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

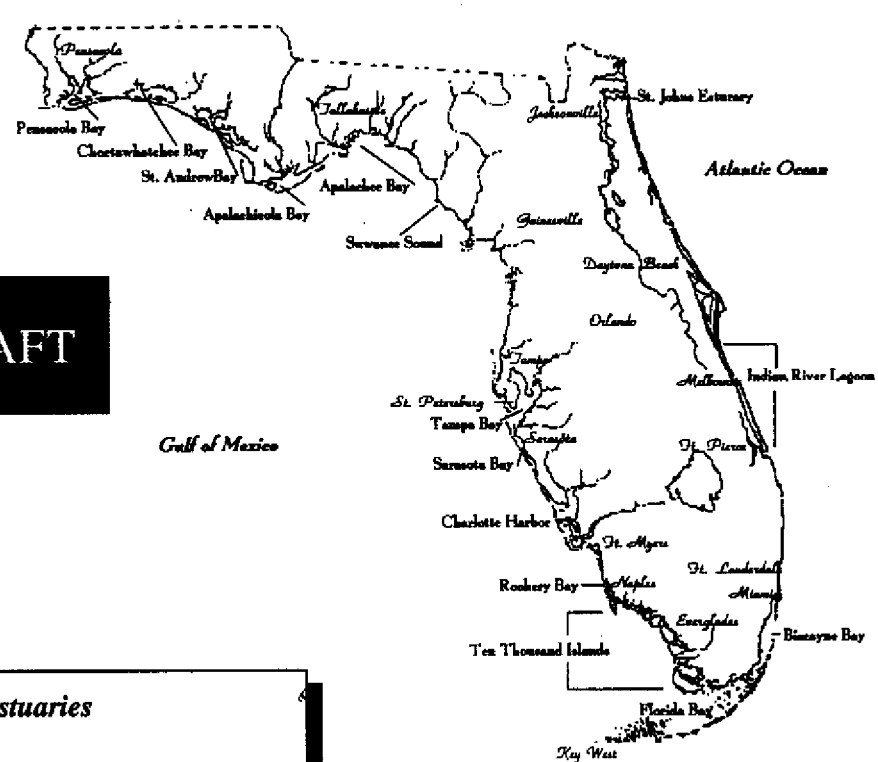
Part 2. An Academic Research Agenda

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 2. An Academic Research Agenda

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Foreword

This document is being used in the 1996 long-range planning process of Florida Sea Grant, as the basis for consultations with varied interests concerned with Florida aquatic ecosystems. Research and extension faculty, agency scientists and various public and private perspectives are being included in an analysis of what Sea Grant priorities ought to be in the field of estuarine and coastal ocean affairs. Our emphasis goes beyond the traditional biological sciences to include disciplines such as policy, geography, law, engineering and economics. Opportunities for research appropriate to academia and for extension/outreach will be considered.

Preparation of this document by Gary Kleppel represents a successful effort to enlist an expert outside the ranks of Florida Sea Grant staff in administration or extension to contribute material for program planning. Further, we are grateful to faculty and agency colleagues who met with him singly or in small groups on various campuses.

Florida Sea Grant is asking tough questions about its future role in "estuarine sciences." The expert reviews we receive concerning this document will guide research, extension and communications priorities in 1997-2002.

William Seaman, Associate Director

James C. Cato, Director

Florida Sea Grant College Program

Gainesville, Florida

October 1996

Acknowledgments

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Burkart (Nova Southeastern University) in many aspects of this project. Finally, the author acknowledges the enormous contribution of the Estuarine Theme Area Panel, who guided both the conceptual and practical aspects of this report. This project was supported by the Florida Sea Grant Program and the Florida Coastal Management Program, Department of Community Affairs to Nova Southeastern University.

I. Introduction

Estuaries are dominant geographic features in Florida, encompassing approximately three quarters of the state's coastline. Further, the surface areas of the watersheds, which empty into the estuaries, are, on average, ten times greater than the areas of the estuaries themselves. Thus most of Florida's population, businesses, governments and recreation occupy space in the estuaries and their watersheds.

Florida's estuaries are valuable natural resources that provide some of the most diverse habitats and productive ecosystems on earth (Odum 1971). They are "multi-use" systems which, in an environment of uncontrolled population growth and development, can be rapidly degraded (as occurred during the period between 1950 and 1972). Today, there is a greater incentive for conservation and restoration but the pressures that strain the abilities of many estuaries to function ecologically remain as well. While the range of impacts has varied from one system to the next, no estuary in the state is free from human influence. Nor is it likely that anthropogenic stress will abate over the next several decades. As such, the need to identify and understand both the natural and the human forcing terms that control the functioning and integrity of Florida's estuaries is crucial. Considerable data already exist. However, many questions about the mechanisms underlying estuarine production remain unresolved. And new questions resulting from environmental changes currently taking place in Florida require attention.

To make sense of the data that exist and to develop useful approaches for acquiring information in new areas, it is helpful to have at hand some underlying conceptual framework that can structure one's thinking about estuaries and provide guidance about the way that questions are asked. It is considered by some that the role of academic research is to identify these underlying principles. Part I (Sea Grant Technical Paper 85) of this report summarizes the results of a search of literature and other information to document the condition of Florida's estuaries and to identify principles that can be used to guide future research on estuaries by the Florida Sea Grant Program. The goal of Part II is to use this philosophical framework to develop a research agenda.

As a program supporting academic research that addresses recognized societal needs, the Florida Sea Grant Program is developing a research theme area on estuaries to provide a uniquely academic product that will augment mission-oriented research undertaken by government and by the private sector. This report is not a call for proposals. It does not prescribe a specific research plan. Rather, it is a concept paper designed to focus research on two broad "organizing themes": (1) the hydrology of Florida's estuaries, and (2) the impact of cyclic environmental variability on estuarine function.

Hydrology, the distribution of water, has repeatedly been shown to be an underlying determinant of estuary function. Ultimately, all attributes of the estuary are affected by water, its distribution, movements and physico-chemical properties. Researchers, whether in the natural or social sciences, must be cognizant of how their particular investigatory questions relate to the hydrology. State freshwater management policies have generally not considered the impact of these policies on the estuaries and, currently, there are several cases of serious freshwater misallocation to critical estuarine ecosystems and tributaries (SWFWMD 1993; FDEP 1993). By all indications, the scope of the problem will widen over the short term.

Although hydrology is readily identified within the management community as an area of concern, the implications of variability to estuary function are not. Estuaries, however, are now considered "pulsing ecosystems", i.e., they vary continuously, but at least a portion of that variability is cyclic (repeating on a predictable frequency) (Odum et al. 1995). The concept of estuarine pulsing was the subject of a special symposium of the Estuarine Research Federation and is presently considered a new paradigm in ecology (Blum 1995). A knowledge of the cycles crucial to estuarine hydrology and ecosystem function is an important tool for management and planning.

This report is divided into several parts. Each part is relatively independent of the others, but each contributes to the total product. This format is intended to provide guidance but not to dictate the approach. It should permit Florida's academic marine scientists to react as individuals to the ideas presented in the report, and to formulate independent ideas about research on the state's estuaries. It is hoped that these individual models will be examined in an open forum. The ideas, i.e., individual research plans, should be debated and ultimately merged to produce a research program that, while guided by the content of this document, is the product of Florida's academic science community.

Following this introduction is a brief history of the project that resulted in the production of this report. In the next section the results and recommendations from Part I are briefly summarized. This is followed by a series of white papers by members of the Estuarine Theme Area Panel, a group of scholars from around the state, who consulted on this project. Finally, a description of the suggested major components and conditions of the research agenda is presented.

II. Background

In the fall of 1994, the Florida Sea Grant College Program began developing the concept of a Research Theme Area on Estuaries. The author of this report was contracted to review existing information on Florida's estuaries and to assist in the development of a research agenda. The Florida Coastal Management Program provided additional support for the review. A detailed description of the information-gathering approach is provided in Part I. A brief synopsis is given here.

The scope of issues associated with estuarine science and policy is enormous and beyond the ability of most individuals to address adequately. Therefore, a multidisciplinary panel of scholars from academia, with recognized expertise in estuarine and environmental issues was convened to guide the review process and to help formulate the research agenda. The Estuarine Theme Area Panel included two marine biologists, a physical oceanographer, a resource economist, an urban and regional planner and an attorney. In addition to attending meetings, participating in discussions and providing reviews of the documents produced during this project, several panelists prepared white papers on specific issues and concepts that were novel or which currently lack clear definition. Three concept papers are included as part of this document. The first, by N.P. Smith, deals with the management of water movements in estuaries. The second, by G.A. Vargo, addresses the definition of a functional estuary. The third white paper, by D.R. Christie, considers a new, incentive-based approach to resource management.

In addition to a review of the literature, interviews were conducted with members of the management and outreach communities and meetings were held with marine and aquatic sciences faculties at various universities in the state. The purpose of these activities was to augment the literature review and to solicit input on research themes and on the potential role of Florida Sea Grant in estuarine research.

The results of this analysis of existing information are disseminated in a two-part report entitled, "The State of Florida's Estuaries and Future Needs in Estuarine Research". Part I of the report entitled, "A Synopsis of Florida's Estuarine Resources with Recommendations for their

Conservation and Management," provides a detailed summary of the physical environment, biology and socioeconomic characteristics of each of ten estuaries. The report focuses on increasingly broader levels of organization, such that the estuary-specific summaries are used to identify features, processes and problems that are generally characteristic of all (or many) of the state's estuaries. At this point, groupings of estuaries (e.g., with respect to human impact, physical environment, ecosystem structure and function) also begin to emerge. The summary is then compressed into a list of findings, from which both specific and more broadly focused recommendations for management, technical development and research are produced. From these sections, the most general level of organization emerges, i.e., the broad organizing themes, hydrology and cyclic variability, described above.

Part II of the report, "An Academic Research Agenda," is a concept paper based on two general themes, hydrology and variability. It provides a way of thinking about issues that can guide the development of a research program. This document has been carefully constructed to serve as a framework and not a manifesto. Its intent is to provide insight. The research program which emerges will be consistent with Sea Grant's mission, but it will be designed by Florida's academic research community.

III. Summary of the Findings and Recommendations from Part I

For the sake of continuity, it is appropriate to provide the list of findings and recommendations from Part I. The reader is encouraged to examine the entire text of the preceding document and to use this section for general recall and reference when considering the research agenda.

A. Findings

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 decade, 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 have 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 approach 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 of water, but in 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 effect 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.

B. Recommendations

1. Recommendations for management:

a. Efforts to document non-point contaminant sources, to reduce their loads and to mitigate their impacts should remain priorities of estuary management.

b. 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 of all new development. Methods for improving septic systems and for separating existing combined sewer systems should be sought.

c. Florida's participation in the National Estuarine Program and similar federal and regional programs that promote the data acquisition, planning, management and education should increase.

d. 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.

e. Investigate approaches for incentive-based management of estuarine water quality and resources including education and public outreach programs. Such efforts should focus on (1) new residents, (2) elected and appointed public officials and (3) developers, as well as (4) the public at large.

f. Incorporate the management of estuaries and estuarine/watershed hydrology into Florida's water policy.

2. Recommendations for the development of tools and protocols:

a. Mechanisms for enlarging the state's Geographic Information System (GIS) data base and for sharing GIS products should be sought.

b. 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.

c. Expand the use and study of restoration technologies to recover habitat and to provide buffer zones against contaminants.

3. Recommendations for research:

a. 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.

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

c. Coinciding with an effort to identify cyclic phenomena on timescales appropriate to management, research should be conducted collaboratively between state agencies and academia. "Representative" estuaries should be identified. Key physical and biotic processes and rates should be measured, and major stressors should be identified. This research must incorporate policy studies to guide development of watershed management strategies which relate scientific data on the ecosystem to demographic trends and associated land uses.

IV. White Papers by Members of Florida's Academic Community on Issues and Concepts Pertaining to the Understanding and Management of Florida's Estuarine Resources

A. **The Movement of Water Within and Through Estuaries: A Critical Link to Management** - *Ned P. Smith*

B. **A Functional Estuary** - *Gabriel A. Vargo*

C. **Managing Resources/Managing People** - *Donna R. Christie*

A. The Movement of Water Within and Through Estuaries: A Critical Link to Management

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An understanding of transport patterns in estuaries and coastal lagoons is a prerequisite for the management of these bodies of water because transport patterns are fundamentally related to the health of the ecosystem. Transport can be subdivided into three categories: the movement of fresh water into and through the estuary, the internal circulation of the estuary, and the exchange of water with the adjacent continental shelf. The movement of fresh water through an estuary can have a cleansing effect that is crucially important for maintaining or re-establishing water quality. Alternately, freshwater inflow sometimes imports pollutants or excessive nutrients and thus can be the source of low-quality water. In either case, it is important to understand this component of the total circulation. The internal circulation of an estuary has a diluting effect and disperses pollutants or any other dissolved or suspended material that enters from a point source. The exchange of water with the adjacent continental shelf, whether by tidal or nontidal forces, has the effect of exporting and importing plants and animals that define both the estuarine and shelf communities. These same exchanges constitute the critical flushing mechanism that removes estuarine water. The significance of transport stems almost entirely from the dissolved and suspended material that is being carried into, through or out of an estuary. This can be larvae, suspended sediments, nutrients and pollutants, among other things.

The purpose of this essay is to examine the causes and effects of estuarine transport, and to discuss the relation of transport to management issues. Although the focus here is almost entirely upon transport within estuaries, estuarine transport patterns are physically coupled with tidal and wind-driven transport patterns over the inner shelf. For example, the import of dissolved and suspended material to an estuary occurs only when this material is held close to the coast by the shelf circulation. Furthermore, to be imported to an estuary, material must be passing an inlet during the flood tide cycle. Similarly, transport within an estuary is physically coupled with the controlled or uncontrolled arrival of fresh water leaving the estuary's watershed. Estuarine circulation patterns often change quickly, either as a result of rainstorm events or as a result of the controlled release of fresh water from drainage canals. This distinction is important, because while precipitation events are unmanageable, freshwater releases are manageable.

Transport patterns in estuaries arise in response to fresh water moving into and through the estuary from river mouths and drainage canals, density gradients associated with salinity differences, tidal and long-period exchanges as coastal sea level rises and falls, and local wind forcing. The interaction of tidal, meteorological and hydrological forcing results in circulation patterns that change dramatically over time scales ranging from hours to seasons.

The movement of fresh water can be virtually undetectable, because the total circulation is usually dominated by other components of the total circulation. While freshwater outflow can vary with the seasons, as well as over shorter periods of wet or dry weather, it always provides a seaward-directed residual flow that can have an important flushing effect.

Transport within an estuary by density currents can be relatively subtle also. But the density-driven inflow of ocean water through near-bottom layers is significant, because it does not reverse with the change of the tide, or with a shift in wind direction. The density-driven flow results in the "salt water wedge" found in many drowned river valley estuaries. The penetration of sea water into the estuary, and the compensating return flow at near-surface levels is a flushing mechanism that can play a major role in maintaining or re-establishing water quality.

In most estuaries, tidal exchanges are pronounced within and immediately landward of inlets and jettied passes. The direct import of sea water and export of estuarine water will occur within the "tidal excursion," the horizontal distance that water moves over any half tidal cycle. This is dependent upon tidal conditions in shelf waters, as well as on the size of the estuary, however it can be several kilometers. Tidal exchanges often vary significantly over biweekly time periods as a result of alternating spring and neap tide conditions. Also, consecutive semidiurnal period exchanges may differ appreciably when diurnal and semidiurnal tidal constituents interact to produce diurnal inequalities. Nevertheless, tidal transport provides a baseline flushing level that is both dependable and predictable.

Nontidal exchanges through inlets are driven by the rise and fall in coastal sea level, which in turn arise from direct and indirect meteorological forcing in shelf waters. Wind stress, for example, has a direct effect, as the across-shelf component of the wind stress vector alternately sets up, then sets down coastal sea level. Wind stress can influence coastal sea level indirectly by driving an along-shelf current. The across-shelf slope maintained by the along-shelf current will lower sea level when the coast is on the left, looking downstream. Conversely, the along-shelf current will raise coastal sea level when the coast is on the right, looking downstream. Although coastal sea level generally rises and falls several centimeters at most, the volume of water forced into or drawn out of the estuary, and thus the magnitude of the flushing, can be considerable. Surface atmospheric pressure gradients force estuary-shelf exchanges of similar magnitudes and over similar time scales, because they are associated with synoptic-scale weather features that move through the coastal zone. Shelf water level will rise and fall under regions of low and high surface pressure, respectively, assuming that water can flow freely from areas of increasing pressure to areas of decreasing pressure. Although time scales are on the order of several days, the effect is similar to that driven by tidal exchanges. As water level rises and falls on the ocean side of the inlet, water is forced into and drawn out of the estuary, producing a slow but effective flushing action.

Another form of transport, associated with turbulent mixing, occurs within estuaries, and especially between the estuary and the adjacent continental shelf. In this case, turbulent eddies transport dissolved and suspended material from regions of high concentrations to regions of low concentrations. Because of the strength and dependability of tidal motions, tide-induced turbulent diffusion is generally a significant fraction of the total transport. Water leaving an estuary on an ebb tide, for example, will be a mixture of the ocean water that arrived on the flood and the estuarine water that was mixed in, less the oceanic water that was mixed out and left behind. Diffusive transport can be an effective mechanism of bringing oceanic water into an estuary, even when the net transport through an inlet is an outflow from the estuary. It is an important baseline flushing mechanism, and it is as important to quantify this process as it is to understand current patterns when water quality is of concern to managers.

Another reason why an understanding of transport is important to managers is that to a significant degree transport is a manageable process. For example, transport patterns are strongly influenced by bottom topography and inlet geometry--both of which can be altered by dredging and filling. Examples of how transport can be manipulated include the enlargement and stabilization of inlets to enhance tidal and nontidal exchanges, the creation of drainage canals through which the amount and timing of freshwater releases can be controlled, the creation of causeways which create a major impediment to the internal circulation of the estuary by connecting the mainland to the barrier island, and the dredging of navigational channels within the estuary to promote shipping or recreational boating. Management decisions may be made more difficult by opposing economic and ecological effects, but dredging and filling are management tools that have profound effects on the transport of water into, through and out of an estuary.

The flushing of an estuary is a complex process, but one that is directly related to water quality. Flushing involves some combination of the effect of fresh water moving through the estuary and the effect of estuarine-shelf exchanges through one or more inlets. The determination of flushing, by whatever mechanism, takes on special significance when the estuary lies along a rapidly growing part of the coast, as is often the case in Florida. Urban estuaries are being subjected to increasing population pressures, and an understanding of the natural flushing ability of an estuary is correspondingly more important to support management decisions related to water quality. The simplest measure of flushing by fresh water is given by the hydraulic replacement time, T_h, defined by

$$T_f = \frac{V}{R_f}$$

where V is the volume of the estuary, in m^3, relative to mean sea level and R_f is the freshwater runoff, in $m^3\ S^{-1}$. While this quotient ignores the internal circulation of the estuary and is thus a crude measure of flushing, it is an easily calculated quantity that relates the rate of freshwater input with the size of the receiving body.

A second measure of flushing is provided by the freshwater replacement time, T_f, defined by

$$T_f = \frac{V}{R_f} \frac{S_o - S_e}{S_o}$$

where S_o is the salinity characteristic of adjacent ocean waters, and S_e is the spatially and temporally averaged salinity of the estuary. T_f also does not consider the internal circulation of the estuary directly, but it implicitly considers the mixing of fresh and salt water within the estuary by including the salinity of both the estuary and the adjacent shelf waters. It is noteworthy that both T_h and T_f are more realistic measures of natural flushing if R_f is replaced by the net freshwater gain (the combined effect of precipitation, evaporation, groundwater seepage and runoff).

A third measure of flushing--the 50% replacement time, T_{50}--quantifies the effect of tidal and nontidal exchanges through inlets and jettied passes. It is important to note that T_{50} (or any other percentage) is not based upon observations, and there is no defining equation. It can be quantified only with computer simulations of estuarine circulation. Once mixing has been specified for the model, one can track the replacement of estuarine water by shelf water, starting at any arbitrary time.

Perhaps the most practical application of an understanding of transport in the form of flushing is in the determination of flushing rates that are needed to counter the effect of wastewater loading at a given place and time. To maintain water quality, the estuary's ability to export pollutants to the inner continental shelf must exceed pollutant loading. Water quality trends are in large part a function of long-term differences between the rates at which pollutants are imported and exported. Just as pollutant loading can be spatially variable from point sources within the estuary, flushing rates will vary within an estuary. For example, flushing is generally active near an inlet as a result of vigorous tidal exchanges, as noted above. Conversely, estuaries often have backwater areas, such as finger canals, where the exchange rate is relatively slow.

In addition to spatial variability, flushing in an estuary can vary in time. For example, to the extent that flushing is wind-driven, seasonal changes in wind speed or direction can change the general circulation patterns that transport dissolved and suspended material through an estuary.

Over shorter time scales, day-to-day changes in weather associated with the movement of high and low pressure centers through the coastal zone can perturb significantly the seasonal flow pattern. The flushing rate of an estuary can therefore change from one region to the next, and flushing in a given region can change with time. As a result of temporary periods and local regions of poor flushing, it may be unwise to use average flushing conditions in an estuary's management plan.

As noted above, transport and therefore flushing can be enhanced or reduced by dredging and filling, respectively. The exchange of water between the estuary and the shelf, for example, is directly related to the size of the inlet. Enlarging the inlet will therefore increase flushing. In the case of a multi-inlet estuary, each inlet will contribute to flushing locally. Studies have shown, however, that the total flushing can be greater than the sum of its parts if the inlets are of unequal size. For reasons unrelated to flushing, this is often the case. For example, one inlet might be designed for commercial shipping, while another might be designed and maintained for recreational boating. The larger of two inlets will show a net outflow, the smaller will show a net inflow and within the estuary a net transport from the smaller inlet to the larger will be maintained. Management decisions may be influenced, given the hydrodynamic response to inlets of unequal size. For example, it may be decided to intentionally increase or decrease the size of a second inlet to produce a desired net inflow or outflow, and thereby improve flushing and water quality.

Navigational channels also aid flushing, especially in very shallow estuaries. A beneficial, if unintended side effect of the Atlantic Intracoastal Waterway (AIW) in Florida's East Coast lagoons has been to enhance the wind-driven circulation. The channel provides a conduit that allows wind-driven currents to move upwind, even as wind stress is forcing surface layers in the downwind direction. The northern sub-basin of Indian River lagoon, north of Sebastian Inlet, is 113 km long and has very limited exchange with Mosquito Lagoon through Haulover Canal at the northern end. Exchanges with the Atlantic Ocean are primarily through Sebastian Inlet, and the volume of the lagoon directly influenced by tidal and nontidal exchanges is distinctly limited. Through the wind-driven internal circulation, considerably enhanced by the AIW, the exchange of lagoon and ocean water is increased. During summer months, when wind stress forces surface layers into the northern sub-basin, the Intracoastal Waterway permits an upwind return flow that brings lagoonal water out of the northern sub-basin to within reach of direct tidal and nontidal lagoon-shelf exchanges. During winter months, when wind stress is out of the northeast, surface layer water is brought out of the northern sub-basin. Again, the waterway acts as a conduit, carrying ocean water upwind into the lagoon. Thus as a result of upwind and downwind transport over seasonal time scales, the residence time of lagoon water is reduced.

A second side effect of the Intracoastal Waterway, however, has been to create relatively poorly flushed areas, as backwater regions are created by closely spaced spoil islands. Strongest tidal currents are generally found along the central axis of an estuary. Fringe regions on either side will have well-defined ebbs and floods only where significant amounts of flooding and ebbing water are forced into and drawn from the nearshore regions. The size and spacing of spoil islands are crucially important factors in determining the degree of isolation and thus the impact on water quality.

Direct measurements of current speed and direction in estuaries provide the most unambiguous picture of transport patterns for those charged with making management decisions. But an alternative approach involves the development and application of computer models. Hydrodynamic models of estuarine circulation in particular serve as useful management tools, because they provide relatively low-cost previews of alternative management decisions before expensive and perhaps irreversible decisions are made. A critical phase in the development of any model is the careful validating of simulated currents and water levels by direct *in situ* measurements. Once verified, the model can be trusted, and one can investigate the likely response to causeways, enlarged inlets, channels, etc., while the work is still in the planning phase. The most informed decisions will be based upon the ecological response as well as the hydrodynamic response, nevertheless computer simulations offer a relatively low-cost and completely reversible preview of the probable outcome of management decisions.

B. A FUNCTIONAL ESTUARY

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What is a functional estuary? Are we asking if the estuary is functioning as might be expected based on one of several basic definitions of an estuary or are we asking if the functional inter-relationships of an estuary are operative? Are these questions one in the same? It can be argued that they are not. Pritchard's (1967) original definition of an estuary is: "An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage." By this definition, as long as fresh water and salt water are mixed in measurable quantities, given the appropriate geomorphology, one would have a functional estuary; whether organisms, their habitats and interactions were present or not. Depending upon your point of view, strict adherence to Pritchard's definition could simplify decision making for use of an estuary. If, for example, managers in an area opted to maintain a 'functional estuary', but presented convincing arguments that the major use for this estuary was to provide port and shipping facilities for several large industries, then only the physical attributes of the estuary would be important, biology could be ignored and the estuary could still be considered a functioning estuary.

However, Pritchard's definition really only encompasses the physical and structural characteristics of an estuary rather than the complex mix of geomorphology, physics and biology that lead to functional inter-relationships that are commonly used to characterize an estuary. It is this mixture of geological, physical and biological attributes that make each estuary unique. Although each estuary may be unique, all estuaries have common features that determine the basic physical circulation patterns, nutrient "handling" characteristics, and the types of primary producers and secondary consumers. Interactions between these components determine the functional nature of an estuary.

Some examples of structural characteristics of an estuary/estuarine ecosystem and their relationship with function are:

Structural	Function
Morphology	Dictates circulation patterns, habitat availability, sediment type, "productivity"
Hydrology	determines freshwater flows, regulates residence time, circulation, nutrient fluxes
Water quality	dictates species composition, dominant primary producers, secondary consumers, aesthetic uses, recreational uses
Primary producers	determine food web characteristics, the types and abundance of secondary consumers, carrying capacity, "use" to man

Stone et al. (1978) have examined these and other structural features of estuaries and offer a conceptual model of an estuary as four linked components: (1) the hydrologic regime, (2) natural resource productivity, (3) basin physiography, and (4) socio-economic processes. Interactions between each of these components in reality represent the functional nature of an estuary. For example, the basin physiography is linked to the hydrologic regime which maintains structural integrity and controls the particular mix of habitat types and areas which, in turn, maintains trophic interaction, enhances biodiversity and ultimately determines the total productivity of the estuary.

Day et al. (1989) attempt to use Odum and Copeland's (1972) energetic analysis scheme for coastal ecosystems to classify estuaries based on their functional qualities. Odum and Copeland (1972) suggest that the "status of an ecosystem is a balance between energies that build structure and order and stresses than cause a loss of structure and order". When energy sources are greater than stresses the system will maintain order and build structure. Sources of energy include 1) the mechanical energy of moving water, 2) sunlight, and 3) organic and inorganic fuels imported into the estuary. The general categories of stresses encompass 1) energy diverted from the system, 2) energy loss due to microscale random disordering, and 3) stress due to forced losses within the system. Although these concepts are a non-traditional way of looking at the functional aspects of estuaries the use of energy terms provides a basis for comparing structural components and their interactions, particularly in estuaries. Nixon (1988) and others argue that it is the energy subsidies provided by the physical components of the estuarine system (tidal, wind, waves) that contribute to the enhanced productivity of these ecosystems. In the example given by Day et al. (1989), the energy provided by water motion can act both as a source and stress on a functional aspect of the ecosystem; at low and moderate current velocities sea grass beds will be maintained by imports of nutrients and exports of waste and degradation products whereas at high velocities sediment erosion would destroy the same sea grass beds.

For the most part we have been discussing an estuary in terms of its basic biotic and abiotic structural components. Based on the interactions between these components some traditional functional characteristics of an estuary would include:

1. **Nutrient transport and regeneration processes**
2. **Waste removal**
3. **Sediment transport**
4. **Support of intricate food chain/webs**
5. **Maintenance of a high biodiversity**
6. **Maintenance of habitat diversity**
7. **Enhancement of productivity to support 4 and 5**

However, given the degree of urbanization that has occurred around all of the major estuaries in Florida and in the U.S., man must also be included as a component of the equation since, as stated by Wilson (1988) "Estuaries are the interface between man and the sea, they are channels for the impact of man on the marine environment". From a biological standpoint, man is usually never included in a list of estuarine species, i.e. as a structural component of the estuary, but he should be. If the species within an estuarine ecosystem are considered from a functional standpoint, i.e. by what they "do" rather than by their phylogenetic affinities, then man will have a major role in determining and affecting the interactions of the estuarine system. When man is included as a component in the estuarine ecosystem additional functional characteristics can be defined:

8. **Particle/suspended solids generation**
9. **Waste/toxin removal via sedimentation and transport**

10. Maintenance of diverse food supplies

11. Provide a contribution to aesthetic values

12. Provide transport/shipping opportunities

13. Provide recreational/research/economic opportunities

14. Provide a source of water for commercial/industrial use

Some might consider the socio-economic component as controlling all other aspects of estuarine function. Some point out that this sector can affect and/or determine the natural resource productivity of an estuary through "management" decisions that regulate harvesting components of the estuary, through dredge and fill operations that affect basin physiography and flow patterns within the estuary and land-use alterations that modify the watershed with effects on hydrologic and productivity components. Schubel and Hirschberg (1987) go even further and argue that estuaries are ephemeral on geological time scales and that organisms which we currently consider to be estuarine-dependent were, in fact, resident in coastal waters before rising sea level created present-day estuaries. They conclude that based on the current uses and demands to which an estuary is subjected "man makes the most demands on estuaries of all the organisms that use them" and "man is clearly the most estuarine-dependent organism in the biosphere".

In its natural state, i.e. without human influence, the basic morphological and physical characteristics of an estuary would, for the most part, determine the biological components of the estuary i.e. the type of primary producers and hence secondary production and final yields (products). Human influence has changed this basic functional characteristic of an estuary. Through the involvement of human settlement and industrialization, the mosaic of land-use in surrounding regions and within the estuary watershed has been altered with subsequent effects on the timing, quality and quantity of fresh water flows and nutrient inputs. Furthermore, industrialization both removes water and returns contaminants (heat, toxics, nutrients) while ports and shipping activities, via channelization and dredge and fill activity, shift circulation patterns and hence nutrient and organism retention times with subsequent changes in the "productivity" of the estuary at all trophic levels. Other uses such as commercial and recreational fishing, may also lead to changes in the characteristic biological interactions within an estuarine system that, in turn, change its functionality from an ideal based on the limits imposed by its geomorphological and physical characteristics to something else. What is that something else, is it still a "functional" estuary? Do all of the basic processes within the estuary still occur within the range determined by its physical and morphological characteristics or has sufficient modification occurred that major components have been lost (e.g. as in Tampa Bay when early patterns of habitat destruction and eutrophication caused a shift from a benthic sea grass and macroalgal driven primary producer system to a water column phytoplankton dominated system [Johannson, et al. 1982].

Unfortunately in today's world the latter is more often true than the former; components of the estuarine system have been lost or modified to the point that they no longer operate as originally intended e.g. organic loading leads to anoxic sediments which can no longer function effectively as a nutrient storage and remineralization compartment and a habitat for infauna.

Man is not only an integral part of a functional estuarine ecosystem but will (and does) determine how it will function. We are responsible for alterations in the watershed, eutrophication, changing flow patterns, and the degradation and elimination of biological components thus altering the productivity and yield of estuarine systems. Man is a major biological component of the estuarine system and must be included when determining the functional characteristics of any estuary. While it is difficult to measure the functional characteristics of an estuary, that must be a major goal in management if the estuary is to act as something more than a conduit for commercial/industrial materials and waste products.

So, in the final analysis, can we provide a reasonable definition of a functional estuary? I would argue that a functional estuary is any estuary that maintains its physical and geo-morphological integrity, has biological characteristics that relate to its physics and morphology and through the interactions of these components, provides a set of functional attributes that are within a range that should be expected given the physical and geomorphological characteristics of the estuary. The role of man and any changes that have been made in the structural characteristics of the estuary must be included in the picture.

Thus, all estuaries will differ from one another because differences in geomorphology will alter physical circulation patterns. As a result, the relative proportions of and types of primary producers will differ. However, within a similar climatic zone, there should be some similarity in functional characteristics such as nutrient cycling and food web dynamics. Although the rates and players may differ in the case of nutrient cycling and food web interactions, the basic responses and interactions will be the same. Thus the ultimate products of each estuary should also be similar, i.e. type of fishery, habitat type, recreational activities. Major divergences between estuaries within similar climatic zones with similar geomorphologies will be the result of and an indicator of the impact man has had on that ecosystem.

References

Day, J.W. Jr., C.A.S. Hall, W.M. Kemp and A. Yanez-Arancibia. 1989. Estuarine Ecology. J. Wiley & Sons, N.Y. 558 p.

Johannson, R., K.A. Steidinger and D.C. Carpenter. 1982. Primary production in Tampa Bay, Florida: A review. pp. 279-298, In: Tampa Bay Area Scientific Information Symposium; S.F. Treat, J.L. Simon, R.R. Lewis III, and R.L. Whitman, Jr. (eds.). Bellwether Press.

Nixon, S.W. 1988. Physical energy inputs and the comparative ecology of lake and marine ecosystems. Limnol. Oceanogr. 33 (4, part 2): 1005-1025.

Odum, H.T. and B.J. Copeland. 1972. Functional classification of coastal ecological systems of the United States. In: B.W. Nelson (ed.), Environmental of Coastal Plain Estuaries. Geol. Soc. Amer. Mem 133: 9-25.

Pritchard, D.W. 1967. What is an estuary: physical viewpoint. pp. 3-5, In: G.H. Lauff (ed.), Estuaries. Amer. Assoc. Adv. Sci. Pub. No. 83. Washington, D.C.

Schubel, J.R. and D.J. Hirschberg. 1978. Estuarine graveyards, climatic change, and the importance of the estuarine environment. pp. 285-303, In: M.L. Wiley (ed.), Estuarine Interactions. Academic Press, N.Y.

Stone, J.H., J.W. Day Jr., L.M. Bahr Jr. and R.A. Muller. 1978. The impact of possible climatic changes on estuarine ecosystems. pp. 305-322, In: M.L. Wiley (ed.), Estuarine Interactions. Academic Press, N.Y.

Wilson, J.G.. 1988. The Biology of Estuarine Management. Croom Helm, Sydney. 204pp.

C. MANAGING RESOURCES/MANAGING PEOPLE

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During the past several years, property owners have become extremely vocal and activist about the effects of land use and environmental regulation on the use and value of land. Many landowners feel that society has elevated the rights of migratory birds, endangered species, and other elements of the environment above the rights of people. Landowners have also found that the legal system has inadequately responded to the burden that many people perceive as being disproportionately borne by a few. Together these perceptions have led to the revolt commonly called the property rights movement.

A large part of the problem may be that regulators have lost sight of the fact that they are not in reality regulating resources or habitat or pollution: they are regulating people and the effects of the activities of people on resources and ecological systems.

The Regulatory Environment

Garret Hardin's famous 1968 *Science* article, "The Tragedy of the Commons,"[1] suggested that governmental regulation was the only response to the short-sighted, economic interests of polluters and developers using common resources. With a strong public sentiment reinforcing the environmental movement through the 1970s, environmental and land use regulation exploded. During the early days of the environmental movement, science also provided a great deal of new information about the effects of pollution and the way ecological systems function. This new information formed the basis for extensive schemes for pollution control, protection of endangered and other species, protection of wetlands and other habitat, and other land use restrictions. Since that time, the amount of regulation has continued to escalate, but the strong public consensus

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[1] 162 Science 1234 (1968).

supporting environmental regulation has eroded. Although science has continued to generate information, the nature of science has not always provided land owners a degree of certainty concerning the negative effects of their activities that they consider proportionate to the degree of restriction on property uses. It is maintained that permits are often denied with "boilerplate" language providing little explanation of the proposed activities' negative effects or alternative activity that might be practical. Many now view regulators as unrestrained and unaccountable.[2] It seems clear that the era of purely "command and control" regulation is over, and the new approaches to environmental policy and regulation need to be explored.[3]

Legal Remedies for "Taking" of Property

Environmental and land use regulations can have drastic effects on the value and uses of land. Although landowners have never had the right to do anything they want with their land, as some people suggest, the ethic in the United States has clearly elevated land ownership and the right to develop land to something closely akin to a constitutional right.[4] In *Pennsylvania Coal v. Mahon,*[5] the U.S. Supreme Court first recognized that regulation could devalue property to an extent that presented the functional equivalent of an act of eminent domain. This concept has been called "regulatory taking" and requires compensation under the Fifth Amendment. In the more than a half of a century since this doctrine was first announced, surprisingly little has been accomplished to clarify the situations in which compensation would be available.[6] Cases are

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[2] *See, generally,* Carol M. Rose, *Property Rights, Regulatory Regimes and the New Takings Jurisprudence - An Evolutionary Approach,* 57 TENNESSEE LAW REVIEW 577 (1990).

[3] *See, e.g.,* JOHN DEWITT, CIVIC ENVIRONMENTALISM, ALTERNATIVES TO REGULATION IN STATES AND COMMUNITIES (1994).

[4] Frank Michelman, *Property as a Constitutional Right,* 38 WASHINGTON AND LEE LAW REVIEW 1097 (1961).

[5] 6260 U.S. 393 (1922).

[6] Goldblatt v. Town of Hempstead, 369 U.S. 590 (1960) ("There is no set formula to determine where regulation ends and taking begins.").

determined primarily on an ad hoc basis by balancing a number of factors, making it almost impossible to predict an outcome in any given situation.[7] Strict procedural and ripeness requirements also make it difficult and expensive to bring claims.[8] To many, this remedy seems largely illusory.

Property rights legislation in many states, including Florida,[9] has sought to establish lower thresholds and clearer criteria for determining when landowners should be compensated for the impacts of regulation on their property interests. The property rights movement can have serious consequences for environmental and land use regulation, however. As Justice Holmes stated in *Pennsylvania Coal*, the case that introduced the regulatory takings doctrine, "[g]overnment could hardly go on if to some extent values incident to property could not be diminished without paying for every such change in the general law." With budget cuts and reform also a priority of legislatures, it may be that government will "hardly go on." In addition, the focus on the market value of land has been almost exclusive of the consideration of the effects of a proposed use of land. The movement virtually ignores some fundamental concepts underlying much of environmental and land use regulation: the principle that development should internalize many of the external costs it imposes on society, and the fact that much regulation creates reciprocal benefits as well as costs.[10]

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[7] *See, e.g.*, Penn Central Transportation Co. v. City of New York, 438 U.S. 104 (1978) (listing factors and providing a balancing test for determining when a regulation constitutes a taking).

[8] *See, e.g.*, Gregory Overstreet, *The Ripeness Doctrine and the Taking Clause: A Survey of Decisions Showing Just How Far Federal Courts Will Go to Avoid Adjudicating Land Use Cases*, 10 JOURNAL OF LAND USE & ENVIRONMENTAL LAW 91 (1994).

[9] 1995 Fla. Laws ch. 95-181.

[10] *See generally*, Joseph L. Sax, *Takings, Private Property and Public Rights*, 81 YALE LAW JOURNAL 149 (1971).

Policy Research Needs to Facilitate Environmental Regulation

What has happened between 1970 and 1990 to make the public become so hostile to environmental regulation? What can be done? As Justice Holmes noted in the early part of the century, it is obvious that government cannot simply pay for the effect on market value of all regulations. Are there alternatives to compensation for decreases in land value and have these alternatives been sufficiently explored?

Education may be one alternative that is an important element for successful protection of the environment. There is a need not only for a broad understanding by the public of effects of activities on their environment, but also an understanding of the nature and role of science.[11] The notion that education will lead to an era of enlightened self-interest and widespread support for environmental protection has, however, been referred to as a romantic and naive approach. But whether it is called education or another title, information must be widely available "both for public policy and for the political process" to function.[12] Information flow operates in both directions between the public and the government and "preference shaping" or "norm creation" can be effected by either side.[13] The public support for growth management in the mid-1980s is an excellent example of preference shaping.

Government also needs new tools. In addition to the fact that command and control regulation has generated a virtual revolt from the regulated public, it has been very unsuccessful in dealing with environmental problems like nonpoint source pollution and ecosystem management.[14] New ideas, like economic incentives, need to be considered. Florida's new property rights

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[11] In general, the public expects science to provide answers - not probabilities. When individuals incur losses to the potential value of land, they often want science to provide a certainty that is not possible.

[12] DEWITT, *supra* note 3 at 259.

[13] Professors Mark Seidenfeld and Jim Rossi of the Florida State University College of Law are currently researching the role of preference shaping by agencies in administrative law. *See also* Carol M. Rose, *Rethinking Environmental Controls: Management Strategies for Common Resources*, 1991 DUKE LAW JOURNAL 1 (1991).

[14] DEWITT, *supra* note 3, at 40.

legislation explores a great deal of new ground in areas of governmental accountability, consideration of alternatives by developers and regulators, and use of alternative methods of dispute resolution. A great deal of analysis and application of the law must be done before it will be clear how it will function, however.

Conclusion

The days of environmental regulation as usual are over. However, environmental problems persist, and we have not developed new approaches and new tools to deal with this new era. Command and control regulation seemed simple, direct and easy; to the public, it has turned out to be complex, arbitrary, and inflexible. In addition, it is not capable of dealing with the problems of the next century that we now place under the heading of "sustainable development." There is a great deal of policy work needed to determine *how* to protect the environment and the economy once science has provided the direction concerning *what* must be done.

V. Components of an Estuarine Research Theme Area

A. Overview

The goals of the research agenda described here are (1) to document naturally and anthropogenically induced changes in the functional integrity of Florida's estuaries, (2) to understand the causes of these changes, and (3) to respond to them by providing tools to facilitate policy development, planning and management. The research agenda that is described here is based on two broad organizing themes: (1) the hydrology of Florida's estuaries and (2) the impact of cyclic environmental variability on estuarine ecosystem function. These themes were described briefly above (see sections I and III) and they were considered in detail Part I of this report.

The application of these organizing themes to an emergent research program will most likely be accomplished by a variety of approaches. Some research will focus directly on the themes themselves. For instance, studies to improve the basic understanding of the hydrology (i.e., not simply the distribution and movement of fresh water, but its relation to saltwater distributions and to the salinity cycle, as well), or to identify longterm patterned variability in certain parameters (e.g., primary production, riverine input) by paleontological techniques will very likely be part of the program. In many cases, however, the organizing themes will be indirect attributes of the research, as for example, studies on the impact of variability in freshwater flow on estuarine ecosystems.

There is also a need (Kleppel 1996) to enhance the capabilities in data base management, quality control, data product output and educational outreach associated with ongoing estuarine research. It is suggested that several ancillary projects in technical development, data management and outreach be attached to the research theme area. These would permit the development of multi-institutional GIS and quality control management systems throughout the state that would minimize redundancy, maximize efficiency and ensure data-product quality and standardization throughout the state. Further, the concept of incentive-based management as it is described above, can only be successful if the public is knowledgeable and actively supports the concept.

B. General Approach

In Part I of this report, ten estuaries that together characterized the range of physiographies, ecosystems, socioeconomic pressures and demographies of Florida's estuaries and their watersheds were examined. The goal of that study was to develop the conceptual framework within which to develop a research agenda on estuaries consistent with the Sea Grant mission.

The conceptual framework, based on the themes of hydrology and cyclic environmental variability, was described above. This portion of the report is intended to provide guidance on how to make the transition from the philosophy to an actual research program. The transition might be envisioned as follows:

1. Develop the concept paper (this document).
2. Conduct a workshop to define a research program.
3. Develop collaborations between Sea Grant and state agencies to participate as partners in this program.
4. Announce the theme area to the academic community.
5. Receive and review proposals and initiate research.

As development of the research agenda proceeds, a simultaneous effort will be initiated through the Florida Sea Grant Extension Program to translate portions of the findings of the study into outreach products. This effort is already underway.

The following is a series of recommendations regarding mechanisms and criteria that might be used to produce the desired research program. These fall into four categories:

1. Selection of estuaries,
2. The composition and timeframe,
3. Ancillary activities, and
4. Transfer of information from the researchers to users.

1. Selection of Estuaries

This will be among the most important and also the most controversial tasks of the program. A long term commitment by Sea Grant to every estuary in the state is unrealistic financially and logistically. From a research perspective, an uncoordinated program will most likely not result in the academic product that is desired. For all of these reasons it is strongly suggested that the estuarine research theme area be developed along pragmatic criteria that will maximize the likelihood of generating research products that will be useful and transferable to society. Among these criteria are:

a. An estuary should be selected because it can be used as a representative of a region (e.g., panhandle region) or a certain type of condition (e.g., pristine);
b. there should be an existing data base on the system, the more complete, the better;
c. research and/or monitoring by federal, state and local government agencies and programs through which research collaborations with Sea Grant researchers can be formed (or already exist) should be on-going;
d. a problem, possibly particular to the estuary or the region should be recognized at the time of selection and a project that can lead to amelioration of the problem should be identifiable.

2. Composition and Timeframe

There was a sense of agreement (the word, consensus, is too strong) from meetings with faculty at several state universities (see Part I of this report) that an estuary research theme area would necessarily involve a strongly multidisciplinary effort. Simply, an important contribution that academia can make in solving problems rests with its (frequently underutilized) ability to harness enormous intellectual diversity and to therefore "see" a problem from a variety of vantage points. Such an effort necessarily suggests that any research project should be conceived as relatively longterm (perhaps five years) by current Sea Grant standards. This timeframe would permit the performance of serial program research that begins with analysis of existing data and ends with products that encompass intellectual growth, policy and management models and education and other public outreach tools. The research program should contain at least several of the following elements:

a. Retrospective analysis of existing data sets;
b. Description of the hydrological and hydrodynamic environments with reference to

their forcing variables (in the watershed) and paleontological characterization of readily identifiable longterm cycles;

c. Surveys of key ecosystems, processes and rates. Conceivably, many academic--agency collaborations would occur. Activities might involve (i) population and community inventories and surveys, (ii) description of the geology, (iii) characterization of population dynamics and trophic dynamics (there are relatively few data of this sort in the literature) in the present and over time, (iv) detection of environmental stress and (v) determining the relation between the hydrological and biotic environments;

d. Analysis of the socioeconomic and demographic structure of the estuary and its watershed. Again, academic-agency cooperation is crucial;

e. Compression of the natural and socioeconomic analyses to determine how the two sets of forcing functions influence the functional integrity of the estuary;

f. Application of hypothesis-driven policy research to explore management options for the system;

g. Merger of the findings on each estuary to identify features and problems common to all (or groups of) estuaries in Florida. A research effort of the sort described here obviously requires expertise from a great many areas. Institutional and multi-institutional research teams would be expected to develop to respond to a call for proposals for the Estuarine Research Theme Area. These teams would be expected to argue for a specific estuary as a research site, and to propose a project that addresses the criteria that were presented above.

3. Ancillary Activities

a. GIS (Geographic Information System) -- Currently, there are massive amounts of data on an enormous range of issues and topics dealing with estuaries in Florida. Effective use of this data base is heavily dependent on the way it is managed. Data base management will be crucial to the success of the estuarine research theme area, as it will to virtually all other state research and management activities in the future.

It is strongly advised that effort be made to develop and maintain a statewide GIS network that will be available on-line to government, academic and private sector users. The system might logically be based at the Florida Marine Research Institute of the Department of Environmental Protection, in St. Petersburg, where sophisticated GIS facilities currently exist. Major data input, management and product distribution responsibilities might be shared by DEP, the universities and the Water Management Districts. Support to organize and develop such a program might be sought from the state.

b. Standardization of Protocols and Quality Control -- The use of historical data bases has been repeatedly stifled by a lack of standardization and poor documentation of methodologies. If a major effort is to be invested in developing an understanding of long term trends and in developing GIS tools, then a system of standard data collection and sample processing must be in place. This effort cannot be aimed solely at academia. Nor can academia be excluded from it. It is suggested that a blue ribbon commission be appointed to define a set of measurements that are key to estuarine research and to develop standard protocols and product assurance practices that guarantee the comparability of measurements from one laboratory to another, through time. The project should include mechanisms for updating procedures to keep up with technological advances.

c. Education and Outreach -- The Sea Grant Extension Program must be a partner in the Estuary Theme Area. The most important roles that the Program will play are in testing incentive-based management models, in linking the academic and the management communities, and in educating the public. Other agencies have outreach programs as well and it would be well for collaborations to occur in extension as well as in research. It is perceived, however, that due to its extensive experience in outreach activity, the Sea Grant Extension Program would play a leading role in these collaborative efforts.

4. Transfer of Information from Researchers to Users

In order to satisfy the mission of Florida Sea Grant, mechanisms must be in place to apply what is learned from research. The approach put forward here provides a variety of mechanisms by which this can be accomplished. Some obvious possibilities include:

a. Upon completion of the multi-estuary research program, a meeting or series of meetings should be convened to begin the process of summarizing the findings of the individual investigations.

b. An editorial board should be established to:

   i. Assist individual PI's in publishing their technical findings.

   ii. Produce a volume summarizing the findings of the individual research projects but, more importantly, revisiting the general topic of the state of Florida's estuaries.

   iii. Work with Sea Grant outreach and media personnel to produce material aimed at non-technical users including:

   A. the general public

   B. policy and decision makers

   C. new residents

   D. developers

c. Advertise the availability of data products from the GIS network and seek federal support for the network.

d. Conduct a series of workshops for the management community that focus on policy options associated with multi-use issues (e.g., water allocation; ports and harbors vs. habitat restoration).

e. Because this project requires collaboration with management and mission-oriented institutions, avenues for technology transfer and the application of data to models and other functions should be available. The state's data management program, which will be improved and broadened as part of the theme area's activities will play a major role in this effort.

VI. Conditions and Criteria

The Estuarine Research Theme Area is seen as a multidisciplinary effort that provides one of the most important contributions that universities make to society, intellectual diversity. This program is designed to build links between academic disciplines that have not communicated and have, as such, missed numerous opportunities to see problems and ideas in new and interesting ways. The program is also designed to link universities to the public (government) and private sectors for two reasons. First, ideologically, transmittal of the academic research product to society requires that it be passed through and possibly "filtered by" government or private sector users. Second, pragmatically, Sea Grant cannot financially support anything like the scale or quality of research that is necessary to even begin to address the question in any single estuary (not to mention a suite of representative estuaries) in the state. Only through the research team approach can this mission succeed. Historically, Sea Grant has encouraged its researchers to develop interactions with government and private sector partners. This program, however, suggests a new and important role for the Florida Sea Grant administration, as mediators of formal links between itself and key agencies such that Sea Grant's Estuarine Research Theme Area becomes Florida's Estuarine Research Theme Area. This effort will require participation by university faculties and will involve a range of interactions from telephone calls between individuals to symposia involving the entire community. In the end, however, this program (in fact, any realistic program) cannot succeed without interaction. As Florida's academic, marine research arm, it is for Sea Grant to take the lead in establishing the direction of the program.

VII. References

Blum, K. 1995. Pulsed ecosystems: a new paradigm? Estuaries 18:545-546.

FDEP (Florida Department of Environmental Protection). 1993. An environmental characterization of the Rookery Bay National Research Reserve: Phase 1. Final Report. Grant NA170RO326-01. Rookery Bay NERR, Naples.

Kleppel, G.S. 1996. The state of Florida's estuaries and future needs in estuarine research. Part I. A synopsis of Florida's estuarine resources with recommendations for their conservation and Management. Technical Paper 85. Florida Sea Grant College Program and Florida Coastal Management Program.

Odum, W.E., E.P. Odum and H.T. Odum. 1995. Nature's pulsing paradigm. Estuaries 18:547-555.

SWFWMD (Southwest Florida Water Management District). 1993. Charlotte Harbor surface water management plan (SWIM). Tampa.