FLORIDA BAY NUTRIENTS

Perspectives on the July 1-2, 1996 Workshop

Report of the

Florida Bay Science Oversight Panel

Ad Hoc Committee on Nutrients

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Florida Bay Oversight Panel
Ad Hoc Committee on Nutrients

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Summary

An *Ad Hoc* Committee on Nutrients convened under the auspices of the Florida Bay Science Oversight Panel participated in a two-day workshop of investigators and program managers on nutrients in Florida Bay. It was asked to evaluate the adequacy of databases and research and monitoring programs for deriving inferences about nutrient sources and processes in Florida Bay and how they may change as freshwater inflows increase in association with hydrological restoration of South Florida. The Committee's main perspectives and recommendations are summarized below:

- An important determinant of the supply of nutrients to the Bay is water flow and circulation, the most poorly quantified element of which is the exchange between western and central Florida Bay. There should be a concerted effort using salinity modeling, tracers and flow measurements to quantify these exchanges and their importance in supplying phosphorus (from deeper Gulf waters) and nitrogen (from the Shark Slough plume into western and central Florida Bay).
- Although nutrient concentrations in freshwater effluents from the Everglades are now adequately monitored, because of the limited duration and high variability of the record recent variations in nutrient concentrations cannot be confidently attributed to water-management practices. The transport and transformation of nitrogen across the mangrove/estuarine transition and in the coastal flows toward Florida Bay remain important unknowns.
- Box models of nutrient budgets for Florida Bay should be developed which include the major forms of N and P and at least three different geographic segments—western (west of Everglades National Park boundary), central and eastern—as a parallel and contributory exercise with the planned numerical simulation model.
- In the shallow, warm, well lit Florida Bay cycling and transformation of nutrients may be as important as sources and concentrations in affecting plant growth. The current research on phytoplankton and biogeochemical processes should be expanded to focus on mechanisms of nutrient cycling rather than simply making inferences from nutrient distribution patterns.
- Studies of nutrient limitation have shown that nitrogen limits phytoplankton growth in the western Bay, several nutrients may co-limit growth in the central Bay, and phosphorus typically limits growth in the eastern Bay. Understanding the causes of algal blooms now requires process studies using modern tracer and enzymatic techniques, intense time-series rather than semi-annual or monthly measurements, and field or mesocosm, as well as *in vitro*, experiments. The Program Management Committee (PMC) should explore opportunities for engaging experts in such approaches and facilitating the intense multidisciplinary studies required.
- The data and observations in support of the divergent perspectives offered regarding the effect on the coral reefs of export of nutrients from Florida Bay of the Florida Keys Marine Sanctuary are sketchy and anecdotal. Nutrient transport

mechanisms and concentrations and grazing pressure on macroalgae must be considered together in addressing this question. The Florida Bay Research Program could contribute to the first of these factors.

- Concerns about the comparability of chlorophyll and nutrient data were raised. Data comparability is essential and quality assurance/quality control exercises now being undertaken should be expanded and maintained.
- Inconsistency of geographic references contributes confusion and interferes with the development of scientific consensus. The PMC should oversee an effort to develop a common set of names and boundaries for regions of Florida Bay. To the extent practicable, a common set of reference sites should also be selected for field measurements and experiments.
- A nutrient-plankton bloom team of investigators should be formed to facilitate interpretation and use of monitoring and research data.
- The Committee fully supports the PMC's efforts to develop a coupled circulation-ecosystem model of Florida Bay as a tool to systematize data, pose hypotheses, and anticipate the effects of different water management scenarios. The coupled model should be designated to describe the dynamics of these key features of the Florida Bay ecosystem: (1) coupled hydrodynamic-nutrient-phytoplankton-water quality variability, (2) suspended sediments and their influence on turbidity, and (3) seagrass populations and their influence on sediment resuspension, nutrient cycling and geochemistry.
- Although hydrologic flow and water level goals guide the restoration of the Everglades, no specific restoration goals for Florida Bay have been set which could guide research as well as management activities. A subcommittee or task force of the South Florida Ecosystem Restoration Program should be established to specifically address the restoration goals for Florida Bay.
- Because the freshwater effluent of the Everglades has very low concentrations of phosphorus and phytoplankton and macroalgal growth in the northeastern Florida Bay is strongly phosphorus limited, the Committee's provisional judgement is that the planned redistribution of fresh water into the Taylor Slough system will not lead to or worsen acute symptoms of over-enrichment in Florida Bay. However, the consequences of this plan have not been assessed with even simple mass balance models and must be regarded as uncertain at this point.

Introduction

Because of concerns that nutrient inputs from upstream sources are contributing to loss of seagrass beds and the continued proliferation of algal blooms in Florida Bay, studies which quantify the sources, fate and effects of nutrients are a major element of the Florida Bay Research Program. The objective of this Research Program is to guide the restoration of Florida Bay and it is directed by a Program Management Committee (PMC), representing the federal and state agencies sponsoring research and monitoring in the Bay. On July 1-2, 1996 the PMC convened the Florida Bay Nutrient Workshop in Key Largo, Florida to exchange data, information and perspectives on a series of questions concerning nutrients that the PMC considers critical for understanding the functioning of Florida Bay as an ecosystem, for defining restoration goals for Florida Bay, and for understanding its relationships to restoration of the larger ecosystem:

1. To what extent increased freshwater flows into Florida Bay will increase loadings of phosphorus and nitrogen?
2. What are implications of shifting the distribution of freshwater flows to Taylor Slough rather than C-111 for nutrient inputs to Florida Bay?
3. What is the relationship of regional hydrological restoration to the quality of water reaching Florida Bay?
4. What is the relative importance of exogenous and endogenous nutrient sources in Florida Bay and how is this likely to change with restoration?
5. To what extent are changes in nutrient loadings related to observed changes in seagrass and water column productivity?
6. What is the spatial pattern in nutrient limitation across Florida Bay and the causes and consequences of the differences?
7. What is the likelihood that increased freshwater flow into Florida Bay will adversely affect coral reefs?

The Florida Bay Science Oversight Panel is a board of experienced scientists from outside of the region that provides peer reviews, assessments and recommendations to the PMC. At the request of the PMC, the Oversight Panel assembled an *Ad Hoc* Committee on Nutrients to participate in the Workshop. The six individuals on the Committee included two members of the Oversight Panel (Drs. Boesch and Cloern) and others invited because of their experience in the scientific and engineering issues concerning nutrient inputs into coastal ecosystems. The PMC specifically asked for the Committee's "views on the adequacy of the nutrient databases and of the research and monitoring programs in place for deriving inferences about the most important nutrient sources and processes and how they may change as freshwater inflows increase in association with plans for hydrological restoration."

Adequacy of Databases and Research and Monitoring Programs

A total of 14 presentations were made at the Workshop. In addition, other Workshop participants contributed information and perspectives from the floor during discussions. The Committee did not critically review each study or presentation. Moreover, it was not the role of the Committee to answer the seven management-oriented questions posed by the PMC by interpreting the information presented. Rather, that task is appropriately the role of the team of investigators based on careful assessment of the data related to this highly complex problem. The Committee, in response to its charge, focused on the adequacy of the databases and research and monitoring programs for answering these and other critical questions. Throughout this report, particularly important observations or recommendations are highlighted by **bold facing**.

Nutrient Sources

1. **Water movements**: Answers to most of the seven management-oriented questions posed by the PMC depend, in part, on an understanding of the quantity and quality of the various sources of nutrients reaching Florida Bay. Nutrient input depends to a large extent on water movements: from the southern Everglades (summarized by Bob Johnson), ground water (addressed by Reide Corbett), and surrounding marine waters (summarized by Tom Lee). At this point, advection from any of these sources is not rigorously quantified. Freshwater flow through Taylor Slough is well measured except under high flow when water levels may overtop the coastal ridge and thus escape metering. Flow through the Shark Slough is reasonably well measured, but how much of this water is advected by coastal currents into Florida Bay has not been reliably estimated. Ground water flux, although it occurs in many parts of the Bay, now seems to be a minor source of nutrient addition. The regional oceanographic circulation is fairly well known and the flow past Cape Sable and between Florida Bay and Hawk Channel has been measured. However, the exchange between the deeper, western Florida Bay (which receives nutrients both from the deep Gulf shelf and the coastal current which bears the Shark Slough effluent) and the shallow basins east of the banks has not been directly quantified. The four circulation models presented at the 1995 Science Conference (i.e. those by Nuttle, Wang, Sheng and Galperin) provide various estimates of this exchange which can be used as a starting point, subject to empirical verification.

   Of these flows, that which is most important to quantify at this point is exchange between western and eastern Florida Bay (i.e. roughly across a line between East Cape and Long Key approximating the western boundary of the Everglades National Park). **There should be a concerted effort using salinity modeling, tracers and flow measurements to quantify the exchanges between western and central Florida Bay and the importance of these exchanges in supplying phosphorus (from deeper Gulf waters) and nitrogen (from the Shark Slough plume into western and central Florida Bay and possibly from central into**

western Florida Bay). The region south of East Cape is particularly interesting in this regard because of the evidence of eastward flow (from Ned Smith's current measurements), deeper channels, high concentrations of N and Si and relative proximity to the regions of persistent blooms in the north-central basins of Florida Bay.

2. **Nutrient concentrations**: More comprehensive information on the concentrations, mass loadings and forms of nutrients flowing through the southern Everglades into coastal waters was presented at the Workshop than at previous Florida Bay conferences. It appears that the Taylor and Shark Slough sources are well monitored and that the concentrations of important forms of nutrients are being adequately characterized. For reasons related to the limited duration of record and high variation in flow during the transition from the dry period of the late 1980s to the wet period of the last few years, recent variations in nutrient concentrations cannot be confidently attributed to changes in water-management practices. However, one of the *Ad Hoc* Committee members, Dr. William Walker, provided analyses and interpretation of long-term trends (1978-1995) in nutrient concentrations flowing from the Everglades Agricultural Area, through the Water Conservation Areas, and into the southern Everglades which suggest that the concentrations of both total phosphorus and nitrogen have been declining rather than increasing and will continue to decline as a result of management practices upstream. His assessment, which is highly relevant to the management questions posed by the PMC, was not presented to the full Workshop or evaluated by the *Ad Hoc* Committee, but is included as Appendix 1.

3. **Nutrient budgets**: It is surprising that only one speaker attempted an inventory or budget for nutrient inputs into Florida Bay. Mass balances can provide a reality check and a frame of reference in which to debate differences constructively. Brian Lapointe presented estimates for nitrogen input from various sources into Florida Bay, including sewage, decomposition of seagrasses during die-offs, atmospheric deposition, and freshwater inputs from the Everglades, on the basis of which he suggested that flows from the Shark Slough were the largest source of N and that the increased flows down the Shark Slough as a result of water management practices have been providing a significant addition of N to the Florida Bay.

Although Dr. Lapointe's attempt of the difficult task of development of a N budget for Florida Bay is commended, there are numerous assumptions in his estimates which need to be more closely examined and better resolved. The most critical of these relate to the amount of N released from Shark Slough that actually reaches Florida Bay. There is uptake and transformation (including denitrification) of this N *en route*, both in the estuarine transition zone and in the coastal water masses of the Gulf of Mexico. In addition, there are atmospheric loadings of N which fall on the southern Everglades below the S-12 structures which have to be accounted for. Greater attention should be paid to measurement of atmospheric nutrient loads over the watershed and Bay. Furthermore, the supply of N from the Gulf shelf (independent of the Shark Slough plume) was not considered in Dr. Lapointe's estimates. This may be large considering the large flow volumes involved (even if the concentrations are low). In addition, the forms of N (inorganic or organic) in the various sources have not yet been distinguished. It was also obvious to the Committee that differences in opinion as to whether the Everglades flow through Shark Slough is providing additional N to Florida Bay is based, to a certain extent, on differences in perception as to what constitutes Florida Bay, with Dr. Lapointe referring to the area west of the banks along the aforementioned East Cape-Long Key line, even extending out to Key West and beyond, and others perceiving Florida Bay in a narrower sense, corresponding mainly to the area in Everglades National Park. There is need for common terminology and an operational definition of the western boundary of the Bay (see Coordination below). **Box models of nutrient budgets for Florida Bay should be developed which include the major forms of N and P and at least three different geographic segments—western (as defined above), central and eastern—as a parallel and contributory exercise with the Corps of Engineers numerical model (see below).**

Nutrient Dynamics in the Mangrove Transition

As mentioned above, the uptake, release and transformation of nutrients in the tidal wetland zone between the lower end of the sloughs and open water of Florida Bay or the Gulf of Mexico must also be considered in assessing land-based nutrient inputs to the Bay. Robert Twilley's studies of southwest Florida mangroves are enlightening. They clearly demonstrate phosphorus limitation in the mangrove transition and the importance of the marine environment in supplying phosphorus to support the greater growth of mangroves at the higher salinity end of the estuary. This suggests that the amount of dissolved inorganic phosphorus (very low concentrations in the fresh water to begin with) that is transported through the mangrove transition to the marine environment must be vanishingly small. The fate of nitrogen in this transition zone is less clear. As phosphorus becomes less limiting toward the marine end (at least at the end of the Shark Slough system as opposed to the P-poor northeastern Florida Bay), there could be N uptake, but Dr. Twilley reported higher N mineralization rates at the marine end of the spectrum as well. Dan Childers described research getting underway on nutrient processing in the mangroves of northern Florida Bay. His hypothesis that refractory organic nitrogen in the Taylor Slough may be mineralized in the estuarine mixing zone (with its different microbial flora) will be difficult to test in the flumes set up in the field because of the scale of the flumes, background noise and limited quantification of nitrogen species. *In vitro* experiments should probably be conducted first to bolster a *prima facie* case for such a hypothesis and determine what best to measure. It also should be kept in mind that, although comparable measurements to those of Dr. Twilley have not been made there, N processing and exchange in the mangrove transition zone at the mouth of Taylor Slough may be very different than at the mouth of Shark Slough because of greater P-limitation of plant and microbial uptake of N at the former site.

Nutrient Cycling in the Bay

It is clear that the paradigm of nutrient cycling in temperate estuaries with clastic sediments does not seem to hold in Florida Bay. The greater importance of phosphorus limitation, sequestration and cycling was appreciated some years ago, but it is now becoming clearer that the low concentrations of available phosphorus limit biological processes that govern transformations of nitrogen. Also phytoplankton bioassay experiments (see next section) suggest that nutrients in addition to N and P (e.g. silica and iron) may also be important and may have to be considered in budgets and models.

Although the phytoplankton bioassays demonstrate that N may limit growth in western and, to a lesser degree, central Florida Bay, it is P and its rate of supply from the Gulf of Mexico that is likely to control primary production and nutrient cycling in the estuarine wetlands and in central and eastern Florida Bay. **The current research on phytoplankton and biogeochemical processes should be expanded to focus on mechanisms of nutrient cycling rather than simply making inferences from nutrient distribution patterns**. An overall research question could be: To what degree does P control N and carbon cycling in the system? Secondary questions of critical importance are: (1) How labile and available are the different forms of P; specifically, under what conditions does acid extractable P become bioavailable? (2) How labile and available are the different constituents of organic N (a large pool of which exists)? (3) Is there competition between bacteria and autotrophs (phytoplankton, seagrass and mangrove) for P and does this differ between fresh water and salt water? 4) To what extent may other elements, such as iron, be controlling phytoplankton production?

Nitrogen seems to behave very differently than the typical picture for temperate estuaries. N in Florida Bay is predominantly in the form of organic nitrogen or ammonium; nitrification rates appear to be very low. Further background research and consultation with individuals experienced in nutrient biogeochemistry in tropical, carbonate systems is recommended. For example, can the scarcity of nitrate be explained by phosphorus limitation of nitrification, or is oxygen limitation or sulfide inhibition controlling nitrification? Direct measurements of nitrification, denitrification, and nitrogen fixation should be made. Other questions which do not appear to be addressed by the current research program are what is the role of benthic macrofauna in controlling N and P cycling and how do processes in the root zone of seagrasses affect N and P availability? For example, the release of organic compounds by seagrasses and bacteria changes the redox, pH, sulfide and oxygen conditions in sediments; this may affect the availability of the different P fractions and N transformations.

Effects on Algal Blooms and Seagrasses

The field data presented suggest that the highest chlorophyll concentrations are in north central Florida Bay which also appears to be an area with higher silica and nitrogen concentrations. Although nutrient limitation of phytoplankton is being addressed with bioassay experiments, this approach has significant limitations. Bioassays generally involve unrealistic nutrient additions and incubation times. These can induce artificial "bottle" effects. Although these efforts, together with stochiometric assessment of nutrient levels, are useful in identifying potential nutrient limitation, they fall short in providing the necessary understanding of the processes responsible for initiating and sustaining phytoplankton blooms. For example, the importance of rapid recycling of low concentrations of labile nutrients may be underestimated, and potentially important sediment-water column exchanges not effectively assessed. Although much new insight has been gained on the distribution, composition and temporal variability of blooms and on the nutrient limitation of phytoplankton and bacterioplankton as a result of the Florida DEP and NOAA studies, there still is not a satisfying answer to the question: why are blooms more intense and prevalent now than they were five or more years ago? Furthermore, can recent variations in algal blooms be explained by climatologic variations alone, or is there an underlying long-term trend? **Understanding the causes of algal blooms now requires process studies using modern tracer and enzymatic techniques, intense time-series rather than semi-annual or monthly measurements, and field or mesocosm, as well as *in vitro*, experiments. The PMC should explore opportunities for engaging experts in such approaches and facilitating the intense multidisciplinary studies required**.

In addition, an important challenge is to be able to unravel the potential interactions between phosphorus, silica, iron, and nitrogen in controlling phytoplankton production. Carmelo Tomas's bioassay studies show that nutrients other than N and P (e.g. Si and Fe) might be important in stimulating or controlling diatom dominated blooms in western Florida Bay.

No new results were presented on nutrient effects on seagrasses at the Workshop. But piecing together the information available to date, there appears to be a lack of evidence that nutrient enrichment stimulated excessive macroalgal over-growth in *Thalassia* beds of central Florida Bay. This is the typical way that eutrophication affects seagrass loss and has been observed in grass beds in proximity to the Keys that are receiving sewage inputs [Lapointe, B.E., D.A. Tomasko, and W.R. Matzie. 1994. *Bull. Mar. Sci*. 53: 696-717]. Seagrass die-off seems to be reduced or reversed in many areas, although some die-off may continue to be associated with algal blooms in conjunction with resuspended sediments, which together reduce light availability. Information about reportedly abundant macroalgae in western Florida Bay is anecdotal. Systematic measurements are needed to verify these supposed trends of increasing microalgal biomass.

Export of Nutrients to the Reefs

The Committee focused its attention primarily on Florida Bay, although the PMC's seventh question regarding the effects on coral reefs is an important and appropriate one. Different perspectives were offered by Alina Szmant (no evidence of excessive nutrients of Florida Bay origin at reef tract; upwelling may be more responsible for nutrient inputs; macroalgal growth results mainly from diminished grazing) and Brian

Lapointe (increasing macroalgal growth related to nutrients escaping Florida Bay; nutrient concentrations exceed threshold concentrations of 1 µM for N and 0.1 µM for SRP). The data and observations in support of both of these different perspectives are sketchy and anecdotal. The Committee cautions against the application of threshold concentrations alone without consideration of the rates of nutrient supply and grazing pressure, which are also factors in determining macroalgal overgrowth. Beyond that, this issue is an important one for Florida Keys National Marine Sanctuary research and monitoring programs. Florida Bay studies of nutrient concentrations and flow should be coordinated with those programs.

Coordination

The Workshop served a very useful purpose of communication and discussion among Florida Bay researchers and managers concerned with the nutrient issue. However, it also made clear that more effective coordination among investigations is needed.

First, there were concerns voiced about comparability of data, particularly for chlorophyll and for nutrients measured in inland versus coastal waters. This is a very serious concern, with major ramifications. **Data comparability is essential and quality assurance/quality control exercises now being undertaken should be expanded and maintained**. Inter-laboratory comparisons of analyses of actual samples from Florida Bay and the coastal transition as well as standards should be included.

Secondly, as mentioned above there seems to be inconsistency of geographic references which contributes confusion and interferes with the development of consensus. **The PMC should oversee an effort to develop a common set of names and boundaries for regions of Florida Bay**. Furthermore, **to the extent practicable, a common set of reference sites should be selected for field measurements and experiments**. For example, Rankin Lake and Sandy Key were included in many of the studies discussed at the workshop, but it was hard to compare among other disparate sampling schemes. If the PMC can agree on a common set of sites, a more complete picture of conditions and mechanisms can be developed for each representative habitat. Routine monitoring efforts should be modified, as appropriate, to include each reference site, so that a long-term water quality record is available for use in interpreting results of field studies.

Finally, as the research program approaches management questions and builds a predictive model, **a nutrient-bloom team of investigators should be formed to facilitate interpretation and use of monitoring and research data.** Data summaries should be produced using region boundaries, statistical methods, and tabular or graphic formats developed by the team and revised to reflect an overall consensus. This will provide a consistent frame of reference for tracking short-term and long-term variations in the ecosystem, help to identify spatial and temporal gaps in ongoing monitoring efforts, and reduce the likelihood that arguments or disputes will develop as a result of differences in data sets or data-summary procedures. The scope should include estimation of nutrient loads, as well as summary of Bay chemical and biological data.

Modeling Needs

Requirements for a Circulation-Ecosystem Model

The *Ad Hoc* Committee is fully supportive of the PMC's efforts to develop a coupled circulation-ecosystem model of Florida Bay as a tool to systematize data, pose hypotheses, and anticipate the effects of different water management scenarios. To analyze the probable causes of the problems and to predict the consequences of the control measures, it will be necessary to use models. We urge the PMC to ensure that models be designed to address specific questions, and that these questions be identified and prioritized before the October 1996 modeling workshop. These questions should include potential water-quality and water-quantity management measures, with model scope and complexity and supporting monitoring sufficient to permit their evaluation. The model should also be used as a research management tool to identify the most sensitive assumptions about processes which bear further resolution.

It is clear that the model will need to be comprised of a number of modules. The divisions are somewhat arbitrary and reflect their historical development. We suggest that **the coupled model be designated to describe the dynamics of these key features of the Florida Bay ecosystem: (1) coupled hydrodynamic-nutrient-phytoplankton-water quality variability, (2) suspended sediments and their influence on turbidity, and (3) seagrass populations and their influence on sediments, nutrients and geochemistry.** The first module is commonly called a "water-quality model." Such models use water circulation computed from numerical hydrodynamic models as their basis and they compute the annual cycle of nutrients and phytoplankton biomass of a number of functional groups. Building such models is a reasonably well understood technology with a good track record (e.g., Chesapeake Bay, Long Island Sound, Massachusetts Bay). The suspended sediment and seagrass modules go beyond what is generally included in water-quality models and are required because (1) the resuspension and deposition of sediment solids influence the transport of phosphorus and, possibly, other nutrients and are themselves a critical component in the extinction of light that can shade sea grasses; and (2) seagrasses constitute a large portion of the biomass of Florida Bay, provide critical habitat, and have a major effect on nutrient cycling and sediment resuspension in this shallow ecosystem

Older versions of suspended sediment models were more empirical with respect to the treatment of settling and resuspension. The new generation of models have more detailed formulations which are based on field characterization of the sediment resuspenability. They are coupled to numerical hydrodynamic models which simulate the bottom shear stress. The newer models have a track record mainly in freshwater applications. Macrophyte models includes successional models as well as efforts coupled with water quality management in the Chesapeake Bay and in South Florida as part of the South Florida Water Management District phosphorus treatment programs. This is a less well developed technology, however models are progressing nicely elsewhere and this appears to be an approachable problem.

Beyond these three modules, the temptation to produce a model which answers all possible questions (e.g. regarding food webs and living resource production) should be avoided. We also caution that numerical models, no matter how complex, are merely approximations of complex natural systems. The utility of numerical models as management tools is limited by the degree of scientific understanding as expressed in conceptual models of ecosystem structure and variability. The nutrients workshop has identified some critical gaps in knowledge that must be addressed to refine the conceptual model, and thus the numerical model of the Florida Bay ecosystem. Some examples of critical questions include:

1. What is the fate of nutrients discharged from the Shark River (e.g. what fraction enters the Florida Bay ecosystem and fuels primary production there)?
2. What is the biological availability of particle-bound P (e.g. can blooms be triggered by resuspension events that move sediment-bound P into the water column)?
3. Why are the features of nitrogen cycling in Florida Bay apparently distinct from those in other coastal water bodies (e.g. what features limit the microbial oxidation of ammonium to nitrate; should “nonstandard” kinetics of N-cycling processes be included in the ecosystem model)?
4. What are the mechanisms that trigger and sustain algal blooms if Florida Bay (and why do these mechanisms appear to operate independently in the different spatial domains)?
5. What are the origins of turbid water (e.g. to what extent has the disappearance of seagrass beds enhanced the mobilization and resuspension of bottom sediments)?

As the scientific community pursues these and other critical research questions, we hope that it will explore a variety of approaches for data synthesis, including multivariate statistical models, material budgets and simple box models. We hope that insights derived from these will be incorporated into the numerical ecosystem model as it continues to evolve.

Proper Model Boundaries

The historical experience relative to placement of model boundaries is that they are almost invariably too close to the region of interest. Usually they are chosen to enclose the region of immediate interest. However, the proper locations are ones where any management scenario that will be simulated will not change the concentrations of interest in unknown ways. In practical terms this usually means far from the influence zone of the sources of nutrients being considered for modification. It is important that this be an informed choice since it limits the range of management scenarios that can be reliably investigated.

With respect to Florida Bay, it would appear that the western boundary should include the zone of influence of the Shark River discharge and the interactions with Gulf of Mexico shelf water masses. If the eastern boundary is at the Keys, then the influence of nutrients on the reefs to the east of the Keys cannot be simulated. If this is part of the problem, then the eastern boundary should probably be at the shelf break. Whatever the choices, it is necessary that sampling stations be established to monitor the concentrations at the boundaries in order to establish boundary conditions for the model.

Measurement Program to Support Modeling Activities

Modern eutrophication models have a relatively large number of state variables for which measurements are necessary. Variables that do not appear to be currently measured are:

- Extinction coefficient of downwelling irradiance using a photometer, beam transmission, turbidity, and the reflectance ratio of upwelling to downwelling irradiance.
- Particulate forms of organic carbon, nitrogen, and phosphorus (POC, PON, POP). These are best measured directly rather than by difference, e.g. POC = TOC - DOC.
- Particulate inorganic phosphorus (PIP), i.e. phosphate sorbed to suspended solids.
- Particulate Ca or $CaCO_3$ or particulate alkalinity. The measurement is intended to confirm that the majority of inorganic suspended solids in the water column are calcium muds from the sediment. This needs to be done until it is clear that inorganic SS = CaCO3.
- Bay wide sediment composition of C, N, P.
- Sediment P fractionation. Most important is the exchangeable PO4, NaOH extractable PO4, and mineral PO4 that corresponds to permanently immobilized PO4.
- Water column mineralization experiments. The question is: what fraction of the TOP and TON can be mineralized. Long-term incubations can be used to determine this.

Restoration Objectives and Strategies

Restoration Goals

It was troubling, but not surprising, to learn that there have been no specific restoration goals set for the Florida Bay which could guide the research program as well as management activities. The South Florida Ecosystem Restoration Program appears to be pursuing the goal of restoration of flow to those hindcast by the natural system model. But what does this mean for Florida Bay? There are two important considerations necessary when developing future management and restoration activities in the area:

1. The system (Everglades and Florida Bay) has been highly modified by human activities (both directly by canal building, railroad closures of keys, etc. and indirectly by urbanization, non-point source pollution, etc.)

2. Restoring the system to the “pristine” state is impossible whether we consider 10, 100, or 500 years ago as the desirable state. Too much has changed over time and too many changes cannot be fully reversed.

The goal should be to “restore” the system so that it (1) functions the way we expect it should, (2) has the habitats and (3) species composition that we expect or desire. These functions, species and habitats all have a value (monetary and intangible) that we as a society want to enhance.

Apparently, there is no management committee focused on Florida Bay that parallels the PMC. **A subcommittee or task force of the South Florida Ecosystem Restoration Program should be established to specifically address the restoration goals for Florida Bay.**

Problem Analysis

A clear distinction needs to be made between problems whose causes and solutions are unknown (research) and problems for which relatively well known methods for analysis and solution are available (engineering). If solutions are needed, then the restoration program should focus the majority of its effort to the extent possible toward problems for which engineering methods are available. However, a balance is necessary to deal with problems for which no clear pathway exists, since they will never be solved if no research effort is expended.

There are practically an infinite number of problems that can be addressed under the heading of Florida Bay restoration. A successful restoration plan targets the problems that appear to be of first order importance, and that can be understood well enough so that a program can be developed to deal with them.

For Florida Bay, the initial indication that something was going wrong was the decline of the seagrasses. This decline is still occurring so that its cause(s) can be studied as part of the program. Following or simultaneous with the decline of sea grasses, large algal blooms have occurred. These will further exacerbate the seagrass die off (presumably) and have undesirable consequences as well. Both of these problems are approachable from the point of view of "a reasonably well understood problem with known methods of solution," especially the algal bloom problem. Therefore, it is recommended that the Florida Bay restoration plan be directed to the questions: What causes and continues to cause the die off of the sea grasses, what is fueling the current algal blooms and what is causing the high turbidity? The objectives of the plan would be to identify measures, e.g. nutrient control, water export policies, circulation modifications etc., to mitigate these problems to the extent practicable.

Present Management Strategies

Management plans are now being developed and implemented to restore the hydrology of South Florida wetlands toward a more natural state. This being done mainly with the Everglades in mind; although increased fresh water input into northeastern Florida

Bay has also been viewed as beneficial. On the other hand, concern has been expressed by some environmental scientists that the augmentation and redistribution of flows into Florida Bay will cause further degradation of habitats and further losses of biotic resources. With this concern in mind, the PMC convened this Workshop to review data and concepts relevant to the linkages between flows, nutrient inputs, and water quality of Florida Bay. **On the basis of the current level of scientific understanding, as revealed in this Workshop, our provisional judgement is that the planned redistribution of fresh water into the Taylor Slough system will not lead to or worsen acute symptoms of over-enrichment in Florida Bay.** Concentrations of phosphorus, including DIP, in Taylor Slough water are very low, lower in fact than in the receiving water. Nitrogen loadings by this effluent, even at increased flow rates, are small with respect to the pool of N in eastern Florida Bay, which is in any case strongly P-limited. Moreover, the higher flows which accompanied the past two wet years have freshened eastern Florida Bay without resulting in algal blooms in that part of the Bay.

However, we must emphasize that this problem has not been analyzed within the context of even first-order nutrient mass balances. Accordingly, present manipulations of freshwater discharge, in effect, constitute an uncontrolled experiment with uncertain outcome. A proper analysis would employ a modern water quality model which would simulate the modifications in transport and salinity to be expected, as well as algal and other plant biomass responses. As a consequence, no conclusive analysis using state-of-the-art tools can be made and the Committee's provisional judgement is offered only to help quell fears that major or irreversible damage would result from restoration of flow in Taylor Slough. It is offered with the following caveats:

1. Alteration of the flow regimes into Florida Bay will certainly cause change in the ecosystem through mechanisms unrelated to nutrient dynamics. For example, augmentation of flows through Taylor Slough will change the salinity distribution in Florida Bay and its role as a feature of habitat quality and a mechanism of water circulation.

2. Human manipulation of ecosystems often leads to unanticipated consequences. Therefore, biological populations and water quality should be monitored continuously as the process of hydrologic restoration proceeds.

3. The level of scientific understanding is not yet sufficient to allow prognostications of ecosystem responses to hydrologic restoration with a high degree of certainty. However, the Florida Bay Research Program is designed to enhance the scientific understanding of key ecosystem processes as a step toward refinement of prognostic capabilities. A key effort at data analysis, synthesis, and prognostication is the multi-agency program to develop an ecosystem model of Florida Bay to describe its circulation, nutrient inputs and cycling, turbidity, and their combined effects on populations of seagrasses and algae.

Florida Bay Science Program Management

Given that the present federal and state investment in the Florida Bay Research Program is now about $7 million per year, it is reasonable to ask if the present managerial structure has evolved enough to meet the need for efficient execution of the program. The *Ad Hoc* Committee reviewed only a portion of the ongoing studies. Recognizing that the Florida Bay Science Oversight Panel will be reviewing the entire program in December, the Committee recommends to the Panel the following improvements to program management:

- Hire or designate a full time program manager whose responsibility it will be to coordinate and track Florida Bay research and make appropriate recommendations to managers.
- Designate standing workgroups in areas of key concern (e.g., modeling, monitoring and QA / QC).
- Establish *ad hoc* workgroups of participating researchers to coordinate activities and develop consensus statements on key topics (e.g. seagrasses, phytoplankton dynamics, nutrients, etc.) Those should meet periodically to compare results.

In addition, the process by which research proposals and projects are selected for funding requires review for both relevance and merit. The former requires active input from individuals familiar with the Florida Bay system and are often drawn from the local scientific and management community. The latter requires scientific and technical reviewers who do not have vested interests in funding decisions or other conflicts of interest. The structure and function of the PMC must be considered accordingly, and if necessary restructured to be responsive to relevancy and merit review considerations.

It is clearly necessary that the PMC regularly reassess and update its Science Plan to insure that it is appropriately addressing management needs. Attendant to this must be specific task lists, that define in unequivocal terms all research, monitoring and data collection activities. This level of specificity will be necessary to provide the data necessary for the modeling effort.

Finally, a responsibility of the PMC is to provide mechanisms for lively, constructive debate about the scientific and technical issues inherent to Florida Bay. Although protracted and public debates have, in an ironic sense, heightened public and official interest in the "Florida Bay problem," the program is reaching a stage where the credibility of science is diminished if mechanisms for resolving differences of opinion are not improved. Accordingly, every effort should be made to have regular data analysis and discussion meetings at which consensus statements are developed and hypotheses posited for incorporation into management models and the science plan. Toward this end, the Committee commends the PMC for convening the Workshop on Florida Bay nutrients. It was a significant step in the right direction.

Similarly, the several Committee members who participated in the 1993 evaluation of evidence related to the deterioration of the Florida Bay or the 1995 annual review of the Florida Bay Research Program note that although much remains to be determined, the

PMC has made substantial progress in getting appropriate science done under complex circumstances—both a complex ecosystem and complex inter-institutional arrangements.

Appendix 1.

Perspective on the Effects of Upstream Activities on Nutrient Delivery to Florida Bay

William M. Walker, Jr.

Characterizations of water-management impacts on nutrient loads to the Water Conservation Areas (WCAs) and to Florida Bay presented at the Workshop were incomplete and inaccurate. In particular, no consideration was given to current trends in nutrient concentrations at inflows and outflows from the WCAs or to the beneficial impacts of future water-quality control measures. Specific comments include:

1. The Interim Action Plan (IAP) (gradually implemented between ~1979 and ~1985) diverted Everglades Agricultural Area (EAA) runoff and nutrient loads away from Lake Okeechobee and into the WCAs. As a result of this plan, flows and loads from the EAA to the WCAs have increased by 10-20 %. Information presented at the workshop suggested that the increase was of greater magnitude.

2. It was represented that current and future water management activities will increase flows and nutrient loads from the EAA. Flow through EAA pump stations is a mixture of EAA runoff and flow released from Lake Okeechobee. Recent (1992-present) water-management changes have increased contributions from Lake Okeechobee, but have not increased flows from the EAA. Lake Okeechobee releases have less impact on nutrient loads to the WCA's because N & P concentrations in the lake releases are ~50% of those found in EAA runoff.

3. Recent year-to-year variations in S12 flows primarily reflect climatologic variations (dry 1989-1990 to wet 1992-1995). Flow increases resulting from changes in water management (Lake Okeechobee releases) have been smaller. The flow and nutrient-budget scenarios presented incorrectly attributed all S12 flow and load variations in recent years to changes in water management.

4. Future water-management plans (mandated by Everglades Forever Act) will increase average inflows to the WCAs from the north by 28% relative to 1979-1988. This increase will be achieved by diverting flows from the C51W basin and by releasing additional flows from Lake Okeechobee.

5. An extensive Best Management Practices program has been implemented in the EAA. As a result of this program, volumes of runoff discharged from the EAA are expected to decrease by 10-20%. Total P load reductions averaged 47% over the last three years with partial BMP implementation, relative to average loads in 1979-1988 and adjusted for variations in rainfall. These load reductions may increase in the future as BMP's are fully implemented and refined. Impacts of BMP's on total nitrogen loads have not been quantified. However, there are

long-term decreasing trends in total N concentrations at the EAA pump stations (-3 to -4 %/yr, 1978-1995).

6. The planned Stormwater Treatment Areas (STAs) are expected to provide further substantial reductions in phosphorus and nitrogen loads to the WCAs from the north. The STAs are designed to achieve a 70-80% reduction in P load. Based upon 18 months of operating data from the Everglades Nutrient Removal Project (STA prototype treating runoff from the S5A basin), a ~40% reduction in total N load is expected.

7. Long-term trends in nutrient concentrations at WCA inflow/outflow stations monitored by the South Florida Water Management District (SFWMD) since 1978 need to be considered in projecting impacts of water management. These include:

a. Total Phosphorus:
Increasing trends at most stations 1978-1991 (~5%/yr)
No trends or decreasing trends 1991-1995

b. Total Nitrogen:
Decreasing trends at EAA pump stations and Everglades National Park (ENP) Shark Slough inflows (-2 to -4%/yr) over whole record (1978-1995).

8. As a consequence of the above factors (diversion strategies, BMPs, STAs, and long-term declining trend in N concentration), substantial reductions in WCA inflow nutrient loads and concentrations are expected in the future. These improvements are expected to cause decreases nutrient concentrations at WCA outflow stations, including discharges to ENP Shark River Slough through S12's and S333. Water quality models under development by SFWMD will provide quantitative predictions.

9. Nutrient concentrations at the S12's are close to marsh background levels. Historical monitoring data from ENP marsh stations (1986-present) presented by Zhen-quan Chenn of SFMWD suggest that spatial variations in nutrient concentrations between the S12's and the upper mangrove fringe area are relatively small. There is some evidence that total nitrogen concentrations increase in the Slough moving south from the S12's. A more intensive monitoring program and a modeling effort are needed to characterize and predict spatial variations in flows and nutrient concentrations in this region. The program should include monitoring along transects to characterize gradients and monitoring at reference sites which are primarily rainfall-driven to characterize background water quality.

10. Given the current and planned water-quality controls and given the fact that nutrient concentrations at inflows to the Park are currently close to background levels, there is reasonable assurance that any additional flows diverted to the

Florida Bay region would have nutrient concentrations at marsh background levels. Associated loads would reflect natural sources and atmospheric deposition. The notion that water management changes will divert agricultural nutrient loads to Florida Bay is incorrect.

11. Average total N & P concentrations in waters pumped into Taylor Slough at S332 are low (~1000 ppb and ~10 ppb, respectively) and appear to be at or below average concentrations in Florida Bay. Over the entire period of record (1983-1995), no trends in S332 nutrient concentrations are evident. A decreasing trend in total N concentration is evident at S18C (-4 %/yr). Further reductions in nutrient concentrations may result from planned implementation of water-quality control measures in the C111 buffer zone.