Tampa Bay Estuary Program Tracking Progress Toward Its Nitrogen Management Goals:

Fifth-Year Assessment of Bay Water Quality Indicators and Models

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July 2001

FOREWORD

This report was prepared by Janicki Environmental, Inc. under the direction of Mr. Dick Eckenrod and Ms. Holly Greening of the Tampa Bay Estuary Program. This work was performed under Contract No. T-98-06 for the Tampa Bay Estuary Program.

ACKNOWLEDGMENTS

We thank Mr. Dick Eckenrod and Ms. Holly Greening of the TBEP for their helpful comments and direction in the course of this work. We also thank the TBEP/SWFWMD Joint Water Quality Subcommittee for its review, insight, and assistance in the evaluations performed. Special thanks are directed to Mr. Roger Johansson, City of Tampa Department of Sanitary Sewers Bay Study Group, for sharing his knowledge of Tampa Bay gained from years of monitoring in its waters, and providing data for this project. Special thanks are also directed to Mr. Craig Kovach, CF Industries, for his assistance in obtaining data necessary for the completion of this work and his helpful comments. We also thank Mr. Tom Cardinale and Mr. Richard Boler of the Environmental Protection Commission of Hillsborough County, Mr. Andy Squires and his staff at the Pinellas County Department of Environmental Management, Mr. Rob Brown and his staff at the Manatee County Environmental Management Department, and Mr. Charles Kovach and his staff at the Florida Department of Environmental Protection for their assistance in obtaining data for this project.

BACKGROUND

The Tampa Bay National Estuary Program (TBNEP) developed a Comprehensive Conservation & Management Plan (CCMP), entitled *Charting the Course,* which was the culmination of five years of effort aimed at bringing together the participants of the TBNEP to address the key environmental issues affecting Tampa Bay. In February 1998 the Tampa Bay National Estuary Program Interlocal Agreement was executed by the following entities:

- City of Clearwater
- City of St. Petersburg
- City of Tampa
- Florida Department of Environmental Protection
- Florida Marine Research Institute
- Florida Game and Freshwater Fish Commission
- Hillsborough County
- Hillsborough County Environmental Protection Commission
- Manatee County
- Pinellas County
- Southwest Florida Water Management District
- Tampa Port Authority
- Tampa Bay Regional Planning Council

These parties and the U.S. Environmental Protection Agency and the U.S. Army Corps of Engineers have approved and adopted the goals set forth in the CCMP. These goals address such issues as water & sediment quality, fish & wildlife habitats, spill prevention & response, and dredging and dredged material management. The Interlocal Agreement requires the parties to make their best efforts to meet the goals within the time frames defined in the CCMP. Generally, these goals are to be met in a cooperative fashion with attempts to achieve all goals in a cost-efficient manner. The Tampa Bay Nitrogen Management Consortium represents the only efforts to meet a goal where the individual parties have specific responsibilities. The Interlocal Agreement also requires the parties to review progress toward these goals at least every five (5) years.

The Interlocal Agreement also provided for the creation of the Tampa Bay Estuary Program (TBEP). The TBEP is comprised of a Policy Board, Management Board, Technical Advisory Committee (TAC), and Citizens Advisory Committee (CAC). In simple terms, the TBEP was established to oversee and assist in the implementation of the CCMP. TBEP has no regulatory or taxation powers.

The implementation of the CCMP will generally be achieved by implementation of the Action Plans set forth in that document. In 1998, the TBEP published *Partnership for Progress*, an action plan for the Tampa Bay Nitrogen Management

Consortium. This plan was the culmination of about two years of planning. The plan defined nitrogen load reduction targets, by bay segment, and specific projects and their expected nitrogen load reduction to which the consortium partners are committed. The plan also sets out an element for tracking progress toward load reduction targets. Another basic tenet of the plan is that tracking will be reviewed every five years.

The objective of this report is to summarize the results from a series of investigations whose purpose was to assess the progress toward meeting the nitrogen management goals of the Tampa Bay Estuary CCMP. Specifically, the status of a number of bay indicators is assessed relative to historical conditions and desired bay management targets. Also, the models employed to develop the nitrogen management strategy are reviewed, using data collected since 1994, to determine if model refinements and ultimately modifications to the load management strategy may be necessary.

Tampa Bay Nitrogen Management Strategy Paradigm

The CCMP specifically addressed several major issues, including water quality and habitat loss. The loss of seagrasses in Tampa Bay drew particular interest, given their important role in the ecological functioning of the bay. Seagrasses provide critical habitat for recreationally and commercially important fish and invertebrate species. Seagrasses in Florida provide juvenile nursery and adult feeding areas for red drum, spotted seatrout, spot, silver perch, sheepshead, snook, shrimp, and the bay scallop (Zieman and Zieman, 1989). Seagrass meadows are also important feeding areas for the Florida manatee. Seagrasses serve to improve water quality by reducing nutrients in the water column and are an important component of the energy and nutrient cycles in coastal environments.

Seagrass extent and condition can be impacted by many factors, including water quality, physical factors such as prop scarring and currents, seagrass disease, and location of seagrass beds in relation to offshore transverse sandbars. The TBNEP Technical Advisory Committee (TAC) recognizes that these and other factors may affect progress towards reaching adopted seagrass restoration goals, and is currently initiating actions which will assist with addressing factors in addition to water clarity and quality (including the initiation of measuring the depth of water at various seagrass beds around the bay, and the monitoring of potential seagrass disease). Actions needed to address additional factors, such as the bay-wide effects of prop scarring or the location of various seagrass beds, will be included in discussions of future monitoring needs.

In Tampa Bay, seagrasses typically grow at depths no deeper than six to eight feet. Light is one of the limiting factors on the depth at which seagrasses can be found. Light requirements for growth vary by seagrass species. Turtle grass, the most common seagrass species in Tampa Bay, has an estimated light requirement of

20.5% of the incident subsurface light (Dixon and Leverone, 1995). For the purposes of seagrass restoration target setting, this was assumed to be the minimum light requirement for seagrasses in Tampa Bay (Janicki and Wade, 1996).

To address the issue of seagrass habitat loss, recommended seagrass protection and restoration targets were developed (Janicki et al., 1995). Seagrass restoration targets were determined by comparing 1990 seagrass extent to that observed in 1950. Seagrass targets were defined as those portions of Tampa Bay that had seagrasses in 1950, did not have seagrasses in 1990, and had not been permanently altered to preclude restoration of seagrasses.

As discussed above, the TBNEP developed the Nitrogen Management Strategy to strive toward the seagrass restoration goals. The Strategy seeks to prevent future impacts due to excessive nitrogen loadings to Tampa Bay. Excessive nitrogen loading can fuel algal growth to the point where the phytoplankton standing stock is sufficiently large to impair water clarity. Such conditions can stress submerged seagrasses that are intolerant of low light conditions. Such was the case prior to the early 1980s, and seagrass loss was significant, particularly along the deep edge of the seagrass beds. Physical alteration through dredging and filling activities has also contributed to some of the losses since the early 1980s. The restoration of lost seagrasses and protection of existing beds, therefore, depends at least in part on the maintenance of a light environment conducive to seagrass growth and reproduction.

A paradigm that relates nitrogen loading to chlorophyll and seagrass was utilized, as shown in Figure 1.

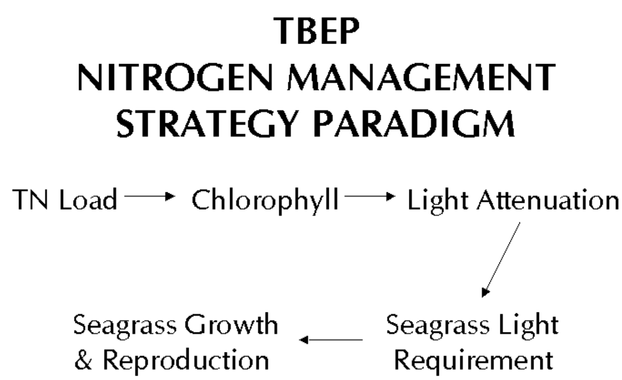

Figure 1. The TBEP Nitrogen Management Strategy Paradigm.

An empirical modeling approach was taken to define quantitatively the relationships between TN loads and chlorophyll a concentrations and between chlorophyll a concentrations and light attenuation (Janicki and Wade, 1996). These relationships were defined for those bay segments (Figure 2) for which sufficient data existed.

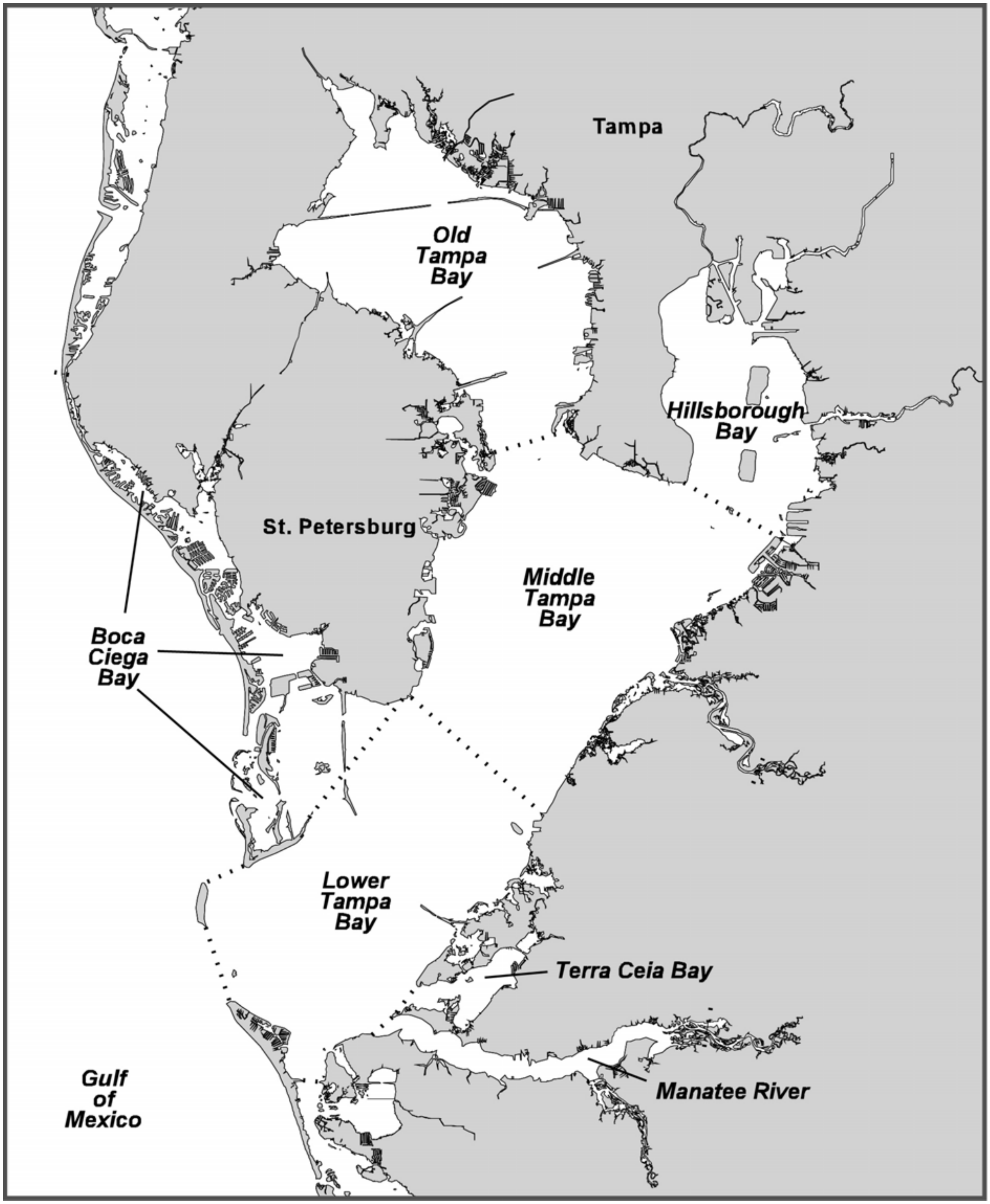

Figure 2. Bay segments of Tampa Bay.

A corollary to the paradigm deals with the relationship between nutrient loading and dissolved oxygen (DO) concentrations in the estuary. Nutrient over-enrichment clearly can lead to excessive algal growth and biomass. The organic matter generated can support rates of oxygen consumption that exceed rates of oxygen production and mixing, leading to the establishment of hypoxia (DO < 2 mg/L) in productive estuarine waters. The northern Gulf of Mexico near the mouth of the Mississippi River is a notable example of such a condition (NRC, 2000). Hypoxic conditions can significantly influence the distribution and abundance of benthic macroinvertebrates and fishes and ultimately the trophic dynamics of a water body. Given the potential for significant impacts on important bay resources, tracking the response of DO concentrations in Tampa Bay to changes in nitrogen loading is another critical component of this assessment.

STATUS OF BAY INDICATORS

To satisfy the objective of tracking progress toward the goals of the TBEP, four critical bay indicators were examined:

- Seagrass areal extent
- Chlorophyll a concentrations
- Nitrogen loading, and
- DO concentrations.

Generally, the status of these indicators of bay health as of 1998 has been examined. In some cases, data collected in 1999 have been included in the analyses.

SEAGRASS EXTENT

The status of seagrass areal extent in Tampa Bay has been reviewed by Pribble et al. (2000) and Tomasko (2000). Several conclusions were drawn:

- From 1990 to 1996, seagrass acreage showed a net increase of 1,690 acres in the bay;

- More than half of the increase observed between 1990 and 1996, approximately 900 acres, occurred in Boca Ciega Bay;

- The rate of increase in bay-wide seagrass acreage slowed from 1994 to 1996, when seagrass acreage increased by approximately 400 acres, compared to the increases observed between 1992 and 1994 (700 acres) and between 1990 and 1992 (600 acres);

- Between 1994 and 1996, seagrass acreage declined by 150 acres in Old Tampa Bay and by 240 acres in Middle Tampa Bay;

- Results from the 1999 areal survey indicate that as much as 2,000 acres of seagrasses (representing an 8% decline) were lost since 1996. The losses were most notable in Old Tampa Bay, especially along its western shore.

The loss of seagrass in Tampa Bay between 1996 and 1999 was similar to that found in other regional estuaries, ranging from 7% in Charlotte Harbor to 10% in Sarasota Bay. These losses are notable but perhaps understandable given the extremely unusual meteorological conditions due to the El Niño – La Niña effects observed in 1997 and 1998.

Recent observations also led to concerns that seagrass goals may not be achieved solely by nitrogen load management. Between the early 1980s and 1996, seagrass acreage in Tampa Bay showed a relatively continuous increase, although varying rates of increase were found between monitoring periods. However, there continued to be areas that did not support seagrass into which seagrass was expected to expand. These expectations were based on considerations including water quality, water column depth, and the presence of seagrass in the 1950 period.

The possible reasons for the continued absence of seagrass in these areas include those associated with physical impacts and those associated with water quality impacts. Physical impacts may include changes in wave energy and loss or movement of transverse sandbars. Water quality impacts may include relatively poorer water quality in near-shore shallow areas than observed in the deeper offshore areas by the ambient monitoring programs in the bay. These alternative hypotheses were investigated at a symposium sponsored by TBEP in 2000. A TBEP seagrass working group was established following the symposium, and this working group is further examining these hypotheses.

Along these lines, an investigation of spatial differences in water quality resulted from the finding of appreciable reductions in seagrass in Old Tampa Bay between 1996 and 1999, especially along the western shoreline. Statistically significant differences were found in chlorophyll and clarity, with the western shore water quality poorer than that along the eastern shore. The TBEP seagrass working group is examining both additional physical and water quality factors and their influences on seagrass recovery.

CHLOROPHYLL a CONCENTRATIONS

Chlorophyll a targets that were consistent with light requirements of seagrasses were previously established (Janicki and Wade, 1996). These targets were:

- Old Tampa Bay – 8.5 μg/L
- Hillsborough Bay – 13.2 μg/L
- Middle Tampa Bay – 7.4 μg/L
- Lower Tampa Bay – 4.7 μg/L

Two studies were completed in 2000 to assess the status of Tampa Bay relative to these targets.

Janicki et al. (1999) and Janicki and Pribble (2000) evaluated and applied a methodological framework for assessing ambient conditions and identifying commensurate management responses to deviations from the desired conditions. The method was developed with the assistance of the TBEP/SWFWMD Joint Water Quality Subcommittee to determine if adopted seagrass acreage goals and water quality targets are being achieved. This method employed a matrix that incorporated the magnitude and duration of chlorophyll and light target exceedances from target levels. Additionally, consideration of changes in seagrass extent are included in a separate decision tree, and in the event of no increase in seagrass extent, more severe management responses may be examined.

The decision matrix of the status tracking process identifies appropriate categories of management actions in response to various outcomes of the chlorophyll a and light attenuation decision formulations.

Decision matrix identifying appropriate categories of management actions in response to various outcomes of the monitoring and assessment of chlorophyll a and light attenuation data.

CHLOROPHYLL	LIGHT ATTENUATION			
	Outcome 0	**Outcome 1**	**Outcome 2**	**Outcome 3**
Outcome 0	*GREEN*	*YELLOW*	*YELLOW*	*RED*
Outcome 1	*YELLOW*	*YELLOW*	*YELLOW*	*RED*
Outcome 2	*YELLOW*	*YELLOW*	*RED*	*RED*
Outcome 3	*YELLOW*	*RED*	*RED*	*RED*

The recommended management actions resulting from the decision matrix are classified by color into three categories, as follows:

- **GREEN** - "Stay the course"; partners continue with planned projects to implement the CCMP. Data summary and reporting via the Baywide Environmental Monitoring Report and annual assessment and progress reports.

- **YELLOW** - TAC and Management Board on caution alert; review monitoring data and loading estimates; attempt to identify causes of target exceedances; TAC report to Management Board on findings and recommended responses if needed.

- **RED** - TAC, Management and Policy Boards on alert; review and report by TAC to Management Board on recommended types of responses. Management and Policy Boards take appropriate actions to get the program back on track.

The decision matrix was applied to the chlorophyll a concentration and water clarity data collected in 1995 through 1999 and the following results were obtained:

Decision matrix results for the period 1995 through 1999.

YEAR	**BAY SEGMENT**			
	Old Tampa Bay	**Hillsborough Bay**	**Middle Tampa Bay**	**Lower Tampa Bay**
1995	*RED*	*YELLOW*	*RED*	*YELLOW*
1996	*YELLOW*	*GREEN*	*YELLOW*	*GREEN*
1997	*YELLOW*	*GREEN*	*RED*	*YELLOW*
1998	*RED*	*RED*	*RED*	*RED*
1999	*YELLOW*	*GREEN*	*YELLOW*	*YELLOW*

Clearly, the increased nitrogen loading due to the higher than normal rainfall during 1997 and 1998 (discussed below) resulted in less than desired conditions in Tampa Bay during that period. Elevated chlorophyll a concentrations and reduced light penetration were found during this period. However, the bay responded favorably to the apparent reduction in loading during 1999.

A second assessment approach entailed examination of long-term trends in water quality in Tampa Bay (Janicki et al., 2000a). The long-term record of water quality in Tampa Bay points to three distinctive periods of water quality conditions in the bay. Relatively poor conditions existed from the mid-1970s to the early 1980s, a transitional period to improved conditions followed until the mid-1980s, and a period of relatively good water quality conditions has persisted since. Thus, long-term improvements in the trophic status of the bay have been observed.

These improvements have occurred despite continuing urbanization and growth in the watershed since the early 1980s. The relatively good water quality conditions persisting since the mid-1980s support the contention that nitrogen management activities are working, precluding increasing nitrogen loads in the watershed typically considered concomitant with increasing development.

Throughout the period of record, Hillsborough Bay has reflected the poorest water quality conditions of the mainstem bay segments. The best water quality conditions are typically observed in Lower Tampa Bay. Comparison with the other five bay segments shows intermediate water quality conditions between those in Hillsborough Bay and Lower Tampa Bay. Long-term declines in nutrient concentrations have also occurred in tributaries to the bay.

As noted above, concern about the lack of seagrass response to apparently improved water quality conditions led to a comparison of water quality between the western and eastern shore areas of Old Tampa Bay. Chlorophyll a concentrations were greater and Secchi disc depths were shallower in sites along the western shore than in sites along the eastern shore. The differences were greatest in the western sites that are located in areas where expected seagrass growth has not been observed in the 1990s.

NITROGEN LOADING

Examination of the nitrogen loading is also a critical component of this assessment. To this end, nitrogen loading estimates were updated through 1998 (Pribble et al., 2001) and the predicted nitrogen loading estimates for 2010 were also refined based on the most recent knowledge of land use change and anticipated changes in point source discharges and atmospheric nitrogen emissions from both stationary and mobile sources (Janicki et al., 2001b).

<u>1995-1998 Loading Estimates</u> - Annual loadings in 1995, 1997, and 1998 were generally higher than those observed during the 1985-1994 period. Specifically, the loadings during these three years exceeded the “hold the line” loadings established by the Nitrogen Management Consortium, which were based on the average TN loadings of the 1992-1994 period.

Examination of the TN loadings data suggests that much of the increase in TN loadings could be explained by the higher rainfall and resultant hydrologic loadings observed in 1995, 1997, and 1998. Most noticeably, the El Niño event of 1997-1998 resulted in relatively higher rainfalls and loadings compared to observations from the period of record. Increases in nonpoint source loadings were the primary contributors to the increased annual loadings. It should be noted, however, that nitrogen management actions being practiced in the watershed likely mitigated the impacts of the high rainfall period with respect to nitrogen loadings to the bay.

2010 Loading Estimates – The future loading estimates for industrial point sources are approximately half of the current condition loading estimates (1998) from these sources. This is largely the result of the unusually high discharges during the current period in response to the high rainfall experienced during that the period. Future loading estimates for domestic point source facilities are very similar to the estimates for the current period. The future loading estimates from material losses are approximately 13% higher than for the current period, reflecting the expected industry growth rate of 1% annually.

As a result of planned decreases in nitrogen emissions from the TECO facilities, future atmospheric deposition loading estimates may be as much as approximately 50% less than the current condition loading from this source.

The future nonpoint source loading estimates are not appreciably different from those for the current condition, despite the future land use having a larger proportion of urban land use than the current period. This is likely due to differences in typical nutrient concentrations in runoff from agricultural and urban land uses and the expected load attenuation from any newly developed urban area.

In summary, the total annual nitrogen loading estimates for 2010 are approximately 700 tons less than for the current condition, largely due to the predicted declines in atmospheric deposition and industrial point source loadings.

HYPOXIA

As discussed above, reductions in bottom DO concentrations are a typical response to nutrient over-enrichment of estuarine waters. Thus, as nitrogen loading in particular changes then changes in bottom DO concentrations should result. If these changes are severe enough, stressful and potentially lethal conditions can result.

To address the concerns about the extent of hypoxia (DO $<$ 2 mg/L) in Tampa Bay, Janicki et al. (2001c) examined the spatial and temporal nature of hypoxia in the bottom waters of the bay. Hypoxic conditions are typically found in late summer, primarily in Hillsborough Bay and less frequently in Old Tampa Bay. In September

1998, for example, hypoxic conditions extended over approximately 19 km^2; most of this area of hypoxia was found in Hillsborough Bay. The frequency of hypoxic conditions observed during the study period in each bay segment is as follows:

- Hillsborough Bay – 26%
- Old Tampa Bay – 1%
- Middle Tampa Bay – <1%
- Lower Tampa Bay - < 1%
- Boca Ciega Bay - 0%
- Terra Ceia Bay and Manatee River – 0%

No significant temporal trends in the areal extent of hypoxic conditions were found. The year-to-year variation in the extent of hypoxia is significantly correlated with rainfall, river flow, the degree of stratification, and nitrogen loads to Hillsborough Bay. Monthly monitoring data reveal that the duration of hypoxia is typically two months or less, while diel monitoring data reveal that at an hourly temporal scale, the duration of hypoxia is typically six hours or less.

Bottom DO concentration declined in Hillsborough Bay and Old Tampa Bay from 1976 through 1998, although the rate of decline was small. These results were largely due to the difference in relatively high bottom DO values between the late 1970s and early 1980s period and during the period since 1985. No change in the bottom DO values in the lower portion of the observed range of concentrations was apparent during the early part of the record. Thus, while a statistically significant trend was detected, more stressful conditions have not necessarily resulted.

Another note of interest emerged from this investigation. Mid-day DO measurements comprise the majority of the data available to assess hypoxia in Tampa Bay. Comparison of these mid-day data to minimum DO data derived from a series of diel DO surveys indicates that the mid-day data correctly reflect the occurrence of hypoxia approximately 75% of the time. There also appears to be a relationship between mid-day and minimum DO; however, more data will allow improvement in the quantification of this relationship.

MODEL REVIEW AND UPDATES

The second major element of this assessment of progress toward bay quality targets is the review of the models that provide the basis of the nitrogen loading strategy paradigm described above. An empirical modeling approach was taken to define quantitatively the relationships between TN loads and chlorophyll a concentrations and between chlorophyll a concentrations and light attenuation (Janicki and Wade, 1996).

Chlorophyll a – Light Attenuation Model - A review of the chlorophyll a – light attenuation regression model which entailed application of the ambient data collected from 1995 through 1998 to the model derived from data collected during the 1986-1994 period has been completed (Janicki et al., 2001d). In general, the chlorophyll a – light model explains the observed variation in light attenuation as a function of chlorophyll a concentrations. However, there appears to be a small bias in the predicted Z values (depths to which 20.5% of the incident light penetrates) at low chlorophyll a concentrations. Specifically, the Z values were somewhat shallower during the 1995-1998 period than had been predicted by the model based on the 1986-1994 data. The bias is expressed at both monthly and annual time scales. A regression model based on data from the extended time period of 1986 through 1998 was examined and the regression coefficients from this model were compared to those from the original model based on 1986-1994 data. Neither the monthly-specific intercept estimates nor the slope estimates from these two models were significantly different.

Several hypotheses emerged that might explain the observed bias. Initially, the residuals (the differences between the predicted and observed Z values) were plotted against turbidity and color to examine whether the variation in either of these variables was related to the residuals. No significant relationships were found. A second hypothesis was that differences in solar radiation might exist between the two periods of interest. No significant differences between periods in solar radiation estimates were detected. A third hypothesis entailed changes in the methods employed to collect and/or analyze the chlorophyll samples between the two periods. No relevant differences in either field or laboratory methods were reported.

Another hypothesis that might explain the observed bias is a change in phytoplankton community structure that could result in changes in light attenuation per unit of algal biomass. Phytoplankton community composition data have been collected by the City of Tampa Bay Study Group since 1978, and can be used to test this hypothesis. Preliminary indications point toward a shift in community dominance in Hillsborough Bay from blue-green algae prior to 1995 to diatoms in the succeeding period.

Nitrogen Loading – Chlorophyll a Model – A Vollenweider-type regression model that relates nutrient loading to phytoplankton biomass was developed for Old Tampa Bay, Hillsborough Bay, and Middle Tampa Bay (Janicki and Wade, 1996). The model included both external nitrogen loading estimates to each segment and the flux of nitrogen between bay segments (for example, between Hillsborough Bay and Middle Tampa Bay). The inclusion of the inter-segment fluxes greatly improved the model since this source of nitrogen may be significantly greater than the external load to a given bay segment. The general form of the model was:

$$\textit{Chlorophyll a} = f\,\{(\textit{external load} + \textit{internal flux}),\ \textit{monthly-specific intercept}\}$$

The monthly loading estimates from the period of 1995-1998 and the chlorophyll a concentration data were used to test the model developed on data collected during the 1986-1994 period (Janicki et al., 2001e). The results from this analysis reflect very good correspondence between predicted and observed chlorophyll a concentrations. Thus, the relationship between nitrogen loading and algal biomass has been relatively consistent during the period of 1986 through 1998.

CONCLUSIONS AND RECOMMENDATIONS

Several conclusions and recommendations can be drawn from this assessment:

- Nitrogen loading to Tampa Bay was greater during the 1995-1998 period than during the 1992-1994 period due to higher than normal rainfall.

- Generally, water quality has improved significantly in Tampa Bay since the mid-1980s, especially with respect to those water quality constituents related to the productivity of the estuary – chlorophyll a concentrations, nutrient concentrations, water clarity, and dissolved oxygen. However, "hot spots" do exist where localized occurrences of degraded water quality are found (western shore of Old Tampa Bay, McKay Bay) and should be closely monitored.

- Undesired water quality responses to higher than normal rainfall do occur but the bay also displays an ability to respond favorably to reduced nutrient loading.

- While seagrasses declined between 1996 and 1999, the decline was within the range of that noted in other estuarine systems in the region, and was perhaps understandable given the extreme rainfall in 1997-1998.

- Areas where seagrass growth should be expected based on apparent ambient water clarity but has not been observed exist. The seagrass working group is examining factors other than water clarity alone that may be more important in these areas. These factors should be examined in the next five-year period.

- The models that comprise the TBEP Nitrogen Loading Paradigm reflected different degrees of similarity to the original model constructs. Output from the loading-chlorophyll a model showed close agreement between observed and predicted chlorophyll a concentrations. There was a small bias in the light attenuation values predicted by the chlorophyll a – light attenuation model. No readily apparent cause for this bias could be found, but it may be that changes in phytoplankton community composition have contributed to this bias. Continued monitoring and analysis of the ambient chlorophyll a concentrations and water clarity is needed to ensure factors other than algal biomass are not contributing significantly to water clarity in the bay.

- Given the observed responses to changes in nutrient loading and the current status of bay indicators associated with its trophic state, there does not appear to be compelling evidence to deviate from the current nitrogen management strategy.

- Appropriate management actions should be identified and applied to address additional factors that are influencing the restoration of seagrasses. Continued seagrass monitoring should occur to support the efforts of the seagrass working group examining these additional factors.

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