

**DEVELOPING AND ESTABLISHING A
PROCESS TO TRACK THE STATUS OF
CHLOROPHYLL-a CONCENTRATIONS
AND LIGHT ATTENUATION TO SUPPORT
SEAGRASS GOALS IN TAMPA BAY**

FINAL REPORTS

December 1999 and October 2000



NOTE:

This document includes two original reports:

“Development of a Process to Track
the Status of Chlorophyll and
Light Attenuation to Support
Seagrass Goals in Tampa Bay”
(Janicki Environmental, December 1999)

and

“Establishing a Process for Tracking
Chlorophyll-*a* Concentrations and
Light Attenuation in Tampa Bay”
(Janicki Environmental, October 2000)

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**DEVELOPMENT OF A PROCESS
TO TRACK THE STATUS OF CHLOROPHYLL
AND LIGHT ATTENUATION TO SUPPORT
SEAGRASS RESTORATION GOALS
IN TAMPA BAY**

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FOREWORD

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1.0 INTRODUCTION

One of the primary goals established in the Tampa Bay National Estuary Program (TBNEP) Comprehensive Conservation and Management Plan (CCMP) is to restore seagrass extent in the bay to levels similar to those observed in the 1950's. Seagrasses are very important to the health of the bay ecosystem, and are thus of concern to those who manage this important resource. Seagrasses provide shelter from predators as well as nursery and feeding habitat for many popular fishes and shellfish including seatrout, snook, red drum, shrimp, and bay scallops. Seagrasses are also important feeding ground for the Florida manatee. Seagrasses also help improve water clarity and stabilize bottom sediments. Because of these characteristics, the TBNEP identified seagrasses as an excellent indicator of overall bay health.

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.

The focus of this document, a product reflecting discussions and recommendations of the Joint Water Quality Modeling Subcommittee of the TBNEP TAC and the Southwest Florida Water Management District's (SWFMWD) SWIM Department, is the development of a method to determine if adopted seagrass acreage goals and water quality targets are being achieved.

1.1 Setting Targets

One of the major concerns identified by the TBNEP was the loss of seagrass habitat that had occurred over the last 50 years. The losses were due to a variety of factors, including dredge and fill projects, poor water clarity, altered bay hydrodynamics, and prop scarring (Lewis and Estevez, 1988; Wade and Janicki, 1993; Sargent et al., 1995; Sargent et al., 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 which had seagrasses in 1950, did not have seagrasses in 1990, and had not been permanently altered to preclude restoration of seagrasses.

Based on the results of this study, the TAC recommended seagrass restoration goals to the TBNEP Management Committee. The TBNEP Management and Policy Committees subsequently adopted the following in October 1996:

To help achieve the desired improvements to bay fisheries, wildlife and water quality, the Management and Policy Committees approve the following actions:

1. The Management and Policy Committees find that the methods recommended by the Technical Advisory Committee provide a technically sound basis adequate for setting goals for seagrass acreage and targets for segment-specific chlorophyll *a* concentrations.
2. Adopt a minimum seagrass acreage goal of 38,000 acres bay-wide. This goal includes the protection of existing 25,650 acres and restoration of 12,350 additional acres.
3. Adopt segment-specific chlorophyll *a* concentration targets equal to the lowest of either the annual average of 1992-1994 or the concentration that supports restoration and protection of 38,000 acres of seagrass. These annual average targets are 8.5 $\mu\text{g/L}$ for Old Tampa Bay, 13.2 $\mu\text{g/L}$ for Hillsborough Bay, 7.4 $\mu\text{g/L}$ for Middle Tampa Bay, and 4.6 $\mu\text{g/L}$ for Lower Tampa Bay.
4. Adopt, as an initial step toward reaching the long-term seagrass goals and chlorophyll *a* targets, a five-year nitrogen strategy to “hold the line” at existing (1992-1994) annual nitrogen loadings for each segment, including the four mainstem segments and Terra Ceia Bay, Boca Ciega Bay, and Manatee River.
5. Review and revise goals, targets and management strategies every 5 years, or more frequently if significant new information becomes available. Report progress towards goals and targets, including chlorophyll *a*, water clarity and seagrass acreage to the Management Board every year.
6. Develop an explicit method to determine whether targets are or are not being met.

To attain the seagrass restoration goal, the TBNEP developed the Nitrogen Management Strategy. The Strategy seeks to prevent future impacts due to excessive nitrogen loadings to Tampa Bay. To address these concerns, a paradigm that relates nitrogen loading to chlorophyll and seagrass was utilized, as shown in Figure 1.

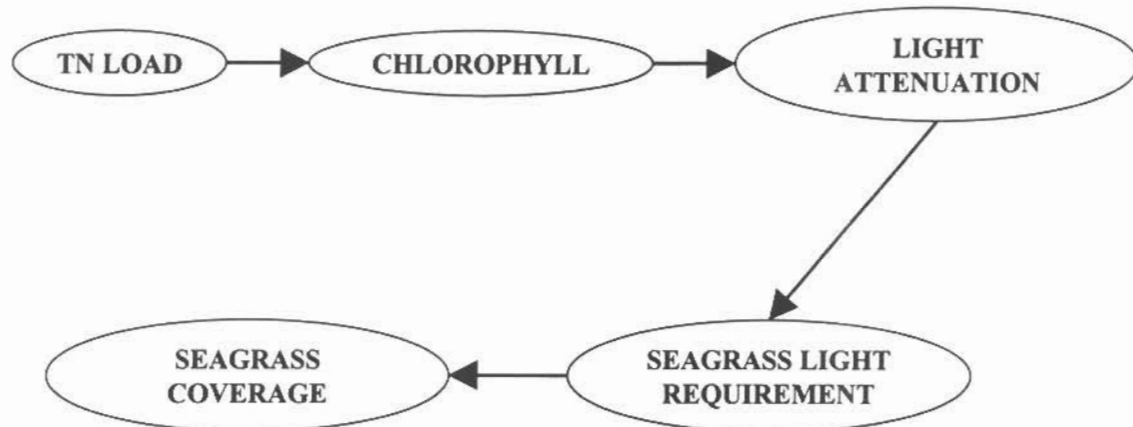


Figure 1. TBNEP Nitrogen Management Paradigm.

To quantify the relationships represented in the paradigm, empirical relationships among these variables were quantified and presented in Janicki and Wade (1996). A parallel mechanistic modeling approach was developed through the SWFWMD SWIM department (ASCI, 1996). The empirical relationships were developed for the Old Tampa Bay (OTB), Hillsborough Bay (HB), Middle Tampa Bay (MTB), and Lower Tampa Bay (LTB) segments. Statistical evaluation of the results of these empirical relationships showed that the relationships explained a significant amount of the variation in chlorophyll-a concentration based on external nitrogen loadings, and a significant amount of the variation in subsurface light availability based on chlorophyll-a concentrations (Janicki and Wade, 1996).

Using these relationships, predictions of the responses in chlorophyll-a concentrations, light attenuation, and the extent of seagrass restoration to changes in external TN loading were derived. The empirical relationships related light attenuation to chlorophyll-a concentration, and estimated the areal extent of bay bottom illuminated by sufficient light for seagrass growth. Seagrass restoration acreage was based only on the area of the bay bottom thus illuminated, with no other factors affecting seagrass growth and restoration considered. The model predictions suggested that light availability necessary for seagrass restoration goals could be met by establishing a “hold the line” strategy for TN loads and setting chlorophyll-a concentration targets for the four mainstem bay segments. Two sets of chlorophyll targets were considered:

- the chlorophyll-a concentrations which would be expected to result in restoration of 95% of the seagrass goals for the segments; and
- the mean chlorophyll-a concentrations observed during the 1992-94 period, i.e., current conditions at the time.

The latter set was considered since all evidence suggested that seagrasses were recovering and their areal coverage was increasing since 1988. It was concluded that the more prudent targets would be the lower of these two sets for each bay segment. The selected chlorophyll-a targets are as stated above.

1.2 Monitoring and Assessing Progress Towards Targets

Another component of the actions taken to restore seagrasses in Tampa Bay is the monitoring of seagrass cover and water quality. Monitoring of chlorophyll-a concentrations and seagrass acreages allows comparisons of these values to the segment-specific targets set by the TBNEP. These comparisons provide the Tampa Bay Estuary Program (TBEP) with information concerning the progress towards achieving the seagrass restoration goals of the program.

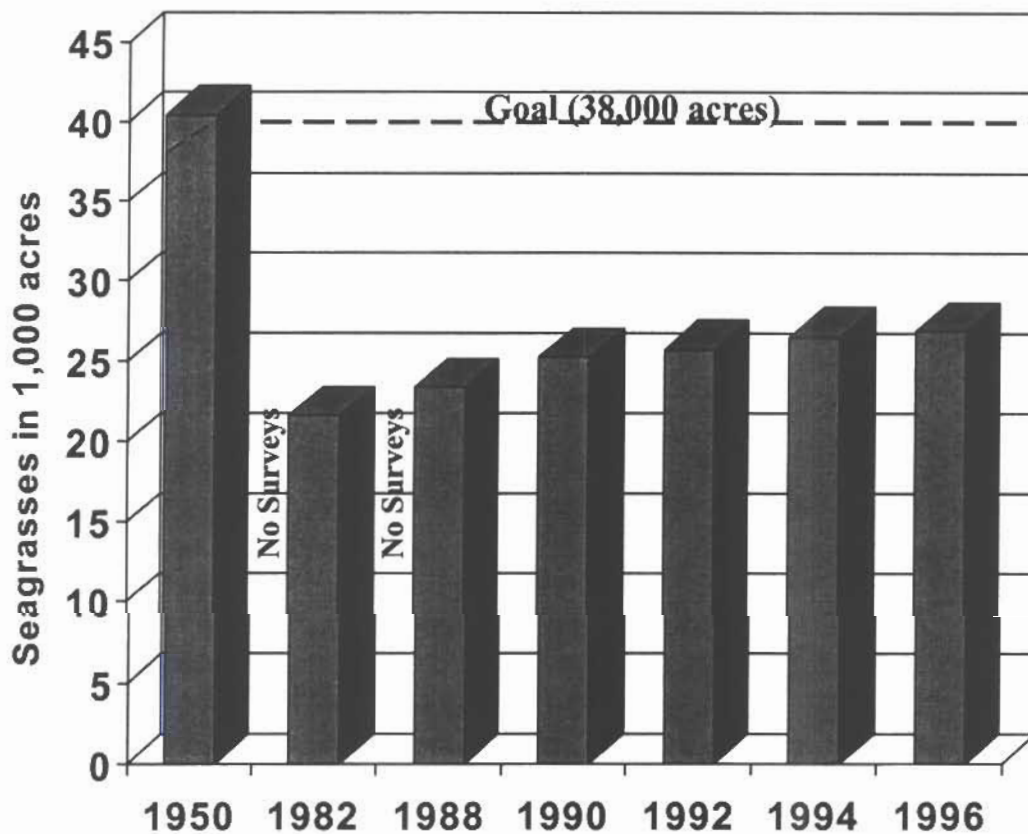
The achievement of the seagrass restoration goals appears to be at least partially dependent on maintaining nitrogen loadings to the bay at 1992-1994 average. Any increases in chlorophyll-a concentrations within any or all of the four bay segments may suggest that progress towards achieving seagrass restoration goals may not be proceeding as hoped. Additionally, increases in chlorophyll-a concentrations may point to additional nitrogen loading beyond the 1992-1994 average loads. Chlorophyll-a concentrations above target levels can serve the TBEP as an early warning system that loadings or other processes are impacting water transparency. Actual measured seagrass acreage is the true measure of successful achievement of target seagrass goals, and other factors (discussed below) are now thought to play an as yet unquantified role, in conjunction with water quality, in the ability of Tampa Bay seagrasses to expand into potential habitat.

The Modeling Subcommittee of the TAC, the full TAC, and the Management and Policy Boards noted that a process is needed by which the status of chlorophyll-a concentrations and seagrass acreage can be assessed with respect to established targets. Despite the commitment of the members of the TBEP to maintain nitrogen loadings to the bay at 1992-1994 average levels, other factors, some of which are amenable to management activities and some of which may not be, may result in increases in chlorophyll-a concentrations or decreases in seagrass acreage. Rainfall in excess of that during 1992-1994 may result in increased nitrogen loadings to the bay, which in turn may lead to increases in chlorophyll-a concentrations. Seagrass response will depend upon the amount of chlorophyll-a concentration increase and the time period over which it occurs. Seagrasses may be subject to biological damage as well, such as that due to *Labyrinthula*, a microorganism which is associated with seagrass disease.

The assessment process that is to be developed must ultimately build on the monitoring of all parameters (not just water quality), in a synoptic or semi-synoptic manner with seagrass mapping, which influence the ability of seagrasses to recolonize former vegetated areas. Additionally, this process should establish criteria that would indicate when any one target

criterion (i.e.: seagrass acreage, water quality, prop scars, etc.) is not being met, and when management actions are needed to maintain the desired rate of expansion of seagrasses into unvegetated bay bottoms. Until some more research is done, the water quality parameters may be the only ones easily measured, but that should not imply that they alone control this process.

Seagrass trends between 1990 and 1996 indicate that the observed seagrass expansion may be slowing on a bay-wide basis. An average gain of approximately 320 acres/year was observed between 1990 and 1994, while an increase of only approximately 200 acres/year was observed between 1994 and 1996, as shown in Figure 2. This bay-wide decrease in seagrass recovery rate was primarily the result of seagrass acreage losses in Old Tampa Bay and Middle Tampa Bay between 1994 and 1996. Potential factors which may be partly responsible for these observed reductions will be examined during a workshop planned for summer 2000.



Source: SWFWMD

Figure 2. Tampa Bay seagrass acreage, 1950-1996.

1.3 Objectives

The Modeling Subcommittee was tasked to provide guidance for the development of the assessment. The primary objectives of the task were:

- 1) To define what constitutes a significant increase in chlorophyll-a in Tampa Bay; and
- 2) To develop a systematic framework for defining potential management responses to such changes.

This report describes existing monitoring programs from which data were used in the development of the decision process (Section 2), the analytical approach taken to develop this process (Section 3), and the recommended approach developed by the subcommittee (Section 4).

2.0 DATA SOURCES

For this project, seagrass acreage, water quality, and bay bathymetry data were needed. Seagrass acreage within Tampa Bay, as mentioned previously, is determined from GIS coverages developed by the SWFWMD. Water quality data used are those recorded by the Environmental Protection Commission of Hillsborough County (EPCHC). A bathymetry coverage was created based on data obtained from the National Oceanographic and Atmospheric Administration (NOAA).

The seagrass coverage used for the development of this process was created by the SWFWMD for 1990. The District developed this coverage based on 1:24,000-scale true color aerial photography flown in the late fall or early winter months, when water clarity is greatest. Seagrass signatures were identified and classified according to Florida Department of Transportation Florida Land Use/Cover Classification System (Kurz et al., 1999).

The EPCHC has collected water quality data, including chlorophyll-a concentration and water transparency, from a network of 54 fixed stations in Tampa Bay from 1974 to the present. These stations are located in the four mainstem segments of the bay, and are sampled monthly. Chlorophyll-a concentrations are measured using the trichromatic method, and reported in units of $\mu\text{g/L}$. Water transparency is determined by Secchi disc depth using a 20-cm diameter disc, and reported in units of inches below the water surface (EPCHC, 1995).

A GIS coverage of bathymetry was created using hydrographic soundings data from the NOAA National Geophysical Data Center which contained more than 350,000 data points collected during the years 1947-1958 in the Tampa Bay area (Janicki et al., 1995). The point soundings and shoreline delineation were used to interpolate a bathymetric GIS coverage utilizing Triangular Irregular Network interpolation software from ESRI (1993).

3.0 THE DECISION PROCESS

Initially, two potential analytical approaches towards developing the decision process were proposed, one subjective and one objective. The subjective approach was based on work completed by the Massachusetts Water Resources Authority (Conner and Sommaripa, 1997). The objective approach involved utilizing a statistical test to determine the significance of temporal changes in chlorophyll-a concentrations.

The subjective approach, used by the Massachusetts Water Resources Authority, called for a Contingency Plan to be developed to respond to caution (small increases) and warning (large increases) levels of variables of concern. Necessary for this approach were definitions of *caution* and *warning* levels. These thresholds would lead to corrective actions if predefined loading or water quality levels were exceeded. A caution level would provide an early indication of unanticipated environmental change, prior to any compromise to environmental health. The warning level would indicate that, although no significant harm had been done, environmental conditions had moved sufficiently far from the baseline conditions to warrant closer examination or corrective action. The Authority uses three methods to set caution and warning levels:

- Use of state water quality standards for those parameters that have numeric standards.
- When no standard exists, thresholds are based on predictions of discharge impacts to receiving waters. The Authority uses EIS-based assumptions addressing potential impacts of nutrient loads to the system to set a caution level at 90% of the predicted loads.
- Guidance by opinions of local scientists and resource managers is used to modify and supplement EIS predictions. A task force that oversees the contingency planning process indicated that a 50% increase in chlorophyll-a in Massachusetts Bay would warrant the same level of scrutiny triggered by a caution level exceedance.

The objective approach, initially recommended by Dr. Gerold Morrison of the SWFWMD, relied on a statistical assessment of change. This approach used a t-test to compare current year chlorophyll-a concentrations and water clarity to those from the baseline period of 1992-94. If the concentrations were found to be significantly higher, then appropriate management actions could be initiated. This approach used a series of moving-average chlorophyll-a concentrations since significant reductions in seagrass recovery rates will be more likely as the duration of the period of aberrant chlorophyll-a concentrations increases.

The two approaches were reviewed and discussed by the Modeling Subcommittee, culminating in the recommendation that the statistical approach be used for the purposes of developing the assessment process. The development of this approach for the assessment process is described in Appendix A. This approach was subsequently modified as described below.

The Modeling Subcommittee discussions returned to several ideas previously identified. One dealt with consideration of not only the chlorophyll-a data but also use of the seagrass and light attenuation monitoring results. The logic was that seagrass restoration is the eventual goal so consideration of the status and trends of seagrass coverage over time was appropriate. Also, changes in light attenuation unrelated to changes in chlorophyll-a concentrations are possible; therefore, monitoring and assessment of light attenuation is also appropriate.

The Modeling Subcommittee also formalized the concepts that had been applied earlier. These included the *magnitude* and *duration* of the difference, the temporal *trend* in the difference, and the *spatial extent* of the difference. The inclusion of these four concepts and three variables of interest (chlorophyll-a concentrations, light attenuation, and seagrass coverage) in a form similar to the decision matrices examined earlier would result in a very complicated formulation of the decision process. To more simply and efficiently visualize and utilize the decision process, alternative methods were developed to guide the decision process. Figure 3 below displays graphically the factors to be considered.

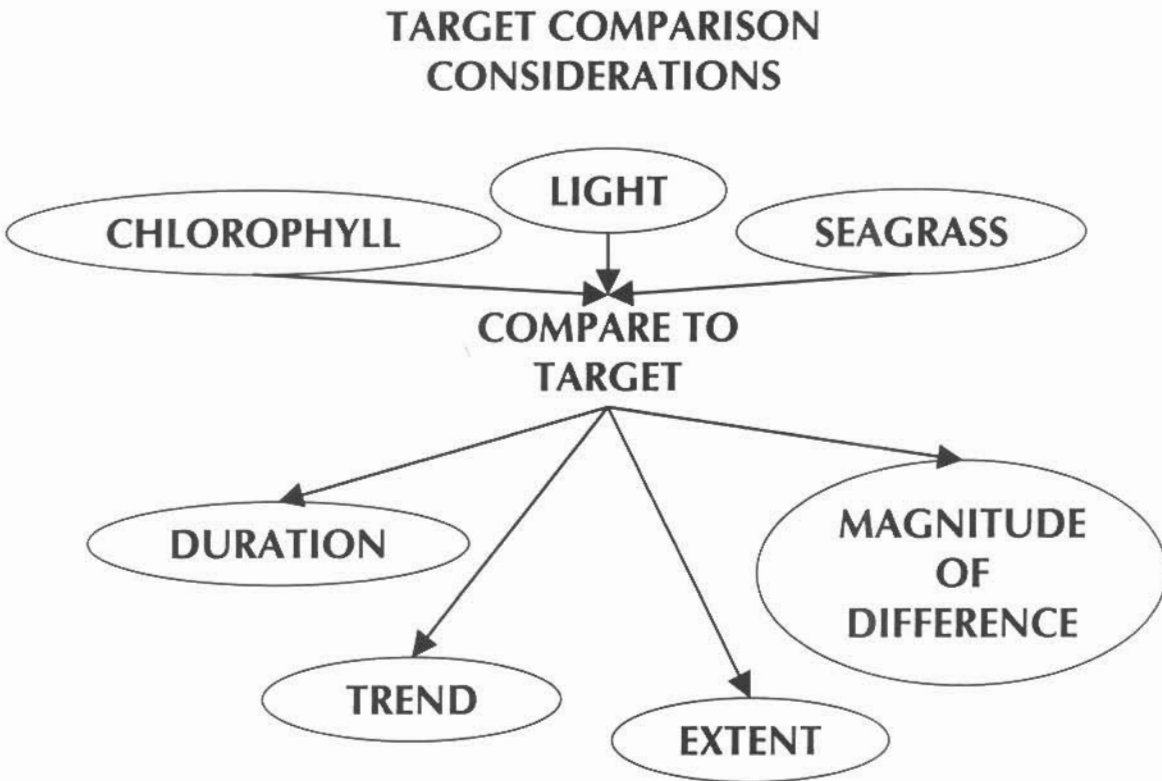


Figure 3. Conceptual model of decision process and its components.

The initial step of the decision process for all variables of interest is comparison of observed values to target values. Following comparison to targets, the decision processes for the individual variables of interest are displayed in Figures 4, 5, and 6, for chlorophyll-a, light attenuation, and seagrass acreage, respectively.

- **Chlorophyll-a** Comparison to targets may result in one of two outcomes. In the first case, estimated chlorophyll-a concentrations are less than or equal to chlorophyll-a target and the action would be to “stay the course” (Outcome 0).

In the second case, the estimated chlorophyll-a concentrations are greater than the chlorophyll-a target. Following this pathway, the next question deals with the **magnitude** of the difference from the target. If the magnitude is defined as small then the pathway follows to the left. If the magnitude is large, then the pathway follows to the right.

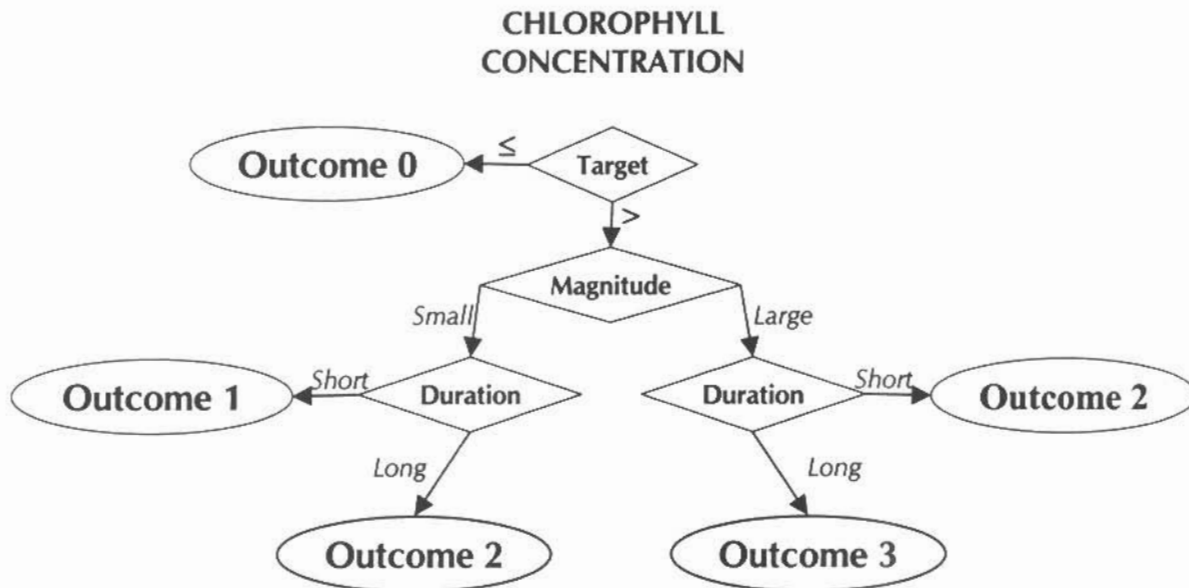


Figure 4. Monitoring and assessment decision tree for chlorophyll-a.

The next question then deals with the **duration** of the difference. If the duration is defined as short (Outcomes 1 and 2), then the next actions should deal with explaining why the observed differences occurred, regardless of the magnitude of the difference. Such explanations could include deviations from the norm in rainfall, changes in monitoring protocols, etc.

If the duration of the difference from the target is defined as long, then two potential outcomes can result. Outcome 2 results from a difference of small magnitude of long duration and Outcome 3 from a difference of large magnitude and long duration.

Based on the magnitude and duration of the difference, four different outcome levels are possible, as shown in the decision tree in Figure 4. These outcome levels have a range of 0-3, with the designation of the outcome representing the relative severity of the observed condition, where 0 represents the most benign condition, and 3 represents the most severe condition. The response to each outcome will be determined on a case by case basis by the Management Conference.

The Modeling Subcommittee pointed to the importance of responding to differences from the target that are of long duration, regardless of the magnitude of the difference. A more persistent problem should therefore be addressed by a more stringent management response.

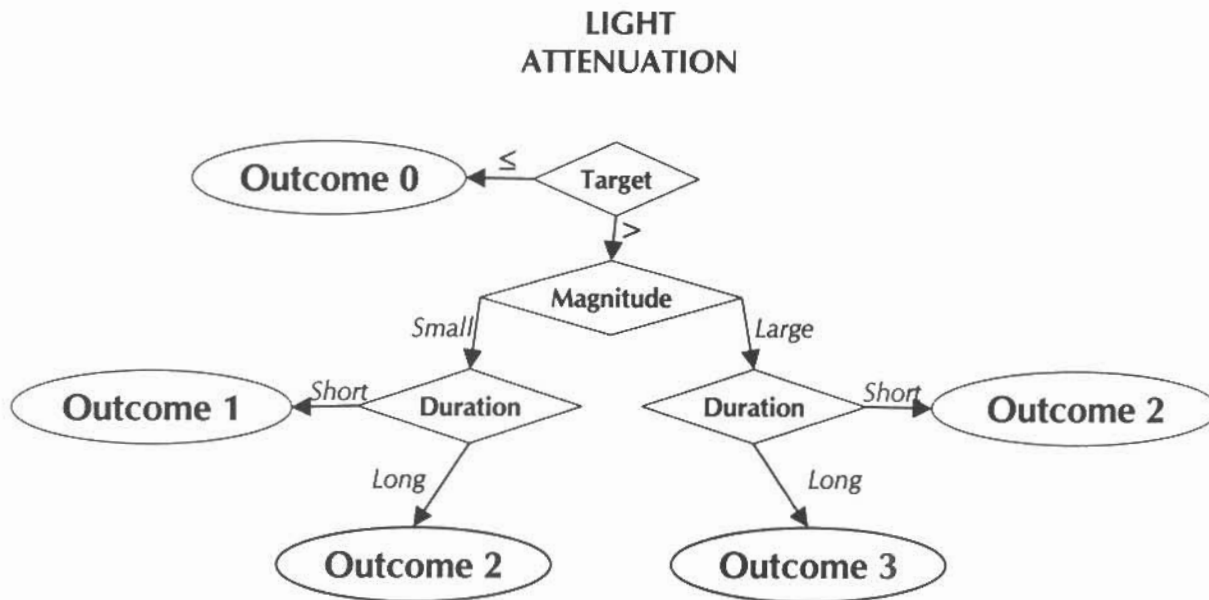


Figure 5. Monitoring and assessment decision tree for light attenuation.

- Light Attenuation** Since the light attenuation and chlorophyll-a concentrations vary in the same manner, i.e., large values of either are considered “bad”, then the logic associated with the pathways shown in Figure 5 are identical to those discussed for chlorophyll-a. The critical outcomes from this analysis are Outcomes 2 and 3, corresponding to differences in light attenuation that are of large magnitude and/or long duration, as had been defined above for such differences in chlorophyll.
- Seagrass** The monitoring and assessment decision tree for seagrass coverage is depicted in Figure 6. This decision tree is not as complicated as those for chlorophyll-a and light attenuation. Initially, an examination of the trend in seagrass acreage is conducted. If this trend is positive (i.e., seagrass acreage increasing), then there is progress towards the seagrass restoration goals and “things are OK.” If the trend in seagrass acreage is not positive, however, an

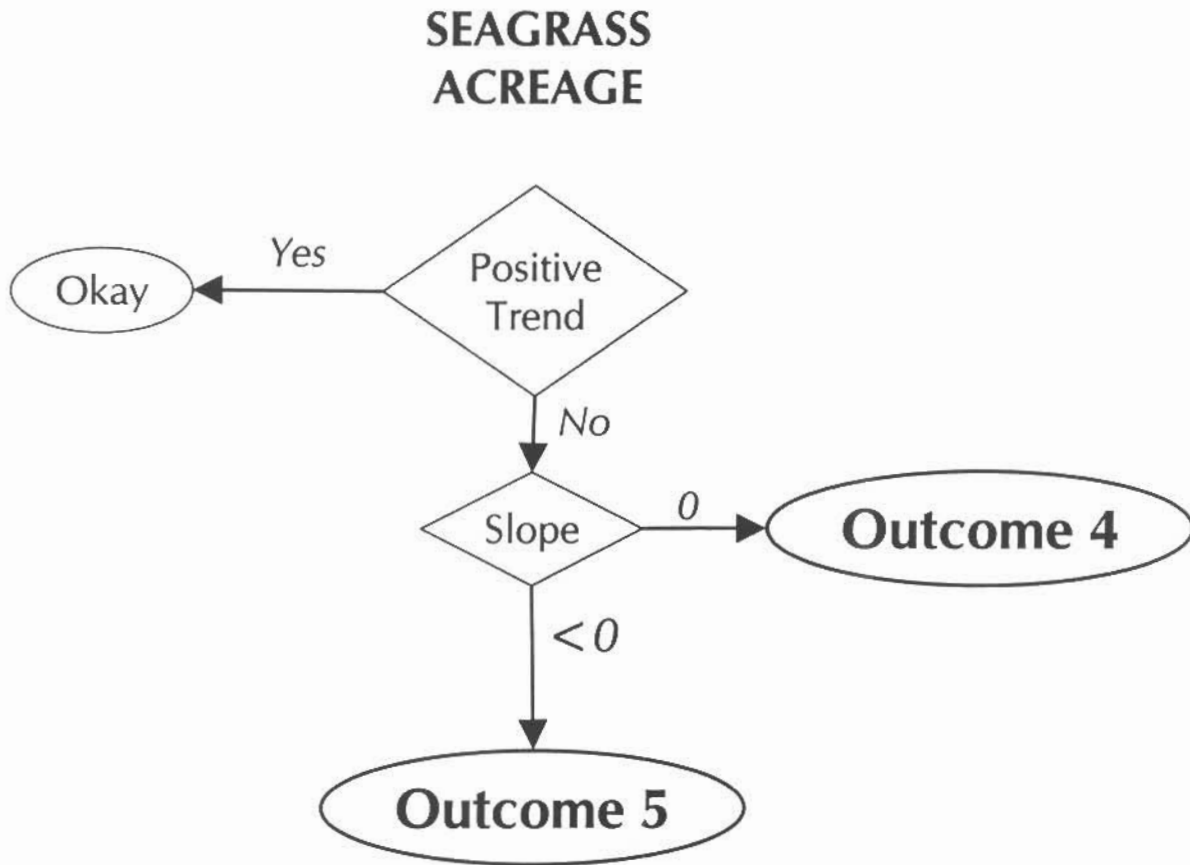


Figure 6. Monitoring and assessment decision tree for seagrass coverage.

analysis of the slope of the trend will determine if the slope is zero (no net change in seagrass acreage) (Outcome 4) or negative (net decrease in seagrass acreage) (Outcome 5).

The outcomes from all three monitoring and assessment decision trees (Outcomes 1-5) represent points in the decision process which are expected to require management actions of some degree. Potential management actions are delineated in the following section, which presents the recommended approach for tracking the status of the variables of interest with respect to targets.

4.0 Recommended Approach to Tracking the Status of Chlorophyll and Light Attenuation in Tampa Bay

With the development of monitoring and assessment decision trees for chlorophyll-a, light attenuation, and seagrass acreage, the Modeling Subcommittee stressed the importance of examination of these three variables **concomitantly** to determine appropriate management responses. Therefore, a method for combining the individual decision trees into one all-encompassing decision process is desirable. Specifically, a method for defining appropriate responses to Outcomes 1 through 5 and any combinations of these outcomes is needed.

The Modeling Subcommittee also expressed the need for defining some specific TBEP responses that could be tied to the possible outcomes of the monitoring and assessment decision trees. For sake of simplicity, the potential responses can be placed into three categories, using a traffic light analogy, that are consistent with their degree of response:

GREEN - "stay the course";

YELLOW - further TAC assessment and possible management action; and

RED - action.

Since seagrass restoration is of paramount concern, if either Outcomes 4 or 5 is realized then a RED response is deemed appropriate. If the analysis of the seagrass data shows a positive trend in seagrass coverage, then examination of the chlorophyll-a and light attenuation data is recommended to identify if management actions are warranted.

Since the chlorophyll-a and light attenuation data are closely related and collected on the same time scale, then a process by which these two variables can be assessed concomitantly is desired. Table 1 presents such a process. The logic supporting this process is that any difference of large magnitude *and* long duration is critical and deserving of significant attention.

Table 1. 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	YELLOW
Outcome 1	YELLOW	YELLOW	YELLOW	RED
Outcome 2	YELLOW	YELLOW	RED	RED
Outcome 3	YELLOW	RED	RED	RED

Recommended management actions in response to combinations of target exceedences of chlorophyll and light attenuation and non-positive slopes in seagrass trends have been developed by the Modeling Subcommittee. Based on the color classification as shown in Table 1, categories of management actions have been defined as either GREEN, YELLOW, or RED. The following identifies recommended management actions that fall into these three categories.

- **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 exceedences; 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.

For completion of the decision process formulation, several terms remained to be defined. The definitions of large and small magnitude changes in chlorophyll-a and light attenuation must be developed. Additionally, the definitions of short and long durations for chlorophyll-a and light attenuation target exceedences must be developed. As each bay segment of Tampa Bay has specific chlorophyll-a and light attenuation targets, these definitions are expected to be developed on a bay segment-specific basis.

The effectiveness of this process to track changes in variables of interest will be dependent on the continuation of consistent data collection. Future funding of existing water quality and seagrass monitoring programs is essential for the success of this process.

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Appendix A

Evaluation of Potential Analytical Approaches - Description of the Statistical Approach

The Statistical Approach

Following the decision to use the statistical approach for development of the assessment process, the Modeling Subcommittee began formulation of the decision process. Initial efforts focused on the development of a decision matrix for chlorophyll-a concentrations, as shown in Table 1 below. The horizontal axis of the matrix, Δ , represented the difference between observed conditions and target levels. The vertical axis, α , represented the probability of concluding that Δ is real when it is not, or more simply the uncertainty in drawing the inference that the ambient chlorophyll-a concentrations are different from the targets. This matrix embodies the concept that the *magnitude* of the difference from the target and the *certainty* there is in that difference being real (i.e., not due to chance alone) are important.

It is intended that each cell of the decision matrix would point to particular management activities to be initiated when conditions fell within the cell. The bottom right cell of the matrix, with large Δ and small α , represented a high certainty that chlorophyll-a concentrations were large relative to target levels, and thus demanded the most strenuous management activities to reduce chlorophyll-a levels. Thus, it can be viewed that the level of management responses would increase as one moves from the upper left portion of the matrix to the lower right.

Δ α	SMALL	MEDIUM	LARGE
0.20			
0.10			
0.05			

This decision matrix was implemented using chlorophyll data from Hillsborough Bay. The values along the horizontal axis were based on the degree to which the target seagrass acreage for Hillsborough Bay would be achieved. Using the empirical model (Janicki and Wade, 1996), chlorophyll-a concentrations corresponding to shortfalls from the target seagrass acreage of 5%, 10%, and 20% were assigned to the Small through Large columns, respectively. This resulted in the decision matrix for Hillsborough Bay presented in Table 2. Here, X represents the ambient mean chlorophyll-a concentration in Hillsborough Bay, which has a chlorophyll-a concentration target of 13.2 $\mu\text{g/L}$. The chlorophyll-a values representing "Small", "Medium",

and “Large” were not meant to serve as final chlorophyll levels for target examination, but were used for approach evaluation only.

Table 2. Potential chlorophyll-a decision matrix for Hillsborough Bay.

$\alpha \backslash X$	SMALL (15.8 $\mu\text{g/L}$)	MEDIUM (16.9 $\mu\text{g/L}$)	LARGE (22.6 $\mu\text{g/L}$)
0.20			
0.10			
0.05			

The appropriateness of the vertical axis values for α was also examined. To accomplish this, a longer time series of chlorophyll-a data than the 1992-94 time series was necessary to assess the α values. Long-term (50-year) data sets were created based on a randomly-generated, log-normal distribution of chlorophyll-a concentrations with means corresponding to the small, medium, and large values of X and a variance equal to that observed over the entire period of record for the EPC data from Hillsborough Bay. Using these three time series of chlorophyll data, one-, three-, and five- year moving averages of chlorophyll concentrations were estimated. Time series plots of these estimates for Hillsborough Bay are presented in Appendix B.

A two-tailed, unequal sample size t-test was run to compare the moving average data to the target chlorophyll for each bay segment. Six different values of α were applied for each test. The values of α tested were 0.2, 0.1, 0.05, 0.01, 0.005, and 0.001.

Results for the 1-year moving average for Hillsborough Bay (Table 3) indicated that because of the very large number of measurements it provided, the monitoring program is sufficiently powerful to detect relatively small changes in chlorophyll-a concentrations nearly 100 percent of the time with a relatively high certainty that the change is real. The results for the 3-year and 5-year moving averages show that significant differences from the target value would be inferred at all levels of α and X . The outcome was substantially the same for the other bay segments.

Table 3. Results of t-tests applied to compare one-year moving average chlorophyll-a data for Hillsborough Bay to the target value of 13.2 $\mu\text{g/L}$. Data reported are the percentage of t-tests with significant differences from the target value.

$\alpha \backslash X$	SMALL (15.8 $\mu\text{g/L}$)	MEDIUM (16.9 $\mu\text{g/L}$)	LARGE (22.6 $\mu\text{g/L}$)
0.20	100	100	100
0.10	100	100	100
0.05	98	100	100
0.01	92	98	100
0.005	78	96	100
0.001	66	92	100

These results demonstrate that the existing monitoring program provides adequate data to detect even small changes in chlorophyll-a with a high level of confidence that differences observed are real and not due to chance alone. Thus, any difference in chlorophyll-a concentrations from the target are likely to be statistically significant. This conclusion is important and points to the need for an alternative approach to the desired process.

Alternative approaches were considered by the Modeling Subcommittee. The importance of the *duration* of the exceedance of the chlorophyll target was discussed. To incorporate this concept, the vertical column of the decision matrix was revised to represent the duration of time that X was exceeded. As the duration of exceedances increased, stronger management responses would be necessary. It was also suggested that this may be a fruitful way by which trends could be detected.

Application of the chlorophyll-a concentration data for 1974-1998 in Hillsborough Bay resulted in the decision matrix presented in Table 4. This matrix included four columns for X values, corresponding to values representative of chlorophyll-a concentrations less than those defining small increases, as well as the three values previously utilized. This approach clearly points out the problem conditions found in Hillsborough Bay and their duration during the late 1970's and early 1980's. It also shows that conditions have improved considerably from that period to the present, with the exception of some one- and two-year periods in which chlorophyll concentrations were somewhat elevated.

Table 4. Decision matrix incorporating duration of the exceedance from the target chlorophyll-a for Hillsborough Bay. Data presented are years in which the duration and magnitude of the difference from the target were realized.

X Duration	< SMALL (< 15.8 $\mu\text{g/L}$)	SMALL (15.8-16.8 $\mu\text{g/L}$)	MEDIUM (16.9-22.6 $\mu\text{g/L}$)	LARGE (> 22.6 $\mu\text{g/L}$)
1 year	1988, 1990, 1992, 1996	1984, 1987, 1989, 1991	1985, 1994, 1998	1974
2 years	1993, 1997		1986, 1995	1975
3 years				1976
4 years				1977
5 years				1978
> 5 years				1979, 1980, 1981, 1982, 1983

A similar analysis was performed for Old Tampa Bay (Table 5). As for Hillsborough Bay, chlorophyll-a concentrations selected were based on shortfalls from the target seagrass coverage of 5%, 10%, and 20%, respectively. Large differences from target chlorophyll-a levels occurred only for the five-year period ending in 1983 in Old Tampa Bay.

Table 5. Decision matrix incorporating duration of the exceedance from the target chlorophyll-a for Old Tampa Bay. Data presented are years in which the duration and magnitude of the difference from the target were realized.

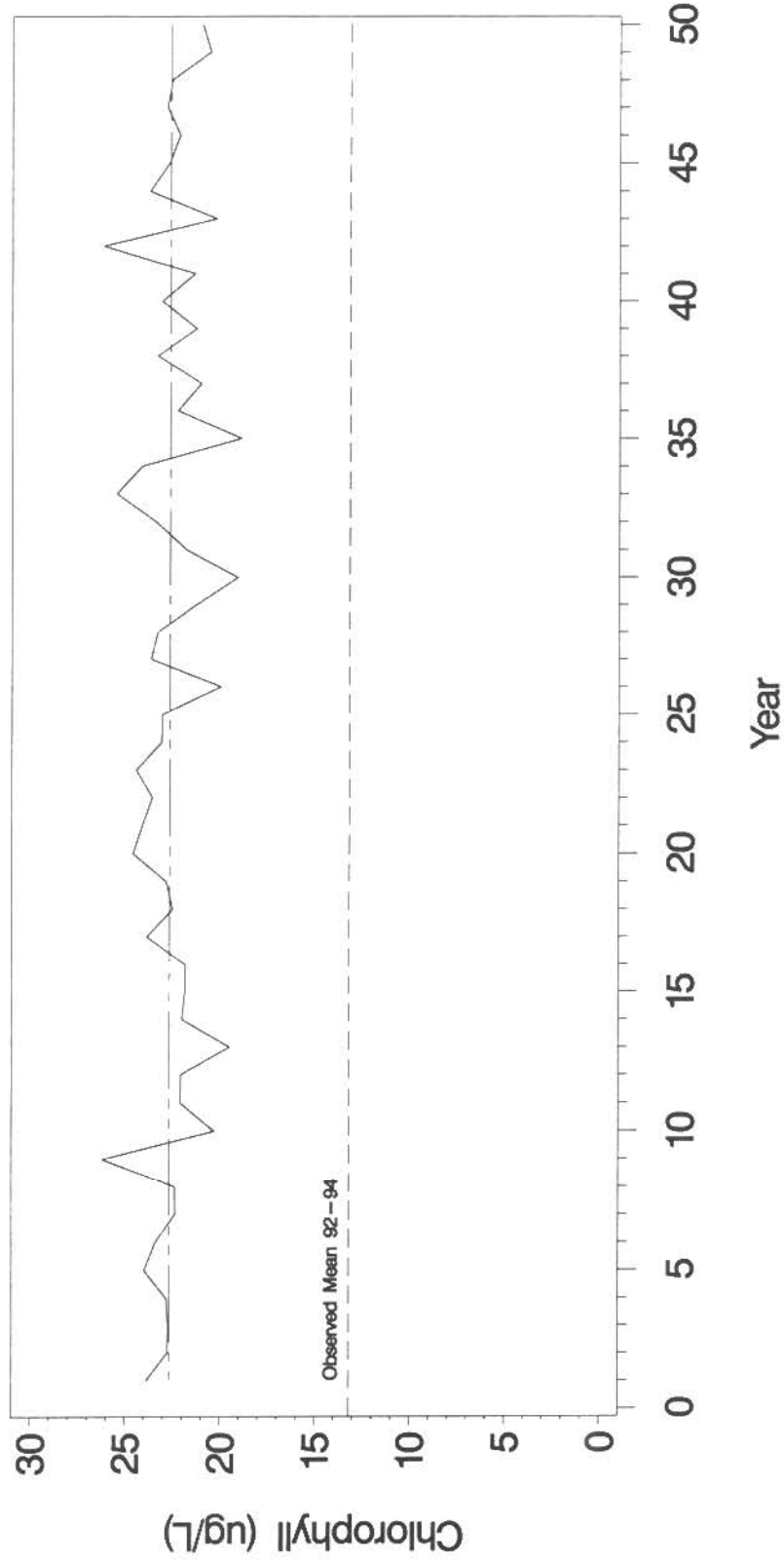
X Duration	< SMALL (< 9.1 $\mu\text{g/L}$)	SMALL (9.1-9.4 $\mu\text{g/L}$)	MEDIUM (9.5-10.5 $\mu\text{g/L}$)	LARGE (> 10.5 $\mu\text{g/L}$)
1 year	1974, 1988, 1991, 1996	1978, 1989, 1994	1984, 1986	1975, 1979, 1985, 1987, 1995, 1998
2 years	1992, 1997	1990		1976, 1980
3 years	1993			1977, 1981
4 years				1982
5 years				1983
> 5 years				

Appendix B

Time series plots of one-, three-, and five-year moving averages of chlorophyll concentrations in Hillsborough Bay from generated datasets.

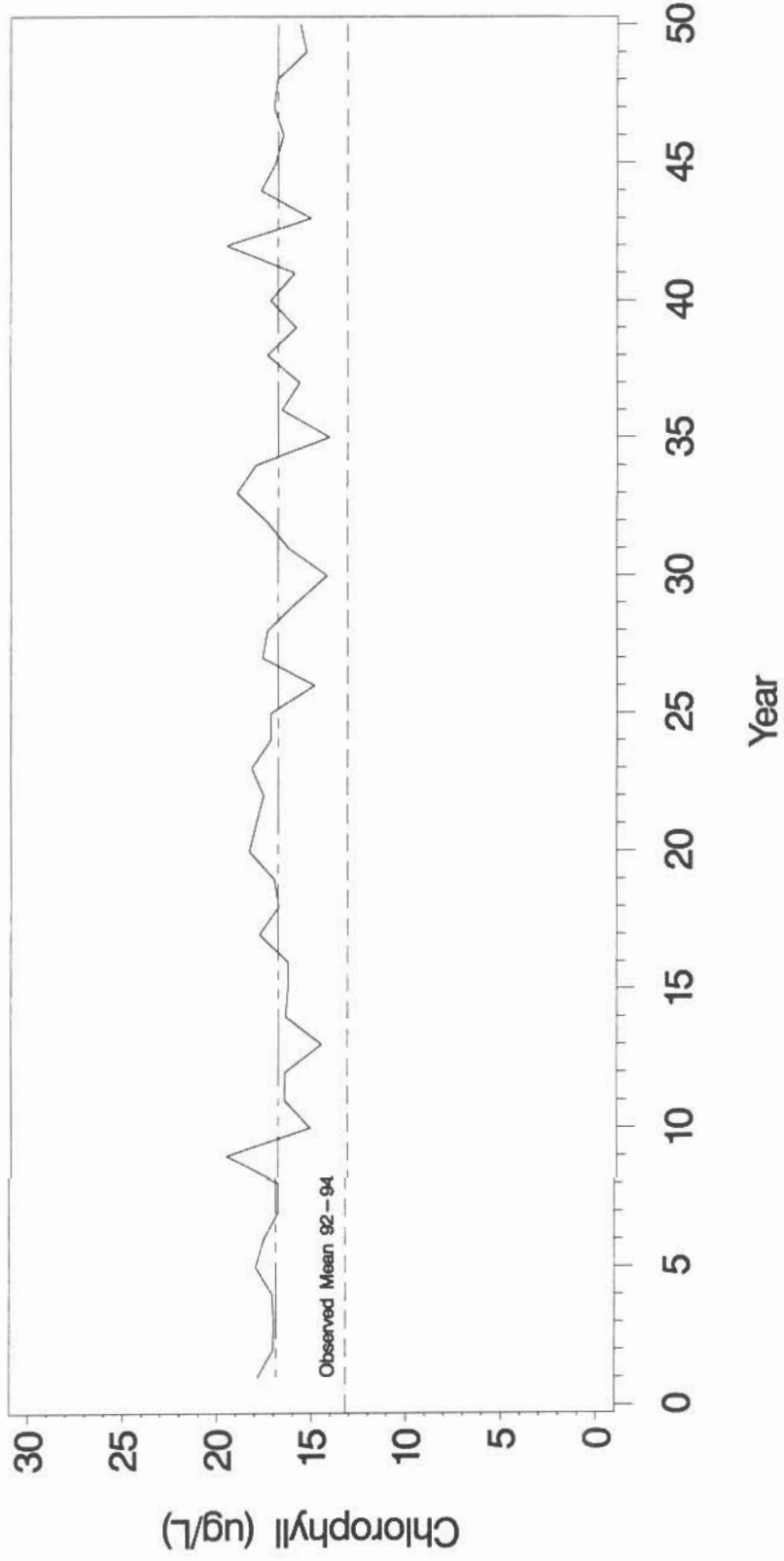
Hillsborough Bay

1-Year Moving Average Chlorophyll
Large Value (22.60 ug/L)



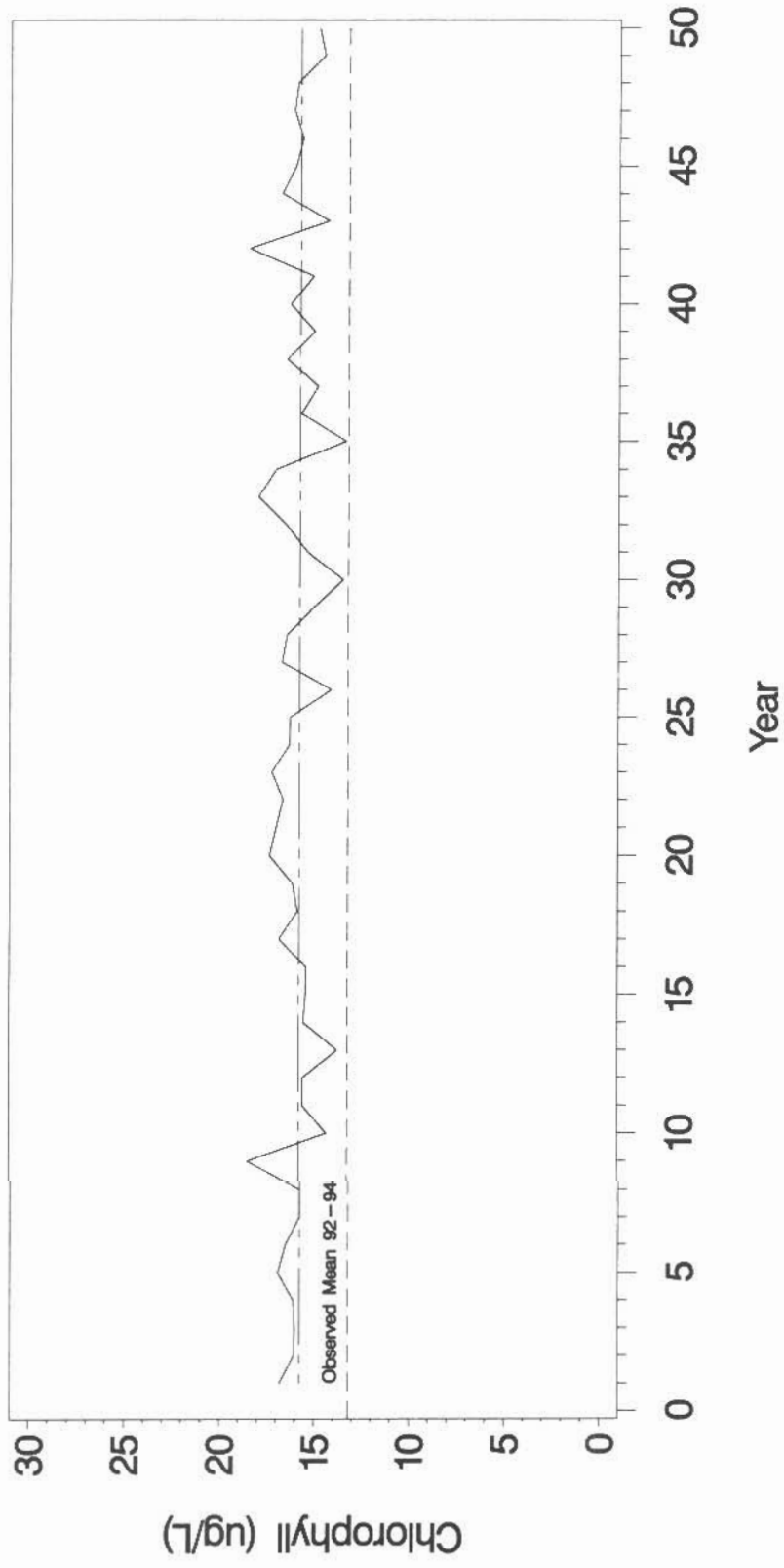
Hillsborough Bay

1-Year Moving Average Chlorophyll
Medium Value (16.87 ug/L)



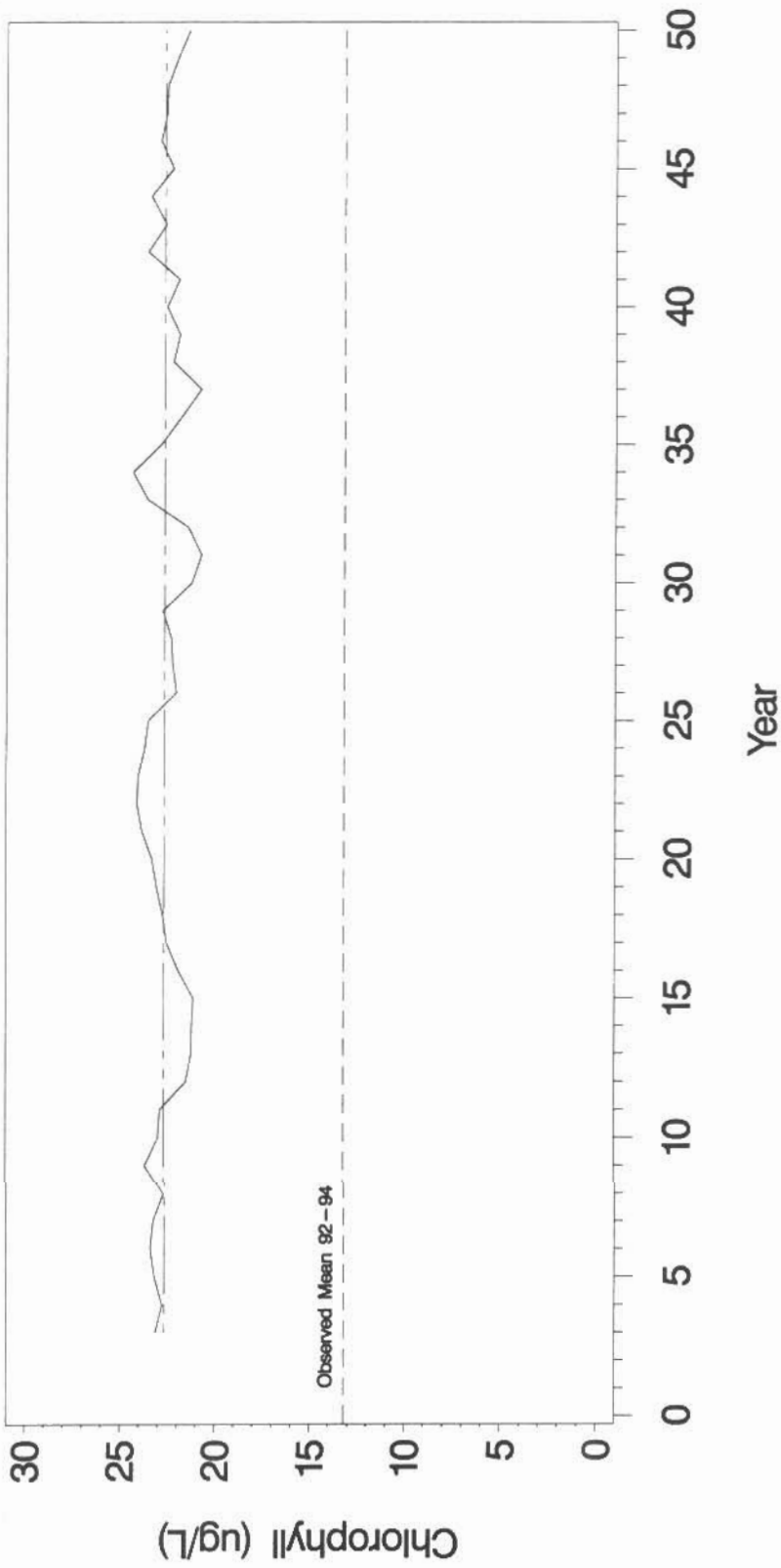
Hillsborough Bay

1-Year Moving Average Chlorophyll
Small Value (15.75 ug/L)



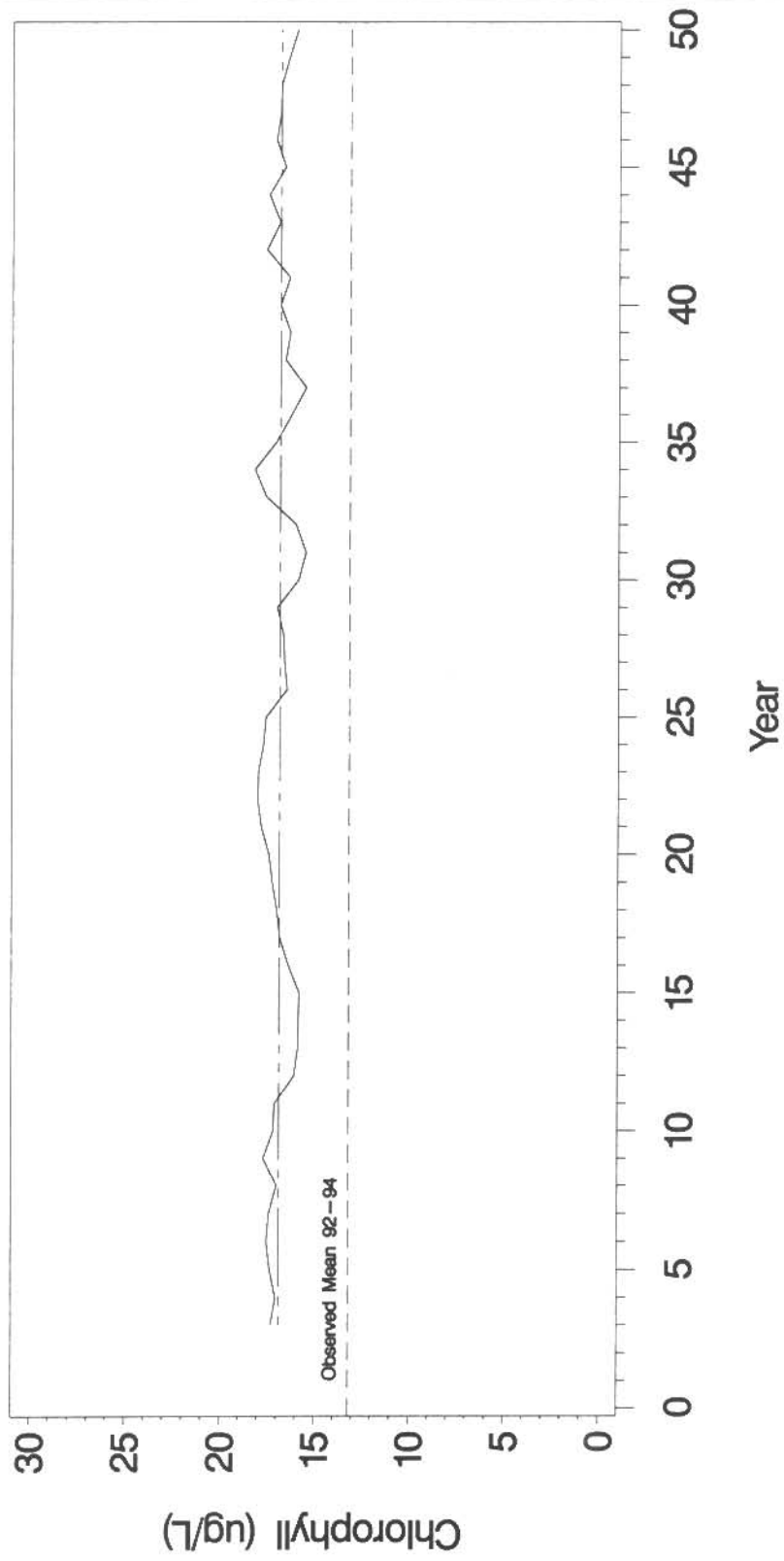
Hillsborough Bay

3-Year Moving Average Chlorophyll
Large Value (22.60 ug/L)



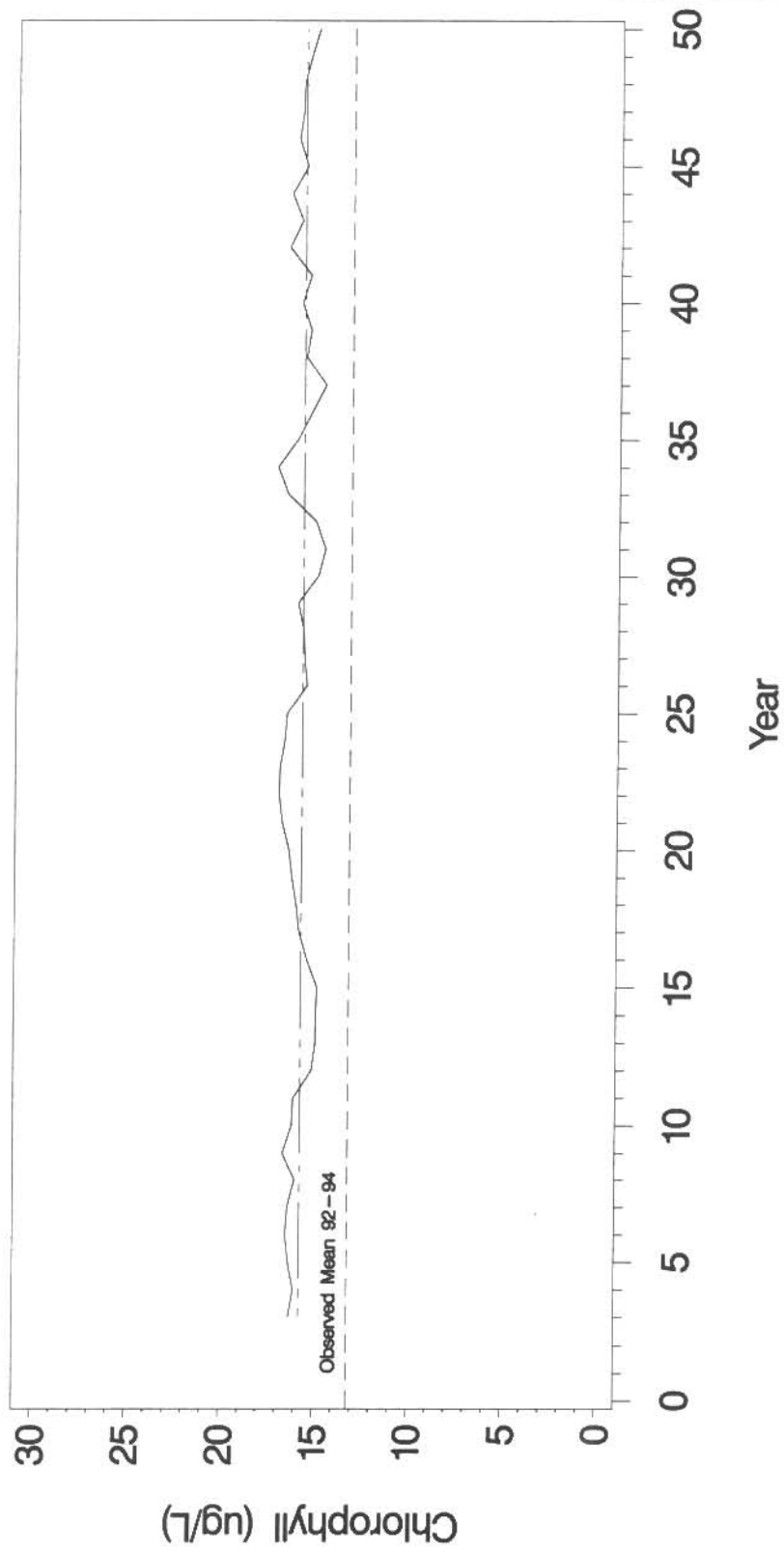
Hillsborough Bay

3--Year Moving Average Chlorophyll
Medium Value (16.87 ug/L)



Hillsborough Bay

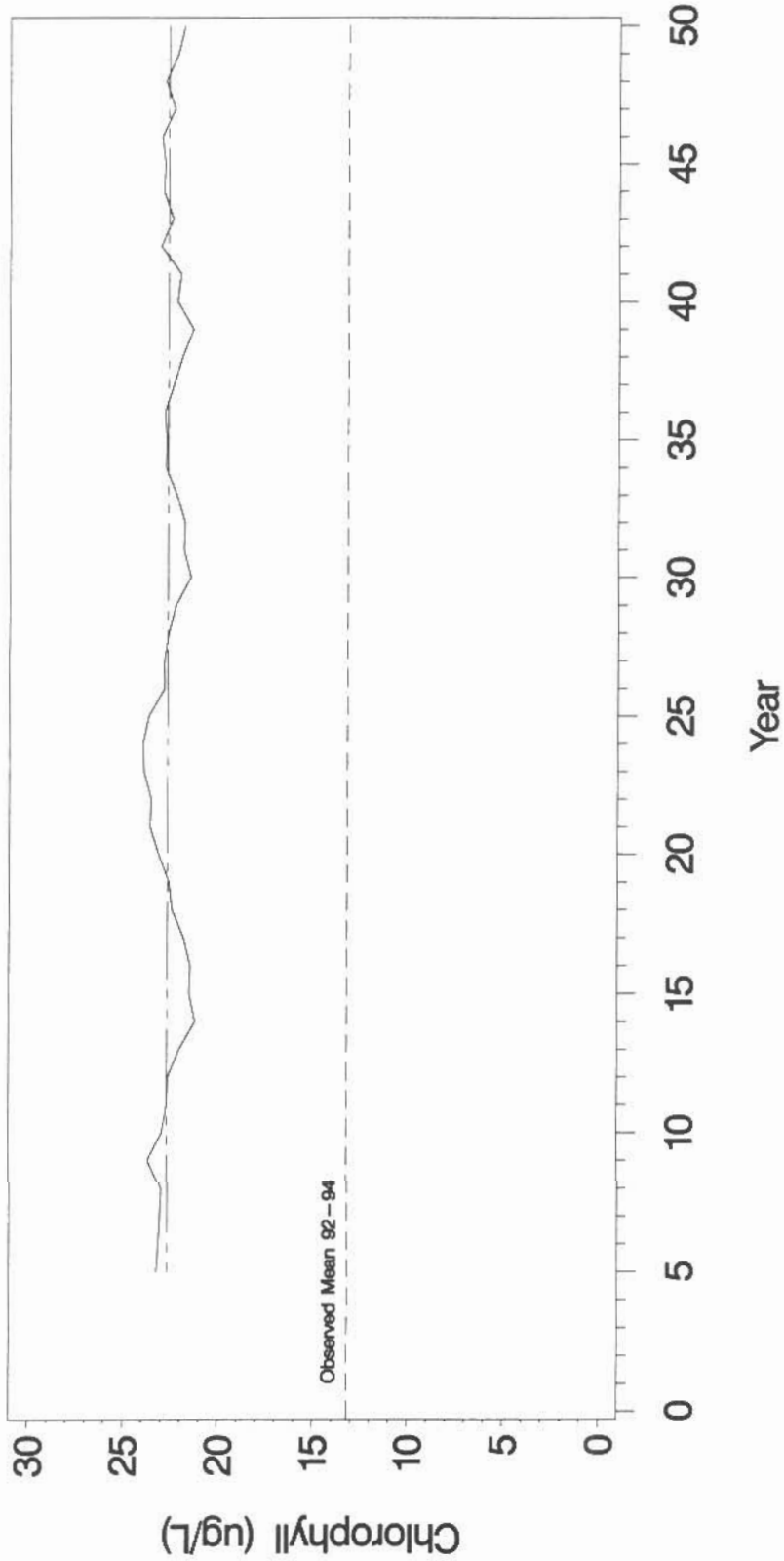
3-Year Moving Average Chlorophyll
Small Value (15.75 ug/L)



Hillsborough Bay

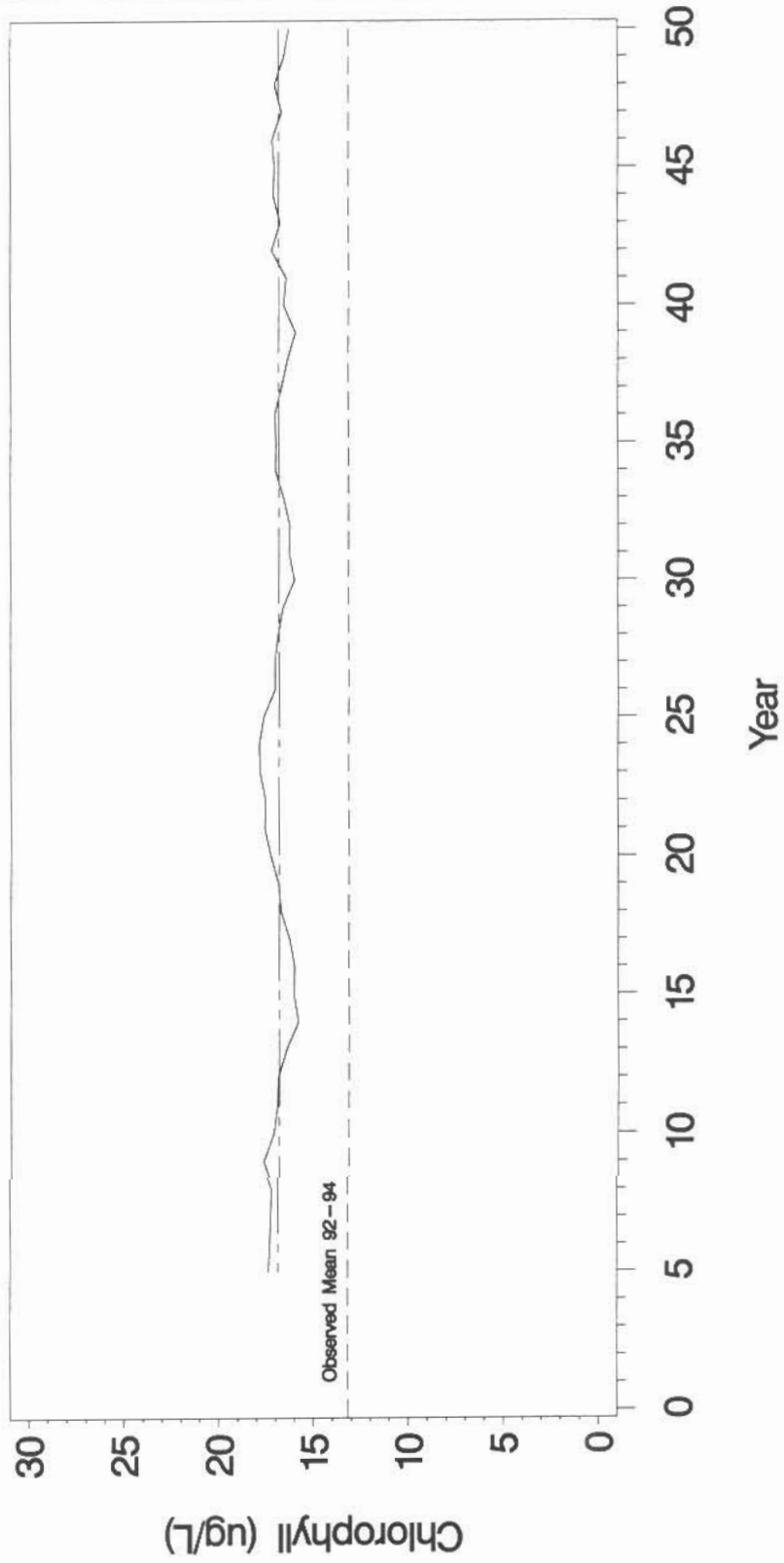
5-Year Moving Average Chlorophyll

Large Value (22.60 ug/L)



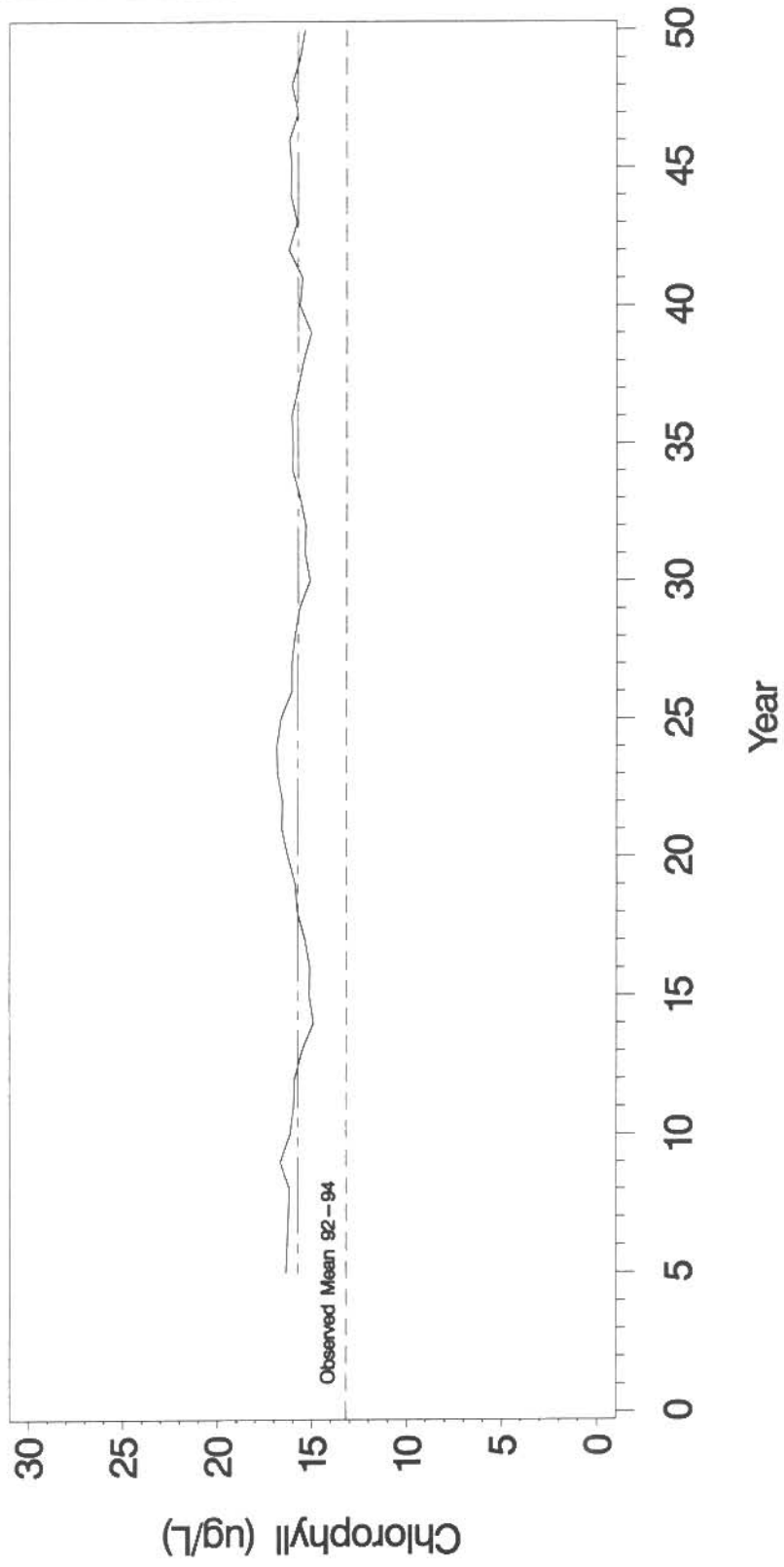
Hillsborough Bay

5-Year Moving Average Chlorophyll
Medium Value (16.87 ug/L)



Hillsborough Bay

5-Year Moving Average Chlorophyll
Small Value (15.75 ug/L)



Establishing a Process for Tracking Chlorophyll-a Concentrations and Light Attenuation in Tampa Bay

Janicki Environmental, Inc.

October 2000

One of the primary goals established in the Tampa Bay National Estuary Program (TBNEP) Comprehensive Conservation and Management Plan (CCMP) (TBNEP, 1996) is to restore seagrass extent in the bay to levels similar to those observed in the 1950's. Seagrass extent and condition can be impacted by many factors, including water quality. Water quality targets have been adopted by the TBNEP Management and Policy Committees for the four mainstem segments of Tampa Bay. The Tampa Bay Estuary Program (TBEP) is currently developing a method to determine if adopted seagrass acreage goals and water quality targets are being achieved (Janicki et al., 2000).

In its current state, the process to track the status of chlorophyll-a concentrations and light attenuation involves a decision framework leading to possible outcomes dependent upon the magnitude and duration of the target exceedence (Figure 1). The decision frameworks for chlorophyll-a concentration and light attenuation are identical. The process then uses a decision matrix approach to estimate the severity of the situation based on a combination of the chlorophyll-a concentration and light attenuation outcomes (Janicki et al., 2000). The Technical Advisory Committee (TAC) and Management Board of the TBEP have adopted this process for use in status tracking.

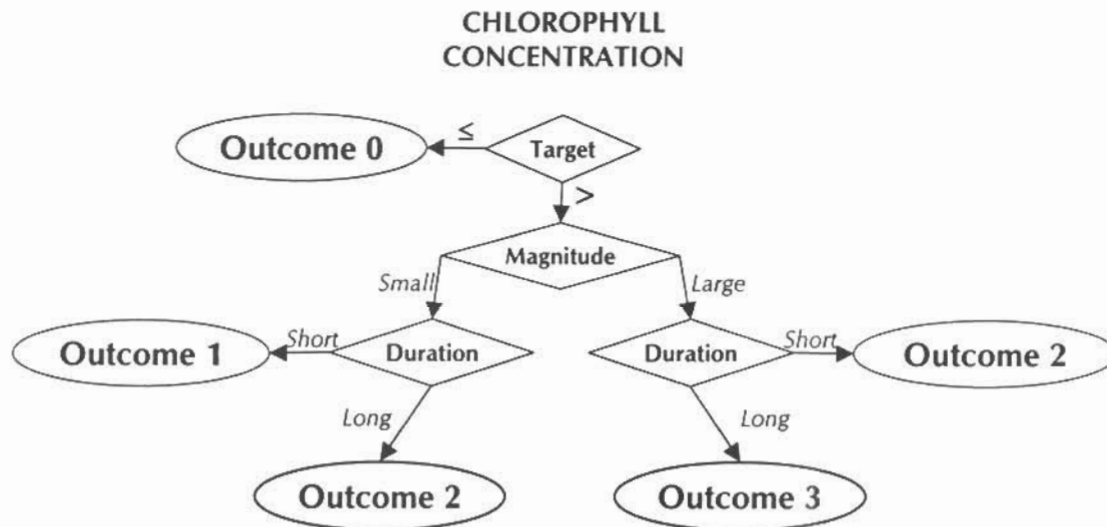


Figure 1. Monitoring and assessment decision framework for chlorophyll-a (from Janicki et al., 2000).

The definitions of the terms used in the decision framework process remains to be accomplished. This document presents definitions of these terms as provisionally accepted by the TBEP Water Quality Subcommittee on October 6, 2000, and the results of the application of the definitions to the chlorophyll-a - light attenuation decision matrix.

Definitions for magnitude and duration of events are needed, as follows;

- Magnitude – large vs. small
- Duration – long vs. short.

The TBEP Water Quality Subcommittee provisionally accepted the following definitions on October 6, 2000, pending review of the results of these definitions, as presented here.

Approach to Defining Terms

The logic employed in deriving the approaches to defining “magnitude” and “duration” focuses on the variation in the data that have been collected by EPCHC during the 1984-1998 period. The Water Quality Subcommittee recognizes that water quality data exist from 1974 to the present, but feels the poor water quality conditions found in the bay prior to 1984 are not likely to be observed in the future, based on changes in wastewater treatment methods prior to 1984. Chlorophyll-a concentrations are directly measured by the EPCHC, while light attenuation (K_d) is calculated from measured Secchi disc depth. Provisionally accepted definitions for duration of difference between the ambient water quality variable value (chlorophyll-a concentration, light attenuation) and the target value are:

- “short”: < 4 years persistence, and
- “long” : \geq 4 years persistence.

The definition of “short” duration is based on the minimum temporal data reporting span. Data reporting is done annually, and targets are based on segment-specific annual averages of water quality constituents. Data review and assessment with respect to targets is performed annually.

The definition of “long” duration is based upon our understanding of the response time of seagrass populations to variations in water quality conditions. This understanding is based on conversations with members of the Joint Modeling Subcommittee. We suggest that significant target exceedences found to occur during four or more consecutive years should be cause for more concern than shorter duration exceedences.

The provisionally accepted method for defining “magnitude” is discussed below. Chlorophyll-a concentration is used as the variable of interest in the development of the method, with the resultant “magnitude” definition for light attenuation following.

The approach to defining “magnitude” focuses on the EPCHC data variation, using the estimation of inter-annual variation in chlorophyll-a. An estimate of the inter-annual variation was calculated by first estimating, by bay segment, the mean annual chlorophyll-a concentrations. The mean annual bay segment chlorophyll-a concentrations were then averaged over the entire period of record, providing a mean chlorophyll-a concentration for the bay segment for the 1984-1998 period. The mean standard error was estimated for this mean 1984-1998 chlorophyll-a concentration. Thus,

where:

- = mean chlorophyll-a concentration for 1984-1998,
- = chlorophyll-a concentration in year j , and
- = number of years (15).

The inter-annual standard error for the time period of 1984 through 1998 is therefore,

where:

- = standard error of mean chlorophyll-a concentration (1984-1998),
- s^2 = variance in annual mean chlorophyll-a concentrations (1984-1998),
- and
- n = number of years (15).

Using these formulae, the bay segment-specific inter-annual standard errors for chlorophyll-a were estimated as follows, using data from the 1984-1998 period:

Old Tampa Bay	0.4 µg/L
Hillsborough Bay	0.9 µg/L
Middle Tampa Bay	0.5 µg/L
Lower Tampa Bay	0.2 µg/L

The definitions for magnitudes of difference between the ambient chlorophyll-a concentration and the chlorophyll-a target concentration are based on the mean inter-annual standard error. In the listing below, the difference is denoted as O-T (observed value minus target value), and the standard error is denoted as SE. The definitions are as follow:

- O-T < 1 SE No difference in magnitude;
- 1 SE ≤ O-T ≤ 2 SE “Small” difference in magnitude; and
- O-T > 2 SE “Large” difference in magnitude.

The “small” and “large” chlorophyll-a magnitudes for each bay segment are shown below.

CHL – Magnitudes Based on Mean Inter-Annual Standard Errors			
Bay Segment	: Target (µg/L)	Small Magnitude (µg/L)	Large Magnitude (µg/L)
Old Tampa Bay	: 8.5	8.9 – 9.3	> 9.3
Hillsborough Bay	: 13.2	14.1 – 15.0	> 15.0
Middle Tampa Bay	: 7.4	7.9 – 8.5	> 8.5
Lower Tampa Bay	: 4.6	4.8 – 5.1	> 5.1

The logic for defining “magnitude” described above was also applied to light attenuation as estimated from Secchi disc depth measured in the 1984-1998 period. The target light attenuation is that light attenuation that allows 20.5% of incident subsurface light to reach the target depths in each bay segment. The target light attenuation is estimated based on bay segment-specific regression parameters relating light attenuation to Secchi disc depth. The target depths, at which 95% of recoverable seagrass acreage is predicted to be achieved, are as follows (Janicki and Wade, 1996):

Old Tampa Bay	1.9 m
Hillsborough Bay	1.0 m
Middle Tampa Bay	1.9 m
Lower Tampa Bay	2.5 m.

The bay segment-specific inter-annual standard errors for light attenuation were estimated as follows, using data from the 1984-1998 period:

Old Tampa Bay	0.03 m ⁻¹
Hillsborough Bay	0.05 m ⁻¹
Middle Tampa Bay	0.04 m ⁻¹
Lower Tampa Bay	0.03 m ⁻¹

The “small” and “large” light attenuation magnitudes for each bay segment are shown below, based on the inter-annual variation of light attenuation.

K_d – Magnitudes Based on Mean Inter-Annual Standard Errors			
Bay Segment	Target (m⁻¹)	Small Magnitude (m⁻¹)	Large Magnitude (m⁻¹)
Old Tampa Bay	: 0.83	0.86 – 0.88	> 0.88
Hillsborough Bay	: 1.58	1.63 – 1.67	> 1.67
Middle Tampa Bay	: 0.83	0.87 – 0.91	> 0.91
Lower Tampa Bay	: 0.63	0.66 – 0.68	> 0.68

Application of Approach

The magnitude and duration definitions were applied to the 1974-1999 chlorophyll-a data. Time series plots of chlorophyll-a concentrations are presented for the four mainstem bay segments (Figures 2-5). The plots show target chlorophyll-a concentrations, small magnitude differences, and large magnitude differences.

The small and large magnitude differences provided by the inter-annual variant approach were applied to the decision formulation for chlorophyll-a (Figure 1), which incorporates both magnitude of difference and duration of difference. The results of this process are shown in Table 1.

The magnitude and duration definitions for light attenuation were also applied to the 1974-1999 light attenuation estimated from Secchi disc depth data. Time series plots of light attenuation are presented for the four mainstem bay segments (Figures 6-9). The plots show target light attenuation, small magnitude differences, and large magnitude differences.

The small and large magnitude differences provided by the inter-annual variant approach were applied to the decision formulation for light attenuation, which parallels that for chlorophyll-a (Figure 1). The results of this process are shown in Table 2.

Year	OTB Outcome	HB Outcome	MTB Outcome	LTB Outcome
1975	2	2	2	0
1976	2	2	2	1
1977	3	3	3	2
1978	3	3	3	1
1979	3	3	3	2
1980	3	3	3	2
1981	3	3	3	2
1982	3	3	3	3
1983	3	3	3	3
1984	2	0	3	0
1985	2	2	3	1
1986	2	2	2	0
1987	2	1	2	0
1988	0	0	0	0
1989	2	1	1	1
1990	2	0	1	0
1991	0	1	0	0
1992	0	0	0	0
1993	0	0	0	0
1994	2	2	2	2
1995	2	2	2	0
1996	0	0	0	0
1997	0	0	1	0
1998	2	2	2	2
1999	0	0	0	0

Table 2. Inter-annual variant decision formulation outcomes for light attenuation.				
Year	OTB Outcome	HB Outcome	MTB Outcome	LTB Outcome
1975	2	2	2	0
1976	2	2	2	2
1977	2	2	3	2
1978	3	3	3	2
1979	3	3	3	3
1980	3	3	3	3
1981	3	3	3	3
1982	3	3	3	3
1983	3	0	3	3
1984	3	0	3	3
1985	3	2	3	2
1986	3	0	3	0
1987	3	0	3	0
1988	3	0	3	0
1989	3	0	3	2
1990	3	0	3	1
1991	0	0	3	2
1992	1	0	3	2
1993	2	0	3	2
1994	0	0	3	3
1995	2	0	3	3
1996	2	0	3	0
1997	2	0	3	2
1998	3	2	3	2
1999	3	0	3	2

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, as shown in Table 3 (Janicki et al., 2000).

Table 3. 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	YELLOW
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 exceedences; 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 results of the application of the definitions for magnitude and duration for chlorophyll-a and light attenuation, shown in Tables 1 and 2, were applied to the decision matrix shown in Table 3. The decision matrix is based on the outcomes, as shown in Figure 1, of duration and magnitude of difference, for both chlorophyll-a

and light attenuation. This resulted in the identification of the management action categories as shown in Table 4.

Table 4. Inter-annual variant decision matrix results.				
Year	OTB Outcome	HB Outcome	MTB Outcome	LTB Outcome
1975	Red	Red	Red	Green
1976	Red	Red	Red	Yellow
1977	Red	Red	Red	Red
1978	Red	Red	Red	Yellow
1979	Red	Red	Red	Red
1980	Red	Red	Red	Red
1981	Red	Red	Red	Red
1982	Red	Red	Red	Red
1983	Red	Yellow	Red	Red
1984	Red	Green	Red	Yellow
1985	Red	Red	Red	Yellow
1986	Red	Yellow	Red	Green
1987	Red	Yellow	Red	Green
1988	Yellow	Green	Yellow	Green
1989	Red	Yellow	Red	Yellow
1990	Red	Green	Red	Yellow
1991	Green	Yellow	Yellow	Yellow
1992	Yellow	Green	Yellow	Yellow
1993	Yellow	Green	Yellow	Yellow
1994	Yellow	Yellow	Red	Red
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

Old Tampa Bay
Chlorophyll a
Inter-annual Variant

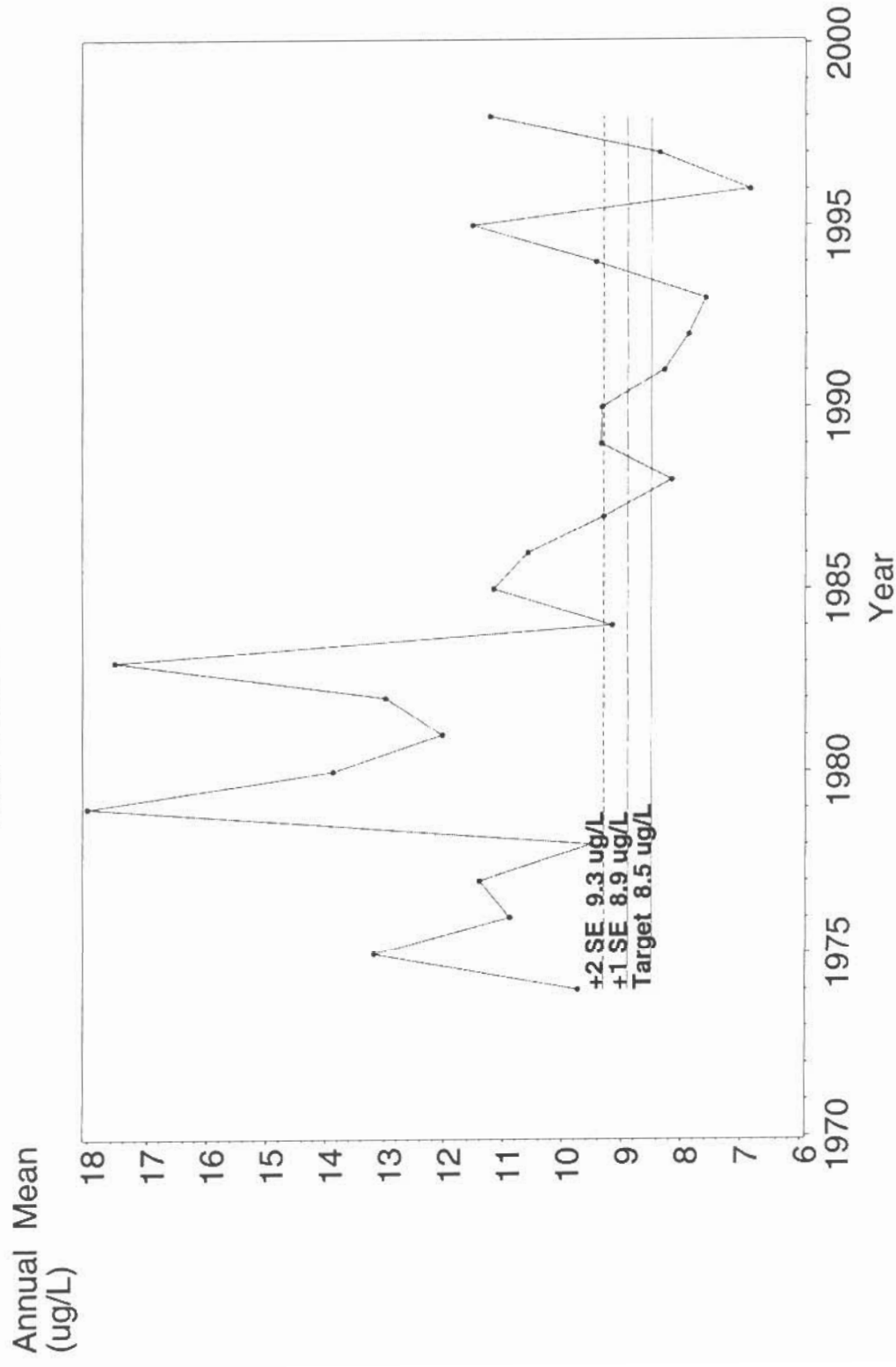


Figure 2. Old Tampa Bay average annual chlorophyll-a concentrations, with target and inter-annual variant-derived small and large magnitude differences.

Hillsborough Bay
Chlorophyll a
Inter-annual Variant

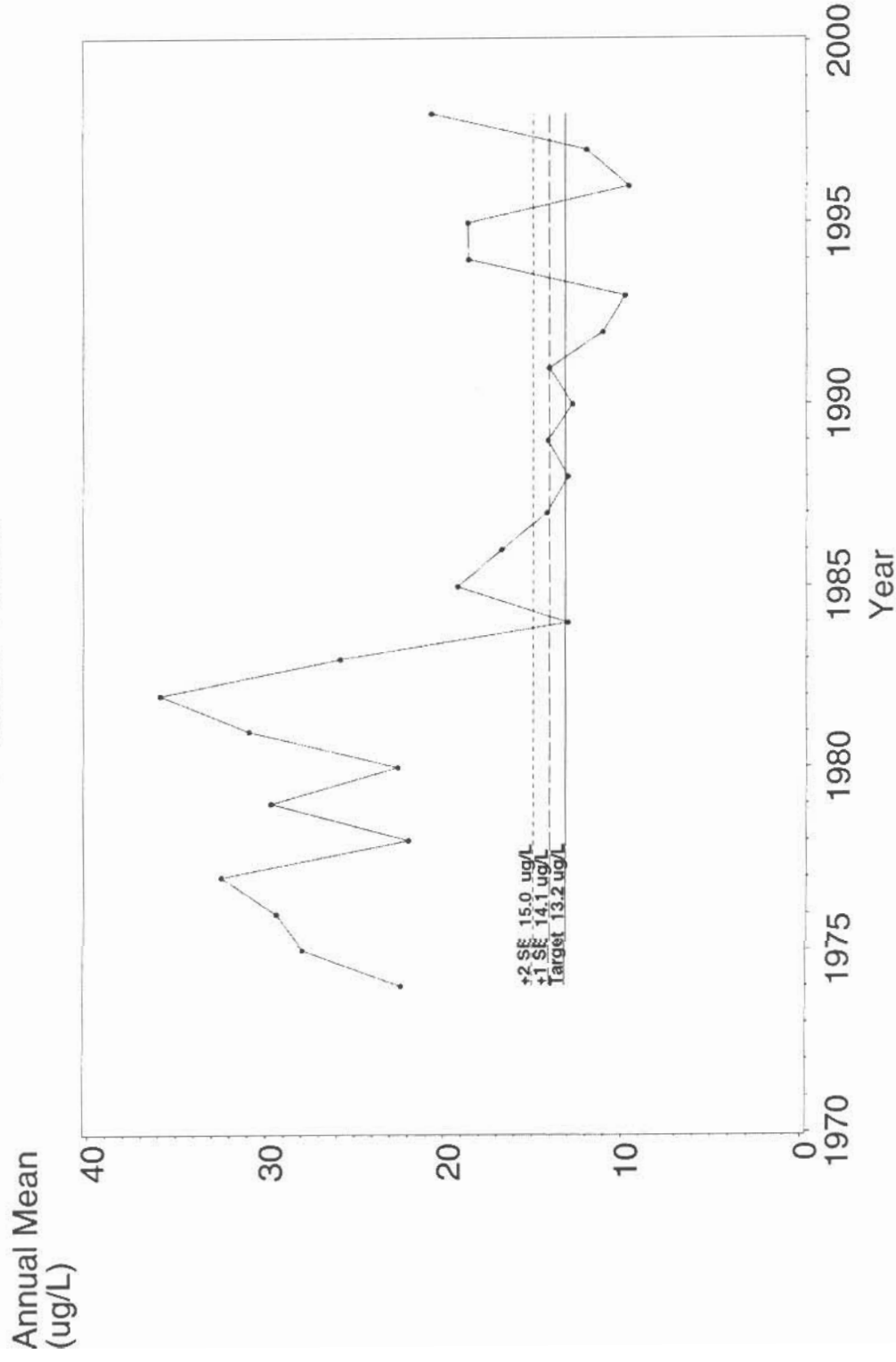


Figure 3. Hillsborough Bay average annual chlorophyll-a concentrations, with target and inter-annual variant-derived small and large magnitude differences.

Middle Tampa Bay
Chlorophyll a
Inter-annual Variant

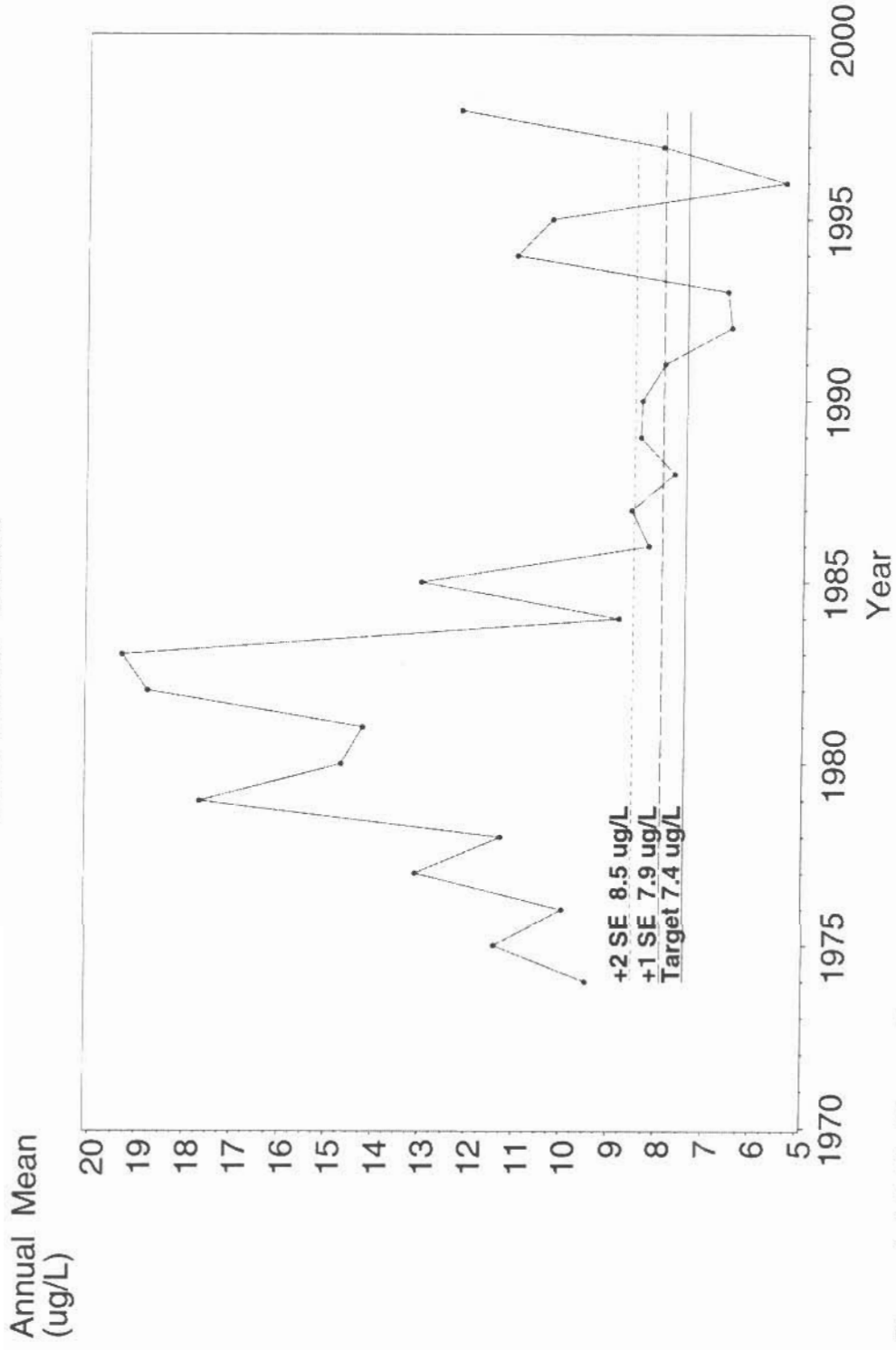


Figure 4. Middle Tampa Bay average annual chlorophyll-a concentrations, with target and inter-annual variant-derived small and large magnitude differences.

Lower Tampa Bay
Chlorophyll a
Inter-annual Variant

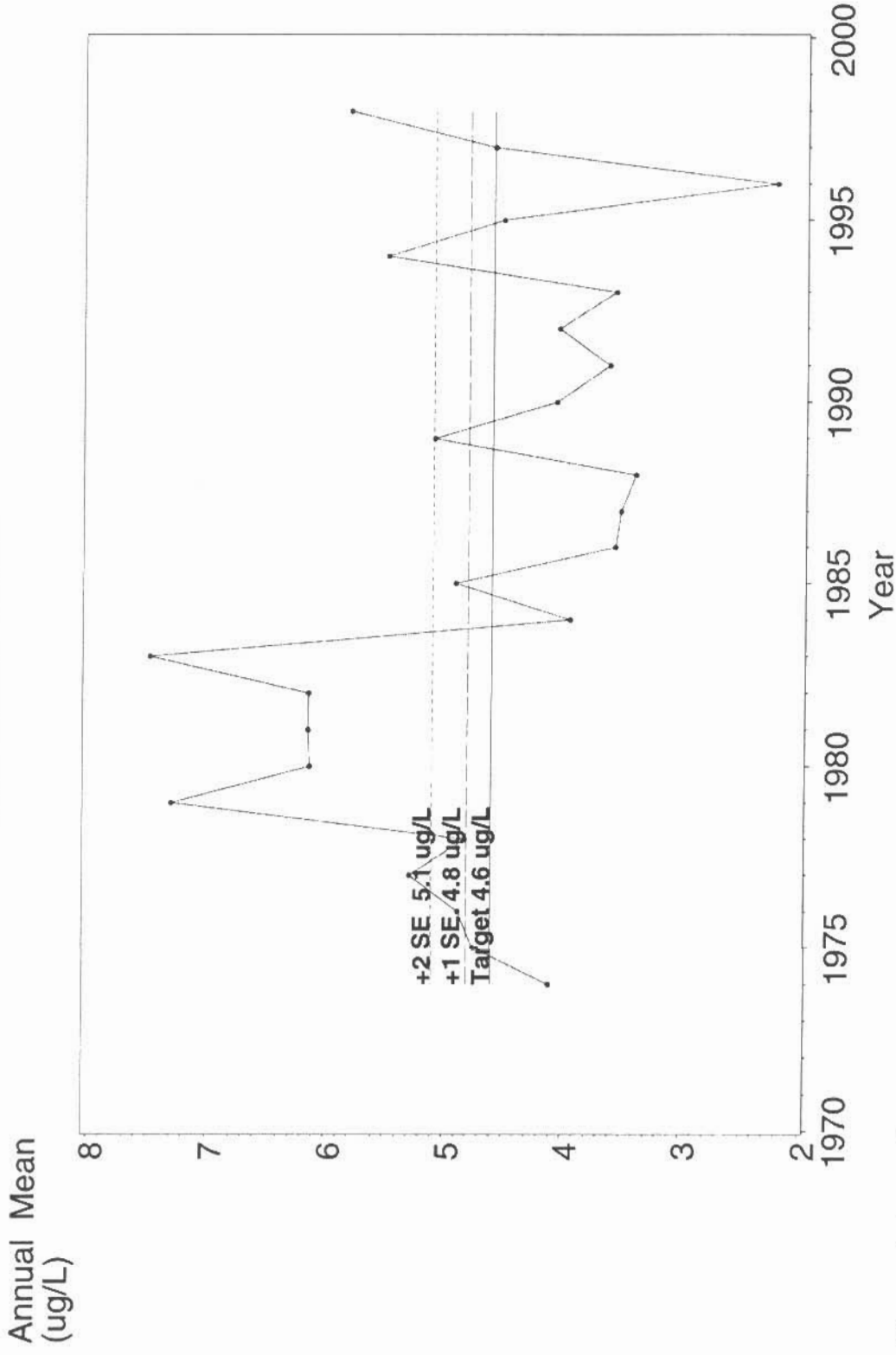


Figure 5. Lower Tampa Bay average annual chlorophyll-a concentrations, with target and inter-annual variant-derived small and large magnitude differences.

Old Tampa Bay
K_d
Inter-annual Variant

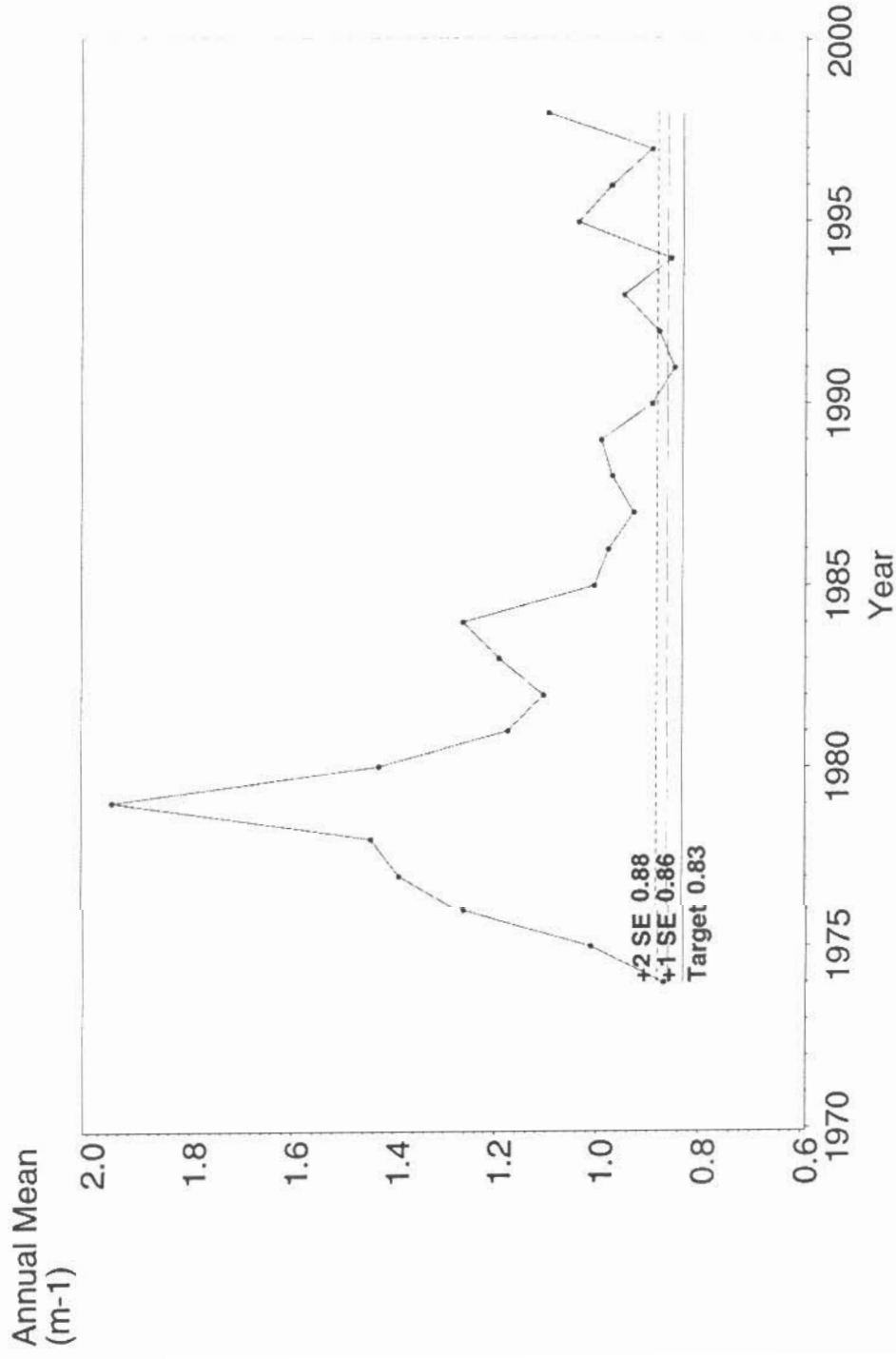


Figure 6. Old Tampa Bay average annual light attenuation, with target and inter-annual variant-derived small and large magnitude differences.

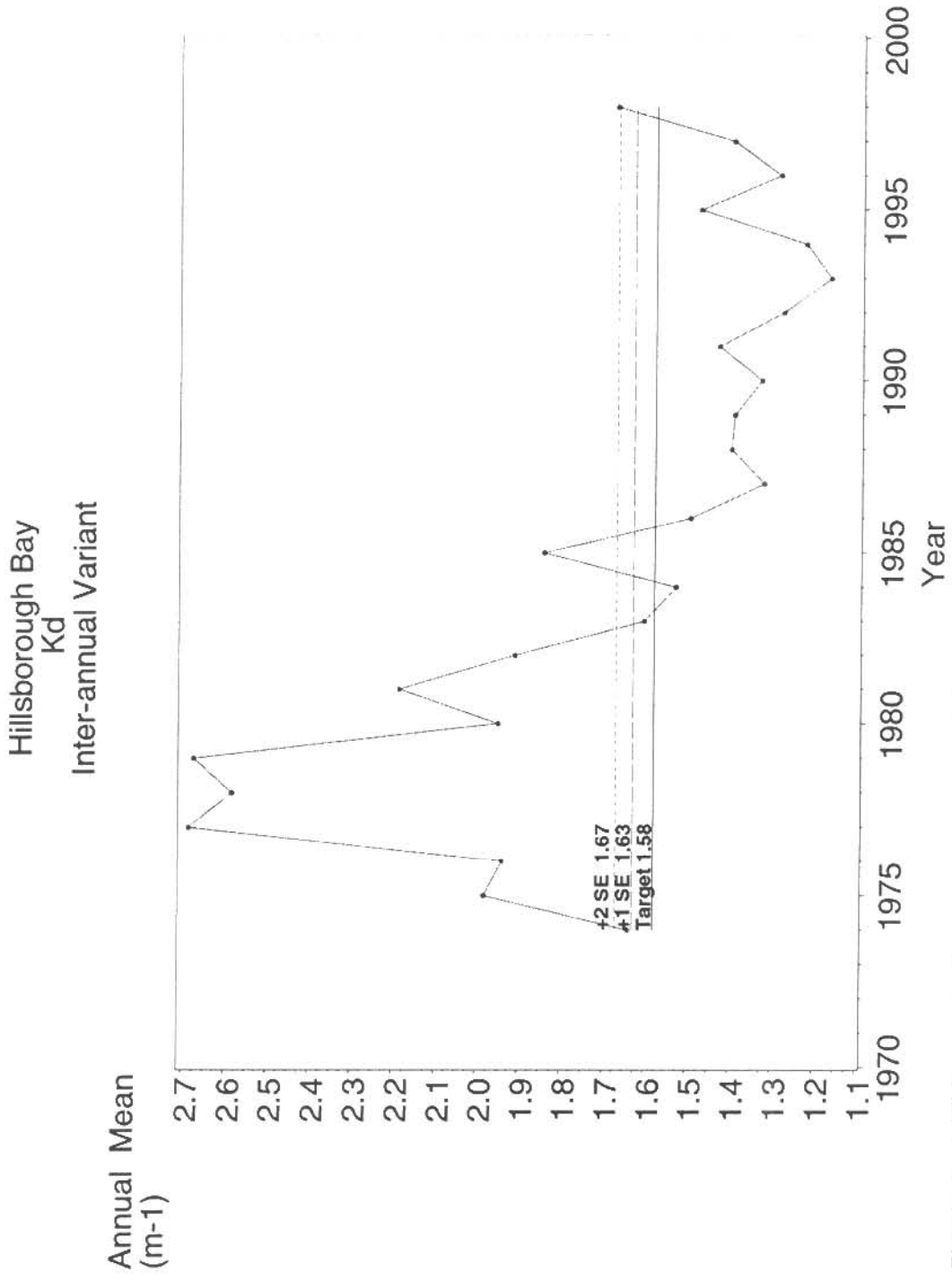


Figure 7. Hillsborough Bay average annual light attenuation, with target and inter-annual variant-derived small and large magnitude differences.

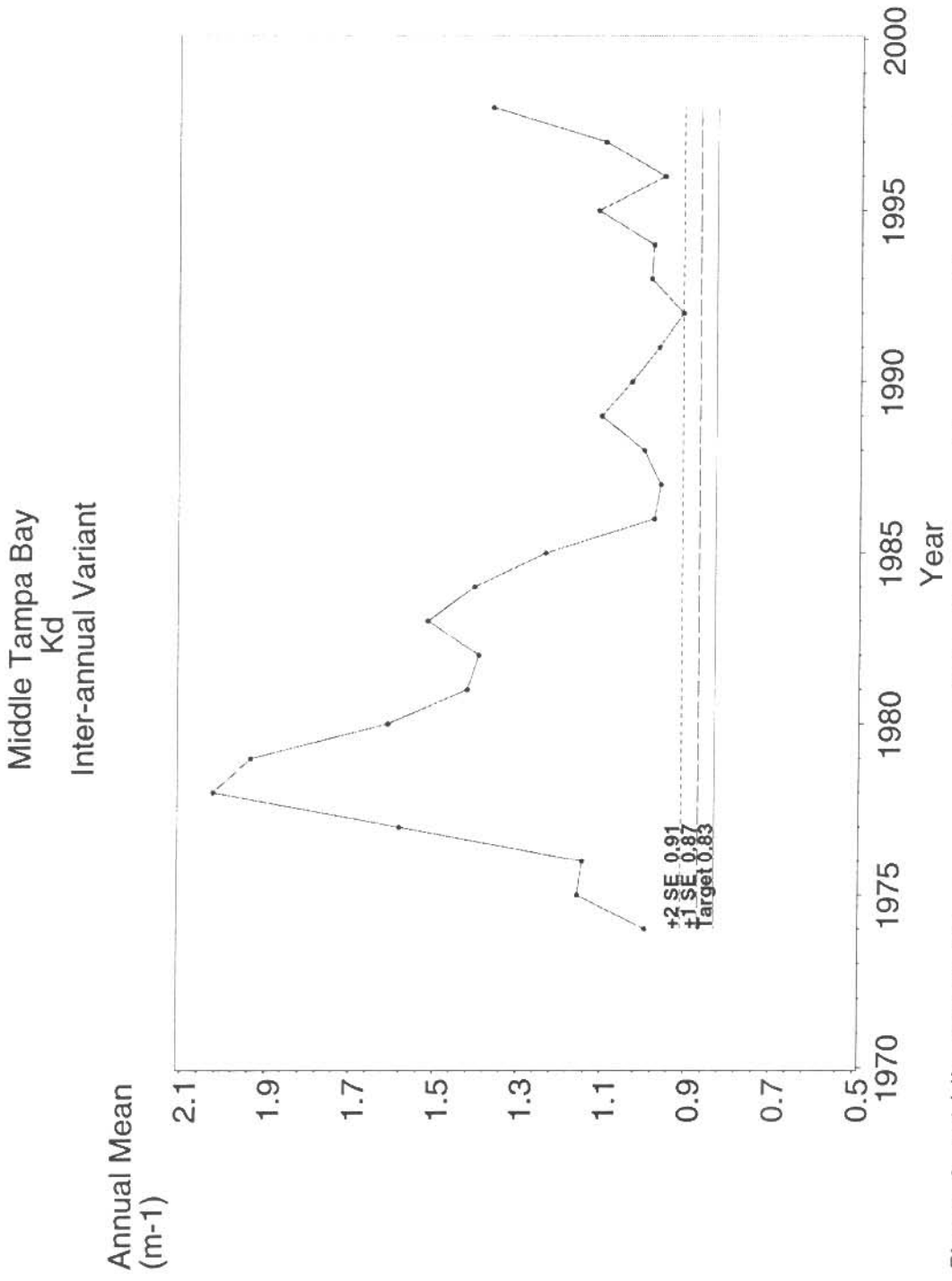


Figure 8. Middle Tampa Bay average annual light attenuation, with target and inter-annual variant-derived small and large magnitude differences.

Lower Tampa Bay
 K_d
Inter-annual Variant

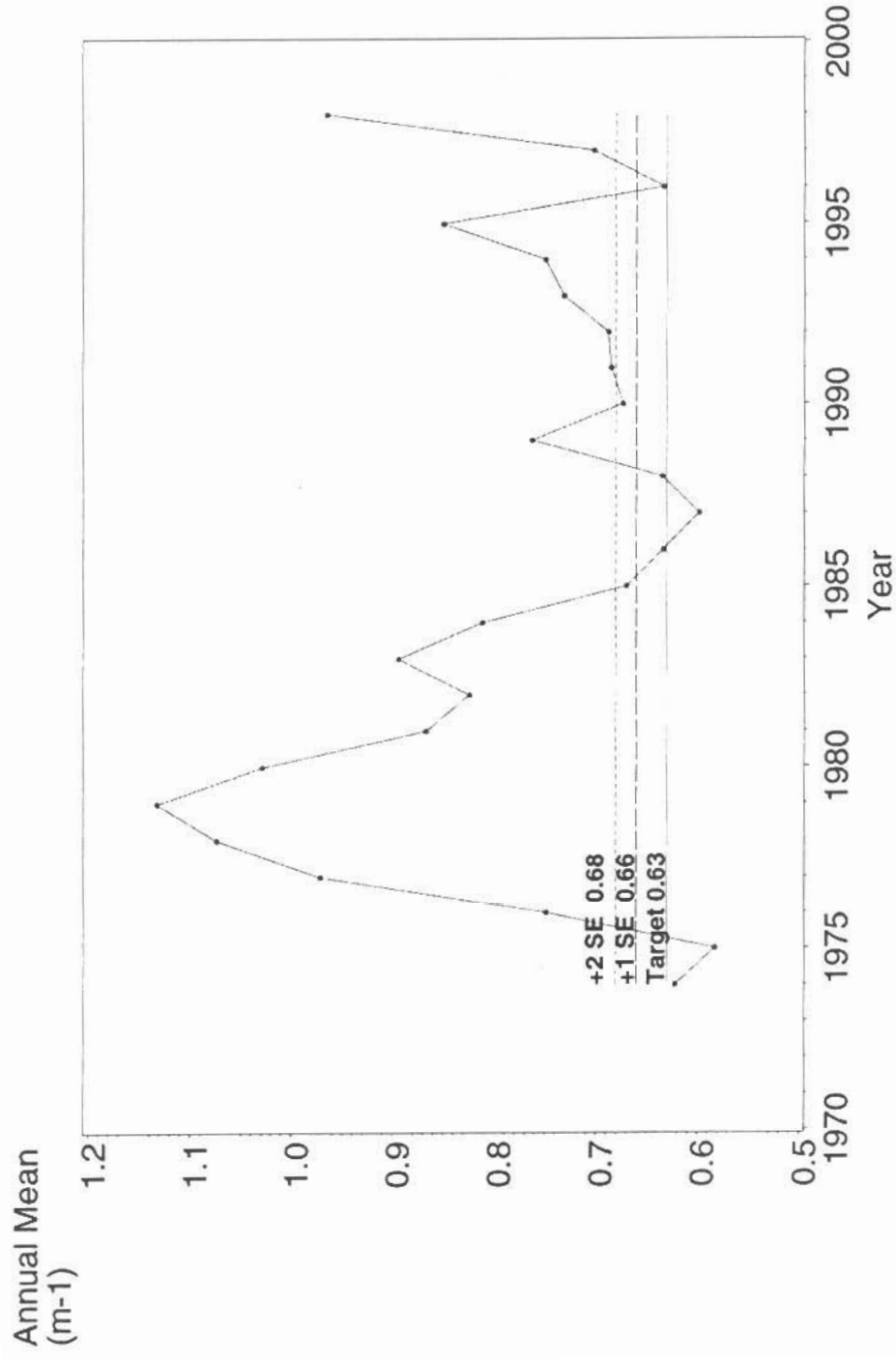


Figure 9. Lower Tampa Bay average annual light attenuation, with target and inter-annual variant-derived small and large magnitude differences.

References

Janicki, A.J., D. Wade, and J.R. Pribble. 2000. Development of a process to track the status of seagrasses, chlorophyll, and light attenuation in Tampa Bay. Prepared for: Tampa Bay Estuary Program. Prepared by: Janicki Environmental, Inc. Tampa Bay Estuary Program Technical Report #01-00.

TBNEP. 1996. *Charting the Course, the Comprehensive Conservation and Management Plan for Tampa Bay*. Tampa Bay National Estuary Program in cooperation with the U.S. Environmental Protection Agency, Region IV.