role of water in the ecosystem and in relation to the annual salinity cycle must be clarified and that information must be used to establish minimum and maximum flow requirements for the state's estuaries.

There has been a change in the underlying focus (i.e., goals) driving water management over the past century. Early-on the goal of water management was flood control. Agriculture (drainage and irrigation) was a second priority; insect control was a third. Today, management is refocused on the problems of providing water to a growing population and on supporting development within the state. The economic and aesthetic values of Florida's estuaries depend upon the success of water management. This, in turn, depends on how well the management community understands the hydrology (and its relation to the resource).

Understanding the hydrology requires a knowledge of cyclic changes in water flow, not only on timescales of seasons, but over years and even decades. An approach to gaining that understanding is presented below.

b. Two sorts of variability exist in nature, patterned and chaotic. The former is predictable, the latter is not. Patterned or cyclic variability can provide information about trends or directions of change. The recommendation made here is not a research product but rather a way of thinking about how to look for answers. A central premise of our argument is that for those parts of the system for which change is cyclic, a level of predictability and manageability exists so long as one understands from where in the cycle one's measurements are being collected.

The model put forth in this document is that environmental and biological variability is continuous (thus, to quote Heraclitus, ca. 500 BC, "The only constant is change") and many processes are patterned. That is, a given variable in the estuary, say seagrass density, changes over time, on scales of tens of years (Fourqurean et al. 1995; Zieman et al. 1995). Hence, seagrass density is a useful indicator of environmental quality if one knows where in the cycle, from low to high seagrass density, one is collecting data. By determining the cycles of key environmental variables and indicators, such as fish population dynamics, hydrology (flows, wet versus dry periods) and vegetation (seagrasses, phytoplankton), it will be possible to provide the time line against which to evaluate data collected in the present. The importance of pulses and cycles has recently been recognized in estuarine ecosystems (Odum et al. 1995). Describing these cycles and understanding their forcing and significance has been described as a new paradigm in estuarine ecology (Blum 1995).

It is unrealistic to believe that research, or even monitoring activities, will extend much beyond five years, a decade at best. These timescales are barely adequate to address the sorts of questions that are needed to set management policies. Alternatively, geological, hydrological and biological cycles (as well as information about climate and hydrodynamics) can be resolved by a paleoecological approach focused on timescales of tens to hundreds of years. Chemical, biochemical, isotopic and geological (including fossil) information can be gathered on this time scale, to paint with at least the accuracy of current models, a picture of the watersheds through a period of time sufficient to identify cyclic phenomena on the order of ten to one hundred years.

The cycles approach must be coupled with a serious collection of data on the contemporary system. These data are then "placed on the time line", or more accurately, into the appropriate cycle. From a management perspective, one can plan activities and modifications to an estuary or watershed that conform to natural cycles. For instance, guidance on the regulation of freshwater flow into an estuary is certain to be obtained from an understanding of flow patterns over the past hundred years. And rather than wait another 50 years for the first century of data, the paleological record can provide much centuries-scale information, for certain variables, relatively quickly.

In the end, however, it must be recognized that an understanding of the natural physical and biological cycles that take place within an estuary is necessary but not sufficient to manage the system. A second set of forcing functions, based in the socioeconomic environment also influences the managed system. As discussed in the Introduction, the broad concepts presented here must be considered in an even broader context which recognizes the influence of society on the ecosystem and plans scientific research within a framework that takes account of the fact that man is a significant, even dominant, component in every estuary in Florida.

c. A research program should be developed to describe the natural and socioeconomic processes which govern the ecosystems of several selected estuaries. The research should seek to relate the natural and human forcing of the ecosystem to the hydrological environment and should identify the relationship of contemporary observations to the longterm pulsing of the environment. This program should be undertaken as a joint venture between the academic and agency scientific communities in coordination with the policy and management sectors of academe and government.

Two characteristics about the scientific data base stand out in the present literature on Florida's estuaries. First, it is apparent, especially in the planning literature, that much of the data are old, and new surveys of resources are in order for some estuaries. Second, most of the data are in the form of standing stock assessments, surveys and resource distributions. Information on processes and biological rates is scarce. There are very few trophic dynamic studies on Florida's estuaries. And direct assessments of stress in the system are almost nonexistent. Data on the relationships between biotic resources and the hydrodynamic environment are not widely available. Collection of these types of data in selected estuaries should be priority objectives of a coordinated research program.

To be useful, the results of the scientific effort must be merged with demographic and socioeconomic data to test hypotheses in environmental policy, particularly as they relate to incentive based approaches to management. The design of the scientific component of this effort must incorporate this multidisciplary context during the planning stage.

C. System-Specific Summaries

1. Lower St. John's River Estuary (Figure 4)

a. Physical setting and climatology - The principal summary documents from which information was obtained on this estuary are St. Johns River Water Management District (1993) and Watkins (1995). Portions of the lower St. Johns River estuary are located within Duval, Clay, St. John's, Putnam, Flagler and Volusia counties. The area of the estuary is 2,777 square miles, which encompasses the region from Welaka to Jacksonville. The estuary has a large drainage basin, 9,562 square miles, encompassing approximately one-sixth of the surface area of the state of Florida. The basin has a maximum elevation of just over 197 feet and is drained by 12 major tributaries. The largest of these is the Ocklawaha River. The St. Johns River is long, with a shallow-grade (0.1foot/mile) and a tidal amplitude of 4.9 feet at Mayport.

The climate is transitional between subtropical and humid southeastern continental. Most of the 52 inches annual precipitation in the basin occurs between June and September; evapotranspiration ranges from 35-43 inches/year.

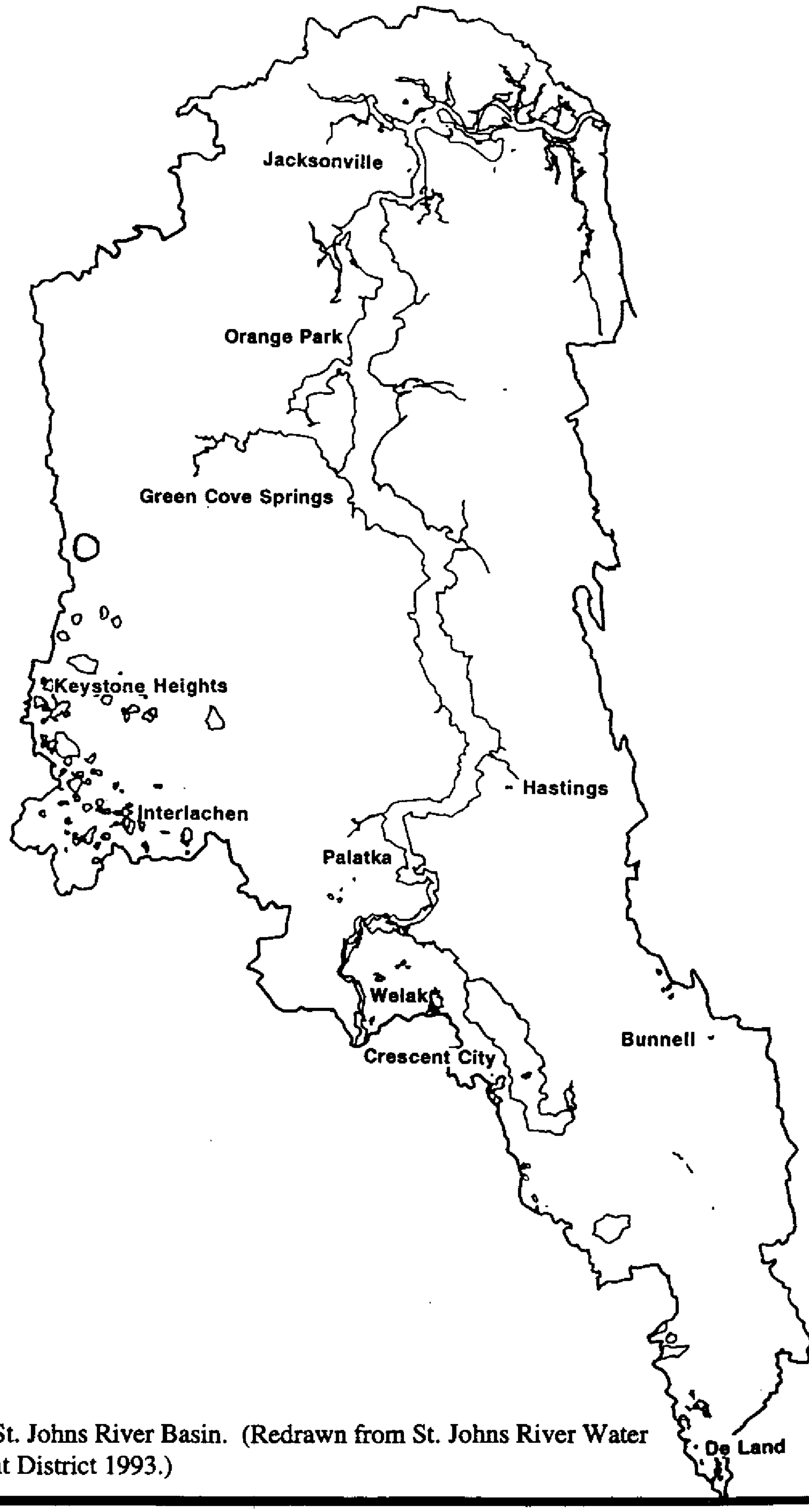

Figure 4. The Lower St. Johns River Basin. (Redrawn from St. Johns River Water Management District 1993.)

Water quality in the estuary ranges from good in sparsely populated areas to poor in the urban reaches, around Jacksonville (Hand and Paulic 1992). However, land use practices upstream, in the drainage basin, seem to be having an impact on the estuary (see below). Expected increases in urbanization will likely result in greater stress to the system and put increased pressure on the resource base. Soil erosion has been slowly changing the river. However, dredging will increase the rate of change in water quality and natural habitats.

The St. Johns River watershed is linked both naturally and artificially to the watershed that drains the Indian River Lagoon system to the south. The circulation of the lower river is tidally dominated and influenced by a salt wedge. Brackish water is found well upstream, however, because calcium-rich ground water seeps occur upstream of Palatka. This permits stingrays, flounders and blue crabs to occur as much as 200 miles from the sea (Odum 1953).

Many lakes drain the basin; Crescent and Doctors Lakes are the principal lakes. The Trail and Crescent-Deland Ridges are important for groundwater recharge.

b. Living resources and ecosystems - In this report an ecosystem is defined in the broadest sense of the term, that is, as consisting of physical habitat, the biological niche and all interactions in time and space within and among organisms, populations and communities with the coincident biotic and abiotic environments. The St. Johns River estuary system contains both freshwater wetlands and salt marshes. The latter are found in northeast Duval County. The total area encompassed by wetlands has, at present, not been completely determined. However, surveys of the wetlands are underway. Most of the wetland ecosystems in the St. Johns River system are freshwater and consist of bottomland hardwood forests and shallow marshes. The marshes are important nursery habitats for fish and they are visited by manatees.

Saltmarshes are nurseries for shrimps and other shellfish, many of which contribute to a commercial fishery worth several million dollars annually (Hale et al. 1990). While it is known that the estuary is an important spawning and nursery area for blue crab, and habitat for juvenile white, brown and pink shrimps, not much is known about the ecology of these crustaceans while they are in the estuary (Joyce 1965; Durako et al. 1988).

Approximately 170 species of teleost fish from 55 families occur in the estuary. Major families include the Clupeidae (herrings) and Cyprinodontidae (killifish), Centrarchidae (sunfish), Scaenidae (drums) and Gobiidae (gobies). The biodiversity of the estuary reflects the diversity of microhabitats and niches within the system, with highest diversity in the lower basin.

The diversity of fish species in the St. Johns River system has resulted in the creation of important sport fisheries, including several centrarchids (e.g., largemouth bass, crappie, bream) and the southern most population of striped bass in the US (though these may not be reproductive and the Florida Game and Freshwater Fish Commission supplements the population with hatchery-reared stocks). Marine fish in the estuary include snappers, spotted sea trout, red drum and sheepshead.

Several protected and endangered species find habitat in the St. Johns River estuary. These include the West Indian manatee, the bald eagle, wood stork, American alligator and the alligator snapping turtle. The Black Creek crayfish is endemic to the upper reaches of the north and south forks of black creek.

c. Demographic patterns and socioeconomic trends - In 1990, more than 2 million people lived in the lower St. Johns River basin (Shermyen 1991). Jacksonville, with a population exceeding 640,000, is the regional urban center and is expected to grow by ca. 38%, to 880,000, during the 20 year period from 1990 to 2010.

The Ocklawaha River is one of the major tributaries of the Lower St. Johns River Basin (LSJRB). The city of Orlando, located in the Middle St. Johns River basin, is one of the largest cities in the region. The population of Orlando, which was 600,000 in 1990, will approach 1 million in 2010. This increase of 67% over 20 years represents the highest growth rate in the region.

In addition to urban growth, development is occurring rapidly in the rural areas in the basin, with development of formerly undeveloped land and urbanization of agricultural land. The result of this growth and the associated development of housing, business and infrastructure is to bolster the economy, at least temporarily. However, it is expected by all state and federal management agencies from which data are available that demographic trends will place a significant burden on the estuary and will create substantial challenges in resource and water quality management.

d. Water and sediment quality - With the exception of one location that is designated as Class II (usable for shellfish propagation or harvesting) all waters within the basin are classified as Class III (recreation, capable of sustaining healthy fish and wildlife populations). Water quality in the lower St. Johns River estuary and its drainage basin ranges from good to poor. Water quality in the tidal portion of the estuary tends to be better than it is in the upper reaches of the river and in the tributaries because of tidally induced dilution (Anderson and Goolsby 1973; FDEP 1994).

The principal environmental problems facing the lower St. Johns River estuary include: eutrophication (i.e., nutrient enrichment) and BOD, introduction of pathogens, heavy metals contamination, turbidity, habitat loss, and the loading of toxic synthetic organic contaminants. The Lower St. Johns River basin has been divided, for purposes of SWIM planning into three basins and 13 sub-basins. It is beyond the scope of this document to provide specific details on the characteristics of each of these, but it is noted here that considerable between-sub-basin variability exists in water quality.

Nutrient enrichment in the estuary has occurred from both point and non-point sources. Between 50 and 90% of the load is from non-point sources, though 260 - 380 wastewater point sources exist in Jacksonville alone. In addition, numerous septic systems, operating with variable effectiveness, exist throughout the basin. Septic system failure is one of the top three causes of surface water quality standards violations in Jacksonville (City of Jacksonville 1987). Septic systems, combined with surface stormwater, agricultural, and industrial runoff constitute non-point sources of nutrients that represent a major challenge to control and mitigation efforts. For example, in Rice Creek, in the west planning region of the St. Johns River Water Management District, pulp mill effluents have resulted in reduced dissolved oxygen (DO) values (<5 mg/l) in more than 85% of the samples tested. As is typical of point source contamination, a variety of water quality parameters have been affected by the pulp mill discharge. These include color, transparency, dissolved nutrient levels, and biological oxygen demand (BOD). The natural blackwater swamp wetlands that contribute to many of the tributaries of the lower St. Johns River basin and the slow circulation that characterizes these systems sets limits on the rate of nutrient and organics loading that they can accommodate (Windsor 1985). In Jacksonville, raw sewage outfalls and paper mill effluents were removed by 1978. Water quality in this area remains poor, however (Wenzel and McVety 1986).

Basin-wide land use practices, not solely those adjacent to the estuary have a significant influence on water quality in the estuary. Urbanization and associated infrastructure and economic development in the lower St. Johns River basin are having an increasing impact on estuarine water quality. Paper and pulp mills, electric power generation, chemical production, food processing, port and maritime activities and manufacturing all occur within the basin. Currently, all of the major basins suffer from low DO, high coliform levels, odor and eutrophication. PCB and heavy metals contamination have been reported in Duval County. Sediments in the river and its tributaries have been contaminated with mercury, cadmium, zinc and lead (Schropp and Windom 1987; Pierce et al. 1988; FDER 1988) as well as polycyclic aromatic and chlorinated hydrocarbons (Pierce et al. 1988). Dissolved metals, loaded along the river tend to come out of solution in the vicinity of the estuarine turbidity maximum and in locations of high solids loading and/or major changes in salinity. Studies by NOAA's Status and Trends Program and US EPA noted significant levels of PCB's, DDT (including DDT-derivatives) and chlordane in the estuary (the lower St. Johns River ranked 17th of 212 test sites around the nation). Other surveys have not replicated this finding, however. Although, certainly not the most significant location for toxic and hazardous wastes, eight sites in Duval County have been targeted for cleanup through the EPA Superfund Program.

e. Aspects of governance, management and planning - As is true for all estuaries in Florida, regulation of water quality, land and water usage, and development around the estuary and its associated drainage basin is influenced by the policies and regulations of federal, state and county governments. The activities of counties and municipal governments are generally mandated by higher authority such as the state and federal governments. There are nineteen counties in the Lower St. Johns River basin, and at least 12 of these may be involved in the development of plans to manage water quality and resources within the estuary (Water Quality Act of 1987). Responsibility for implementation of regulations at the state level falls primarily with two agencies, the Florida Department of Environmental Protection (FDEP) and the water management district, in this case, St. Johns River Water Management District (SJRWMD). The former is responsible for data collection with the goals of law enforcement and development of new knowledge of system function. The SJRWMD is responsible for basin wide planning and resource management. The lower St. Johns River estuary has also become part of the National Estuary Program, which provides federal assistance for resource conservation, water quality improvement, and planning.

Although a few locations within the basin qualify for special protection due to the superior quality of their waters, most are the subject of a variety of planning and resource management schemes. Principal among these are SWIM and NEP planning. Among the key action items to be addressed are:

i. Improved identification and management of non-point source contamination. This includes both current urban sites and upstream locations particularly in the areas adjacent to Orlando.

ii. Habitat protection and restoration. Development of the NEP and associated planning will help in fulfilling this objective.

iii. Public education and outreach. In the current environment of reduced regulation, public awareness of estuary resources and function are crucial to development of a conservation consciousness.

iv. Coordination between agencies. Collaborative planning must be enhanced and the involvement and support of upstream communities must be obtained in order to control growth in areas that will ultimately impact the estuary. Further coordination of monitoring and data base management are crucial.

2. Indian River Lagoon (Figure 5)

a. Physical setting and climatology - The principal sources of information on the Indian River Lagoon system were Barile (1988), Woodward-Clyde (1994a-i), St. Johns River Water Management District and South Florida Water Management District (1993). The Indian River Lagoon (IRL) system is a lagoonal estuary running north-south and bounded to the east by sandy barrier beach islands and to the

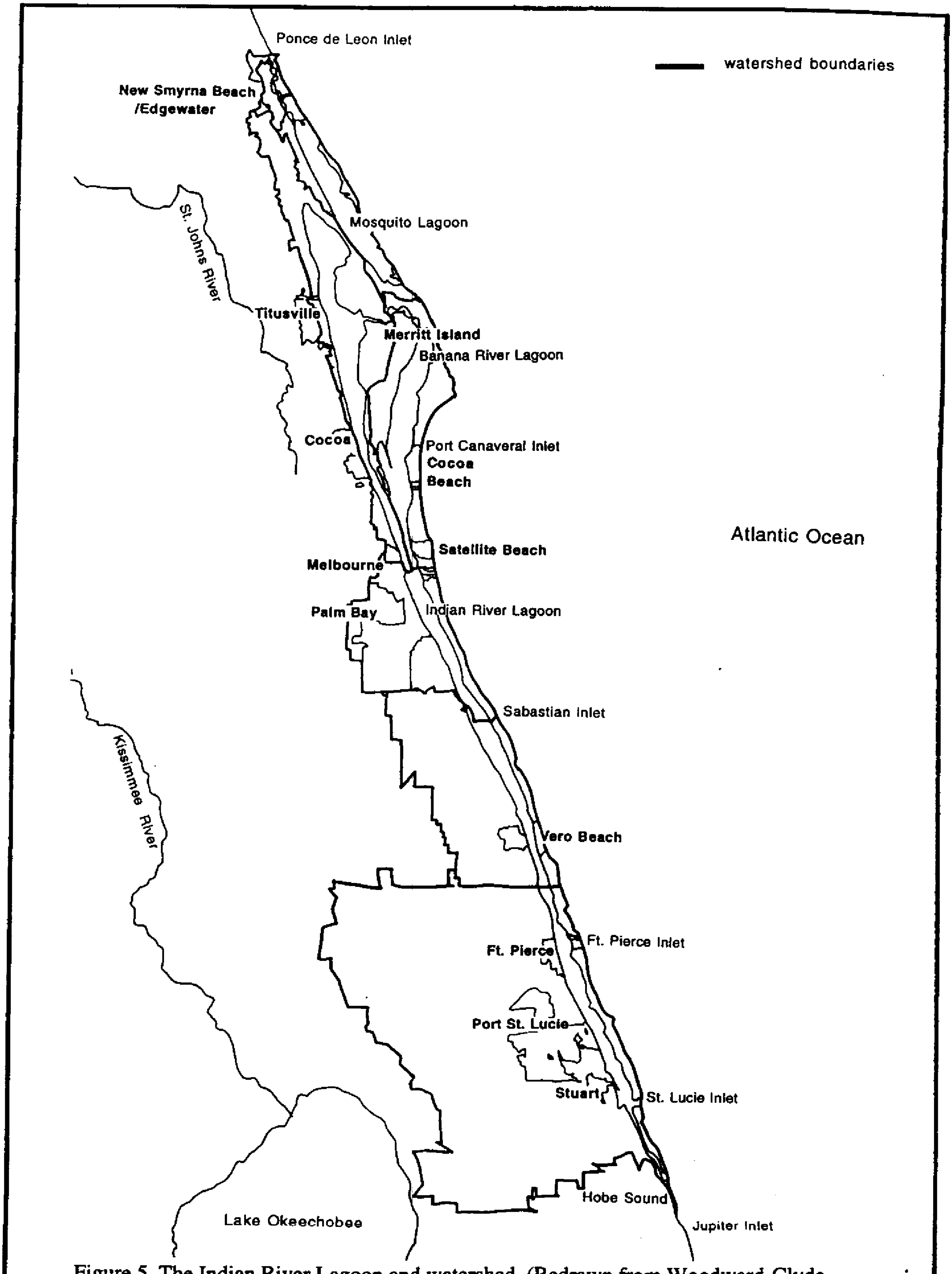

Figure 5. The Indian River Lagoon and watershed. (Redrawn from Woodward-Clyde 1994a.)

west by the Florida peninsula. The IRL estuary is located in seven counties extending 155 miles from Ponce de Leon Inlet in Volusia County, south to Jupiter Inlet in Palm Beach County. The western boundary of the watershed is not clearly established in every part of the system (due to artificial expansion of the watershed) though the Atlantic Coastal ridge forms one natural boundary.

The IRL system consists of three principal water bodies: Mosquito Lagoon, the Banana River and the IRL proper. Several categorizations of the sub-basins have been used in descriptions of the system. One way of characterizing the IRL system is as six subdivisions: (1) North Mosquito Lagoon; (2) the Cape Lagoon Complex, includes the northern reaches of the IRL and the Banana River; (3) the Central Lagoon sub-division; (4) Indian River Narrows, from Wabasso Causeway to the Main Canal at Vero Beach; (5) the Southern Lagoon sub-division, a shallow portion of the lagoon as well as St. Lucie and Jupiter Inlets; (6) Jupiter Narrows, south of St. Lucie Inlet as well as the small open water areas that separate Hobe Sound and Jupiter Inlet from the rest of the IRL complex. Another method of describing the IRL system is as six segments based on the three principal water bodies (Clapp 1987; Glatzel and Da Costa 1988): 1. Mosquito Lagoon, 2. Banana River, 3. North IRL, 4. North Central IRL, 5. South Central IRL, 6. South IRL. The first three segments are to the north and are characterized by low flow, small watersheds and wide open-water expanses. The north central region is dominated by Sebastian Inlet and is characterized by greater freshwater influx and stream flow, a relatively large watershed and relatively low, variable salinity. The two southern segments have artificially enlarged watersheds and experience a substantial tidal influence due to the occurrence of three inlets in the region. Prior to 1987, the IRL watershed was 2,279 square miles. Since that time, 4-5 square miles have be redirected to drain into the St. Johns River. The current watershed is 2,234 square miles of which only 871 square miles (39%) is natural. The remainder has been artificially produced by drainage ditch and canal construction since the early part of the 20th century.

Like the lower St. Johns River estuary, the IRL is perceived to be in a climatologically transitional region between temperate (humid continental or Carolinian temperate) and sub-tropical zones, with two seasons, wet (May to October) and dry (November to April). Winters are mild; summers are hot. Annual mean temperature is 72.6°F. Climate has a substantial influence on the IRL. Temperature influences dissolved oxygen (DO) levels in the estuary, as well as bacterial activities. Winds influence circulation patterns, wave heights, and evapotranspiration (potentially affecting local salinities). Rainfall, of course, also influences salinity as well as turbidity and contaminant loadings. The region is also susceptible to periodic, catastrophic perturbation by hurricanes and tornadoes. The climate has encouraged agriculture and, more recently, intensive development.

Hydrodynamically, the IRL system is affected by its long, narrow shape and shallow sand-mud substrate. Generation of tides within the lagoon is negligible. In Mosquito Lagoon, the Banana River and North IRL, flow is slow. Tidal flow and flushing increase to the south. However, numerous modifications have been made to lagoon system which have affected the circulation and hydrodynamics of the estuary. For example, the inlets have been "stabilized" (normally their positions vary), a deep (ca. 12 ft) channel, the Atlantic Intracoastal Waterway, has been dredged through the shallow (<3 to 6 ft) estuary, and numerous bridges and causeways have been constructed. While early wooden bridges did not restrict the flow of water through the estuary, solid fill causeways constructed between 1920 and 1970 have altered the circulation considerably. Since 1970, there has been an effort to reestablish the flow that was interrupted by the causeways.

The hydrological cycle of the IRL has been described with a four-compartment model consisting of the atmosphere, watershed and aquifers, receiving waters (the estuary proper), and the Atlantic Ocean. Water balance in the northern segments differs from that in other segments. In the Banana River and Mosquito Lagoon, high evaporation and low freshwater input create a hydrologic deficit that must be recovered by the supplement of saline water from the south. In the south, freshwater input always exceeds evaporative losses. This creates a "negative estuary" in the Banana River throughout the year and is characterized by water debits that are balanced by input from the south. The result is that the northern segments tend to be susceptible to retention of contaminant loads.

b. Living resources and ecosystems - Vegetative communities include submerged vascular plants (e.g., seagrasses), phytoplankton, saltmarshes and mangrove stands. Beds of the seagrasses *Thalassia testudinum, Haladule wrightii* and *Syringodium filiforme* and four other species (including at least one very rare *Halophila* species are, as in most of Florida's estuaries, productive and important (Heffernan and Gibson 1983).

Between 1970 and 1986 seagrass coverage in the IRL decreased by 11% (Hoffman and Haddad 1988). However, in 1986, an increase in submerged aquatic vegetative cover was apparent as a function of recruitment of *Halophila* and the alga, *Caulerpa* to deeper areas. This represented an increase from the 16 year period prior to 1986 from 36 to 38% bottom coverage. However, during the ensuing 6 year period (1986-1992), coverage by submerged aquatic vegetation declined by 6% to 32% of bottom area. In the North IRL, seagrass coverage declined by 42% between 1940 and 1992, and by 38% between Melbourne and Sebastian Inlets. In some portions of the lagoon seagrass losses exceed 83% and as of 1994, loss of seagrass habitat in the entire IRL was on the order of 27% (Morris and Tomasko 1993). The continued loss of seagrass habitat reflects a trend toward deterioration in water clarity that is generally interpreted as indicative of degraded water quality. However, it is important to recognize that longterm (i.e., 30-50 year) patterns in sea grass population dynamics and total floristics are complex. The data needed to understand these phenomena are scarce. Hence, data must be interpreted cautiously. Nonetheless, within the context of water clarity criteria, a definite downward trend seems to characterize the lagoonal system. Recovery of seagrass communities can only be accomplished by restoration of habitat, and as such seagrasses may serve as indicators of the recovery of water clarity during future conservation efforts.

Seagrass beds tend to contain the biologically most diverse communities; biodiversity decreases substantially outside of seagrass beds (Virnstein et al. 1983). Phytoplankton accounts for only a small proportion (2-7%) of the lagoonal primary production. Seagrasses contribute 50-85% of the carbon fixation to the system, and with the inclusion of macrophytic algae, accounts for up to 90% of the primary production in the IRL. There is some evidence, though not definitive as yet, that nitrogen is the principal nutrient limiting primary production in the estuary. However, many exceptions to this relationship have been documented in other estuaries (see Biscayne and Florida Bays). Chlorophyll levels in the estuary have declined, on average, over the past decade.

Censuses of the wetland and faunal communities of the estuary have been conducted by the National Estuarine Program in the Indian River Lagoon (Woodward-Clyde 1994a). A brief synopsis is presented here.

Approximately 700 species of invertebrates including many mollusks (some of which are commercially important, e.g., certain bivalves), amphipods and other crustaceans have been collected in the IRL. Approximately 10% of Florida's salt marshes occur in the IRL, but most are restricted to the northern segments (Myers and Ewel 1990). Mangrove communities also occur throughout the lagoon, but healthy adult stands tend to be thermally restricted to the area south of Sebastian Inlet. The red mangrove, *Rhizophora mangle*, is the dominant species.

The practice of impounding, common in the Indian River Lagoon from the 1930s to the 1970s as a method of mosquito control permitted reduced application of DDT. However, the alteration of water levels produced in mosquito impoundments tended to kill back mangroves and other marsh plants resulting in decreased primary production, as well as loss of perches and nesting sites for roosting birds. In addition, the impoundments have modified flows and natural exchanges of materials and biota and they have enhanced the propagation of exotic species (Gilmore et al. 1982; 1987; Rey and Gilmore 1989). The impoundment of 40,000 acres of lagoon was estimated to represent a significant loss of estuarine productivity (Montague and Wiegert 1990) and today the practice is not considered to be a sound management approach.

The diversity of finfish in the IRL and adjacent waters is among the highest in the United States; more than 680 species have been identified. Species diversity in the southern segments of the IRL is about double that in the northern segments (Gilmore 1977; Snelson 1983). The inlets and hard-bottom reefs have the richest fish assemblages. As would be expected, forage species (mullets, bay anchovies, etc.) make the largest contribution to the fish biomass in the estuary. The abundances of many gamefish (e.g., snook, red drum) in the estuary have been increasing since the late 1950s, but spotted sea trout populations seem to be declining. Removal of mosquito impoundments are having a generally positive influence on fish populations.

Mollusks and crustaceans are important components of the IRL biota and several fisheries target these resources. Oyster (i.e., American oyster) fishing as been a key enterprise in the IRL for more than a century. Blue crab and southern hard clam are also important, with the latter surpassing oyster landings since 1977. Shellfish landings have, in general, declined in the IRL since the mid 1980s; the cause is not clear. Among the possible reasons for reductions in the fishery are closure of shellfish beds due to bacterial contamination (thought to be associated with septic tank usage; see below).

In addition to fish, 367 species of birds (125 of which breed and 172 of which over-winter) have been documented in the IRL. More than 200,000 individual birds have been counted in a single census. Fifty-two reptile species, including several endangered sea turtles, and approximately 30 mammal species, including 20% of the endangered manatee population occur in the IRL. A total of 11 species currently listed by the US Fish and Wildlife Service as endangered and 9 listed as threatened occur in the IRL.

c. Demographic patterns and socioeconomic trends - Human habitation of the IRL can be traced to prehistoric times. From 1820 to 1940, the entire population of the region was $<$100,000. By 1960, the population approximately doubled. And during the ensuing decade (1960 to 1970), it increased by an additional 100% (to ca. 302,000). Between 1970 and 1990, population in the IRL increased 124%, on average (range for segments= 35 to 220%). The population is expected to grow at a lower rate (60%, on average) for the two decades between 1990 and 2010. At this rate, however, 400,000 more people will enter the region. Maximum growth rates during this period are expected to occur in the southern portion of the estuary where a 94% increase in population has been projected.

For the past two centuries the Indian River Lagoon has been the focal point of commerce and transportation. Efforts to drain the land and regulate the lagoonal hydrology for agriculture date back to the mid-eighteenth century (Barille 1988). Flagler's railroad connected the IRL region to the rest of Florida increasing trade and land exploitation and by the early part of the 20th century, the region was a focal point for citrus cultivation in the state. At the same time, several inlets were stabilized and opened to ship traffic. This had a negative impact on the endemic salt marshes, but it was during this period that several major fisheries were initiated in the IRL. Additional factors responsible for development in the IRL region and its upstream tributaries include: improved drainage for flood control and mosquito control, completion of the Intracoastal Waterway, and construction of Port Canaveral, with a man-made inlet and the Barge Canal. During the second World War, pilot and PT boat training facilities were located in the estuary. Since 1950 the region has been growing, initially through agriculture and fishery activity, and more recently through aerospace, leisure and retirement-oriented industries. Currently the IRL region accounts for 16% of Florida's fisheries landings, 38% of its citrus crop and 16% of its hotels and restaurants.

Urbanization around the estuary and in the watershed has had dramatic impacts on the environment. Legislative and regulatory efforts to mitigate and ameliorate impacts continue to the present day. However, between 1940 and 1987 there was an 895% increase in the land devoted to urban use (e.g., housing, industry) and a 352% increase in the amount of land devoted to agriculture. Projections are that urban land use will increase by 240% by the year 2010, while the amount of land used for agriculture will decline by 6%.

d. Water and sediment quality - The IRL NEP and the water management districts have together sought to evaluate water quality in the estuary. Historically, wastewater treatment was provided by individual septic systems or by as many as 152 small municipal wastewater treatment facilities (mostly in the southern IRL) called "package plants" which process up to 1 million gallons per day (MGD) of sewage. Although these are being phased out, they discharge directly into the lagoon and aquifers. FDEP (1991) determined that these plants threaten water quality in the IRL contributing on average, 30% of the nutrient load to the IRL. Currently, regional plants at Fort Pierce and Cocoa Beach discharge >5 MGD and 10 subregional plants discharge 1.5-5.0 MGD. All discharge into the IRL is scheduled to cease by 1996, resulting in a reduction in wastewater loading to the estuary of 24 MGD.

Industrial point sources to the estuary include thermal effluents from four power plants (1,800 MGD), 4.1 MGD of brine from desalination and 51 MGD from the citrus and seafood processing industries and from land fill borrow pits. DEP has ordered the seafood packing industry at Port Canaveral to cease discharging into the estuary. The impacts of point source loading depend upon the nature of the load and tend to be localized.

Septic systems are among the principal non-point sources of loading to the estuary. They are of particular concern to the management community because septic systems tend to fail when the soil is sandy and the water table is shallow (both characteristic of Florida's estuary regions). More than 270,000 acres of septic fields are considered problematic in the IRL. They have been linked to eutrophication and pathogenic contamination in the estuary and are of special concern in the vicinity of shellfish beds. Unfortunately, septic systems treat approximately 40% of the total domestic wastewater load in the IRL.

Additional non-point sources occur through stormwater drainage into streams and tributaries and through direct runoff. It has been estimated that 99% of the suspended solids, 90% of the metals and DO consuming materials and 50% of the nutrients loaded to Florida waters arrive from non-point sources (Livingston 1984). The St. Johns River Water Management District has developed a model to predict non-point source loading. The model indicates that the highest loads will occur in the south IRL, and that loads, particularly BOD will increase by approximately one third during the next 15-40 years (though the loading of lead and zinc will decline) especially in the central and south IRL. The result is projected to be an 84% increase in BOD and a 16% rise in suspended solids. Land use practices greatly affect the occurrence and impacts of non-point sources. Amelioration of these effects may be achieved through a combination of careful zoning and structural engineering.

Analyses of long term water quality data bases have revealed difficulties in merging data sets and in making comparisons due to a lack of standardization and documentation in monitoring protocols. In general, however, in the northern segments of the IRL water quality tends to decline in developed areas and to be higher in undeveloped areas. Sewage inputs are major causes for water quality deterioration. Total Kjeldahl nitrogen levels are higher in the northern segments than in the south . Phytoplankton blooms tend to occur near waste discharge sites and in the vicinity of septic tank fields. The sediments off Cocoa Beach have high levels of metals, but in most of the northern segments metals levels are not elevated. The south portion of the Banana River, in part because of the nature of its circulation, tends to be a problem area with respect to water and sediment quality. In the north central and south IRL, water quality begins to become more of a problem, with elevated nutrients, tannins (affecting color) and turbidity levels occurring throughout the segments. Metals concentrations are also high in some locations.

e. Aspects of governance, management and planning - As is true for all estuaries within the state, regulation of water quality, land and water usage, and development around the estuary and its associated drainage basin is influenced by the policies and regulations of federal, state and local governments. The activities of counties and municipal governments are generally mandated by higher authority such as the state and federal governments. Seven counties border the IRL system. Responsibility for implementation of regulations at the state level falls primarily to the Department of Environmental Protection (DEP) and the water management district. The IRL is a shared jurisdiction between the St. Johns River and the South Florida Water Management Districts. While in some respects this seems an awkward arrangement, it is justified by the merger (and to some extent the uncertainty) of portions of the IRL and St. Johns River watersheds. Further, there are some strong arguments in favor of multibasin planning. Responsibility for the management of environmental quality has been a concern within the state since the mid-1950s, though regulation has been less than perfect. However, the IRL has for several years been of concern because of the uniqueness of the resources that it encompasses. Thus, by 1969, six aquatic preserves, encompassing 60% of the area of the lagoon were created. The Endangered Species Act has helped to protect sensitive habitats within the estuary. In 1972, the management districts were created and in the late 1980s and early 1990s, SWIM planning was initiated. Water quality regulations were provided in 1972 with the Federal Clean Water Act and in 1990 by Florida's Indian River Lagoon Act. The latter prohibited direct waste water discharge into the estuary. Additional federal and state legislation during the period from 1969-1990, has produced a matrix of regulatory protection for the estuary. Further, in 1990, the IRL became an NEP site. The appropriate question, however, in the present environment of deregulation, is whether or not the IRL can be protected from degradation with reduced enforcement and rescission of legal constraints on alteration of environmental quality. Thoughts on this subject are provided below and in the overview section of this report.

Among the most positive attributes of this area is what appears to be an effort to collaborate among agencies. The NEP and water management districts have identified certain priorities in their programs, both in terms of information needs and management goals that appear more feasible when addressed through a multi-agency effort. There is a strong indication that the public has to be drawn into the process of managing and protecting the system. Public outreach and education are considered part of the management process. It is also clear that population growth and urban development will have a substantial impact on this region. Research and management communities will be challenged to develop novel, tractable impact amelioration and resource protection strategies.

3. Biscayne Bay (Figure 6)

a. Physical setting and climatology - Summary documents on Biscayne Bay that provided information for this report were Dade County DERM (1981; 1987) and South Florida Water Management District (1989). Biscayne Bay is a shallow, well mixed, subtropical estuary in southeastern Florida. The bay consists of three hydrologic regions: 1. North Bay, which runs south from Dumfoundling Bay (at the Broward County line) to the Port of Miami; 2. Central Bay, Port of Miami, south to a line from

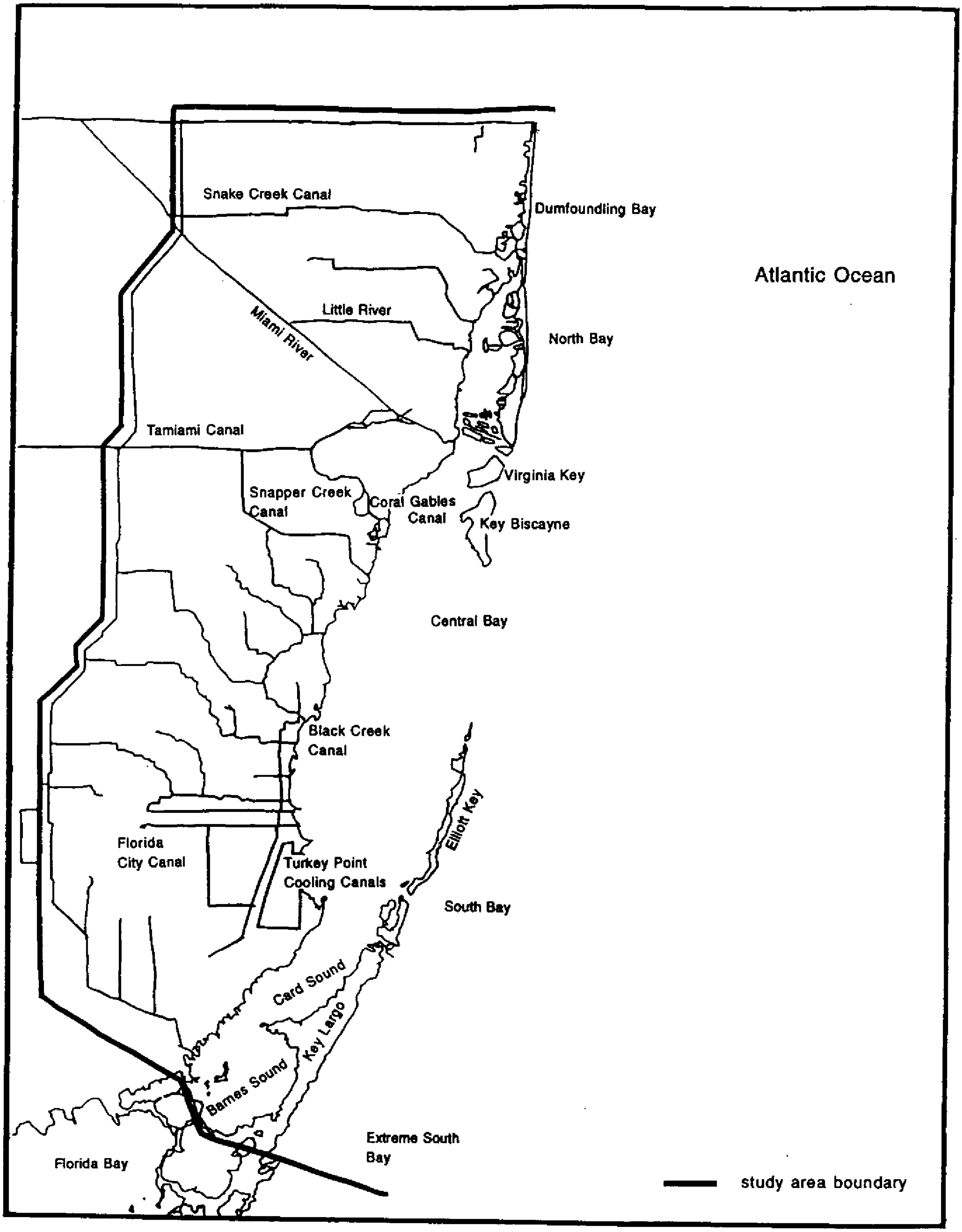

Figure 6. The Biscayne Bay area. (Redrawn from South Florida Water Management District 1989.)

Featherbed Bank to Black Point; 3. South Bay, from Featherbed Bank to US Route 1, including Card sound, Little Card Sound, Barnes Sound and Manatee Bay.

Biscayne Bay drains a relatively small watershed of 938 square miles, which, unlike many of the state's estuaries, is mostly within a single county, i.e., Dade. Four physiographic zones are designated from east to west as: (1) Mangrove and Coastal Glades; (2) the Atlantic Coastal ridge; (3) the Sandy Flatlands; and (4) the Everglades. The mangrove and coastal glades, historically a wetlands system has been drained for agriculture and urban development. The Atlantic Coastal Ridge is 2-10 miles wide and 8-22 feet (south to north) above mean sea level. The Sandy Flatlands is four miles wide and has been developed. The area was poorly drained and characterized by numerous ponds. The flatlands is succeeded by the Everglades which extends inshore some 40 miles, and ranges in elevation from 4 to 13 feet above sea level. The Everglades has poor natural drainage, though portions have been drained for agricultural use and urbanization. Freshwater was provided by seepage directly into the bay from the Biscayne aquifer as well as by surface flow. Draw down of the water table, however, has obviated, this source of freshwater.

There is a mean 2.5 foot semidiurnal tide in the bay, with an average wind speed of <10 knots, 75% of the time. The predominant wind directions are east and southeast. The climate in the bay is subtropical and is characterized by wet and dry, i.e., high and low flow, seasons. High flow into the bay occurs between June and October; low from, from November to May. The total annual flow into Biscayne Bay is 2.98×10^5 million gallons (daily average=818 MGD) with 34%, 26% and 40% going to the North, Central and South Bays, respectively.

Water flow is regulated during most periods. Drainage from eastern Dade County into the bay is regulated largely by a series of primary canals, levees and control structures and secondary ditches and smaller canals. However, surface runoff, precipitation and groundwater seepage also contribute to freshwater input and prevent saltwater intrusion during droughts and periods of reduced flow. Exchange with the Atlantic Ocean occurs through several tidal inlets.

North Bay is crossed by six causeways, dividing the region into seven sections; crossectional areas of causeway openings and inlets determine exchange of water between sections. There are 3 inlets in the North Bay, such that the three middle sections do not connect directly with the ocean. The hydrodynamics of water exchange in the Bay were described by van der Kreeke and Wang (1984). Residence times of water in North Bay vary, as a function of proximity to an inlet, from 3.2-13.2 days.

The hydrodynamics of the Central and South Bays were modeled by Swakon and Wang (1977) and by Chinn Fatt and Wang (1987). Exchange with the ocean is maintained through the Safety Valve, Bear

Cut and Caesar Creek. South Bay is well mixed and vertically homogeneous, with salinity contours running in a north-south direction, parallel to the western shoreline (Chinn Fatt and Wang 1987). Low tidal velocities in South Bay result in long residence times, on the order of 6-26 days, periodically, resulting in hypersaline conditions (Lee 1975). Extreme South Bay (Barnes and Card Sound) also have slow circulation and long residence times. Salinities range from 33-40 ppt during the wet season and 39-46 ppt during the dry season.

Wanless et al. (1984) identified eleven kinds of bottom substrate in Biscayne Bay: rocky, dredged rocky, sand, quartz sand, barrier island sand, skeletal carbonate sand, mud, barren mud, carbonate mud, spoil margin and mangrove soils.

Groundwater enters Biscayne Bay through seepage and direct flow (Parker et al. 1955). Prior to channelization, there was a seepage zone around the bay. Several of these flows were due to groundwater. Today these flows are no longer large enough to produce springs.

b. **Living resources and ecosystems** - As in many estuaries, population growth and rapid development have had a negative impact on habitat integrity and biodiversity. Efforts to restore portions of the Biscayne Bay ecosystem have had notable success during the past few years. Habitats of the drainage basin include submerged, coastal wetlands and coastal uplands.

Submerged habitats support planktonic, micronektonic and nektonic organisms (including fish), as well as benthic and demersal flora and fauna (e.g., seagrass, macrophytic algae, hard and barren bottom organisms). Coastal wetlands and uplands are defined by specific plant communities that are associated with certain shoreline morphologies and proximities to water, elevations, sediment and soil types and nutrient sources.

Seagrasses are among the most important submerged aquatic communities, given their abundance, and the ecological and geological roles they play. Seagrasses support the most diverse biological communities of any habitat in Biscayne Bay (Thorhaug 1976). They help to stabilize soft bottoms (Metro-Dade County Planning Department 1986). The principal kinds of seagrasses are manatee and shoal grasses in the North Bay (where light is limited) and turtle grass in the Central and South Bays. Although dredged and turbid areas of Biscayne Bay no longer support seagrasses because light is insufficient (Fourqurean et al. 1990) and algal blooms further limit light penetration (Wanless et al. 1984), the biomass of seagrasses in the Bay is fairly large, amounting to 400 g/m^2 (=2 tons of carbon per acre).

Hardbottom communities occur throughout the estuary but bare hardbottom communities are found only in the North Bay. The latter constitutes 14% of the bay bottom area. Hardbottoms are not as productive as the extensive soft bottom seagrass beds, though there are seagrasses, sponges, and various hard and soft coraline species associated with them. Bare bottoms, as the name implies are devoid of biota except for crabs, tunicates and a few others species. These communities may be indicators of perturbation.

Typical of tropical estuaries, phytoplankton biomass in Biscayne Bay tends to be low (see below) compared with that of temperate estuaries (Roman et al. 1983). The macronutrient thought to limit the growth of autotrophs in the bay is phosphorus. Chlorophyll concentrations in the North Bay tend to be higher than in Central and South Bay (Brand 1988) with values in the former region on the order of 1-3 ug/l and values of < 1 ug/l typical of the most of the Central and South Bays. The exception is on the west shoreline of the bay, where chlorophyll concentrations tend to exceed 2 ug/l much of the time. A variety of zooplanktonic organisms, ranging from protozoans to gelatinous species occurs (with considerable temporal variation in some forms) in the bay. Zooplankton biomass increases from east to west and from south to north (Roman et al. 1983; Houde and Lovdal 1984). Most fish in the bay are spawned outside the bay and enter during immature life history stages (deSylva 1976). Fish egg and larval abundances are highest in the spring and summer (Houde and Lovdal 1984).

The principal coastal wetland communities around Biscayne Bay include mangrove forests dominated by red, white and black mangroves and buttonwood. Very few mangrove stands remain in the North Bay region, but several robust communities are present in the Central and South Bays, in parks and recreational areas. Inland from the mangrove forests are saltmarshes. These tend to be brackish and salt tolerant grass communities such as salt grass, cord grass, black rush, salt wart and sea purslane. Additionally, inland estuarine marshes, dominated by *Spartina*, function as ecotones between fresh and salt water habitats. A variety of other intertidal communities exist on muddy, sandy and rocky shores. Coastal uplands include hammocks, pinelands and strand communities (beaches and dunes). Two kinds of hammocks are found in Biscayne Bay, oak/palm and tropical/West Indian. The former exist only as remnant communities today; tropical hammocks are climax forests and are characterized by high biodiversity. Pinelands, primarily slash pine, contain numerous endangered forms and a rich and diverse understory. Pinelands are fire subclimax communities. Beach and dune communities were prevalent on the barrier islands before major land development occurred. Through the efforts of the Dade County Department of Environmental Resource Management (DERM), these communities are being restored. They consist of a scrub, grass and vine vegetation above the high water mark.

The fauna of Biscayne Bay includes some 800 species of benthic and pelagic invertebrates (Schroeder 1984), some 512 species of fish from some 9 different habitat types (e.g. , oceanic, coral reef, etc.), a variety of reptile and amphibian taxa, including several endangered species (Kushlan and Mazotti 1973; Ogden 1978; Florida Power and Light 1987), and an abundant and diverse avifauna (Owre 1976). Two species of mammals (bottlenose dolphin and West Indian Manatee) obtain foraging habitat in the bay (Odell 1976). Biscayne Bay and the Florida Keys provide critical habitat for several endangered or threatened species as well as species of special concern.

Four kinds of fisheries occur in the estuary: food fish (e.g., groupers, snappers), sport fish (e.g., tarpon, bone fish), crustaceans (crabs, shrimps) and bait fish (pilchard, ballyhoo, mullet). At the retail level, the commercial fishery is conservatively valued at ca. 2.8 million dollars annually (Berkley 1984).

c. Demographic patterns and socioeconomic trends - Land use around Biscayne Bay is approximately one-third urbanized, one-third agricultural and one-third wetlands. Human population density around the North Bay is among the highest in Florida. Land use in the area is largely residential and the economy is strongly tourism-based. Commercial development is dominated by Port-and-Harbor related activity. Thus, impacts to the system are generally not related to heavy industrial development, but rather to the effects of dredging, bulkheading, domestic waste discharge and spillage, and fuel and petroleum-based contamination, including contamination by jet fuels and products associated with the air-transport industry (Baddour 1983). Nonetheless, due to the shallow water table, and the location of industrial facilities above the Biscayne aquifer, metals and solvents have become significant comtaminants. Thus, 83 sites in northern Dade County are designated Superfund priority sites (EPA 1990). Impacts in the agriculturally developed region adjacent to the Central Bay are due to non-point source pesticide and fertilizer input. Expected growth and continued urbanization in Dade County are expected to have an impact on drainage into the Central and South Bays in the coming decades. Efforts to ameliorate impacts of urbanization in the North and Central Bays have been successful and are ongoing.

d. Water and sediment quality - Water quality in Biscayne Bay is generally good. Dissolved oxygen (DO) has averaged ca. 5 mg/l, with lower values in the tributaries (as is typical of area influenced by groundwater seepage). Nitrogen levels are sometimes elevated in the canals and tributaries; and while not considered the growth-limiting macronutrient in the system (but see Tomas and Bendis 1995), variations in concentration, mode of delivery and chemical species of nitrogens may affect the succession and structure of resident primary producers. Dissolved ammonium levels exceeded Dade County standards (there is no state standard for ammonium) in 49% of the samples that were analyzed. The South Florida Water Management District (1989) suggested that aquatic plant community structure within Biscayne National Park may be sensitive to nitrogen loading.

It is generally thought that South Florida estuaries are unusual in being clear-water ecosystems, capable of sustaining a rich bottom flora, and particularly, seagrasses. The minimum was transparency for seagrass growth is ca. 6 feet. Since Biscayne Bay is relatively shallow, much of the bay should support bottom plant growth. Further nephthalometrically determined turbidity standards are met at >80% of the stations that have been examined. However, the rate of light attenuation (the rate at which light is absorbed by the water and the particles therein) at 30 of 70 stations in the bay, exceeds the minimum required for seagrass growth (Alleman 1991; SFWMD 1994a). Most of these stations were located in the North Bay, near tributaries. Predictably, they are characterized by phytoplankton-dominated primary production, rather than by submerged grasses.

In general, heavy metals are not a problem, though levels of certain metals were higher in Biscayne National Park than in the North Bay, which would be the expect source area. It is unclear why this pattern has been detected. Levels of tributylin (a component of antifouling paints) in the estuary were elevated above standards in nearly half of the stations sampled (mostly near marinas). Prohibitions on the use of tributylin should result in a decrease in its presence in the environment. However, the rate of decay and levels of contamination of sediments are not known. Shellfish in Biscayne Bay have exhibited small elevations in the concentrations of certain heavy metals and synthetic hydrocarbons, but the data do not indicate significant contamination.

Biscayne Bay is an urban estuary. Given the population density, the bay is potentially susceptible to large anthropogenic impacts. It is commendable that efforts at restoration and conservation, at monitoring and collection of data bases, and at regulation of contaminant sources have shown a degree of success. Of 150 significant trends in the data, 117 (78%) indicate significant improvement. This would suggest that environmental management efforts are paying off.

e. Aspects of regulation, management and planning - As is true throughout the state, county, state and federal agencies regulate aspects of environmental quality, development and natural resource utilization around the estuary. Because much of Biscayne Bay lies within a national park, considerable authority for management and regulation rests with the Parks Service. The layering of regulations and regulatory responsibility is complex.

The South Florida Water Management District (SFWMD) and the Dade County Department of Environmental Resource Management (DERM) seem to work together to collect information about the estuary and the use of that information in the planning process. These agencies coordinate their efforts with the South Florida Regional Planning Council, the City of Miami, the Dade County Planning Office, the Department of Transportation and other local agencies, as well as with the National Parks Service, NOAA and EPA.

SFWMD and DERM have attempted to compile much of the existing data and have collected an extensive (1979-1992 has been analyzed) time-series on water quality for the entire Biscayne Bay basin.

Data acquisition and analysis is continuing. This data set and the cooperation between the management district and DERM have facilitated planning for (a) improved responsiveness to natural disasters (special attention has been given to the environmental perturbations and disruptions of services and regulatory effectiveness following hurricane Andrew), (b) more effectively managing canal discharges and both natural and anthropogenically induced variability in bay salinity (Lee 1975; Chin Fatt and Wang 1987). The seasonal salinity cycle is important to habitat integrity and numerous biological processes depend upon this cycle (Zieman et al. 1984; Colby et al. 1985; Thayer et al. 1987). Ground water movements are also a focus of current attention (Klein and Hull 1978). SFWMD has suggested, unofficially, the establishment of minimum flow criteria for the estuary.

4. Florida Bay (Figure 7)

Information on Florida Bay was obtained from Boesch et al. (1993), NOAA (1995a,b,c), South Florida Water Management District (1994a) and Cato and Brock (1995). The data on Florida Bay are presently rather fragmented; no major summaries seem to have been completed as yet. Efforts are underway, however, to summarize the existing literature. It is therefore necessary to modify the format is used to describe most of the other estuaries in this report.

a. Physical setting and climatology - Florida Bay is a shallow (<3 feet), lagoonal estuary located at the southern tip of Florida. The bay is separated from the Atlantic Ocean, i.e., the Straits of Florida, by the Florida Keys and from the Gulf of Mexico by a shoaling of the bottom and a salinity gradient (see Wang and Lee 1995). The surface area of the estuary is 850 square miles. The bay is divided by mudbanks into numerous sub-basins, characterized by fine sediment to eroded bottoms, scoured to their Pleistocene limestone bedrock. It appears that winter storms are eroding the northern and eastern mudbank slopes and that sediment is accumulating in the lee of the banks at a rate of ca. 0.5 to 2 inches annually (Halley et al. 1995). Numerous mangrove islands are present in the bay; these flood on a lunar cycle (Kramer et al. 1995).

Circulation in Florida Bay is influenced primarily by winds and tides (Smith 1995; Wang and Lee 1995). The hydrodynamics of the estuary are strongly influenced by shear associated with the shallow depth of the water column and the mudbank-sub-basin topography of the region (Smith 1995).

b. Living resources and ecosystems - During the early to middle 1980s, water clarity was relatively high and sea grass was the dominant submerged vegetation. Mangrove islands were abundant and mangrove stands occurred along the shoreline. In 1987, substantial changes were reported in these

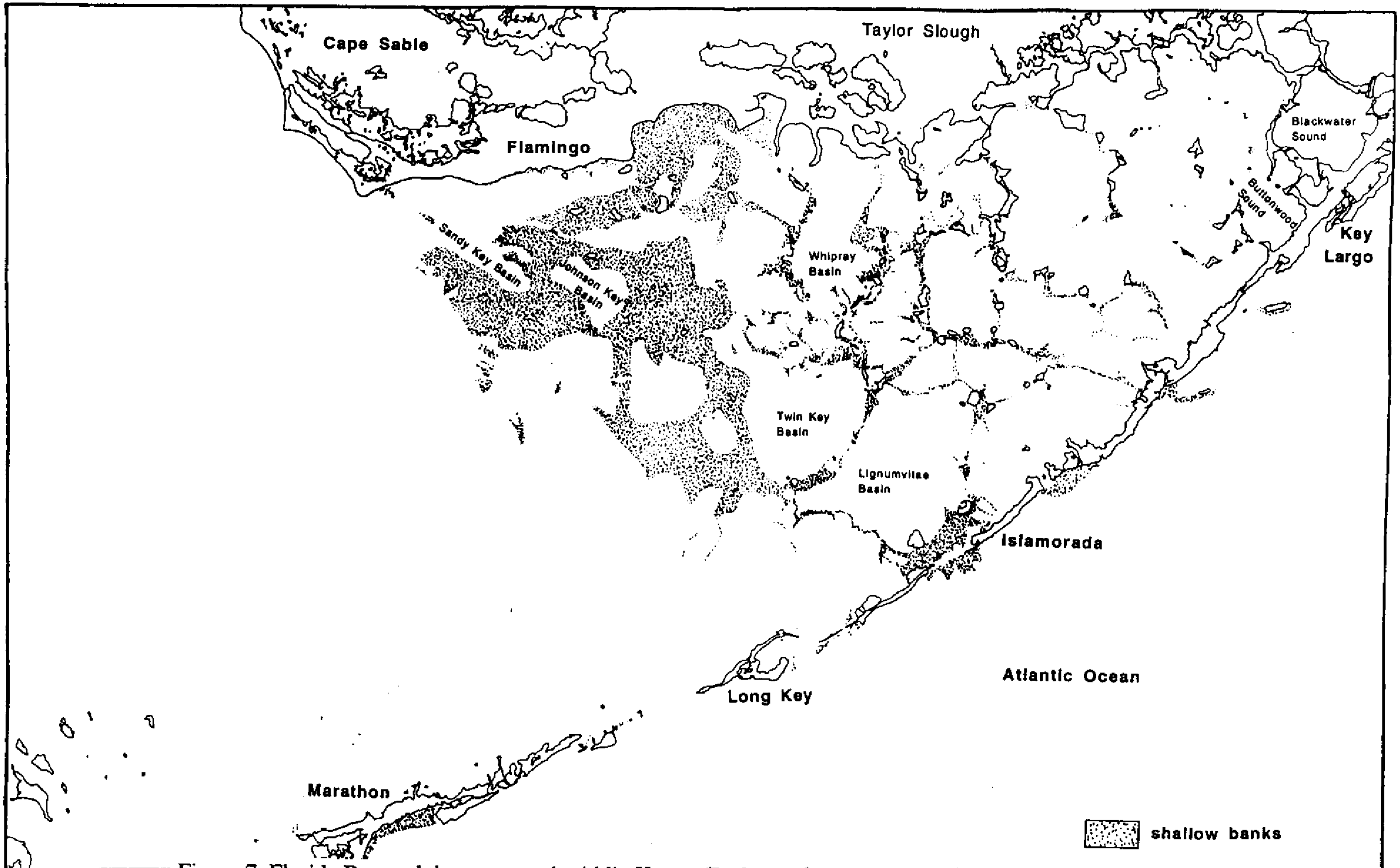

Figure 7. Florida Bay and the upper and middle Keys. (Redrawn from a map produced by the Florida Department of Environmental Protection Marine Research Institute.)

ecosystems. Seagrass die offs, sediment resuspension and nuisance (probably cyanobacterial) blooms occurred. The observed floristic changes in the estuary are thought to be due to long term alterations in the salinity of the basin and to the input of nutrients (particularly phosphorus; Fourqurean et al. 1992) and possibly to modification of nutrient ratios (Tomas and Bendis 1995) in the bay. As a result, the primary production of the estuary seems to have shifted from the benthos (sea grass) to the water column or water column + benthos, but it is not known whether the total primary production/unit area has changed dramatically. Further, it now appears that while seagrass coverage has declined in recent years, primary production of the remaining beds is higher than it was during the early 1980s, when seagrass density was high but primary productivity was low (Zieman et al. 1995).

Interestingly, there has been little change in the abundance of top avian predators in Florida Bay (Robertson 1995), suggesting that the system is rather stable trophodynamically. One possibility is that the estuary vacillates between clear (benthos dominated) and turbid (water column dominated) modes but that the overall production moving up to the apex is relatively constant. Predictably, that changes in seagrass densities will be reflected in changes in the biological communities associated with seagrasses. There is some evidence to suggest, however, that increases in phytoplankton production are coupled with similar increases in zooplankton production (Kleppel et al. 1995). Thus, while biological communities in Florida Bay are changing, it is not necessarily true that total ecosystem productivity is declining. It is apparent, however, that the increase in salinity, eutrophication and other stresses are associated with diseases of seagrasses, corals and sponges (Stevely and Sweat 1995). The tight coupling of ecosystem components in Florida Bay (e.g., sponges and juvenile lobster) impacts on one component translate rapidly to others (Herrnkind et al. 1995).

c. Aspects of governance, management and planning - Florida Bay is nearly entirely within the jurisdictions of the Keys Marine sanctuary (NOAA) and Everglades National Park (National Park Service). Efforts to more clearly understand the ecosystem of this estuary and to identify and ameliorate damage are underway through NOAA, the Parks Service, the Florida Department of Environmental Protection, and the South Florida Water Management District, as well as the National Biological Service and the US Geological Service. Major themes associated with restoration of bay water quality are: to sustain a water quality monitoring network in the bay, to research the historical characteristics of the bay and to model its ecology and hydrology, and to develop and implement water management actions to restore ecosystem integrity. Several such management schemes have been proposed and a large research effort to understand and model the bay is presently underway.

4. Rookery Bay (Figure 8)

Rookery Bay is designated as a National Estuarine Research Reserve (NERR). The site is administered by the Florida Department of Environmental Protection. The summary of information on Rookery Bay will not follow the pattern that we have used throughout this report, because the methods by which data have been collected and compiled and the demography of the NERR are different from those in other estuaries.

Until 1993 no effort had been made to bring together the literature, research and data on Rookery Bay. A first effort at such a summary is now available (FDEP 1993). Currently, we are aware of no effort to describe the relationship between the watershed, which has been heavily modified for agriculture and will no doubt become increasingly susceptible to urban development, and the estuary. Documentation on the distributions of biotic and abiotic resources is underway, as are retrospective studies.

Rookery Bay is a relatively small estuary. It is unique however, as a south Florida estuary that is relatively unaffected by human activity. Therefore, inclusion of information on Rookery Bay (FDEP 1993) in this report is considered important.

a. Physical setting and climatology - Rookery Bay encompasses 14.8 square miles in Collier County. Its climate and physiography are similar to those of other south Florida estuaries. The estuary is formed of a series of barrier islands, small mangrove keys and shallow basins, similar physiographically to Florida Bay.

The climate is subtropical, with distinct dry and wet seasons. Seasonal variability has a major impact on abiotic and associated biotic variables. The wet season occurs between June and October; the dry season, from November to May.

The principal habitat in Rookery Bay is mangrove forest, of which all three species red, black and white are present. Several other habitats have been identified in the system, including, sea grass, mud flats and oyster bars, salt and freshwater ponds, ephemeral freshwater ponds, xeric scrub uplands, savannah uplands and wet pine woods.

In the 1960s, the Deltona Corporation purchased Marco Island and 23 square miles of mangrove forest north of Marco Island for residential development. Conservation groups began a campaign to begin purchasing land in the estuary that intensified during the 1980s when population growth in the Collier County-Naples area was among the highest in the nation (ca. 120%). The initial 6 square mile parcel of Rookery Bay, purchased during the 1960s, has grown to its present size over the past 30 years.

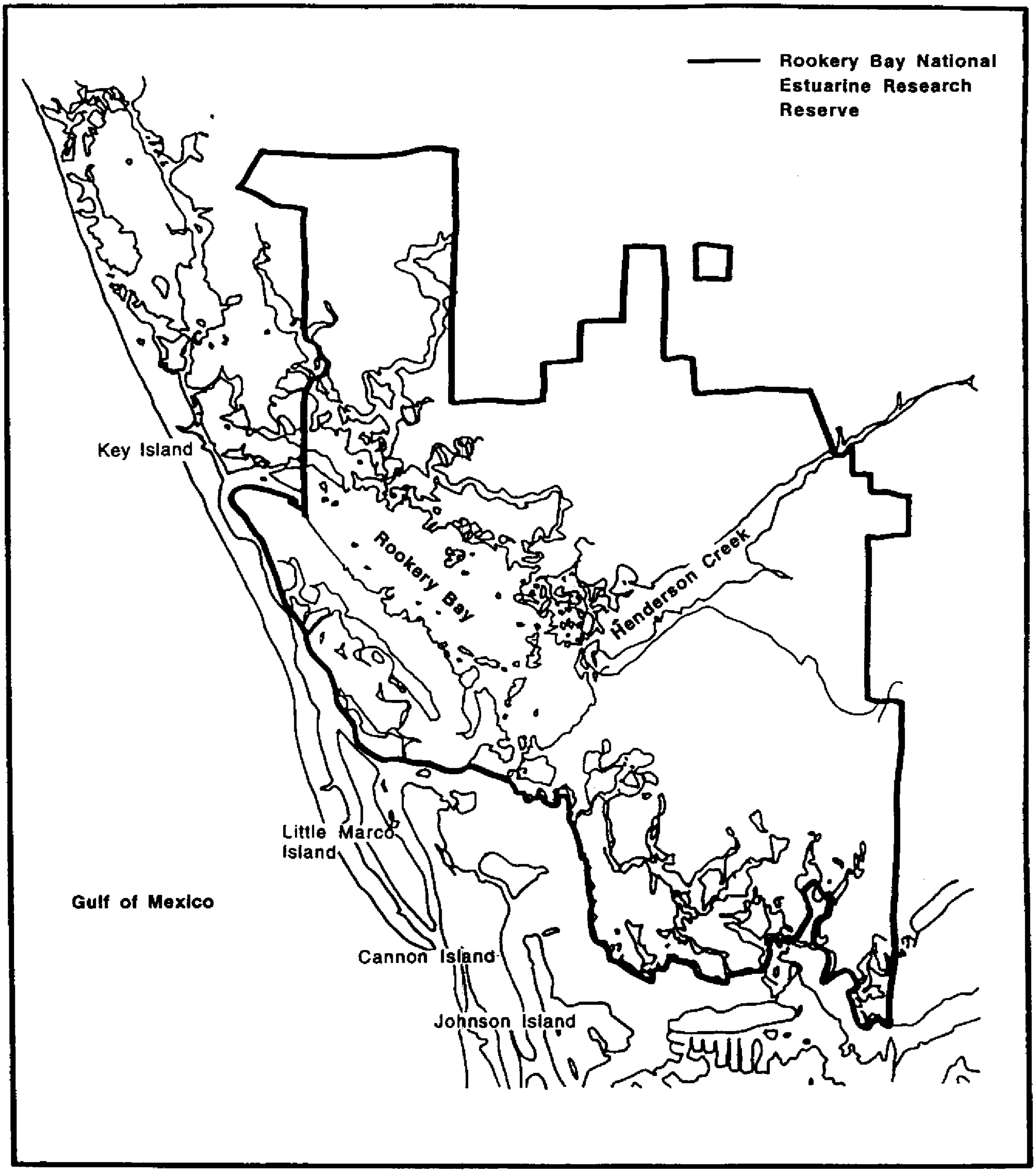

Figure 8. Rookery Bay National Estuary Research Reserve. (Redrawn from Florida Department of Environmental Protection 1993.)

b. Environmental conditions - Salinity in Rookery Bay varies spatially, with mean upstream values averaging 13 ppt and downstream values averaging 33 ppt. Salinity is 2 ppt higher, on average, at depth than at the surface. Salinity is strongly influenced by rainfall patterns and tends to peak in May. Lowest values are recorded during the middle of the wet season, around August and September. During, the winter upstream areas may actually become hypersaline as freshwater flow declines to a minimum. Some indication of a 4-6 year cycle in salinity, coincident with precipitation patterns, has been detected in the long term data. Identification of such patterns, if accompanied by reasonably small variance, may be useful for planning and management.

Dissolved oxygen (DO) varies with temperature, salinity and organic loading. Inshore stations, though lower in salinity, tend to exhibit lower average DO levels than do those off shore, especially when temperatures are high. Seasonally, average DO values are higher in the winter (mean=6.5 mg/l; maximum occurs in January to February) than in the summer (mean=4.0 mg/l; minimum occurs in between August and September). Though shallow, a consistent 0.2 mg/l vertical gradient in dissolved oxygen has been detected in parts of the estuary.

Turbidity decreases from onshore to offshore. Upstream turbidity appears to be due to phytoplankton growth rather than to resuspension of sediments. Phosphorus limitation is thought to limit primary production in the bay. With the onset of the wet season, freshwater carrying a large pulse of phosphate, enters the bay. Phytoplankton blooms ensue.

Rookery Bay provides an example of the sensitivity of south Florida's estuaries to the annual freshwater/salinity cycle. It also suggests that hydrologic manipulations and land use practices upstream have a significant impact on the estuary. Over the past decade, increasing amounts of freshwater have been flushed through Rookery Bay. This has had a dramatic impact on habitat and ecosystem structure, the extent of which is still not fully documented or understood. At Monument Point, for example, average wet season salinity has been >10 ppt, i.e., in the brackish range. In 1992, salinity at this location was 0. The biological implications of this relatively small change are enormous. The change in salinity was sufficient to completely alter the habitat. Many organisms utilize brackish nursery habitats. Salinities must be above 0.5 ppt (usually >5 ppt) in order for the system to function as a brackish habitat. Although macroscopically the habitat may not appear to have changed, its ability to function as an estuary has been lost.

At present, macroscopic biotic patterns appear to be independent of manipulations in the estuary. Variability in fish stocks, for example, seem to be driven by longer term population dynamics cycles and not by seasonal processes such as the salinity which may be responding to anthropogenic forcing. Thus, from 1982-1987 catches declined in the estuary. However, in 1988 and 1989 fish landings increased. Data are currently being uploaded to the data base, and analysis will require some time to complete.

c. Management and planning - Rookery Bay is designed to serve as a source of information about estuarine function in Florida. As such it represents a critical resource to Florida. Rookery Bay can provide a window into the natural variability occurring within living ecosystems. Among the most difficult jobs of scientists and managers is to distinguish natural from anthropogenic variability. Managed reserves, if monitored and studied can serve that function, so long as processes external to the basin can be identified and their impacts ameliorated. To the extent that stock assessments and retrospective studies are underway, much will be learned about the estuary. However, it is clear that impacts are occurring from outside of the system and these must be dealt with by management processes that may exceed the jurisdiction for oversite by DEP. Interagency cooperation coupled with outreach and education may help to develop land use practices that are consistent with maintanence of Rookery Bay as a barometer for documenting the natural variability in the state's southernmost estuaries.

5. Charlotte Harbor (Figure 9)

a. Physical setting and climatology - The key summary documents used to obtain information for this report were reports from the Southwest Florida Water Management District (SWFWMD 1993) and reports by Coastal Environmental Consultants (1995a-c). Charlotte Harbor is located on the west coast of Florida off Fort Myers, between Rookery Bay to the south and Tampa Bay to the north. It has a basin of 270 square miles and a watershed of 4500 square miles. Charlotte Harbor is sixth on the SWIM priority list.

Three major tributaries enter the estuary: the Myakka, the Peace and the Caloosahatchee Rivers. These rivers drain a region from Green Swamp to Lake Okeechobee. The estuary is separated from the Gulf of Mexico by a series of barrier islands. Connections to the Gulf are made by a series of passes, the largest being Boca Grande, which enters San Carlos Bay in the central and southern portions of the estuary. The mean depth of Charlotte Harbor is 7 feet; the maximum is 50 feet in Boca Grande Pass (Stoker 1986). The water column is partially to completely mixed in most reaches of the estuary, though salinity stratification occurs during high flow periods. The Floridian and the surficial Hawthorne aquifers influence the system.

The climate is subtropical and humid. The mean temperature is 72° F; mean annual rainfall is 52 inches. Typical Floridian precipitation patterns prevail (maxima between June and September; minima in

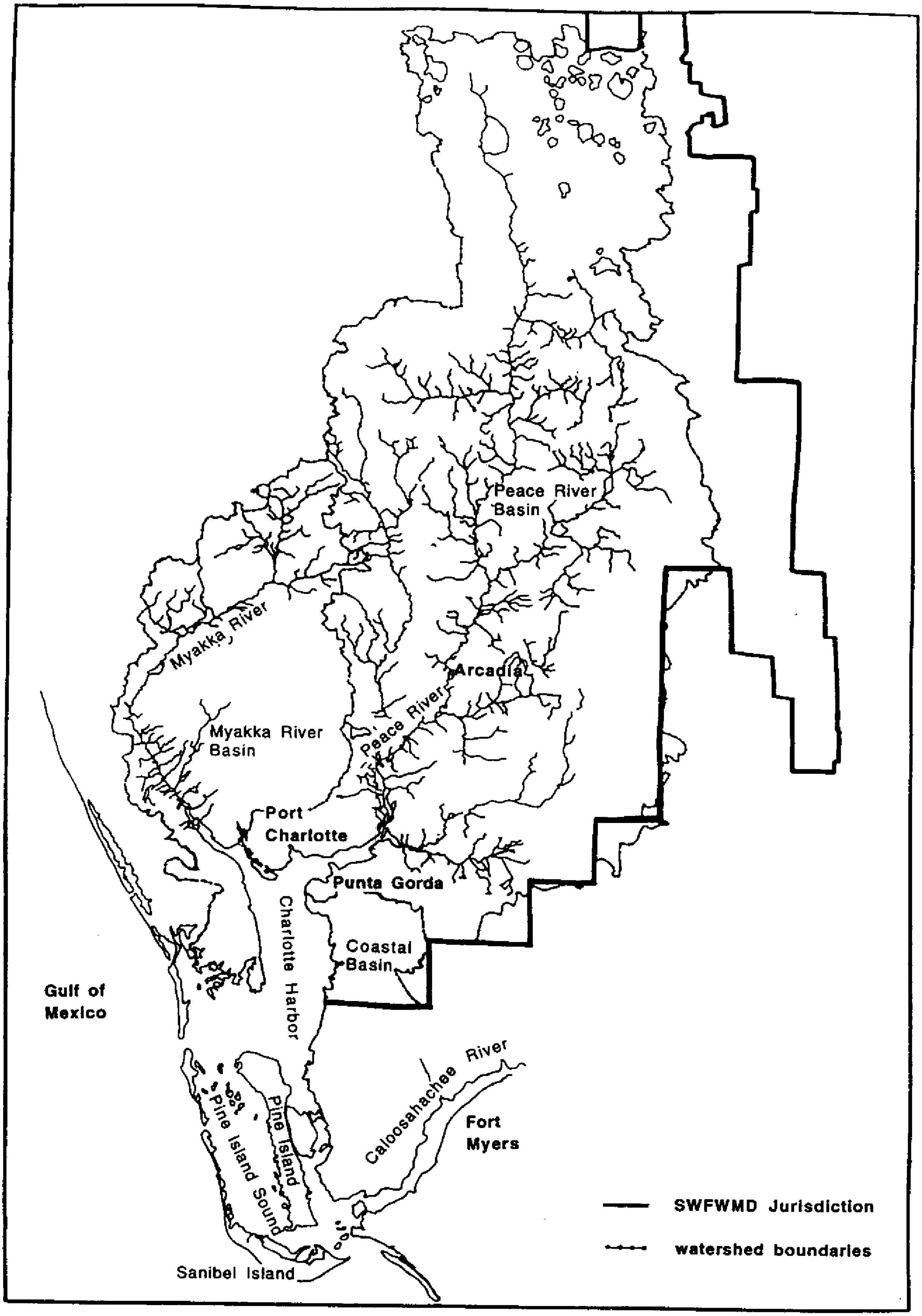

Figure 9. The Charlotte Harbor watershed including the Peace and Myakka River Basins. (Redrawn from Southwest Florida Water Management District 1993).

November) with lowest stream flows between April and May. Typical of the subtropical, southern climate, hurricanes can be a problem. On average, tropical storms and hurricanes make 2 landfalls/10 miles of coastline/100 years. These storms obviously impact demographics, socioeconomic patterns and policy considerations. They also cause dramatic changes in the Florida's estuarine physiographies and ecosystems.

b. Living resources and ecosystems - Charlotte Harbor is considered a relatively pristine estuary. It is characterized by seagrass, saltmarsh and mangrove primary-producer communities. Phytoplankton blooms also occur in the estuary, apparently as a function of eutrophication. It would appear that a comprehensive evaluation of habitat structure and biotic resources has not been undertaken for Charlotte Harbor. However, the region has important commercial and recreational fisheries for spotted sea trout, grouper, snapper, tarpon and several crustaceans. Habitat for some thirty endangered species exists in the estuary. It would appear that land use practices in the watershed, particularly along the Peace and Myakka Rivers, are having a measurable impact upon water quality in the estuary. Development and eutrophication are responsible for the loss of >29% of the seagrass habitat and >51% of the natural saltmarsh since 1945. However, mangrove habitat has increased slightly (by 10%) over the same time period.

c. Demographic patterns and socioeconomic trends - As is true of many of Florida's aquatic resources Charlotte Harbor was an important center for native American culture from pre-Columbian times up until the early nineteenth century. From approximately 1820 to 1920 the governance of the estuary became increasingly complex as the number of counties with jurisdiction over the region increased from one to eight.

After the Civil War, the area around the estuary was used primarily for agriculture. The rivers were transport routes and phosphate was mined along the Peace River (principally by strip mining).

Development of the region increased slowly through the 1940s but by the 1950s, the Charlotte Harbor area saw significant growth in residential development and tourism. Currently, enormous growth is expected within the watershed.

There has been a continuous shift away from agriculture toward urbanization. Prior to 1984, 70% of the total area of the watershed was under citrus cultivation or used for cattle grazing. On the order of 10-15% of the Peace and Myakka River basins and 30% of the coastal basin were wetlands (Hammet 1988). Thus, while citrus farming is the principal agribusiness in the region today, farmers have been leaving the coasts, as these areas become increasingly urbanized.

Current demographic patterns are reflective of improved air and highway links to the area. In 1983, the Southwest Florida Regional Airport was completed, and since the 1970s increasingly improved highway connections, notably via Interstate 75, have been underway. Recent improvements along Alligator Alley have helped to link the west and east coasts of south Florida (particularly to the greater Miami/Fort Lauderdale metropolitan areas) by a modern highway. Additional growth is planned for the airport.

In summary, Charlotte Harbor and its watershed have, like the Indian River Lagoon, become regions of intensive tourism and enormous population growth. A doubling of the 1980 population size, to 847,000, is predicted by the year 2020. Eutrophication has already had a substantial impact on coastal resources. Continued development and growth to nearly one million people within the watershed by 2020, will create tremendous challenges in environmental conservation and resource management. Currently, the commitment to recovery and conservation of ecosystem integrity does not appear to be a major focus of government in the region.

d. Water and sediment quality - Status and trends data on water quality in the estuary and tributaries have been compiled and summarized by Hand et al. (1990) and Hammet (1988; 1990). The data base extends back to 1963. Contaminants data are also available from (FDEP 1995). Water quality in the estuary is considered fair to good. In the Myakka and Peace Rivers, water quality is considered between good and fair to poor, respectively.

In 1993, 97 point source discharges were permitted in the watershed. Most of these are in Polk County and they range from large municipal facilities to small package plants. The principal impacts on the Myakka River are from agricultural and urban runoff. Between 1963 and 1985, the US Geological Survey reported a significant decline in water quality in the Myakka River. The Peace River receives both domestic and industrial point source discharges, along with major stormwater loadings and phosphate loadings from mining activities. Water quality of lakes in the upper Peace River basin has been reduced by point source contamination. Chemicals associated with phosphate mining and processing are caustic and have severe environmental impacts. Spills of these chemicals, especially in the vicinity of Bartow, Fort Meade and Zolfo Springs, have been frequent. There is evidence that such spills affect both surface and ground waters. At present, the Peace River receives 6 tons of phosphate and 9 tons of nitrogen daily. The Myakka is not subjected to such intensive loading but still receives over one ton of nitrogen per day.

In addition to the phosphate and chemical industries, the citrus industry produces a significant loading to the Peace Riter in the form of an acidic, high organic carbon content waste, as well as through pesticide residuals and peel oils. Citrus processing has negatively impacted several lakes in the basin.

Total phosphate levels are elevated throughout the estuary due to the Peace River discharges, and phytoplankton growth is regulated by nitrogen and/or silicate in areas where salinity exceeds ca. 20 ppt and by light (and possibly micronutrients) in the less saline reaches of the estuary. Light limitation is primarily due to the presence of suspended sediments and colored substances. Phytoplankton contribute only 4% to light attenuation in the estuary. Reductions in water clarity have been caused by dredging and filling operations both within the estuary and its tributaries. Phosphate mining and chemical processing along with the diversion of freshwater for use by developing municipalities within the watershed and the destruction of freshwater wetland "filters" for the estuary are expected during the next to decade, to increase the stress on Charlotte Harbor. The current trend to reduced water clarity is having an effect upon resident seagrass beds in the estuary, and managers are presently concerned that continued stress on seagrass habitat could result in dissolved oxygen problems in the estuary in the near future.

As of 1990, most parameters in the Myakka and Peace Rivers exhibited a trend indicative of declining water quality. However, in the Myakka River, total nitrogen loadings have declined since 1963 (phosphate inputs are not significant) and in the Peace River, total phosphate loads have declined since 1975 (though nitrogen loading has risen). Point source loading of nitrogen and phosphorus to the system will increase by about 23% and 6%, respectively over the next two decades.

Perhaps the most significant challenge to water quality and the integrity of the Charlotte Harbor estuarine ecosystem is the reduction in freshwater flow into the system. Water removal over the past 50 years both at the surface and particularly through the aquifers, has already had dramatic effects on the Peace River (e.g., Kissengen Springs disappeared in 1955, Zolfo Springs will be gone within the next century). By 1960, two years before records began to be collected by SWFWMD, flow on the Peace River had declined 30-50% of the long term mean (1930-1960) flow (S. Dudley pers. comm.). Additional diversion of fresh and low salinity water is planned for the Peace River. Charlotte County has challenged the policies of the Southern Water Use Caution Area and the Consumptive Water Use Permit of the Peace River Manasota Regional Water Supply Authority that will permit continued and increased reduction in Peace River flow.

e. Aspects of governance, management and planning - In 1979, the Charlotte Harbor Resources Planning and Management Committee was appointed by the governor's office to address problems related to the impact of population growth on the estuary. The objective of the committee was to ensure the protection of the estuary against environmental damage by accomplishing two goals: (1) To maintain and improve the functional and structural integrity of the estuary's ecosystems and related coastal components by managing human impacts in the upland and freshwater portions of the watershed; and (2) To identify and address the impacts of growth on Charlotte Harbor.

In addition, responsibility for water management planning and improvement currently rests with two water management districts (WMDs), the Southwest Florida WMD (SWFMWD) and the South Florida

WMD (SFWMD). The former agency has jurisdiction for northern Charlotte Harbor, Gasparilla Sound and the Myakka and Peace Rivers. SFWMD is responsible for the southern portion of Charlotte Harbor. Through Surface Water Improvement and Management planning the districts are attempting to: (1) protect water quality by reducing nutrient and contaminant loading to the estuary, (2) optimize freshwater flows to the estuary; (3) protect and restore degraded habitat, (4) build public support for estuarine conservation and sound management through education and citizen involvement programs.

The rapid growth of the entire region, however, leads one to question whether any management strategy can accomplish these goals. From the literature gathered for this report, the consensus public policy seems to be on continued growth.

6. Tampa Bay (Figure 10)

a. Physical setting and climatology - The principal sources of summary information for this synopsis were Tampa Bay NEP (1991, 1992a-h; 1993a-c; 1994a-f; 1995) and SWFWMD (1992). Tampa Bay is a riverine estuary centered at 27.5° N latitude and 82.5° W longitude on the west coast of the Florida peninsula. The position of Tampa Bay, north of Charlotte Harbor and just south of the "Big Bend" region is a demarcation between the subtropical and Carolinian temperate climatic zones. The bay is the largest open water estuary in the state, with a surface area of 400 square miles and a watershed of 2,300 square miles. The average depth of the water column is 12 feet, though the main shipping channel is maintained at 43 feet.

Tampa Bay encompasses Pinellas, Hillsborough and Manatee Counties. The watershed extends into Pasco and Polk Counties as well. The Bay consists of three basins: Lower and Middle Bays forming the main basin, Old Tampa Bay in the northwestern portion of the estuary and Hillsborough Bay to the east of Old Tampa Bay. Three seaports are located within the bay -- the Port of Tampa in Hillsborough Bay, the Port of St. Petersburg in Middle Tampa Bay and Port Manatee in Lower Tampa Bay.

b. Living resources and ecosystems - Between the 1950s and the 1970s, a period of virtually unmanaged growth occurred in the watershed. More than half of the wetlands in Tampa Bay were destroyed.

Between 1950 and 1982, nearly half of the original 40,000 acres of seagrass (i.e. only 21,600 acres remained) in the bay and the entire 2,700 acres of seagrass in Hillsborough Bay was destroyed. These losses were due to reductions in water clarity (see Water quality section) that ensued from resuspension of sediments mediated by dredging and from algal blooms which occurred as a result of eutrophication

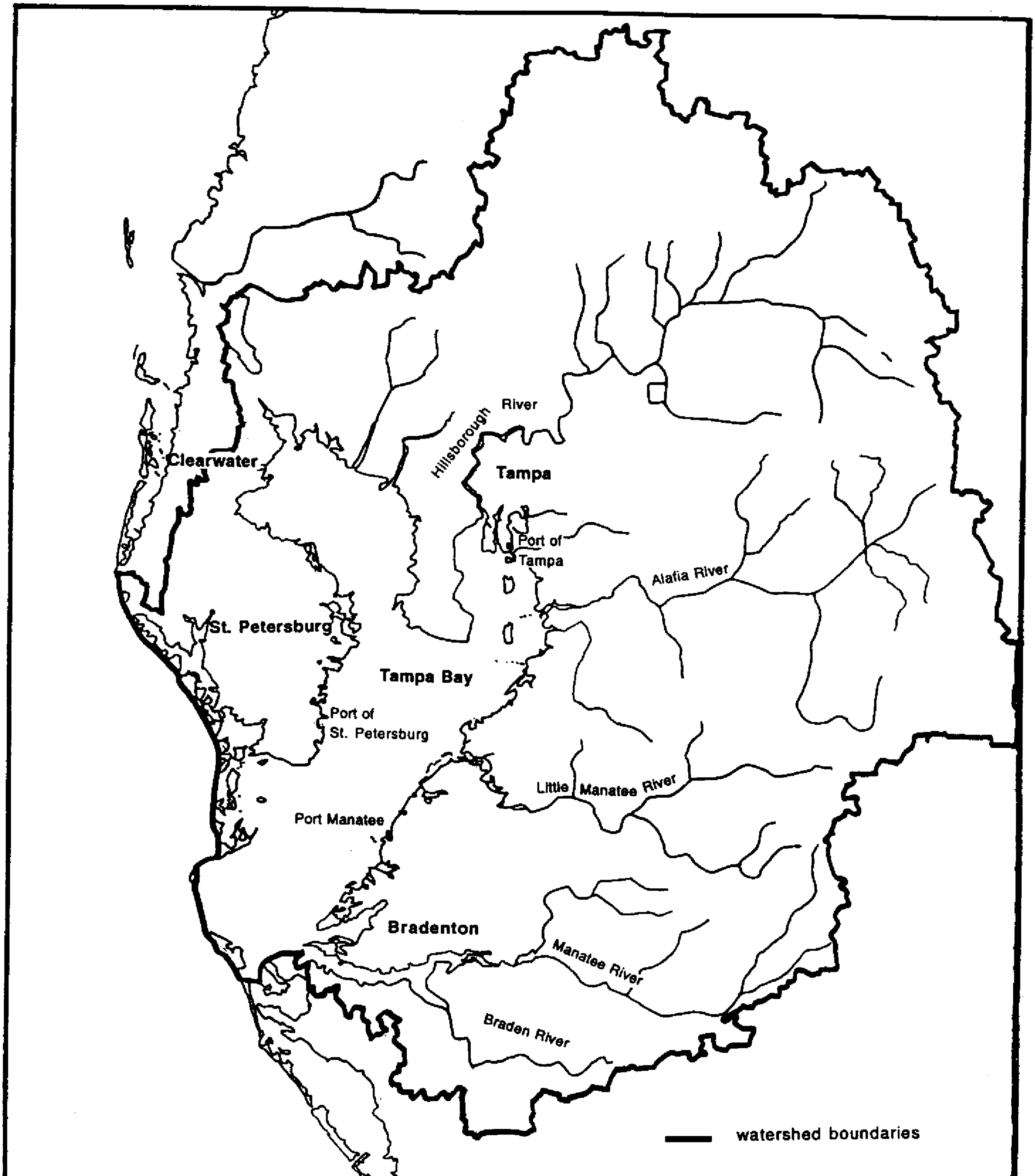

Figure 10. Tampa Bay and its watershed. (Redrawn from Tampa Bay National Estuary Program 1995.)

(specifically, discharges of dissolved nutrients into the water column). Details on water clarity and nutrient loading are presented in the section on water and sediment quality, below. In the decade following 1982, 3,500 acres of seagrass were recovered by efforts to improve water clarity and to control eutrophication. The species, *Halodule wrightii*, a seagrass that is relatively tolerant of reduced transparency and prefers high nutrient environments has dominated the recovery. *Thalassia testudinum*, a species (thought to be the climax species in Florida estuaries, but this may not be the case; see Fourqurean et al. 1995) that tends to thrive in more oligotrophic conditions, has not recovered as well. Benthic habitats in Tampa Bay include hard and soft bottoms. The dominant benthic habitat in the bay (83% of the bay bottom) is soft-bottom. Most of this substrate occurs at 20 or more feet in the dredged portion of the estuary. This bottom is unvegetated by macrophytes and represents habitat for burrowing invertebrates. Hard bottom habitat, from rocky outcroppings on the bay floor, support a diverse community of attached animals such as sponges, seawhips and sea fans. Oyster reefs also occur within the bay. There is hard bottom habitat in several locations in Old Tampa Bay, and in Middle and Lower Tampa Bays. In addition, thirteen artificial reefs in the bay provide hard bottom habitat and may enhance fishing.

Emergent wetlands vegetation, saltmarshes and mangroves account for 15-20% of the primary production in the bay (phytoplankton is the dominant producer contributing 70% of the annual photosynthesis). Nonetheless, mangroves and saltmarsh habitats are dynamic and important. Between 1950 and 1990, an estimated 5,900 to 9,700 acres of wetlands were destroyed by development. There are presently approximately 13,800 acres of mangroves and 4,100 acres of saltmarsh in the bay. In addition to mangroves and salt marshes, the bay contains numerous intertidal mudflats.

Upland of the intertidal zone are pine forest, hammock and shrub lands. These habitats are important to the estuarine ecosystem and have been heavily impacted by development. Wet pine forests support more than 360 species of plants. These systems are among the most diverse plant communities in south Florida. These are key hunting and nesting grounds, providing habitat for several endangered bird and mammal species. About 40% of the pine habitat and most of the salt barren have been lost.

Oligo- and mesohaline sections of the estuary and tidal portions of the rivers are crucial juvenile fish habitats. Water demand on the rivers, however, especially during the dry season, has greatly reduced freshwater input to the estuary.

Fish stocks in Tampa Bay are currently in a state of flux. Some species seem to be increasing (snook, red drum), largely as a result of management efforts; other species (e.g., black mullet, spotted sea trout) are in decline. Habitat destruction, overfishing and contamination have been responsible for significant losses to fisheries during the past 40 years. Habitat destruction may be the principal impediment to recruitment of fish to the estuary. For example, the Critical Fisheries Monitoring Program of the Florida Marine Research Institute (DEP) observed that between 1980 and 1991, ca. 80% of all juvenile spotted sea trout collected, were taken from seagrass beds. There was an 87% decline in sea trout landings between 1960 and 1990. Red drum catches in the bay also declined precipitously between 1950 and 1981, but management has helped this species to recover. Shellfisheries have been affected by poor water quality which has lead to the complete collapse of the oyster fishery.

c. **Water and sediment quality** - Wastewater discharge practices in Tampa Bay and its tributaries during the 1950s, 60s and 70s along with extensive growth and development in the wetlands and adjacent watershed led to severe deterioration of water quality in Tampa Bay. Data collection by various agencies within NOAA, in cooperation with the Florida Departments of Natural Resources and Environmental Regulation (now combined into the FDEP) and the Hillsborough County Environmental Protection Commission, has resulted in a reasonably strong data base that dates to 1974.

Review of water quality data suggests a slow but persistent improvement of bay water quality during the past decade. In the Lower, Middle and Old Tampa Bays water clarity exceeds 6.5 feet. Hillsborough Bay is the receiving water for the largest nutrient load to the estuary, and clarity there is less than 4 feet. Improved water clarity represents part of the equation for seagrass recruitment. Expansion of seagrass beds to 3 feet in depth in Hillsborough Bay and to ca. 6 feet elsewhere is a goal of future management of the system. The aim is to recover 14,000 acres of seagrass beds over the next decade. Water clarity is better in the winter than summer when phytoplankton blooms occur. Chlorophyll levels in the bay have been declining indicating a reduction in bloom intensity and therefore an improvement in water transparency. Progress toward environmental restoration is judged by water clarity criteria and seagrass recruitment. A goal of 20% light penetration has been set for the bay by the Tampa Bay NEP.

Phytoplankton production in Tampa Bay is thought to be nitrogen limited. Thus, reduction in the nitrogen load should reduce phytoplankton production and thereby improve water clarity in much of the Bay. Currently 17 treatment plants discharge into Tampa Bay and its tributaries. All employ advanced wastewater treatment which removes about 90% of the nitrogen from the load; St. Petersburg is testing a wastewater reuse program. Nonetheless, the annual nitrogen load to Tampa Bay exceeds 4,000 tons. On average, 37.5% of the load is derived from atmospheric deposition (1,000 tons of nitrogen fall into the Bay annually; 6,300 tons fall into the watershed). The major sources of atmospherically deposited nitrogen are automotive and power plant emissions. Interestingly, Tampa Bay seems to be the only estuary for which atmospheric deposition rates are known. Nearly 50% (12% to 71.9%) of the nitrogen load is from other non-point sources (e.g., stormwater runoff). The remaining 12.5% of the nitrogen load is derived from point sources and groundwater (<2%). The largest contribution to the stormwater derived nitrogen load is urban, residential runoff (ca. 60% of the load), primarily from fertilizer use. Industrial inputs amount to about one-third of this.

In addition to loading nitrogen, stormwater runoff carries more than 65% of the toxic heavy metals (cadmium, zinc, chromium, mercury and lead) loaded to the bay. Stormwater accounts for 336 billion gallons (40%) of the annual freshwater input to the estuary. About 14% of the annual runoff is derived from agricultural lands. Although this is only a small percentage of the total runoff, it tends to be an important source of pesticides.

Septic systems service only 20% of the watershed, but nitrogen loadings may be substantial in certain areas. About 7% of the nitrogen input to the system is from fertilizer loadings.

The Port of Tampa is the state's largest seaport, which, along with the other two ports (Port of St. Petersburg and Port Manatee), generate some $4 billion in income annually. The Tampa Harbor Deepening Project (1972-1988) removed 100 million cubic yards of bay bottom; an additional 1 million cubic yards of sediment are removed each year, to ensure major transport and commerce operations in the bay. Smaller dredging projects are continuously underway. A shortage of spoil sites may require ocean dumping of dredged sediments.

d. Aspects of governance, management and planning - As is true with all of the estuaries in Florida, federal regulation and data analysis are superimposed on several layers of region and local control. Several federal, state and county agencies collect water quality and resources data in the bay. Timeseries date back to the early to mid-seventies. Interpretation of data and planning are undertaken by the Southwest Florida Water Management District and the National Estuary Program in cooperation with US EPA and various state and local agencies. Efforts to plan into the future and to set tractable management goals appear to have been relatively successful. Plans for the management of fisheries, water and sediment quality, and spill prevention and control are in place. Efforts to manage the impact of dredging have not met with great success but recognition of the problem and attempts to educate the public and its representatives may eventually result in improved control of dredging and spoil removal in the bay.

8. Suwannee River Estuary (Figure 11)

Information on the Suwannee River Estuary and Basin was obtained principally from the Suwannee River Water Management District SWIM planning document (1991). The Suwannee River estuary, at the mouth of the Suwannee River is thought to be one of the more pristine estuaries within the state. Although

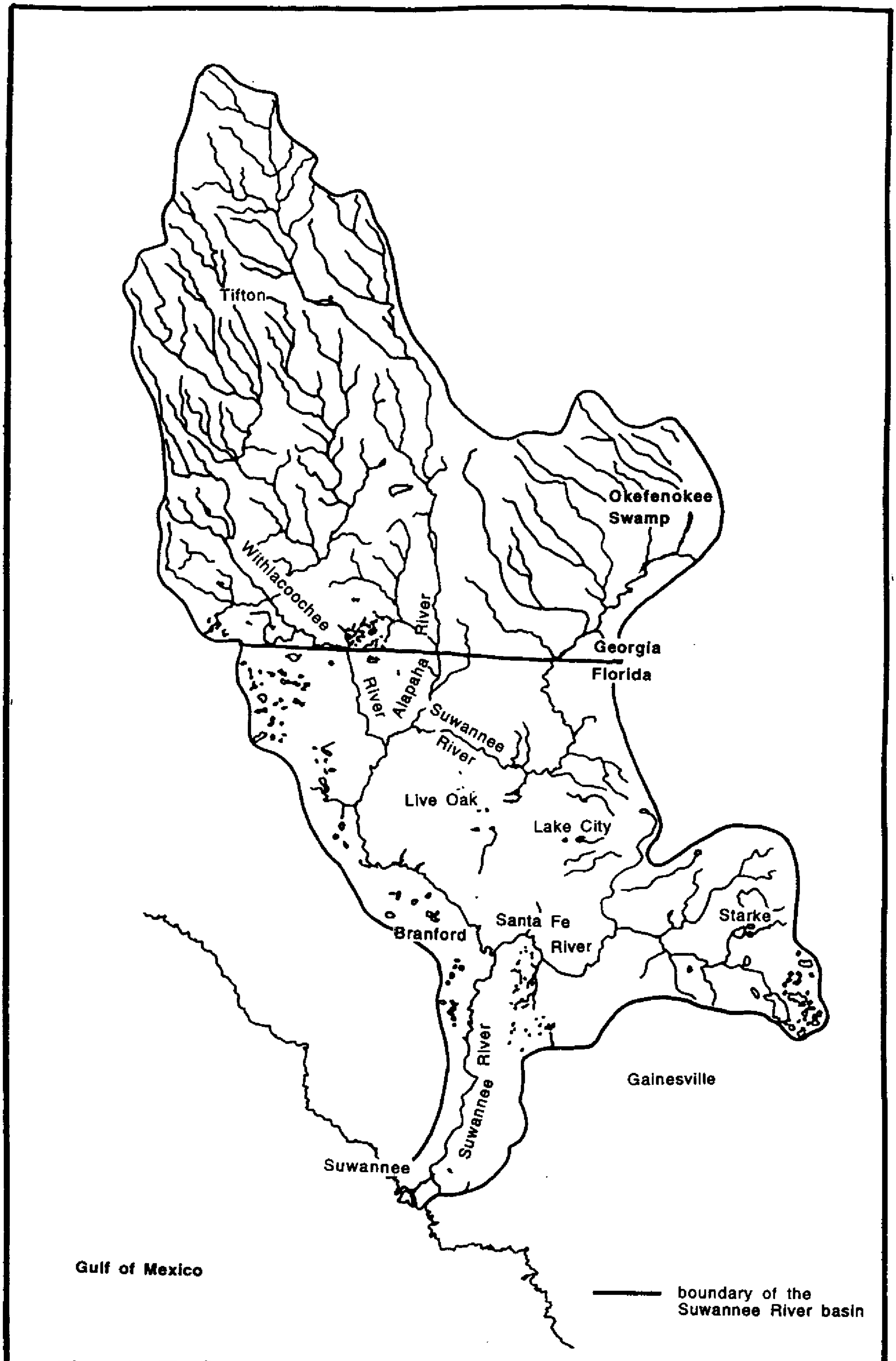

Figure 11. The Suwannee River Basin. (Redrawn from Wolfe and Wolfe 1985.)

a considerable regional planning and documentation effort has been undertaken within the watershed, information specific to the estuary is relatively sparse. As often happens, development of baseline data sets on pristine systems tend to be low priority until some perturbation forces examination of the system. At that point, however, it may be difficult to discern the natural from the dysfunctional system. Careful study of the rare, unperturbed estuaries of Florida is crucial to provide the fundamental information about how these systems are likely to respond to population growth, changing land use practices, hydrological modifications and similar potential stressors. The ability to manage the inevitable pressure on the Suwannee system in the near future, will depend upon the extent to which an understanding of the system can be developed over the next few years.

a. Physical setting and climatology - The relatively large (9950 square mile) drainage basin of the Suwannee River is located in Florida (42.5% of the basin) and Georgia (57.5%). The basin can be divided into Northern Highlands (upper basin) and Coastal Lowlands (lower basin) separated by the Cody Scarp, the 110 foot contour, in the upper Suwannee Basin. Elevations range from 15 feet below to 150 feet above mean sea level. The region is characterized by flatlands to gently rolling hills, with many limestone solution sinks and mature karst topography.

Summers in the region are subtropical and humid, winters are southern (Carolinian) temperate. Mean annual temperature is 67° F, with a June-August mean of 90° and a minimum temperature averaging in the mid-40s during December to January, though brief freezes are not unusual.

Precipitation averages approximately 54-56 inches annually; peak rainfall occurs in June to August, during which 50% of the rain falls (within a three month period). During the winter, precipitation occurs along evenly distributed fronts. Precipitation is lowest between October and November. Mean annual evapotranspiration is 42 inches.

The Suwannee River originates in the Okeefenokee Swamp in Georgia, and is fed initially by aquifers in the upper reaches and by artesian springs, which overlay the Florida aquifer, in the central portion. The Alapaha and Withlacoochee Rivers originate in the south central portion of the basin and merge with the Suwannee providing 15-24% of the total flow to the Suwannee. Substantial changes in ion balance, pH, color and DO occur as the river traverses downstream and is influenced by groundwater inputs.

b. Living resources and ecosystems - There are three major aquatic ecosystems within the Suwannee basin: riverine, lacustrine and coastal. The riverine system consists of a variety of floodplain habitats, forested wetlands and habitats associated with the river channel. Six types of wetlands ecosystems occur in the basin: forested wetlands dominated by needle-leaved deciduous trees, forested wetlands dominated by broadleaf evergreen hardwoods, forested wetlands dominated by broadleaf deciduous hardwoods, herbaceous marshes, oligohaline marshes, and coastal saltmarshes. The latter two systems are found in the estuary. The oligohaline marshes are vegetated by sawgrass, bull and needle rushes. The coastal saltmarshes are vegetated by cord grasses and needle rush.

Aspects of the ecology of the estuaries have been considered by Wolfe and Wolfe (1985) and by Matson and Rowan (1989). Just above the estuary is a freshwater region (salinity <0.5 ppt) the extent of which is determined by tides. This tidal freshwater zone is composed of hardwood swampland and is dominated by freshwater species. Nonetheless, some estuarine species do occur in these areas. For example, fiddler crabs, olive nerites, blue crabs, grass shrimp, marine red algae, mojarra, sheepshead, Atlantic needle fish, grey snapper and mullet occur in the tidal freshwater zone.

The oligohaline region of the river has a salinity between 0.5 and 5 ppt and is considered brackish marsh. Sawgrass, blackrush, giant reed and bullrushes, as well as submerged widgeon and eel grasses dominate the marsh. The region is very important avian, fish and invertebrate habitat (Rozas and Hackney 1983).

A mesohaline zone encompassing a salinity gradient from 5-18 ppt consists of submerged and emergent vegetation that is similar to that found in the oligohaline zone. Economically as well as ecologically important invertebrates, such as oysters and mussels occur here, as do snails, crabs, snapping shrimp and several important reef fish. Oyster catcher, ruddy turnstone and other birds find habitat in mesohaline marshes.

A polyhaline zone, characterized by salinities of 18 to 30 ppt, that includes saltmarshes of smooth cordgrass, black rush, and a variety of submerged sea grasses is the next step in the succession toward a marine habitat. Sand and mud flats are highly productive parts of the polyhaline ecosystem.

The polyhaline zone merges with a series of euryhaline habitats that are characterized by salinities of 30 ppt and higher. These are regions of saltmarshes, inter and subtidal mud flats and oyster reefs. The relationship between the flow of freshwater in the river and the structure of the habitats in the estuary is not well understood and needs to be clarified.

Several transitional habitats, ecotones between wetland and upland systems occur in the basin. These include coastal wet prairie/flatwoods, lowland hardwood hammocks and lowland pine flatwoods. The region is an important faunal transition zone with half of the species in the river at the southern or eastern limits of their ranges. Some 39 amphibian, 73 reptile, 42 mammal and 232 avian species have been documented in the Suwannee basin (FDNR 1989).

c. Demographic patterns and socioeconomic trends - Although high population growth rates are expected in many watersheds in the coming decades, population growth in the Suwannee Basin is not expected to be as rapid as in other areas. However, decentralization of the population, from urban to rural areas, is expected to have an impact on land use practices. It is widely held that land use practices within the watersheds are among the chief determinants of water quality in an estuary. Population decentralization in the basin will result in increased residential and urban development of lands that are currently used for agriculture or are undeveloped. The still widespread use of domestic septic systems and other factors that influence drainage and runoff are also likely to stress the system even though population growth will be moderate. Commercial and recreational fisheries (oystering is the principal fishery; several teleost species are also fished), and wildlife related industries, as well as the value of the region as wildlife refuge relies on high water and environmental quality. There are clear signs that the demographic profile of the region is changing (e.g., the proportion of the economy devoted to agriculture, forestry and mining declined from 53% in 1930 to 12% in 1980). Further, the demand for resources, such as freshwater, in regions experiencing pressure on the local resource base, is expected to create pressure on resources in rural areas from which these resources may be diverted. The impacts of such activities and pressures are not currently predictable, in part because the understanding of the Suwannee River estuarine ecosystem is not complete (SRWMD 1991). Expected impacts include: modification of the hydroperiod, changes in water quality and habitat disruption.

Although agriculture, silviculture and grazing activities have traditionally constituted the principal land uses in the Suwannee basin, phosphorus mining has been important in Hamilton County. Logging was also a major industry in the late 19th and early 20th centuries. Reforestation efforts have taken place during the 20th century.

The chief uses of aquatic resources in the basin have historically been for transportation, potable water supplies, recreation and food fisheries. Presently the river receives domestic and industrial discharges and is used for power plant cooling water. Recreation and commercial fisheries remain important on the river and in the estuary, and agricultural interests within the basin obtain some water from the river.

The Suwannee is currently classified as an outstanding Florida Water and receives regulatory protection against degradation. This includes limitations on discharges, population density and urbanization, forestry and agriculture along the river banks.

d. Water and sediment quality - The Suwannee River system is pristine. Water quality in the basin is protected by its status as an Outstanding Florida Water (see above). The area is forested and development is mostly agricultural (low density). Tributary rivers, the Withlacoochee and Alapaha, have extensive agricultural and small town development along their banks and therefore serve, as a source of contaminants to the Suwannee. There are 15 domestic point sources (waste water treatment plants) and 5 industrial point sources along the river. Of these, 20 point sources, only 5 are in Florida. The two domestic (secondary treated) wastewater sources to the estuary discharge a total of 0.25 MGD. The industrial sources include a chemical and agricultural products company (which discharges phosphorus, fluoride, sulfates, nitrates and ammonia and radium), a poultry processing plant and the Florida Power Company which discharges 176 MDG of cooling water.

Non-point sources to the basin, as elsewhere, have not been adequately studied, but erosion and agricultural runoff and especially domestic septic systems are thought to be potential problem sources. In 1990, the Suwannee River Water Management District identified 1200 septic systems in the basin, of which some 70% were considered capable of violating water quality standards. To date, 90% of the violations have been corrected. The potential, however, exists for increased stress to the basin through the use of septic systems as the population in the area continues to grow.

e. **Aspects of governance, management and planning** - The Suwannee River passes through seven counties in Florida and five counties in Georgia. The drainage basin encompasses 13 counties in Florida and 21 counties in Georgia. The estuary itself, however, borders Dixie and Levy Counties. Because of the size of the basin watershed management would seem to require interstate cooperation. Evidence of a coordinated water management policy by Georgia and Florida was not apparent in planning documents though such cooperation may exist. The regional management of the Floridian portion of the basin is regulated by the Suwannee River Water Management District (SRWMD). There is evidence of cooperation in management and enforcement between the state and the district. Stated priorities include point and non-point source contaminant identification and amelioration of pollutant loads, resource monitoring, development of coordinated intergovernmental management programs, determination of surface and ground water interactions, and establishment of minimum flow requirements for the wetlands and estuaries. In addition, acquisition of land to form a buffer against perturbation of the system, development of a coastal and estuary management plan, permit tracking and data base development remain goals of the water management district (SRWMD 1991). In addition, an update of older survey data is recommended.

9. Apalachicola Bay (Figure 12)

a. **Physical setting and climatology** - The chief summary document used in this report was the SWIM planning document of the Northwest Florida Water Management District (NWFWMD 1992). This is a relatively small estuary, of 212 square miles, with a large drainage basin of 19,600 square miles, which

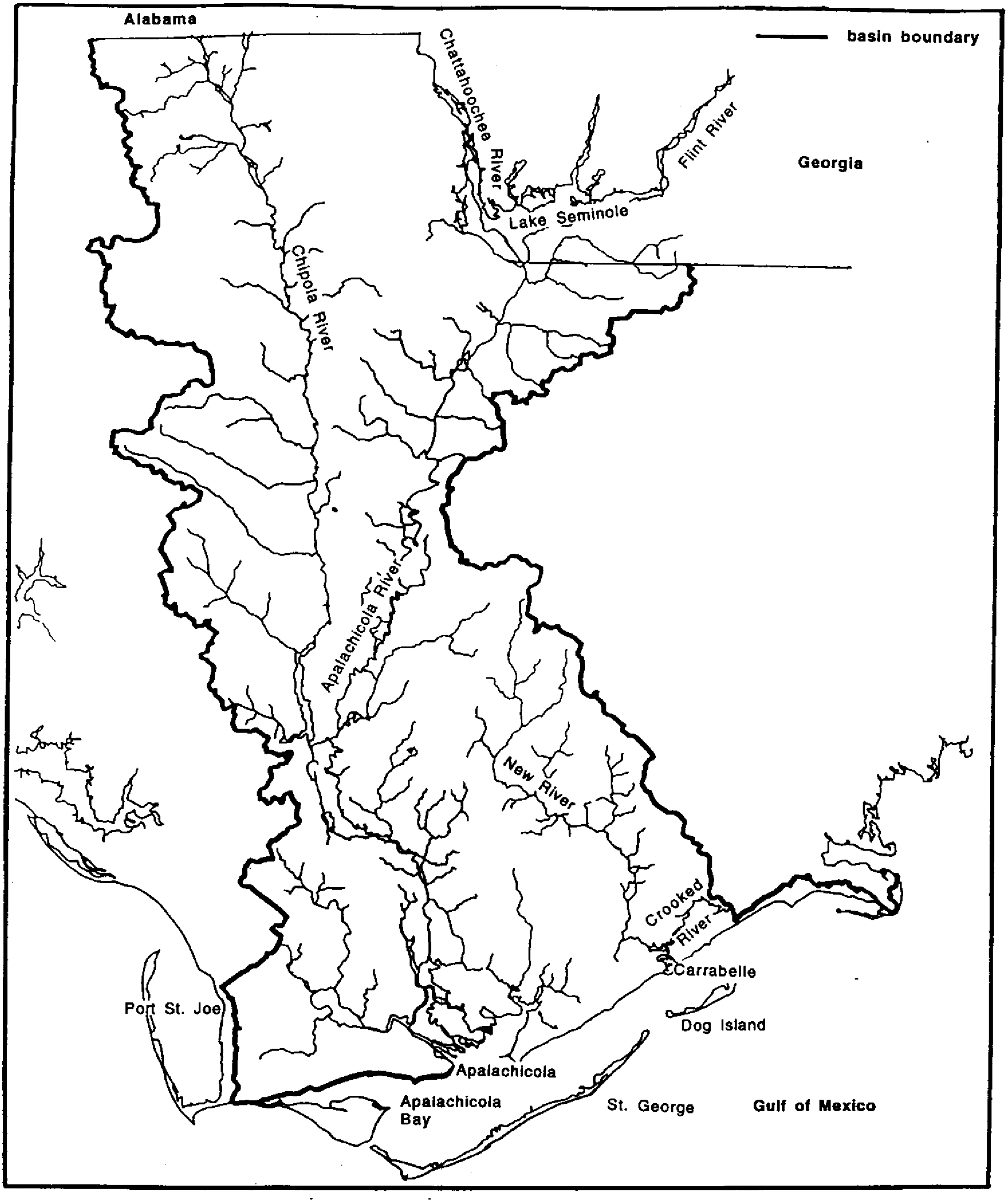

Figure 12. The Apalachicola drainage basin. (Redrawn from Northwest Florida Water Management District 1992.)

extends from the Florida panhandle into Alabama and Georgia. Approximately 2,400 square miles of the basin (ca. 12%) are located within Florida.

The estuary is formed by the alluvial, Apalachicola River, the largest river on the Gulf coast of Florida, and the lower portion of the Apalachicola- Chattahoochee-Flint River system. It is separated from the Gulf of Mexico by four barrier beach islands: St. Vincent Island, St. George Island, Cape St. George Island and Dog Island. The Apalachicola is the only river in Florida to stretch from the southern Appalachian piedmont to the Gulf of Mexico (Barkuloo et al. 1987). Except for Dog Island, much of which is owned by the Nature Conservancy, the barrier islands are all or partly protected as state or federal parks or preserves.

Freshwater input to the estuary is determined by overflow across the Jim Woodruff Lock and Dam (in Georgia) which retains Lake Seminole (with portions in each state). The latter is supplied by the Chatahootchee and Flint Rivers. The principal tributary of the Apalachicola River below the lake is the springfed (calcareous) Chipola River, which drains about half of Floridian portion of the basin. The river and its estuary are part of the lower coastal plain on both the Gulf-Atlantic Rolling Plain and the Gulf-Atlantic Coastal Flats (Leitman 1983). Fifteen other tributaries contribute to the drainage basin. Within these regions are the Northern Highlands, and the Mariana and Gulf Coastal Lowlands, that sandwich the highlands to the north and south, respectively. Details of the riverine physiography have been described by Leitman et al. (1984) and by Edmiston and Tuck (1987). Much of the river system is dammed and managed for hydroelectric power.

The climate of Apalachicola Bay is transitional, with wet and dry seasons, though the actual difference between seasons (only 55% of the total rainfall occurs in the wet season) is not extreme. Regional precipitation averages 56 inches; evapotranspiration rates are high, between 37 and 43 inches. Therefore, there is no strong increase in flow during the late summer peak rainfall (because much of the excess evaporates). Air temperatures around the bay range from a winter mean low of 54.4° F to a high of 81.4° F in August-September.

Apalachicola Bay can be divided into East Bay, St. Vincents Sound, Apalachicola Bay and St. George Sound. East and Apalachicola Bays are partially separated by a causeway.

Much of East Bay, St. Vincent Sound and Apalachicola Bay are shallow (3-4 feet, on average). Apalachicola Bay is separated from St. Vincent Sound by shoals and oyster bars. St. George Sound has an average depth of nine feet.

The geology of the barrier beach islands and basin of Apalachicola Bay have been studied by several workers, including Kofoed (1961), Kofoed and Gorseline (1963), Stapor (1973), Schade (1985), Donoghue

(1987). The bay is a relatively young, cuspate estuary with about 10% of its sediment derived from upstream sands, the remainder being supplied to the delta as clay and silt. The basin floor of the estuary is quartz sand with a thin cover of clay in the central basin. Oyster reefs have added considerable calcareous sediment. There has been a change from silty sand sediments to clayey sand sediments in the estuary during the past century and a half due to changes in upstream activities, namely the damming of the rivers and creation of manmade lakes (e.g., Seminole Lake) (Isphording 1985).

Apalachicola Bay is a transitional region between semidiurnal and diurnal tides characteristic of southwest and northwest Florida, respectively. normal tidal ranges are 1-2 feet. Tides and wind speeds are the principal factors forcing local circulation; river flow and bay physiography are secondary forcing functions (Conner et al. 1982). Net water movement is east to west; saline Gulf water enters at St. George Sound and moves to East and Apalachicola Bays. The water returns to the gulf via the western passes.

Most of the bay is shallow and well mixed; stratification occurs periodically in the deeper reaches under certain conditions (Clarke 1975). Salinity driven stratification is thought to be principally weather-induced (Weisberg 1987). The salinity characteristics of the estuary are ultimately determined by freshwater loading patterns. These have a profound influence on biological distributions (Livingston 1983a). Low river flows, and subsequent high salinities in the estuary occur in the summer. High river flows occur in the winter, and salinities generally decline (Livingston 1984). Prevailing wind patterns at this time can set up a salinity stratification in the bay. The Apalachicola Bay pattern represents a departure of the wet-dry seasonal salinity pattern (low salinities during the wet summer, high salinities in the dry winter) frequently observed in the estuaries in south Florida.

b. Living resources and ecosystems - The forested floodplain of the Apalachicola River is the largest floodplain in Florida, ca. 173 square miles. The estuary is biologically complex and biodiversity is high. Such biological richness derives in part from the habitat diversity arising from the piedmont to floodplain physiography of the watershed. About 15% of the Florida portion of the basin is floodplain, the remainder encompasses palustrine, riverine, lacustrine and terrestrial habitats. At least fourteen upland habitats, ranging from drylands to swamps and bogs, have been identified. Many rare and endangered plants occur in the eastern portion of the watershed.

The floristics and animal communities of the watershed have been summarized by the Northwest Florida Water Management District (NWFWMD) and detailed by Means (1977) Yerger (1977), Leitman et al. (1984) Barkuloo et al. (1987) and others. This report will concentrate more heavily upon the biology of the estuary.

Apalachicola Bay is thought to be one of the more productive and pristine estuaries in the state. It ought to be noted, however, that much of the survey information that is available dates back to the early 1980s. Data on the oyster fishery date to the 1960s. A reexamination of this estuary would seem appropriate.

Both seagrass and phytoplankton production are important in Apalachicola Bay. The principal grasses are *Halodule wrightii* in Apalachicola Bay and in St. George and St. Vincent Sounds. An assemblage of *Mytiopyooum americanum, Potamogeton pectinatus, Vallisneria americana* and *Ruppia maritima* dominates East Bay. *Syringodium filliforme* and the red alga *Gracilaria* spp. are also abundant. Sea grasses are limited to the shoals and shallow lagoons and is sparse-to-absent in St. Vincent Sound. Several strictly brackish and freshwater species are found in the estuary especially in marshy East Bay, where an alarming increase (from 30 to 90% coverage) in an exotic grass, *Myriophyllum spicatum*, was noted during the 1980s (Livingston 1983; Continental Shelf Associates 1985). Although mapping techniques and other artifacts are partially responsible, there seems, nonetheless, to be a real trend toward decreasing seagrass abundance in the Apalachicola Bay system between 1980 (Livingston 1980) and 1985 (Continental Shelf Associates 1985).

Wetland and salt marshes covered ca. 14% of the estuary in 1980 (Livingston 1980). Bull and needle rushes, cattails and saw and cord grasses have been reported in the bay, especially along the river and in East Bay. The lagoons and creeks of St. George and Cape St. George Islands are vegetated with more brackish saltmarsh species. These areas and adjacent tidal flats provide key habitat for diverse invertebrate communities (Edmiston and Tuck 1987), as well as for a variety of vertebrates including mammals and birds (Taylor et al. 1973).

Microbial, phytoplankton and zooplankton communities are thought to form an important component of the estuarine ecosystem. Both marine and freshwater communities occur in the bays and creeks (Estabrook 1973) but production and trophic patterns have not been characterized in many years. The loading of nutrients and detritus from the river would lead, logically to strong multivorous and microbial food webs. These systems have not been described or quantified in the Apalachicola Bay system.

The benthic invertebrate fauna of Apalachicola Bay are principally soft bottom forms; 78% of the substrate is soft bottom habitat. Nonetheless, seagrass communities are also rich, exhibiting in the early 1980s, the highest biodiversity in Florida (Livingston 1984). Oyster bars and reefs provide a third major benthic habitat in the estuary, supporting a hardbottom, reef community. During the early 1980s, Apalachicola Bay was the most productive oyster fishery in the state. Shrimps (*Penaeus* spp.) and blue crabs (*Callinectes sapidus*) are also important fishery species; white, pink and brown shrimp all occur in the bay. White shrimp are most abundant. *C. sapidus* is one of the most abundant macroinvertebrates in the bay. Apalachicola Bay is a major spawning area in the Gulf (Oesterling and Evink 1977).

Several commercially valuable finfish occur in the estuary and approximately 75% have an estuarine-dependent life cycle. These include striped mullet, flounder, speckled and sand sea trout, croaker, red drum and spot. Several other important species occur in the bay during a portion of the life cycle. These include Gulf sturgeon, striped bass, Alabama shad, and skipjack herring, as well as low-salinity species, such as bluegill and red ear sunfish. Several species of mammals and birds (we could not find a census, though we suspect that such data exist), reptiles and amphibians live in the estuary continuously or periodically. Many of the inhabitants are riverine, rather than marine.

c. Demographic patterns and socioeconomic trends - Evidence of human habitation of the Apalachicola Bay and river basin extends back more than 10,000 years. Early European exploitation of the region was for trading and security. Antebellum cotton farming as well as steamboat and other transportation were important in the region. Currently, the Apalachicola River and Bay are bordered by six counties in Florida: Jackson, Gadsden, Calhoun, Franklin and Gulf. Population densities are relatively low; Gadsden County has the highest population at <50,000. SWIM documents by the Northwest Florida Water Management District acknowledge the need to plan for future population growth. The estuary and its drainage basin will, however, likely be subject to increased population growth during the coming decades.

Currently fishing, silviculture, agriculture and recreation are major economic activities in the region. In Franklin County 65-85% of the population depends on commercial fishing for income (NWFWMD 1992). Blue crabs, oysters, shrimp and mullet are major fishery products. A few other fish are also economically valuable. Although Apalachicola Bay fisheries generate 90% of Florida's oyster landings, shrimp is the largest fishery in the estuary. It is expected that the recent State constitutional amendment banning gill netting will have a significant impact upon the economy of this area. However, at the time that this report was produced, the impact of the net ban had not been documented quantitatively.

Approximately 73% of the land in the Apalachicola basin is forested (from Ediston and Tuck 1987), and silviculture is the principal activity in the region. Fifty-five percent of the Florida portion of the basin is forested. Agriculture accounts for 15% of the land use. Only about 1% of the land had been developed for urban uses in 1987 (Ediston and Tuck 1987). The largest urban and agricultural activity occurs within the Chipola River basin. Wetlands and open water cover 20 and 9% of the total basin, respectively.

d. Water and sediment quality - With the exception of a two mile radius around the city of Apalachicola, the entire estuary is classified as Class II waters, i.e., safe for shellfish harvesting and propagation. Generally water quality is very good, though several "hot spots" characterized by low DO and high fecal coliform levels have been repeatedly detected in creeks and near marinas. As of 1992, there were 27 permitted domestic waste water and nine industrial point sources in the Florida portion of the basin. Problems with compliance are dealt with by the Florida DEP. Due to the relatively low population density, major contamination of the system does not appear to be an immediate problem. As population in the region grows, however, an increase in planning and management will be necessary. Nonpoint source contamination is recognized as a significant problem in the basin because of the wide use of septic systems (on the order of 20-40% of these have been found to be unsatisfactory), the importance of recreational activities that contribute wastewater, the addition of fertilizers, pesticides and soil to the system by agriculture and silviculture activities and the necessity for dredging to ensure navigable channels. To date, nonpoint source loading to large portions of the Apalachicola Basin have not been determined. At the time when the planning documents that we reviewed were prepared, interstate cooperation to control point and nonpoint loading did not appear to be well developed.

Livingston et al. (1978) and Winger et al. (1984) reported elevated synthetic hydrocarbon (DDT, PCB's, toxaphene) concentrations in animals in the estuary. The sources of these contaminants are currently thought to be upstream. Elevated concentrations of several heavy metals have been detected in association with marinas, certain creeks and receiving waters near agricultural areas. Nonetheless, Apalachicola Bay remains one of the more pristine estuaries in Florida.

e. Aspects of governance, management and planning - As is true for every other estuary within Florida, Apalachicola Bay falls under federal, state, county, regional and county jurisdictions. In addition, regional planning councils assist in developing policy for the estuary. Apalachicola Bay receives additional protection as the site of a National Estuarine Research Reserve (since 1979), an Aquatic Preserve (since 1969) and a United Nations International Biosphere Reserve (lower Apalachicola Bay, since 1984). In addition, the City of Apalachicola is a state Area of Critical Concern. These protective institutions provide the opportunity for research and planning that can help to mitigate impacts both on the Apalachicola system and through understanding and education assist in conservation and management of other estuaries as well. The extent to which agencies cooperate in efforts to affect management is not clear. Such cooperation will be critical in the future.

10. Pensacola Bay (Figure 13)

a. **Physical setting and climatology** - Northwest Florida Water Management Districts (NWFWMD 1990a-b) provided major summary documentation for this report. The Pensacola Bay system is located in the western panhandle, near the Alabama border. The estuary extends 20 miles inland from the Gulf of Mexico, and covers ca. 144 square miles. The drainage basin covers nearly 7,000 square miles (about 33% is in Florida). The estuary is composed of four interconnected embayments: Escambia bay, Pensacola Bay, Blackwater Bay and East Bay. The Escambia, Blackwater, East Bay and Yellow Rivers are the principal tributaries. The Escambia River has a mean flow of >6,500 cubic feet per second (cfs). The river receives significant contaminant (natural and anthropogenic) loads from upstream. Blackwater River is designated an Outstanding Florida Water, and drains 860 square miles through three major creeks which are fed largely by groundwater seeps. The mean flow is ca. 1,500 cfs (Musgove et al. 1965). The Yellow River enters the eastern side of Blackwater Bay, and drains 1,365 square miles. The river has a wide, forested flood plain and a marsh that is an aquatic preserve. Tidal influence can be detected some 19 miles upriver. The flow is ca. 2,500 cfs. Evidence of cultural eutrophication exist in several of the tributaries of the Yellow River. East Bay River flows into the eastern side of East Bay. It drains 100 square miles of southeastern Santa Rosa and southwestern Okaloosa Counties. The estuary and adjacent Santa Rosa Sound discharge to the Gulf of Mexico through a narrow pass, Caucas Channel, below Pensacola Bay that is maintained at a depth of 50 feet (to permit military traffic through the inlet). The estuary is relatively shallow, ranging from 4-9 feet. Pensacola Bay is deeper, however, with a mean depth of 19.5 feet.

Soils in and around the basin range from excessively drained to poorly drained. In general the soils occurring at lower elevations, e.g., in swamplands along the rivers and saltmarshes in the bays, are the least permeable.

The Pensacola Bay system is in the coastal lowlands of the Coastal Plain Province. This area is underlain by sand, silt, limestone and clay. Land surfaces are less than 100 feet above sea level and frequently <30 feet above sea level. The grade is level throughout much of the coastal region. The Escambia Bay Bluffs, bordering Pensacola are protected from development by designation an Outstanding Florida Water. The southern boundary of the bay is formed by the Gulf Breeze Peninsula, a barrier beach.

Tidal flux in the estuarine basins is low. Tides are diurnal with a fluctuation of ca. 1.5 feet (FDNR 1976). Tidal flux and circulation are affected by wind and freshwater flows. The rate of tidal flushing of the system is uncertain and has been estimated to be from 18 (Little and Quick 1976) to 34 (Olinger et al.

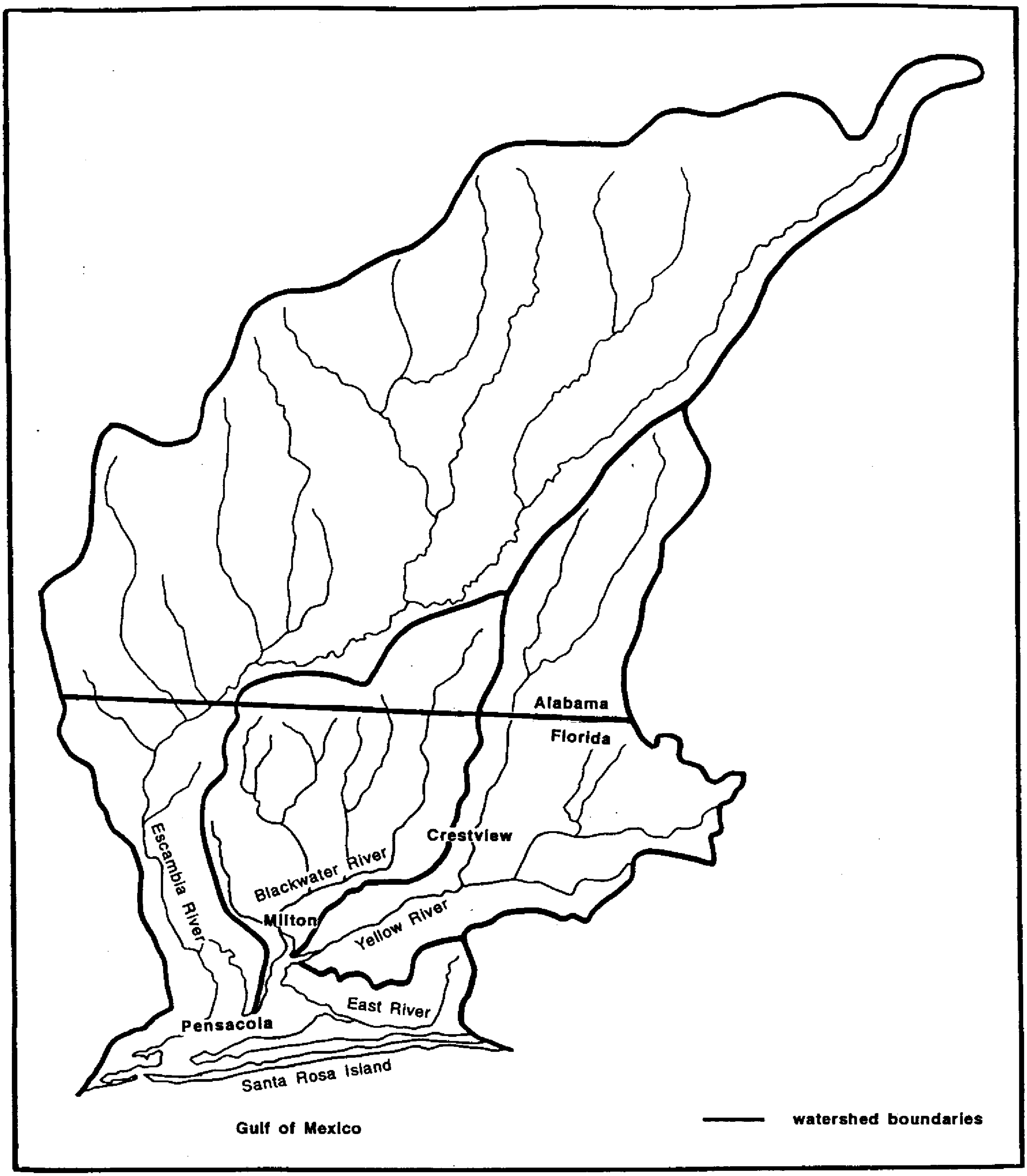

Figure 13. Boundary of the Pensacola Bay watershed including the drainage basins of the Escambia, Blackwater, Yellow and East Rivers. (Redrawn from Northwest Florida Water Management District 1990b.)

1975) days. One estimate of 200 days has been reported (NWFWMD 1990a). The system tends to be stratified; in the upper bay, surface salinities are 10 ppt or less; bottom salinities tend to vary between 20 and 30 ppt (EPA 1971). Stratification in Escambia Bay tends to be influenced by Escambia River flow, tides and winds. Reduced Escambia River flow and strong, local surface winds and tides reduce stratification; high flow, weak tides and low winds increase it. Pensacola Bay is generally strongly stratified with surface and bottom salinities on the order of <1 and >20 ppt, respectively (McNulty et al. 1972). Surface salinities are variable; bottom salinities are stable.

Circulation patterns in the bay are not well documented, but they are influenced by the wind. Inflowing bottom water moves along the south side of the estuary. Blackwater and East Bays have not been studied extensively, but stratification has been observed.

The climate of Pensacola Bay is considered humid subtropical. The range in monthly mean temperatures is 52° (January) to 85° F (July, August). Humidity averages 74%. Winds vary from north and northeast in winter to southerly in the summer. Average annual rainfall is 64 inches (range <29 to >90 inches). Precipitation is highest between July and September and lowest in October and November. Short droughts are common and can affect freshwater input and circulation patterns in the bay.

b. Living resources and ecosystems - Northwest Florida Water Management District (1990b) summarized the vegetative regions within the bay. Bottomland hardwoods predominate in the river flood plains; pines and shrub communities dominate in the uplands. The coastal zone is fringed with wetlands. The barrier beaches are vegetated by dune grasses; the coasts by saltmarshes. Seagrass is sparse in the subtidal zones. More detailed analyses are provided by Stith et al. (1984), Wolfe et al. (1988) and US Department of Interior (1988). These divide the system into several vegetative habitats, namely: pine, beech-magnolia, scrub oak, bottomland hardwoods, beach dunes (mainly on Santa Rosa Island), shrub and herb bogs, titi and various bay swamps, blackwater streams, marshes, intertidal flats, oyster reefs and seagrass beds. The latter are not abundant and are dominated by *Thalassia testudinum, Syringodum filiforme, Halodule wrightii, Vallisneria americana* and *Rupia maritima*. Loss of seagrass coverage was first reported in the 1950s (Hopkins 1973). Losses were clearly documented by Rogers and Bisterfield (1975) and it is not currently known whether significant recovery has occurred.

Information on phytoplankton and zooplankton biomass and production has not been found in our literature search. Oliger et al. (1975) in a major study of Pensacola Bay described eight benthic macroinvertebrate communities: sand shelf, transitional, mud plain, oyster beds, seagrass beds, sewage treatment plant outfalls, industrial plant outfalls, and deep muds. The oyster and seagrass beds sustained the highest biodiversity. Indications are, on the basis of rather old data, that macroinvertebrate communities in the bay were heavily impacted by environmental perturbations but had begun to recover or at least stabilized by the mid 1970s.

Some 200 species of shell and finfish have been documented in the Pensacola Bay system. Principal species are spot, bay anchovy, Atlantic croaker, sand sea trout, Gulf menhaden, several gobies, blue crab, oysters and shrimps. Several reptiles and amphibians occur in the bay and >250 resident and migratory bird species have been counted. Numerous terrestrial mammal species have been documented in the basin; bottlenose dolphin are important marine mammals that are periodically observed in the bays. Sixteen faunal species on the federal threatened or endangered species lists and 22 faunal species on the state list have been reported to occur in the Pensacola Bay system. Numerous threatened or endangered plants also occur in the basin.

c. **Demographic and socioeconomic patterns** - The Floridian portion of the Pensacola Bay system is located within four counties: Escambia, Santa Rosa, Okaloosa and Walton. Pensacola is the principal city in the region. By comparison with areas in the southern part of the state, population density in the Pensacola Basin is low. Escambia County has relatively high population density (ca. 282,500 in 1988) and its population is expected to increase by 33% during the next 30 years. Most of the residents of the region live in unincorporated portions of Pensacola, in southern Escambia County. The population of Okaloosa County was approximately 154,000 in 1988, and is expected to increase by about 55% by the year 2020. The populations of Santa Rosa and Walton Counties are each under 100,000. The populations of these counties is not expected to exceed 100,000 by 2020.

The economic base of the region is tied to tourism, military, retirement activities, agriculture and manufacturing. The military interests in the region are the Pensacola Naval Air Station in Escambia County and Whiting Field in Santa Rosa County and Elgin Air Force Base in Okaloosa County. Agriculture and silviculture are important industries in the region, with 300,000 to 400,000 acres under cultivation and 70-80% of the farmland being used for silviculture (20-30% for crops). The northern portion of Okaloosa is largely State forest and development is regulated. Chemical manufacturing takes place on the north side of Escambia Bay.

Land use within the watershed includes a relatively limited amount of urban development, development for recreation, agriculture and silviculture, and conservation and military use. The eastern portion of the basin is less developed than the western portion. The city of Pensacola is located to the northwest of Escambia and Pensacola Bays and is developed for industry, commerce and residential use. Much of the industrial and warehousing activity associated with the Port of Pensacola and the chemical manufacturing activities on Bayou Chico are located on waterfront and are thought to have a impact on water quality in the estuary. Other commercial development in the city, while often associated with the waterfront, probably has a smaller impact on local aquatic resources. Military and residential development tends to be localized in Escambia and Santa Rosa Counties to the west side of the basin. The eastern side of the bay is less urbanized.

The Gulf Breeze pensinsula contains both urban and forest lands, but the peninsula is being developed (i.e., urbanized) rapidly and currently this is the largest urban area on the east side of the estuary. Commercial and residential development of Santa Rosa Island have also been rapid, though conservation of much of the island has been mandated by its inclusion as part of the Gulf Islands National Seashore. The principal land uses in Okaloosa and Walton Counties are agriculture and silviculture.

d. Water and sediment quality - Water quality in the bayous and bays of the Pensacola Bay system underwent a relatively steady decline during the 1960s and 1970s. Alterations in water quality included depression of dissolved oxygen (DO) levels and increases in nutrient and sediment loads resulting from urban stormwater runoff to the bayous and bay. Further, sediment loading to the bay and bayous from agriculture and silviculture in the watershed as well as point and non-point source nutrient loading have caused severe degradation in water quality in the bays (particularly in upper Escambia Bay). Industrial contamination including metals and organics loading has been recorded but the impacts of these loads are poorly understood.

Coincident with these loadings has been a loss of nearly all seagrass beds, reductions in fish landings, closure of shellfish beds and loss of critical estuarine habitat. Both point and non-point sources have been problematic. Research during the 1970s and early 1980s, that focused primarily on the impacts of point sources of contaminants, demonstrated that the water and sediments of the bays, particularly Escambia and Pensacola, and bayous, including Bayou Grande, Bayou Chico and Bayou Texar, were heavily contaminated with organics, nitrogens, synthetic hydrocarbons and heavy metals from wastewater treatment plants and intensive industrial activity. Much of this activity has been stopped at this point and the number of waste water treatment plants has been significantly reduced. Phosphorus, while sometimes present at levels capable of causing algal blooms (Young 1985), has decreased over the years (Olinger et al. 1975) and may be limiting in some bays (e.g., Pensacola)(FDER 1988). Whereas Escambia Bay tends to exhibit wide variations in DO levels (U.S. Department of Interior 1970), Pensacola Bay tends to be above minimum criteria in most cases. Blackwater and East Bays are not subject to the point source loads that Escambia and Pensacola Bays endure. However, the relatively slow circulation in these bays causes them to be susceptible to hypoxia (Olinger et al. 1975). Young (1981) noted the presence of a sludge layer (of total organic carbon, TOC=4-5 mg/l) throughout the basins (2 mg/l is considered the level above which

TOC becomes problematic; National Academy of Sciences 1972). Total nitrogen in these bays (ca. 19 uM) is about 69% of that found in Escambia Bay (28 uM). More recent studies (Young 1981) suggest, however, that total nitrogen levels have risen significantly in Blackwater Bay (27 uM).

Sediments in the Pensacola Bay system have been contaminated with a variety of toxic, synthetic hydrocarbons. Among the worst sources of contamination was a spill of PCB into the Escambia River by Monsanto Corporation in 1969. Sediments were heavily contaminated in 1974 in many parts of the estuary (Olinger et al. 1975). Little has been done to follow the fate of this contaminant into the present, though the periodic observations that have been made indicate that levels remain elevated. Although PCBs were not detected in Pensacola Bay, chlordane and pentachlorophenol were present (FDER 1984). In addition to synthetic organics, the total organic carbon load tends to be very high, up to 50 g/kg just east of Bayou Mulatto.

As the Northwest Florida Water Management District (1990b) points out, much of the data on contaminant loads, water and sediment quality in the Pensacola Bay system are (more than 20 years) old. Newer data should be available (or may already be, but have not yet been summarized in a form accessible to this review) relatively soon. A better understanding of the hydrodynamics of the estuary is needed to more fully utilize the data being produced on water chemistry.

Non-point sources of contamination to the Pensacola Bay system include urban stormwater runoff, agriculture and silviculture, dredging operations, septic systems, groundwater seepage and marina. Livingston et al. (1989) determined that construction, urban runoff and septic system seepage were among the chief sources of contamination to Escambia and East Bays. Livingston et al. suggested that these sources were responsible for increased turbidity, impacts on fisheries and closure of fishing areas. Runoff from farms have been responsible not only for particulate loading but for eutrophication and input of pesticides as well.

e. Aspects of governance, management and planning - As is true for other estuaries in the state, a complex layering of management and regulatory responsibility exists for the Pensacola Bay system. In addition to federal, state and local jurisdictions, we have noted the existence of specially protected areas in and around the basin due to national and state special designations. For instance, there is an Outstanding Florida Water and a state park within the basin. Portions of the estuary are protected as national seashore. Nonetheless, Pensacola is an interesting area because it is one that is characterized by low population density but high impact due to the effects of unregulated industrial activity. There has, in the past, been an effort to document the damage caused by urbanization and industrialization, and SWIM planning involves continued efforts to ameliorate impacts and to document sources and effects of contaminants.

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