EMPIRICAL AND MECHANISTIC APPROACHES TO ESTABLISHING PLRGS IN THE TIDAL PEACE AND MYAKKA RIVERS

FINAL REPORT

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FOREWORD

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EXECUTIVE SUMMARY

The tidal reaches of the Peace and Myakka rivers are potentially vulnerable to eutrophication and other water quality impacts caused by pollutant loadings discharged from their watersheds. The objective of this project was to investigate the existing water quality and loading data for these rivers, and to provide a technically sound foundation for the management of their water quality. In particular, the focus was on developing alternative modeling methods of establishing Pollutant Load Reduction Goals (PLRGs) to support the development of trophic state goals and nitrogen management targets for the tidal reaches of the two rivers

Analyses of historical data support findings of declining phosphorus concentrations in the Peace River and possible increasing nitrogen levels. Due to a lack of long-term monitoring data, however, there is no direct evidence as to how such concentrations may compare to ambient levels prior to the late 1970s. Estimated changes in land use indicate very significant increases in residential, commercial, industrial, and mining through the Charlotte Harbor Estuary's watershed between 1950 and 1990. Such changes, as well as subsequent environmental regulations reducing point source discharges, may have resulted in changes in the water quality of freshwater inflows into the estuary. Given the absence of long-term data, however, there is no hard evidence to support or disprove such conjectures.

Determination of nitrogen management targets should ideally be based on estimating the maximum loading of this nutrient that can be assimilated by the system without resulting in unacceptable degradation of resources within the estuarine system. If the maximum "acceptable" loading level is exceeded, then the potential exists for the development of conditions under which certain uses of the harbor's living resources could be impaired.

There are several resources of concern whose uses may either be currently impaired, or may well become so in the future in the absence of appropriate resource management. Resources which may be at risk due to the potential for future increased nutrient loadings are those affected by hypoxic conditions in the lower Peace River and Upper Harbor. Currently there are at least two known impaired uses of resources in the lower Peace River which are associated with poor water quality: excessive algal blooms in the freshwater portion of the river reduce the ability of the Peace River/Manasota Regional Water Supply Authority to withdraw water from the Peace River, and shellfish beds in the tidal reach are currently closed to harvesting due to episodically high bacterial counts.

Two methods of relating loadings to water quality conditions were utilized in this study. Empirical and mechanistic models were assessed for their abilities to relate hydrology, nutrient loadings, and water quality for the study area.

For the empirical approach, measured data were used to describe observed relationships between external nitrogen loads and water quality without regard to the internal processes which affect the response (e.g., loss of nutrients to sediments, internal load sources, internal cycling, temperature, etc.). Several water quality variables measured by the Environmental Quality Laboratory (EQL) and the Southwest Florida Water Management District Surface Water Improvement and Management Program (SWFWMD SWIM) were considered as potential indicators of trophic state conditions in the tidally influenced river reaches. These parameters included total nitrogen (TN), total phosphorus (TP), TN:TP ratio, chlorophyll-a, and photosynthetic compensation depth (operationally defined as depth of 1% surface light).

Comprehensive analysis of available data showed several trends, listed below:

- An increasing trend in time in median annual TN:TP ratio was observed in the Middle Peace River segment and the Lower Peace and Myakka River segments. The increasing trend in TN:TP was primarily associated with a long-term decreasing trend in TP concentrations.

- Nutrient loads from the Peace River are strongly related to color and water clarity in the tidal reaches of the Peace River. Higher loads are associated with higher color and lower water clarity in the tidal river segments.

- No strong or significant relationships were found between river loadings and the living resource response variables of Trophic State Index (TSI) and chlorophyll-a concentration measured in the tidally influenced segments of the rivers.

- Peace River loads are more strongly related to TSI in the lower segment (EQL station 8) of the Myakka River compared to loading from the Myakka River itself.

- Although some relationships (correlations) were stronger than others, no significant relationships have been found between the analyzed response variables (TSI, chlorophyll-a) measured in the tidal portions of the Peace or Myakka rivers and the estimated external nutrient loadings delivered to those tidally influenced areas.

The relationship of total external nitrogen load to chlorophyll-a concentration was investigated using nitrogen loading estimates and chlorophyll-a concentration observations from the EQL fixed station data (1976-1990) and the EQL salinity-based station data (1983-1994). Regression analyses also indicated that no significant relationship was observed for the Upper and Lower Peace River segments. However, a significant relationship was observed between 1) TP concentration and TP loading, 2) TN:TP ratio and TN concentration, and 3) TN:TP ratio and TP concentration for the Middle Peace River segment.

the robustness of the hydrodynamic simulation, the eutrophication model was constructed utilizing these same hydrodynamic parameterizations.

The eutrophication model was limited to the Peace River, the Myakka River, and the Upper Harbor. The primary effort in the attempt to calibrate the eutrophication model was towards simulating chlorophyll and dissolved oxygen values representative of those from the data record. This effort was not effective for chlorophyll, and the dissolved oxygen results, while somewhat better, were still not adequate to serve as a predictive tool in understanding the response of the water body to loadings.

The lack of fit of simulated chlorophyll concentration to observed values may be the result of several factors. Limitations of the data available for the study were found, including the lack of light attenuation data in the EQL fixed station database, a temporally and spatially sparse data record from both the EQL fixed station and the SWFWMD databases, and paucity of chlorophyll measurements from the EQL fixed station database for the bottom boxes of the simulated system. Other limitations on the simulation were imposed by the EUTRO5 model construct itself. Perhaps most important is the inability of the model to vary growth rates in time and space, which may be necessary to accurately simulate algal growth rates and concentrations in this highly dynamic system..

Given that PLRG determination should ideally be postulated on the thesis that a stressor exists with which a quantifiable response is associated, it is necessary to establish a link between a given stressor (e.g., nitrogen loading) and a response (e.g., chlorophyll biomass). Intuitively, there should be a quantifiable relationship between nutrient loading and chlorophyll biomass within a system. However, using currently available data, the lack of correlation between water quality factors related through the empirical model approach, and the inability of the mechanistic model to simulate observed water quality responses given observed and estimated hydrodynamic forcing functions, disallows either of these approaches, as currently utilized, from being used to determine PLRGs.

The data sets utilized for the model approaches used for this study were taken from programs in which the data sampling efforts were not designed in support of modeling efforts. Given additional data sets, either from existing (SWFWMD/FDEP/EQL) sampling programs, or more comprehensive and statistically rigorous sampling designs (Coastal Environmental, Inc., 1995a), efforts along these lines may be more productive.

The establishment of water quality goals and nitrogen management targets, however, is ultimately a resource management question. Given the importance of the resources within Charlotte Harbor, it may be not be prudent to await further data gathering and analyses prior to suggesting initial goals and targets. A recent proposal for an initial nitrogen management target (Morrison, 1997) calls for reductions in dissolved inorganic nitrogen loads of 1% per year over 10 years. The purpose of this target is to provide a "glide path" for long-term achievement of the trophic state goal, with assessment of data obtained over the 10-year period to determine the effects of this load reduction.

1.0 PROJECT OBJECTIVES

The tidal reaches of the Peace and Myakka rivers are potentially vulnerable to eutrophication and other water quality impacts caused by pollutant loadings discharged from their watersheds. The objective of this project was to investigate the existing water quality and loading data for these rivers, and to provide a technically sound foundation for the management of their water quality. In particular, the focus was on developing alternative methods of establishing Pollutant Load Reduction Goals (PLRGs). This report presents the results of empirical and mechanistic models relating hydrology, nutrient loadings, and water quality, and discusses the applicability of these results for determining PLRGs for the study area. In addition, recommendations for future monitoring to provide data more amenable to determination of PLRGs are provided.

1.1 Pollutant Load Reduction Goals

The focus of this report was on developing alternative methods of establishing PLRGs for the estuarine regimes of the two rivers. Chapter 62-40 of the Florida Administrative Code requires the Department of Environmental Protection and the Southwest Florida Water Management District (SWFWMD) to establish PLRGs that will preserve and restore the beneficial uses of the waterbodies to be managed. Surface Water Improvement and Management (SWIM) waterbodies form the first tier of waterbodies for which PLRGs will be developed, and the Peace and Myakka rivers are included in this first tier. The SWFWMD SWIM Program designated the estuary a priority water body pursuant to the SWIM Act of 1987 (Chapter 87-97, F.S.).

The intention of this project was to develop management tools for establishing PLRGs within the constraints of multi-use/multi-objective watershed management. This project addresses PLRGs from an objective, living resource target perspective only, and the responsible management agencies will use this technical information and other information in the overall PLRG process. They will include important considerations which are necessary to balance the multiple uses of the watersheds with pollutant load reduction. These other considerations include, but are not limited to:

- the need to maintain environmentally appropriate freshwater flows to the Charlotte Harbor estuary,
- the recognition of existing urban, agricultural, and industrial development within the watersheds, and
- the understanding that the lower portions of the Peace River and the Myakka River comprise highly dynamic estuarine systems whose biological communities vary naturally in response to changing rainfall levels and loadings of nutrients, color, and other water quality constituents.

Thus, the PLRG tools developed can be used to produce recommended load reduction values, but these values must be considered in concert with the complete set of management objectives.

In simple terms, the PLRG-setting process involves the identification of water quality targets which will restore and preserve the beneficial uses of the rivers, and it utilizes observed data to identify pollutant loads that are consistent with these water quality targets.

For the first part of this process, the SWFWMD is considering the use of several alternative sets of water quality targets for the establishment of PLRGs. These alternatives include:

- Maintenance of maximum monthly chlorophyll-a concentrations of less than 60 μg/L, a level considered indicative of hypereutrophication by the National Oceanographic and Atmospheric Administration (NOAA) (NOAA, 1996),
- Reduction of peak monthly chlorophyll-a concentrations in terms of frequency and magnitude as observed over 1990-1994, and
- Prevention of a change of more than 10 percent (from natural conditions) in the average annual photosynthetic compensation depth (where compensation depth is operationally defined as the depth at which exists 1% of the incident light occurring just below the water surface), pursuant to State water quality standards.

For the second part of this process, estimated pollutant loadings and water observed quality data were used to develop methods of identifying pollutant loads that would be consistent with these alternative water quality targets. We have applied a two-pronged approach to the development of these methods based on work previously completed for the Tampa Bay National Estuary Program. The first prong of this approach was to make best use of the relationships observed in the available data to identify statistical relationships between pollutant loads and water quality indicators. The second prong of this approach was to develop a mechanistic (box) model of the estuary which could be used in a predictive mode to examine the response of water quality indicators to various pollutant load reduction scenarios. This report presents the results of both methods of approach.

A principal tenet in the PLRG development process is that to be effectively managed, the receiving water for which PLRGs are being established (estuary, river, or lake) must be examined within the context of its watershed. Watershed-based activities are often the major determinants influencing the environmental condition of a surface water body. This inter-relationship is manifested in the link between pollutant loads that are generated within the watershed and delivered to the receiving water (via streamflow, direct runoff, point source discharges, etc.), and the receiving water's ability to utilize, disperse, or otherwise assimilate these loads. The level of assimilation that is necessary is determined by water quality targets which are based on the environmental requirements of selected critical living resources.

Therefore, the development of PLRGs requires that both the waterbody and its tributary watershed be evaluated. The critical step in this evaluation is to identify major loading sources within the watershed, and to identify the processes and quantify the extent to which these loads can be neutralized within the target waterbody. Ideally, six steps would be taken in the development and implementation of PLRGs:

1) Define target values for water quality indicators based on the environmental requirements of selected critical living resources;

2) Establish allowable loading limits based on a receiving water's ability to assimilate these loads and maintain adequate water quality;

3) Quantify existing stormwater, point source, and other pollutant loadings;

4) Estimate load reductions, if any, that are needed to achieve the water quality targets;

5) Implement watershed management strategies to achieve the load reductions; and

6) Conduct monitoring to assess progress and refine targets if necessary.

For Step 1, alternative water quality targets as discussed above have been identified. Next (Step 2), allowable loading limits must be established, based on each water body's ability to assimilate nutrient loads from the watershed. This entails developing relationships between loadings and water quality in the target water body, as described above. The empirical and mechanistic models presented in this report were developed to complete this step. A thorough nutrient loading analysis (Step 3) comprises the next step, including all major identified sources. The watershed loadings were developed and used as input for the mechanistic model. More detailed results of the loadings analysis are presented under separate cover (Coastal Environmental, 1997). Then, loading rates that result in measured existing water quality conditions will be identified. The following step (Step 4) will be completed by subtracting the existing loading rates from those necessary to achieve the water quality targets. It may be found that no loading reductions are necessary to meet the water quality targets. However, this does not mean that no management actions are needed. Estimates of future loadings will be used to estimate potential affects under future conditions. It is possible that, even if existing condition loadings do not warrant reduction, estimated future loadings may be shown to cause water quality degradation. Step 5 will be accomplished through the development and acceptance of the watershed-specific management strategies. These strategies will include a detailed evaluation of the factors that are required for successful management program implementation. Assessment monitoring (Step 6) will be accomplished either through the continuation of the SWFWMD's existing monitoring program, or through the implementation of a monitoring program specifically intended to assess the level of success of the implemented management actions.

2.0 WATERSHED CHARACTERIZATION

The study area for this project, the lower Peace and Myakka rivers, represents the principal inflows to the Charlotte Harbor Estuary (Figure 2-1). The estuary has a surface area of approximately 270 square miles and an average depth of approximately seven feet, and the ratio of the estuary's watershed area (and estimated freshwater inflow rate) to its volume is relatively large in comparison to other peninsular Florida estuaries. Hence, inputs of nutrients and other chemicals from the Peace and Myakka rivers can exert a significant influence on the estuary.

The Charlotte Harbor watershed in total encompasses over 3,300 square miles, extending northeast to the Chain of Lakes in Polk County and the Highlands Ridge, and northwest to the Manatee River basin in Sarasota County. The major drainage basins that comprise the watershed include the Peace River and Myakka River watersheds, the subject areas for this study.

The geology and hydrogeology of the Charlotte Harbor area and watershed have been investigated and described earlier. Three separate aquifers exist in the harbor area - the surficial aquifer, the intermediate aquifer system, and the deeper Floridan aquifer. Both the intermediate and Floridan aquifers are confined by low-permeability strata. The top of the Floridan aquifer ranges from approximately 200 feet below land surface near the north end of the harbor to more than 400 feet below land surface near Pine Island Sound to the south (Healy, 1974; Jones, 1990). Because of the multiple confining layers above the Floridan aquifer, potential inflow from this aquifer is considered negligible (Bennett, 1994).

The surficial aquifer ranges in thickness from about 25 feet in northern Lee County to 100 feet in northern Charlotte County and southern Sarasota County near the harbor (Camp, Dresser, & McKee, 1994). This unconfined aquifer is comprised mainly of sand, clayey sand, shell, and marl. Fill material, which may contain a higher percentage of organic material, is found in areas of coastal dredge and fill projects. Freshwater inflow rates from the surficial aquifer to the harbor and tributaries vary with aquifer transmissivity and the head difference between the water table (top of the surficial aquifer) and the surface water elevation. This head difference is a function of land surface elevation and tide stage.

Numerous springs are shown on maps of the lower Peace and Myakka drainage areas, but only a few have had or now have sufficient discharge to be of note. In addition, at least one major spring - Kissingen Spring, south of Bartow - ceased to flow in the early 1950s. Little Salt Spring, near the lower Myakka River, currently has negligible flow and historically flowed at a few cubic feet per second (cfs) at best. Warm Mineral Spring, also located near the lower Myakka River, discharges to a pool and then flows two miles to the Myakka River. The average discharge from the spring is approximately 10 cfs.

The intermediate aquifer is comprised of the Hawthorn Layer and the top of the Tampa Limestone unit. This aquifer is also confined but is shallower than the Floridan. The

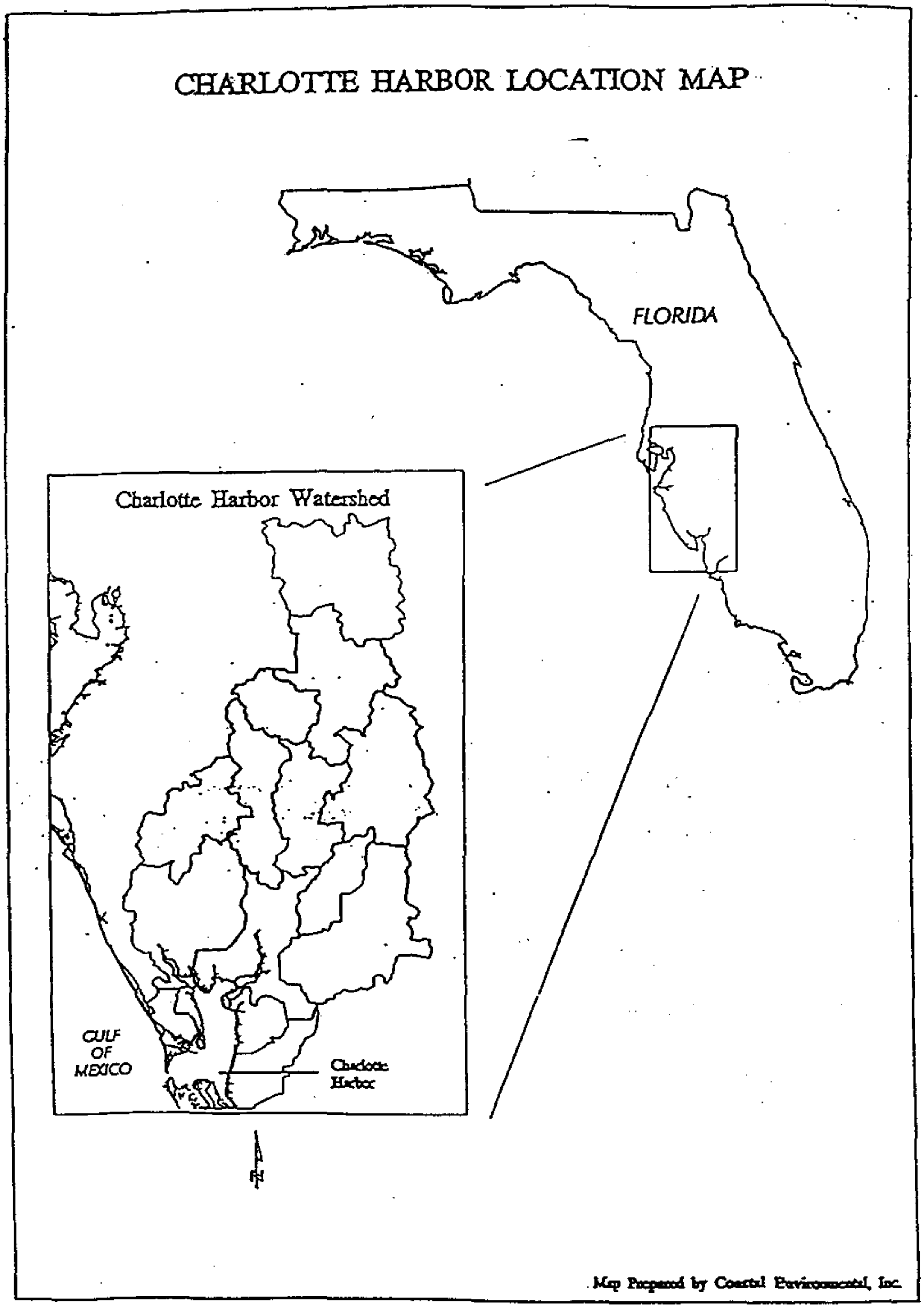

Figure 2-1. **Location of the Charlotte Harbor Estuary and watershed.**

potentiometric surface (pressure head) of the intermediate aquifer reaches an altitude of approximately 30 feet NGVD in coastal portions of the Charlotte Harbor watershed (Sutcliffe, 1975). Because of the high potentiometric surface at the coast and the absence of multiple confining layers, some inflow from this aquifer system to the estuary can be assumed to occur. Freshwater inflows from the intermediate aquifer to the harbor and tributaries vary as a function of aquifer transmissivity and the head difference between the potentiometric surface and the surface water elevation. A review of USGS potentiometric surface maps from water years 1986, 1989, and 1991 indicates that the overall hydraulic gradient of the intermediate and Floridan aquifers has changed very little over this period.

2.1 Peace River and its Watershed

The entire Peace River drainage area includes approximately 2,140 square miles (Figure 2-2). The major tributary streams of the Peace River include Horse Creek, Shell Creek, Joshua Creek, Payne Creek, and Charlie Creek.

Flow in the Peace River has been influenced by a variety of factors including meteorological patterns, groundwater conditions, land use activities, and water use needs. The Peace River is a free-flowing river over its entire reach. Two of its tributaries, however, have regulated flow, including a control structure (P-11) in its headwaters on Saddle Creek south of Lake Hancock, and a dam at the City of Punta Gorda's water supply reservoir on Shell Creek. In addition, water withdrawals are made from the river at the Peace River/Manasota Water Supply Authority water plant south of Arcadia.

Special designations for portions of the Peace River basin include Outstanding Florida Water within Highlands Hammock State Park (on the extreme eastern edge of the watershed northeast of Arcadia) and Class I waters (potable) for a portion of Horse Creek near its confluence with the Peace River. Although at least one spring (Kissingen Spring) historically discharged in the upper Peace River basin, no significant spring discharges now occur. Springs near Zolfo Springs currently flow, but discharges are very small.

Agricultural land and open land, mainly rangeland, dominate much of the Peace River watershed, accounting for more than 50% of the total land cover (Table 2-1). Water bodies and wetlands are relatively evenly distributed throughout the watershed, mainly near the river and its tributaries. The urban centers in the Peace River watershed include the cities of Lakeland, Winter Haven, and Bartow to the north, the smaller towns of Ft. Meade, Zolfo Springs, Wauchula, and Arcadia along the Peace River, and a portion of Avon Park to the east.

Phosphate mining activities within the Charlotte Harbor watershed have historically been confined almost exclusively to the northwest portion of the Peace River headwaters, and in the Payne Creek, McCullough Creek, and Whidden Creek basins. However, mining interests are currently exploring more southern portions of the watershed for future operations. At this time, areas

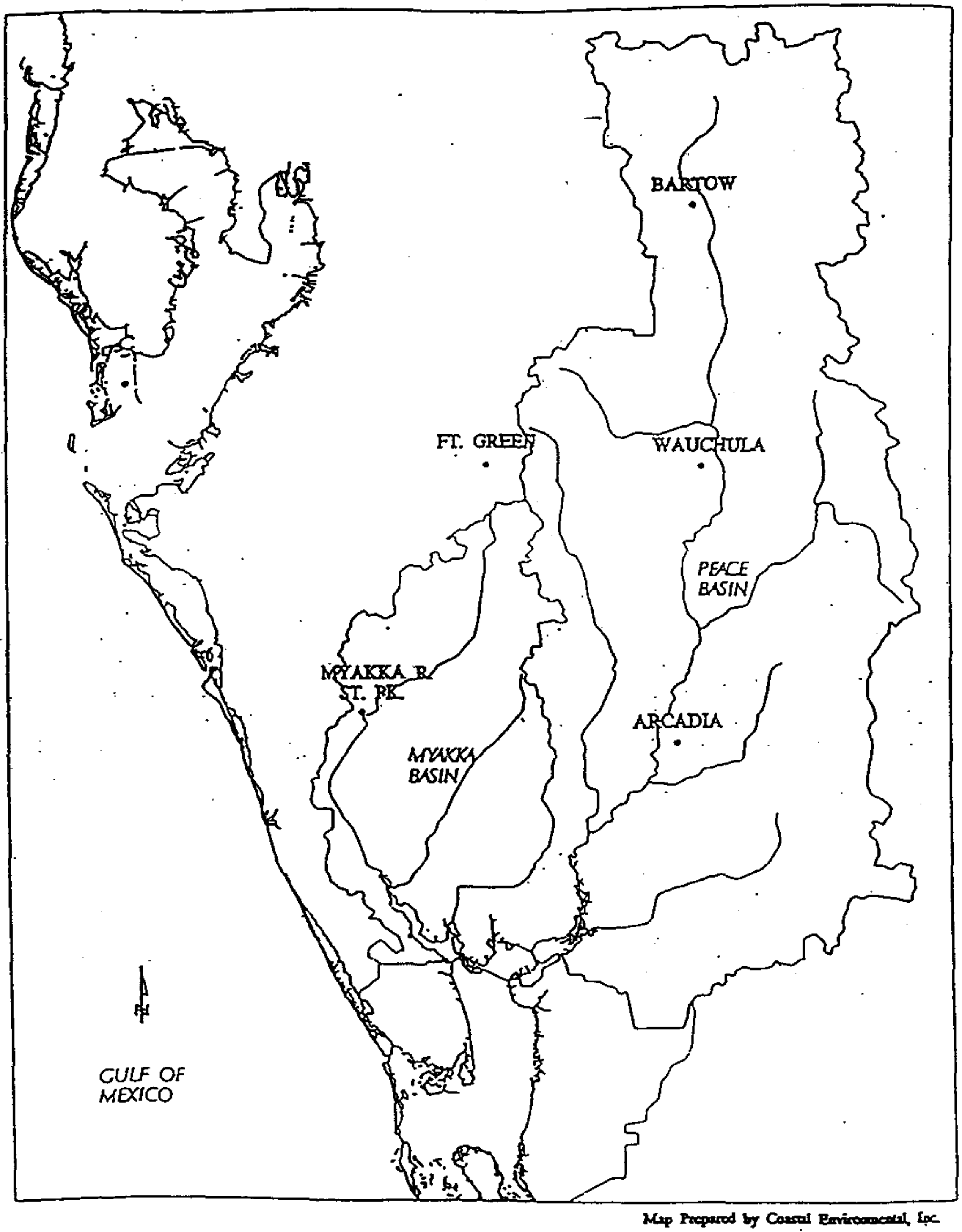

Figure 2-2. **Peace River and Myakka River watersheds.**

within the Peace River and Myakka River basins that are proposed for phosphate mining in the future include the IMC-Agrico Fort Green Extension tract, in the upper Horse Creek basin. CF Industries has built a beneficiation plant on their Hardee Complex II tract, along the western Polk-Hardee county line. Other land holdings in the watershed that have not yet been mined include the CMI DeSoto County tract, which has had its Development of Regional Impact application withdrawn; Nu-Gulf Industries, which is currently not in operation; and several parcels owned by Texaco in Hardee County and southern Polk County.

Table 2-1. Land Use Summaries for Tidal Peace and Myakka River Watersheds.

Land Use Type	Tidal Peace River (acres)	Tidal Myakka River (acres)
Single family residential	26,182	8,282
Medium density residential	49,950	2,357
Multi-family residential	6,691	1,465
Commercial	11,579	287
Industrial	3,600	71
Mining	49,611	737
Institutional	11,743	2,161
Non-forested open land	183,429	105,716
Barren land	1,848	878
Pasture	431,894	83,252
Citrus groves	181,828	3,673
Feet lot/dairy	367	287
Nursery	1,096	165
Row crop	2,493	7,886
Upland Forest	138,012	72,450
Fresh water	43,396	5,534
Salt water	483	5,461
Forested FW wetland	127,681	34,082
Salt water wetland	7,030	2,206
Non-forested FW wetland	90,418	43,867
Tidal flat	351	31
TOTAL	1,369,682	380,850

2.2 Myakka River and its Watershed

The Myakka River drainage area includes approximately 595 square miles (Figure 2-2). The USGS stream gage near Sarasota defines the most downstream extent of the gaged watershed. Major tributaries of the Myakka River include Deer Prairie Slough and Big Slough Canal (Myakkahatchee Creek).

Remnants of two streamflow control structures exist on the Myakka River and affect its morphology. In 1941, a levee was constructed at the upper lake outfall to divert water away from adjacent low-lying pastureland and to retain water in the lake during droughts (Flippo et al., 1968). Although a control weir was included in that levee, it is no longer operated and remains open. However, it is estimated that the levee impedes flow in the river sufficiently to keep the water level of Upper Myakka Lake one to two feet higher than prior to levee construction. The south structure remnant is a dam or levee that was constructed to stabilize the water level in Lower Lake Myakka. Although only traces of this levee remain, it still impedes flow to a small degree.

The Myakka River upstream of the Sarasota/Manatee county line has been designated a Class III water (suitable for recreation). The reach of the river from the county line south to the City of North Port is designated a Class I water, Wild and Scenic River and Outstanding Florida Waters. From North Port to Charlotte Harbor, the river has been designated a Class II water (suitable for shellfish propagation or harvesting) (Hart, 1993). Big Slough is classified as Class I, and is the major potable water supply for the City of North Port.

Two springs, Warm Mineral Springs and Little Salt Springs, have been identified in the lower Myakka River basin. Little Salt Springs currently generates little if any flow. Warm Mineral Springs discharges through a tributary to the Myakka River. The discharge water is very saline and results from artesian flow from the Floridan aquifer (Hart, 1993).

The Myakka River watershed is less developed than the Peace River watershed (Table 2-1). Only approximately 5% of the Myakka watershed is urbanized, while about 25% is characterized by agricultural land uses. Non-forested open land (28%) and upland forest (19%) are the other major land cover types in the Myakka River watershed.

2.3 Historical Charlotte Harbor Water Quality Trends

The characterization of water quality conditions in Charlotte Harbor has not benefited from a unified comprehensive long-term monitoring program. Instead, a description of water quality conditions must be pieced together from data provided by a variety of monitoring programs, each of which has had different objectives, covered different geographic regions, utilized different methods, and measured different parameters.

Existing water quality data have been reviewed by the SWFWMD (Coastal Environmental, Inc., 1993). Priority for this review was placed on long-term data sets that could potentially be used for trend analyses. The information compiled in this project provided a basis for identifying pertinent data available in the lower Peace and Myakka rivers. Except for data available from STORET, most of the early data collections (1949-1975) are not available in a digital format. Most data collected after 1975 are available in computerized formats. Generally speaking, the earlier studies did not follow standard QA/QC protocols and their collection periods were usually of short duration. After 1975, some of the more useful and available data collection programs were initiated in the region.

An example of one of the more extensive of such investigations was the study for which data were collected over 10 months in 1976 by the Ecological Services of Texas Instruments, Inc., for Florida Power & Light. During this study, both physical and chemical measurements were conducted at a number of stations in the Peace River and Upper Charlotte Harbor. The extensive parameter list included typically measured minerals and nutrients, common trace metals and selected pesticides.

The establishment of the EQL in the early 1970s brought a number of long-term water quality monitoring programs to the harbor. Locations of fixed sampling stations utilized by the EQL may be found in EQL (1986). The EQL collected a data set between 1976 and 1990 for General Development Corp. Sampling stations were located along the lower Peace River downstream of Horse Creek and within areas of Upper Charlotte Harbor, including stations near the U.S. 41 bridge crossing of the Peace River at Punta Gorda and the S.R. 756 bridge over the Myakka River at El Jobean. Additional data have been collected on an extended basis at these two latter locations in additional studies, listed below.

1) The Myakka bridge location has been sampled between 1980 and 1997 as a background condition under permit conditions for the South Gulf Cove Development's interceptor lagoon.

2) The U.S. 41 Peace River Bridge location has also been sampled between 1980 and 1997 as a background condition for the Manchester Waterway Lock System permit.

3) Both of these sites have been sampled monthly (1993-1997) as part of the SWFWMD Charlotte Harbor monitoring efforts.

Most of these programs were related to permitting requirements by the State of Florida, the U.S. Army Corps of Engineers, and the SWFWMD. With the creation of the SWFWMD SWIM Program, greater attention has been focused on the importance of collecting comprehensive water quality data from the Charlotte Harbor system. The SWFWMD SWIM began implementing this effort by initiating a monthly water quality sampling program in January of 1993. It has also funded the design of a long-term water quality monitoring program (Coastal Environmental, Inc., 1995a) intended to be adopted by local governments that would benefit from assuring that Charlotte Harbor water quality is maintained or improved in the future. Figure 2-3 presents the distributions of the SWFWMD water quality sampling stations located within the tidal Peace and Myakka rivers and those in Charlotte Harbor proper.

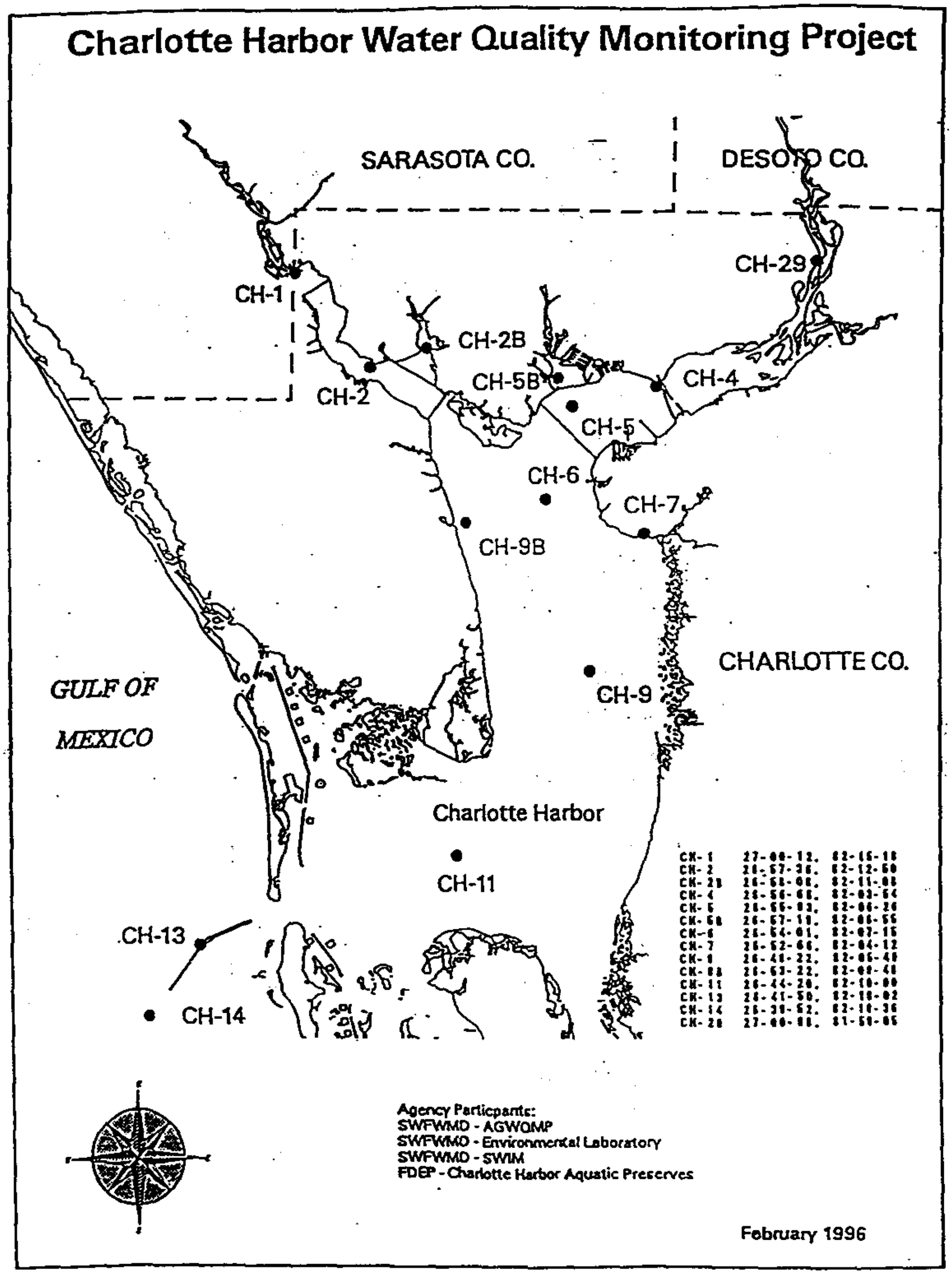

Figure 2-3. Locations of SWFWMD water quality sampling stations in the Charlotte Harbor Estuary.

In a subsequent report to the SWFWMD (Coastal Environmental, Inc., 1994a), several data sets were used to characterize water quality conditions in Charlotte Harbor; however, long-term comparisons among harbor segments were difficult due to the wide variety of sampling programs and methods used. The most appropriate data were compiled for gross regional comparisons. Tables 2-2 and 2-3 present long-term (1976-1993) and existing (1993) water quality conditions in the lower Peace and lower Myakka rivers. In these two regions the following ranges of average annual values were observed: Secchi disc depth —1.04-1.22 m; TN concentrations — 0.97-1.07 mg l^{-1}; TP concentrations — 0.24-0.29 mg l^{-1}; and chlorophyll-a — 15.7-17.5 µg l^{-1}. TP concentrations were about 25% lower in the lower Peace during 1993 than in the earlier years. This may be due to the decline in the phosphate industry during the 1980s relative to previous years. Trophic State Index (TSI) values for the two regions reflect a greater degree of eutrophy in the tidal Peace and Myakka river segments than in the lower portions of the harbor. Also, the 1993 TSI values are somewhat greater than during the earlier years examined.

In order to evaluate long-term differences in water quality near the mouths of the Myakka and Peace rivers, data from all of these studies at those stations near the U.S. 41 bridge crossing of the Peace River at Punta Gorda and the S.R. 756 bridge over the Myakka River were combined for analyses. There is some need for care in grouping such long-term data, since detection limits and methods can vary. However, the influences of such problems are reduced as all but the first few years of SWIM data were analyzed by EQL, in addition to that data collected by EQL.

Box and whisker plots indicating differences between measured forms of nitrogen, phosphorus, chlorophyll-a, and coliform bacteria at the mouths of the two rivers in the upper estuary are presented in Figure 2-4. In order to evaluate possible changes within the combined sampling records of these monitoring programs, similar plots covering five sequential four-year periods are shown in Figure 2-5 for each river for the two most common forms of inorganic nitrogen, total phosphorus, and chlorophyll-a. Table 2-4 provides further summaries of mean, minimum and maximum concentrations of these four water quality characteristics by river and time period.

The mean water quality conditions in both lower river regions have shown considerable seasonal variability (Coastal Environmental, Inc., 1994a). In 1993, both regions experienced phytoplankton blooms during the summer to early fall months. Chlorophyll-a values in the lower Peace River reached nearly 100 μg l^{-1}, while those in the lower Myakka River were as high as 120 µg l^{-1}. Records show that during the last 10-15 years these two regions have periodically experienced high phytoplankton biomass conditions during the warmer months.

It should be recognized that although the mean water quality concentrations are very similar in the lower reaches of these two tributaries, the impacts to the harbor are not similar due to the greater flow from the Peace River. Based on estimates from empirical data reported in Coastal Environmental, Inc. (1994a), mean monthly nitrogen loadings from the Peace River relative to the Myakka River are about four times greater during the wet season and nearly five times greater during the dry season.

Table 2-2. Mean water quality values, nutrient ratios, and mean TSI values calculated from Combined Data Set (1976-1993) (from Coastal, 1994).

TSI Estuary 0-49=Good 50-59=Fair 60-100=Poor

SEGMENT	Secchi Disk Depth (m)	SD_{TSI}	Total Nitrogen (mg/L)	TN_{TSI}	Total Phosphorus (mg/L)	TP_{TSI}	Chlorophyll a (µg/L)	CHL_{TSI}	TN/TP Ratio	Mean TSI
Lower Myakka	1.1	57.7	0.93	54.6	0.28	86.4	13.0	53.7	3.32	55.3
Lower Peace	1.1	57.1	0.91	54.1	0.38	92.1	15.7	56.5	2.39	55.9
Upper Harbor	1.6	45.9	0.82	52.1	0.27	85.7	11.2	51.6	3.04	49.8
Middle Harbor	2.4	34.1	0.74	50.0	0.20	80.1	5.5	41.3	3.70	41.8
Lower Harbor	2.1	37.7	0.57	44.9	0.12	70.6	3.1	33.1	4.75	38.6

Table 2-3. Mean water quality values, nutrient ratios, and mean TSI values calculated from SWFWMD data collected monthly in Charlotte Harbor during 1993 (from Coastal, 1994).

TSI Estuary 0-49=Good 50-59=Fair 60-100=Poor

SEGMENT	Secchi Disk Depth (m)	SD_{TSI}	Total Nitrogen (mg/L)	TN_{TSI}	Total Phosphorus (mg/L)	TP_{TSI}	Chlorophyll a (µg/L)	CHL_{TSI}	TN/TP Ratio	Mean TSI
Lower Myakka	1.04	59.1	1.07	57.1	0.24	83.5	15.7	56.2	4.5	57.5
Lower Peace	1.22	54.4	0.97	55.2	0.29	86.6	17.5	57.6	3.4	55.7
Upper Harbor	1.58	46.7	0.77	50.7	0.18	77.7	6.4	43.4	4.4	46.9
Middle Harbor	2.76	29.5	0.60	45.9	0.11	69.0	3.8	36.0	5.5	37.2
Lower Harbor	2.16	36.9	0.40	37.9	0.10	67.3	3.6	35.2	4.0	36.7

The analyses of the data from stations near the mouths of the rivers support other findings of declining phosphorus concentrations in the Peace River and possible increasing inorganic nitrogen levels. However, there is no direct evidence as to how such concentrations may compare to ambient levels prior to the late 1970s. Estimated changes in land use (see Appendix B of Coastal Environmental, Inc., 1995b) indicate very significant increases in residential, commercial, industrial, and mining through the Charlotte Harbor Estuary's watershed between 1950 and 1990. Such changes, as well as subsequent environmental regulations reducing point source discharges, may have resulted in changes in the water quality of freshwater inflows into the estuary. However, there is no hard evidence to support or disprove such conjectures. Such theoretical extensions into the historic past become increasingly more problematic.

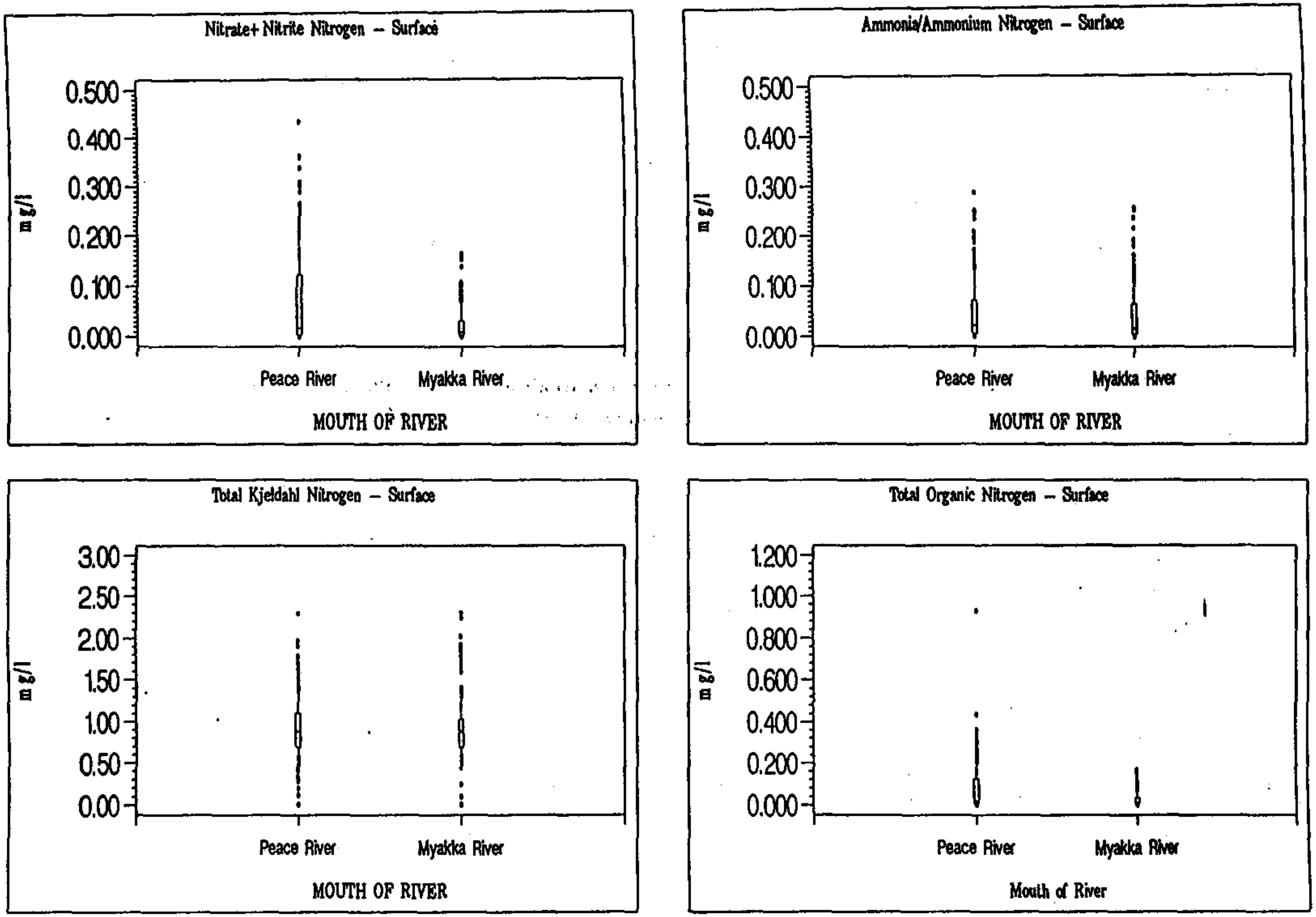

Figure 2-4. Box and whisker plots of water quality parameters from stations near the mouths of the Peace and Myakka rivers - all data.

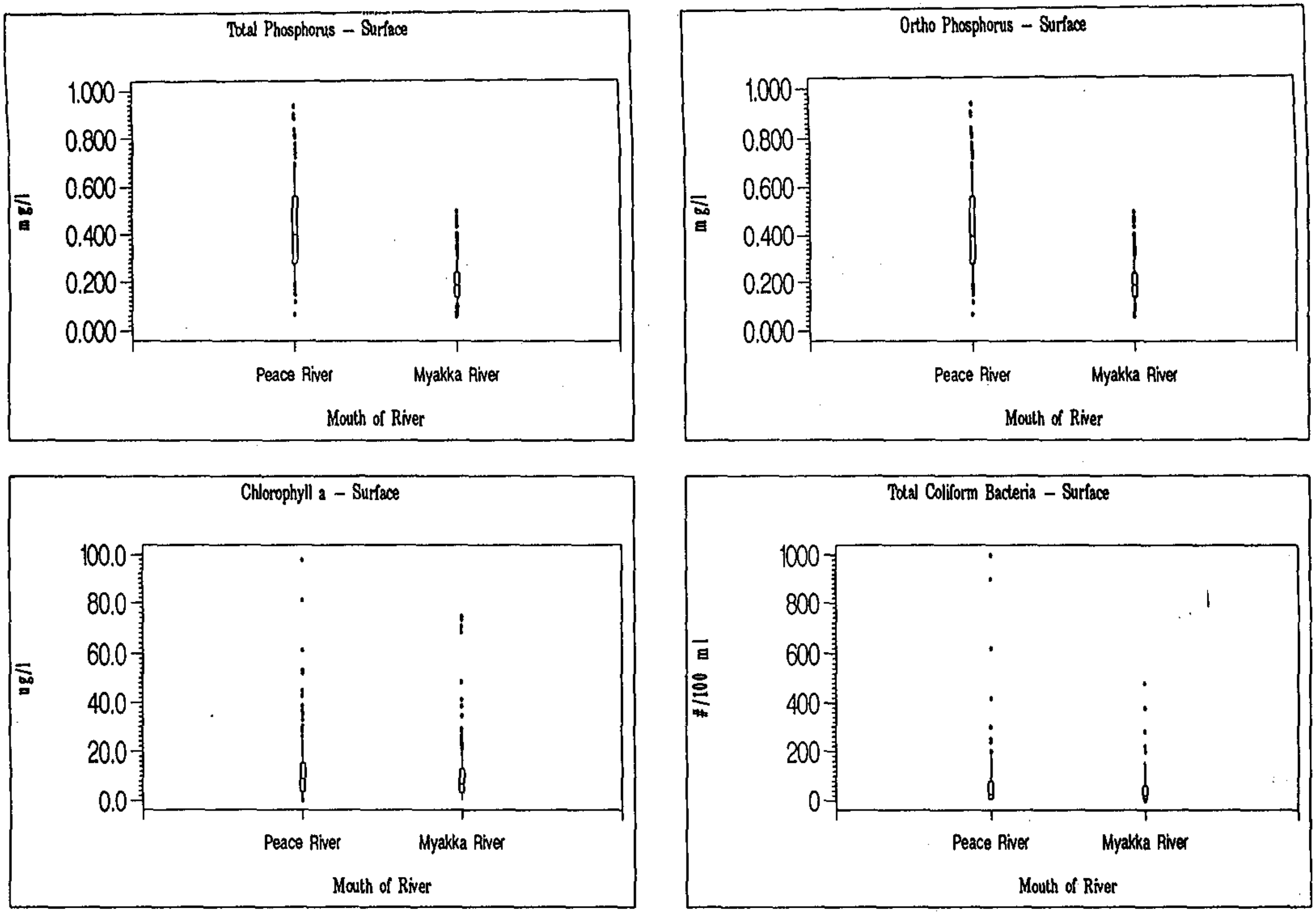

Figure 2-4(cont). **Box and whisker plots of water quality parameters from stations near the mouths of the Peace and Myakka rivers - all data.**

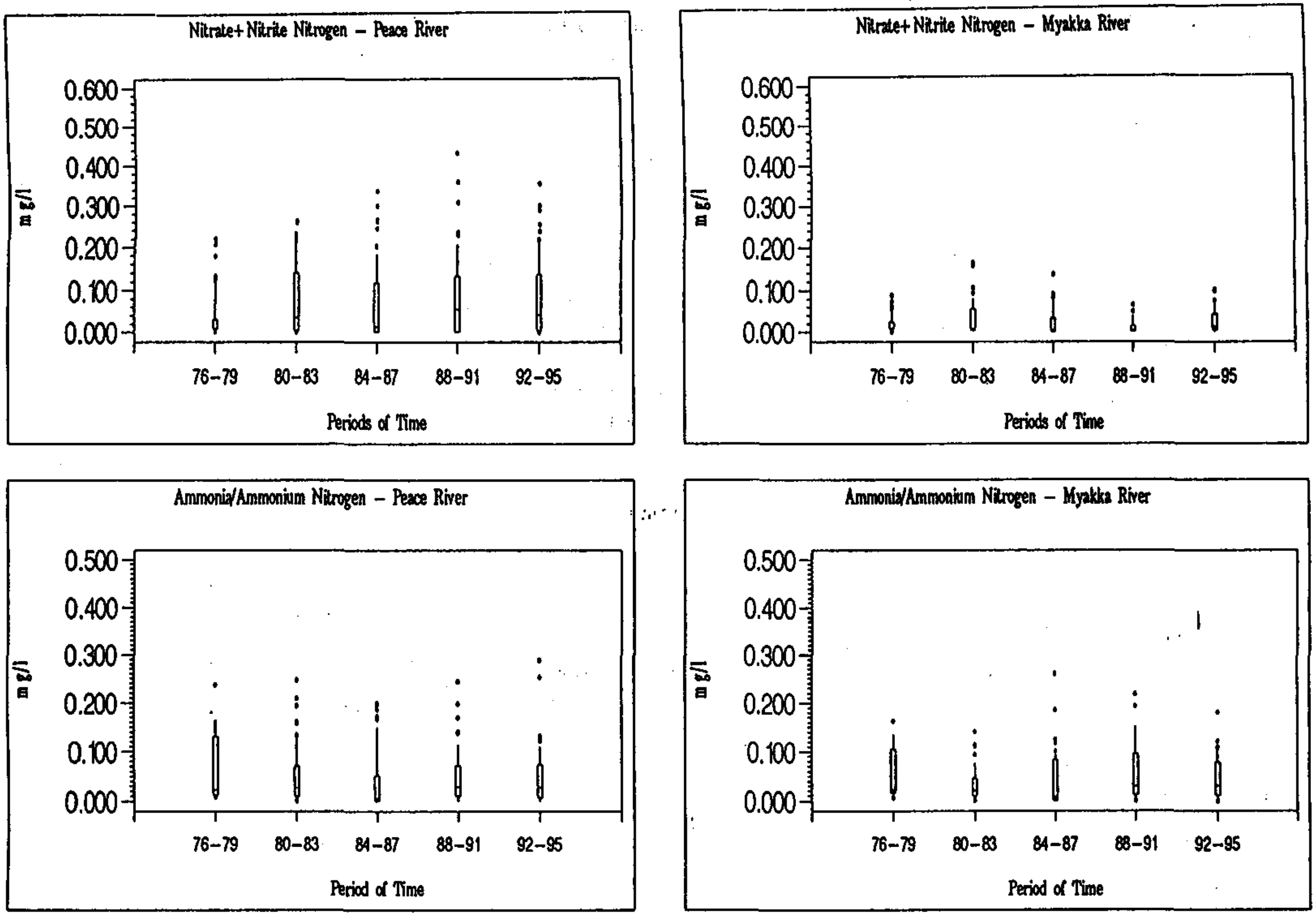

Figure 2-5. Box and whisker plots of water quality parameters from stations near the mouths of the Peace and Myakka rivers - four-year periods.

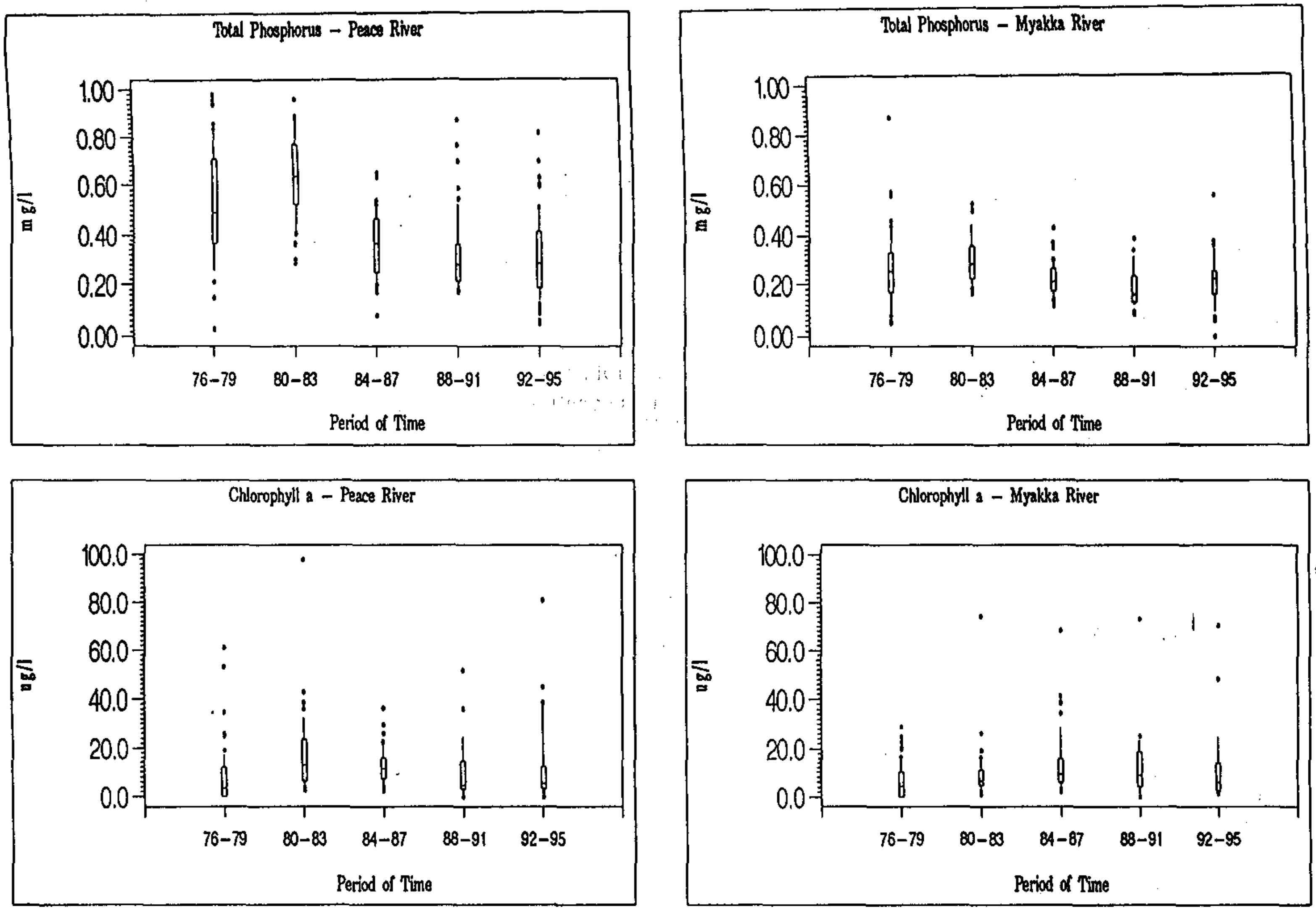

Figure 2-5(cont). Box and whisker plots of water quality parameters from stations near the mouths of the Peace and Myakka rivers - four-year periods.

Table 2-4. Water quality characteristics near the mouths of the Peace and Myakka rivers.

Nitrite/Nitrate (mg/l)

Location	Group	N Obs	Mean	Std Dev	Minimum	Maximum
Peace River	76-79	69	0.034	0.050	0.002	0.220
	80-83	64	0.076	0.085	0.001	0.265
	84-87	65	0.066	0.089	0.001	0.339
	88-91	55	0.179	0.600	0.001	4.410
	92-95	64	0.080	0.091	0.000	0.359
Myakka River	76-79	68	0.020	0.020	0.001	0.090
	80-83	47	0.031	0.040	0.001	0.165
	84-87	48	0.022	0.034	0.001	0.138
	88-91	25	0.211	0.735	0.001	3.390
	92-95	35	0.026	0.029	0.000	0.103

Ammonia/Ammonium (mg/l)

Location	Group	N Obs	Mean	Std Dev	Minimum	Maximum
Peace River	76-79	69	0.063	0.071	0.009	0.237
	80-83	64	0.050	0.056	0.001	0.247
	84-87	65	0.040	0.060	0.001	0.200
	88-91	55	0.049	0.054	0.001	0.244
	92-95	64	0.048	0.057	0.000	0.289
Myakka River	76-79	68	0.057	0.053	0.007	0.163
	80-83	47	0.033	0.033	0.001	0.141
	84-87	48	0.041	0.056	0.001	0.260
	88-91	25	0.061	0.064	0.001	0.219
	92-95	35	0.046	0.044	0.000	0.181

Table 2-4 (cont). **Water quality characteristics near the mouths of the Peace and Myakka rivers.**

Total Phosphorus (mg/l)

Location	Group	N Obs	Mean	Std Dev	Minimum	Maximum
Peace River	76-79	69	0.558	0.274	0.030	1.710
	80-83	64	0.663	0.181	0.290	1.110
	84-87	65	0.368	0.129	0.080	0.654
	88-91	55	0.323	0.150	0.173	0.873
	92-95	64	0.315	0.160	0.049	0.820
Myakka River	76-79	68	0.266	0.143	0.050	0.875
	80-83	47	0.298	0.091	0.164	0.527
	84-87	48	0.225	0.066	0.120	0.434
	88-91	25	0.190	0.081	0.086	0.393
	92-95	35	0.221	0.106	0.001	0.566

Chlorophyll a (µg/l)

Location	Group	N Obs	Mean	Std Dev	Minimum	Maximum
Peace River	76-79	69	12.01	26.33	0.100	182.000
	80-83	64	16.91	15.83	2.850	98.000
	84-87	65	18.47	29.91	2.450	173.000
	88-91	55	10.27	12.38	0.100	52.000
	92-95	64	12.19	16.55	0.058	81.080
Myakka River	76-79	68	6.028	6.982	0.100	29.100
	80-83	47	9.496	10.95	1.260	74.500
	84-87	48	12.98	12.17	2.220	68.500
	88-91	25	17.38	26.08	0.100	120.564
	92-95	35	12.55	17.23	1.480	70.710

3.0 POTENTIAL FOR IMPAIRED USES

Setting pollutant load reduction goals (PLRGs) is an important step in developing feasible and effective management plans for the lower Peace and Myakka rivers and Upper Charlotte Harbor. PLRGs should be based on estimating the maximum level of pollutant loading that can be assimilated by the system without resulting in unacceptable degradation of resources within the estuarine system. If the maximum "acceptable" loading level is exceeded, then the potential exists for the development of conditions under which selective uses of the harbor's living resources could be impaired.

There are several resources of concern whose uses may either be currently impaired, or may well become so in the future in the absence of appropriate resource management. The threat of potential future impacts to living resources should be as important a motivation to implementing management activities as existing impacts. Two examples of existing resources within the upper estuary which may be at risk due to the potential for future increased nutrient loadings are noted.

Low oxygen, or hypoxic, conditions often occur in the lower Peace River and Upper Charlotte Harbor, especially during summer months. Research is currently (1997) ongoing to identify and quantify the relative significance of potential natural and anthropogenic causes of hypoxia. Hypoxia may result from the combined influences of both natural high wet-season rainfall resulting in water column stratification during periods of elevated water temperatures, and anthropogenic influences, such as nutrient and/or biochemical oxygen demand (BOD) loadings. Setting PLRGs to minimize the duration, extent, and severity of hypoxia in the tidal rivers/Upper Harbor could contribute to reducing the extent and magnitude of disruptions in the occurrence and distributions of natural communities which currently seem to be influenced by such hypoxic conditions.

Water quality monitoring has shown that the tidal Peace River contains elevated concentrations of nitrogen with respect to median stream concentrations state-wide. A significant fraction of the nitrogen is in a readily-available form, dissolved inorganic nitrogen (DIN). High nitrogen availability can contribute to widespread algae blooms, which can result in reduced night time dissolved oxygen concentrations, and cause secondary alterations in the taxonomic structure of aquatic communities. Establishing nutrient loading PLRGs which seek as their goal to reduce or limit the future areal extent, frequency, and duration of algal blooms could result in a reduction of such potential impacts

There are also currently at least two impaired uses of resources in the tidally-influenced river/Upper Harbor system associated with poor water quality. Addressing the problems causing these impairments is beyond the scope of this project, but the problems are of sufficient importance to note.

The first impaired use is the reduction of the ability of the Peace River/Manasota Regional Water Supply Authority to take permitted quantities of freshwater for potable use due to excessive blue-green algae blooms within the Peace River upstream of their intake structure. The interactions between extended periods of high and low river flow, and nutrient concentrations which result in such excessive algae blooms, are currently not known, and are currently being studied. However, nutrient inputs from the upper watershed are thought to potentially play a significant role.

Another impaired use involves the closure of shellfish beds for harvesting. Much of the submerged lands of the tidal Myakka River and Upper Charlotte Harbor are designated Class II waters in Chapter 62-302, Florida Administrative Code (FAC). Class II waters include all of Charlotte Harbor and Gasparilla Sound proper, and the tidal Myakka River. Class II waters have a designated use of being suitable for shellfish harvesting for human consumption. High bacteria counts are often reported in the tidal Myakka River and Upper Charlotte Harbor by FDEP, resulting in frequent closure of the shellfish beds in these areas. Exceedence of Class II criteria for fecal coliform and total coliform bacteria may result from a variety of causes, including stormwater runoff; infiltration of inadequately treated septic tank leachate from improperly located, constructed, or maintained septic tanks; or spills of untreated wastewater from treatment plants. Setting PLRGs for bacteria is difficult because specific loading sources are often unknown or infrequent. However, establishment of goals related to reducing the areal extent and frequency of shellfish bed closing could result in changes in management practices relating to known causes.

The implementation of PLRGs could aid in controlling current and potential future nutrient loadings and contribute to reducing the level of impairment of living resources of the tidal Peace River, tidal Myakka River, and Upper Charlotte Harbor.

4.0 DIAGNOSTIC WATERSHED STUDY

The purpose of the SWIM-funded watershed diagnostic assessment project (Coastal Environmental, Inc., 1995a) was to identify and inventory potential sources of pollution within the watershed, to estimate existing conditions and projected future conditions pollutant loading to the watershed, and to prioritize sections of the watershed that have the greatest potential for negatively impacting the harbor system.

The delivery of excess nutrients (nitrogen and phosphorus) may cause eutrophication in the estuary and affect desirable living resources, as discussed previously; therefore, nitrogen and phosphorus loadings were investigated. Inputs of suspended solids can increase turbidity in a surface water body, and can carry toxic contaminants from the watershed to the estuary. Thus, total suspended solids loadings were also evaluated.

Identified major sources of nutrient and solids loadings included nonpoint sources, domestic and industrial point sources, atmospheric deposition, and groundwater and springs. The potential for loadings from septic systems (on-site wastewater treatment systems - OWTS) in the coastal area was also evaluated. Pollutant loadings were estimated for current (1985-91) and projected future (circa 2010) conditions. Freshwater inflows were estimated for historical (circa 1948-55), current, and projected future conditions. Measured environmental data, including rainfall, streamflow, and groundwater quantity and quality, as well as quantity and quality of reported point source discharges, were used to the greatest extent feasible in this evaluation. In situations where measured data did not exist or their use was not recommended, modeling techniques were used to estimate pollutant loadings and freshwater inflows.

Results of the existing condition (1985-91) analysis suggest that nonpoint source inputs are the largest source of pollutant loadings to the estuary. Approximately 67% of the TN loads, 41% of the TP loads, and 90% of the TSS loads were estimated to be delivered to the estuary via streamflow and direct runoff. Of the nonpoint source loadings, an estimated 1,800 tons/year of TN, 600 tons/year of TP, and 15,000 tons/year of TSS are delivered to Charlotte Harbor from the Peace River.

Atmospheric deposition was the second most significant source of nutrients to Charlotte Harbor, contributing approximately 20% and 39% of the TN and TP loads, respectively. Point sources contributed almost 10% of the TN load, 19% of the TP load, and 10% of the TSS load. Current conditions loadings for groundwater and OWTS were small - only a few percent.

For future conditions, nonpoint source loadings are projected to remain the largest loading source of all three constituents. The most substantial change in the relative importance of future loadings was estimated to be for OWTS, which were projected to increase in relative contribution. Future OWTS loadings were estimated assuming that no large-scale increases to central sewer service would occur by the year 2010. If central sewer were to be significantly expanded, then the projected future OWTS load would drop.

A trend analysis investigating freshwater inflows to the estuary was completed. Previous documentation indicates that streamflow in the Peace River has declined significantly over the past 50 years (e.g. Hammett, 1988). Various hypotheses exist as to the cause of this decline. One of the more widely-voiced theories is that a deficit in rainfall over the Peace River basin has caused the decreased flows. Using statistical methods, it was determined that a rainfall deficit does exist in the Peace River basin, but that lower rainfall amounts do not alone account for the total decline in streamflow of the Peace River. Additional factors contributing to declining flow may include reduced groundwater discharge to the river caused by lower potentiometric surface levels, increases in surface water withdrawals from the river, or a decline in the amount of stormwater runoff that reaches the river. It was recommended that additional investigations be undertaken to evaluate the relative importance of various factors that may influence the Peace River's flow patterns.

4.1 Empirical Approach To PLRG Development

The empirical management tools for establishing PLRGs must be developed and used within the constraints of multi-use/multi-objective watershed management. A guiding tenet of the empirical PLRG development process is that to be effectively managed, the receiving water body for which PLRGs are being established must be considered within the context of its watershed. Watershed-based activities are often the major determinants influencing the environmental condition of a surface water body. This interrelationship is manifested in the link between pollutant loads that are generated within the watershed and delivered to the receiving water (via streamflow, direct runoff, point source discharges, etc.) and the receiving water's ability to utilize, disperse, or otherwise assimilate these loads. The level of assimilation that is necessary to maintain desirable ambient conditions is determined by water quality targets which are based on the environmental requirements of selected critical living resources.

Therefore, the development of an empirically-based PLRGs requires that both the waterbody, and its tributary watershed, be evaluated. Under this approach, the **net** water quality response in the lower portions of the rivers to **external** load sources from the watershed is the focus.

4.1.1 General Empirical Approach

For the empirical approach, we used measured data to describe observed relationships between external nitrogen loads and water quality without regard to the internal processes which affect the response (e.g., loss of nutrients to sediments, internal load sources, internal cycling, temperature, etc...). The variation in these relationships due to the factors listed above and others was reported with the empirical regression results. Under any given nutrient load, this variation represents the range of water quality conditions to which the biota in the rivers will likely be exposed. In a certain (pragmatic) sense, the only important explanatory variable in the empirical relationships is the one that can be managed, the external nutrient loads.

The advantages of the empirical approach include:

- It provides a simple, statistically-based explanation of the observed data.
- It does not require important assumptions to be made regarding internal processes.
- It is robust to prediction errors.

The disadvantages of using an empirical approach include:

- It is subject to potential prediction errors caused by autocorrelation of the independent variables. For example, if nitrogen load and chlorophyll-a concentration were affected by a third seasonally varying parameter and were not directly related to each other, then one might still observe a clear pattern between nitrogen load and chlorophyll-a in monthly data and falsely conclude that chlorophyll-a varied as a response to nitrogen loads.

  This disadvantage was addressed in the empirical analyses by removing the potential for seasonal effects by using annual average data for the regressions used to develop the management tools.

- It provides predictions limited to the range of observed data. Predictions beyond the range of the observed data must be extrapolated based on the regression models.

  Fortunately, the range of the observed nutrient load and water quality response data varied widely, and enveloped the range of values which would likely be selected for PLRG targets.

Relationships Investigated in the Observed Data

Several water quality variables measured by the EQL and the SWFWMD SWIM were considered appropriate as potential living-resource water quality targets and/or indicators of eutrophic conditions in the tidally influenced river reaches. These parameters included TN, TP, TN:TP ratio, chlorophyll-a, and photosynthetic compensation depth (operationally defined as depth of 1% surface light).

The water quality-related parameters were chosen for analyses since they can be tied to State water quality standards applicable to tidal Myakka River (Class II waterbody, and OFW) and the tidal Peace River (Class III waterbody).

- For nutrients in both Class II and III waterbodies, State water quality criteria state that "... In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna."

  Changes in TN, TP, and/or TN:TP ratio thus represent ambient nutrient concentrations and could be directly tied to this State water quality criterion. Furthermore, since chlorophyll-a is a measure of phytoplankton biomass, it is a measure of a natural population of aquatic flora and can be tied to this nutrient criterion.

- For transparency in both Class II and Class III waterbodies, State water quality criteria state that "... the depth of the compensation point for photosynthetic activity shall not be reduced by more than 10% as compared to natural background value."

  Compensation depth can be operationally defined as the depth of 1% surface light, and thus a change by more than 10% would be a violation of State water quality standards for water transparency.

In order to meet the objectives of this project, two types of nutrient load-to-water quality relationships were investigated. The first type was a two-step relationship of external nutrient loads from the watershed to chlorophyll concentrations in the lower portions of the rivers, and chlorophyll concentrations to light penetration. The second type was the relationship of external nutrient loads from the watershed to total nitrogen/total phosphorous ratios in the receiving waters.

In order to provide a focus for the investigation of these two types of relationships, specific functions were defined for the empirical management tools:

- to predict chlorophyll-a concentrations given an external nitrogen load quantity,
- to predict water column light attenuation given a chlorophyll-a concentration, and
- to predict the total nitrogen:total phosphorous concentration given an external nitrogen load and external phosphorous load.

4.1.2 Acquisition, Compilation, and Review of Data

Data were acquired from three sources: the USGS, the EQL, and the SWFWMD SWIM Department.

USGS

Monthly USGS data acquired were from gages in the Charlotte Harbor watershed for flow and water quality (as available). The gages and the period of record of data compiled is presented in Table 4-1.

Table 4-1. USGS gaging stations and the period of record of monthly data compiled.

Gage Number	Gage Name	Data Record Retrieved
02296750	Peace River Arcadia	1970 - 95
02298830	Myakka River nr Sarasota	1970 - 95
02297310	Horse Creek	1970 - 95
02295637	Peace River Zolfo Springs	1970 - 95
02294898	Peace River Ft. Meade	1974 - 95
02294650	Peace River Bartow	1970 - 95
02298202	Shell Creek nr Punta Gorda	1965 - 87

Shell Creek flow data after September 1987 were obtained from Mr. Sid Flannery of the SWFWMD. Mr. Flannery calculated Shell Creek flows after September 1987 using the 1987 USGS rating table that provides flow estimates from USGS gage height measurements at the fixed crest weir (dam) at Shell Creek.

Environmental Quality Laboratory (EQL)

The EQL in Port Charlotte, Florida, has been collecting water quality data from Charlotte Harbor since the mid-1970s. Two long-term data sets were obtained from the EQL in November 1994. One data set contained monthly water quality data from 1976-1990 from an array of fixed station locations throughout the Charlotte Harbor system. The other data set contained monthly water quality data (1983-94) from four stations along the axis of the Peace River at predetermined salinities. Salinity-based stations 1, 2, 3, and 4, had salinities of 0, 6, 12, and 20 ppt, respectively. Water quality parameters measured by the EQL for these programs are listed below.

We also obtained monthly water quality data from 1991-95 collected by the EQL from Shell Creek. Water quality data (TN [total Kjeldahl nitrogen + nitrite+nitrate nitrogen], TP, and TSS) from station 3 (at Shell Creek dam) from 1991-1994 were used with flow records to calculate "best estimate" loadings from Shell Creek during that time period.

SWFWMD SWIM

The SWFWMD SWIM Program has been collecting water quality data monthly from the Charlotte Harbor estuarine system since January 1993. Monthly records (January 1993 through December 1995) collected from surface and bottom depths were extracted from the SWFWMD data and converted to a SAS data set for use in data analyses.

4.1.3 Initial Review of Available Data and Measured Parameters

The available data compiled from the USGS, the EQL, and the SWFWMD were reviewed for measured parameters appropriate for developing empirical-based PLRG targets. In order to estimate loadings to the lower Peace and Myakka river systems, USGS flow and water quality data from gages and the EQL Shell Creek water quality data were used to calculate gaged loads into water bodies. Water quality data collected by the EQL and the SWFWMD provided measures of ambient conditions in these water bodies. A base set of parameters was used from these data sets to develop watershed loads for water, TN, TP, and TSS, and to assess water quality/eutrophication-related conditions in the tidal reaches of the Peace and Myakka rivers. A matrix of the measured parameters used and the data sets from which they were obtained are shown in Table 4-2.

Loading Calculations

Loadings from USGS Gages

Estimated loadings delivered from each USGS gage were calculated by multiplying the water quality constituent concentration by the flow volume. Missing monthly USGS flow and concentration data were interpolated using mean monthly flow values from the nearest previous and succeeding data records reported. Concentration data were used for total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) as available. Monthly loadings at each gage were calculated by multiplying flow and concentration (TN,TP, and TSS).

Loading from Dilution Method

Estimated loadings were also calculated based on the dilution curve of concentration (TN,TP, TSS) and salinity in data collected from the tidal Peace River. This approach for estimating nutrient loadings was based on a method described by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP, 1987; Balls, 1994; Johansson, 1996).

Table 4-2. Measured parameters from data collected in the Charlotte Harbor watershed and estuarine system.

Water Quality Parameter	USGS Gages	EQL Shell Creek	EQL Fixed Station	EQL Salinity-Based	SWFWMD SWIM
Flow	X				
Temperature			X	X	X
Salinity			X	X	X
Conductivity			X	X	X
Dissolved Oxygen			X	X	X
pH			X	X	X
Chloride			X	X	X
Color			X	X	X
Total Suspended Solids	X	X	X	X	X
Turbidity			X	X	X
Total Nitrogen	X				
Total Kjeldahl Nitrogen		X	X	X	X
Nitrite+Nitrate Nitrogen		X	X	X	X
Total Phosphorus		X	X	X	X
Chlorophyll-a			X	X	X
Extinction Coefficient				X	X
Secchi Disk Depth					X

The method was used with the assumption that the lower Peace River concentrations of TN and TP change as a linear function of salinity. Monthly fixed station EQL salinity and concentration data from sites 9, 10, 12 and 14 were regressed by year (1976-1990) using the least-squares method to fit general linear models (SAS Institute, Inc., 1988). Likewise, EQL salinity and concentration data collected from three salinity-based stations (station 2 = 6 ppt.; station 3 = 12 ppt; station 4 = 20 ppt), were also regressed by year (1983-1994). The y-intercept from these models was assumed to represent the nutrient concentration at 0.0 ppt salinity. Thus the y-intercept multiplied times the hydrologic load to the lower Peace River would serve to estimate load without actual measurements of nutrient concentration at each freshwater input point into the system. Theoretically, the dilution method should represent loadings from all nutrient sources (known and unknown), including losses or additions of nutrients to the water column from internal nutrient cycling processes.

The annual y-intercept, r^2, and significance level for EQL fixed-based station and salinity-based station data were calculated as described above. Relationships yielding an r^2 less than 0.90 were dropped, and all other resulting y-intercept values for a given year were averaged from both data sources to develop mean TN and TP concentrations (based on the y-intercept) for each complete year of data, 1976-1993.

Finally, nutrient loadings were estimated from dilution curve-estimated TN and TP concentrations and the Peace River hydrologic load (flow) as reported by USGS from the Peace River at Arcadia gage. Upon comparing these nutrient loads to those calculated using available monthly concentration data measured at the Peace River at Arcadia gage, dilution curve estimated loads were an average of 18% and 12% lower for TN and TP, respectively, so that the product of the flow and water quality constituent concentration gives a load estimate 12-18% less than that from the dilution curve method. The dilution curve method of estimating loads for Charlotte Harbor demonstrated an alternate method of estimating nutrient loadings to the lower Peace River without the need to use concentration data collected at downstream gages.

Time Series Observations

USGS Gage Data for Nutrient Concentration and Flow

Gages in the Peace River basin generally showed a drop in TN concentration during the 1970s, and a substantial decrease in TP concentration over the entire time period. The decreasing TP concentrations were the primary factors resulting in a general TN:TP ratio increase with time found at the Peace at Arcadia, Peace at Zolfo, Peace at Bartow, and Horse Creek near Arcadia gage sites. Conversely, in the Myakka River basin, TN:TP ratios at Myakka near Sarasota declined since 1970, primarily from a decrease in TN and an increase in TP over time. The concentrations of TN and especially TP were much greater in the Peace basin compared to the Myakka basin throughout the period examined.

EQL Peace and Myakka River TN and TP Concentrations

The EQL data showed three general patterns:

- Middle and Lower Peace segments showed increasing TN:TP vs. time
- Lower Myakka stations also showed increasing TN:TP vs. time
- Upper Myakka stations did not show increasing TN:TP vs. time

EQL Peace and Myakka River Trophic State Index (TSI) Values

Monthly EQL TN, TP, and chlorophyll-a data were used to calculate monthly TSI values using the equations found in Hand et al. (1994). To further examine possible relationships between receiving water trophic level (TSI) and watershed loadings, plots of TSI versus water load, TN load, and TP load delivered from USGS gages in the watershed were also examined. No obvious patterns between TSI and water and nutrient loads were observed. Correlations were also calculated to provide a more quantitative and objective method of determining if any definable relationships exist.

Correlation Analysis

Previously calculated TSI values based on pooled EQL fixed-station and salinity-based station data sets analyzed by river and river segment were used to calculate correlation coefficients. Pearson correlation coefficients (SAS Institute, Inc., 1988) were calculated between mean TSI values for each river segment or each river reach and water or nutrient loads delivered from USGS gages. In addition to TSI, correlation coefficients were also calculated between river or river segment chlorophyll-a, TN, TP, TN:TP ratio, color, and extinction coefficient versus water and nutrient loads delivered from USGS gages.

These analyses suggested the presence of the following relationships.

- The strongest relationships between watershed loads and ambient water quality downstream in the tidal Peace and Myakka rivers were between loadings of freshwater from the Peace and Myakka rivers and color measured downstream in the respective river segments.

  For example, in the Lower and Middle Peace River segments, at least 80% (r^2=0.80) of the variability in color could be explained by the variability in freshwater load from the USGS Arcadia gage.

- The next strongest relationships were between Peace River loadings and water clarity (extinction coefficient) measured downstream in the respective tidal segment of the Peace and Myakka rivers. The strongest of these relationships was between Arcadia freshwater load and color measured downstream (r^2=0.80) in the Lower Peace River segment.

- No potential direct relationships were found between watershed loadings and the living resource response variables of TSI and chlorophyll-a measured in the tidally influenced segments of the rivers.

- Although no correlations were significant, relationships between river loadings (freshwater, TN, and TP) from various gages in the Peace River watershed and TSI downstream were strongest between loads in the upper watershed gages of Zolfo Springs, Ft. Meade, and Bartow, and the Upper Peace River segments compared to all other gage locations tested. This relationship was strongest between Ft. Meade loads and Upper Peace River TSI. Interestingly, loads from Ft. Meade also showed a relatively strong relationship to TSI measured in the Lower Myakka River.

- Relationships between river loadings and chlorophyll-a measured downstream were similar to what was found for TSI. Highest correlations were found between loads from the gages of Zolfo Springs, Ft. Meade, and Bartow, and the Upper Peace River segments compared to all other gage locations tested. In this case, however, relatively high correlations were not observed between any gage loads and chlorophyll-a measured in the Lower Myakka River.

Summary of Findings of Initial Data Review

- An increasing trend in time in median annual TN:TP ratio was observed in the Middle Peace River segment and the Lower Peace and Myakka River segments. The increasing trend in TN:TP was primarily associated with a long-term decreasing trend in TP concentrations.

- Loads from the Peace River are strongly related to color and water clarity in the tidal reaches of the Peace River. Higher loads are associated with higher color and lower water clarity in the tidal river segments.

- No potential direct relationships were found between river loadings and the living resource response variables of TSI and chlorophyll-a measured in the tidally influenced segments of the rivers.

- Water quality (TSI) in the lower segment (EQL station 8) of the Myakka River was more strongly correlated with estimated Peace River loadings than with loadings from the Myakka River itself.

- Although some relationships (correlations) were stronger than others, no direct relationships were found between potential living resource response variables (TSI, chlorophyll-a) measured in the tidal portions of the Peace or Myakka rivers and estimated loadings delivered to those tidally influenced areas.

4.1.4 The Relationship of Total External Nitrogen Load to Chlorophyll-a Concentration

The relationship of total external nitrogen load to chlorophyll-a concentration was investigated using nitrogen loading estimates calculated as discussed above and chlorophyll-a concentration observations from the EQL fixed station data and the EQL salinity-based station data. External nitrogen loads for the tidal reach of the Peace River were computed as the sum of the estimated loads for the Peace River at Arcadia and Horse Creek near Arcadia gages. As discussed previously, the potential for seasonal autocorrelation effects were removed by using annual average data for the regressions.

EQL Fixed Station Observations

No significant relationships between estimated nutrient loads and measured chlorophyll concentrations could be found in the EQL fixed station data. A complete listing of the results of these analyses is presented in Appendix A.

In summary, the following results were obtained for the linear model:

$$\textit{Chlorophyll-a} = \alpha + \beta\ (\textit{External TN Load})$$

using annual average chlorophyll-a concentrations and annual total nitrogen load estimates. The parameters α and β were fit by ordinary least squares regression analysis. No slope parameters were significantly different from zero at a probability > |T| of 0.05.

EQL Salinity-based Station Observations

The EQL salinity-based station data indicated that a significant relationship existed between the chlorophyll-a concentrations in the middle segment of the Peace River and external nitrogen loads on an annual basis.

The Peace River salinity-based station data from 1985 through 1994 were assigned to geographic segments of the river as follows:

- Upper Peace River = 2 to 14 kilometers downstream of EQL Station 20 (EQL Station 20 was just south of the mouth of Horse Creek),

- Middle Peace River = 14 to 21.5 kilometers downstream of EQL Station 20, and
- Lower Peace River = 21.5 to 30 kilometers downstream of EQL Station 20.

A general functional form was selected for these relationships which fit the shape of the observed data distributions well, and had very few parameters to be fit:

$$Chlorophyll\text{-}a = \frac{1}{External\ TN\ Load}$$

This functional form describes only a family of curve-forms for the relationship, and by itself does not imply that chlorophyll-a decreases with increasing external TN load. The positive or negative slope of the relationship was estimated using regression parameters. We used a linear regression model this form was expressed as:

$$\ln(Chlorophyll\text{-}a) = \alpha + \beta\ \ln(External\ TN\ Load)$$

where α and β were parameters fit by least squares regression analysis.

The results of the regression analysis indicated that no significant relationship was observed for the Upper and Lower Peace River segments (R-square values of 0.06 and 0.04 respectively). However, a significant relationship was observed for the Middle Peace River segment. Appendix B presents a complete listing of the results of these analyses.

Figure 4-1 presents the observed annual data for the Middle Peace River segment, and a solid line indicating the prediction curve defined by the estimated regression parameters. A plot of the predicted versus observed chlorophyll-a concentrations reiterates the significant fit of this model (Figure 4-2). The R-square value for these data was 0.93, and the slope parameter β was significantly different from zero with a probability > |T| less than 0.001.

The data also indicated that an interesting pattern existed in the unexplained variation from this relationship over the 1985 to 1994 time period. Figure 4-3 presents the time series of annual chlorophyll-a concentrations for the Middle Peace River Segment presented as solid circles with a solid line indicating the predicted chlorophyll-a concentrations. As evident in this figure, the model tended to slightly underpredict chlorophyll concentrations in the earlier years of the time series, and slightly overpredict chlorophyll concentrations in the later years. This phenomena did not appear to be related to the magnitude of the chlorophyll concentrations or the magnitude of the external nitrogen loads. Figure 4-4 presents these data expressed as residual values and plotted against year, and the trend is clearly visible in this figure.

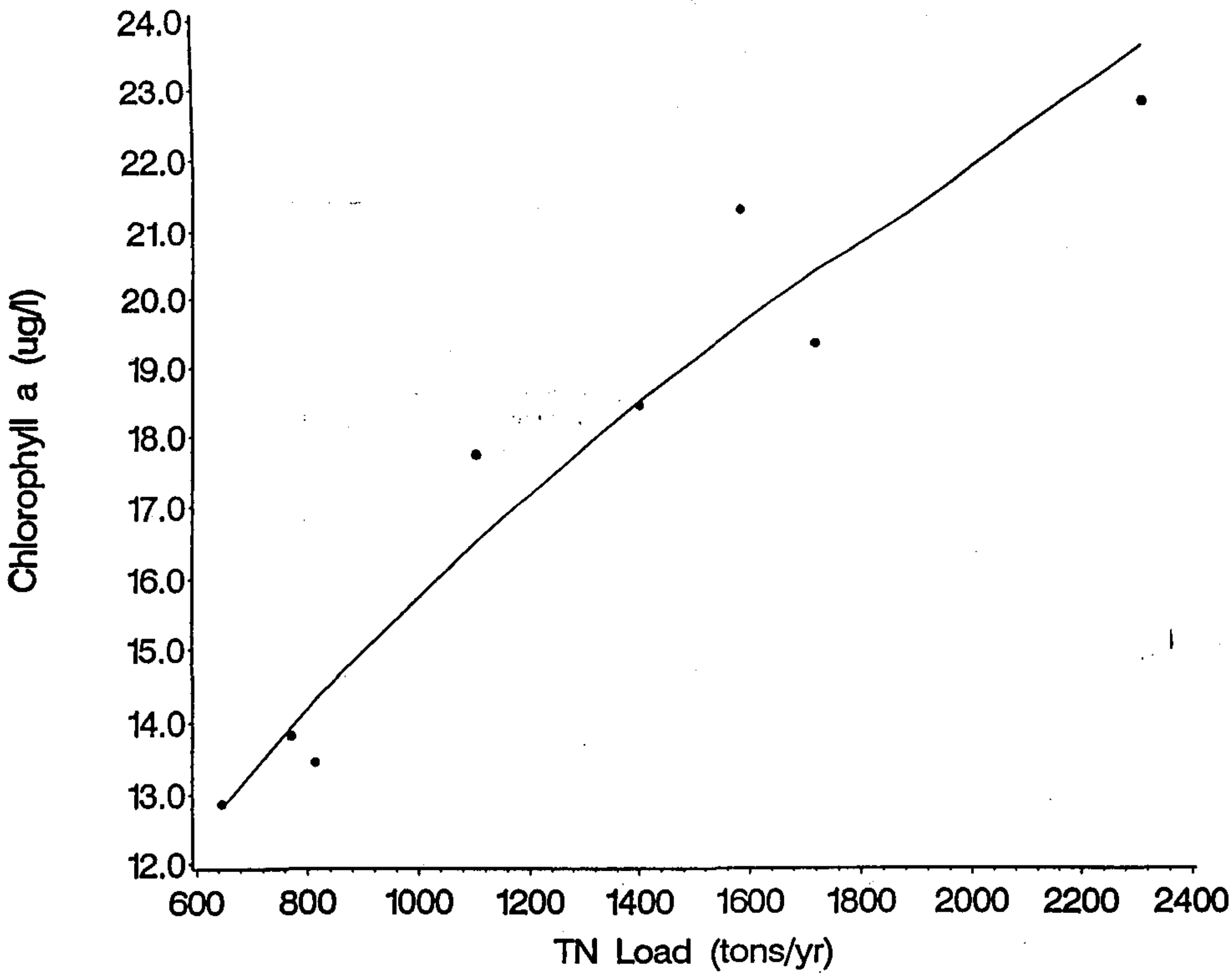

Figure 4-1. Annual average chlorophyll-a concentration (solid circles) plotted against total annual TN load. Solid line indicates prediction line defined by regression parameter estimates.

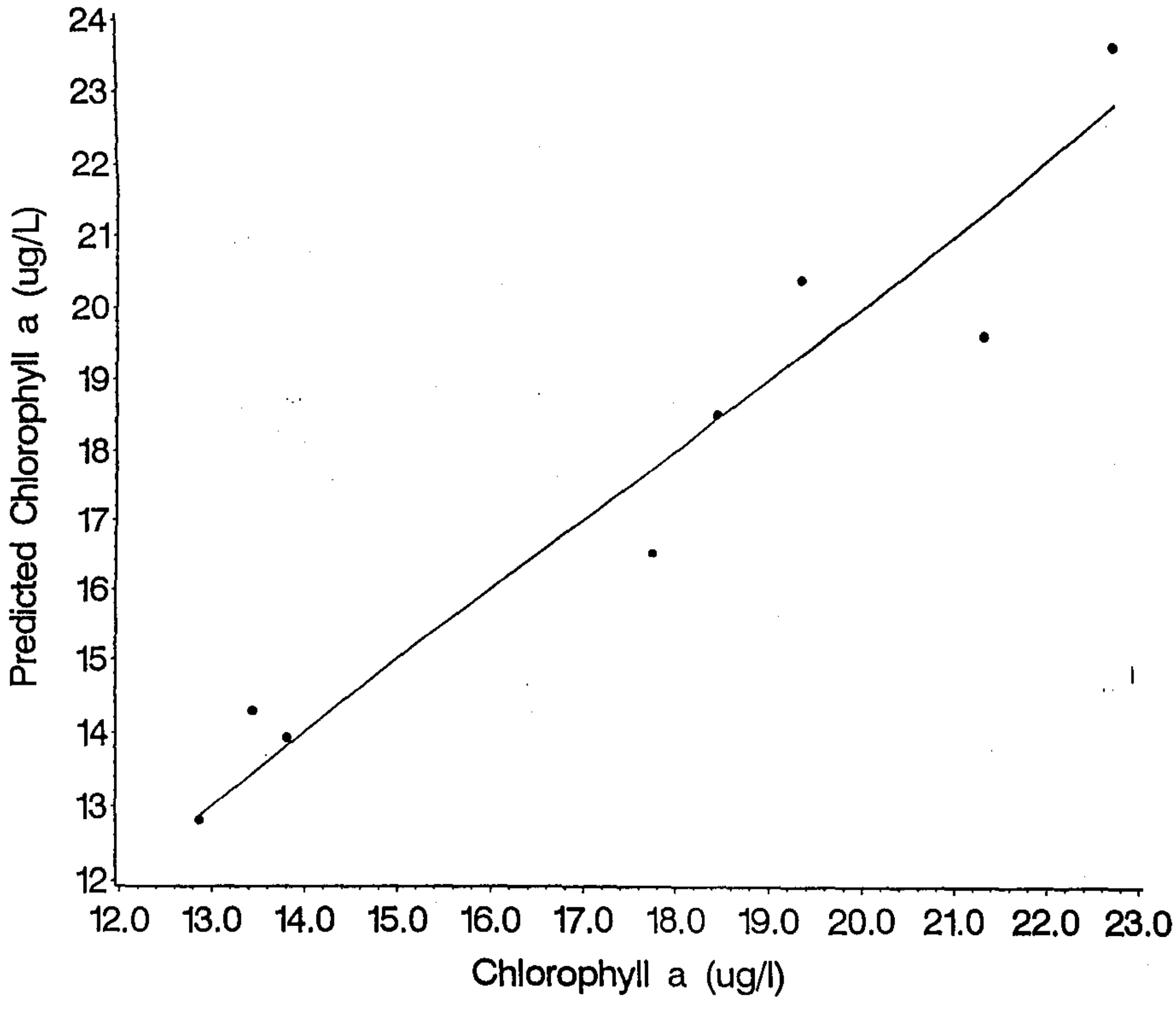

Figure 4-2. Predicted and observed average annual chlorophyll-a concentrations. Solid line indicates 1:1 fit of predicted and observed.

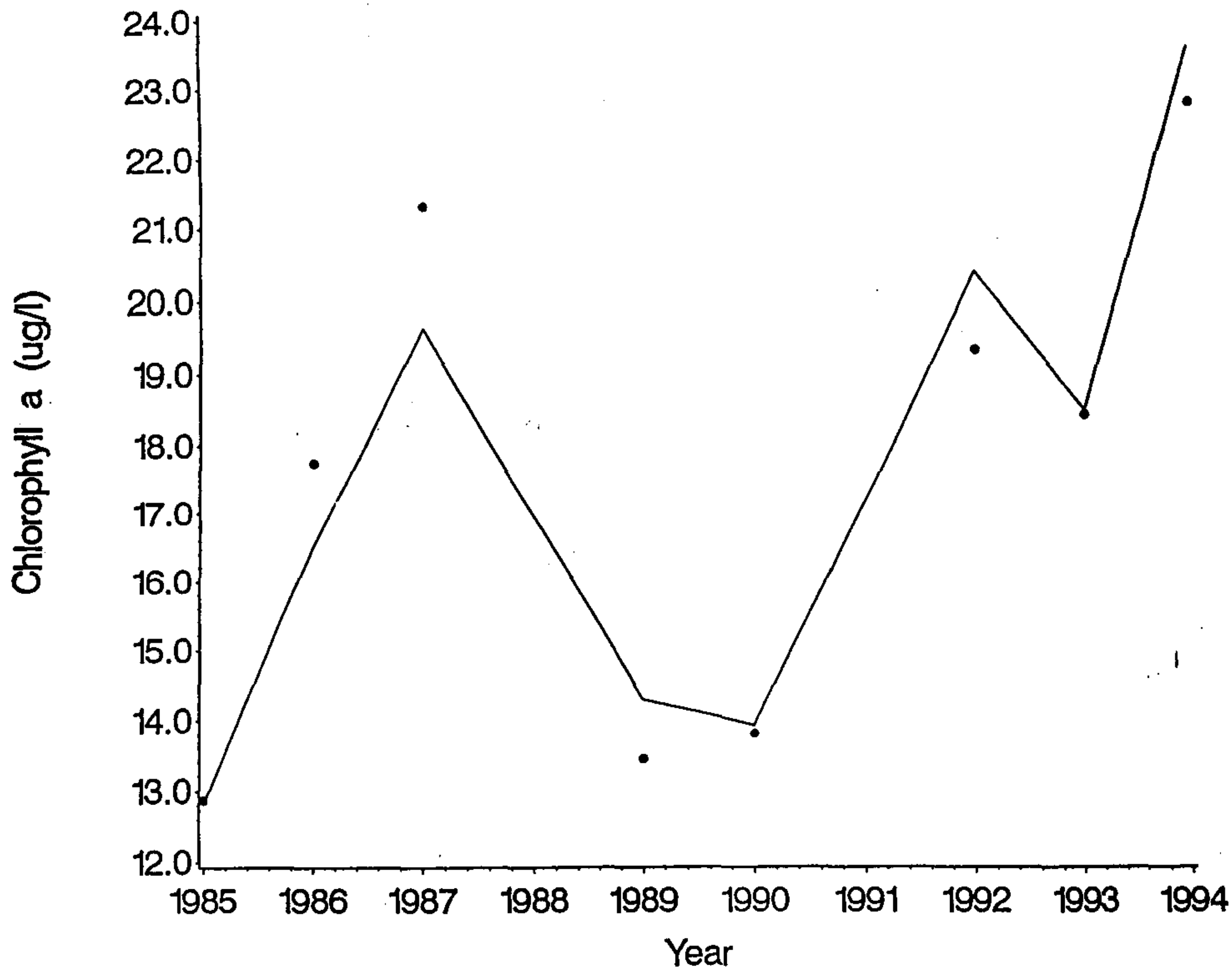

Figure 4-3. Average annual chlorophyll-a concentration plotted against year (solid circles). Solid line indicates predicted values.

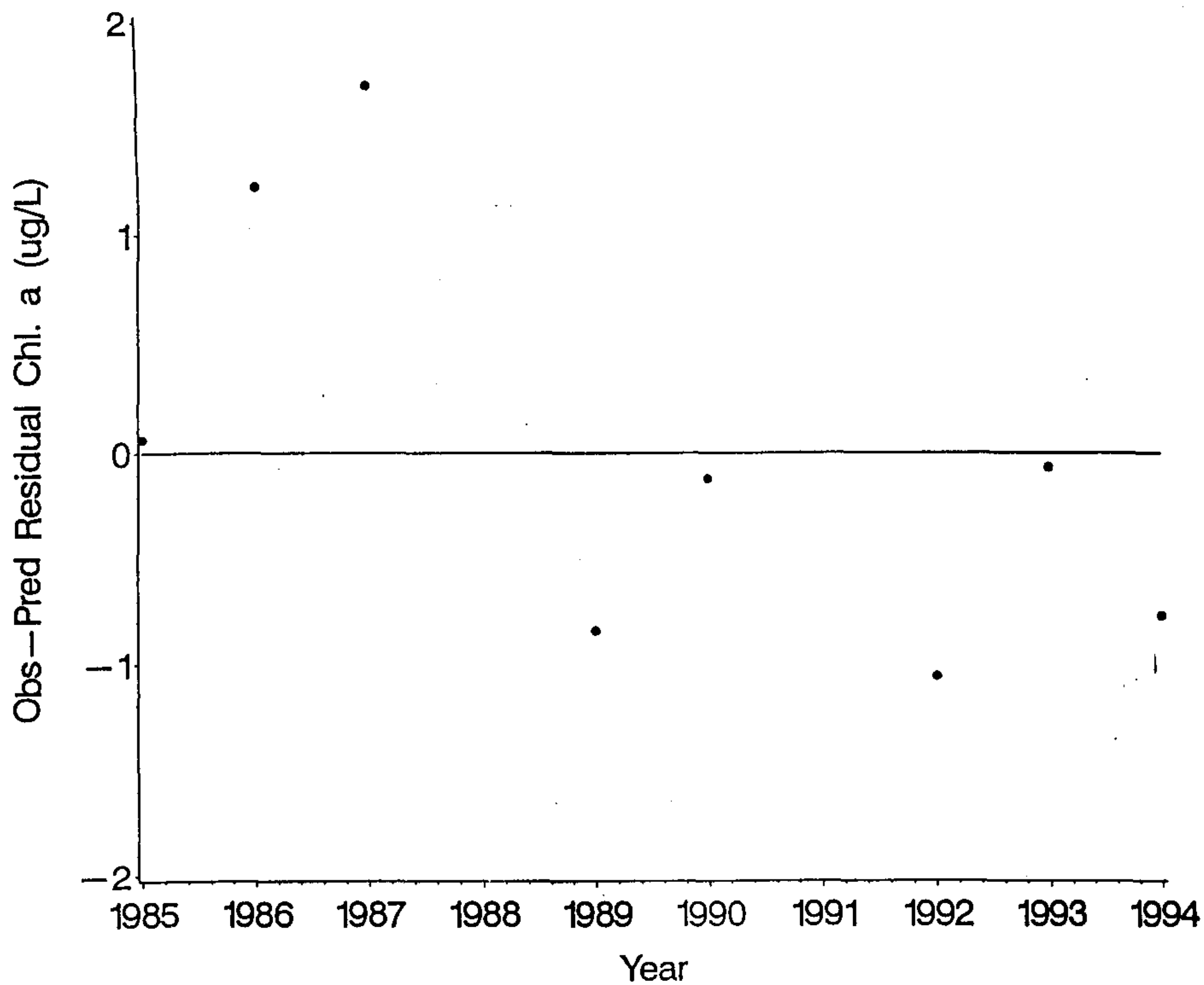

Figure 4-4. Residuals from chlorophyll prediction regression model plotted against year (solid circles). Points plotted above the horizontal line are overestimates of the chlorophyll concentration observed in that year.

4.1.5 The Relationship of Chlorophyll-a Concentration to Light Attenuation

The relationship of chlorophyll-a concentration to water column light attenuation was investigated using water quality observations from the EQL fixed station data and the EQL salinity-based station data. As discussed previously, the potential for seasonal autocorrelation effects was removed by using annual average data for the regressions. Light attenuation for these analyses was recorded in the sampled data as an extinction coefficient in the units m^{-1}.. For PLRG development, the light attenuation data were then expressed as the depth to which 1% of the light found immediately below the water surface penetrated. The compensation depth was computed using the equation:

$$Z = \frac{-\ln\left(\frac{I_Z}{I_0}\right)}{K_D}$$

where

Z is depth to which 1% of the light at the surface penetrates,

K_D is the measured light extinction coefficient (m^{-1}),

I_Z is the incident light at depth Z, and

I_o is the incident light at the top of the water column (subsurface irradiance).

EQL Fixed Station Observations

Although the fixed station data were recorded from 1975 through 1994, light extinction data were not reported until 1983. Thus, the 1983 through 1994 data were used for this analysis. The fixed station data from the Peace River from 1985 through 1984 were assigned to geographic segments of the river as follows:

- Upper Peace River = Station 14,
- Middle Peace River = Station 12, and
- Lower Peace River = Station 10.

A linear regression model was expressed as:

$$Z = \alpha + \beta(Chlorophyll\text{-}a) + \gamma(color)$$

and was fit by stepwise least squares regression analysis and ordinary least squares regression analysis.

The results of the regression analyses indicated that no significant relationship was observed between compensation depth and chlorophyll-a concentrations, similar to the results of McPherson and Miller (1987). Color was selected as the best explanatory variables for all segments, and the slope parameter β was not significantly different from zero for all segments at an alpha level for probability > |T| =0.05. A complete set of results from this regression analysis is presented in Appendix C. The results of the regression analysis which were significant are summarized as follows:

Stepwise Least Squares Regression Results for Compensation Depth as a Linear Function of Water Quality Parameters			
River	**Segment**	**Explanatory Variable(s) Selected**	**R-square Value**
Peace	Upper	Color	0.74
Peace	Middle	Color	0.52
Peace	Lower	Color	0.64

A regression analysis pooling all of the data from the three segments was also completed, and color was selected as the only significant explanatory variable. The R-square value for this pooled analysis was 0.54.

EQL Salinity-based Station Observations

The salinity-based station data from the Peace River from 1985 through 1984 were assigned to geographic segments of the river as follows:

- Upper Peace River = 2 to 14 kilometers downstream of EQL Station 20,
- Middle Peace River = 14 to 21.5 kilometers downstream of EQL Station 20, and
- Lower Peace River = 21.5 to 30 kilometers downstream of EQL Station 20.

A linear regression model was expressed as:

$$Z = \alpha + \beta(\mathit{Chlorophyll\text{-}a}) + \gamma(\mathit{color}) + \theta(\mathit{turbidity})$$

and was fit by stepwise least squares regression analysis.

The results of the stepwise regression analysis indicated that no significant relationship was observed between compensation depth and chlorophyll a concentrations. Color was selected as the best explanatory variables for all segments. Turbidity data were not available for the complete time series, and thus, were not entered into the stepwise model to determine if the variation in compensation depth could be explained by the variation in chlorophyll a. A complete set of results from this regression analysis is presented in Appendix D. The results of the regression analysis which were significant are summarized as follows:

Stepwise Least Squares Regression Results for Compensation Depth as a Linear Function of Water Quality Parameters			
River	**Segment**	**Explanatory Variable(s) Selected**	**R-square Value**
Peace	Upper	Color	0.42
Peace	Middle	Color	0.38
Peace	Lower	Color	0.31

A regression analysis pooling all of the data from the three segments was also completed, and color was selected as the only significant explanatory variable. The R-square value for this pooled analysis was 0.52.

4.1.6 The Relationship of Nutrient Load to TN:TP Concentration Ratio

The relationship of external nutrient loads to TN:TP concentration ratios in the receiving waters was investigated using nitrogen loading estimates as discussed above and nutrient concentration observations from the EQL fixed station data. External nitrogen loads for the Peace River were computed as the sum of the estimated loads for the USGS gage at Arcadia and the USGS gage at Horse Creek. As discussed previously, the potential for seasonal autocorrelation effects were removed by using annual average data for the regressions.

EQL Fixed Station Observations

A series of regression models was analyzed using the EQL fixed station data to investigate the relationships between nitrogen and phosphorous concentrations and nitrogen and phosphorous loads. Significant relationships were found only for Station 10 in the Peace River. A listing of the results of these analyses is presented in Appendix E.

As discussed in the preliminary review of the data, there was a general trend of a declining TP concentration in both the Peace and Myakka Rivers, and an associated increase in the TN:TP concentration ratio. The TN and TP load observations were highly correlated. Thus, they could not be used together to develop a defensible predictive regression model without making the important assumption that the correlation structure would remain unchanged for any future period for which predictions are to be made. The trends noted in the observed data suggest that this is not likely to be a robust assumption.

In summary, the following results were obtained for TN concentration, TP concentration, and TN:TP concentration ratio models fit by ordinary least squares regression analysis and one explanatory variable per model.

Least Squares Regression Results				
River	**Fixed Station**	**Response Variable**	**Explanatory Variable**	**R-square Value**
Myakka	8	TN conc TP conc TN:TP conc TN:TP conc	TN TP TN TP	Slope Not Significant Slope Not Significant Slope Not Significant Slope Not Significant
Myakka	31	TN conc TP conc TN:TP conc TN:TP conc	TN TP TN TP	Slope Not Significant Slope Not Significant Slope Not Significant Slope Not Significant
Myakka	32	TN conc TP conc TN:TP conc TN:TP conc	TN TP TN TP	Slope Not Significant Slope Not Significant Slope Not Significant Slope Not Significant
Peace	10	TN conc TP conc TN:TP conc TN:TP conc	TN TP TN TP	Slope Not Significant 0.83 0.76 0.86
Peace	12	TN conc TP conc TN:TP conc TN:TP conc	TN TP TN TP	Slope Not Significant Slope Not Significant Slope Not Significant Slope Not Significant
Peace	14	TN conc TP conc TN:TP conc TN:TP conc	TN TP TN TP	Slope Not Significant Slope Not Significant Slope Not Significant Slope Not Significant

4.2 Mechanistic Approach to PLRG Development

WASP Water Quality Model

As a means of providing another avenue to determine the effects of loadings on the tidal Peace and Myakka rivers and the Upper Harbor, a mechanistic model of the system was constructed. The water quality model selected for this study was EUTRO5, a submodel of the Water Quality Analysis Simulation Program, WASP. WASP and its submodels are supported by the U.S. Environmental Protection Agency, and are designed to be dynamic modeling programs for aquatic systems, considering the effects of advection, dispersion, nutrient loadings, and boundary exchanges of water quality parameters. The EUTRO5 submodel has been used when studying water quality in a wide variety of aquatic systems (Ambrose et al., 1993). The EUTRO5 model has undergone extensive testing and application to various waterbodies, and has recently been used for a management-oriented study of the Tampa Bay estuarine system (Martin et al., 1996).

The EUTRO5 submodel allows for spatially multi-dimensional and temporally variable prediction of considered variables. The submodel can simulate values of up to eight state variables: chlorophyll-a, dissolved oxygen, biological oxygen demand, ammonia, nitrate, organic nitrogen, ortho-phosphorus, and organic phosphorus. Kinetic interactions between these state variables occur within four dynamic systems: phytoplankton kinetics, the phosphorus cycle, the nitrogen cycle, and the dissolved oxygen balance. Advective flow rates may be included either directly within the input data file, or calculated through hydrodynamic models. Dispersive exchange coefficients are input directly to the datafile used by EUTRO5.

The EUTRO5 submodel is a general model designed for ease of modification for specific aquatic systems. However, the submodel does have some limitations. For example, phytoplankton growth rates may not be varied in space to simulate diverse species assemblages which may be signatory of dissimilar environments. In addition, this model does not fully discern processes affecting sediment-water column nutrient interactions, nor those affecting sediment oxygen demand. Therefore, these processes must be simulated using zero-order rate terms.

Limitations on the model imposed by data availability for the simulated system also exist. Data on sediment oxygen demand and nutrient release rates within the study area were not obtained for this study. Similarly, no data were found for either water column biological oxygen demand or for loadings of this variable during the simulation time period. In addition, the water quality model simulates three chemical species of nitrogen and two of phosphorus, although nutrient loading estimates were only for total nitrogen and total phosphorus. This necessitated the division of these loads based on estimates of species ratios obtained from other studies. Finally, light attenuation was not available in the EQL fixed-station data record for the stations used in, and the time period over which, this simulation was run.

Model Segmentation

The Peace and Myakka Rivers and Charlotte Harbor were segmented into five horizontal boxes, based on the segmentation previously done for the harbor (Coastal Environmental, Inc., 1995b) (Figure 4-5). Segment 1 represented the tidal Peace River, Segment 2 was representative of the tidal Myakka River, Segment 3 contained the Upper Harbor, Segment 4 was the Middle Harbor, and Segment 5 was defined as the Lower Harbor. Segments 1-4 were divided into two vertical boxes each, with the top box of all segments having a depth of 0.5 m, and the bottom boxes containing the remainder of the water column. Segment 5 was not divided vertically.

Vertical resolution of two boxes for each segment was determined to be necessary because of the vertical gradients found in water quality parameters when analyzing the SWFWMD data covering 1993-1994. The influx of fresh water from the Peace and Myakka rivers creates a vertical salinity gradient in the model domain, most strongly evident in the Peace River segment. The physical descriptors for each of the nine boxes are shown in Table 4-3, in which all areas external to the model domain are signified by Box 0.

Geomorphic features of the simulated system were determined from Geographic Information System (GIS) coverages of the harbor, with the shoreline determined based on a coverage obtained from the SWFWMD and the bathymetry determined from a coverage generated from NOAA depth data. These coverages were used to determine box volumes, the depths of the bottom boxes, the interfacial areas, both vertically and horizontally, of all boxes, and the exchange lengths between boxes. Flows and loadings to the simulated system were determined based on calculations for 1975-1990 for the system.

For the purposes of simulating salinity, as a test of the ability of the model to simulate the hydrodynamics of the harbor, the nine boxes discussed above, and shown in Figure 4-6, were used, with the Gulf of Mexico as the downstream boundary condition. This boundary condition was selected as most representative of a boundary condition which would remain relatively unaffected by varying hydrologic and nutrient loads, as salinity concentrations within the harbor may be strongly affected by freshwater inflows (Environmental Quality Laboratory, Inc., 1992).

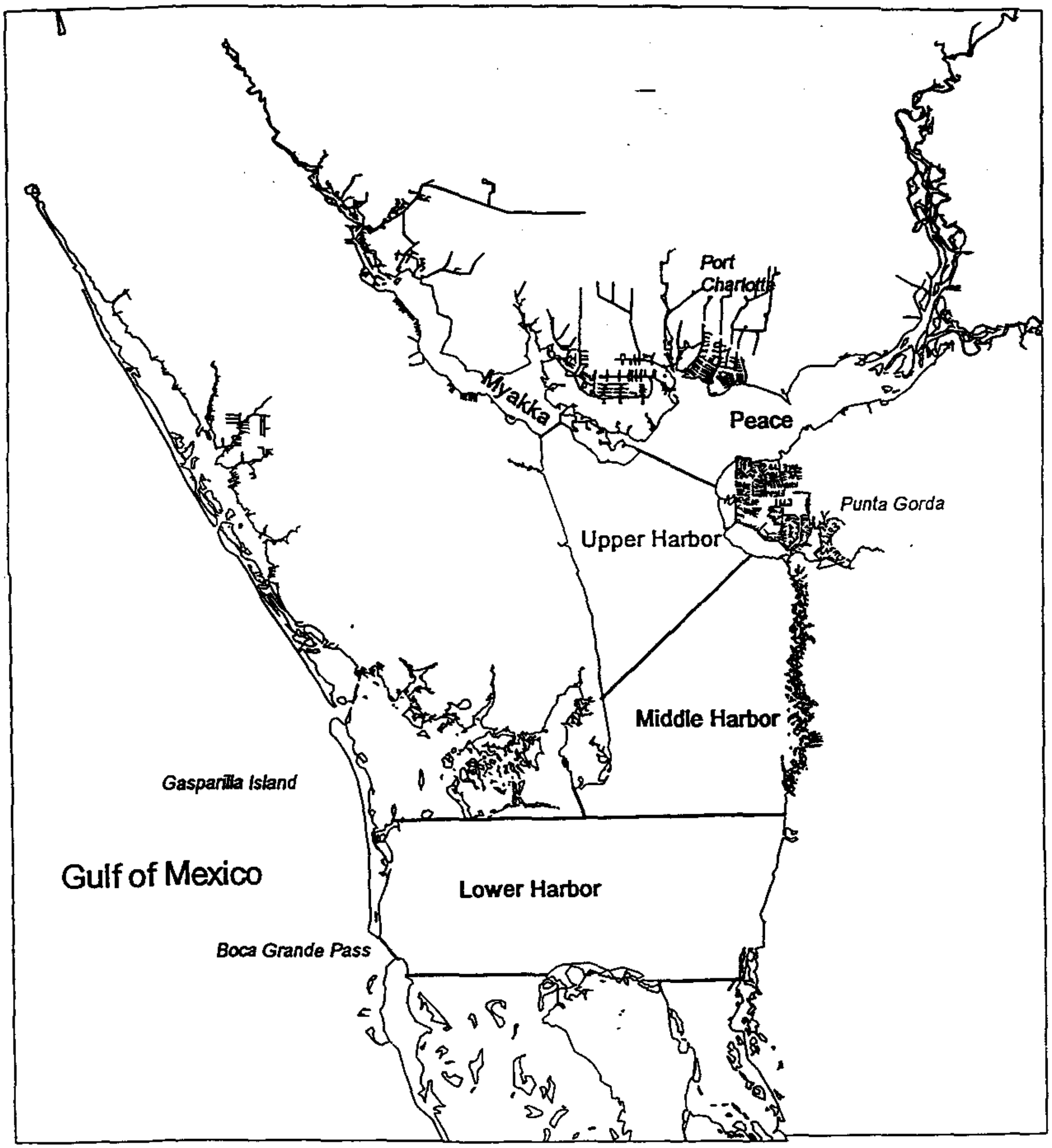

Figure 4-5. **Segments of the Charlotte Harbor Estuary.**

Table 4-3. Boxes, volumes, interfacial areas, depths, and mixing lengths for the Peace and Myakka rivers and upper Charlotte Harbor.

Box	Volume (m^3)	Depth (m)	Interface (Box-Box)	Area (m^2)	Mixing Length (m)
1 TP	19,947,628	0.50	1-5	1,974	10,064
2 BP	43,205,499	0.92	2-6	7,824	10,064
3 TM	8,178,616	0.50	3-5	554.2	11,721
4 BM	11,930,582	0.58	4-6	1,567	11,721
5 TUH	28,951,441	0.50	5-7	4,518	9,588
6 BUH	135,654,835	2.23	6-8	23,073	9,588
7 TMH	48,460,298	0.50	7-9	4,548	10,107
8 BMH	237,124,322	2.33	8-9	22,594	10,107
9 LH	397,087,975	2.89	9-0	43,029	20,447
1 TP - Top Peace 2 BP - Bottom Peace 3 TM - Top Myakka 4 BM - Bottom Myakka 5 TUH - Top Upper Harbor 6 BUH - Bottom Upper Harbor 7 TMH - Top Middle Harbor 8 BMH - Bottom Middle Harbor 9 LH - Lower Harbor			1-2	35,428,225	0.71
			3-4	14,028,904	0.54
			5-6	55,550,069	1.365
			7-8	92,891,891	1.415

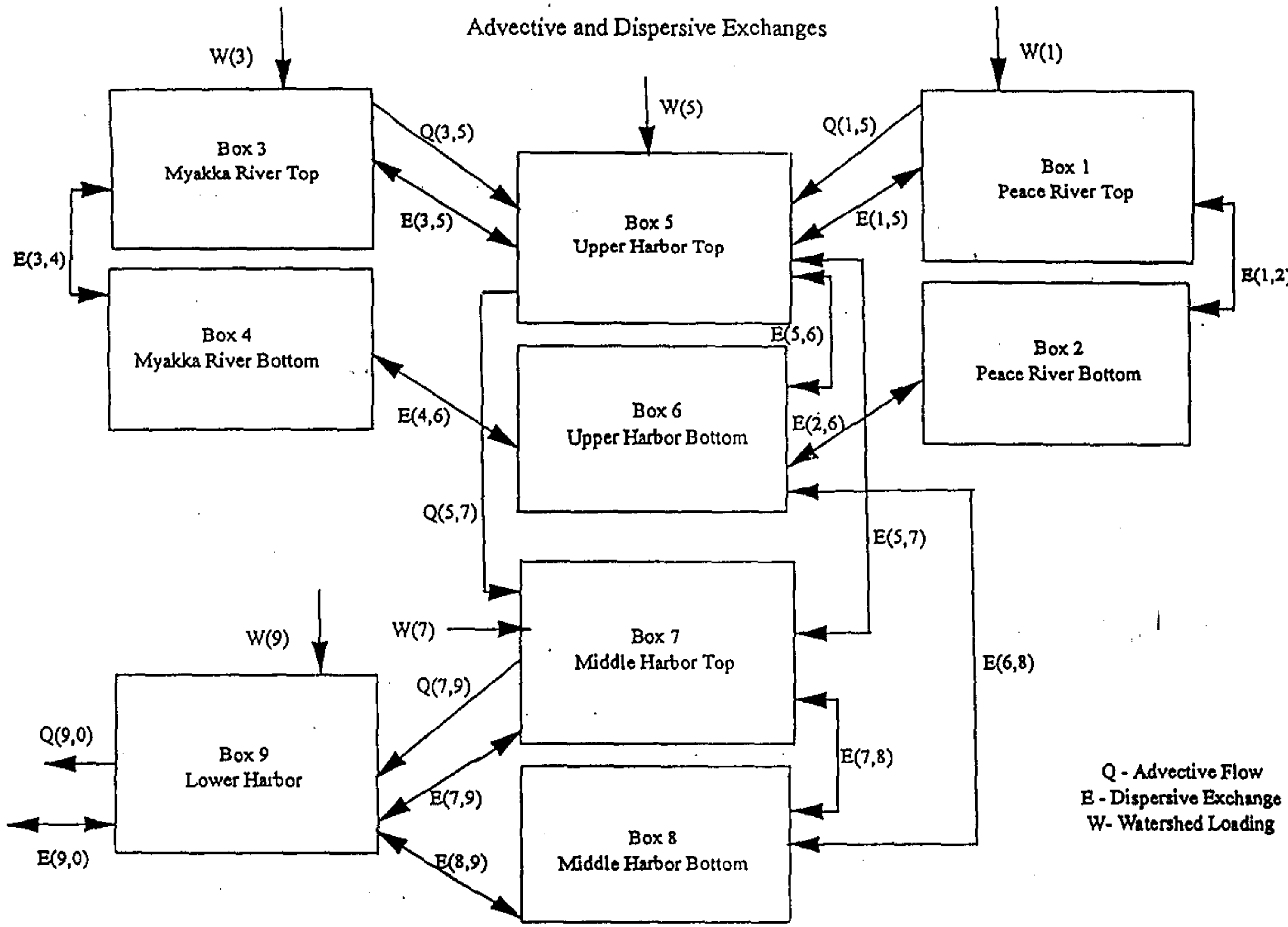

Figure 4-6. Advective, dispersive, and watershed flow diagram of segmented Charlotte Harbor used in salinity simulation.

4.2.1 Salinity Balance - Calibration

The hydrodynamics of the study area were simulated by utilizing the set of model boxes, and a series of simple dilution equations were fit to account for the interbox exchange of water quality constituents. The transfer coefficients between boxes were empirically estimated using observed salinity data measured by the EQL from 1975 to 1990 and freshwater inflow estimates for the same time period.

The basic form of the dilution equations was:

$$0 = W_i - Q_i C_i + E_{i,j}(C_j - C_i)$$

where W_i= the external load of a dissolved substance to box I from its watershed (kg/month),

Q_i= the freshwater inflow rate to box I from its watershed (m3/month),

C_i= the concentration of a dissolved substance (e.g., salt) in box I (kg/m3),

C_j= the concentration of a dissolved substance in the adjacent box j (kg/m3), and

$E_{i,j}$= a transfer coefficient from box I to the adjacent box j (m3/month).

A dilution equation was written in this manner for each of the modeled boxes.

To estimate the average net transfer of water and dissolved substances between the boxes, the system of equations was initially solved using salt as a conservative dissolved substance. The word "conservative" refers to the fact that salt is expected to be freely transported among the bay segments, and there are not expected to be any significant sources or sinks of salt (other than the Gulf water at the mouth of Charlotte Harbor).

Using salt as a conservative substance, the only terms in each equation which remain unknown are the values of the transfer coefficients (E). Because there were dilution equations for each box and unknown E values for both lateral and vertical transfer, there were more unknown values than equations. Thus, a closed form solution could not be derived for the system of equations and fit using the observed salinity and freshwater inflow data. The equations were expressed in the form of multiple linear equations, and least squares regression methods were used to estimate exchange coefficients for four three-month periods from the 16 years of data. Several coefficients to be estimated were present in more than one of the regression equations. The final values for these parameters were estimated by weighted average, where the weight of each observation was assigned the inverse of the standard error of the estimate from the regression equation, then adjusted to provide more accurate fits utilizing multiple model runs. In simple terms, estimates for which there was less uncertainty due to month-to-month variability in observed salinity were given more weight in the final averages.

Initial calibration of the Peace and Myakka rivers and the upper Charlotte Harbor model was for estimation of quarterly non-advective (dispersive) exchange coefficients. The model was calibrated against measured salinity values within each of the nine boxes of the model domain for each month of the 1975-1990 time period, using monthly inflows for the same period. Some of the results of the parameterization and a summary of the goodness of fit of the hydrodynamic equations are presented in Table 4-4 below.

Table 4-4. Comparisons of simulation results and monthly field observations for salinity, 1975-1990.

SALINITY	MODEL BOX									
	1	2	3	4	5	6	7	8	9	Total
SAMPLE SIZE (n)	174	174	344	172	171	171	78	78	86	1448
MEAN ERROR	1.25	1.05	1.47	1.44	1.04	1.57	0.06	-0.63	0.46	1.10
RELATIVE ERROR	1.30	0.45	0.95	0.36	0.23	0.14	0.14	0.09	0.09	0.54
r	0.68	0.61	0.71	0.72	0.68	0.62	0.72	0.70	0.64	0.80
r^2	0.46	0.38	0.50	0.52	0.46	0.39	0.52	0.49	0.41	0.58

Coefficients of determination (r^2) for the nine boxes ranged from 0.39 to 0.52, with an r^2 of 0.58 over all nine boxes, as shown in Table 4-4. Mean errors ranged from -0.63 to 1.57, and relative errors varied from 0.09 to 1.30, with a total of 0.54. Figure 4-1 displays the simulated salinities and observed values for the nine boxes as a function of time. Plots of simulated versus observed values for the entire temporal and spatial domain of the model are shown in Figure 4-7.

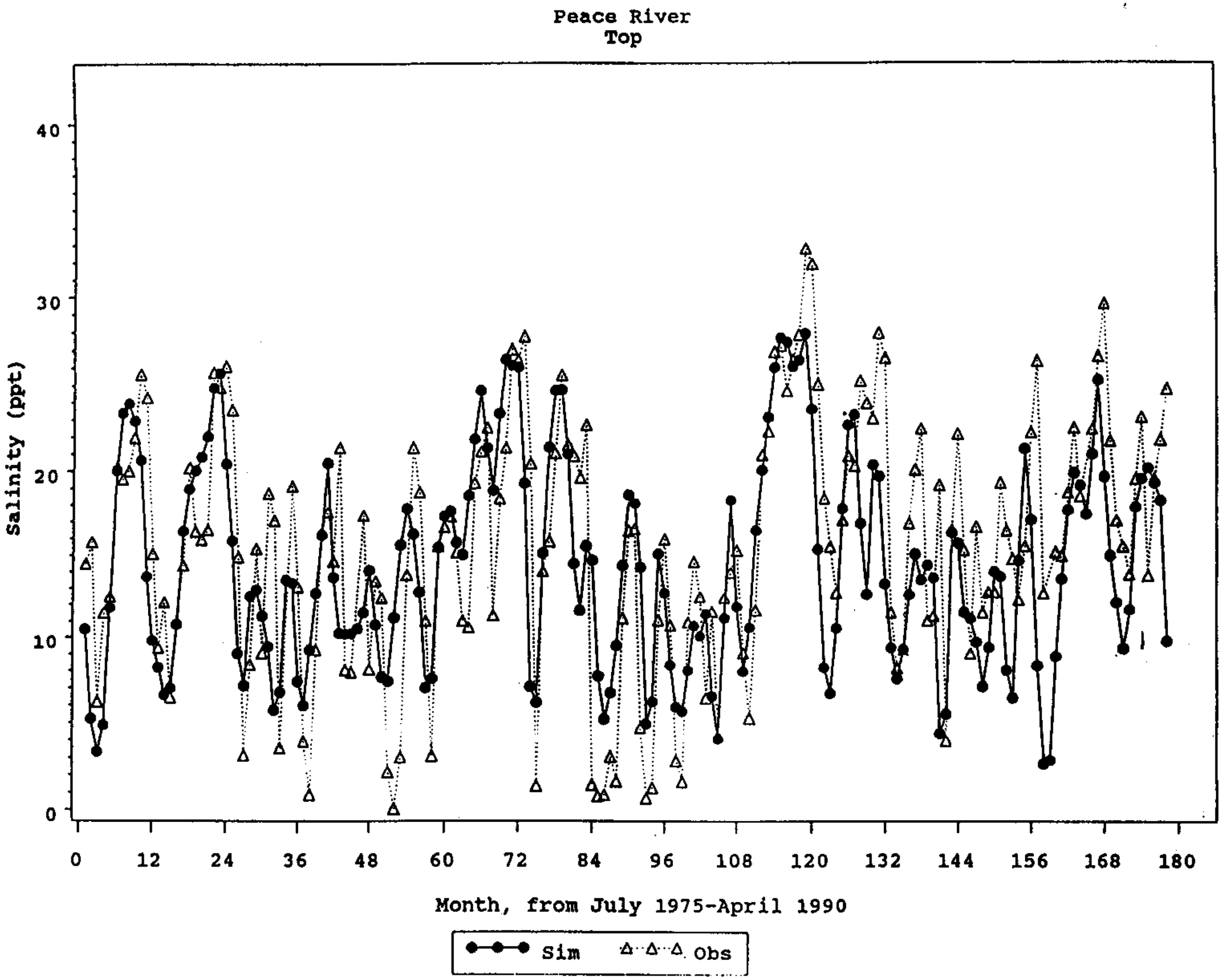

Figure 4-7a. Simulated and observed salinity, calibration, Box 1 (Top Peace River).

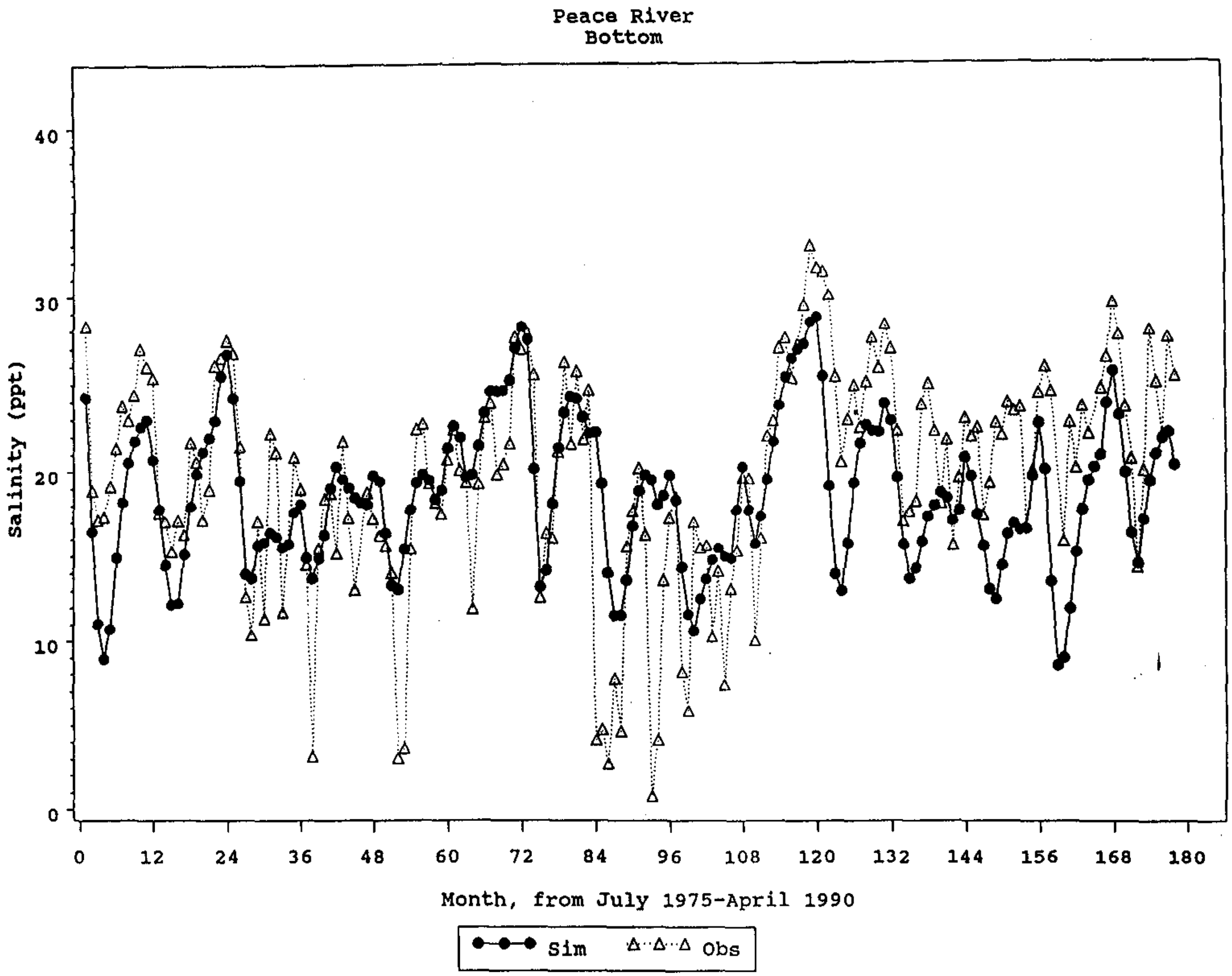

Figure 4-7b. Simulated and observed salinity, calibration, Box 2 (Bottom Peace River).

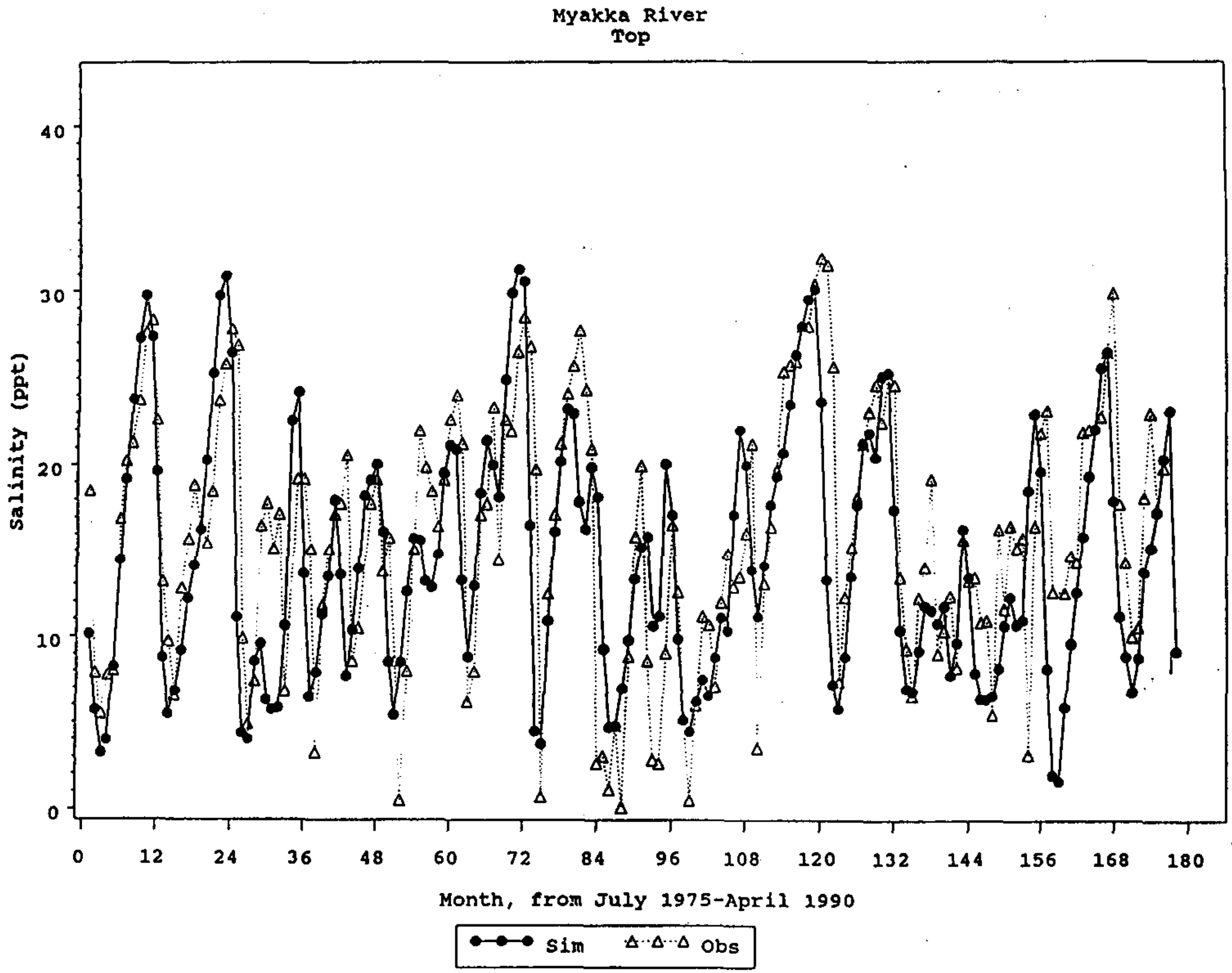

Figure 4-7c. Simulated and observed salinity, calibration, Box 3 (Top Myakka River).

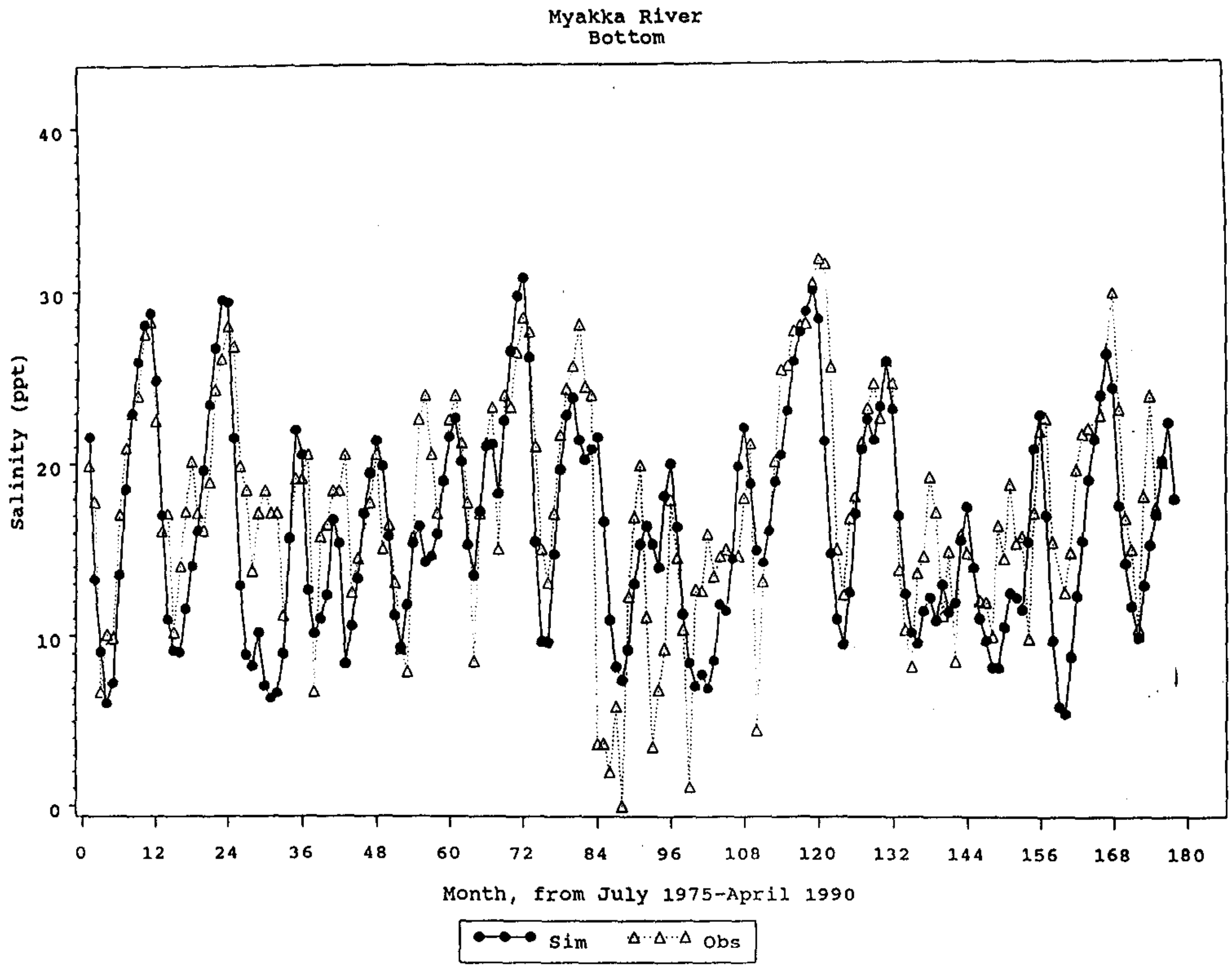

Figure 4-7d. Simulated and observed salinity, calibration, Box 4 (Bottom Myakka River).

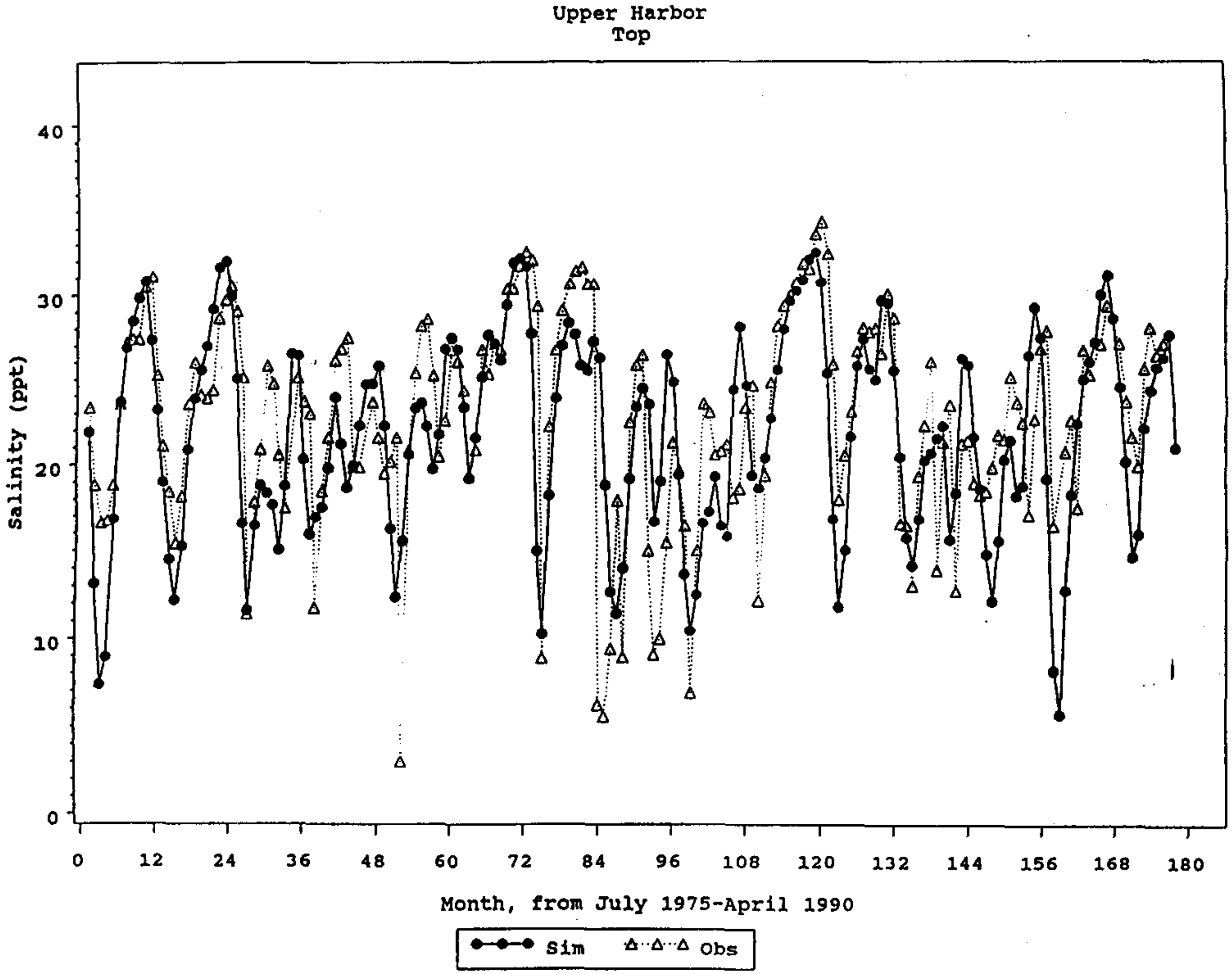

Figure 4-7e. Simulated and observed salinity, calibration, Box 5 (Top Upper Harbor).

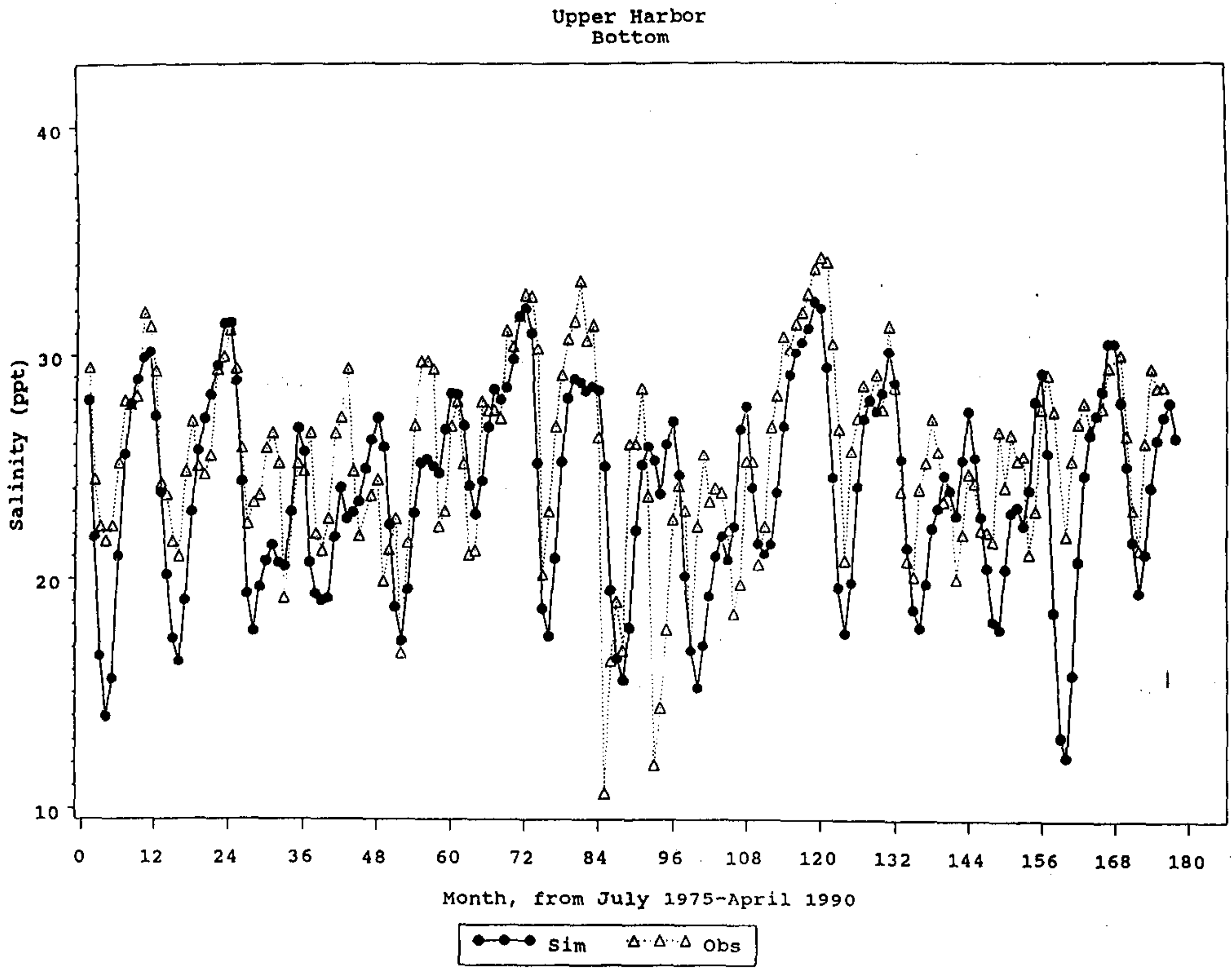

Figure 4-7f. Simulated and observed salinity, calibration, Box 6 (Bottom Upper Harbor).

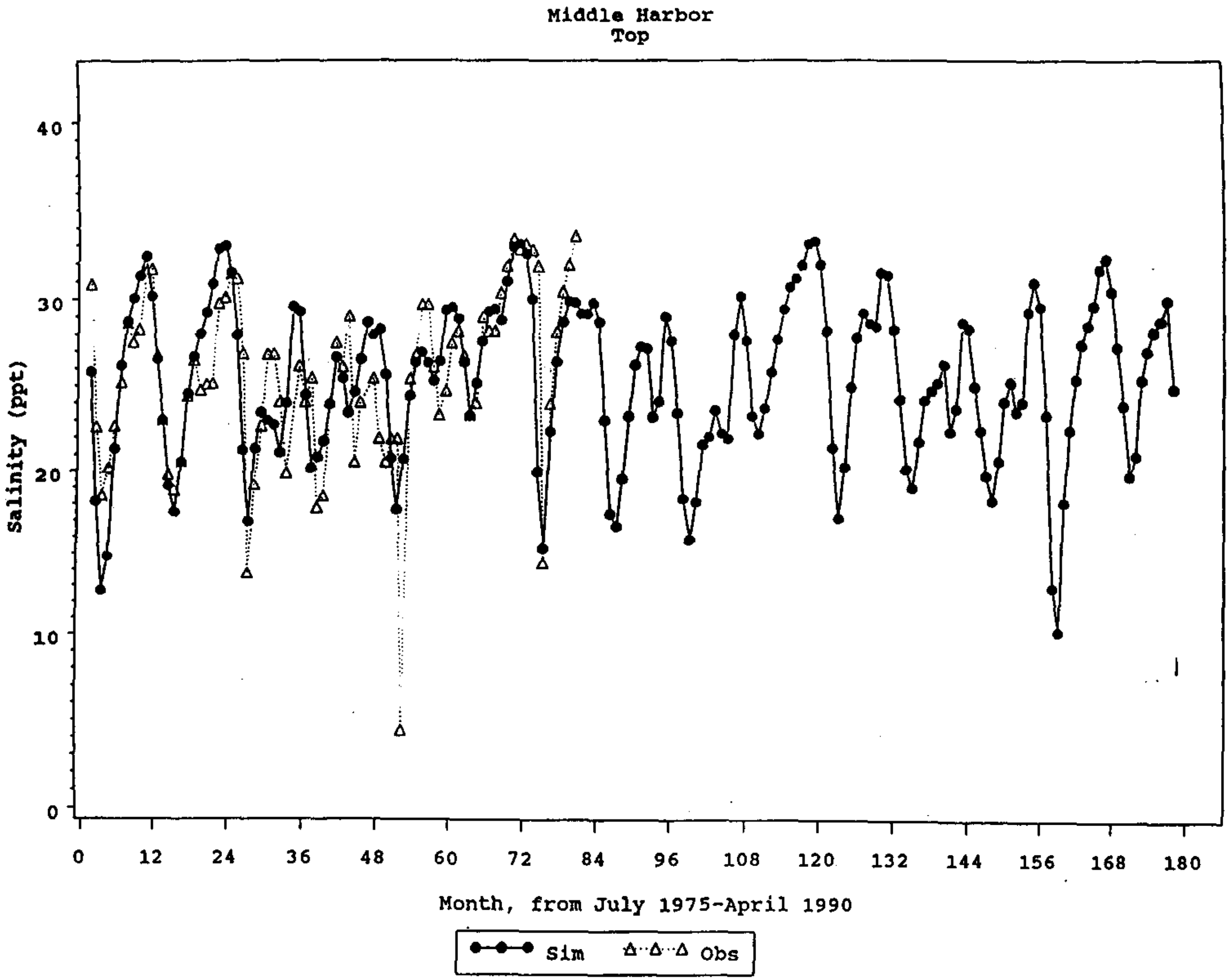

Figure 4-7g. Simulated and observed salinity, calibration, Box 7 (Top Middle Harbor).

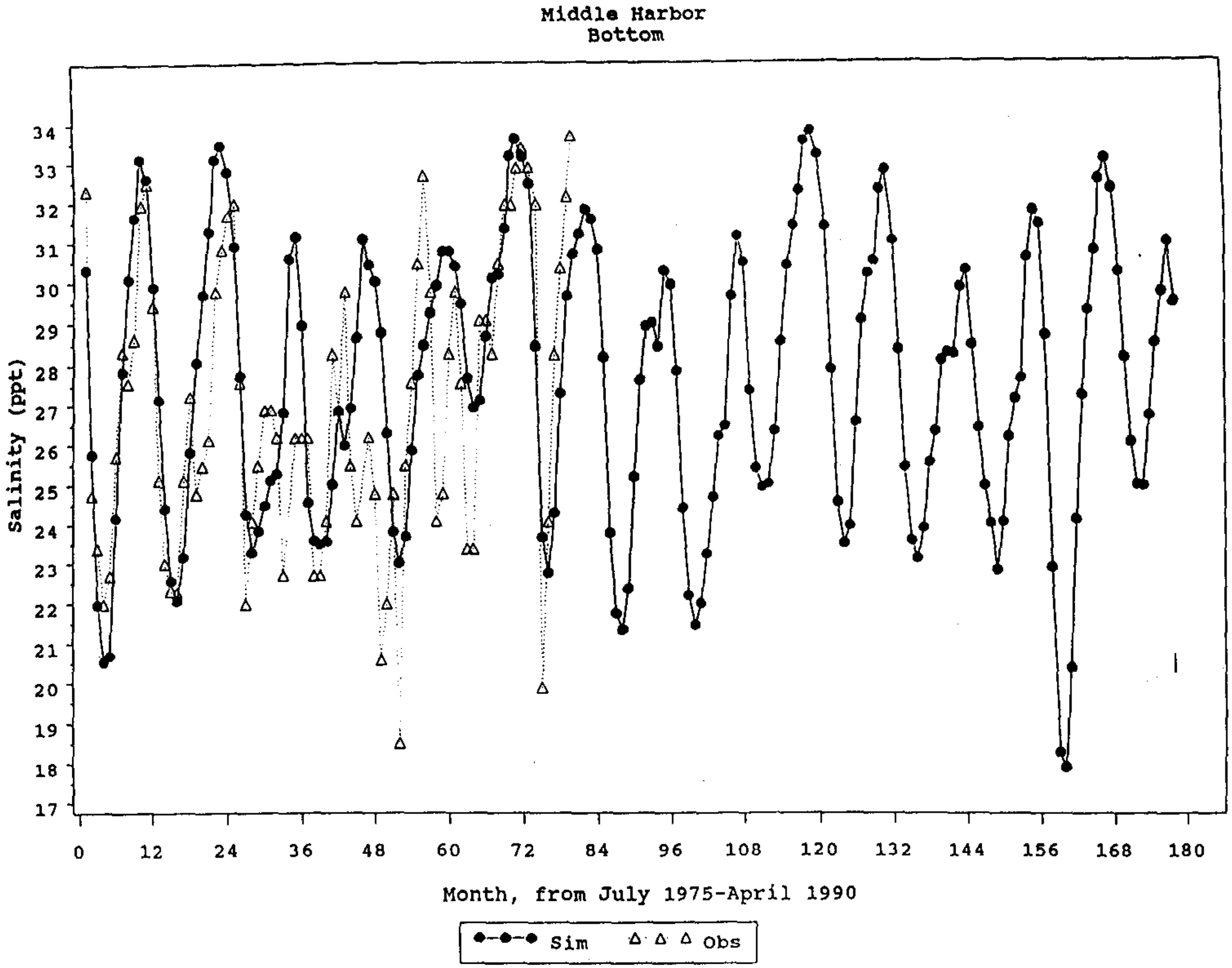

Figure 4-7h. Simulated and observed salinity, calibration, Box 8 (Bottom Middle Harbor).

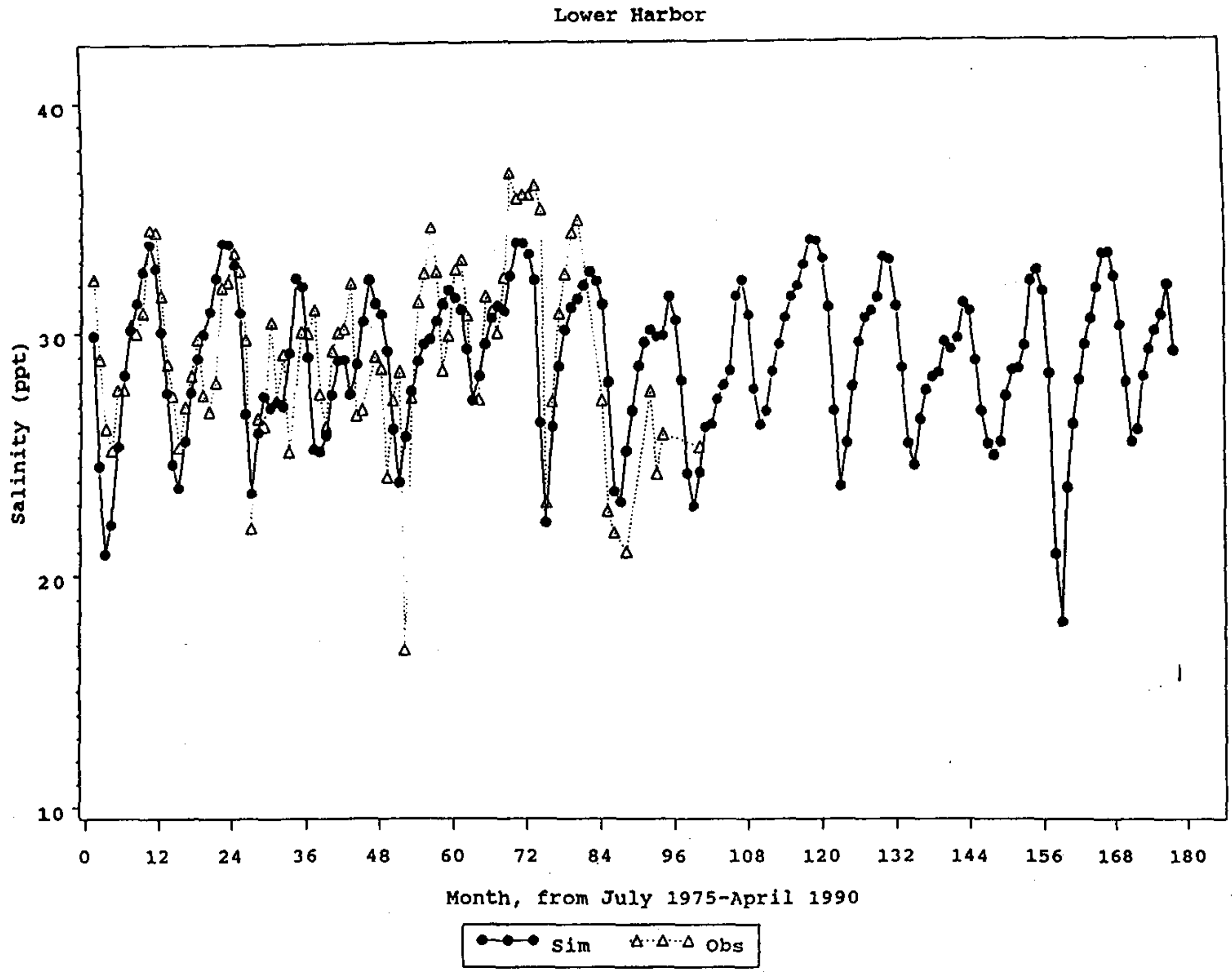

Figure 4-7i. Simulated and observed salinity, calibration, Box 9 (Lower Harbor).

4.2.2 Salinity Balance - Validation

After the simulation was calibrated with salinity for determination of diffusive exchange coefficients, it was necessary to test the model using a dataset from a different time period, during which hydrologic loadings vary from those utilized in the calibration phase. This validation provides a measure of the robustness of the hydrodynamic calculations which is later used to drive the eutrophication model.

A dataset from the SWFWMD contains salinity measurements from 1993 to 1994 over the model domain. A validation run of the model was set up to run over the 23-month period from February 1993 to December 1994 utilizing January 1993 data for initial conditions. Flows and loadings to the simulated system were determined based on calculations for 1993-1994 for the system (Coastal Environmental, 1997). The quarterly diffusive exchange coefficients determined from the calibration run over 1975-1990 were used in this validation run. Some of the results of the parameterization and a summary of the goodness of fit of the hydrodynamic equations are presented in Table 4-5 below.

Table 4-5. Comparisons of simulation results and monthly field observations for salinity, 1993-1994.

SALINITY	MODEL BOX									
	1	2	3	4	5	6	7	8	9	Total
SAMPLE SIZE (n)	24	24	24	23	24	23	23	23	21	209
MEAN ERROR	1.64	4.87	3.49	0.43	0.70	-0.16	1.47	-0.43	1.13	1.49
RELATIVE ERROR	0.29	0.23	0.31	0.90	0.22	0.17	0.12	0.12	0.08	0.27
r	0.76	0.62	0.80	0.76	0.77	0.61	0.85	0.72	0.86	0.85
r^2	0.58	0.39	0.64	0.58	0.59	0.37	0.72	0.52	0.73	0.61

In this validation simulation, coefficients of determination (r^2) for the nine boxes ranged from 0.39 to 0.73, with an r^2 of 0.61 over all nine boxes, as shown in Table 4-5. This overall r^2 is similar to that of the calibration run, 0.58 (see Table 4-4). Mean errors from the validation run ranged from -0.43 to 4.87, and relative errors varied from 0.08 to 0.90, with a total of 0.27, half of the total relative error derived from the calibration run. Figure 4-8 displays the simulated salinities and observed values for the nine boxes as a function of time.

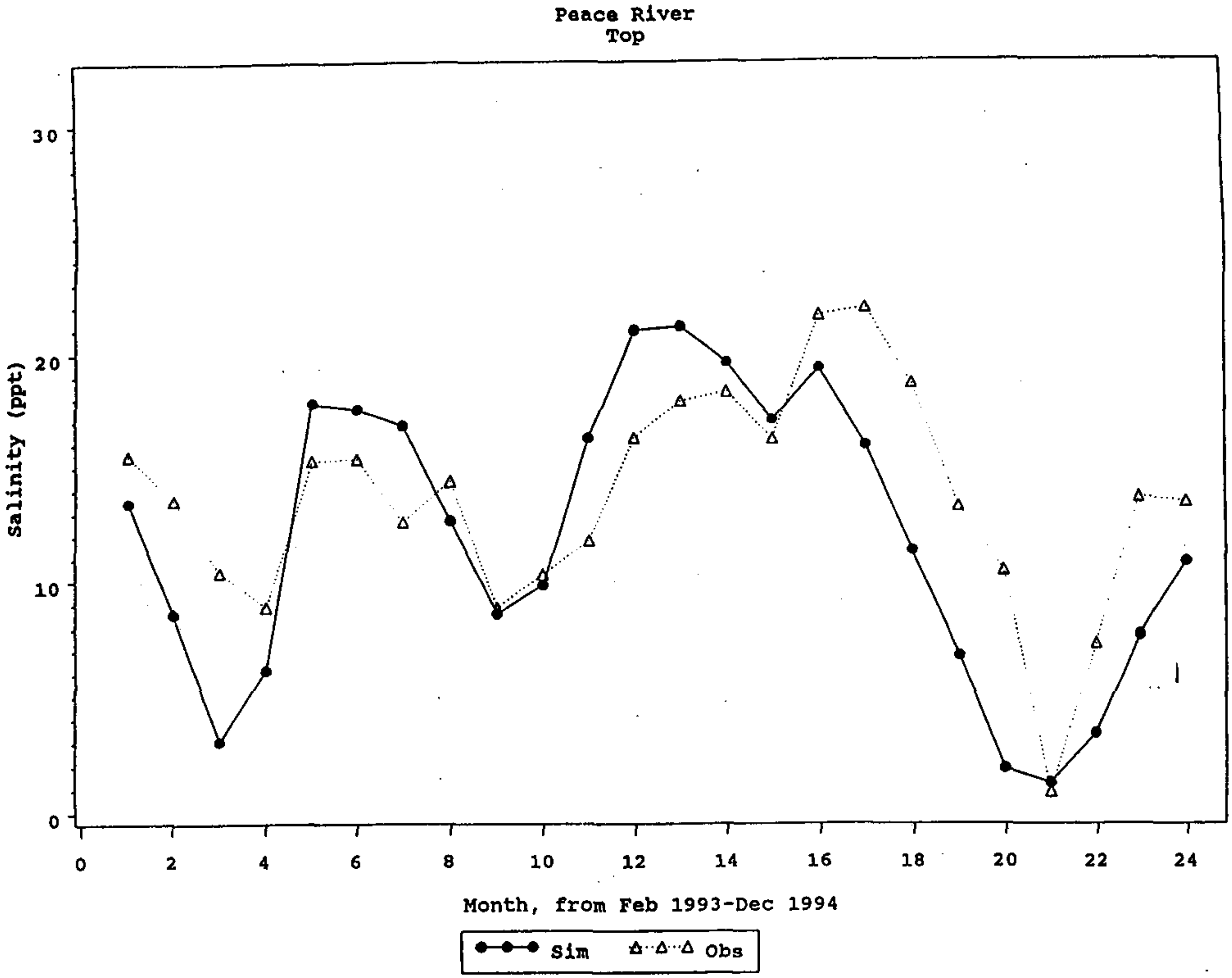

Figure 4-8a. Simulated and observed salinity, validation, Box 1 (Top Peace River).

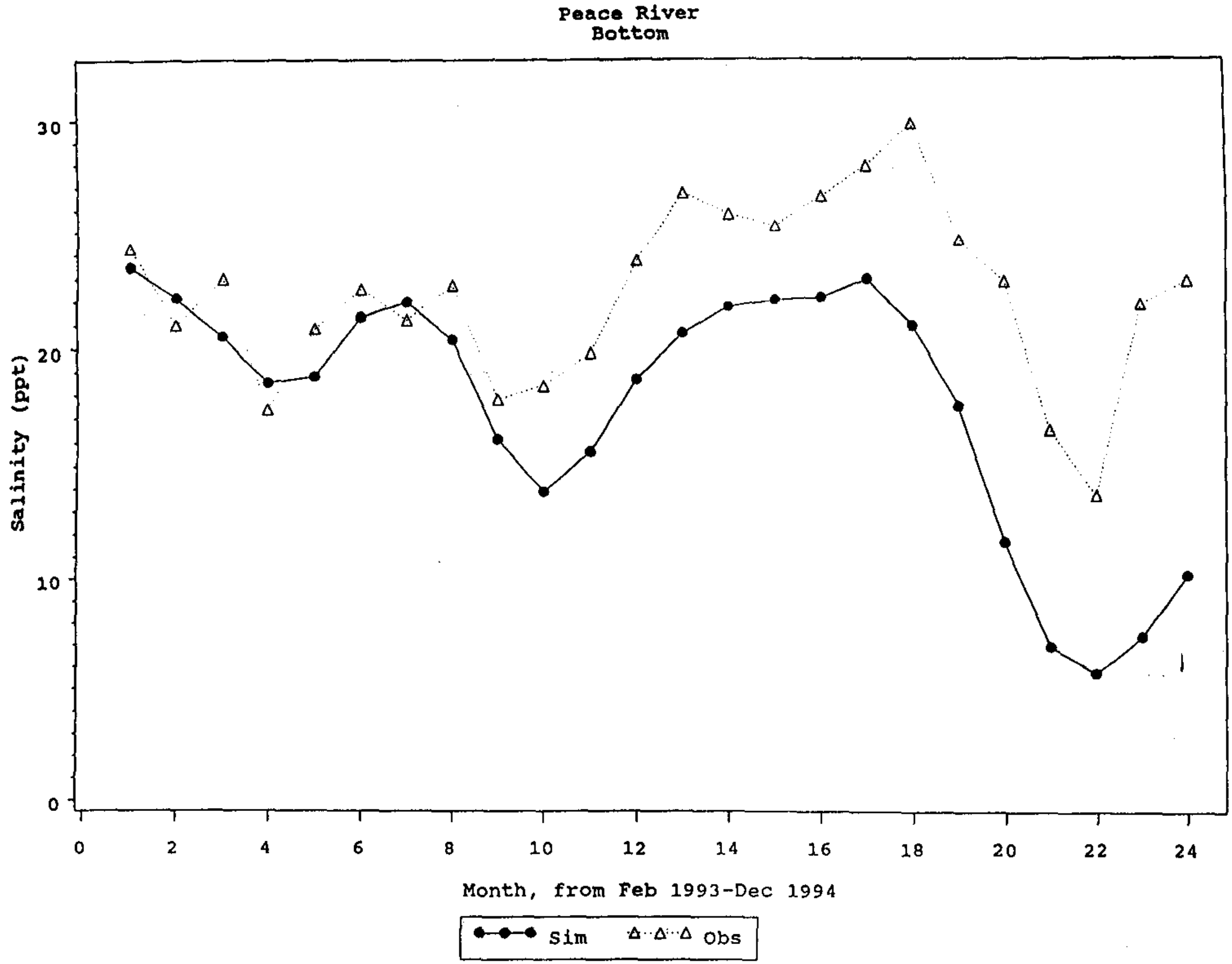

Figure 4-8b. Simulated and observed salinity, validation, Box 2 (Bottom Peace River).

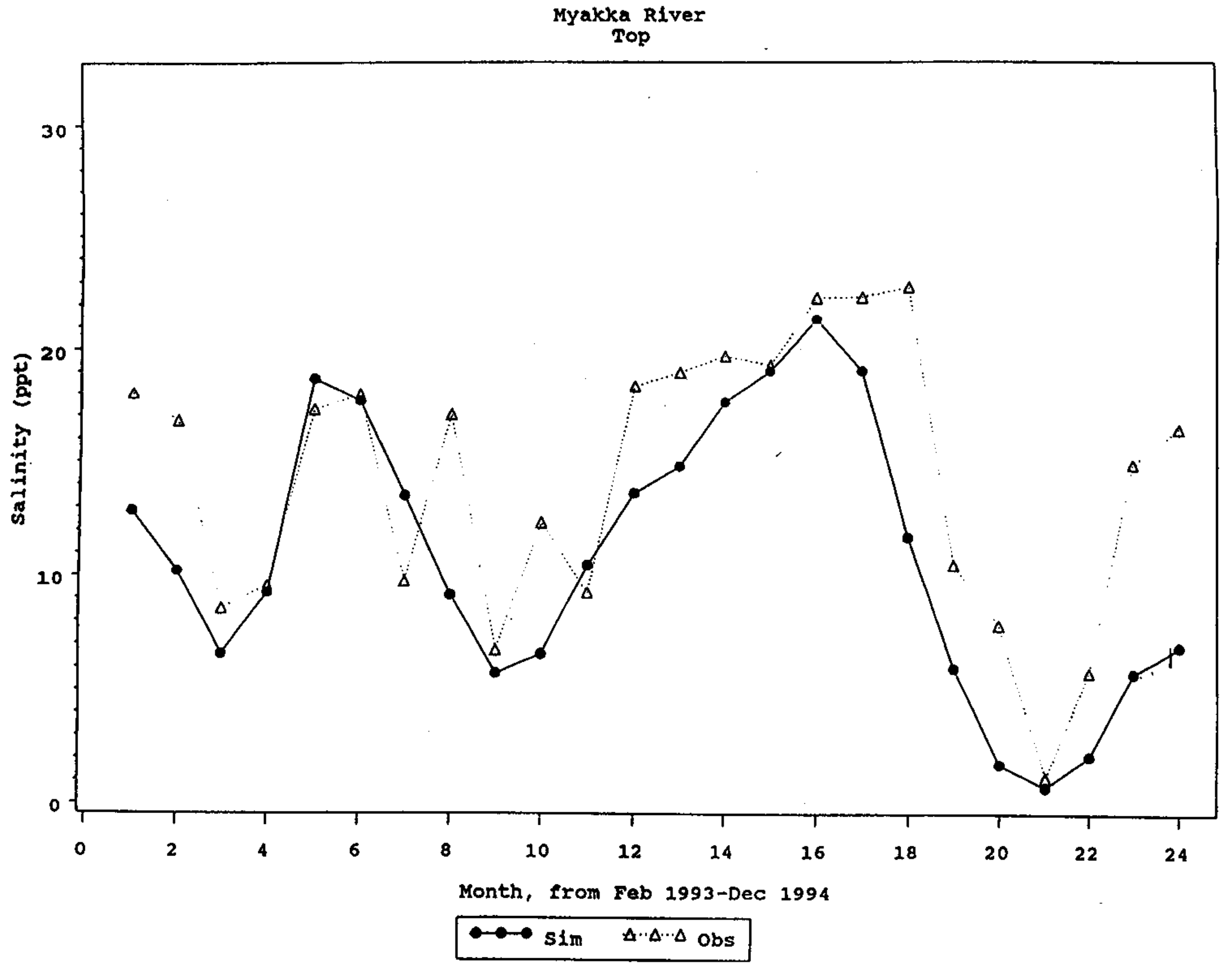

Figure 4-8c. Simulated and observed salinity, validation, Box 3 (Top Myakka River).

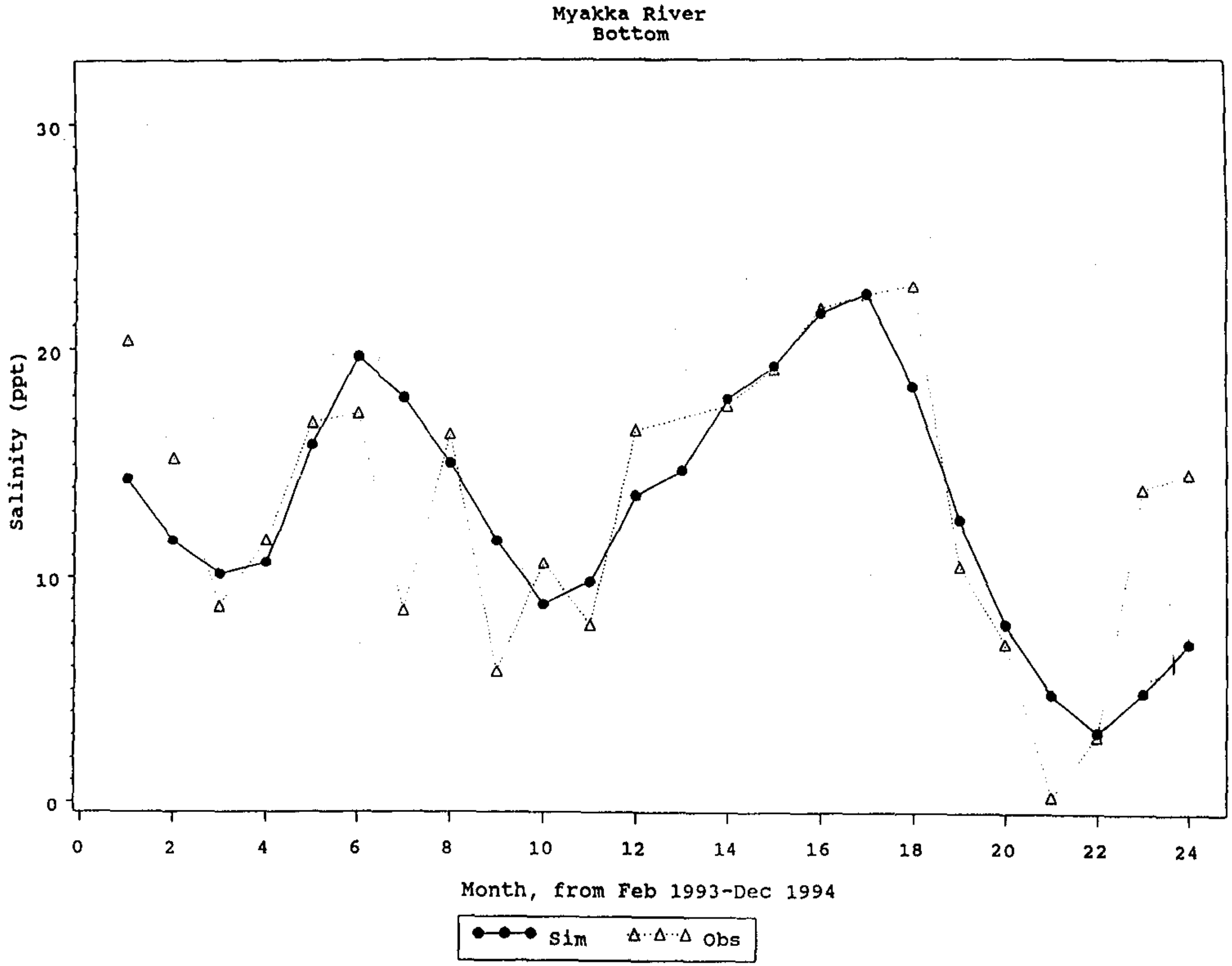

Figure 4-8d. Simulated and observed salinity, validation, Box 4 (Bottom Myakka River).

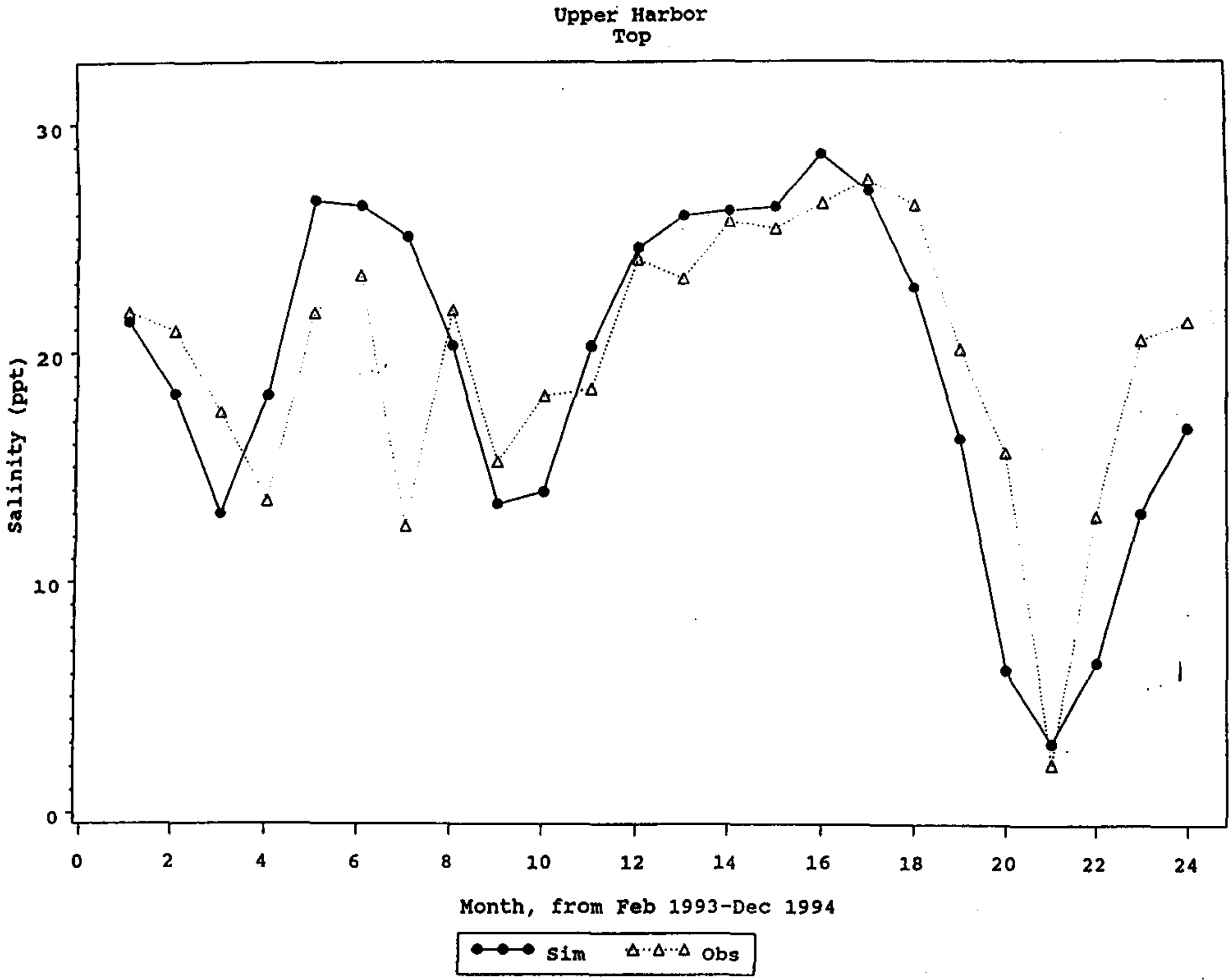

Figure 4-8e. Simulated and observed salinity, validation, Box 5 (Top Upper Harbor).

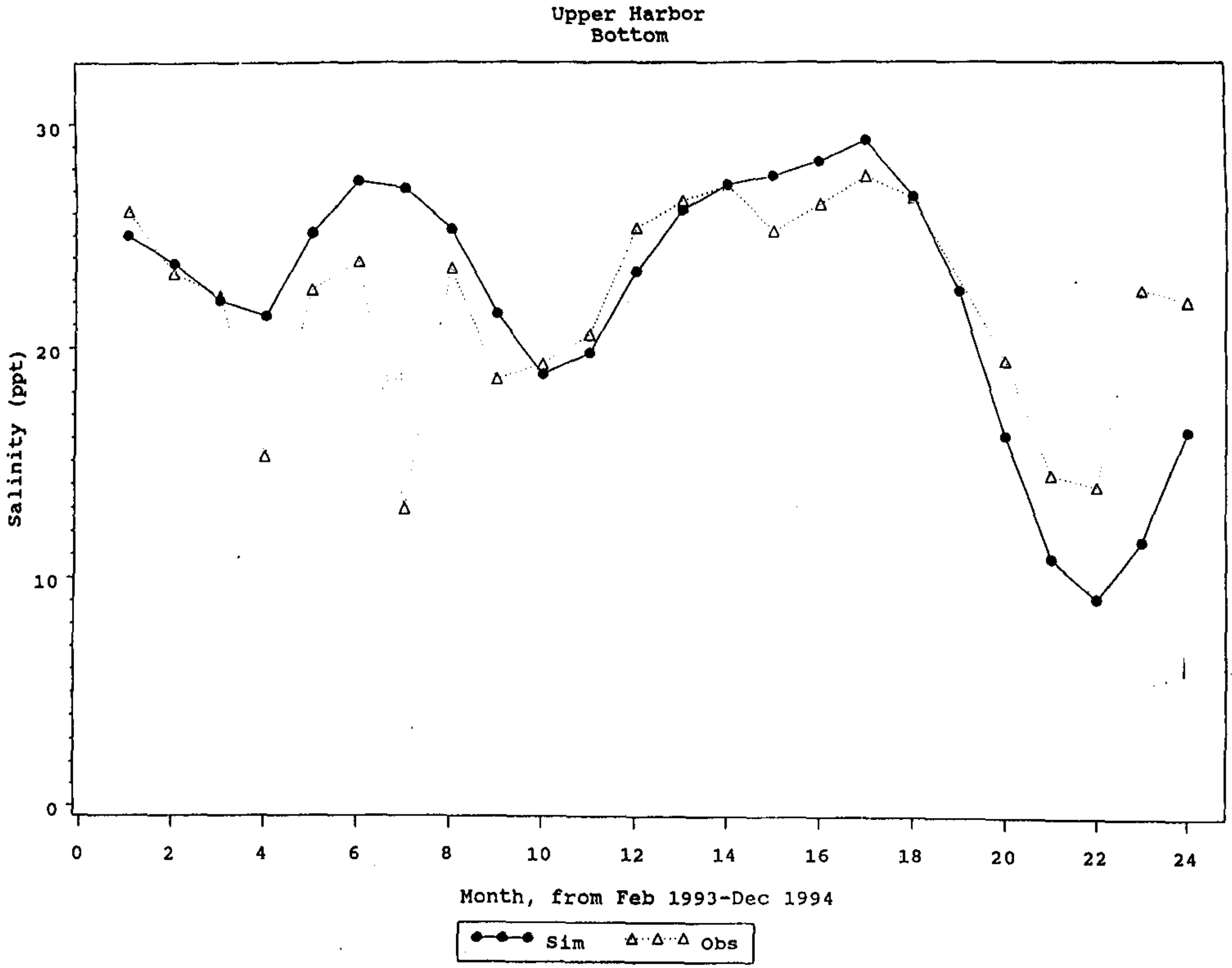

Figure 4-8f. Simulated and observed salinity, validation, Box 6 (Bottom Upper Harbor).

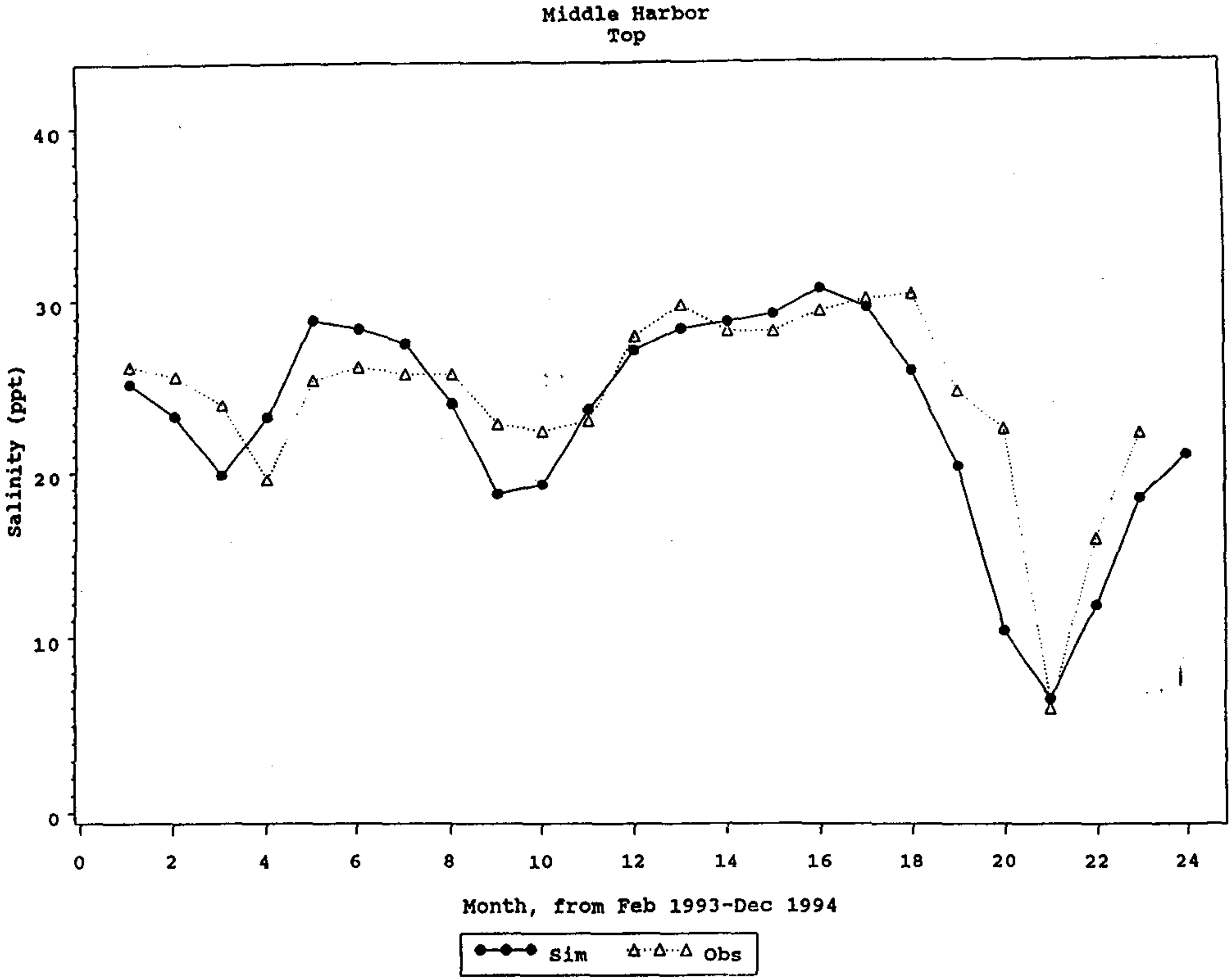

Figure 4-8g. Simulated and observed salinity, validation, Box 7 (Top Middle Harbor).

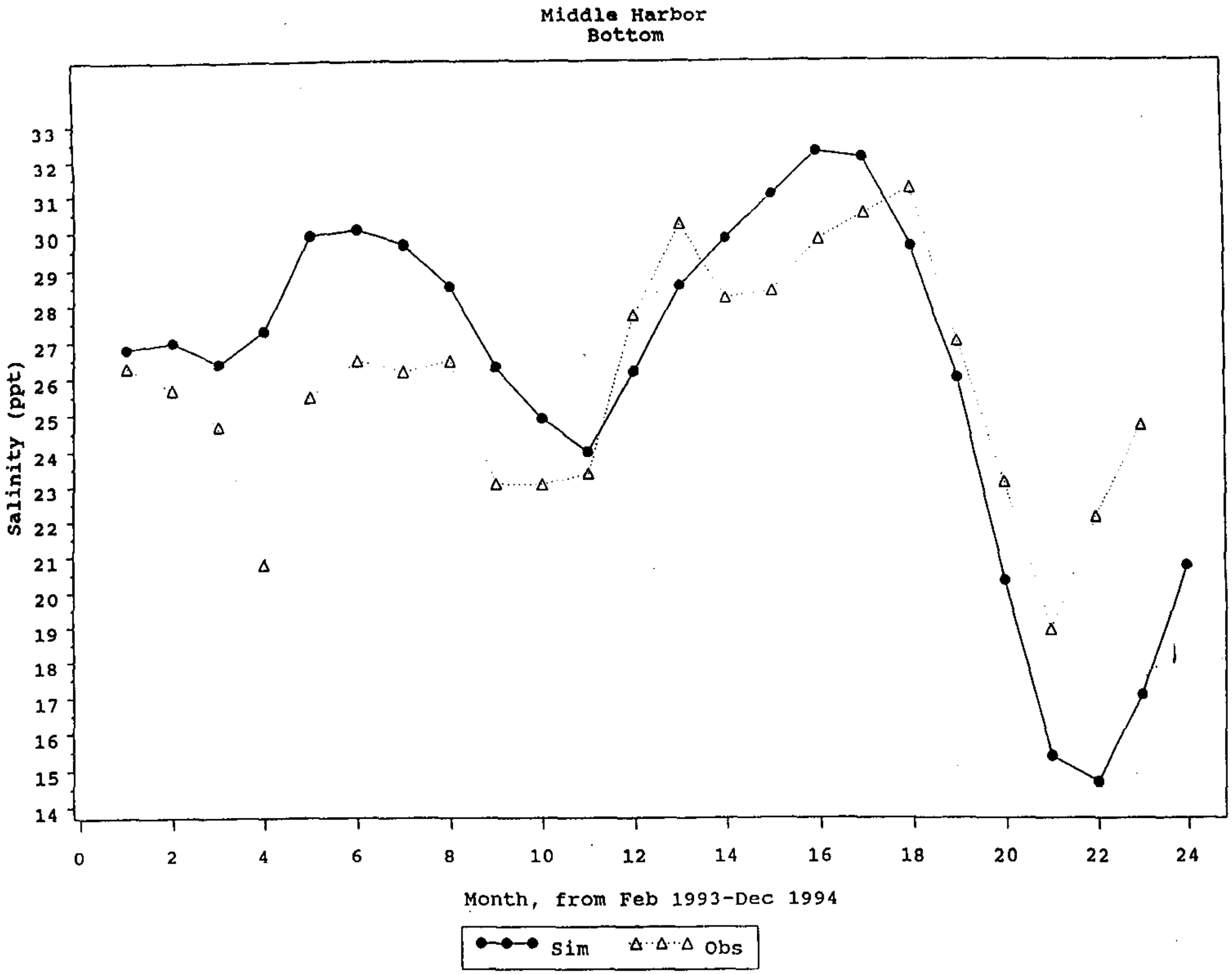

Figure 4-8h. Simulated and observed salinity, validation, Box 8 (Bottom Middle Harbor).

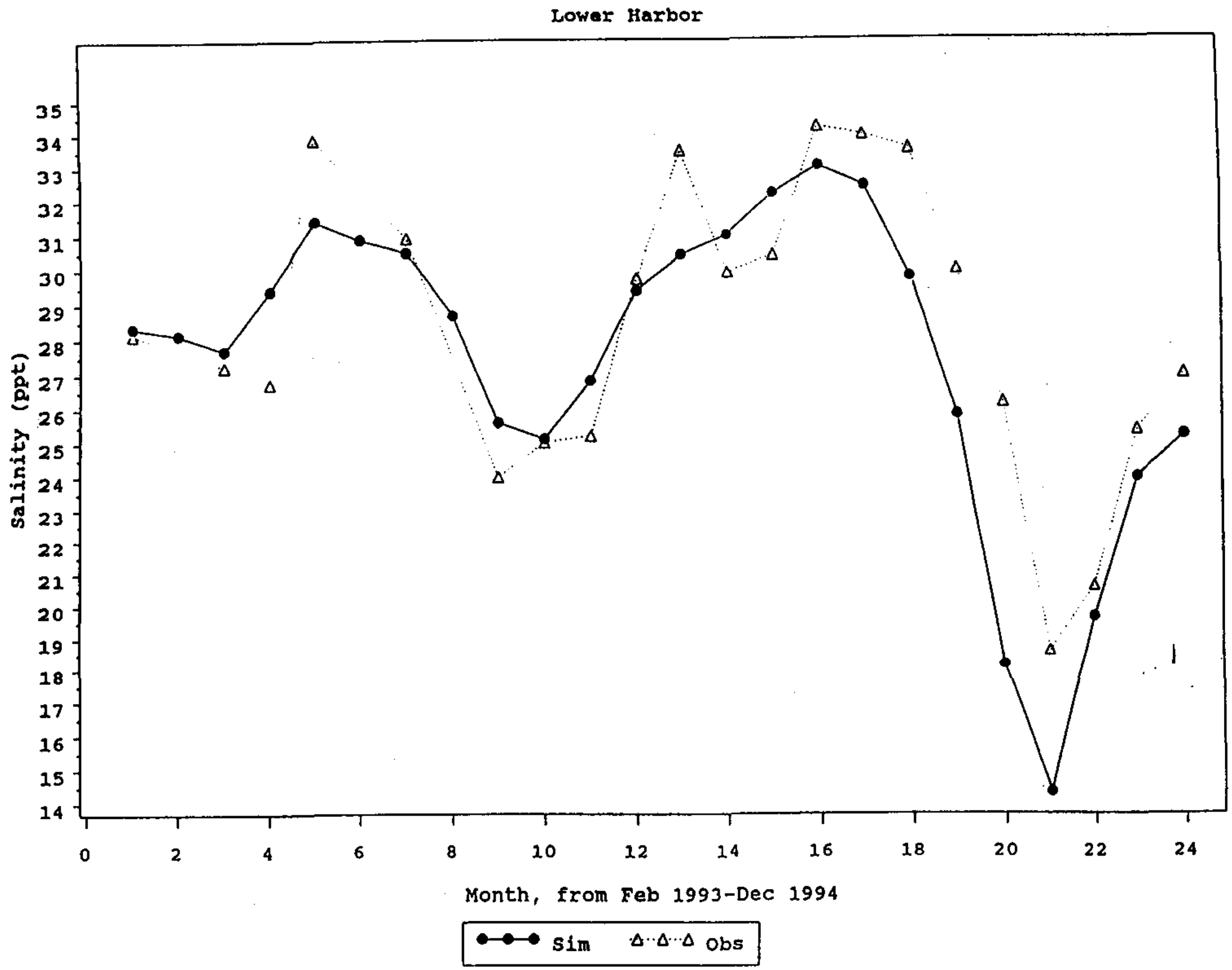

Figure 4-8i. Simulated and observed salinity, validation, Box 9 (Lower Harbor).

The results of the validation model suggest that the diffusive exchange coefficients derived from the 1975-1990 salinity data yield an adequate representation of the hydrodynamics for the 1993-1994 time period as well, despite the disparity in hydrologic loads between the two time periods. Given the robustness of the hydrodynamic simulation, the eutrophication model is constructed utilizing these same diffusive exchange coefficients.

4.2.3 Eutrophication Model Application

The WASP model for the tidal Peace and Myakka rivers and Upper Charlotte Harbor requires input data concerning the physical and chemical parameters of and affecting the system. These parameters were determined for the eutrophication simulation over the July 1978-April 1990 time period utilizing the EQL data set. The eutrophication model was limited to Boxes 1-6 of Figure 4-6, with the downstream boundary condition set by water quality values measured in Boxes 7 and 8, so that only the Peace River, the Myakka River, and the Upper Harbor were subjected to simulation.

Flows and loadings to the simulated system, as mentioned previously, were determined based on calculations for 1975-1990 for the system. Chemical species of nitrogen and phosphorus necessary for the simulation were determined based on the total nitrogen and phosphorus loads. The total nitrogen loads were divided into loads of ammonia, nitrate, and organic nitrogen. The total phosphorus loads were divided into loads of ortho-phosphorus and organic phosphorus. These divisions were based on the ratios of these constituents at upstream stations in the Peace and Myakka rivers, with river-specific ratios determined. Data from the Peace River were from USGS Station 02296750 at Arcadia, with those from the Myakka River from USGS Station 02298830 near Sarasota (Coffin and Fletcher, 1994; 1995). The nutrient loads to the top Upper Harbor box from its watershed were proportioned based on the mean of the ratios utilized for the Peace and Myakka rivers for each constituent. These ratios are given in Table 4-6.

Table 4-6. Nutrient species ratios.

Ratio	Peace River	Myakka River	Upper Harbor
NH_3:TN	0.0327	0.0349	0.0338
NO_3:TN	0.4378	0.0505	0.24415
ON:TN	0.5614	0.9096	0.7355
PO_4:TP	0.9384	0.9317	0.9351
OP:TP	0.0616	0.0683	0.0650

Climatological data used as input to the simulation were air temperature and average daily solar radiation. Air temperature and average daily solar radiation was obtained from databases of the SWFWMD and the National Weather Service. Monthly averaged values of illuminated daylength were determined for the latitude of Charlotte Harbor (Kirk, 1983). Monthly water temperatures were determined for each simulated box based on geometric means of data collected by the EQL over 1978-1990.

The model parameterization also included the input of initial conditions for all simulated water quality parameters as determined by the geometric means of the water quality constituents collected by the EQL in June 1978. Downstream water quality boundary conditions for each simulated month were also determined from data collected by the EQL.

Following parameterization of the model, the model was run for the Peace and Myakka rivers and Upper Harbor using the EQL data collected from July 1978 to June 1990. The eutrophication model was run for simulation of water quality parameters within the system utilizing the exchange coefficients determined from the salinity calibration and validation, and the nutrient loads previously calculated. Rate constants involved in the eutrophication process were varied during the eutrophication calibration tests in an attempt to arrive at a best set of parameters for describing the interactions involved in the simulation of the system.

Rate constants utilized in the model are listed in Tables 4-7 and 4-8. No estimates were available for BOD loadings to the system, and no data for this time period were available for BOD concentrations within the simulated system. Estimates of BOD rate constants were set using values from a similar model of Tampa Bay (Martin et al., 1996). Sediment oxygen demand (SOD) was estimated for each box within the model domain, with values ranging from 0.05 to 0.9 $g\ m^{-2}\ d^{-1}$, with the minimum value for the bottom box of the Myakka River and the maximum value for the bottom box of the Upper Harbor. Both the top and bottom boxes of each segment were subjected to SOD, as the top boxes, being 0.5 m in depth, were in contact with the sediments where the real-world depth was less than 0.5 m. Sediment release rates of ammonia were set to 30 $mg\ m^{-2}\ d^{-1}$, and phosphate release rates to 4 $mg\ m^{-2}\ d^{-1}$ for all boxes, similar to values used for Tampa Bay (Martin et al., 1996).

Simulation results were evaluated utilizing graphical and statistical methods, as discussed previously. The system was initially found to be greatly over-estimating chlorophyll-a concentrations within all boxes, even at a relatively low maximum growth rate. This problem was resolved by initially inputting phytoplankton settling velocities specific for each box, month, and year. After calibration of the settling velocities to provide best matches with the observed chlorophyll-a values, the settling velocities were averaged over quarters for each box. Quarterly settling velocities for each box were then used to arrive at the final box-specific settling velocities used in the model, with values ranging from 0.05 $m\ d^{-1}$ for the top box of the Upper Harbor during October-March to 7.00 $m\ d^{-1}$ for the bottom box of the Peace River during July-September.

Graphical comparisons of average quarterly simulation predictions, from simulation output four times monthly, and the quarterly geometric means of observed data follow for chlorophyll, dissolved oxygen, ammonia, nitrate, organic nitrogen, ortho-phosphorus, and organic phosphorus. The statistical evaluations of the relationships between the simulated and observed data are shown in Tables 4-4 - 4-6.

Table 4-7. WASP rate constants used in Peace and Myakka model.

DESCRIPTION	UNITS	TYPICAL VALUE/RANGE	VALUE USED IN CHARLOTTE HARBOR MODEL
Nitrification rate (20°C)	day^{-1}	0.09[a] 0.02 - 0.2[b]	0.08[c]
Temperature coefficient for nitrification	---	1.08[a] 1.02 - 1.08[b]	1.08[c]
Half-saturation constant for nitrification oxygen limitation	mg O^2/L	2.0[a]	2.0[c]
Denitrification rate (20°C)	day^{-1}	0.09[a] 0.0 - 1.0[b]	0.09[c]
Temperature coefficient for denitrification	---	1.045[a] 1.02 - 1.09[b]	1.04[c]
Half-saturation constant for denitrification oxygen limitation	mg O^2/L	0.1[a]	0.1[c]
Mineralization rate of dissolved organic nitrogen	day^{-1}	0.075[a] 0.02 - 0.075[b]	0.1[c]
Temperature coefficient for ON mineralization	---	1.08[b]	1.07[c]
Mineralization rate of dissolved organic phosphorus	day^{-1}	0.22[a] 0.22[b]	0.27[c]
Temperature coefficient for OP mineralization	---	1.08[a,b]	1.07[c]

[a]Ambrose et al. (1991)
[b]Bowie et al. (1985)
[c]Used in Tampa Bay Model, Martin et al. (1996)

Table 4-8. WASP eutrophication constants used in Peace and Myakka model.

DESCRIPTION	UNITS	TYPICAL VALUE/RANGE	VALUE USED IN CHARLOTTE HARBOR MODEL
Saturation growth rate	day^{-1}	2.0[a] 0.2 - 8[b]	1.20
Temperature coefficient for growth	---	1.068[a]	1.09[c]
Carbon:Chlorophyll ratio	---	21 - 45[a] 10 - 112[b]	100
Saturation light intensity	Ly/day	200 - 350[b]	300
N half-saturation constant for algal growth	mg N/m^3	25[a] 1.5 - 400[b]	0.5
P half-saturation constant for algal growth	mg PO^4-P/m^3	1[a] 0.5 - 30[b]	1[c]
Endogenous respiration rate (20°C)	day^{-1}	0.125[a] 0.02 - 0.6[b]	0.075
Temperature coefficient for respiration	---	1.045[a]	1.05[c]
Non-predatory death rate	day^{-1}	0.02[a] 0.005 - 0.172[b]	0.005[c]
Grazing rate on phytoplankton	L/cell-day	0.0[a]	0.0[c]
Phosphorus:Carbon ratio	---	0.025[a] 0.005 - 0.05[b]	0.027[c]
Nitrogen:Carbon ratio	---	0.25[a] 0.05 - 0.43[b]	0.15[c]
Oxygen:Carbon ratio	---	2.67[a]	2.67[c]

[a]Ambrose et al. (1991)
[b]Bowie et al. (1985)
[c]Martin et al. (1996)

4.2.4 Simulation Problems

The primary effort in the attempt to calibrate the eutrophication model was towards simulating chlorophyll and dissolved oxygen values representative of those from the data record. It is obvious from the statistical analysis of the chlorophyll results (Table 4-9) that this effort was not effective for this variable. The dissolved oxygen results (Table 4-9), while somewhat better, were still not useful enough to serve as a predictive tool in understanding the response of the water body to loadings. Given the inability of the simulation to predict chlorophyll and oxygen, it is not surprising that the model also yields results for the other water quality variables simulated (Tables 4-10 and 4-11) which are not representative of the measured data.

The lack of fit of the simulated chlorophyll in comparison to that observed may be the result of several factors. Limitations on the data available for the study were found. The EQL fixed-station database for 1975-1990 does not include light attenuation depths, so that no observed light attenuation due to chlorophyll and color was included in the simulation. Light attenuation due to color can often be the controlling factor on realized phytoplankton growth rates in the tidal rivers (EQL, 1992). Data measurements only occurred once monthly, so that the data record is sparse temporally, and no monthly average for a representative point within each box may be obtained. Additionally, very few chlorophyll measurements were obtained for the bottom boxes of the tidal Peace and Myakka rivers and the Upper Harbor (see Table 4-9). Spatially, only one datapoint existed in the tidal Myakka segment of the model, and only one datapoint existed in the downstream boundary condition segment, the Middle Harbor segment. This also presents problems of representativeness of data measurements when used as mean conditions for an entire box volume. Other limitations on the simulation were imposed by the EUTRO5 model construct itself. Perhaps most importantly is the inability of the model to vary growth rates in time and space, which is necessary to accurately represent varying algal assemblages. The surrogate used for growth rate variation, chlorophyll settling, results in confounding the simulation by rearranging chlorophyll concentrations vertically in this two-layered model, and thus affects concentration gradients and fluxes between boxes of all water quality variables.

Comparison of the observed and simulated chlorophyll data is shown in Figure 4-9 for the top boxes of the Peace and Myakka rivers and the Upper Harbor. It should be noted that, although the patterns of high and low chlorophyll values observed are not always matched temporally, the simulated chlorophyll biomass is of the same order of magnitude as the observed chlorophyll concentration in most cases, the exception being those periods during which the highest observed chlorophyll peaks occurred. The observed chlorophyll peaks do not always occur during the same quarter of each year, possibly because of the real-world variation of phytoplankton assemblage makeup in response to varying flow regimes and loadings of nutrients and color. In using a quarterly-specific algal settling velocity as a surrogate for varying species assemblages and growth rates, it becomes difficult to match low chlorophyll signals and high chlorophyll signals within the same quarter of different years.

Because of the lack of fit of the simulated water quality variables in comparison to those observed during the calibration attempt, the eutrophication model was not tested using the SWFWMD validation data set.

Table 4-9. Comparisons of simulation results and monthly field observations for chlorophyll and dissolved oxygen, 1978-1990.

CHLOROPHYLL-A	MODEL BOX						
	1	2	3	4	5	6	Total
SAMPLE SIZE (n)	48	7	47	6	47	6	161
MEAN ERROR	0.25	1.04	1.95	6.62	2.61	1.85	1.77
RELATIVE ERROR	0.49	0.80	0.59	0.72	0.54	0.38	0.55
r	0.14	0.11	0.04	0.90	0.47	0.35	0.46
r^2	0.02	0.01	0.00	0.81	0.22	0.13	0.21

DISSOLVED OXYGEN	MODEL BOX						
	1	2	3	4	5	6	Total
SAMPLE SIZE (n)	48	48	47	47	47	47	284
MEAN ERROR	-0.66	-0.65	-0.75	0.46	-0.60	2.01	-0.04
RELATIVE ERROR	0.14	0.79	0.15	0.30	0.13	0.58	0.35
r	0.57	0.28	0.57	0.70	0.34	0.69	0.48
r^2	0.33	0.08	0.33	0.49	0.12	0.48	0.23

Table 4-10. Comparisons of simulation results and monthly field observations for ammonia, nitrate, and organic nitrogen, 1978-1990.

AMMONIA	MODEL BOX						
	1	2	3	4	5	6	Total
SAMPLE SIZE (n)	38	38	37	37	37	37	224
MEAN ERROR	-0.04	0.06	0.03	0.02	-0.01	0.04	0.02
RELATIVE ERROR	4.64	0.82	1.19	4.12	7.44	6.19	4.05
r	0.02	0.00	-0.19	-0.44	0.23	-0.47	-0.12
r^2	0.00	0.00	0.04	0.19	0.05	0.22	0.01

NITRATE	MODEL BOX						
	1	2	3	4	5	6	Total
SAMPLE SIZE (n)	38	38	37	37	37	37	224
MEAN ERROR	0.05	0.00	0.02	-0.01	-0.03	-0.01	0.01
RELATIVE ERROR	1.07	6.11	3.58	11.29	11.21	6.75	6.64
r	0.27	0.19	-0.18	-0.31	0.42	0.10	0.51
r^2	0.07	0.03	0.03	0.10	0.18	0.01	0.26

ORGANIC NITROGEN	MODEL BOX						
	1	2	3	4	5	6	Total
SAMPLE SIZE (n)	37	37	37	37	36	36	220
MEAN ERROR	0.29	0.60	0.49	0.67	0.01	0.22	0.38
RELATIVE ERROR	0.29	0.76	0.58	0.84	0.24	0.39	0.52
r	0.51	0.01	0.27	-0.08	0.36	-0.07	0.10
r^2	0.26	0.00	0.07	0.01	0.13	0.01	0.01

Table 4-11. Comparisons of simulation results and monthly field observations for orthophosphorus and organic phosphorus, 1978-1990.

ORTHO-PHOSPHORUS	MODEL BOX						
	1	2	3	4	5	6	Total
SAMPLE SIZE (n)	48	48	47	47	47	47	284
MEAN ERROR	0.05	0.25	0.19	0.22	0.08	0.15	0.16
RELATIVE ERROR	0.34	0.69	0.87	0.93	0.40	0.80	0.67
r	0.56	0.51	0.21	0.06	0.75	0.68	0.68
r^2	0.32	0.26	0.05	0.00	0.57	0.47	0.47

ORGANIC PHOSPHORUS	MODEL BOX						
	1	2	3	4	5	6	Total
SAMPLE SIZE (n)	48	48	47	47	47	47	284
MEAN ERROR	-0.01	0.01	0.00	0.03	-0.03	-0.01	0.00
RELATIVE ERROR	0.99	0.86	0.95	0.59	3.11	2.89	1.56
r	0.40	0.01	0.33	0.40	0.54	-0.04	0.14
r^2	0.16	0.00	0.11	0.16	0.29	0.00	0.02

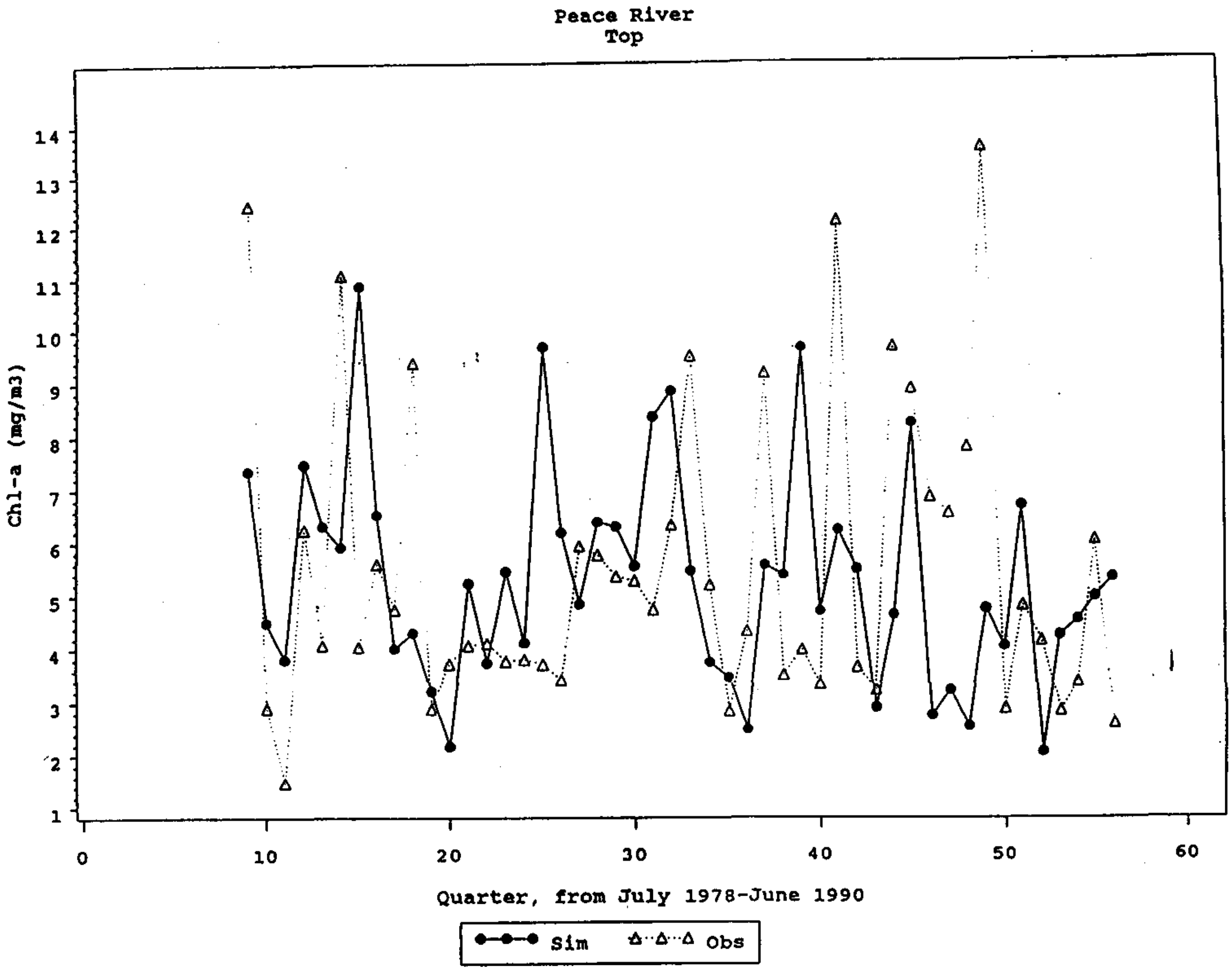

Figure 4-9a. Simulated and observed chlorophyll, Box 1 (Top Peace River).

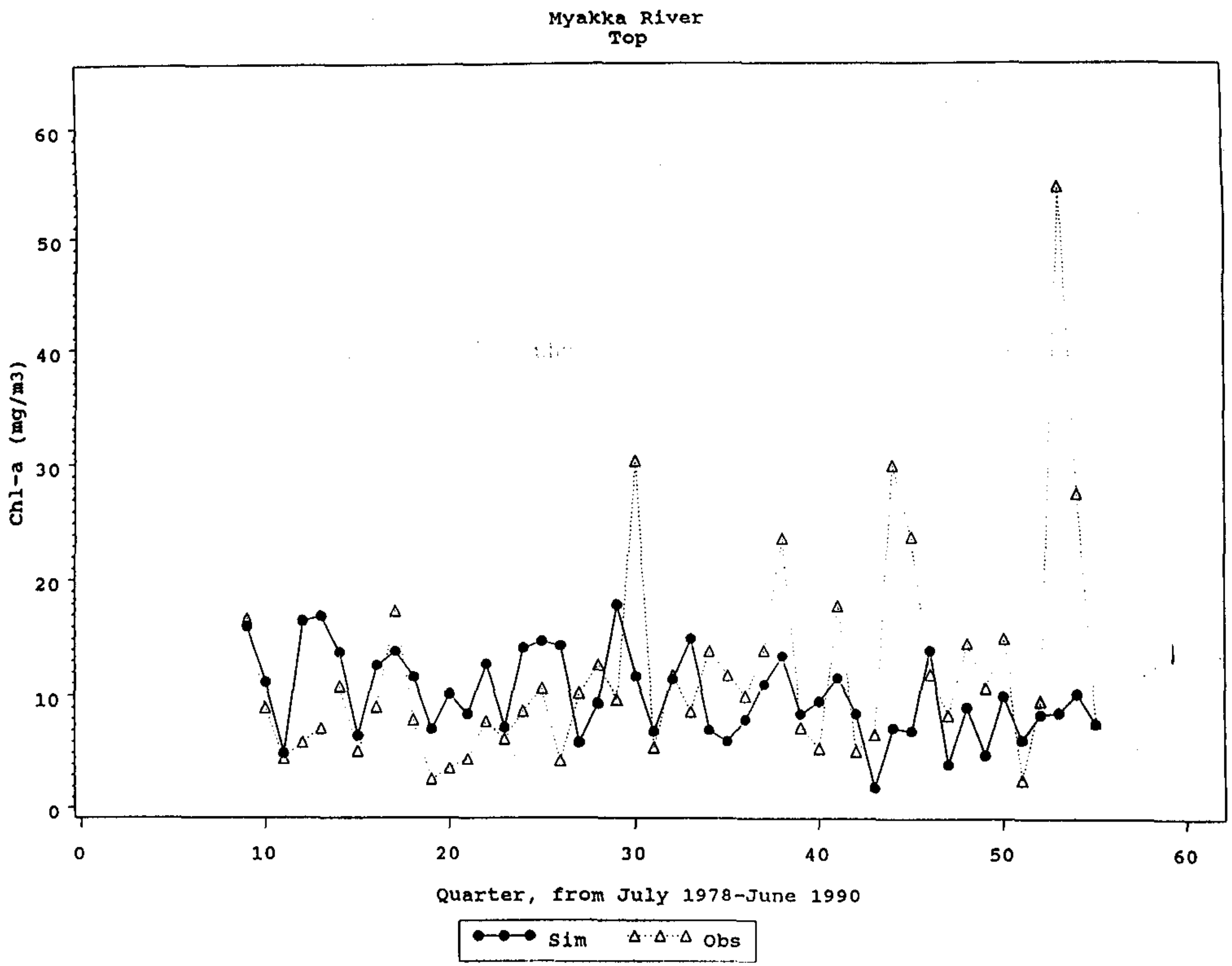

Figure 4-9b. Simulated and observed chlorophyll, Box 3 (Top Myakka River).

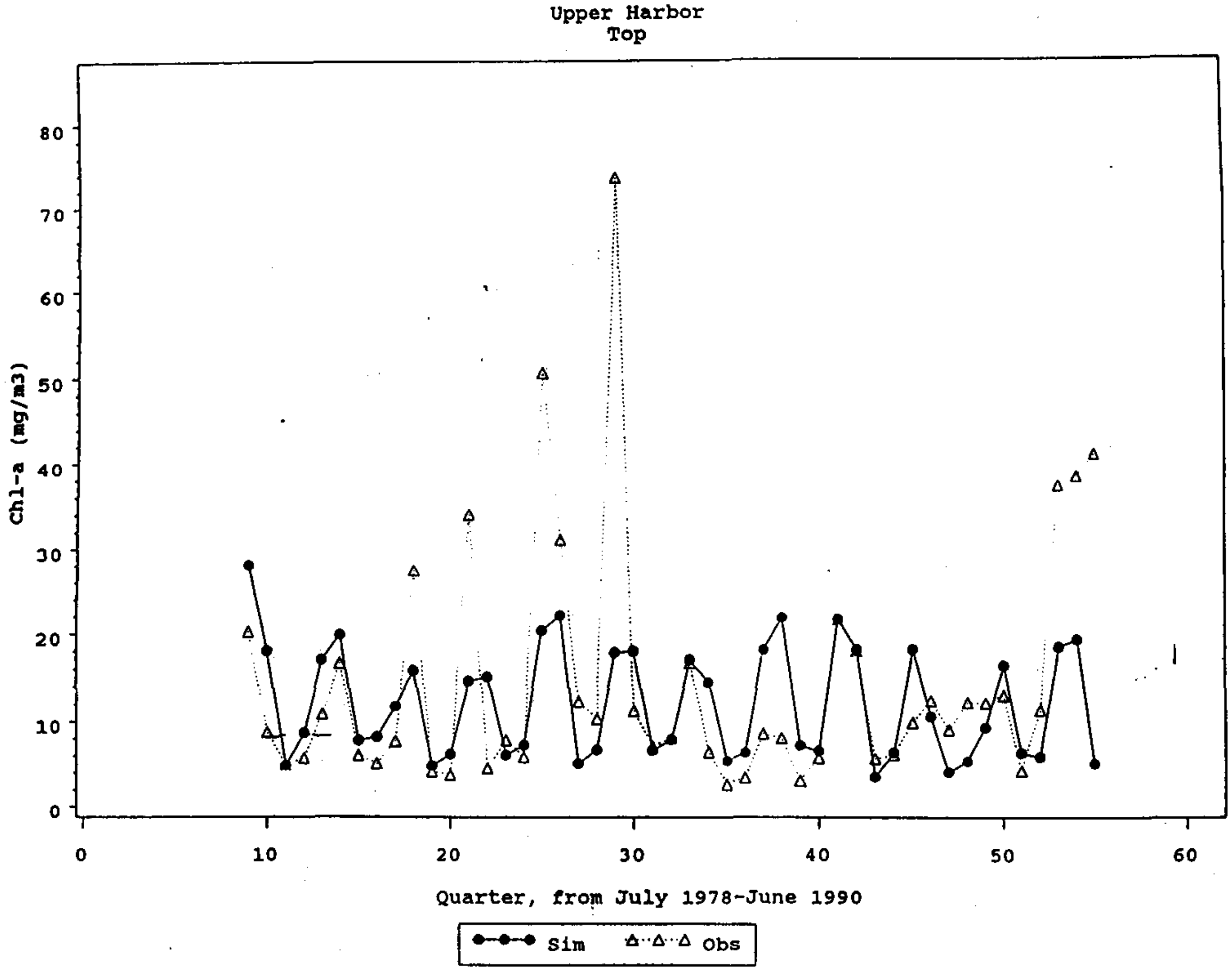

Figure 4-9c. Simulated and observed chlorophyll, Box 5 (Top Upper Harbor).

5.0 CONCLUSIONS

The tidal reaches of the Peace and Myakka rivers are potentially vulnerable to eutrophication and other water quality impacts caused by pollutant loadings discharged from their watersheds. The objective of this project was to investigate the existing water quality and loading data for these rivers, and to provide a technically sound foundation for the management of their water quality. In particular, the focus was on developing potential alternative methods for the establishment of Pollutant Load Reduction Goals (PLRGs).

Analyses of historical data support findings of declining phosphorus concentrations in the Peace River and possible increasing nitrogen levels. However, there is no direct evidence as to how such concentrations compare to ambient levels prior to the late 1970s. Estimated changes in land use indicate substantial increases in residential, commercial, industrial, and mining land uses in the Charlotte Harbor watershed between 1950 and 1990. Such changes, as well as subsequent environmental regulations reducing point source discharges, may have resulted in changes in the water quality of freshwater inflows into the estuary. However, at present there is no hard evidence to support or disprove such conjectures.

Selection of PLRGs should ideally be based on estimating the maximum level of pollutant loading that can be assimilated by the system without resulting in unacceptable degradation of resources within the estuarine system. If the maximum "acceptable" loading level is exceeded, then the potential exists for the development of conditions under which selective uses of the harbor's living resources could be impaired. If relationships between pollutant loadings and watere quality cannot be clearly established, however, more subjective methods of PLRG selection may be requires, while pursueing other monitoring and modeling efforts using current methods and available data.

There are several resources of concern whose uses may either be currently impaired, or may well become so in the future in the absence of appropriate resource management. Resources which may be at risk due to the potential for future increased nutrient loadings are those affected by hypoxic conditions in the lower Peace River and Upper Harbor. Currently there are at least two impaired uses of resources in the study area associated with poor water quality; excessive algal blooms reduce the ability of the Peace River/Manasota Regional Water Supply Authority to withdraw water from the Peace River; and shellfish beds are subject to closure in the region due to high bacterial counts.

Two methods of relating loadings to water quality conditions were utilized in this study. Empirical and mechanistic models were assessed for their abilities to relate hydrology, nutrient loadings, and water quality for the study area.

For the empirical approach, statistically methods were used to describe relationships between external nitrogen loads and water quality indicators without regard to internal processes which may affect the responses of these indicators (e.g., loss of nutrients to sediments, internal load sources, internal cycling, temperature, etc.). The variation in these relationships was reported with the empirical regression results. Under any given nutrient load, this variation represents the range of water quality conditions that the biota in the rivers will likely be exposed to.

Several water quality variables measured by the EQL and the SWFWMD SWIM were considered appropriate as potential living-resource water quality targets and/or indicators of trophic state conditions in the tidally influenced river reaches. These parameters included TN, TP, TN:TP ratio, chlorophyll-a, and compensation depth (operationally defined as the depth of penetration of 1% of the surface light).

Comprehensive analyses of available data showed several trends, listed below.

- Within the tidal river reaches, an increasing trend in time in median annual TN:TP ratio was observed in the Middle Peace River (14-21.5 km downstream of the mouth of Horse Creek) segment and the Lower Peace and Myakka River segments. The increasing trend in TN:TP was primarily associated with a long-term decreasing trend in TP concentrations.

- Loads from the Peace River watershed were strongly related to color and water clarity in the tidal reaches of the Peace River. Higher loads are associated with higher color and lower water clarity in the tidal river segments.

- No direct relationships were found between river loadings and the living resource response variables of TSI and chlorophyll-a measured in the tidally influenced segments of the rivers.

- Peace River loads were more strongly related to trophic state (TSI) in the Lower Myakka River than were loadings from the Myakka River itself.

- Although some relationships (correlations) were stronger than others, no direct relationships were found between living resource response variables (TSI, chlorophyll-a) measured in the tidal portions of the Peace or Myakka rivers and estimated loadings delivered to those tidally influenced areas.

The relationship of total external nitrogen load to chlorophyll-a concentration was investigated using nitrogen loading estimates and chlorophyll-a concentration observations from the EQL fixed station data and the EQL salinity-based station data. The regression analysis indicated that no direct relationship occurred in the Upper and Lower Peace River segments (2-14 km downstream and 21.5-30 km downstream, respectively, of the mouth of Horse Creek). However, a significant relationship was observed for the Middle Segment of the tidal Peace River.

The relationship of chlorophyll-a concentration to water column light attenuation was also investigated using water quality observations from the EQL fixed station data and the EQL salinity-based station data. The EQL fixed station data indicated that a significant relationship was not present between light attenuation and chlorophyll-a concentrations in the Peace River. Light attenuation data were not reported for the Myakka River from this sampling program. The light attenuation data indicated that variation in color alone explained a large proportion of the observed variation in light attenuation. The EQL salinity-based station data also indicated that a significant relationship was not observed between chlorophyll-a concentrations and light attenuation in the Peace River. The light attenuation data recorded for this sampling effort indicated that color and, to a lesser extent, turbidity were good explanatory variables for light attenuation.

The relationship of external nutrient loads to TN:TP concentration ratios in the receiving waters was investigated using nitrogen loading estimates and nutrient concentration observations from the EQL fixed station data. Significant relationships were found only for Station 10 in the Peace River.

The lack of significant relationships found during the empirical study does not imply that loads do not affect chlorophyll levels, however. Rather, the realtionship between loads and chlorophyll are clearly more complex than some simple, direct relationships such as exist for Tampa Bay. Thus, we evaluated the applicability of a mechanistic approach to investigating the relationship.

A mechanistic box model of the system was constructed as another method of linking responses to loadings. The water quality model selected for this study was EUTRO5, a submodel of WASP5. This model has been previously utilized in a water quality study of Tampa Bay. The Peace and Myakka rivers and Charlotte Harbor were segmented into five horizontal boxes. Vertical resolution of two boxes for each segment, excepting the Lower Harbor segment, was determined to be necessary because of the vertical gradients found in water quality parameters when analyzing existing data.

The hydrodynamics of the study area were simulated by utilizing the set of model boxes, and a series of simple dilution equations were fit to account for the interbox exchange of water quality constituents. The model was calibrated against measured salinity values within each of the nine boxes of the model domain for each month of the 1975-1990 time period and monthly inflows for the same period. The calibration model run resulted in coefficients of determination (r^2) for the nine boxes ranging from 0.39 to 0.52, with an r^2 of 0.58 over all nine boxes.

After the simulation was calibrated with salinity, it was necessary to test the model using a dataset from a different time period. This validation provides a measure of the robustness of the hydrodynamic calculations. The SWFWMD data set from 1993 to 1994 was used, with a validation run of the model set up to run over the 23-month period from February 1993 to December 1994. Flows and loadings to the simulated system were determined based on calculations for 1993-1994 for the system. In this validation simulation, coefficients of determination (r^2) for the nine boxes ranged from 0.39 to 0.73, with an r^2 of 0.61 over all nine boxes. This overall r^2 is similar to that of the calibration run (0.58).

The results of the validation model suggest that the hydrodynamic paraterizations derived from the 1975-1990 salinity data yield an adequate representation of the hydrodynamics for the 1993-1994 time period as well, despite the disparity in hydrologic loads between the two time periods. Given the robustness of the hydrodynamic simulation, the eutrophication model is constructed utilizing these same hydrodynamic parameterizations.

The eutrophication model was limited to the Peace River, the Myakka River, and the Upper Harbor. The primary effort in the attempt to calibrate the eutrophication model was towards simulating chlorophyll and dissolved oxygen values respresentative of those from the data record. This effort was not effective for chlorophyll, and the dissolved oxygen results, while somewhat better, were still not useful enough to serve as a predictive tool in understanding the response of the water body to loadings.

The lack of fit of the simulated chlorophyll in comparison to that observed may be the result of several factors. Limitations on the data available for the study were found. The EQL fixed station database for 1975-1990 does not include light attenuation depths, so that no observed light attenuation due to chlorophyll and color was included in the simulation. Light attenuation due to color can often be the controlling factor on realized phytoplankton growth rates. It is probable that loads, water color, and the hydrodynamics of the system contribute in concert to the response of chlorophyll biomass under a given loading regime. Data measurements only occurred once monthly, so that the data record is sparse temporally, and no monthly average for a representative point within each box may be obtained. Additionally, very few chlorophyll measurements were obtained for the bottom boxes of the tidal Peace and Mykka rivers and the Upper Harbor. Spatially, only one datapoint existed in the tidal Myakka segment of the model, and only one datapoint existed in the downstream boundary codition segment, the Middle Harbor segment. This also presents problems of representativeness of data measurements when used as mean conditions for an entire box volume. Other limitations on the simulation were imposed by the EUTRO5 model construct itself. Perhaps most importantly is the inability of the model to vary growth rates in time and space, which is necessary to accurately represent varying algal assemblages. The surrogate used for growth rate variation, chlorophyll settling, results in confounding the simulation by rearranging chlorophyll concentrations vertically in this two-layered model, and thus affects concentration gradients and fluxes between boxes of all water quality variables.

Given that PLRG determination should ideally be postulated on the thesis that a stressor exists with which a quantifiable response is associated, it is necessary to establish a link between a given stressor (e.g., nitrogen loading) and a response (e.g., chlorophyll biomass). Intuitively, there should be a quantifiable relationship between nutrient loading and chlorophyll biomass within a system. However, using currently available data, the lack of correlation between water quality factors related through the empirical model approach, and the inability of the mechanistic model to simulate observed water quality responses given observed and estimated hydrodynamic forcing functions, disallows either of these approaches, as currently utilized, from being used to determine PLRGs.

The inability of the empirical and mechanistic approaches to determining PLRGs for the tidal Peace and Myakka rivers, however, is at least partially dependent on currently available data sets. Bias in station locations from the EQL fixed station study make it difficult to obtain representative data for water volumes. Given additional data sets, either from existing (SWFWMD/FDEP/EQL) sampling programs, or more comprehensive and statistically rigorous sampling designs (Coastal Environmental, Inc., 1995a), efforts along these lines may be more productive.

The establishment of PLRGs, however, is ultimately a resource management question. Given the importance of the resources within Charlotte Harbor, it may be not be prudent to await further data gathering and analyses prior to suggesting PLRGs to address nutrient loading. A recent proposal for an initial nitrogen management goal (Morrison, 1997) calls for reductions in dissolved inorganic nitrogen loads of 1% per year over 10 years. The purpose of this goal is to provide a "glide path" for long-term achievement of the trophic state goal, with assessment of data obtained over the 10-year period to determine the effects of this load reduction.

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