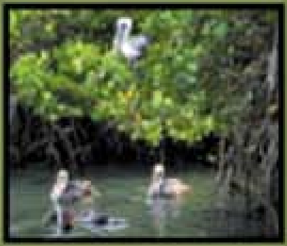

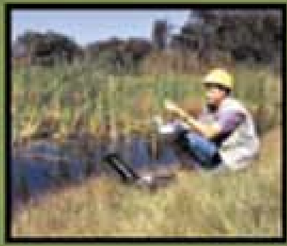

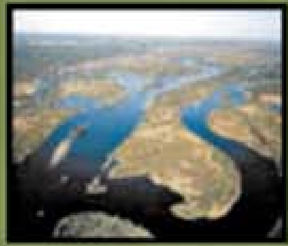

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YEAR THREE INTERPRETIVE REPORT

Peace River Hydrobiological Monitoring Program

Prepared for:

Peace River Manasota Regional Water Supply Authority

Prepared by:

PBSJ

Janicki Environmental, Inc.

February 2002

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- **Environmental Quality Laboratory** - conducted the moving, isohaline station physical and chemical water quality measurements, as well as the phytoplankton carbon uptake and biomass measurements. EQL was also responsible for the collection of all historical HBMP data collected during the period 1975-1996.

- **Florida Environmental** - was responsible for all work associated with the long-term studies of riparian vegetation.

- **U.S. Geological Survey** - conducted all physical and chemical water quality measurements taken along the river transect series of fixed station locations during the period 1996-1998. In addition, they were responsible for all data collected by the three tide gauges and the associated measurements of surface and bottom conductivity.

- **Peace River/Manasota Regional Water Supply Authority** - provided daily measurements of flow from the U.S.G.S. Arcadia gauge and withdrawals by the facility.

- **Dr. Susan Jensen** - conducted all phytoplankton taxonomic identifications.

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Executive Summary

The Southwest Florida Water Management District's (District) 1996 renewal of the Water Use Permit (WUP) to the Peace River/Manasota Regional Water Supply Authority (Authority) specifies the continuation of the Hydrobiological Monitoring Program (HBMP) for the Lower Peace River/Upper Charlotte Harbor estuary. The HBMP builds upon the monitoring activities that have been ongoing since 1975. The overall goal of the HBMP is to provide the District with sufficient information to determine whether the biological communities of the Lower Peace River/Upper Charlotte Harbor estuarine system are significantly impacted by permitted freshwater withdrawals at the Peace River/Manasota Regional Water Supply Authority's water treatment facility. A corollary goal of the HBMP is to provide periodic assessments of the effectiveness of the withdrawal schedule in preventing any such adverse impacts.

This report constitutes the first *Year Three Report,* mid-term interpretive report and, as specified in the permit, includes descriptions of the monitoring progress and observed changes in streamflow, salinity and selected variables. In addition, this report addresses other issues, as suggested by the Scientific Review Panel, related to the effectiveness of the current HBMP design in meeting the stated program objectives. As such, recommendations are made regarding the potential deletion of certain variables from the current HBMP design, as well as the evaluation of other variables for continuation and/or modification.

The major findings and conclusions presented in the Year Three Report are summarized below.

Conceptual Model

- As part of the Year Three Report analysis, a conceptual model was developed to illustrate the qualitative relationships between river discharges or freshwater inflow, and other important water quality and biotic variables in the Peace River estuarine system.

- The conceptual model defines those variables that have the highest probability of detecting hydrobiological change specifically in response to changes in freshwater inflow. The conceptual model illustrates that the most effective HBMP variables are those that are most directly linked to flow variations, with the fewest number of mediating steps and feedback loops (e.g., salinity, inorganic nitrogen concentrations, color), as well as those that are closely associated with the directly affected variables (e.g., chlorophyll *a* as measure of nutrient assimilation).

- Variables that are related to, but not directly or solely driven by, freshwater inflows (e.g., organic carbon) provide little insight into potential hydrobiological impacts of withdrawals. Consequently, the interpretation of data for variables that are far removed from the direct effects of withdrawals is often speculative at best.

Rainfall

- Over both the recent historic period of record (1966-1998) and the period during which the HBMP has been in effect (1976-1998) there have been no consistent increasing or decreasing rainfall patterns in the Upper Peace River watershed. In recent years, however, rainfall has significantly increased in the Peace River watershed, largely as a result of the unusually heavy rains of 1995, and the 1997/1998 El Niño event.

Rainfall to Flow Relationship

- Analyses using "double mass" curves indicated that since 1966 there have been no conspicuous changes in the general relationships between flow and rainfall in Peace River basin or any of the three tributary sub-basins (Horse, Joshua and Shell Creeks), although some small differences have occurred during extended wet and dry periods. It should however be noted that others have reported statistically significant increasing trends in base flow in several of these tributaries during normally dry periods. These patterns, combined with corresponding increases in mineralization, have strongly suggested that such increasing dry-season flows are directly linked to increasing agricultural irrigation within these watersheds.

Freshwater Inflow

- During the period of approximately the last thirty years, freshwater inflows in all of the gaged major Peace River tributaries have been either stable or increasing.

Withdrawals

- In response to increasing potable water demand, Peace River Facility withdrawals have steadily and progressively increased since being initiated in 1980. However, the magnitude of withdrawals has remained extremely small when compared to the natural seasonal variability of freshwater inflows. Currently withdrawals comprise less than 1% of total freshwater inflow at the mouth of the Peace River.

Salinity

- Trend analyses over the period 1976-1989 of salinities at a series of fixed sampling sites in the Lower Peace River did not detect any statistically significant long-term patterns except at river kilometer (RK) 30.4 (upstream of the point of withdrawal). The observed increase in salinity at this typically freshwater area of the Lower Peace

River corresponded with the extended drought conditions that followed the 1983 El Niño.

- Even with the effects of the 1997/1998 El Niño, the distribution pattern of median salinities along the Lower Peace River during the most recent three year period (1996-1998) was not substantially different than the long-term average.

Impact of Withdrawals on Salinity

- As part of the Year Three Report analysis, statistical models were developed with the objective of establishing a "predictive" relationship between gaged flows and salinity in the Lower Peace River, and for discerning the incremental effect of past and future permitted withdrawals on the salinity structure of the estuary downstream of the Peace River Facility.

- Model results indicated that, on average, the influences of past withdrawals on the spatial distribution of salinity patterns in the Lower Peace River between the U.S. 41 Bridge and the Peace River Facility have historically resulted in maximum changes of less than 0.3 ppt. These model results also indicated that the largest changes resulting from past withdrawals have occurred between river kilometers 14 and 18 in the Lower Peace River.

- Statistical models were also used to predict what the potential magnitude of salinity changes might be under the maximum permitted daily withdrawals during Arcadia flows between 200 and 1,000 cfs. Model results predict that a maximum salinity change of < 0.5 ppt would occur between river kilometers 14 and 18 when Arcadia flows range between 400 and 1000 cfs. With Arcadia flows of 200 cfs, the results predict that similar changes in salinity (< 0.5 ppt) would occur further upstream.

Water Quality

- Surface dissolved oxygen concentrations tend to increase from the Peace River Facility downstream towards the mouth of the river. On average, dissolved oxygen concentrations along the Lower Peace River between the Peace River Facility and the mouth of the river are above the State Class III 24 hour average standard of 5.0 mg/L (the instantaneous standard is 4.0 mg/L).

- Except for slightly elevated levels of phosphorus and color, many of the water quality characteristics of the Lower Peace River are similar to those of other Southwest Florida rivers despite the fact that the watershed area of the Peace River is much larger than that of most comparable rivers.

- Recent water quality characteristics of the Lower Peace River indicate only small differences when compared to the longer-term averages (1976-1998), with the most notable exception being a long-term reduction in phosphorus for the period 1984-

1998. This reduction probably reflects more stringent regulatory requirements for the treatment of point and non-point discharges in the upper Peace River Basin.

Vegetation

- Long-term comparisons of upstream and downstream occurrences of selected indicator plant species along the Lower Peace River indicate that the distribution of most species has varied very little over time.

Evaluation of the Current HBMP Design

- As part of the Year Three Report analysis, several physical, chemical, and biological parameters of the existing HBMP were evaluated with respect to their continued relevance to the objectives of the program. It is recommended that the following variables be discontinued from future HBMP studies: turbidity; alkalinity, chlorides, ammonia/ammonium, total phosphorus; silica; inorganic carbon; dissolved organic carbon; total organic carbon; phytoplankton species counts; carbon uptake; and chlorophyll *a* size fractions. It is also recommended that two other variables, extinction coefficient and vegetation, be further evaluated for continued inclusion in the HBMP design.

- The current HBMP design includes three sampling strategies: 1) fixed, continuous sampling at two stations and two depths; 2) fixed, monthly sampling at seventeen stations, and 3) "moving station" monthly sampling at four selected salinities. Under the current HBMP sampling design, there is clearly an unequal representation of the lower river. Specifically, the portion of the river between RK 15.3 and RK 21.1 is under represented in comparison to more upstream reaches of the lower river. However, this area includes the major portion of the river where the relationship between river flow, withdrawals, and salinity are most pronounced and is characterized by far fewer samples than the portion of the river above RK 21.1.

- It is recommended that further examination of the existing HBMP design be pursued in the Year Five Report to more definitively address whether the program is adequate with respect to the sampling of those areas of the Lower Peace River predicted to potentially be most effected by changes in salinities resulting from Peace River Facility withdrawals.

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Chapter I

Introduction

1.1 Purpose of Report

Water Use Permit No 2010420.02, issued by the Southwest Florida Water Management District (District) to the Peace River/Manasota Regional Water Supply Authority on March 26, 1996, specified the continuation of the Hydrobiological Monitoring Program (HBMP) for the Lower Peace River/Upper Charlotte Harbor estuary. The required HBMP was to build upon the monitoring activities that have been ongoing since 1975. The objectives of the HBMP, as defined in the permit, include the following:

- Monitor withdrawals from the Peace River at the water treatment plant and evaluate data for gauged tributary flows for Joshua Creek, Horse Creek, Shell Creek, and the Peace River at Arcadia, and direct rainfall to the Lower Peace River, as provided by the District.

- Evaluate ecological relationships of the Lower Peace River/Upper Charlotte Harbor estuary to freshwater inflows.

- Monitor selected water quality and biological variables in order to determine if the ecological characteristics of the estuary related to freshwater inflows are changing over time.

- Determine the relative effect of withdrawals from the Peace River at the water treatment plant on ecological changes that may occur.

- Evaluate if these withdrawals significantly contribute to any adverse ecological impacts the estuary may experience as a result of extended periods of low freshwater inflows.

- Evaluate if the withdrawals have any other significant effect on the ecology of the estuary, such as nutrient loadings, fish abundance, or seagrass distributions as shown by data collected by other studies conducted by the District or other parties.

The overall goal of the HBMP is to provide the District with sufficient information to determine whether the biological communities of the Lower Peace River/Upper Charlotte Harbor estuarine system have been, or are being, adversely impacted by permitted freshwater withdrawals at the Peace River/Manasota Regional Water Supply Authority's water treatment facility. Also, based on the expanding base of ecological information for the lower river, the results of the HBMP will be used to periodically evaluate the effectiveness of the withdrawal schedule with regard to preventing significant adverse impacts to the Lower Peace River/Upper Charlotte Harbor estuary.

The permit also specifies reporting requirements with respect to data collected and interpreted under the HBMP. This report constitutes the required *Year Three Report*. The minimum scope of work for the Year Three Report is specified in the permit as follows:

> *After year three, the Authority will submit an expanded, mid-term data report that contains the raw data for year three. The mid-term report will also contain basic figures, tables and statistical summaries for the entire period of record.*
>
> *Interpretive text in the mid-term report will be restricted to a description of monitoring progress and observed changes in streamflow, salinity and other selected variables. In addition, all raw data for years one, two and three will be submitted to the District with the Year Three Report on an electronic medium in a database meeting District requirements.*

This report fulfills the minimum scope of work specified in the permit. In addition, this report, as suggested by the Scientific Review Panel, addresses other issues related to the efficacy of the current HBMP design in meeting stated program objectives. As such, recommendations are made regarding the potential deletion of certain variables from the current HBMP design, as well as the evaluation of other variables for continuation and/or modification in future HBMP activities.

1.2 Peace River Facility Overview

The Peace River is the largest flowing surface water body in the southern region of the Southwest Florida Water Management District. The Authority's Peace River Facility is located next to the Peace River in southwest DeSoto County and has a present capacity to treat and supply up to 12 million gallons per day (mgd), which is equal to 18.6 cubic feet per second (cfs). The existing raw water river pump station has three pumps with a combined maximum capacity of 22 mgd (34.0 cfs). In comparison, the long-term average annual daily river flow at the Peace River Facility is approximately 970 mgd (1500 cfs). During periods of high river flow, raw river water is stored in an off-stream reservoir and any excess treated water is stored in the System's nine aquifer storage/recovery (ASR) wells. Conversely, when water is unavailable from the Peace River, water can be pumped from the raw water reservoir to the Peace River Facility for treatment, and/or previously treated water can also be recovered from the ASR system to meet the water supply demands of the Authority's customers.

Although the System has only been operated by the Authority since 1991, the Peace River Facility has been operating and withdrawing water from the Peace River since 1980. An extensive river monitoring program has been in place since 1975 prior to Peace

River Facility withdrawals, and to date, no adverse environmental impacts have been detected.

1.3 Overview of the Peace River Facility's History and Permits

In the early 1970s, General Development Utilities (GDU) actively began to search for a major regional water supply that would support the projected population growth for a number of large communities in Southwest Florida under construction or planned by its parent company, General Development Corporation (GDC). These developments included the City of North Port in Sarasota County, Port Charlotte in Charlotte County, South Gulf Cove in Charlotte County, and two Developments of Regional Impact for which development orders were later abandoned: Myakka Estates in Sarasota County and Villages of DeSoto in Desoto County. Population projections estimated over a quarter of a million new residents in these planned communities by the year 2020. The primary goal of General Development Utilities was to establish a reliable and expandable source of potable water to supply this projected population growth. After reviewing a number of potential alternative sources, it was determined that the site of the current Peace River Facility in Desoto County provided the greatest opportunity for a sustainable water supply for the planned future population growth within the three county area.

An assessment study was needed to evaluate the feasibility of locating a regional water supply system to provide potable water to Port Charlotte and adjacent areas on the Peace River in Desoto County near State Road No. 761. General Development Corporation therefore contracted with staff of the Rosenstiel School of Marine and Atmospheric Science (University of Miami) (Michel *et al.* 1975) to assess potential environmental impacts. The specific purpose of this study was to:

- Collect baseline biological and physical data;
- Develop relationships between freshwater flows, tides and salinity for the area of the Peace River downstream of the proposed Peace River Facility location;
- Investigate potential interactions between salinity and biological communities;
- Develop predictive models to assess potential effects of proposed freshwater withdrawals on the distribution of salinity along the lower Peace River downstream of the purposed Peace River Facility; and
- Provide initial data to form the basis for future long-term monitoring studies.

The information on biological communities and salinity/flow relationships developed during these initial field investigations by University of Miami staff were based on data collected between 1973 and 1974. During this period, Peace River flows (measured at the Arcadia gage) ranged from a low of 62 cubic feet per second (cfs) to more than 10,000 cfs. Fortuitously, the relationships between salinity and flow developed during this relatively short period of study, and subsequently used in calibrating their numerical models, were characteristic of the normal range of variation in flows that have subsequently occurred during both extended wet and dry periods.

A series of numerical models were then developed to predict changes in salinity at a series of points extending from the mouth of the river upstream to the planned future site of the Peace River Facility. Changes in salinities were modeled under worst-case conditions assuming freshwater withdrawals during naturally occurring periods of low river flow. The report (Michel *et al.* 1975) concluded that "under these conditions of flow and withdrawal, biological data indicated that such slight salinity increases, above the naturally occurring values of low flow periods, should add little additional stress on the plants and animals of the study area." This conclusion was based on what was found to be the highly dynamic natural seasonal changes in salinity within portions of the lower Peace River due to difference in flows during wet and dry periods. The final report also strongly recommended that an extensive monitoring program be implemented to assess the validity of the predicted results.

Specific conditions of the Southwest Florida Water Management District's (District) initial and subsequent consumptive use permits for the Peace River Facility have set forth requirements that the Regional Water Supply Authority implement a comprehensive HBMP. The District's continuing expressed purpose in mandating this requirement has been to ensure the continuing development of sufficient long-term data needed to establish and assess the responses of various physical, chemical and biological characteristics of the Charlotte Harbor estuary to changes in Peace River flow. These long-term monitoring programs have specifically been designed to evaluate the consequences and significance of natural salinity changes inherently associated with seasonal variations in freshwater input. In particular, a number of HBMP study elements have sought to establish the effects of natural long-term variations in river flow on the overall health of aquatic fauna and flora communities in the lower Peace River and upper Charlotte Harbor. Once having established the influences of natural variations, a corollary goal of the long-term monitoring program has been to determine if freshwater withdrawals by the Peace River Facility can be shown to have measurable impacts or result in quantifiable alterations of the biological communities of the upper Charlotte Harbor estuary.

General Development Corporation initiated a background monitoring effort in 1975, and the HBMP began in 1976 with the issuance by District of the first Consumptive Use Permit (CUP). Construction of the Peace River Facility was completed and withdrawals began in the spring of 1980. As part of the initial construction, a small off-stream surface water reservoir was constructed and soon thereafter construction began on a series of aquifer storage recovery wells (ASR). Adequate storage was identified as an important issue early in the initial evaluation and planning for the Peace River Facility. Unlike many other water treatment plants that utilize surface waters, there is no in-stream barrier in the Peace River to impound water during the typically dry winter and spring months. In addition, the District mandated as an initial permit condition that no withdrawals could be made below certain low flows. As a result the Peace River Plant has always relied on off-stream storage to maintain supplies during the dry season and/or drought conditions.

At the time of the first permit renewal in 1982, withdrawals had only recently begun and there were only a small number of changes made to the HBMP. However, with the second permit renewal in 1988, extensive amounts of data had been collected as part of the ongoing HBMP and these data were used to make significant modifications to both the monitoring efforts and withdrawal schedule.

Prior to 1988, the regulatory limit for maximum daily withdrawals from the Peace River was 22 mgd (34.0 cfs). This permitted quantity could be withdrawn from the Peace River as long as the measured streamflow at the Arcadia gage was above the regulatory minimum flow for each of the twelve respective months. These monthly minimum flow values were calculated based on a general formula that had been established under the District's first "Water Use Rules" adopted in 1975. This formula used the previous twenty years of streamflow records to establish a separate minimum flow for each calendar month. The monthly minimum flows for the Peace River used to establish the freshwater withdrawal schedule prior to 1988 ranged from 100 cfs in April and May to 664 cfs in September. As a result, during low flow periods in the spring, maximum daily withdrawals of 34 cfs could reduce flows (as measured at Arcadia) by as much as 25 percent on some days; while conversely, during September, no water could be taken from the river until flows exceeded 664 cfs.

When the permit was renewed in 1988, General Development Utility's (GDU) consulting scientists and the District agreed that the existing withdrawal schedule caused the Peace River Facility to rely too heavily on periods of low to moderate flows. It was agreed that site-specific information should be used to establish regulatory minimum flows and daily withdrawal limits from the Peace River. Using the long-term data collected under the HBMP, statistical models were developed to analyze the location of the freshwater/saltwater boundary as a function of flow, and predicted salinity changes that might result from permitted withdrawals.

Based on these analyses, the District and the permittee (GDU) agreed that the withdrawal schedule should be modified. A minimum criterion was established of no withdrawals when flows at Arcadia were below 100 cfs during the spring months (March April, and May) and 130 cfs during the remainder of the year. Beyond that, withdrawals could equal up to 10% of the daily measured gaged flow at Arcadia, up to a maximum not to exceed 22.0 mgd (34 cfs). This schedule increased minimum flows to the estuary, and allowed withdrawals to more closely follow the natural variability of rainfall and flow.

In 1990 General Development Corporation filed for bankruptcy protection. Charlotte County took control of General Development Utilities facilities within Charlotte County, and ownership of the Peace River Water Treatment Plant was transferred to the Peace River/Manasota Regional Water Supply Authority (Authority). The Authority was formed and functions through agreements made among Manatee, Sarasota, Desoto and Charlotte counties. With the Authority's ownership of the Peace River Facility, the Authority soon began making plans for expansion of the treatment facilities to provide more water to the region as originally envisioned by General Development Utilities. A further goal of the Authority has been to develop a series of interconnections among the member county's water supplies to reduce potential effects of natural disasters and other interruptions in supply and allow improved regional management of water sources. The

Authority's current expansion of the Peace River Facility in Desoto County and interconnection with the Carlton Water Treatment Plant in Sarasota County is the first step toward that goal and is referred to as the "Peace River Option."

The twenty-year Water Use Permit (WUP) issued by the District in 1996 sets a maximum annual average quantity of 32.7 mgd (50.6 cfs). This newest permit increases the minimum flows measured at the upstream Arcadia gage, under which no withdrawal can occur, to 130 cfs during all months. Beyond that, withdrawals can still not exceed 10% of the average daily Arcadia flow. Under this permit the Regional Water Supply Authority will withdraw, treat and store more river water under high flows. The existing permit limits withdrawals under high flow conditions to 10%, not exceeding 90 mgd (139 cfs) on any day or 38.1 mgd (58.9 cfs) as a monthly average.

It should be noted that the permitted withdrawals by the Peace River Facility have always been more conservative and well below the original "safe" levels proposed by the University of Miami Study.

1.4 Purpose of the Year Three Report

The current Water Use Permit requires that the Authority submit annual data reports containing all raw data collected during the preceding year. The permit specifies that these data reports contain limited text describing the monitoring efforts, variables measured, problems encountered and any important (or unusual) observations during the reporting period. In addition, such data reports are to contain all data in tabular form.

After the third year of monitoring under the permit, the Authority is required to submit to the District an expanded, mid-term data report that also contains basic figures, tables, and statistical summaries of the data for the entire period of record for selected variables. Based on discussions with District staff, it was decided to expand the initial intent of the permit requirements of the mid-term report. It is the expressed purpose of this interpretative Year Three Report to provide an overall description of the monitoring progress, as well as documenting and comparing any observed changes in freshwater inflows, salinity distributions and other selected variables.

1.5 Report Organization and Primary Objectives

The following briefly summarizes the organization and primary objectives of each of the remaining sections of this Year Three Report.

- **Chapter II – Description of the Existing HBMP Design**. The primary focus of this chapter is to:
  1) Provide a summary of the existing HBMP study elements;
  2) Explain why these elements are part of the HBMP;
  3) Describe what physical parameters and biological communities are being monitored;
  4) Provide an overview of when and where samples are being taken; and

5) Explain who is conducting each of these primary monitoring efforts.

- **Chapter III – Conceptual Model.** The purpose of this chapter is to provide a discussion and conceptual model illustrating the relationships between freshwater inflows and other water quality and biotic variables in the lower Peace River estuarine system. This discussion will be used to build a framework within which to determine the likelihood of potential impacts resulting from permitted withdrawals and to determine the efficacy of the existing indicators being monitored.

- **Chapter IV – Status and Trends in the Health of the Lower Peace River**. This chapter has two primary functions:
  1) Provide a description and analysis of current condition, status, and importance of spatial patterns in assessing the health of the lower Peace River, and
  2) Determine the existence and importance of observed trends in key physical and biological parameters.

- **Chapter V – Evaluation of the Potential Impacts of Peace River Facility Withdrawals.** This chapter presents discussions and summaries of the statistical approaches used in relating selected HBMP variables to temporal variations in freshwater inflows and potential withdrawals by the Peace River Facility.

- **Chapter VI – Assessment of the HBMP Design.** The primary focus of this chapter is to provide an assessment of the variables currently being monitored as elements of the HBMP, and to determine if these variables are able to assess potential impacts of withdrawals to the biological communities of the Lower Peace River/Upper Charlotte Harbor estuarine system.

- **Chapter VII – Conclusions and Recommendations.** The final chapter presents a summary of the overall conclusions developed from the various analyses presented in the preceding sections. In addition, recommendations are offered regarding potential modifications that may be appropriate to improving and refocusing HBMP study elements in the future.

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Chapter II

Description of the Existing Hydrobiological Monitoring Program

2.1 Overview of HBMP Objectives

As a special permit condition of the current Water Use Permit (WUP), the expressed purpose of the combined HBMP study elements is to build upon the base of scientific information that has been developed as part of the ongoing monitoring efforts that first began in 1975. The overriding goal of the program is to provide the District with sufficient information to ensure that the biological communities of the Lower Peace River/Upper Charlotte Harbor estuarine system are not significantly adversely impacted as a result of the permitted freshwater withdrawals by the Peace River Facility. As such, a corollary goal of the program is to provide periodic assessments of the effectiveness of the withdrawal schedule in preventing any such adverse impacts.

In order to provide such assurance, the HBMP has been designed with the following six primary objectives in mind:

1. Establish a framework for monitoring withdrawals by the Peace River Facility and evaluate these data in comparison to the gaged inflows measured for the:
   - Peace River at Arcadia
   - Horse Creek near Arcadia
   - Joshua Creek at Nocatee
   - Shell Creek near Punta Gorda
   - Rainfall measurements in the Peace River Basin

2. Evaluate ecological relationships among physical and biological variables within the Lower Peace River/Upper Charlotte Harbor estuary in response to variations in freshwater inflow.

3. Monitor selected water quality and biological variables in order to determine if the ecological characteristics of the estuary are changing with time in relation to differences in freshwater inflow.

4. Determine the relative effect of withdrawals from the Peace River Facility on any such observed changes.

5. Evaluate whether withdrawals by the Peace River Facility have significantly contributed to any adverse ecological impacts in the Lower Peace River/Upper Charlotte Harbor estuary due to extended periods of low freshwater inflow.

6. Evaluate whether withdrawals by the Peace River Facility have had any other significant effects on the ecology of the estuary, such as nutrient loadings, fish abundance, or seagrass distributions based on data collected by the District and/or other parties.

2.2 Ongoing HBMP Program Study Elements

An expanded HBMP was approved by the District in March 1996 as a part of the Water Use Permit renewal (WUP#2010420.03) for implementation in 1996 and subsequent years. Specific conditions within the permit include major expansions of both the physical and biological elements of the Hydrobiological Monitoring Program. An explicit element of the updated HBMP was the development of a standardized distance scale covering the entire study area and a set of station descriptors to be applied across all program elements. As part of the required morphometric study (see description below), the "mouth" of the Peace River was defined using USGS standardized protocols as an imaginary line extending from Punta Gorda Point to Hog Island (**Figure 2.1**). Table 2.1 provides a summary of the locations of all of the ongoing long-term fixed study elements, and provides a cross-reference to previous station identifications. The following briefly outlines each of the current HBMP study elements.

2.2.1 Continuous Recorders

The primary goal of this element of the HBMP was to develop an extensive database of short-term (daily or more frequent) changes in surface and near bottom salinity in the Lower Peace River. These data, combined with corresponding gage height, freshwater inflows and withdrawals would then be used to develop detailed spatial and temporal relationships between these variables. A secondary goal was to assess potential long-term changes in river salinity, which might be explained by predicted increases in sea level.

In 1996 the U.S. Geological Survey (USGS) installed automated 15-minute interval water level recorders at two locations (**Figure 2.2**):

- At Boca Grande, which is the estuary's largest opening to the Gulf of Mexico; and
- Approximately 15.5 kilometers upstream of the river's mouth at Harbour Heights. The gaging station at Harbour Heights also measures surface and bottom conductivity at 15-minute intervals.

In November 1997 a third gage was installed at approximately river kilometer (RK) 26.7 just downstream of the Peace River Facility. This gage also measures both water level as well as surface and bottom conductivity at 15-minute intervals.

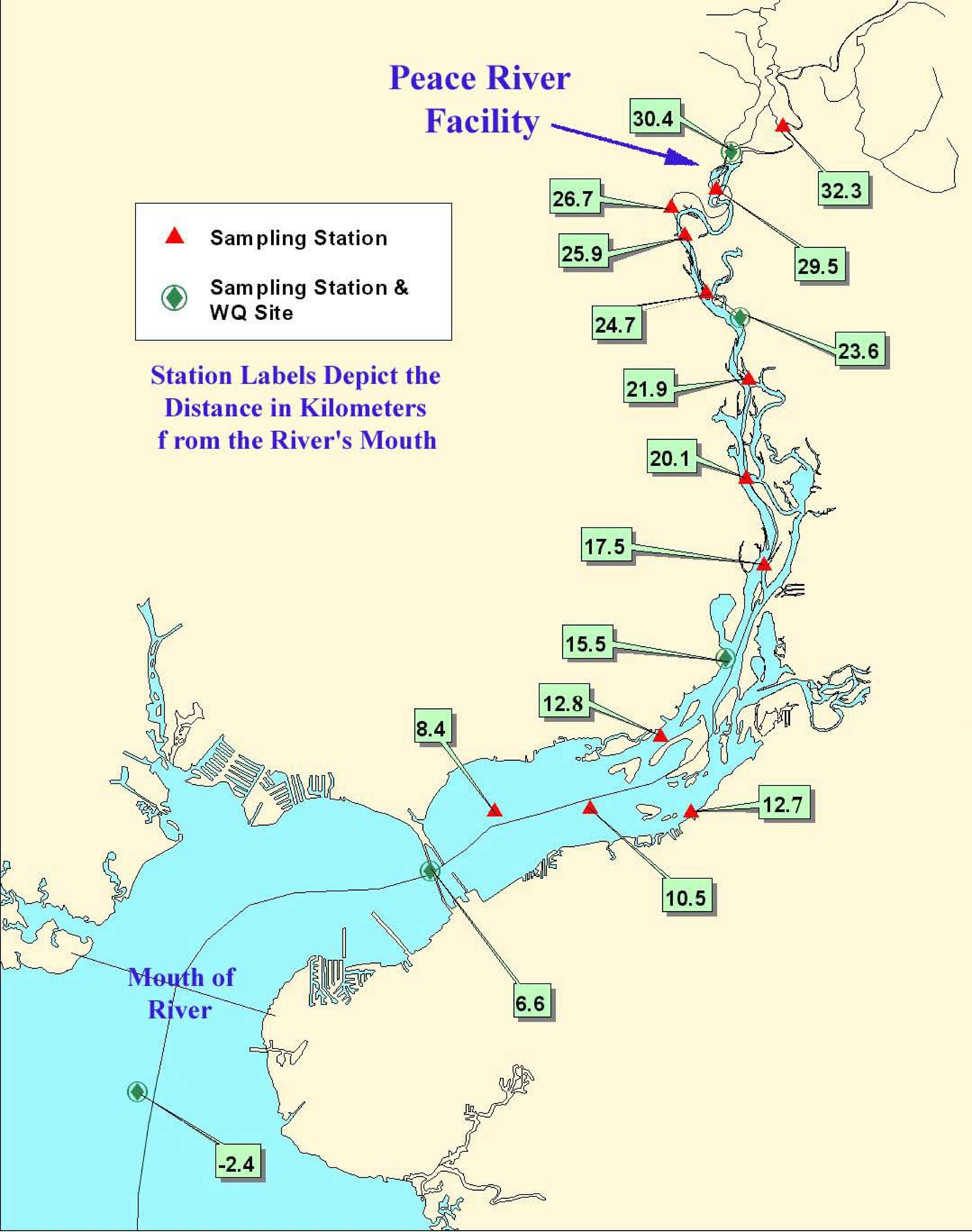
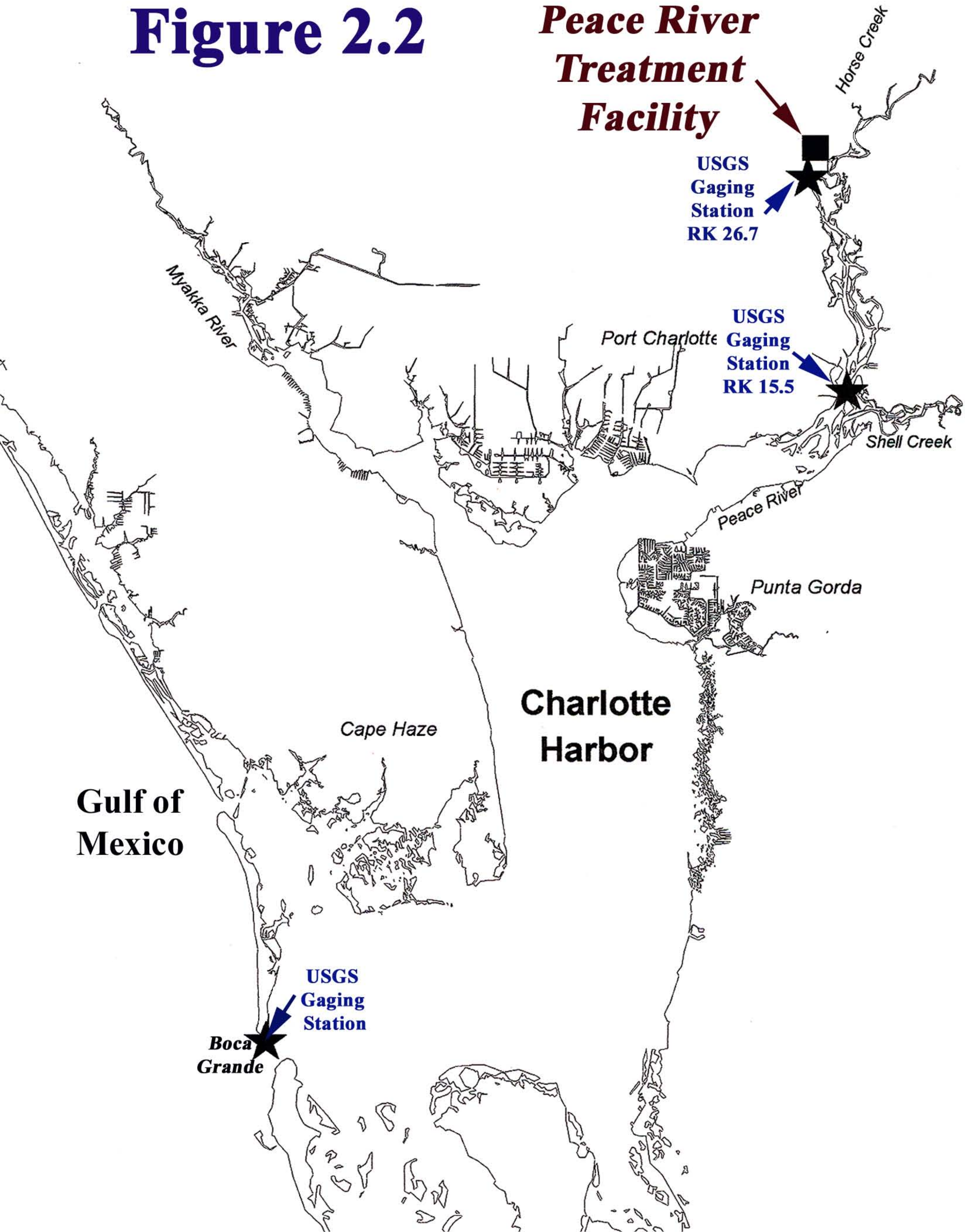

Peace River Facility
Sampling Station
Sampling Station & WQ Site
Station Labels Depict the Distance in Kilometers f rom the River's Mouth
30.4
32.3
26.7
29.5
25.9
24.7
23.6
21.9
20.1
17.5
15.5
12.8
8.4
12.7
10.5
6.6
Mouth of River
-2.4

Figure 2.2



Peace River Treatment Facility
Horse Creek
USGS Gaging Station RK 26.7
Myakka River
Port Charlotte
USGS Gaging Station RK 15.5
Shell Creek
Peace River
Punta Gorda
Charlotte Harbor
Cape Haze
Gulf of Mexico
USGS Gaging Station
Boca Grande

Table 2.1 HBMP Fixed Sampling Locations				
USGS River Mile	**USGS Location Number**	**Previous EQL Station Number**	**Additional Sampling**	**New River Kilometer designation based on Morphometric Study**
Current *In Situ* Water Column Profile Sampling				
CH6	265355082075500	9	Water Quality	**-2.4**
RM3.95	265640082033500	10	Water Quality	**6.6**
RM4.88	265724082024400	21		**8.4**
RM6.25	265727082012800	11		**10.5**
RM8.61	265711081595500	Shell Creek 9		**12.7**
RM8.6B	265819082003200	22		**12.8**
RM10.2	2297460	12	Water Quality/Tide Gage/Conductivity	**15.5**
RM11.2	270022081591000	23		**17.5**
RM 12.55	270124081592500	13		**20.1**
RM13.95	270235081592400	24		**21.9**
RM14.82	270318081593100	14	Water Quality	**23.6**
RM15.45	270337081595800	25		**24.7**
RM16.29	270418082001600	15		**25.9**
N/A	2297350	N/A	Tide Gage/ Conductivity	**26.7**
RM18.25	270451081595100	17		**29.5**
RM18.95	2297330	18	Water Quality	**30.4**
RM19.5	270537081585800	19		**32.3**
Vegetation Transect Locations				
N/A	N/A	I		**15.6**
N/A	N/A	II		**22.3**
N/A	N/A	III		**20.4**
Previous EQL Water Column and Chemistry Sampling Sites				
N/A	N/A	16		**27.1**
N/A	N/A	20		**34.1**

2.2.2 Water Chemistry and Water Column Physical Profiles

There are a number of goals associated with the study elements in which physical and chemical water quality are measured. On an overall "Health of the Harbor" level, a primary goal is to collect sufficient long-term data to statistically describe spatial and seasonal variability in the water quality characteristics of the Lower Peace River/Upper Charlotte Harbor estuary, and test for significant changes over time (trends). A second goal is to determine if significant relationships exist between freshwater inflows and the seasonal/spatial variability of these water quality parameters. If such relationships can be shown, then the ultimate goal is to determine the potential magnitude of change that might result from permitted withdrawals, and compare such predictions with the range of observed natural variability.

Physical and chemical water quality parameters are measured within the Lower Peace River/Upper Charlotte Harbor estuary under two different HBMP study elements. The first is the monthly "fixed" station water quality characterization study being conducted by the USGS. Additional water quality measurements are also conducted in conjunction with the monthly "moving" isohaline station phytoplankton/primary production study being conducted by Environmental Quality Laboratory (EQL). Physical *in situ* water column profile measurement of water quality characteristics (temperature, dissolved oxygen, pH, conductivity and salinity) are made at 0.5 meter intervals during both of these study elements. In addition both HBMP study elements measure the penetration of photosynthetically active radiation (PAR) to determine ambient extinction coefficients at each sampling location. Both studies also include the analyses of an extensive list of chemical water quality parameters (Table 2.2). The only difference is that at the "fixed" stations sampled by the USGS, both sub-surface and near-bottom samples are collected at each site, while EQL only collects sub-surface samples as part of it's phytoplankton/primary production study.

Table 2.2 HBMP Chemical Water Quality Measurements

Salinity	Nitrate + Nitrite Nitrogen	Inorganic Carbon
Chloride	Ammonia/Ammonium Nitrogen	Total Organic Carbon
Color	Total Kjeldahl Nitrogen	Dissolved Organic Carbon
Turbidity	Total Nitrogen	Chlorophyll *a*
Alkalinity	Ortho-Phosphorus	both total and by size fraction
Suspended Solids	Total Phosphorus	1) > 20 *u*
Volatile Solids	Silica	2) 5 to 20 *u* 3) 5 > *u*

"Fixed" Station Locations - This study element requires the USGS to conduct monthly water column physical profiles near high tide at sixteen locations along a transect running from just below the river's mouth upstream to a point just above the Peace River Facility (see **Figure 2.1** and Table 2.1). Sub-surface and near-bottom samples are also collected at five of these locations for the measurement of selected chemical parameters (see Table 2.2).

"Moving" Salinity Based Stations – EQL staff conduct physical water column profiles and take sub-surface water chemistry samples monthly within plus or minus two hours of noon (EST) at four salinity based isohalines (0, 6, 12 and 20 ppt) along an imaginary center line running down the Peace River from above its junction with Horse Creek to Boca Grande Pass. The relative monthly location of each sampling is based on the first occurrence of each isohaline.

2.2.3 HBMP Study of Long-Term Changes in Vegetation

Identification of potential adverse effects to emergent vegetation and riverine wetlands caused by freshwater withdrawals initially requires determining the magnitude of the spatial and temporal responses of these vegetative communities to the natural variation resulting from extended periods of drought and flood. The next step would be developing methodologies that would allow differentiating between long-term natural changes in riverine vegetative patterns and withdrawal induced changes. The vegetative monitoring elements of the HBMP provide information for determining relationships between vegetation patterns and freshwater inflows by observing the positions of the freshwater and salt-tolerant plant communities, especially in the salinity transitional zone of the river. A permanent shift of more salt-tolerant plants upriver would be an indication that withdrawals were impacting the river corridor wetlands, as long as natural variability (drought) or man-made causes could be eliminated. All vegetation elements of the HBMP studies are currently being done by Florida Environmental, Inc.

Photointerpretation - This long-term element of the HBMP initially began in 1976. Initially aerial infra-red photography was taken yearly of the vegetative communities along the Lower Peace River, starting at the US 41 Bridge (river kilometer 6.6) and extending upstream above the Peace River Facility to near the area where Horse Creek enters the river (river kilometer 39.5). Under the 1996 HBMP permit modifications, such aerial surveys will continue to be conducted at two years intervals. All post-1996 aerial photography is being taken in a corrected, GIS compatible format, thus allowing for accurate quantification of any observed changes. Photointerpretation of these images, in conjunction with field observations, is being used to develop maps of the river's vegetation associations. Both qualitative and quantitative data will be used to assess potential changes associated with extended natural periods of both low and high freshwater inflows.

First and Last Occurrence of Indicator Plant Species - At approximately two year intervals, since 1976, the first and last occurrence of a large number of indicator plant species has been recorded along the banks of the Peace River downstream of the Peace River Facility. As part of the vegetation study element of the HBMP, detailed maps using the standardized river kilometer scale are to be made, identifying the first and last occurrences of individual and substantial populations of key indicator species. The current permit requires a detailed photographic record be compiled in conjunction with this effort. These data are then used in conjunction with the aerial photography to assess the influences of long-term natural variations in river flow.

Vegetation Transition Sites – Under the current permit, this portion of the HBMP study extends and expands the detailed monitoring begun in 1979 of plant communities along the river's banks at fixed locations. The vegetative communities at three permanent transects sites (see **Figure 2.3** and Table 2.1) are sampled at approximately two year intervals (**Table 2.3**). At each monitoring location, three transects from the top of the bank to the water's edge are surveyed. The vegetation one meter to each side of the transects are identified, and the location and density recorded. These long-term data will be used to further assess the response of the riverine vegetative communities to natural variations in freshwater inflows.

2.2.4 Phytoplankton Studies

Environmental Quality Laboratory, Inc is conducting these HBMP investigations. Sub-surface samples are being collected in conjunction with the moving station physical and chemical water quality data described above.

Carbon Uptake - Since 1983, monthly *in situ* measurements have been conducted within plus or minus two hours of apparent noon (EST) at each of the four "moving" isohalines (0, 6, 12, 20 ppt salinity). Replicate (5) rates of carbon uptake are determined for each of three separate phytoplankton size fractions: 1) greater than 20 microns; 2) less than 20 micons and greater than 5 microns; and 3) those cells less than 5 microns.

Chlorophyll *a* Biomass - corresponding values for sub-surface concentrations are determined for each of the above size fractions.

Species Composition - Since 1989, monthly sub-surface samples have been collected, preserved and identified to the lowest practical taxon in conjunction with the carbon uptake measurements at each of the four isohalines. Dr. Susan Jensen has made all taxonomic identifications.

2.3 Special Studies Associated with the HBMP

In addition to the current, ongoing elements of the HBMP outlined above, the revised HBMP program implemented in 1996 also required the Authority to conduct and/or contribute to a number of duration-limited studies designed to answer specific resource management questions. The following outlines the major goals of each of these special studies. Each of these special investigations will result in a stand-alone report to be submitted to the District. Where applicable, all pertinent data collected during these specific studies will be incorporated into other study elements of the HBMP.

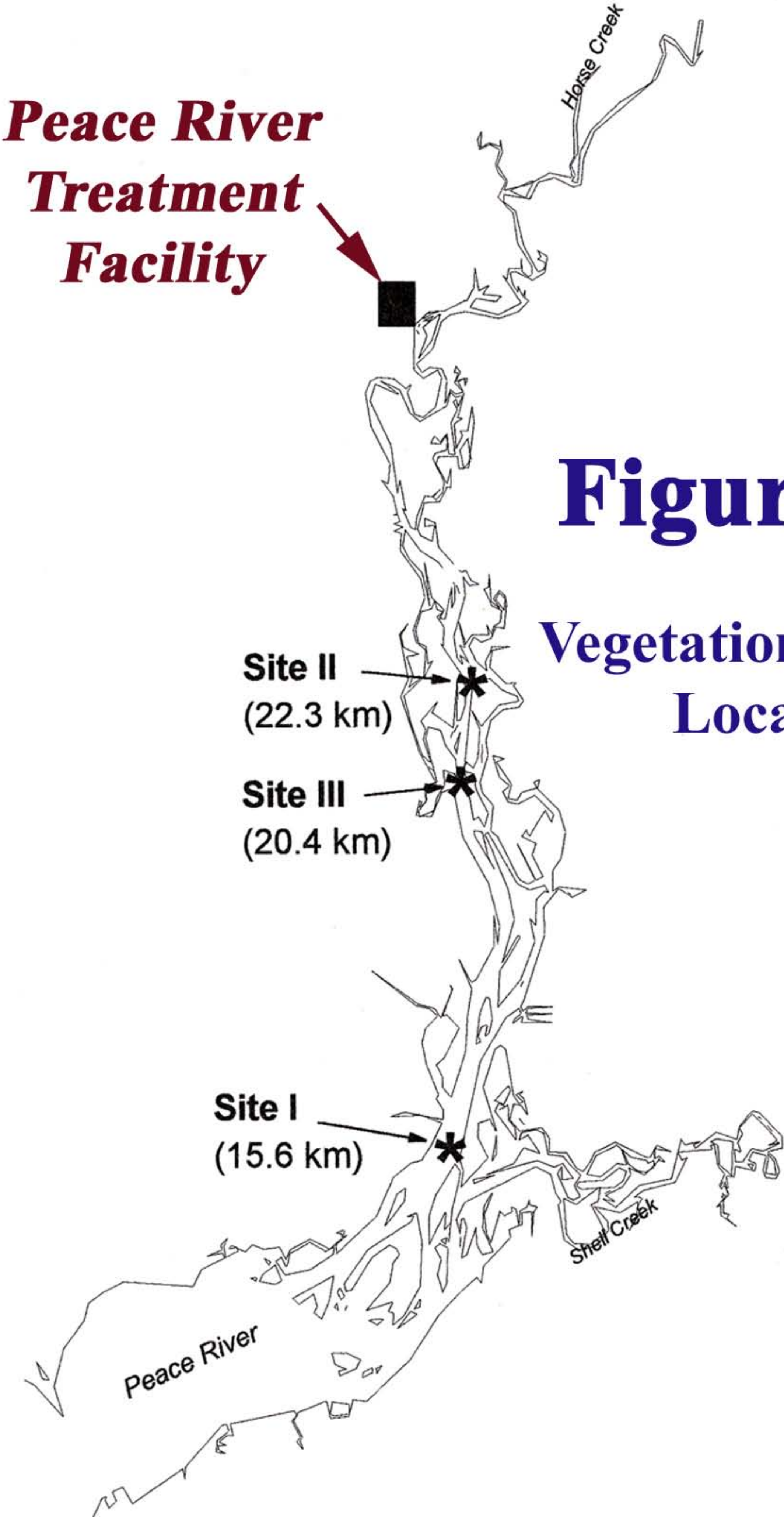


Figure 2.3

Vegetation Transect Locations

Table 2.3 Time Lines For Major HBMP Study Elements

	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
Indicator Benthic Species	■	■	■	■	■	■	■	■	■														
Sea Star	■	■	■	■	■	■	■	■	■														
Upper Harbor Juvenile Fishes	■	■	■	■	■	■	■	■	■	■	■	■											
Vegetation																							
Aerial Photography	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■		■
First and Last		■				■	■	■	■				■		■	■		■		■		■	■
Transect Sites		■				■	■	■	■				■		■	■		■		■		■	■
Phytoplankton (Isohalines)																							
Primary Production								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Species Identification														■	■	■	■	■	■	■	■	■	■
Zooplankton (Isohalines)														■	■	■	■	■	■	■	■		
Physical Water Quality																							
Lower /Middle Harbor																							
Stations 1, 3, 5, 6	■	■	■	■	■	■																	
● Stations 2, 4, 7	■	■	■	■	■	■	■	■	■														
Upper Harbor																							
● Station 9	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						■	■	■
Lower River																							
● Stations 10, 12, 14, 18	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						■	■	■
● Stations 16, 20	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								
Stations 11, 13, 15, 17, 19	■	■	■	■	■	■	■	■	■												■	■	■
Stations 21, 22, 23, 24, 25							■	■	■												■	■	■
● Note: Includes Water Chemistry																							
Continuous Recorders																					■	■	■
Benthic Invertebrates & Mollusc																							■
Larval Fish/Plankton																						■	■

Note: The station locations used in this table refer to the historically used numerical identifications, since not all of the sites in the Lower/Upper Harbor were sampled along the current River Kilometer Centerline. Table 2.1 provides conversions to the currently used centerline identification system Stations 9 through 25.

2.3.1 Morphometric Investigation

The goal of this effort, conducted by PBS&J, was to develop maps and tabular files indicating: typical cross-sections; open-water area; water volume; shoreline length; and areas/types of adjacent wetland habitats corresponding to 0.5 kilometer intervals along a developed centerline extending from the mouth of the Peace River near Punta Gorda to a point well upstream of the Water Peace River Facility. In addition, a summary table was developed indicating the locations of both current and previous fixed water quality and vegetation sampling locations in relation to the new centerline kilometer distance scale developed during the morphometeric analysis. The results of the morphometeric study have been submitted to the District. Table 2.1 and **Figure 2.1** indicate the permanent river kilometer distances that will be used in all future HBMP documents, in relation to both USGS river miles and EQL station locations.

2.3.2 Benthic Macroinvertebrate and Mollusc Study

This special study element of the HBMP is being conducted by Mote Marine Laboratory, and a separate report summarizing the findings is expected in 2001. The primary objectives of the two investigations being conducted as part of this effort are to:

- Describe the distribution of major macroinvertebrate habitats and communities in the Lower Peace River.

- Determine whether benthic organisms and/or their community structure can be used to assess natural variations in freshwater inflows and, measure potential influences caused by the diversions of the Peace River Facility.

The approach of these studies has been to characterize the tidal area of the river downstream of the Peace River Facility based on a series of criteria, including: 1) the magnitude of tidal influence, 2) dominant shoreline habitats, and 3) observed gradients in physical and/or chemical characteristics, or other features found to be significant. Important riverine characteristics of significance to the distribution of benthic invertebrate communities would include physical/chemical parameters such as the sediment granulometry of the riverbed, as well as spatial differences with depth in salinity and dissolved oxygen.

Macroinvertebrates – The design of this sampling effort incorporated dividing the Lower Peace River into four “salinity segments” based on historic gradients from data gathered as part of the HBMP.

- < 0.5 ppt
- > 0.5 & < 8 ppt
- > 8 & < 16 ppt
- > 16 ppt

Core samples, the colonization of artificial substrates, and sweep nets were used to characterize the benthic invertebrate communities from two depths: 1) the intertidal zone; and 2) from Mean Low Low Water down to a depth of 3.7 meters; within each of the four identified salinity zones.

Mollusc Study - A second corollary investigation has been undertaken of the distribution of benthic, hard-shell mollusc communities, examining both live and dead shells to delineate ecological zones in the estuary and attempting to relate the observed patterns to recent seasonal patterns in flows and observed variations in near bottom salinity. This investigation has incorporated intensive sampling at 0.5 km intervals along the lower river.

2.3.3 Fish Nursery Study

The University of South Florida is undertaking this special short-term program. A two-year study is being funded by the Authority and the Water Management District to define seasonal and spatial patterns of fish nursery use within the Lower Peace River/Upper Charlotte Harbor Estuary to determine the influences/relationships freshwater inflows have on such patterns. Estimates of the relative distribution and abundance of fishes and selected invertebrate taxa will be made from five minute, three-step (bottom-midwater-surface) oblique tows collected during night, flood tide conditions using a weighted, flowmeter-equipped plankton net. Monthly samples have been collected at seven zones within the Lower Peace River. A separate Summary Report is expected to be finished in 2002.

2.4 Significant Changes during the course of the HBMP

The HBMP has incorporated a wide variety of study elements since its initial inception. A summary of the time-lines for major components is presented in **Table 2.3**. Summaries of the findings of these investigations are contained within the 1999 report, *Summary of Historical Information Relevant to the Hydrobiological Monitoring of the Lower Peace River and Upper Charlotte Harbor Estuarine System* (PBS&J 1999). Between 1976 and 1996, the staff of EQL conducted all elements of the HBMP. Since the expansion of the permit requirements in 1996, the individual programs have been divided among a number of researchers as described above.

The HBMP was not conceived of as a rigid monitoring program but rather a flexible study design that could be periodically restructured based on updated findings and identified research needs. When the first discussion began in 1975 about what might be included within such an effort, very little was known about either salinity/flow relationships, or the spatial/temporal distributions of other physical/chemical water quality parameters in the Lower Peace River/Upper Charlotte Harbor Estuary. Even less was known about the biological communities that studies in other estuarine systems had indicated could potentially be negatively affected by freshwater diversions. As a result, much of the effort under the initial HBMP study design was directed toward developing sufficient data to statistically describe the spatial distribution and seasonal variability of physical and chemical indicators within this estuarine system, and to determine potential relationships with naturally occurring variation in freshwater inflows. Such HBMP investigations included the collection of monthly *in situ* water column profile characteristics, and surface and near bottom water chemistry at a wide variety of sites located throughout the estuary (see **Table 2.3**).

In addition, initial attempts were begun to determine if key indicator species or biological communities could be identified to assess responses to natural variations in freshwater inflows. Determining the presence of such long-term relationships was thought to be especially important since, with only a small percentage of total flow being diverted, the direct effects of withdrawals were projected to be extremely small in comparison to natural variation. These HBMP elements included: 1) the initial long-term study of the seasonal pattern of juvenile fishes in the Upper Harbor; 2) the studies of benthic indicator species; 3) the investigation of the seasonal distribution of sea stars in the Harbor and lower River; and 4) the vegetation study of first and last occurrence of selected plant taxa along the Lower Peace River.

In the 1980s, studies of phytoplankton and zooplankton community production and structure were added to the HBMP. These studies were again not intended to directly evaluate the influences of withdrawals, but rather were designed to address issues related to the “Health of the Harbor” and the influences of naturally occurring extended periods of drought and flood conditions. Two of the most recent additions to the HBMP program, the benthic invertebrate studies and the fish nursery investigation, again were not designed to directly measure the influences of withdrawal directly but rather are designed to investigate the response of biological communities to natural variations in freshwater inflows.

To date, the most promising HBMP element for detecting possible changes directly resulting from diversion by the Peace River Facility has been the installation of the two continuous conductivity recorders downstream of the point of withdrawal. Surface and bottom conductivity measurements, as well as water levels, are recorded at 15 minute intervals at these two locations. The goal of this HBMP element is to collect data of sufficient frequency to be able to detect small scale variations in salinity and develop accurate empirical statistical models capable of determining changes in salinity at these locations along the lower river resulting from freshwater withdrawals.

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Chapter III

Conceptual Model

The objective of this chapter is to present a conceptual model developed to illustrate the relationships between river discharges or freshwater inflow, and other important water quality and biotic variables in the Peace River estuarine system. The purpose of the conceptual model is to qualitatively demonstrate the potential effects of freshwater withdrawals by the Peace River Facility on the Peace River estuary, and to justify the selection of critical indicators for monitoring and analysis as part of the HBMP. Relevant physical and chemical processes and interactions will be discussed, and logical pathways between freshwater withdrawals and variables of concern will be presented.

Although there are numerous definitions of *estuary* in the literature, one of the most comprehensive and applicable definitions is that of Fairbridge (1980):

> *An estuary is an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into three sectors: (a) a marine or lower estuary, in free connection with the open sea; (b) a middle estuary subject to strong salt and freshwater mixing; and (c) an upper of fluvial estuary, characterized by freshwater but subject to daily tidal action. The limits between these sectors are variable, and subject to constant changes in the river discharge.*

From this definition, it should be noted that estuaries are ecosystems that are, to a large degree, dominated by physical and chemical processes. Furthermore, river discharge, or freshwater inflow, is one of the most important variables determining the spatial limits of, and the physical and chemical interactions within, an estuary. Therefore, it follows that the volume and timing of freshwater discharges from rivers is often the most critical factor driving the biological functions of estuaries. To discern the potential effects of freshwater withdrawals on the estuary, it is first critical to have a general understanding of the structure and function of estuaries. The primary physical and chemical processes that drive the biological functions in the Peace River estuarine system are discussed below. It is recommended that readers familiar with this material skip to section 3.5 for a discussion of the conceptual model specific to the Peace River estuary.

3.1 Physical Processes

Estuaries represent regions where salt water mixes with freshwater derived from land drainage. The term *mixing* describes the process by which a parcel of water, or a water mass, is diluted by, or redistributed within, other water masses. The mixing process is both advective and dispersive in nature. The distinction between these two terms is based on the time scale involved but is somewhat arbitrary by definition. Mixing over a longer time scale is generally referred to as *advection*, whereas *dispersion* refers to mixing over a shorter time scale. Estuarine circulation or advective mixing is generally considered most important with respect to biological interactions (Day et al, 1989).

The distribution of salt in the estuary is the most commonly used indicator of mixing for three reasons: 1) salinity is a conservative constituent, that is, the salt concentration is essentially not altered by biogeochemical processes but only by mixing processes – advection and dispersion – and, to a lesser degree, by local rainfall and evaporation; 2) most estuarine salt is derived from one source, the ocean, with a very constant concentration; and 3) salinity is easy and inexpensive to determine, and does not require great precision because of the large temporal and spatial salt gradients within most estuaries (Day et al, 1989).

Circulation, or the advective movement and exchange of water masses in an estuary, is a physical process that, in turn, affects or controls many chemical and biological processes. For example, the residence time of a particular parcel of water in an estuary is a function of the circulation patterns, and the ratio of the residence time to various biogeochemical turnover rates indicates the degree to which hydrodynamics dominate or modify the structure and functions of the estuarine system.

Estuarine circulation is normally defined as the residual or time-averaged water movement, meaning that short-term effects are averaged out. Three main driving forces are responsible for estuarine circulation, and in effect define a particular type of circulation. These include: 1) gravitational circulation; 2) tidal circulation; and 3) wind-driven circulation. Although all three forces drive circulation patterns in all estuaries to some degree, most estuaries are dominated by one type of circulation.

Circulation induced by density and elevation differences between freshwater inflows and salt water is called gravitational circulation. The less dense freshwater river inflow has a tendency to remain primarily in the surface layer of an estuary; whereas the more dense salt water entering from the sea tends to remain along the bottom layers. The effect of tide and wind, however, is to mix the water column, causing a vertical exchange between fresher surface waters and saltier water from below. This mixing process explains the existence of longitudinal and vertical salinity and density gradients observed in “partially mixed” estuaries such as the Peace River estuary. Furthermore, the pressure surfaces tilt seaward in the less dense surface layer, and landward in the saltier and more dense bottom layers, the net result of which is that the surface is characterized by net seaward flows and the bottom is characterized by net landward flows. This two-way circulation pattern has been termed “classical” estuarine gravitational circulation (Pritchard, 1956), and is illustrated in **Figure 3.1.**

In the absence of strong density gradients caused by river discharge, circulation in most estuaries is driven primarily by tidal currents associated with the oscillatory rise and fall of water levels caused by the gravitational pull of the moon and the sun on the sea. However, in broad shallow estuaries with relatively low tidal ranges, such as the Peace River estuary, wind may exert a dominant influence on water levels, water column mixing, and circulation over short-term time scales (e.g., days) during significant meteorological events such as tropical storms. Nonetheless, freshwater inflow from the Peace River, and the associated density gradients caused by river discharge, is the primary force driving circulation in the Peace River estuary.

3.2 Chemical Processes

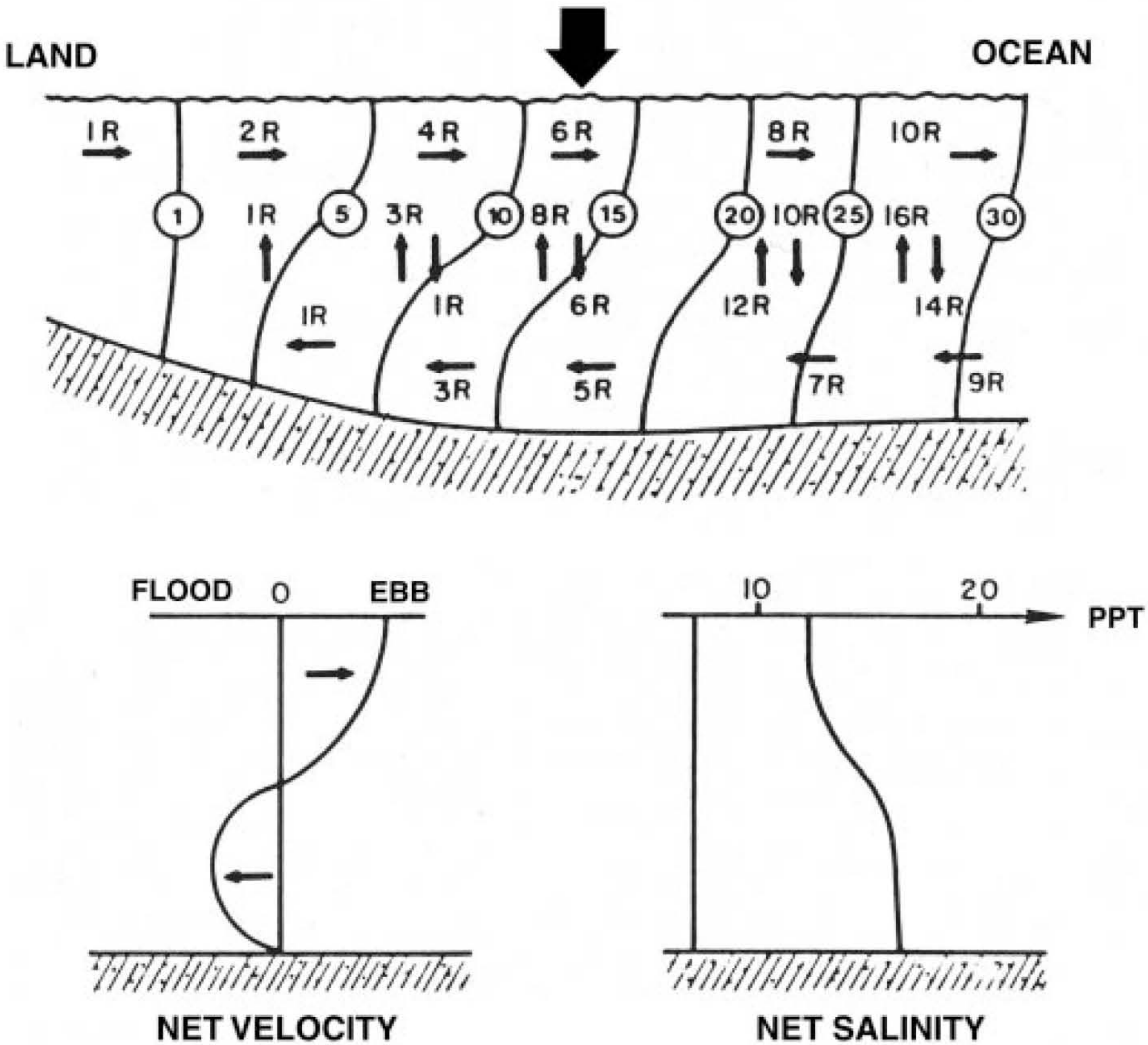
Since estuaries are, by definition, zones where rivers meet the sea, the nature of the chemical processes occurring in an estuary depends on the quantity and kind of materials transported by the fresh and salt water sources, the different chemical reactions that occur when fresh and salt water mix, and the residence time of river water in the estuary.

The composition of river water in terms of types and amounts of dissolved substances varies widely, and can even vary substantially between adjacent basins. Seawater, however, is remarkably uniform in terms of its major dissolved constituents no matter where in the world it is measured. The salts and other constituents dissolved in river water arise from three primary sources: 1) the products of rock weathering; 2) precipitation-derived salts in rain originally derived from sea spray and wind eroded terrestrial dust; and, 3) constituents deposited upon the landscape or directly discharged to the river by man.

The most important constituents of seawater are chloride, sodium sulfate, and magnesium. For globally averaged river water, however, the most important constituents are bicarbonate, calcium, silicon, and sulfate. The majority of the biologically important compounds entering an estuary are from riverine sources (e.g., silicon, iron, nitrogen, phosphorus, and organic compounds); however, other compounds essential to estuarine chemistry are derived predominantly from the sea. (e.g., sulfate and bicarbonate) (Day et al., 1989).

As river water mixes with seawater during its retention in an estuarine basin the dissolved and particulate constituents may behave conservatively (i.e., the concentrations are changed only by dilution), or they may undergo marked transformations in response to physical, chemical, and biological processes. The distribution of salts, as measured by salinity, is the most important conservative constituent in estuarine waters. Many of the most important reactions, however, are transformations between dissolved and particulate forms. These processes include: 1) adsorption upon particle surfaces; 2) flocculation and precipitation; and 3) biotic assimilation or excretion.

Figure 3.1
Schematic Representation of the Net Circulation in the Mixing Zone of a Partially-Mixed Estuary



Representation of the net circulation in the mixing zone of a partially mixed estuary. Horizonal and vertical water volume exchanges are expressed in units of river flow R. Isopleths of salinity (isohalines) in parts per thousand are superimposed in the circulation, indicating the change of net salinity profiles (and stratification) from the tidal river zone to the nearshor zone (Dyer 1979).

Although the chemical composition of estuarine waters is clearly a major determinant of the abundance and distribution of biological communities, it should be noted that biological processes can also readily alter the chemical composition of estuarine waters. Due to the complex chemical and biological interactions that take place when river discharges mix with seawater, some chemical constituents will behave conservatively (e.g., salinity), whereas for others the estuary will serve as either a source or a sink (see **Figure 3.2**).

3.2.1 Dissolved Ions and Particulates

In estuaries, both adsorption (the adhesion of chemical ions to particles) and flocculation (the coalescing of colloidal particles into larger aggregates) are a function of salinity; therefore, these processes tend to vary along the estuarine salinity gradient. Suspended silts, clays, and colloidal humic acids, which are transported into an estuary via river inflow, tend to carry negative electrovalent charges. In freshwater, repulsion between the negatively charged particles dominates so that stable suspensions are formed. But with increasing salinity, the interparticle forces become attractive; so that when particles collide they agglomerate into flocs, which may settle to the bottom. This process of flocculation as a result of change in charge has been shown to occur between 0 and 5 ppt salinity (Duinker, 1980). Between salinity values of 0 and 18 ppt phosphorus and metals such as iron, manganese, and aluminum are rapidly removed from solution. The removal appears to be closely associated with the flocculation of humic acids and hydrous iron oxides (Sholkovitch, 1976).

Direct adsorption of dissolved ions contained in river discharges to estuarine sediments can be particularly important for highly charged ions such as phosphate (PO_4). As much as 80-90% of the phosphate entering estuaries from river discharges can be trapped in estuarine sediments via adsorption (Jitts, 1959). In the Peace River estuary, however, far less phosphorus is removed from solution, primarily because of the naturally high concentrations in surface waters derived from phosphate rich soil deposits.

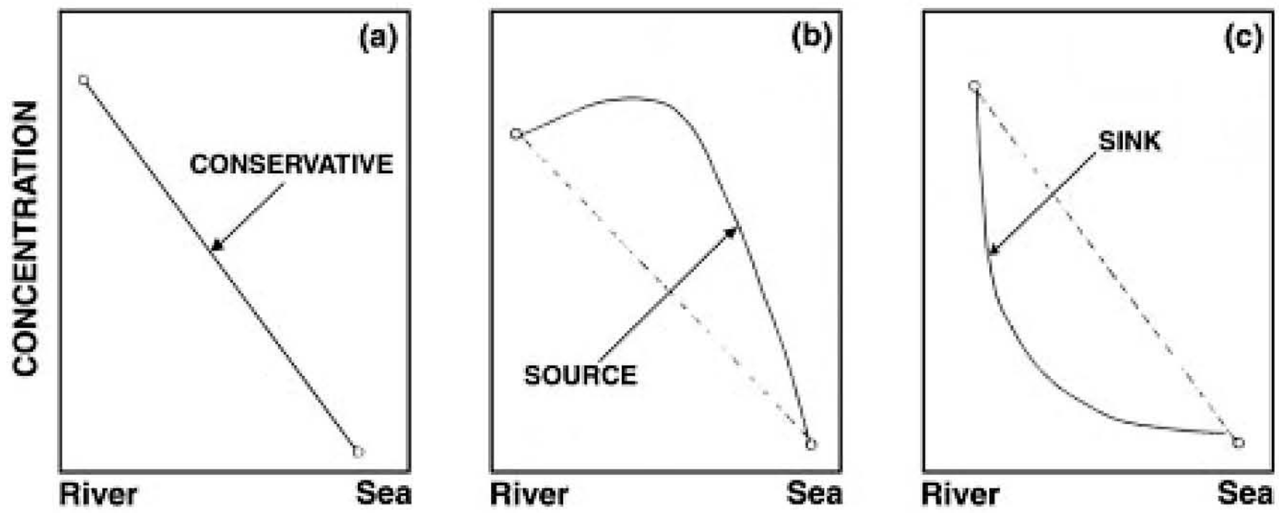
Adsorption and flocculation coupled with estuarine circulation patterns provides an important mechanism for entrapping dissolved chemical constituents, particulate organic matter, and other suspended solids contained in river discharges into estuarine sediments. Bacteria, as discussed below, subsequently utilize organic matter deposited in estuarine sediments anaerobically.

3.2.2 Metabolic Gases

A number of important substances in estuarine ecosystems occur primarily as gases, including carbon dioxide (CO_2) and oxygen (O_2). These gases are reactants and products in various key metabolic processes involving estuarine organisms.

The behavior of carbon dioxide in estuarine and other natural waters is markedly different from that of other gases in that it reacts with the water itself. In doing so, the CO_2-H_2O system establishes a chemical equilibrium, which in turn imparts special

Figure 3.2
Mixing Diagram for Conservative Variables (a), and for Variables for which the Estuary is a Source (b) or a sink



Mixing diagrams. The three panels show idealized patterns for: a) conservative mixing; b) when an estuary acts as a source; and c) or a sink, for a given parameter.

properties to the aquatic system. In freshwater the addition of dissolved CO_2, as from respiration, will cause the equilibrium to change with the consequence of more protons being released, and consequently the pH declines. However, in estuarine waters, with substantially greater amounts of total CO_2 imported from the ocean, some of the effects of adding this acid (CO_2) is absorbed by the formation of intermediate carbonate species (H_2CO_3, HCO_3), producing a reduced response in pH compared to what would occur in freshwater. This buffering effect is extremely important to the chemistry of estuaries where the pH generally ranges between 7.5 and 8.8.

The presence of dissolved oxygen in sufficient concentrations is critical to numerous biogeochemical reactions as well as to the survival of living organisms in estuaries. Temporal and spatial variation in the concentration of oxygen and dissolved carbon dioxide are commonly used to estimate rates of biological production and consumption of organic matter in aquatic ecosystems. Because dissolved CO_2 cannot be directly measured, pH is typically used as a surrogate by applying the theoretical inverse relationship between pH and CO_2. Diel changes in pH and oxygen can then be used to indicate production and consumption where daytime increases in oxygen and pH (decreases in CO_2) represent photosynthetic production, and decreases at night provide a measure of community respiration. Such estimates of production and respiration in estuaries are, however, complicated by the dynamic nature of physical circulation. In most estuaries, physical processes move water masses extensively and hence can dominate observed diel oxygen variations at any one location.

An important problem in partially-mixed estuaries such as the Peace River is that bottom waters often become hypoxic or anoxic during summer conditions when high river flows establish and maintain a marked vertical stratification. There is evidence from several estuaries that increased inputs of organic matter, either from upstream production or from downstream export of detritus, can substantially increase the magnitude, spatial extent, and temporal duration of hypoxia and anoxia resulting from increased bacterial respiration in the bottom strata water column (Day et al., 1989). Periodic hypoxia and anoxia have caused fish kills, and likely affect the abundance and distribution of benthic organisms, in the affected portions of the Lower Peace River estuary.

3.2.3 Nutrient Forms and Distribution

Among the most important chemical elements in the functioning of estuarine ecosystems are the autotrophic nutrients that serve as raw materials for the primary production of organic matter. The nutritional requirements of phytoplankton and other estuarine autotrophs include predominantly carbon, nitrogen, phosphorus, silicon, and a host of trace metals. Since carbon is extremely abundant in estuarine waters, the other macronutrients – N, P, and Si - are most likely to be found in limiting concentrations relative to algal requirements, although silicon is used only by diatoms. Because seawater is relatively nutrient depauperate, concentrations of these limiting macronutrients in estuaries are derived primarily from terrigenous runoff delivered in river discharges.

The limiting macronutrients are constantly cycling between organic and inorganic forms, as well as among different organic components in the food chain. They occur in estuarine waters in many forms that can be described primarily in terms of oxidation state, solid-liquid-gas phase, or chemical structure. The forms of nitrogen are most diverse with the oxidation state ranging from nitrate (NO_3, +5) to ammonium (NH_4, -3), and compounds exist in all oxidation states in between. Inorganic phosphorus most often occurs as the phosphate ion (PO_4, +5). Silicon is present in estuaries in three principle forms: detrital quartz, aluminosilicate clays, and dissolved silicon in the form of silicic acid (H_2SiO_4, +4).
Concentrations of the limiting macronutrients in estuaries are also constantly changing in time and space due to inputs and outputs from river flows and oceanic exchange, as well as biological uptake and regeneration. Although temporal and spatial patterns in the distribution of nutrients are highly variable among estuaries, certain common patterns have been observed. For example, most estuaries exhibit a mid-summer peak in phosphate concentrations typically resulting from temperature-regulated respiratory regeneration and changes in sediment redox conditions. On the other hand most estuaries exhibit a fall and winter peak in nitrate concentrations primarily driven by high river discharges (Day et al., 1989).

In west central Florida estuaries, naturally occurring phosphate mineral deposits tend to maintain phosphorus concentrations above limiting levels virtually year round, whereas maximum nitrate concentrations tend to occur in the late summer and fall corresponding to high river discharges during and following the summer wet season. In addition to these temporal patterns, nutrient concentrations exhibit both upstream and downstream spatial gradients corresponding with river discharges as well as biological uptake and regeneration.

3.2.4 Nutrient Assimilation and Primary Productivity

Dissolved inorganic salts and some organic forms of N, P, and Si are incorporated into particulate organic matter primarily via the assimilative processes of autotrophic and photosynthetic organisms. In the estuarine environment competition for assimilable nutrients is intense among various phytoplankton and macrophytic species, as well as between algae and autotrophic bacteria. Although there is a great deal of variability in assimilative capacity (e.g., the kinetic half saturation coefficient K_s) of the various photosynthetic taxa, this variability simply indicates that plants have adapted to the average nutrient concentrations they have encountered in their habitats. For example, phytoplankton and benthic microalgae have a distinct competitive advantage over macrophytes for assimilating nutrients in the low nutrient conditions of the water column; whereas, rooted macrophytes like seagrasses, mangroves, and marsh plants, are able to take greater advantage of the much higher nutrient concentrations typically found in sediment interstitial waters.

Phytoplankton productivity is the major source of primary food-energy for most estuarine ecosystems throughout the world. As with all green plants, photosynthesis by phytoplankton occurs by the conversion of light energy in solar photons into biological energy via the fixation of carbon dioxide, the splitting of the water molecule, and the production of carbohydrates and oxygen. Numerous factors regulate the magnitude, seasonal pattern, and species composition of phytoplankton photosynthesis, including temperature, light, nutrients, physical transport processes, and herbivory (Boynton et al., 1982), all of which can be influenced by seasonal and interannual variations in river flow. Changes in river flow can influence phytoplankton production and taxonomic distribution in an estuarine systems through several mechanisms, including: 1) changing the input of nutrients from the watershed (e.g., river discharges) to the estuary (e.g., internal regeneration); 2) changing the rates of dilution or advection of algal cells out of the estuary; and, 3) changing light availability through gravitational circulation and subsequent vertical stratification, and turbidity pulses (Day et al, 1989).

Annual means of phytoplankton production and abundance have been significantly correlated to riverine nutrient inputs for numerous estuarine systems. The delivery of large pulses of nutrients from river discharges resulting from major rainfall events can cause significant increases in annual productivity over several years, as was observed in the Chesapeake Bay following hurricane Agnes in 1972 (Boynton et al., 1982). On the other hand, high river flows can lead to low phytoplankton abundance when growth rates are less than the rates of advective removal of cells.

Variations in river flow can also control the location of the region of maximum phytoplankton production within an estuary. For example, under summer-fall low flow conditions, Filardo and Dunstan (1985) found peak chlorophyll-a concentrations occurring in the brackish regions of the James River estuary; however, with increasing river flow, a portion of this algal biomass was transported downstream and the highest phytoplankton growth was centered in the lower estuary with a markedly different species composition. In addition, Tyler (1986) found that during low flow periods, weaker stratification and greater mixing in the water column of the Patuxant River resulted in an increased dominance by diatoms, reduced zones of hypoxia, and upstream transport of several phytoplankton species typically found in the lower estuary. These trends were reversed during a period of high river flow.

3.2.5 Oxidation-Reduction Reactions

Much of the particulate organic matter carried to an estuary by rivers, as well as that produced *in situ* by phytoplankton, seagrasses, mangroves, and marshes, eventually comes to rest on the sediment surface. This detrital material provides the primary energy source for a diverse group of microbial organisms living on and in the sediments. Chemically, this energy source can be viewed as electron donors. The respiratory processes of these microbial organisms are essentially oxidation-reduction (redox) reactions involving a variety of oxidizing agents (electron acceptors). Such redox reactions are defined as the transfer of electrons from one material to another, and much of the energy flow in estuarine sediments is regulated by the availability of suitable electron acceptors. Oxygen gas (O_2) is the most important electron acceptor in the biosphere, but in the low layers of the estuarine water column oxygen concentrations may be depleted especially when stratification reduces the rate of replenishment from the atmosphere above. Below the sediment surface, oxygen is rapidly depleted to the point where sulfate (SO_4) becomes the dominant electron acceptor.

In most estuarine sediment environments both aerobic respiration and sulfate reduction generally appear to follow seasonal temperature cycles, with rates peaking during the summer months. On an average annual basis, however, it is estimated that roughly half the total respiration in most estuarine sediments is associated with sulfate reduction (Day et al., 1989). Microbial and sediment oxygen demand via the sulfur cycle, therefore, can influence oxygen concentrations in the overlying water, especially during periods of stratification.

Comprehensive measurements in estuarine sediments have shown that much of the energy flowing through estuarine ecosystems is modulated through anaerobic microbial metabolism. For example, measurements of sulfate reduction in a Massachusetts salt marsh suggest that an actual majority of the organic matter fixed in photosynthesis is channeled into the sulfur cycle (Howarth and Teal, 1980).

3.2.6 Nutrient Regeneration

As discussed above, organic matter resulting from the accumulation of dead plant and animal tissue is subjected to enzymatic decomposition by microorganisms (bacteria and fungi). Microorganisms obtain energy in this process, and the elements composing the organic matter are released in dissolved inorganic forms if the decomposition process is complete. In this case nutrients are released in the same relative proportions as the organic matter from which they were derived, and again become available for photosynthetic assimilation.

In the estuarine environment, microbially mediated decomposition occurs in relatively shallow water depths and rapid settling rates result in fairly short residence times for detrital matter in the water column. Therefore, most of the microbial regeneration of nutrients takes place on or in the sediments. In temperate estuaries seasonal patterns of benthic nutrient regeneration generally exhibit strong summer maxima, which correlate well with water temperature. The rates of nutrient regeneration measured from estuarine sediments are relatively large. From 20 to 200% of the respective nutrient demands for phytoplankton assimilation in overlying waters can be supplied by benthic decomposition of organic matter, indicating the large potential importance of nutrient regeneration for primary production by plankton (Day et al., 1989).

A portion of the nutrients assimilated by phytoplankton and other microbes in estuarine waters is regenerated from particulate to dissolved form as dead algae sink through the water column. While some of this water column regeneration results from bacterial decomposition of the dead plankton cells, much of it arises from the excretion of waste products by zooplankton. Nitrogen and phosphorus are excreted in the form of ammonium and dissolve organic nitrogen compounds (urea, uric acid, and amino acids), and as phosphate and dissolved organic phosphorus. Whereas this type of planktonic nutrient regeneration may be more significant in support of “recycled” production, “new” production is related more to nutrient inputs from river discharges and benthic regeneration (Kemp and Boynton, 1984).

3.3 The Estuarine Food Web

The transfer of food energy form the source in plants through a series of organisms, with sequential steps of consumption from lower to higher level animals, is referred to as a *food chain*. At each transfer a large proportion, up to 80-90%, of the potential energy is lost as heat. Therefore, the number of steps or links in a sequence is limited, usually to four or five. Thus, shorter food chains have greater inherent available energy. Food chains are of two basic types: the *grazing* food chain, which, starting from a green plant base, goes to grazing herbivores and on to carnivores; and the *detritus* food chain, which goes from dead organic matter into microorganisms and then to detritus-feeding organisms (detritivores) and their predators (Odum, 1971).

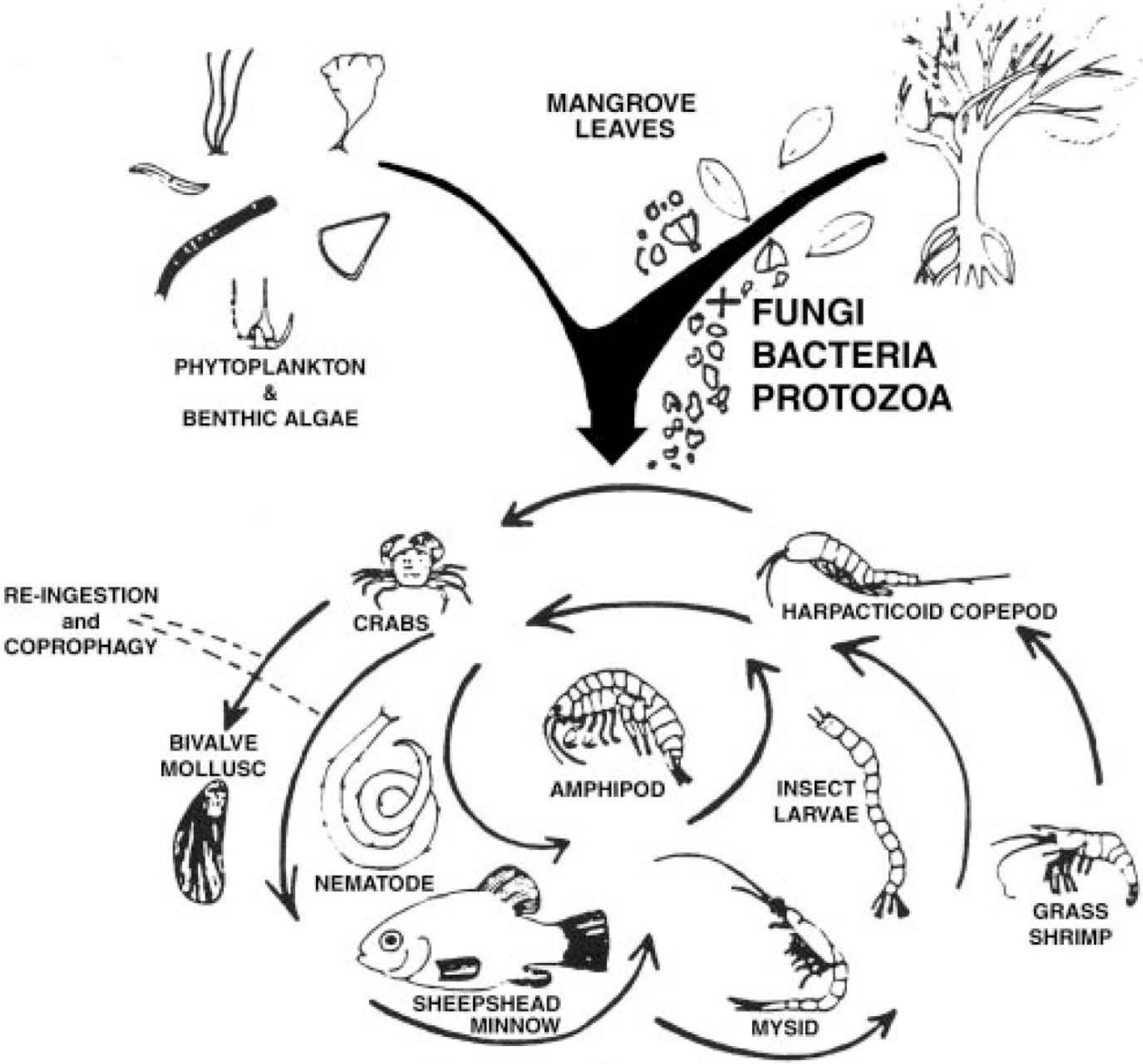
In complex natural communities, organisms whose food is obtained from plants by the same number of steps are said to belong to the same trophic level. Thus, green plants (producers) occupy the first trophic level, plant-eaters the second level (primary consumers), carnivores which eat herbivores the third level (secondary consumers), and secondary carnivores which eat other carnivores (tertiary consumers). The energy flow through a trophic level equals the total assimilation at that level, which in turn, equals the production of biomass plus respiration (Odum, 1971).

Food chains are not isolated sequences, but are interconnected with one another, with the interconnected chains referred to as a *food web*. The estuarine food web is made up of both grazing and detritus food chain components. A central concept in estuarine ecology through the 1970s was that organic detritus, derived primarily from vascular plants (e.g., mangroves) is the major food source in estuaries. A "picture model" of the estuarine food web, emphasizing the importance of detritivores, is presented in **Figure 3.3** (from Odum, 1971). Over the past two decades, however, the measurement of naturally occurring carbon isotopes in different estuarine producers and consumers has raised questions regarding the relative importance of vascular plants, and has indicated that phytoplankton are much more important as producers in the estuarine food web than originally thought. Nonetheless, the bulk of the evidence continues to support the fundamental role of the detrital food chain in estuarine trophic dynamics (Day et al., 1989).

3.4 Salinity Tolerance of Estuarine Organisms

Largely in response to widely variable water chemistry, including substantial fluctuations in salinity and dissolved oxygen concentrations, organisms that live in estuaries have evolved to tolerate the associated physiological stress. Consequently, most estuarine plants and animals can persist and flourish within a broad range of salinity. For example, black needlerush marshes (*Juncus roemerianus*) typically occur in the headwaters of tidal rivers and in the upper reaches of bays and estuaries where salinities range between 0 and 30 ppt (Eleuterius, 1984). While this species may be an extreme example of hardiness,

Figure 3.3
Picture Model of an Estuarine Food Web



Detritus Consumers

Small Carnivores
(minnows, small game fish, etc.)

Large (top) Carnivores
(game fish, fish eating birds)

most plant species that exist in estuaries, as well as many estuarine benthic invertebrates and fishes, can tolerate similar variations in salinity, at least over short time scales (Longley, 1994).

Despite their tolerance for wide fluctuations in salinity, the distribution and abundance of estuarine plants and animals still tend to segregate across a salinity gradient, indicating that most species have optimal salinity ranges with respect to environmental physiology and ecological competition. For example, although black needlerush can tolerate salinities ranging from 0 to 30 ppt over the short term, the spatial distribution of this species is generally limited to those portions of the estuary where the long-term average salinity ranges between 5 and 15 ppt (Longley, 1994). The species composition of the phytoplankton community at any given point in an estuary is also strongly driven by salinity; however, because algal cells drift with water masses and have very short life cycles, phytoplankton distribution and abundance can be extremely variable both spatially and temporally. Nonetheless, general patterns do exist. In temperate and subtropical estuaries chlorophytes and dinoflagellates tend to dominate in lower salinity areas, whereas in mid to high salinity regions of the estuary diatoms tend to be most dominant (Day et al., 1989).

3.5 Development of Conceptual Model

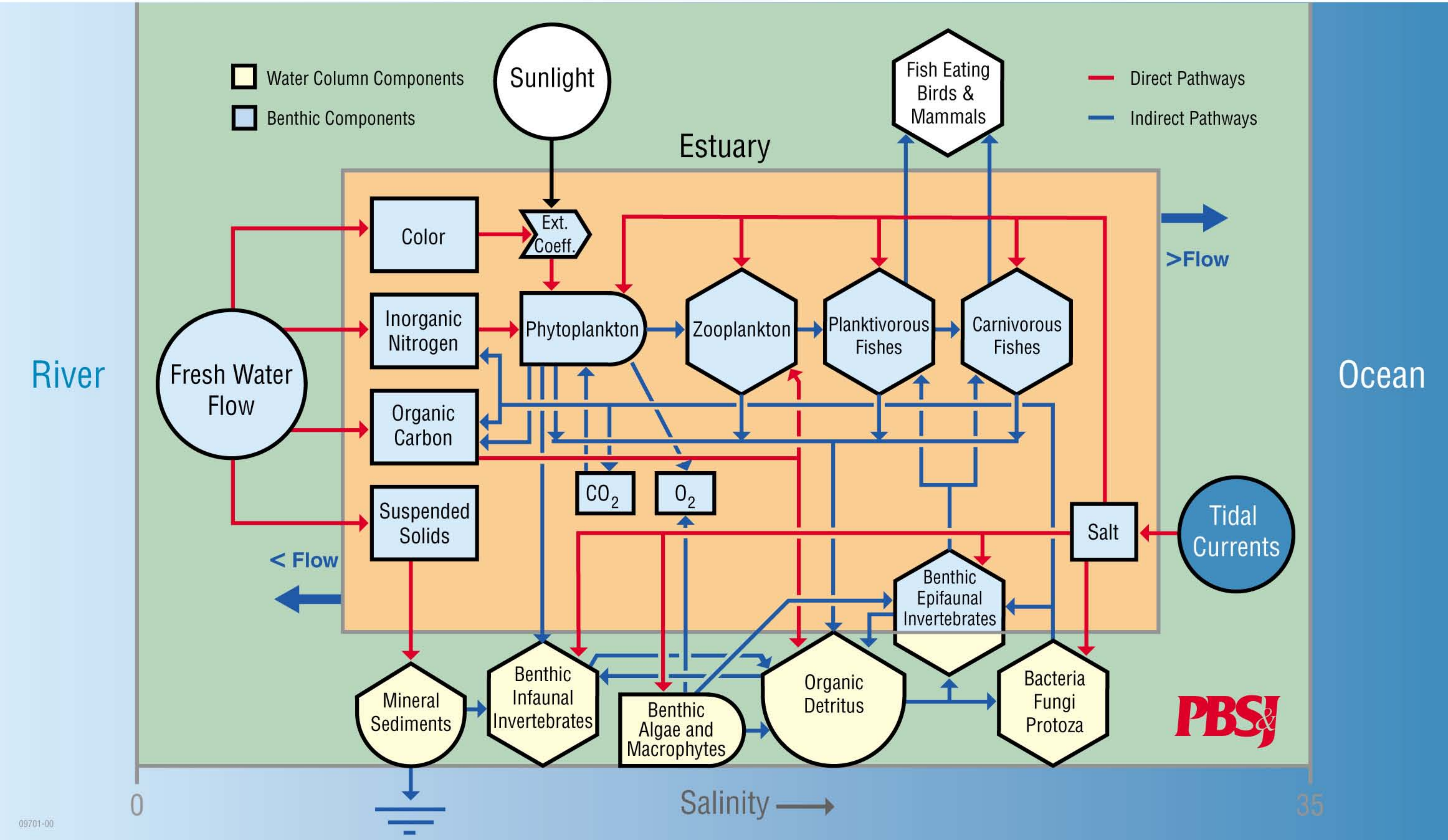
The above sections summarize the primary physical and chemical processes, and biological interactions, common to most shallow, partially-mixed estuaries such as the Peace River estuary. These processes and interactions have been synthesized into a "compartment model" which conceptually illustrates the structure and function of the Peace River estuary. This conceptual model is presented in **Figure 3.4.**

The conceptual model frames trophic energy flow within the spatial context of the river axis, and illustrates how variations in river discharge cause a shift in the horizontal (e.g., upstream and downstream) location of the estuarine mixing zone, as well as the physical, chemical and biological processes that occur in the estuary. From this model, the following general effects of variations in river discharge, whether from freshwater withdrawals or natural climatic variability, on the structure and function of the estuary can be discerned.

- Salinity is a major determining factor controlling the distribution, abundance and species composition of all biotic communities in the estuary. The primary mode of action on plants and animals is ionic and osmoregulatory adaptations to particular salinity regimes.

- The interactions between the physical, chemical and biological processes and the biological components of the estuarine ecosystem are exceedingly complex. Most of the effects of changes in freshwater inflow on trophic energy flow in the estuary are mediated and modulated by numerous steps and feedback loops.

Figure 3.4
Conceptual Model of the Peace River Estuarine System



- Changes in freshwater inflows generally result in a horizontal shift in the location of the estuarine mixing zone along the river axis. Greater freshwater inflows cause a downstream shift, whereas lesser flows cause an upstream shift.

- The physical, chemical and biological processes, and trophic energy flows, that take place in the estuarine mixing zone (e.g., adsorption, flocculation, assimilation, and regeneration) are translocated upstream or downstream corresponding to changes in the horizontal location and areal extent of the mixing zone.

- The distribution of the planktonic (drifting) and nektonic (swimming) communities, including phytoplankton, zooplankton, and fishes, and the trophic interactions between these communities, can be translocated upstream or downstream in response to changes in salinity over both short (e.g., hours, days) and longer (e.g., seasons, years) time scales.

- The distribution of the benthic (bottom) communities - including rooted macrophytes, sediment microbes, and benthic invertebrates - and the trophic interactions between these communities, are typically translocated upstream or downstream primarily in response to changes in salinity over much long time scales (e.g., months, years, decades).

- If the magnitude and duration of variations in river discharge are large enough, spatial discontinuities can be created between the stationary and non-stationary variables of the estuarine ecosystem. For example, if freshwater inflows were to be reduced such that there was a substantial upstream shift in the long-term average position of the bottom isohalines, a discontinuity would exist between the stationary biological resources, such as rooted macrophytes and benthic invertebrates, and the overlying water column. That is, the stationary living resources would no longer be spatially distributed within the zone of their “preferred” salinity range, potentially leading to extirpations and shifts in species composition.

This latter effect can also be extended to more complex interactions between biological variables. For example, Browder and Moore (1983) have postulated that such discontinuities between planktonic fish and invertebrate larvae, which tend to be distributed within preferred salinity ranges, and critical stationary habitats such as salt marsh vegetation can lead to reduced survival and recruitment. It should be noted, however, that such spatial discontinuities are also temporary by virtue of the fact that estuaries are dynamic, and no natural variable in the estuarine ecosystem is truly stationary or fixed in space. That is, the distributions of variables typically considered as stationary (e.g., rooted macrophyte and benthic invertebrate communities) actually shift over much longer time scales, on the order of years to decades, in response to an environmental change of sufficient magnitude and duration. Although extirpations and shifts in species composition may occur relative to a fixed location in the estuary, the ecosystem as a whole eventually reaches a new equilibrium with respect to the spatial distribution of the “stationary” variables. However, long-term reductions in freshwater inflows and the a net movement of biological communities further upstream may result in reduced productivity, as suitable habitats may not be as abundant in morphologically different upstream estuarine areas.

One significant effect of variations in river discharge that cannot be readily discerned from the conceptual model involves the physical, chemical and biological processes associated with water column stratification. As discussed above, strong gravitational circulation patterns can develop in shallow partially-mixed estuaries under high flow and low turbulence conditions, especially during summer months when water temperatures are highest. Persistent water column stratification often leads to hypoxia, and even anoxia, which can significantly alter the distribution and abundance of planktonic, nektonic and benthic plants and animals. Periodic hypoxia/anoxia has been well documented in the Peace River estuary during periods of high flow.

3.6 HBMP Variables and the Conceptual Model

This section provides a discussion of the relative sensitivity of each of the variables measured under the existing HBMP with respect to changes in freshwater inflow. In addition, each variable is evaluated in the context of the conceptual model presented above. In the discussion that follows, those variables that are considered to be important in the conceptual model are those that: 1) most directly affect the distribution, abundance, and species composition of estuarine plants and animals; 2) most directly affect trophic energy flow through the estuary; and 3) are most directly related to changes in freshwater inflow.

- **Salinity** – Although it behaves as a conservative variable in estuaries, salinity is perhaps the most important variable measured under the existing HBMP. Vertical salinity gradients drive the development and maintenance of gravitational circulation patterns, whereas horizontal salinity gradients largely dictate the spatial distribution and abundance of estuarine plants and animals. The vertical and horizontal distribution of salinity in the estuary is directly controlled by variations in freshwater inflow from river discharges, therefore, salinity is considered to be an extremely important variable in the conceptual model.

- **Chlorides** – Chlorides are a primary mineral constituents in the measurement of salinity, or the dilution of salts in seawater. In the estuary, relatively small concentrations of chlorides are also delivered via groundwater seepage into river discharges. Chlorides behave as a conservative variable in response to variations in freshwater inflow, but are essentially a surrogate or redundant measure of salinity in the estuary. For this reason chlorides are not considered to be an important variable in the conceptual model.

- **Alkalinity –** Alkalinity is a measure of carbonate and bicarbonate concentrations, and is used as a means to calculate inorganic carbon concentrations. Because carbonates are transformed in the carbon cycle, alkalinity is a non-conservative variable. However, variations in freshwater inflow do affect the spatial distribution of alkalinity, with concentrations generally increasing downstream. Because salinity is a better direct measure of dilutional mixing, and because carbonate concentrations are not limiting with respect to biological processes in the estuary, alkalinity is not considered to be an important variable in the conceptual model.

- **Dissolved Oxygen** – Dissolved oxygen behaves as a non-conservative variable in estuaries in that ambient concentrations are substantially affected by reactive processes (e.g., photosynthesis, respiration, redox). Variations in freshwater inflow can affect dissolved oxygen concentrations both directly through advection, and indirectly through numerous mediated steps and processes including translocation of phytoplankton production, and water column stratification combined with benthic respiration. Dissolved oxygen is considered to be an extremely important variable in the conceptual model.

- **Nitrogen (total nitrogen, nitrate/nitrite, ammonia, organic nitrogen)** – Nitrogen is typically the most important macronutrient controlling algal production in most estuaries. In Florida estuaries, nitrogen is almost always the limiting nutrient due to the naturally occurring high concentrations of phosphorus. The cycling of nitrogen through the ecosystem via uptake and regeneration plays a major role in carbon fixation and energy flow through the estuary. As such, it is a non-conservative variable. River discharges contribute the majority of inorganic nitrogen to the estuary, and nitrogen concentrations within the estuary are directly affected by variations in freshwater inflow. Therefore, nitrogen in its various forms is considered to be an extremely important variable in the conceptual model.

- **Phosphorus (total phosphorus, orthophosphorus)** – Phosphorus is an important macronutrient essential to algal production, and as such, it is a non-conservative variable. Phosphorous concentrations in estuaries are derived both from river discharges and via regeneration from sediments, and therefore can be directly affected by variations in freshwater inflow. However, phosphorus is rarely a limiting nutrient to algal growth, especially in west central Florida estuaries due to substantial natural deposits of phosphate in the soils, and high sediment regeneration rates. For these reasons, phosphorus behaves as a conservative variable in the Peace River estuary. Therefore, phosphorus is not considered to be an important variable in the conceptual model.

- **Silica** – Silica is a critical macronutrient for diatom production, and as such it is a non-conservative variable. Although HBMP data have indicated that ambient silica concentrations decline during spring diatom blooms in the lower estuary, there is little evidence that silica concentrations are ever limiting. Because silica is delivered to the estuary primarily via river discharges, variations in freshwater inflow directly affect silica concentrations in the estuary. However, silica is not considered to be an important variable in the conceptual model because it is rarely limiting in Florida estuaries.

- **Organic Carbon (dissolved organic carbon and total organic carbon)** – Both dissolved and particulate forms of organic carbon are delivered to the estuary in river discharges and are deposited via adsorption and flocculation. In addition, inorganic carbon is assimilated in the estuary via photosynthesis and regenerated via respiration. Therefore, carbon compounds behave non-conservatively in the estuary. While variations in freshwater inflow do affect the delivery of dissolved and total organic carbon (e.g., dissolved plus particulate forms), it is unlikely that these sources of carbon are ever limiting with respect to carbon fixation and energy flow, where the regeneration and assimilation of inorganic carbon may be more important. In addition, any potential impacts associated with changes in dissolved and particulate organic carbon inputs to the estuary would be mediated by numerous steps and processes in the detrital food chain. For these reasons, organic carbon is not considered to be an important variable in the conceptual model.

- **Color** – Color is primarily the result of the leaching of tannic and humic acids from tree roots and leaf litter into surface waters. Although some of the tannic and humic acids are adsorbed and flocculated out of the water column in the estuarine mixing zone, color for the most part behaves as a conservative variable. Because the source compounds that cause color in surface waters are derived primarily from forest runoff, changes in freshwater inflow directly affect the concentration of those compounds in the estuary. In addition, by reducing light penetration, color can significantly affect phytoplankton production even when nutrients are not limiting. Therefore, color is considered to be an important variable in the conceptual model.

- **Turbidity** – Turbidity is a measure of the sum total of all light scattering particles in the water column. As such turbidity can be affected by a variety of sources including suspended solids and phytoplankton cells. Turbidity is typically not closely related to river discharge in most Florida estuaries because river sediment loads are relatively minimal compared to local sources of turbidity in the estuary (e.g., wave turbulence, algal production, etc). Therefore, turbidity is not considered to be an important variable in the conceptual model.

- **Total Suspended Solids** – Total suspended solids include mineral and organic particulates suspended in the water column. As a component of turbidity, suspended solids also scatter light in the water column, and can periodically cause light limiting conditions for plant production (e.g., following a clay slime spill). Suspended solids are generated by watershed runoff and by internal resuspension caused by water column turbulence. Suspended solids delivered from river discharge also contribute to the accumulation of unconsolidated sediments in the estuary. Although sediment loads in Florida Rivers are relatively small under normal flow conditions, total suspended solids may be directly related to freshwater inflow during periods of high flow when erosion and scouring are greatest. Nonetheless, normally total suspended solids are not considered to be an important variable in the conceptual model.

- **Extinction Coefficient** – The extinction coefficient of light is a composite measure of the net effect of all scattering, absorbing particles and dissolved compounds in the water column. This comprehensive measure of the attenuation of photosynthetically active radiation provides key information regarding a major limiting factor for production by both phytoplankton and submerged aquatic vegetation. In the Lower Peace River estuarine system, color and chlorophyll *a* are both primary influences on light attenuation and directly are in turn related to variations in freshwater inflow. Thus, light extinction should be considered to be an important component of the overall conceptual estuarine model.

- **Chlorophyll *a*** – As a measure of algal biomass, chlorophyll-a is non-conservative variable. Variations in freshwater inflow can affect chlorophyll *a* concentrations directly through advection and translocation of phytoplankton production, and indirectly through the delivery of nutrients from river discharge which in turn fuel algal production. Because it is both directly and indirectly related to variations in freshwater inflow, chlorophyll *a* is considered to be an important variable in the conceptual model.

- **Carbon Uptake** – Carbon uptake is an instantaneous measure of algal primary production (e.g., carbon fixation) and growth. Algal growth over longer time scales is assessed via other variables in the HBMP (e.g., chlorophyll *a*), therefore, the measurement of carbon uptake is considered to be redundant and not important with respect to the conceptual model.

- **Phytoplankton Species Composition** – The distribution and abundance of phytoplankton taxa as a function of variations in freshwater inflow can be assessed in two different manners: 1) changes in taxa with respect to fixed locations along the axis of the river; and 2) changes in taxa with respect to a moving isohaline. The former can be used to detect changes in algal taxa in response to upstream or downstream movement of isohalines; whereas the latter can be used to detect changes in algal taxa in response to changes in concentrations of nutrients, color and other algal limiting constituents delivered in river discharges. This latter approach has been applied in the current HBMP. Phytoplankton communities are, however, not always good indicators of changes in freshwater inflows since species composition is also controlled by seasonal factors and herbivory. In terms of energy flow in the estuarine ecosystem, phytoplankton species composition is probably far less important than algal production and biomass. Therefore, phytoplankton species composition is not considered to be an important variable in the conceptual model.

- **Vegetation Species Upstream/Downstream Extent** – As discussed above, if freshwater inflows were to be reduced such that there was a substantial upstream shift in the long-term average position of the bottom isohalines, a discontinuity would exist between the stationary biological resources and the overlying water column. That is, the stationary communities would no longer be spatially distributed within their "preferred" salinity range, potentially leading to extirpations and shifts in species composition. Upstream and downstream changes in the distribution of key vegetation species should theoretically serve as a valuable indicator of salinity change in response to variations in freshwater inflow. Discontinuities between stationary variables and the overlying water column may in turn significantly affect energy flow through the estuarine ecosystem. Therefore, the upstream/downstream extent of vegetation species is considered to be an important variable in the conceptual model.

In conclusion, the conceptual model attempts to illustrate the complexity of the estuarine ecosystem. In reality, the physical, chemical, and biological processes and interactions that take place in the estuary are far more complex than can possibly be depicted on a two-dimensional flow diagram. In defining the variables that have the highest probability of detecting hydrobiological change specifically in response to changes in freshwater flow, it is apparent that those variables that are most directly linked to flow variations, with the fewest number of mediating steps and feedback loops, will be most efficacious.

For this purpose, salinity is perhaps the most useful variable in that it is conservative, and its distribution directly affects other critical physical and chemical processes, as well as the spatial distribution of biological communities. Other useful variables include those that are directly affected by changes in freshwater inflow (e.g., nitrogen concentrations, color), as well as those that are closely associated with the directly affected variables (e.g., chlorophyll *a* as measure of nutrient assimilation).

On the other hand, variables that are related to, but not directly or solely driven by, freshwater inflows provide little insight into potential hydrobiological impacts of withdrawals. For example, while variations in freshwater inflows do affect the delivery of total organic carbon, any potential impacts associated with changes in riverine organic carbon inputs to the estuary would likely be expressed in some change in biological productivity which would be mediated by a vast number steps and processes, and confounded by numerous other interacting factors. Consequently, the interpretation of data for variables that are far removed from the direct effects of withdrawals is often speculative at best.

3.7 Chapter III Summary

1. Estuaries are ecosystems that are, to a large degree, dominated by physical and chemical processes. Furthermore, river discharge, or freshwater inflow, is one of the most important variables determining the spatial limits of, and the physical and chemical interactions within, an estuary. Therefore, the volume and timing of freshwater discharges from rivers is often the most critical factor driving the biological functions of estuaries.

2. Energy flow through estuarine ecosystems is extremely complex involving numerous physical, chemical, and biological processes and interactions. The estuarine food web is made up of both grazing and detritus food chain components.

3. Largely in response to widely variable water chemistry, including substantial fluctuations in salinity and dissolved oxygen concentrations, organisms that live in estuaries have evolved to tolerate the associated physiological stress. Consequently, most estuarine plants and animals can persist and flourish within a broad range of salinity. However, despite their tolerance for wide fluctuations in salinity, the

distribution and abundance of estuarine plants and animals still tend to segregate across a salinity gradient, indicating that most species have optimal salinity ranges with respect to environmental physiology and ecological competition.

4. The conceptual model illustrates that variations in river discharge, whether from freshwater withdrawals or natural climatic variability, can affect the structure and function of the estuary in the following ways:

   - Salinity alone is a major determining factor controlling the distribution, abundance and species composition of all biotic communities in the estuary. The primary mode of action on plants and animals is ionic and osmoregulatory adaptations to particular salinity regimes.

   - The interactions between the physical, chemical and biological processes and the biological components of the estuarine ecosystem are exceedingly complex. Most of the effects of changes in freshwater inflow on trophic energy flow in the estuary are mediated and modulated by numerous steps and feedback loops.

   - Changes in freshwater inflows generally result in a horizontal shift in the location of the estuarine mixing zone along the river axis. Greater freshwater inflows cause a downstream shift, whereas lesser flows cause an upstream shift.

   - The physical, chemical and biological processes, and trophic energy flows, that take place in the estuarine mixing zone (e.g., adsorption, flocculation, assimilation, and regeneration) are translocated upstream or downstream corresponding to changes in the horizontal location and areal extent of the mixing zone.

   - The distribution of the planktonic (drifting) and nektonic (swimming) communities, including phytoplankton, zooplankton, and fishes, and the trophic interactions between these communities, are translocated upstream or downstream primarily in response to changes in salinity over short time scales (e.g., hours, days).

   - The distribution of the benthic (bottom) communities - including rooted macrophytes, sediment microbes, and benthic invertebrates - and the trophic interactions between these communities, are translocated upstream or downstream primarily in response to changes in salinity over long time scales (e.g., months, years, decades).

   - If the magnitude and duration of variations in river discharge are large enough, spatial discontinuities can be created between the stationary and non-stationary variables of the estuarine ecosystem. For example, if freshwater inflows were to be reduced such that there was a substantial upstream shift in the long-term average position of the bottom isohalines, a discontinuity would exist between the stationary biological resources, such as rooted macrophytes and benthic invertebrates, and the overlying water column. That is, the stationary living resources would no longer be spatially distributed within the zone of their “preferred” salinity range, potentially leading to extirpations and shifts in species composition.

- Strong gravitational circulation patterns can develop in shallow partially mixed estuaries under high flow and low turbulence conditions, especially during summer months when water temperatures are highest. Persistent water column stratification often leads to hypoxia, and even anoxia, which can significantly alter the distribution and abundance of planktonic, nektonic and benthic plants and animals. Periodic hypoxia/anoxia has been well documented in the Peace River estuary during periods of high flow.

5. In defining the variables that have the highest probability of detecting hydrobiological change specifically in response to changes in freshwater inflow, it is apparent that those variables that are most directly linked to flow variations, with the fewest number of mediating steps and feedback loops, will be most efficacious. For this purpose, salinity is perhaps the most useful variable in that it is conservative, and its distribution directly affects other critical physical and chemical processes, as well as the spatial distribution of biological communities. Other useful variables include those that are directly affected by changes in freshwater inflow (e.g., nitrogen concentrations, color), as well as those that are closely associated with the directly affected variables (e.g., chlorophyll *a* as measure of nutrient assimilation).

6. Variables that are related to, but not directly or solely driven by freshwater inflows, are much more complex with regard to evaluating the potential effects of withdrawals. For example, while variations in freshwater inflows do affect the delivery of total organic carbon, it is unlikely that these sources of carbon are ever limiting with respect to detrital food webs in the Peace River estuary where autochthonous sources may be more important. In addition, any potential impacts associated with changes in riverine organic carbon inputs to the estuary would likely be expressed in some change in biological productivity which would be mediated by a vast number steps and processes, and confounded by numerous other interacting factors. Consequently, the interpretation of data for variables that are far removed from the direct effects of withdrawals is often speculative at best.

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Chapter IV

Status and Trends in the Lower Peace River

4.1 Overview

This chapter assesses the health of the Lower Peace River in the context of the ambient freshwater inflows. The health of the river is defined in terms of water quality, phytoplankton community composition and biomass, and emergent and riparian vegetation. Assessments include examinations of both the “status” and “trends” in the health of the lower river. Assessments of water quality, and biological communities, can vary both spatially and temporally as functions of the complex and simultaneous interactions of numerous both large and small-scale processes.

“Status” refers to the current state of the river and, in part, is evaluated by comparing the spatial patterns between the long-term averages (1976-1998) with those of data collected during the three-year period after the most recent permit renewal (1996-1998). Patterns in river conditions are expressed within a spatial frame using the standardized, centerline river kilometer transect developed as part of the Morphometric Study (PBS&J 2000) discussed in **Chapter II**.

Statistical analyses were conducted to determine the presence and magnitude of long-term “trends”, which refers to progressive, continuing changes in the mean or median level of a variable caused by the influences of an external factor. As such, “trends” are characteristically distinct from the commonly occurring "seasonal" and shorter-term oscillating patterns that primarily result from repeating natural processes. From a temporal viewpoint, a trend defines “where the river has been” and perhaps even “where the river is headed.”

The analysis and determination of the presence and/or absence of long-term trends within the data, collected as part of the HBMP, is a key component to assessing the effectiveness of the overall goals prescribed by the Water Use Permit (WUP). As permitted freshwater withdrawals are projected to increase, it becomes increasingly important to be able to determine and partition the potential influences of other long-term changes (rainfall/inflows), as well as assess potential biotic and abiotic responses within the Lower Peace River/Upper Charlotte Harbor estuary to withdrawals. The ability to detect and quantify (or determine the lack of) progressive changes over time is a crucial element to assessing the health of the estuarine system and providing a framework and basis for determining future management decisions regarding freshwater diversions.

4.2 Rainfall and Freshwater Inflows

A much more detailed and thorough analysis of hydrologic relationships and patterns in the Lower Peace River watershed is presented in **Chapter V**. This later section specifically evaluates the magnitude of the potential changes in salinity associated with permitted Peace River Facility withdrawals. As part of that discussion, analyses are presented of long-term hydrologic changes over different recent historic periods in both upper basin rainfall, and flows in each of the four major gaged tributaries.

A significant portion of the data contained within the discussion of status and trends below, however, was collected in conjunction with the "moving" isohaline element of the HBMP program that began in 1984. The discussions of hydrologic trends presented in Chapter V deals with longer time periods. It is important to put any discussions of status and trends in the "more" recent isohaline data in context with patterns in rainfall and freshwater inflows during the same period. Table 4.1 summarizes the results of trend analyses of hydrologic conditions for the period 1984-1998. Detailed statistical summaries (Tau, P-Value, Slope) for each of these trend tests are presented in **Table 4.2**. (These statistical tables use bold marking to distinguish between the appropriate use of autocorrelation corrections when necessary, and colors to differentiate between trends significant at the 0.5 and 0.1 levels. A comprehensive explanation of the methodology used in developing these tables is provided in **Appendix A**.)

The increasing trends in rainfall and flows during the period 1984-1998, to a great extent, reflect the somewhat unusual conditions that marked both the start and end of this fifteen year period. The first three years followed the strong 1983 El Niño event and were unusually dry, while the last four years of the period were much wetter than average and characterized by the extended 1997/1998 El Niño. As a result, any trends observed in the data gathered as part of the isohaline study need to be evaluated in relation to the parallel significant increase in Lower Peace River flows.

Table 4.1 Trends Rainfall, Flows and Flow to Rainfall Ratios 1984-1998

Measurement Location	Trend	Time Series	Box Plot	Correlogram
Rainfall				
Rainfall at Arcadia	N.S	B-001	B-002	B-003
Rainfall at Wauchula	▲	B-004	B-005	B-006
Rainfall at Bartow	▲	B-007	B-008	B-009
Flow to Rainfall Ratios				
Ratio Flow at Arcadia to Rainfall at Arcadia	▲	B-013	B-014	B-015
Ratio Flow at Arcadia to Rainfall at Arcadia + Wauchula + Bartow	▲	B-016	B-017	B-018
Gaged Flow				
Peace at Arcadia	▲	B-010	B-011	B-012
Total Upstream of US 41 Bridge	▲	B-019	B-020	B-021

Table 4.2 Trends in Rainfall (inches) in the Upper Peace River Basin and Gauged Flows at Arcadia and Above US 41 Bridge During the Period 1984-1998					
Measurement Location	**Tau Statistic**	**P-Value without Serial Correlation**	**P-Value with Serial Correlaion**	**Slope Statistic**	**Trend**
Rainfall					
Rainfall at Arcadia	0.016	0.800	0.807	0.012	
Rainfall at Wauchula	0.096	0.107	**0.053**	0.056	▲
Rainfall at Bartow	0.128	0.027	0.023	0.090	▲
Ratio of Flow to Rainfall					
Ratio Flow at Arcadia to Rainfall at Arcadia	0.253	0.000	0.010	7.885	▲
Gauged Flow					
Peace River at Arcadia	0.203	0.000	0.032	20.75	▲
U.S. 41 Bridge	0.201	0.000	0.034	35.32	▲

4.3 Physical Characteristics

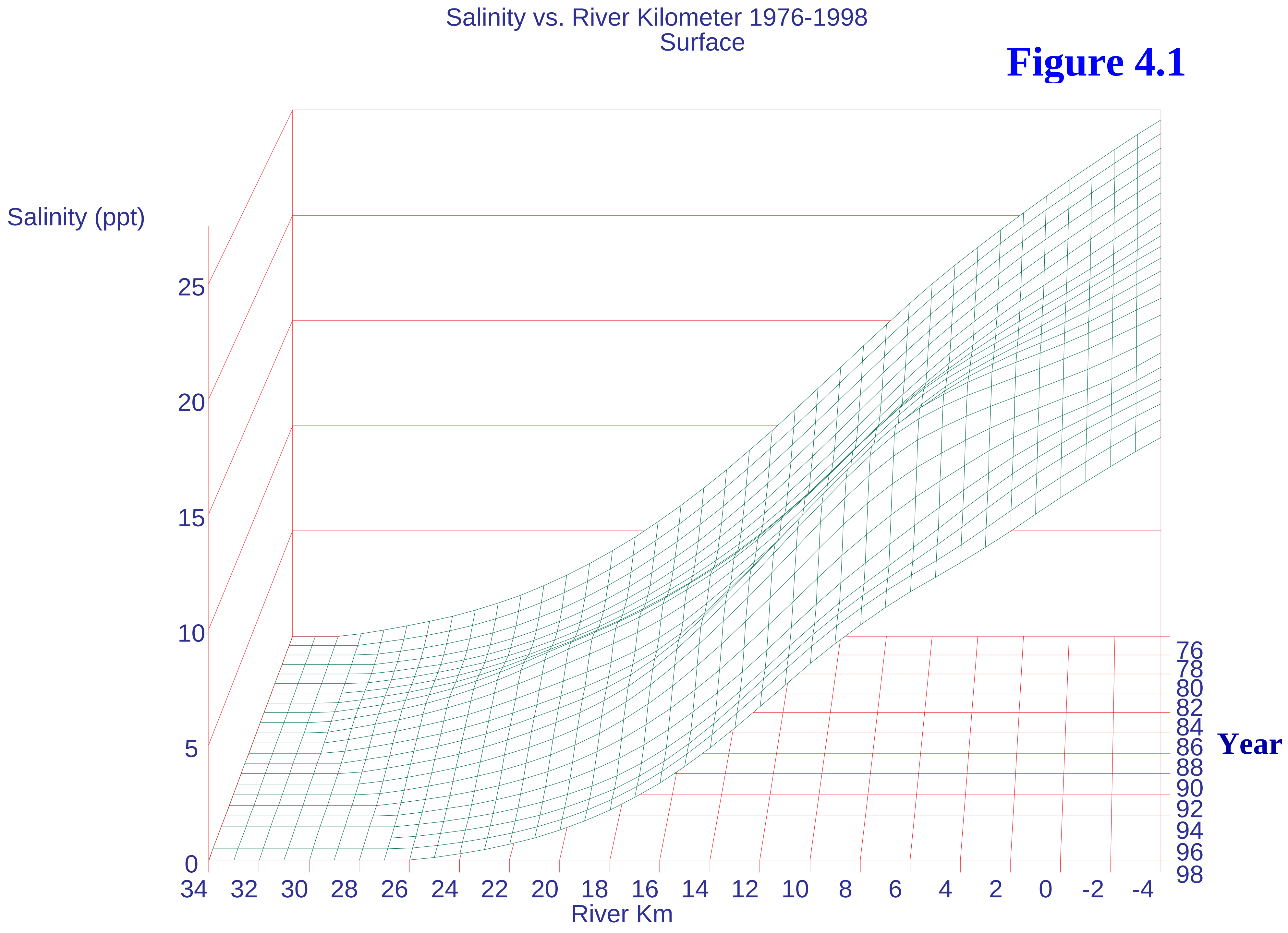
The two physical/chemical water quality measurements common to many of the HBMP study elements are salinity and dissolved oxygen, since both influence the occurrence and distribution of biological communities through the processes of recruitment/reproduction, growth and survival. Water withdrawals by the Peace River Facility could potentially affect the distribution of the salinity gradient within the lower river system through a reduction in the amount of freshwater entering the estuary. As such, the HBMP has had two primary goals with regard to the measurement of salinity. The first has been to characterize the salinity gradient's natural seasonal and long-term spatial variability downstream of the Peace River Facility. The second has been to develop a sufficient database to allow accurate determination of flow/salinity relationships along this gradient in order to develop accurate statistical estimates of the magnitude of change potentially resulting from the permitted Peace River Facility withdrawal schedule (see **Chapter V**).

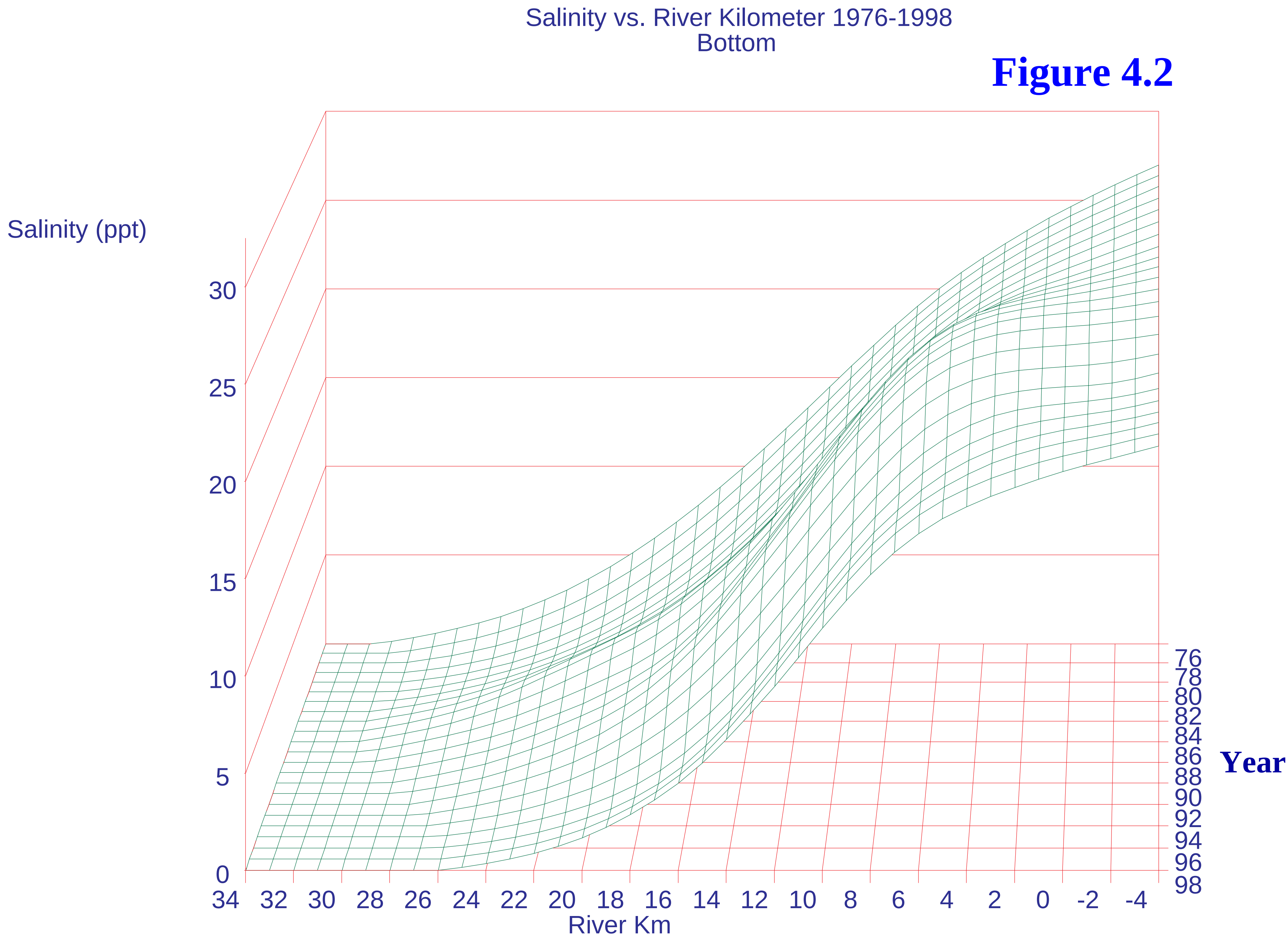
HBMP data gathered prior to the start of withdrawals by the Peace River Facility were the first to document the magnitude and extent of the extensive anoxic/hypoxic bottom conditions that develop near the mouth of the river and in the Harbor during periods of high summer freshwater inflow (see *Summary of Historical Information Relevant to the Hydrobiological Monitoring of the Lower Peace River and Upper Charlotte Harbor Estuarine System*, PBS&J 1999). Questions, however, remained regarding the seasonal and spatial patterns of dissolved oxygen levels along the lower river downstream of the Peace River Facility and whether ambient concentrations might be affected by the permitted withdrawals.

4.3.1 Salinity

Figures 4.1 and **4.2** present three dimensional "response surfaces" produced by integrating all of the surface and bottom salinity measurements collected by both the "moving" and "fixed" station HBMP water quality studies. These figures provide average salinity levels integrated by both year and location along the Lower Peace River estuary. Both surface and bottom models clearly indicate the increases in salinity that occurred from the mouth of the river upstream to near the Peace River Facility (RK 30.2) as a result of the extended period of low flows that occurred between 1984 and 1988, following the 1983 El Niño event.

The degree of variability in surface and bottom salinity levels is depicted in the series of box and whisker plots listed in Table 4.3, comparing both the long-term (1976-1998) and the three-year period (1996-1998) since the recent permit renewal. It should be noted that these graphics include all pertinent HBMP data, from both "moving" and "fixed" station monitoring elements. Care should be taken when interpreting univariate plots from these two separate efforts when both are combined and plotted by river kilometer. This is because there are many more data points at the "fixed" stations, which are sampled monthly at the same river kilometer in comparison to the "moving" data that by design are temporally unbalanced.


Salinity vs. River Kilometer 1976-1998
Surface
Figure 4.1
Salinity (ppt)
0
5
10
15
20
25
34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0 -2 -4
River Km
76 78 80 82 84 86 88 90 92 94 96 98
Year


Salinity vs. River Kilometer 1976-1998
Bottom
Figure 4.2
Salinity (ppt)
30
25
20
15
10
5
0
34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0 -2 -4
River Km
76
78
80
82
84
86
88
90
92
94
96
98
Year

Comparisons between data gathered over the longer and recent time periods provide an indication of the relative recent "status" of the spatial distribution of salinity within the lower river. Reference lines are provided indicating the locations of the US 41 Bridge (RK 6.6) and the Peace River Facility (RK 30.2). Some conclusions drawn from the data include:

- These plots indicate that the region of the lower river downstream of approximately river kilometer 24.0 can experience fairly wide changes in salinity both over the short and long term.

- Analyses of the long-term salinity data (1976-1998) indicate a strong increase in the range of the 75th percentile starting near RK 8.0. This strongly suggests than there is a marked increase in the frequency of higher salinities downstream of RK8.0. Conversley, there is a downward inflection of the 25th percentile upstream of RK 11.0, indicating an increase in the frequency of lower salinities upstream of that point.

- These plots also clearly define the range of extreme values, with salinities greater than 5 ppt being rare upstream of RK 24.0 and conversely the occurrence readings less than 5 ppt being equally infrequent downstream of RK 5.

The plots of median salinities listed in Table 4.3 also summarize the degree of spatial difference in surface and bottom salinity levels along the transect, from near the river's mouth to upstream of the Peace River Facility. Median levels are presented overall, and by wet and dry seasons, over both the long and short term. These results indicate that the distributions of median surface and bottom salinities have been quite similar between the two periods. As expected, a contrast of wet and dry seasons indicates higher salinities and a shift slightly upstream during the characteristically drier months.

Table 4.3 Salinity Gradient Along the Lower Peace River					
	Box and Whisker Plots		**Median Salinity by River Kilometer**		
	Surface	**Bottom**	**Overall**	**Wet season**	**Dry-season**
1976-1998	**B-022**	**B-023**	**B-024**	**B-025**	**B-026**
1996-1998	**B-027**	**B-028**	**B-029**	**B-030**	**B-031**

Monthly "fixed" station water quality data were collected between 1976 and 1989, and not added back into the HBMP again until 1996. The intervening six-year gap makes use of conventional statistical trend procedures problematic. Once sufficient data have been collected post 1996, it may be possible to comparatively test for differences between slopes in the trends for data collected over the two periods. In the meantime, Table 4.4 provides graphics that present the results of trend analyses of surface and bottom salinities at a series of fixed locations along the Lower Peace River transect for the period 1976-1989. The dotted "predicted" line in the time series graphics indicates the estimated slope of a fitted linear regression. A similar series of analyses using the Seasonal Kendal Tau procedures were presented in the Summary Report submitted in 1995 by the Authority. Complete statistical summaries are presented in **Table 4.5**.

Table 4.5 Trends in Surface and Bottom Salinities at Fixed Stations (1976-1989)					
Location Depth	**Tau Statistic**	**P-Value without Serial Correlation**	**P-Value with Serial Correlation**	**Slope Statistic**	**Trend**
River Kilometer -2.4					
Surface	0.020	0.741	0.870	0.017	
Bottom	0.023	0.704	0.839	0.024	
River Kilometer 6.6					
Surface	0.024	0.694	0.839	0.030	
Bottom	0.046	0.442	0.687	0.070	
River Kilometer 15.5					
Surface	-0.045	0.444	0.653	-0.013	
Bottom	-0.068	0.249	0.513	-0.033	
River Kilometer 23.6					
Surface	0.101	0.074	**0.328**	0.000	
Bottom	0.108	0.058	**0.298**	0.000	
River Kilometer 30.4					
Surface	0.195	**0.000**	0.079	0.000	▲
Bottom	0.271	0.000	0.015	0.003	▲

This series of analyses indicates, that over the initial fourteen-year period of HBMP sampling, only salinities at the most upstream locations near the Peace River Facility were found to have significantly changed, increasing at both the surface and bottom. As previously discussed, this pattern probably reflects the effects associated with the extended unusually dry period, characterized by periods of very low flows, that followed the 1983 El Niño event. Comparison of the monthly Box Plots listed in Table 4.4 of surface and bottom salinities at these fixed locations indicates distinctive differences with regard to the degree of seasonal variability. In absolute terms, the greatest seasonal variations in salinity occur in the surface waters near the mouth of the river. However, the relative percent change is far greater along the bottom upstream, during the typically dry spring months when high salinity waters move farther up river.

Table 4.4 Trends in Salinity at Fixed Locations (1976-1989)

River Kilometer Depth	Trend	Time Series	Box Plot	Correl-ogram		River Kilometer Depth	Trend	Time Series	Box Plot	Correl-ogram
RK –2.4						**RK 23.6**				
Surface	N.S	**B-032**	**B-033**	**B-034**		**Surface**	N.S	**B-050**	**B-051**	**B-052**
Bottom	N.S	**B-035**	**B-036**	**B-037**		**Bottom**	N.S	**B-053**	**B-054**	**B-055**
RK 6.6						**RK 30.4**				
Surface	N.S	**B-038**	**B-039**	**B-040**		**Surface**	▲	**B-056**	**B-057**	**B-058**
Bottom	N.S	**B-041**	**B-042**	**B-043**		**Bottom**	▲	**B-059**	**B-060**	**B-061**
RK 15.5										
Surface	N.S	**B-044**	**B-045**	**B-046**						
Bottom	N.S	**B-047**	**B-048**	**B-049**						

Another method that has been used during the HBMP of evaluating seasonal and long-term changes along the Lower Peace River/Charlotte Harbor salinity gradient has been to track the relative monthly locations during the period 1983-1998 of the "moving" isohaline sampling sites to the river's mouth. The results of the univariate analyses presented in **Table 4.6** indicate the relative degree of differences in the seasonal locations among the four isohalines. These data show that both the divergences between wet and dry seasons, and minimum and maximum distances increase with increasing salinity. These patterns are further emphasized in the comparative univariate plots of all four isohalines over the entire period 1983-1998 (**Figure 4a**), as well as for the wet- and dry-seasons (**Figure 4b**) during the sixteen year period.

Trend analyses were conducted, and summarized in Table 4.7, of both the monthly location of each isohaline, as well as calculated monthly estimates of the percentage of the Lower Peace River area between the Peace River Facility (RK 29.8) and the US 41 Bridge (RK 6.8) having salinities = 0, < 6, <12 and < 20 ppt. These analyses track the monthly percentages of differing isohalines within a twenty-three kilometer reach of Lower Peace River estuarine system, and as such provides useful insight into potential relations between stationary and non-stationary ecosystem components (see **Chapter III**). Unlike the "fixed" station data, monthly collections have been made continuously since 1983. As previously indicated (see Section 4.2), freshwater inflows during this period were found to have significantly increased. As indicated, this greater flow was

Table 4.6 Seasonal Differences in the Location (River Kilometers) of Isohalines for the Time Period 1984-1998

Season	Isohaline	Mean		Percentiles						
				0 (min)	5th	25th	50th	75th	95th	100 (max)
Dry	0 ppt	21.4		3.4	12.2	16.7	21.9	25.9	30.3	33.8
Dry	6 ppt	13.3		-14.4	4.6	9.6	13.3	16.8	22.1	26.4
Dry	12 ppt	8.5		-18.8	-1.4	6.6	9.4	11.8	16.4	21.7
Dry	20 ppt	1.9		-29.6	-19.4	-0.5	3.9	7.2	10.4	14.2
Wet	0 ppt	17.3		7.5	10.3	13.6	16.7	19.6	26.8	29.2
Wet	6 ppt	8		-16.3	-0.7	5	8.7	11.5	14.1	22
Wet	12 ppt	0.5		-30.1	-24.5	-1.6	4.7	7.2	10.4	15.4
Wet	20 ppt	-10.1		-36.3	-29.5	-17.9	-10	1.2	7.3	11.5

Figure 4a.   Box & Whiskers of relative isohaline distances (km) from the mouth of the river (1983-1998).

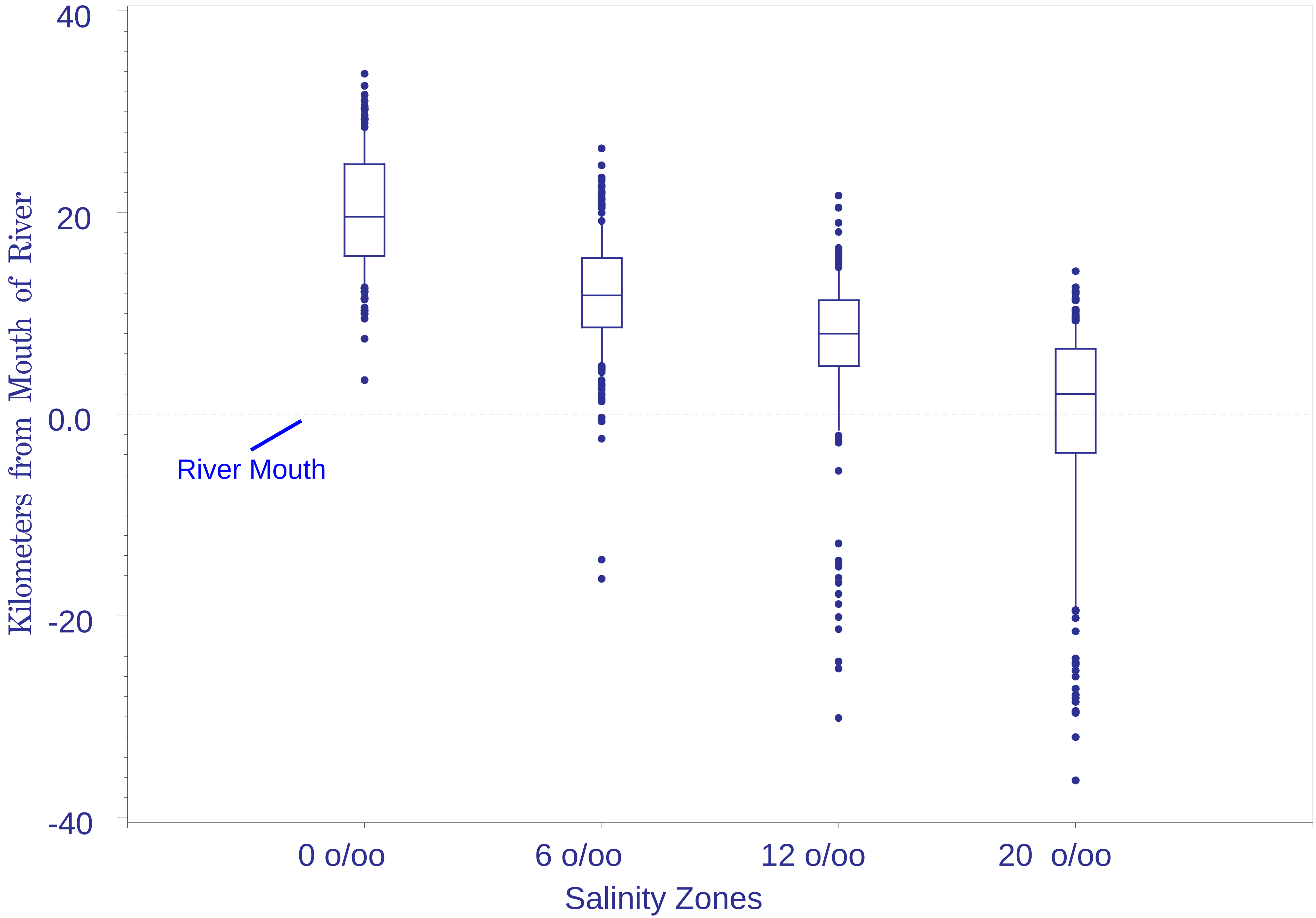
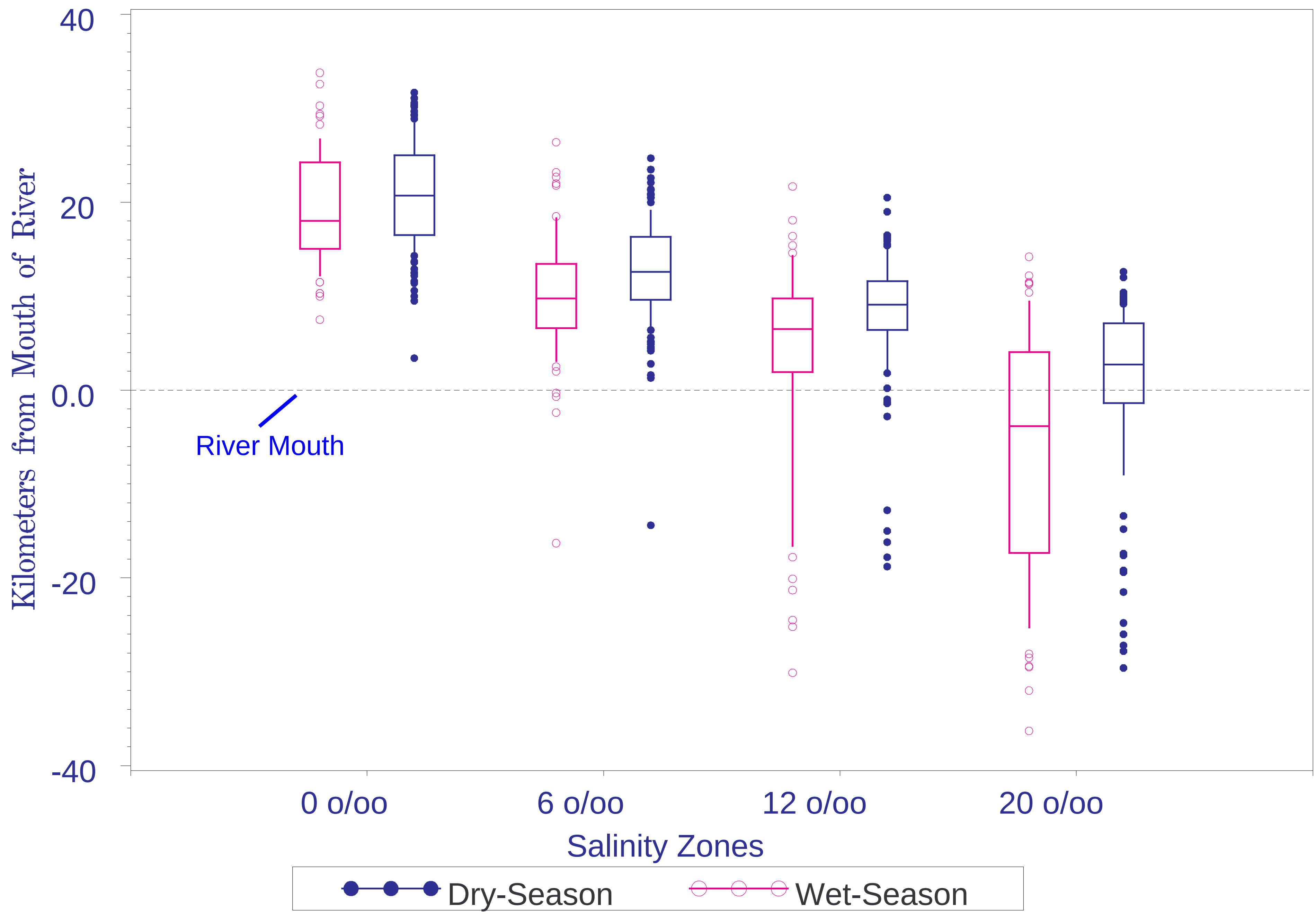


Figure 4B. Box & Whiskers of relative isohaline distances (km) from the mouth of the river during wet and dry-seasons (1983-1998).



further reflected in the statistically significant movement of the three higher isohaline locations farther downstream (smaller values), and a corresponding increase in the expansion of lower regions of lower salinity water within the Lower Peace River. Detailed statistical summaries are presented in **Table 4.8**.

Table 4.7 Trends in Location of Isohalines (1984-1998)

Time Period Isohaline	Trend	Time Series	Box Plot	Correl-ogram		Time Period Isohaline	Trend	Time Series	Box Plot	Correl-ogram
Location of Isohalines (River Kilometer)						Percent of River Between Facility and US 41 Bridge				
1984-1998						1984-1998				
0 ppt	N.S.	B-062	B-063	B-064		= 0 ppt	N.S.	B-074	B-075	B-076
6 ppt	▼	B-065	B-066	B-067		< 6 ppt	▲	B-077	B-078	B-079
12 ppt	▼	B-068	B-069	B-070		< 12 ppt	▲	B-080	B-081	B-082
20 ppt	▼	B-071	B-072	B-073		< 20 ppt	▲	B-083	B-084	B-085

4.3.2 Dissolved Oxygen

Figures 4.3 and **4.4** present three dimensional "response surfaces" model results produced by integrating all of the surface and bottom dissolved oxygen readings recorded between 1976-1998 in conjunction with both the "moving" and "fixed" station HBMP study elements. These figures indicate average dissolved oxygen concentrations integrated across both years and distance along the Lower Peace River transect. The key points indicated by these graphics are that:

1) Both surface and bottom dissolved oxygen levels are, on average, above 5 mg/L (State regulatory standard for a twenty-four hour average);
2) The spatial pattern of dissolved oxygen readings at the surface slightly increases downstream towards the area of the river's mouth;
3) Conversely, predicted average bottom dissolved oxygen levels show a fairly steady decline from 7 to near 5 mg/L progressing from upstream near the Peace River Facility down toward the mouth of the river;
4) Overall the data seem to indicate a very slight decline in average dissolved oxygen concentrations with time, which seems to be related to a decline in higher values.

Both the range and relative variability in measured surface and bottom dissolved oxygen levels are depicted through a series of box and whisker plots listed in Table 4.9 for both the long-term (1976-1998) and recent period (1996-1998). Again, it should be noted that these graphics include all pertinent HBMP data, from both "moving" and "fixed" station monitoring elements. Thus, care should be taken when interpreting univariate plots from these two separate efforts when both are combined and plotted by river kilometer, since there are many more data points at the "fixed" in comparison to the "moving" station data. Reference lines are provided in the graphics indicating the locations of the US 41 Bridge (RK 6.6) and the Peace River Facility (30.2). These figures indicate a number of additional details regarding dissolved oxygen spatial patterns along the Lower Peace River:

Table 4.8 (a) Location of Isohalines

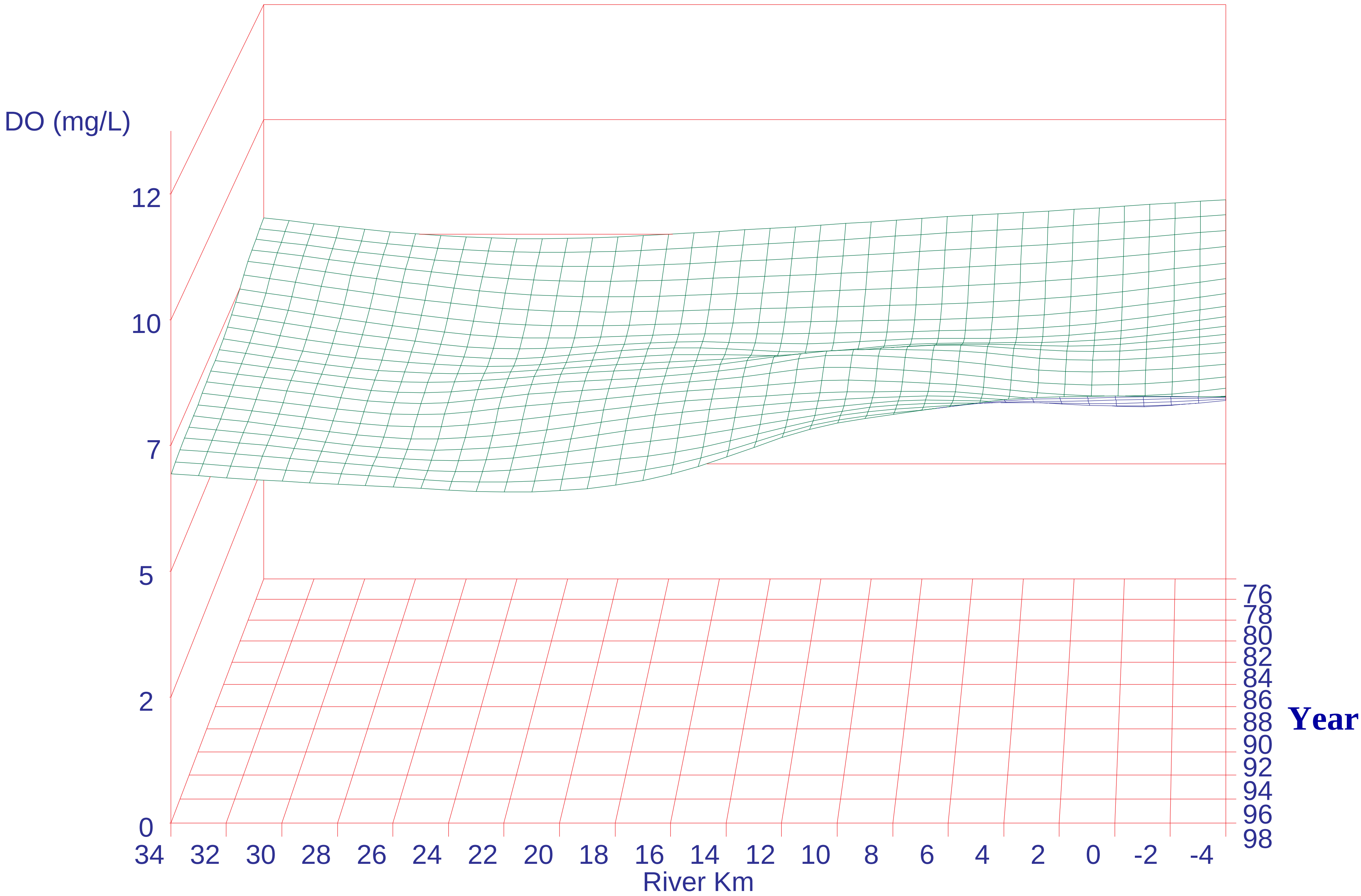
Time Period Location	Tau Statistic	P-Value without Serial Correlation	P-Value with Serial Correlation	Slope Statistic	Trend
1984-1998					
0 ppt	-0.102	0.067	**0.339**	-0.187	
6 ppt	-0.2260	0.000	0.044	-0.355	▼
12 ppt	-0.222	0.000	0.045	-0.361	▼
20 ppt	-0.250	0.000	0.036	-0.477	▼
Total Gauged Freshwater Inflows above US 41 Bridge (1984-1998)	.2010	0.000	0.033	35.320	▼

Table 4.8 (b) Percent of River Between Facility and US 41 Bridge

Time Period Percent of River	Tau Statistic	P-Value without Serial Correlation	P-Value with Serial Correlation	Slope Statistic	Trend
1984-1998					
0 ppt	0.099	0.075	**0.351**	0.574	
< 6 ppt	0.226	0.000	0.044	1.186	▲
< 12 ppt	0.223	0.000	0.042	1.000	▲
< 20 ppt	0.224	0.000	0.043	0.235	▲

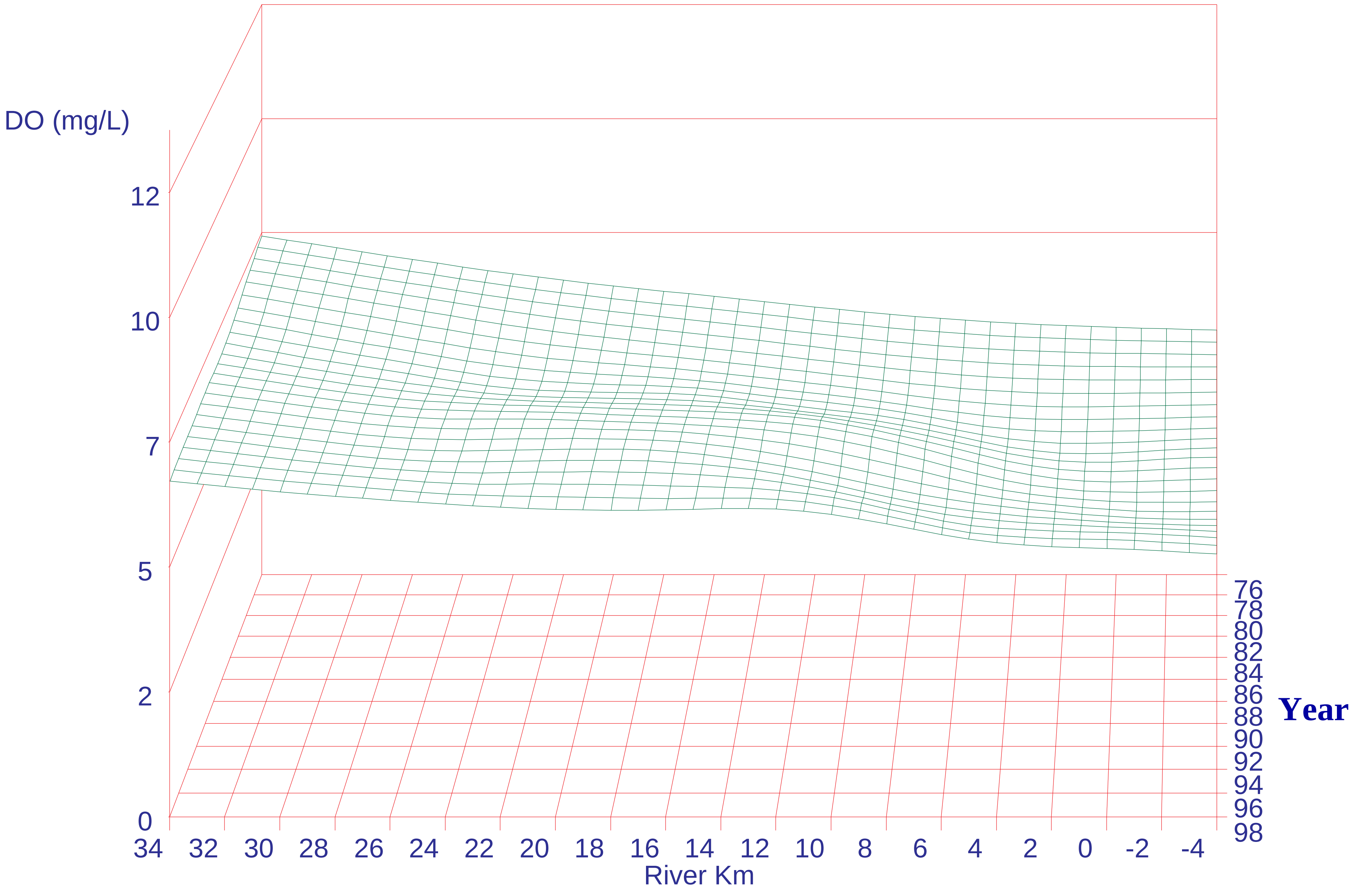
Dissolved Oxygen vs. River Kilometer 1976-1998
Surface

Figure 4.3



Dissolved Oxygen vs. River Kilometer 1976-1998
Bottom

Figure 4.4



1) Although not common, very high dissolved surface oxygen readings (> 12 mg/L) do occur on occasion. (Such events in the river are almost always associated with large phytoplankton blooms.)
2) Surface dissolved oxygen levels are generally above 5 mg/L and never indicative of hypoxia (< 2 mg/L).
3) By comparison, approximately ten percent of all near bottom dissolved oxygen readings downstream of the US 41 Bridge were < 2 mg/L, and four percent of all measurements were < 0.5 mg/L.
4) Although the occurrence of very low bottom dissolved oxygen concentrations becomes less frequent upstream of the US 41 Bridge (RK 6.6), it is not until slightly after the area of the I-75 Bridge (RK 10.8) that hypoxic conditions disappear. From this point on upstream, dissolved oxygen levels are almost always above that generally thought to provide the minimum for the maintenance of healthy benthic communities.

The median difference in surface and bottom dissolved oxygen levels along the transect from near the river's mouth to upstream of the Peace River Facility is presented overall and by both wet and dry seasons by the graphics listed in Table 4.9, over the history of the HBMP and for the past three years. During the past three years (1996-1998), average surface dissolved oxygen concentrations have been slightly higher downstream of the US 41 Bridge than those for this area based on the longer-term average. This observation can be linked to the higher than average flows during the recent period, which have resulted in an increase in phytoplankton blooms near the mouth of the River. A comparison of averages between the wet and dry seasons indicates that both the characteristic low dissolved oxygen bottom waters, and the very high surface readings, observed downstream of the US 41 Bridge often result under high flow conditions. The low dissolved oxygen levels in the lower portion of the water column is the result of stratification and the isolation of higher saline bottom waters; while the very high surface values are associated with phytoplankton blooms stimulated by increased nutrient inputs during higher flows.

Table 4.9 Dissolved Oxygen Gradient Along the Lower Peace River

	Box and Whisker Plots		Median Dissolved Oxygen by River Kilometer		
	Surface	Bottom	Overall	Wet season	Dry-season
1976-1998	B-086	B-087	B-088	B-089	B-090
1996-1998	B-091	B-092	B-093	B-094	B-095

Trend analyses of ambient dissolved oxygen concentrations over the entire period of the HBMP (1976-1998) is complicated by the lack of any uniform data for the years 1990 through 1995 (see above discussion of salinity). However, a summary of trend analyses of surface and near bottom dissolved oxygen levels over the first fourteen years of the monitoring period is provided in Table 4.10, with corresponding statistical results in **Table 4.11**.

Table 4.11 Trends in Surface and Bottom Dissolved Oxygen at Fixed Stations (1976-1989)					
Location Depth	**Tau Statistic**	**P-Value without Serial Correlation**	**P-Value with Serial Correlation**	**Slope Statistic**	**Trend**
River Kilometer -2.4					
Surface	0.020	0.741	0.870	0.017	
Bottom	0.023	0.704	0.839	0.024	
River Kilometer 6.6					
Surface	0.024	0.694	0.839	0.030	
Bottom	0.046	0.442	0.687	0.070	
River Kilometer 15.5					
Surface	-0.045	0.444	0.653	-0.013	
Bottom	-0.068	0.249	0.513	-0.033	
River Kilometer 23.6					
Surface	0.101	0.074	**0.328**	0.000	
Bottom	0.108	0.058	**0.298**	0.000	
River Kilometer 30.4					
Surface	0.195	**0.000**	0.079	0.000	▲
Bottom	0.271	0.000	0.015	0.003	▲

What is apparent from these analyses is that over this period there were statistically significant declines in surface, and upstream bottom, dissolved oxygen concentrations. In other estuarine systems such trends have been noted with some degree of alarm. However, a review of the data (see Time Series Plots) clearly indicates that rather than a general decline, characterized by both lower lows and lower highs, what occurred during this period was a marked decline of the very high levels commonly observed between 1976 and 1981. While some small amount of the observed change may reflect the progressive improvement of *in situ* oxygen probe technology, most of the reduction probably resulted from regulatory changes in the Upper Peace River Basin. The unusually high ambient dissolved oxygen concentrations observed during this period were often associated with corresponding unusually high phytoplankton biomass (chlorophyll *a*) levels. The period 1976-1981 corresponds with sharp reductions in phosphorus concentrations in the Lower Peace River/Upper Charlotte Harbor estuary (see below) caused by changes in regulatory requirements controlling point and non-point runoff from extensive areas of phosphate mining in the headwaters of the Peace River. This decline in phosphorus concentrations corresponded with marked reductions in green/blue-green algae blooms in the lower river. Since there is no evidence that suggests that phosphorus ever limits phytoplankton growth in the Peace River estuarine systems, the mechanism that might explain this apparent interrelation remains unclear.

A review of the presented Box Plots clearly shows the strong seasonality in bottom dissolved oxygen concentrations, with characteristically lower levels throughout the lower estuary during the wetter months of July through September. Also apparent during these wetter months is the declining gradient in bottom dissolved oxygen levels downstream toward the mouth of the river.

Table 4.10 Trends in Dissolved Oxygen at Fixed Locations (1976-1989)

River Kilometer Depth	Trend	Time Series	Box Plot	Correl-ogram		River Kilometer Depth	Trend	Time Series	Box Plot	Correl-ogram
RK –2.4						RK 23.6				
Surface	▼	B-096	B-097	B-098		Surface	N.S.	B-114	B-115	B-116
Bottom	N.S.	B-099	B-100	B-101		Bottom	▼	B-117	B-118	B-119
RK 6.6	N.S.					RK 30.4	▼			
Surface	▼	B-102	B-103	B-104		Surface	N.S.	B-120	B-121	B-122
Bottom	N.S.	B-105	B-106	B-107		Bottom	▼	B-123	B-124	B-125
RK 15.5										
Surface	▼	B-108	B-109	B-110						
Bottom	▼	B-111	B-112	B-113						

4.4 Water Quality Characteristics

In order to put the water quality characteristic of the Lower Peace River into context, Table 4.12 compares the water quality of a series of other Southwest Florida coastal rivers for the period of 1996-1998. These rivers include:

- Caloosahatchee (data source: EPA STORET)

- Manatee (data source: Manatee County)
- Little Manatee (data source: EPC Hillsborough County)
- Alafia (data source: EPC Hillsborough County)
- Hillsborough (data source: EPC Hillsborough County)

Table 4.12 Characteristic Water Quality of Southwest Florida Rivers

Parameter	River Systems					
	Peace	Caloosahatchee	Manatee	Little Manatee	Alafia	Hillsborough
Chlorophyll *a*	11.5	10.3	8.3	5.3	5.4	13.0
Total Phosphorus	0.61	0.16	0.26	0.50	4.97*	0.25
Total Nitrogen	0.99	0.90	0.80	1.20	1.95	0.98
Dissolved Inorganic Nitrogen	0.37	-	0.11	0.50	1.13	0.23
Color	123	54	37	63	39	52
Turbidity	4	4	-	4	6	3

* Note: A mining spill on the Alafia River in December 1997 resulted in highly elevated average levels.)

The water quality characteristics of the Lower Peace River are generally similar to the other rivers on Florida's west coast. The Lower Peace River is more highly colored and has somewhat higher total phosphorus levels than most of the other rivers.

The following discussions describe both the temporal and spatial distributions of each of these water quality measurements within the Lower Peace River/Upper Charlotte Harbor estuarine system, and summarize tests for the presence of long-term trends.

4.4.1 Status and Spatial Distribution

Plots of each of the six selected water quality parameters are shown plotted (Table 4.13) in relation to distance along the river centerline from slightly below the river's mouth, to upstream to just above the Peace River Facility. The first two series of figures depict the degree of spatial variability in surface and bottom measurements, both over the entire period of record (1976-1998) and during the most recent three years (1996-1998), through the use of univariate Box and Whisker Plots. (Note: bottom water quality samples were only collected as part of the fixed sampling HBMP element, see **Chapter II**). As noted previously, these graphics include all pertinent HBMP data, from both "moving" and "fixed" station monitoring elements, and care should be taken since there are many more data points at the "fixed" in comparison to the "moving" station data.

In order to provide a further comparison of the "status" of each of these water quality characteristics, plots of median surface measurements are shown by river kilometer along the transect in relation to median surface salinities for each of these two periods. Reference lines indicate the relative locations of the US 41 Bridge (RK 6.6) and the Peace River Facility (RK 30.2). These figures also provide clues as to the conservative/non-conservative nature of nutrients and a methodology of detecting additional input sources within the portion of the Lower Peace River. Care should be used in making comparisons between these plots and the Box and Whisker Plots since different scales were used.

Table 4.13 Gradients in Water Quality Parameters Along the Lower Peace River						
	Box & Whiskers 1976-1998		Box & Whiskers 1996-1998		Plotted Against Salinity Gradient along Transect	
Parameter	**Surface**	**Bottom**	**Surface**	**Bottom**	**1976-1998**	**1996-1998**
Color	B-126	B-127	B-128	B-129	B-130	B-131
Turbidity	B-132	B-133	B-134	B-135	B-136	B-137
Total Phosphorus	B-138	B-139	B-140	B-141	B-142	B-143
Dissolved Inorganic Nitrogen	B-144	B-145	B-146	B-147	B-148	B-149
Chlorophyll *a*	B-150	B-151	B-152	B-153	B-154	B-155
Carbon Uptake	B-156	Not Measured	B-157	Not Measured	B-158	B-159

The important results and patterns indicated by these analyses include:

1. Color

- The very high color levels and characteristic variability of the waters of the Lower Peace River are evident from the Box and Whisker Plots.
- The highest median levels of color do not occur at the most upstream sampling sites below Horse Creek, but rather downriver near the braided areas that receive ungaged freshwater inputs from Lettuce Lake, Hunter Creek, and Deep Creek. These results indicate that a substantial amount of highly colored water may come from these other sources.
- Downstream of this area of maximum color, levels decline fairly uniformly in relation to mixing with more saline harbor waters.

2. Turbidity

- These analyses indicate that turbidity levels in both surface and bottom waters of the Lower Peace River are characteristically low (< 7 NTU).
- As with color, the data seem to indicate that there may be an unusual source of turbidity near river kilometer 20, which is the Liverpool area where the northern branch of Hunter Creek joins the Peace River.

3. Total Phosphorus

- A comparison of the two sets of Box and Whisker Plots for the entire HBMP historic period (1976-1998) and during the most recent three years (1996-1998) clearly shows the reduction in phosphorus concentrations that resulted with the regulatory changes in point and non-point discharges of water from the mining operations in the upper portions of the Peace River Basin.
- Comparisons of median phosphorus concentrations and salinity along the Lower Peace River transect indicate that the very high ambient concentrations of this macronutrient cause it to behave conservatively; that is generally following a fairly straightforward pattern of dilution with higher saline waters.

4. Dissolved Inorganic Nitrogen

- Previous studies (see Synthesis of Existing Information, PBS&J 1999) have found, that due to the unusually high ambient phosphorus concentrations in the river, nitrogen is the nutrient that limits phytoplankton production both in the river and throughout the estuary.

- The Box and Whisker Plots show that nitrogen concentrations along the Lower Peace River can range from near detection to well over a milligram per liter (mg/L). These figures also indicate that both the concentration and range of variation steadily decline from upstream to downstream.
- When median values are plotted against salinity, the graphics distinctly demonstrate that nitrogen is not just being diluted, but rather is rapidly being depleted (most likely due to phytoplankton uptake) in the upstream brackish areas where high nutrient freshwater first begins to mix with higher saline water from the Harbor.

5. Chlorophyll *a*

- The Box and Whisker Plots of chlorophyll *a* from samples collected along the Lower Peace River over the history of the HBMP demonstrate that while levels have generally been below 30 mg/L, occurrences of much higher concentrations have not been uncommon.
- Comparisons of median chlorophyll *a* concentrations and salinity with river kilometer, over the long and short term, suggest the presence of a maxima in the area of the river upstream of the US 41 Bridge (RK 6.8).

6. Carbon Uptake

- The graphics relating to carbon uptake indicate a similar increase in the same region of the lower river characterized by the chlorophyll maxima. However, unlike the observed chlorophyll *a* pattern, carbon uptake rates continue increasing toward the river's mouth.

4.4.2 Temporal Trends

The only extensive water quality data set with an uninterrupted record among the HBMP study elements is that of the surface water quality data collected in conjunction with the phytoplankton studies at the four "moving" isohalines. Using these data, analyses were conducted to determine if there had been any detectable systematic changes in a selected number of key measurements over the period of sampling (1984-1998). As discussed above, this interval was marked by both statistically significant increases in freshwater inflows to the Lower Peace River estuary and the movement of isohalines farther downstream. The results of these trend analyses are summarized in Table 4.14, while statistical details are provided in **Table 4.15**.

Table 4.14 Status and Trends in Water Quality (1984-1998)

Parameter Isohaline	Trend	Time Series	Box Plot	Correl-ogram		Parameter Isohaline	Trend	Time Series	Box Plot	Correl-Ogram
Color						**D. I. Nitrogen**				
0 ppt	▲	B-160	B-161	B-162		0 ppt	N.S.	B-196	B-197	B-198
6 ppt	N.S.	B-163	B-164	B-165		6 ppt	N.S.	B-199	B-200	B-201
12 ppt	▲	B-166	B-167	B-168		12 ppt	N.S.	B-202	B-203	B-204
20 ppt	▲	B-169	B-170	B-171		20 ppt	▲	B-205	B-206	B-207

Table 4.15 Trends (1984-1998) in Water Quality Parameter by Isohaline					
Water Quality Parameter Location	**Tau Statistic**	**P-Value without Serial Correlation**	**P-Value with Serial Correlation**	**Slope Statistic**	**Trend**
Color					
0 ppt	0.142	0.009	**0.056**	3.00	▲
6 ppt	0.124	0.0255	**0.152**	1.818	
12 ppt	0.169	0.002	0.047	1.375	▲
20 ppt	0.1555	0.005	**0.075**	0.750	▲
Turbidity					
0 ppt	0.155	0.046	**0.300**	0.129	
6 ppt	-0.141	**0.070**	0.299	-0.100	▼
12 ppt	-0.129	**0.095**	0.251	-0.066	▼
20 ppt	-0.173	**0.025**	0.079	-0.112	▼
Total Phosphorus					
0 ppt	-0.286	0.000	0.014	-0.017	▼
6 ppt	-0.342	0.000	0.003	-0.013	▼
12 ppt	-0.289	0.000	0.005	-0.009	▼
20 ppt	-0.270	0.000	0.037	-0.006	▼

Table 4.15 (cont.) Trends (1984-1998) in Water Quality Parameter by Isohaline					
Water Quality Parameter Location	**Tau Statistic**	**P-Value without Serial Correlation**	**P-Value with Serial Correlation**	**Slope Statistic**	**Trend**
Dissolved Inorganic Nitrogen					
0 ppt	0.0746	0.186	0.339	0.004	
6 ppt	-0.073	0.194	0.303	-0.002	
12 ppt	0.0184	0.751	0.789	0.000	
20 ppt	0.166	**0.002**	0.068	0.001	▲
Chlorophyll *a*					
0 ppt	-0.102	**0.069**	0.245	-0.125	▼
6 ppt	-0.021	0.714	0.756	-0.069	
12 ppt	-0.0762	0.178	0.291	-0.166	
20 ppt	-0.114	**0.042**	0.084	-0.188	▼
Carbon Uptake					
0 ppt	-0.146	**0.008**	0.09	-0.192	▼
6 ppt	-0.024	0.668	0.747	-0.075	
12 ppt	-0.066	0.235	0.306	-0.170	
20 ppt	-0.073	0.193	0.233	-0.162	

Table 4.14 Status and Trends in Water Quality (1984-1998)										
Parameter Isohaline	**Trend**	**Time Series**	**Box Plot**	**Correl-ogram**		**Parameter Isohaline**	**Trend**	**Time Series**	**Box Plot**	**Correl-Ogram**
Turbidity						**Chlorophyll *a***				
0 ppt	N.S.	B-172	B-173	B-174		**0 ppt**	▼	B-208	B-209	B-210
6 ppt	▼	B-175	B-176	B-177		**6 ppt**	N.S.	B-211	B-212	B-213
12 ppt	▼	B-178	B-179	B-180		**12 ppt**	N.S.	B-214	B-215	B-216
20 ppt	▼	B-181	B-182	B-183		**20 ppt**	▼	B-217	B-218	B-219
Total Phosphorus						**Carbon Uptake**				
0 ppt	▼	B-184	B-185	B-186		**0 ppt**	▼	B-220	B-221	B-222
6 ppt	▼	B-187	B-188	B-189		**6 ppt**	N.S.	B-223	B-224	B-225
12 ppt	▼	B-190	B-191	B-192		**12 ppt**	N.S.	B-226	B-227	B-228
20 ppt	▼	B-193	B-194	B-195		**20 ppt**	N.S.	B-229	B-230	B-231

The important results and patterns indicated by these analyses include:

1. Color

- As indicated by each of the three types of plots listed in Table 4.14, the high concentrations of tanic/humic compounds associated with freshwater inflows result in color levels throughout the estuary being highly seasonal. As revealed by the Box Plots, the magnitude of this seasonal variation shows a marked decline from the low to higher salinities.
- The observed statistical increasing trends in water color during the period 1984-1998 can be directly attributable to the previously documented corresponding increases in upper basin rainfall and freshwater inflows.

2. Turbidity

- Turbidity was added to the monitoring program during the 1988 permit renewal, and the first complete year of data collection for this parameter was 1990.
- Both the Time Series and Box Plots indicate that in the Lower Peace River/Charlotte Harbor estuary, turbidity does not follow the same seasonal pattern as rainfall. These graphics indicate that the largest increases in turbidity usually occur either in the spring or fall, which is similar to that for chlorophyll *a*. However, trend analyses for chlorophyll *a* for the same time period, 1990-1998, did not show the same declining pattern evident with turbidity.
- The data for the period 1990-1998 indicate that turbidity levels significantly declined at three of the four isohalines. It is unclear whether or not these changes in turbidity over the past eight years are simply an artifact of two unusually high flow episodes that characterize this period.

3. Total Phosphorus

- The Charlotte Harbor estuarine system is highly enriched in phosphorus due to extensive natural deposits in the watershed. However, as previously discussed, there have been marked declines in ambient concentrations due to the implementation in the late 1970s of stricter regulations covering both point and non-point discharges of surface waters from phosphate mining operations.

- These analyses indicate that phosphorus concentrations have continued to decline, even though some of the largest recorded drops occurred prior to the period 1984-1998.
- A comparison of the monthly Box and Whisker Plots indicates that highest phosphorus concentrations are typically associated with periods of low river flow, when the influences of groundwater are more pronounced and/or there is less direct dilution. This occurs since groundwater in many areas of the Peace River watershed are characterized by naturally elevated inorganic phosphorus concentrations.

4. Dissolved Inorganic Nitrogen

- Other studies have found nitrogen to be the limiting nutrient for phytoplankton growth throughout the Lower Peace River/Charlotte Harbor estuary.
- Marked seasonal patterns are evident in comparisons among the Box Plots for each of the isohalines. These figures depict the interactions between increased nitrogen inputs during the wet-season and phytoplankton uptake during the spring, summer and early fall.
- The lowest nitrogen concentrations occur near the end of the spring dry-season as phytoplankton populations deplete the available nitrogen previously built up during the preceding cooler winter months.
- As discussed previously, a comparison among the isohalines indicates a strong gradient in available inorganic nitrogen, as concentrations rapidly decline with increasing salinity.
- The Time Series Plot of nitrogen concentrations at the 20 ppt isohaline shows that the significant increasing trend at this isohaline resulted from the combined influences of a series of unusually high peaks during the four years between 1987 and 1991, and a lack of very low values during the unusually wet period from 1995 through 1998.

5. Chlorophyll *a*

- Phytoplankton biomass, as measured by chlorophyll *a*, along the Lower Peace River/Upper Charlotte Harbor transect is dependent upon the complex interactions of water color which limits the availability of light, and the availability of inorganic nitrogen.
- This interaction results, as evident in the Times Series and Box Plots, in average chlorophyll *a* levels being much higher at the two intermediate salinities (6 & 12 ppt), which are characterized by lower color than the freshwater isohaline and higher nitrogen than the 20 ppt isohaline.
- As evident from the Time Series Plot, the observed significant decline in chlorophyll *a* levels within the 0 ppt isohaline reflects a decline in the phytoplankton blooms that occurred in the river during the unusually dry years that followed the 1983 El Niño event. As flows and average water color increased during the wetter years of the 1990s, both the frequency and magnitude of such blooms decreased.
- The detected decline in chlorophyll *a* levels at the highest salinity (20 ppt) seems to be associated with an increased frequency of lower chlorophyll *a* levels during the 1990s rather than a lack of periodic blooms. Whether this decline in phytoplankton

biomass is related to the corresponding statistically significant observed increase in color at this isohaline is unclear.

6. Carbon Uptake

- Carbon uptake is best viewed as a measurement of potential growth within the cells comprising a phytoplankton community. Since the *in situ* method utilized standardized incubations of two hours at fifty percent of ambient surface irradiation, the resulting values were affected primarily by: 1) number of cells; 2) their relative stage of growth (health); 3) water temperature; and 4) the availability of nutrients (nitrogen).
- A comparison of the Box and Whiskers Plots between those for chlorophyll *a* and carbon uptake indicate the differences between biomass and growth.
- Carbon uptake rates show a steady progression of peak uptake among the isohalines, changing from mid summer to late summer/early fall, with increasing salinity. This pattern can probably be directly attributed to the lag effect in the time required for nutrient rich freshwater to mix farther down into the harbor during the wet-season.
- The statistically significant decline in the rate of measured carbon uptake between 1984 and 1998 at the 0 ppt isohaline, can be ascribed to the previously discussed decline in phytoplankton biomass resulting from increased freshwater inflows and color within the freshwater areas of the Lower Peace River during the 1990s.

4.5 Phytoplankton

As discussed above, the production and growth of estuarine phytoplankton populations are dependent upon the complex interrelations of a series of dynamic processes mediated through a number of external physical forces, including seasonal cycles in light, temperature and precipitation. Freshwater inflows not only provide nitrogen, which stimulates growth, but also color that at the same time limits phytoplankton production by reducing the availability of light. As a result of these interactions, a grasp of the dynamics of the intermediate salinity zones is key to an overall understanding of phytoplankton production and community structure within the Lower Peace River/ Upper Charlotte Harbor estuarine system. It is extremely important to keep in mind that increases in river flow not only stimulate primary production with the estuary's intermediate salinity zones; it also dramatically expands and contracts the seasonal extent of these areas within the estuary. As a result of the somewhat funnel-shaped morphology of the estuary (see Vegetation Section below), the actual aerial extent of surface area of the estuary included within these important mixed salinity zones expands and contracts tremendously with changes in the river flow.

4.5.1 Size Fraction Determinations

In addition to estimates of biomass and growth, knowledge of the relative distribution within size fractions provides important information to both phytoplankton community structure as well as potential patterns of energy flow to primary consumers, such as zooplankton and filter feeders. The average spatial distributions along the Lower Peace River of phytoplankton chlorophyll *a* biomass are depicted over both the long and short term in **Figures 4.5** and **4.6**. These figures indicate the relative percent composition within each of three measured size ranges: 1) the >20 µm (net) size fraction; 2) the <20 µm and >5 µm (micro) size fraction; and 3) the <5 µm (nano) size fraction.

As documented in the 1995 HBMP Summary Report, a large proportion of phytoplankton biomass (and production) within the Lower Peace River/Upper Charlotte Harbor estuary system is contained within the smallest, nano (<5 µm) size fraction. The relative importance of slightly larger phytoplankton taxa (<20 µm and >5 µm) increases downstream with increasing salinity. Net plankton, species >20 µm, by comparison generally comprise less than twenty percent of the phytoplankton biomass.

4.5.2 Taxonomic Determinations of Phytoplankton Community Structure

Collection of monthly samples for the analysis of phytoplankton community structure began in 1989 in conjunction with the ongoing monitoring of physical/chemical water quality and primary production at each of the four moving isohalines. Phytoplankton community structure has been widely used in other estuarine systems as a tool in assessing both temporal and long-term changes in water quality. The collection of taxonomic phytoplankton data has indicated a number of distinct spatial and temporal patterns.

1. **0 ppt Salinity –** Within the freshwater reaches of the Lower Peace River, blue-green algae are a major component of the phytoplankton community during the period from February through April. Green algae by comparison typically become dominant or show major increases in May during periods characterized by low Peace River flow. In contrast, freshwater flagellates increase in importance within the phytoplankton community as summer river flows increase. Freshwater diatoms are less frequent during periods of high river flow, and are important or show major peaks during the late fall and winter months, as flow and water temperature decline. Dinoflagellates are not an important component of the phytoplankton community in the strictly freshwater areas of the Lower Peace River.

2. **6 ppt Salinity –** As salinity increases, the taxonomic structure of the phytoplankton community shows a dramatic decline in the importance of both green and blue-green algae. This salinity zone is characterized by alternating increases of diatoms and flagellates, with periodic large dinoflagelates “blooms”.

3. **12 ppt Salinity –** The phytoplankton community at this salinity is characterized by alternating seasonal blooms of flagellates, diatoms and dinoflagellates. Flagellates typically dominate through the cooler months and well into beginning of the summer wet-season. As river flow and temperature increase diatoms become more important.

4. **20 ppt Salinity –** The seasonal patterns of the major taxonomic groups at this salinity zone follow patterns generally similar to those observed at 12 ppt, with diatoms and dinoflagellates, increasing in their relative importance within the phytoplankton community.

Figure 4.5

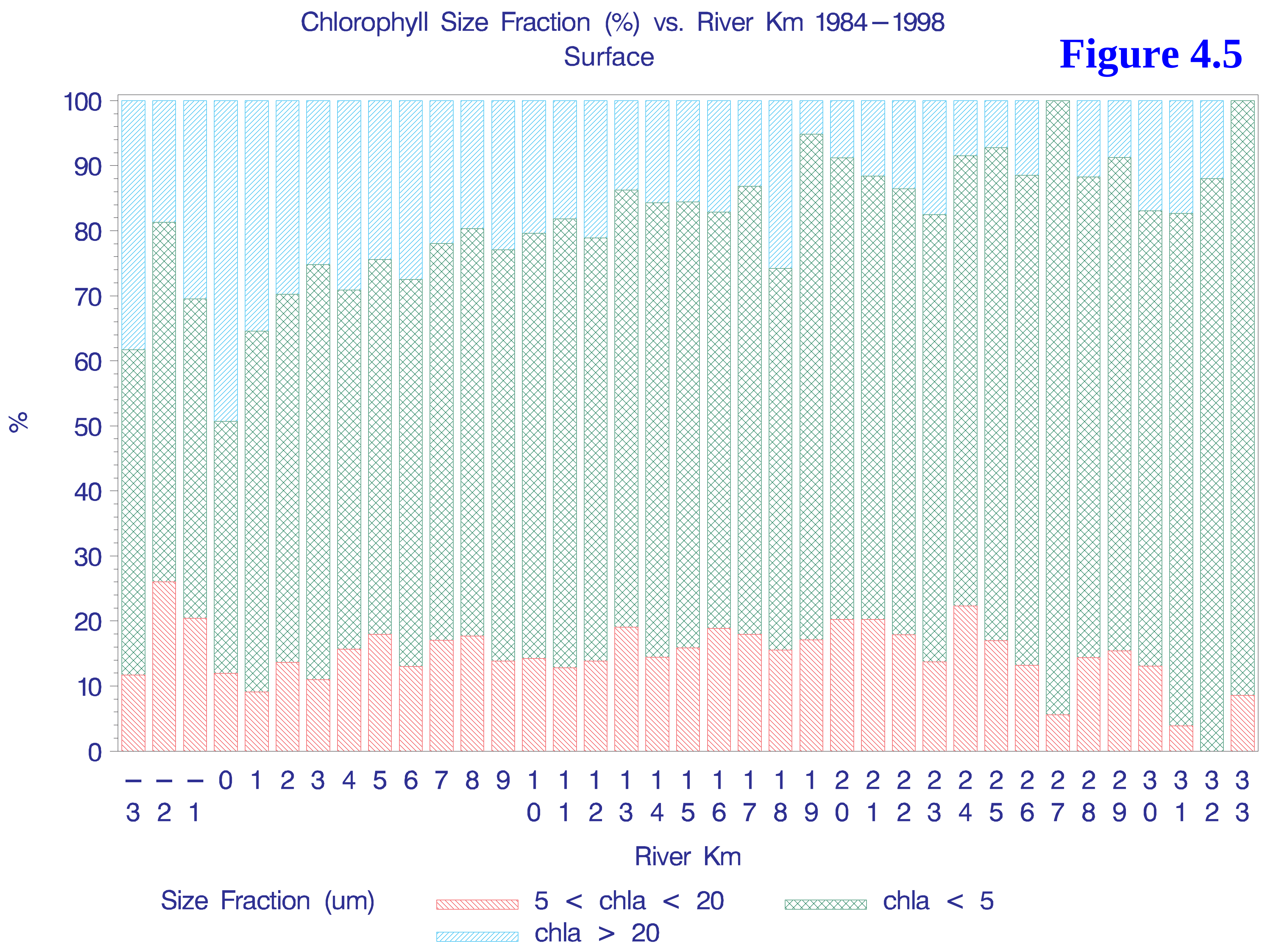

Chlorophyll Size Fraction (%) vs. River Km 1984–1998
Surface
%
100
90
80
70
60
50
40
30
20
10
0
-3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
River Km
Size Fraction (um)
5 < chla < 20
chla < 5
chla > 20

Figure 4.6

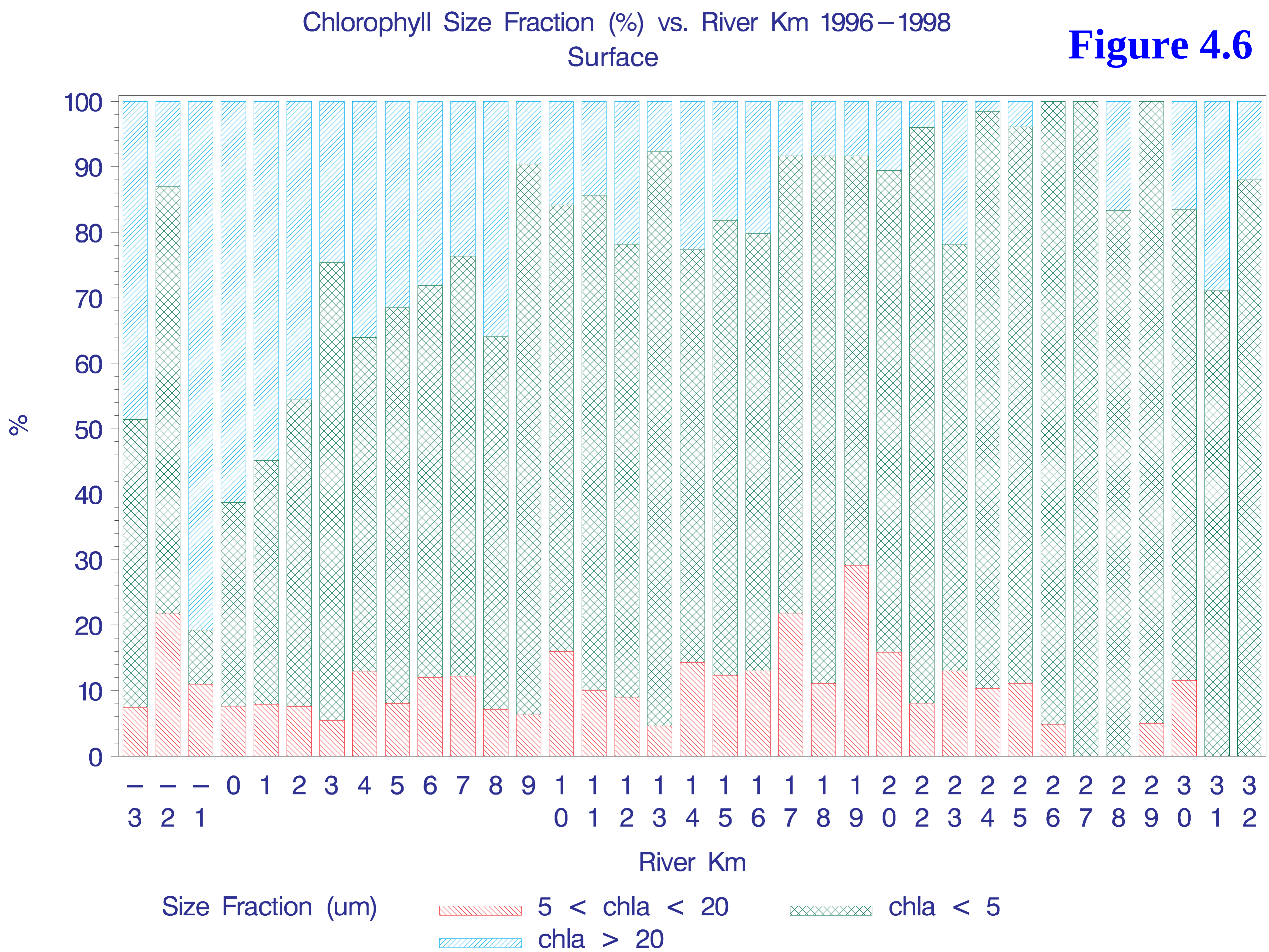

Chlorophyll Size Fraction (%) vs. River Km 1996–1998
Surface
%
0
10
20
30
40
50
60
70
80
90
100
-3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 22 23 24 25 26 27 28 29 30 31 32
River Km
Size Fraction (um)
5 < chla < 20
chla < 5
chla > 20

Table 4.16 summarizes the findings of the series of analyses conducted to determine seasonal and long-term changes, within each of the four "moving" isohalines. These changes are expressed as in the relative percentages of five major functional taxonomic groups. Complete statistical results from the trend analyses are contained in **Table 4.17**.

1. Green Algae (Chlorophyta)

- Members of this taxonomic group are important components within the freshwater areas of the Lower Peace River, where they are often dominant at the end of the dry-season and late in the fall when freshwater inflows are typically low.
- These taxa are typically associated with very low salinity conditions and, as the data indicate, rapidly decline in importance among the isohalines with increasing salinity.
- Somewhat surprisingly the results of the trend analyses indicated statistically significant increases in the percentages of these taxa at the two higher salinities. As the Time Series Plots indicate, these increases can be directly attributed to the unusual influences of the 1997/99 El Niño event, and the flushing of large amounts of freshwater into the lower portions of the estuary.

2. Blue-Green Algae (Cyanophyta)

- Both freshwater and brackish/marine species within this broad taxonomic group of algae are important components of the phytoplankton communities within the Charlotte Harbor estuarine system.
- The Time Series Plots clearly indicate that, within each of the four isohalines, the relative importance of this group can vary dramatically from month-to-month as a result of "blooms" of particular species.
- A comparison among the monthly Box Plots indicates that blue-green algae species tend to be more important during the spring and early summer and then generally decline during the late summer/fall.

Table 4.16 Trends in Phytoplankton Community Parameters (1989-1998)

Taxonomic Group Isohaline	Trend	Time Series	Box Plot	Correl-ogram	Population Metric Isohaline	Trend	Time Series	Box Plot	Correl-ogram
Percent Green Algae					**Cell Density (# / ml)**				
0 ppt	N.S.	B-232	B-233	B-234	0 ppt	N.S.	B-292	B-293	B-294
6 ppt	▼	B-235	B-236	B-237	6 ppt	N.S.	B-295	B-296	B-297
12 ppt	▲	B-238	B-239	B-240	12 ppt	N.S.	B-298	B-299	B-300
20 ppt	▲	B-241	B-242	B-243	20 ppt	N.S.	B-301	B-302	B-303
Percent Blue-Green Algae					**Number of Species**				
0 ppt	N.S.	B-244	B-245	B-246	0 ppt	▼	B-304	B-305	B-306
6 ppt	N.S.	B-247	B-248	B-249	6 ppt	▼	B-307	B-308	B-309
12 ppt	N.S.	B-250	B-251	B-252	12 ppt	▼	B-310	B-311	B-312
20 ppt	N.S.	B-253	B-254	B-255	20 ppt	▼	B-313	B-314	B-315
Percent Flagellates					**Number of Genera**				
0 ppt	N.S.	B-256	B-257	B-258	0 ppt	▼	B-316	B-317	B-318
6 ppt	▼	B-259	B-260	B-261	6 ppt	▼	B-319	B-320	B-321

Table 4.17 Trends in Major Phytoplankton Taxonomic Groups by Isohaline (1989-1998)

Taxonomic Group Isohaline	Tau Statistic	P-Value without Serial Correlation	P-Value with Serial Correlation	Slope Statistic	Trend
Percent Green Algae					
0 ppt	0.098	0.178	0.442	0.666	
6 ppt	-0.152	**0.034**	0.155	-0.200	▼
12 ppt	0.188	0.007	0.027	0.100	▲
20 ppt	0.212	0.001	0.045	0.000	▲
Percent Blue-Green Algae					
0 ppt	0.096	0.187	0.393	1.21	
6 ppt	0.099	0.174	0.412	1.04	
12 ppt	-0.031	0.679	0.780	-0.160	
20 ppt	0.851	0.243	0.465	0.256	
Percent Flagellates					
0 ppt	-0.050	0.453	0.458	-0.200	
6 ppt	-0.128	**0.079**	0.233	-1.10	▼
12 ppt	-0.161	**0.026**	0.270	-1.16	▼
20 ppt	-0.172	**0.017**	0.193	-1.20	▼
Percent Dinoflagellates					
0 ppt	-0.085	0.233	0.397	-0.000	
6 ppt	-0.041	0.581	0.650	-0.040	
12 ppt	0.000	1.0	1.0	0.0	
20 ppt	0.050	0.501	0.653	0.066	
Percent Diatoms					
0 ppt	-0.301	0.000	0.025	-0.690	▼
6 ppt	-0.105	0.150	0.322	-0.400	
12 ppt	0.037	0.623	0.753	0.290	
20 ppt	0.090	0.215	0.251	0.800	

Table 4.16 Trends in Phytoplankton Community Parameters (1989-1998)

Taxonomic Group Isohaline	Trend	Time Series	Box Plot	Correl-ogram		Population Metric Isohaline	Trend	Time Series	Box Plot	Correl-ogram
12 ppt	▼	B-262	B-263	B-264		12 ppt	▼	B-322	B-323	B-324
20 ppt	▼	B-265	B-266	B-267		20 ppt	▼	B-325	B-326	B-327
Percent Dinoflagellates						Diversity H Prime				
0 ppt	N.S.	B-268	B-269	B-270		0 ppt	▼	B-328	B-329	B-330
6 ppt	N.S.	B-271	B-272	B-273		6 ppt	▼	B-331	B-332	B-333
12 ppt	N.S.	B-274	B-275	B-276		12 ppt	N.S.	B-334	B-335	B-336
20 ppt	N.S.	B-277	B-278	B-279		20 ppt	N.S.	B-337	B-338	B-339
Percent Diatoms						Evenness J Prime				
0 ppt	▼	B-280	B-281	B-282		0 ppt	N.S.	B-340	B-341	B-342
6 ppt	N.S.	B-283	B-284	B-285		6 ppt		B-343	B-344	B-345
12 ppt	N.S.	B-286	B-287	B-288		12 ppt	▲	B-346	B-347	B-348
20 ppt	N.S.	B-289	B-290	B-291		20 ppt	▲	B-349	B-350	B-351

3. Flagellates (Euglenophyta and Pyrophyta)

- This grouping includes a wide and diverse number of freshwater/estuarine/marine algae species.
- Members of this group comprise a large portion of the small, nano (<5 µm) plankton size fraction.
- The monthly Box Plots of the three higher salinities clearly indicate marked seasonal declines in the occurrence of these algae during the summer wet-season.
- This decline during periods of higher freshwater inflow is further reflected in the statistically significant declines of this group at each of the three higher isohalines. The corresponding Time Series Plots clearly illustrate the influences of unusually high inflows during 1995 and 1997/1998 on this group.

4. Dinoflagellates

- Blooms of several species within this group are quite common at all three of the higher isohalines, with different species often common during different times of the year, and the greatest numbers occurring in the late fall/early winter months.

5. Diatoms (Bacillariophyceae)

- As indicated by the Box Plots, this group of algae becomes increasingly more important (larger relative percentage) within the estuarine phytoplankton communities with higher salinities.
- These plots also clearly show a strong seasonal response of this taxonomic group, at higher salinities, to the increased flows during the summer wet-season. These cells are typically larger and have longer division times than many other smaller algae. As a result, they are generally less abundant seasonally during extreme periods of nutrient limitation.
- Again, the significant decline at the freshwater interface probably reflects the high flows during 1995 and 1997/1998. Due to their size and lack of mobility, these

species can easily be affected in the river by both washout and high water color during periods of unusually high flow.

4.5.3 Metrics of Community Structure

In addition to percentages of major taxonomic groups, Table 4.16 provides summary results of analyses for metrics commonly applied to the analysis of phytoplankton community structure. Cell density, like chlorophyll *a*, provides a relative biomass estimate, while both the number of species and genera have been used as measures of community structure and dominance. Two other indices, diversity and evenness, have also been widely used for this purpose. Both these indices allow large amounts of information relevant to the richness and equitability of species within a community to be reduced to a single quantitative value. Complete statistical summaries of trend analyses for each of these metrics are provided in **Table 4.18**.

1. Cell Density

- The relative frequency and magnitude of phytoplankton "blooms" within the four isohalines can be seen among comparisons of the Time Series Plots.
- The Box Plots show that, seasonally, the highest cell densities generally occur at the freshwater interface (0 ppt) during June. Similar peaks in numbers steadily progress towards later in the year with increasing salinity, in response to increasing flow.

2. Number of Species & Genera

- Neither the numbers of phytoplankton species nor genera show any consistent seasonal patterns at any of the four isohalines (Box Plots).
- What is strikingly apparent however from the Time Series and statistical tests, is that the ten year period from 1989 to 1998 was marked by significant declines in the number of identified taxa.
- As pointed out in the discussion of methods in **Chapter II**, the same individual, using the same methods, and the same taxonomic reference collection, counted all of the phytoplankton samples during this period.
- A review of the actual counts indicates that at the lowest salinity the decline can be attributed to fewer occurrences of diatom and flagellate taxa. At the higher salinities, declines in flagellates account for the largest portion of the observed changes. As previously discussed with regard to percent composition, the high freshwater inflows during 1995 and with the 1997/1998 El Niño event specifically reduced the occurrence of these taxonomic groups in these areas of the estuary.

3. Diversity & Evenness

- Neither of these measurements of phytoplankton community structure indicated any clear seasonal patterns at any of the four isohalines.
- The decline in taxa at the two lowest salinity zones was enough to result in a decline in the taxa sensitive diversity index. By comparison, the decline in numbers of rarer species (flagellates) at the two highest salinities resulted in increases in evenness, which is a measure of the equitable distribution among taxa.

Table 4.18 Trends in Phytoplankton Community Parameters by Isohaline (1989-1998)

Population Metric Isohaline	Tau Statistic	P-Value without Serial Correlation	P-Value with Serial Correlation	Slope Statistic	Trend
Density (cells/ml)					
0 ppt	0.050	0.501	0.719	12.0	
6 ppt	-0.035	0.637	0.792	-6.66	
12 ppt	-0.097	0.182	0.383	-25.0	
20 ppt	0.024	0.756	0.833	4.07	
Number of Species					
0 ppt	-0.364	0.000	0.017	-1.000	▼
6 ppt	-0.523	0.000	0.009	-1.000	▼
12 ppt	-0.187	0.009	0.023	-.428	▼
20 ppt	-0.218	**0.002**	0.072	-0.333	▼
Number of Genera					
0 ppt	-0.351	0.000	0.017	-0.690	▼
6 ppt	-0.436	0.000	0.006	-0.750	▼
12 ppt	-0.170	0.014	0.029	-0.333	▼
20 ppt	-0.196	**0.005**	0.103	-0.25	▼
Diversity (H Prime)					
0 ppt	-0.144	**0.046**	0.134	-0.044	▼
6 ppt	-0.237	-0.001	0.014	-0.062	▼
12 ppt	-0.042	0.569	0.577	-0.010	
20 ppt	0.105	0.147	0.221	0.025	
Evenness (J Prime)					
0 ppt	0.035	0.641	0.710	0.002	
6 ppt	-0.090	0.219	0.254	-0.006	
12 ppt	0.125	**0.083**	0.136	0.013	▲
20 ppt	0.242	0.001	0.033	0.020	▲

4.6 Vegetation

4.6.1 Morphometric/Shoreline Studies

During the 1996 permit renewal, two of the specified short-term study elements that were added to the HBMP are directly related to the ongoing long-term monitoring of vegetation communities along the Lower Peace River. The first of these was the requirement that a baseline map be developed and used by all existing and future HBMP studies. The primary feature of this map was the designation of a standardized centerline, scaled in 0.1 kilometer units, extending from the river's mouth both upstream to above the Peace River Facility and downstream to Boca Grande Pass. The second requirement was for a comprehensive morphometric analysis along the Lower Peace River starting between the I-75 and US 41 bridges and extending upstream to above where Horse Creek enters the river. This morphometric study was based on river segments delineated by perpendicular lines plotted at 0.5 kilometer intervals to the established standardized centerline. These 0.5 kilometer river segments were then used to develop and quantify:

- Typical river cross-sections;
- Total river segment shoreline lengths;
- Areas of open-water within each river segment;
- The volume of water in each segment; and
- Areas of shoreline habitat type (based on existing District GIS coverages) within each river segment.

The morphometric report was submitted to the District in January 2000. Selected graphics from that report have been modified and are presented here to provide a context within which to discuss other elements of the HBMP. Figure **B-352** clearly demonstrates the "funnel like" physical nature of the river as it progressively expands downstream in cross-section (the relative location of the Peace River Facility is shown by the vertical dashed line). In comparison, Figure **B-353** provides a visual representation of the amount of shoreline in relation to river kilometer. As evident, the highly braided nature of the river channel results in marked increases, in specific areas, of potential shoreline habitat for emergent vegetation.

Using the District's existing Graphical Information System (GIS) vegetation coverages for the Lower Peace River, the relative aerial extent of selected key vegetation associations were plotted against distance along the standardized river centerline. These plots are listed in Table 4.19. In this series of graphics, vertical reference lines were added to indicate both the locations of the US 41 Bridge (RK 6.6) and the Water Peace River Facility (RK 30.2). A thicker dashed line has also been added indicating the cumulative percentage this vegetation association comprises of the total shoreline vegetation between river kilometers 0.0 and 43.0.

Table 4.19 Dominant Vegetation Communities Along the Lower Peace River				
Vegetation Group			**Vegetation Group**	
Mangrove Swamp	B-354		**Bottomland Hardwoods**	B-357
Saltwater Marsh	B-355		**Cypress**	B-358
Cordgrass	B-356		**Freshwater Marsh**	B-359

As the first two figures indicate, both mangrove swamp and saltwater marsh comprise very closely the same percentage of the total shoreline, and extend upriver almost the exact same distance. This area, near river kilometer (RK) 20, also marks a fairly sharp transition in the importance of bottom hardwood communities along the lower river. Extensive areas of cypress, by comparison, do not occur along the river until well upstream of the Peace River Facility.

4.6.2 Long-term Studies of First and Last Occurrence of Indicator Species

Initially the HBMP study of first and last occurrences of indicator plant species began near the US 41 Bridge (RK 6.6) and continued along the main river channel corridor to the S.R. 761 Bridge (RK 30.3) located just upstream of the Peace River Facility. As a result of the modifications made in 1996 to the Water Use Permit, vegetation monitoring currently begins slightly farther upstream, near the I-75 Bridge (RK 10.8) and continues to the same point above the Peace River Facility.

The representative plant species utilized to evaluate long-term changes in the first and last occurrence survey are listed in **Table 4.20**. Documentation of the first and last occurrence of these indicator species during each monitoring event has been based on the main occurrence of each species rather than isolated single occurrence of individual plants. All observations have been made by the visual identification of individual taxa by a group of biologists working from a slow-moving boat along each riverbank.

The frequency of data collection (see **Table 2.3**) of this HBMP element invalidates most standard statistical methods of testing for trends. Instead, seven common representative taxa were selected to attempt to graphically document the potential extent of long-term variability within these representative species. These taxa were selected based on their life history, relative importance along the river, and sensitivity (or lack thereof) to changes in salinity. Table 4.21 lists two different types of graphical comparisons for each of the seven indicator plant species. The first graphic depicts the first and last occurrence of the species during each of ten sampling events over the period 1977 to 1998. Both the occurrences of the selected taxa and average surface salinity are shown in relation to river kilometer. In the second graphic, the same first and last occurrence data are plotted against time along the X-axis and river kilometer on the Y-axis. A second line has then been added indicating yearly median freshwater inflows from the three gaged sources upstream of the Peace River Facility.

Table 4.20

First and Last Occurrence of Conspicuous Indicator Species

Species Name	Common Name
Ulmus americana	American Elm
Colocasia esculenta	Taro
Quercus laurifolia	Laurel Oak
Carya aquatica	Water Hickory
Fraxinus caroliniana	Water Ash
Sambucus canadensis	Southern Elderberry
Acer rubrum	Red Maple
Persea palustris	Swamp Bay
Taxodium distichum	Bald Cypress
Cladium jamaicense	Sawgrass
Serenoa repens	Saw Palmetto
Quercus virginiana	Live Oak
Myrica cerifera	Wax Myrtle
Annona glabra	Pond Apple
Scirpus validus	Bulrush
Typha domingensis	Southern Cattail
Spartina bakeri	Sand Cordgrass
Sabal palmetto	Sabal Palm
Rhizophora mangle	Red Mangrove
Juncus roemerianus	Black Needle Rush
Laguncularia racemosa	White Mangrove
Schinus terebinthifolius	Brazilian Pepper
Acrostichum danaeifolium	Leather Fern

Table 4.21 Vegetation – First and Last Occurrence			
Common Name	**Species Name**	**In Relation to Median Salinity Gradient**	**In Relation to Median Flow (Peace at Arcadia + Horse + Joshua Creeks)**
Sawgrass	*Cladium jamaicense*	**B-360**	**B-361**
Bulrush	*Scirpus validus*	**B-362**	**B-363**
Southern Cattail	*Typha domingensis*	**B-364**	**B-365**
Sand Cordgrass	*Spartina bakeri*	**B-366**	**B-367**
Black Needle Rush	*Juncus roemerianus*	**B-368**	**B-369**
Leather Fern	*Acrostichum danaeifol*	**B-370**	**B-371**
Red Mangrove	*Rhizophora mangle*	**B-372**	**B-373**

It is apparent from a comparison among these graphical representations that the first and last occurrences of some of these selected species have varied very little, while others have changed considerably back and forth over the extended period of this study. Some of these changes have been the result of either the creation and destruction of bar and/or shoal areas along the edges of the river during periods of low and high flow. The cause of other observed changes is less obvious. However, what these graphics clearly indicate is that it is difficult to document any meaningful relationships between freshwater inflows and the long-term distributions of these selected taxa (even considering the possible requirements for substantial lag affects).

- **Sawgrass** – The downstream extent of this species coincides with the region of the Lower Peace River characterized by a marked long-term average increase in surface salinity. The upstream extent has generally been observed near river kilometer 24. Upstream of this area, the river narrows and is characterized by distinct banks and hardwood flood plains to either side. The presented graphical comparison with long-term median flows indicates that the occurrence of sawgrass neither moved downstream during the high flows of the early 1980s or later part of the 1990s, nor upstream during extended drought following the 1983 El Niño.

- **Bulrush** – The range of this species was observed to extend both downstream and upstream the range of sawgrass. Again, long-term changes in river flow seem to have had little influence on the distribution of bulrush along the lower river.

- **Southern Cattail** – A comparison of the graphics indicates that the ranges and patterns of bulrush and cattail have, over the long-term, been quite similar. Both of these emergent species occur in similar areas along the river and are often found in close proximity or in mixed stands.

- **Sand Cordgrass** – This species occurs farther up the bank than typical emergent species. The broad extent of the range recorded during the early 1980s probably reflects a difference during that period of what was considered “riverine” vegetation. Again, there is no indication that the distribution of this species has been influenced by either extended periods of either high or low freshwater inflows.

- **Black Needle Rush** – The indicated downstream extent of this species marks the lower boundary of the vegetation study rather than the species limit. As indicated, this taxa is rare in the characteristically freshwater reaches of the lower river. It is interesting to note that the one instance when a substantial area of *Juncus* was observed farther upstream coincided with the drought following the 1983 El Niño.

- **Leather Fern** – Although the distribution of this species was documented during the initial survey of the lower river prior to construction of the Peace River Facility, the first and last occurrences of this species were not recorded until recently. Previously this species had been excluded since it typically occurs farther up the bank in areas that only flood during very high flows (or very strong storm events).

- **Red Mangrove** – The long-term distribution of this mangrove species is very similar to that previously noted for *Juncus*. Again the farthest upstream observations coincided with the extended drought during the mid/later 1980s. In the Lower Peace River the upstream extent of mangroves is probably set by both competition for space with freshwater taxa, and the frequency and severity of freezing temperatures farther inland.

4.7 Chapter IV Summary

1. Rainfall/Flows

- Largely as a result of the unusually heavy rains of 1995 and the 1997/1998 El Niño event, both rainfall and river flow significantly increased in the Peace River watershed over the fifteen year period (1984-1998), during which the isohaline based monitoring element of the HBMP has been conducted.

2. Salinity

- Salinity increases moving downstream from the Peace River Facility. The upstream movement of higher salinity waters has been observed both seasonally and during extended dry periods, such as occurred during the mid 1980s.

- The largest seasonal variations in salinity occur in the surface waters near the mouth of the river; however, the greatest relative percent changes take place upstream along the bottom.

- Even with the effects of the 1997/1998 El Niño, the median spatial distribution of salinity along the Lower Peace River during the most recent three year period (1996-1998) was not substantially different than the longer-term average.

- Trend analyses at the fixed stations for the long-term period 1976-1989 (the last few years of which included a series of very dry years) were only able to identify a significant increase in salinity at the most upstream location.

- By comparison, trend analyses (1984-1998) of the monthly locations of the four isohalines show significant downstream movements, indicating the influence of the unusually wet series of years during the 1990s.

3. Dissolved Oxygen

- On average dissolved oxygen concentration along the Lower Peace River between the Peace River Facility and the mouth of the river are above the State Class III standard of 5.0 mg/L for a twenty-four hour average.

- Surface dissolved oxygen concentrations tend to increase from the Peace River Facility downstream towards the mouth of the river.

- The occurrence of hypoxic bottom waters downstream of the US 41 Bridge is not uncommon, with many observations indicating near anoxic conditions. However, hypoxic bottom waters have not been observed upstream of river kilometer 10.8 (I-75 Bridge).

- Long-term trend analyses (1976-1998) indicate widespread significant declines in dissolved oxygen concentrations along the Lower Peace River. This trend is caused primarily by a marked decline in the very high dissolved oxygen concentrations associated with the extensive blue-green algae blooms that commonly occurred in the river during that latter part of the 1970s and early 1980s.

4. Water Quality

- Except for slightly elevated levels of phosphorus and color, many of the water quality characteristics of the Lower Peace River are similar to those of other Southwest Florida rivers despite the fact that the watershed area of the Peace River is substantially larger than that of most comparable rivers. The higher phosphorus concentrations are due to both naturally high phosphate deposits in local soils as well as the extensive phosphate mining that occurs in the basin. The higher color concentrations are due to the large area of riparian forested wetlands in the basin.

- The HBMP data at the fixed sampling sites is discontinuous between 1990 and 1996. This makes analyses of temporal trends using Seasonal Kendal Tau procedures difficult. However, other statistical trend procedures will be applicable after sufficient monthly data have been collected post 1996. The analysis of temporal trends from the moving station data does not provide a complete spatial overview of the Lower Peace River/Upper Charlotte Harbor system since the isohalines are typically seasonally biased towards either the upper or lower parts of the river depending on freshwater inflows.

- For the majority of the water quality variables analyzed, strong seasonal trends and spatial gradients are evident, with nitrogen being the most notable. Other variables, such as turbidity show little or no temporal trends or spatial gradients.

- Recent water quality characteristics of the Lower Peace River indicate only small differences when compared to the longer-term averages (1976-1998), with the most notable exception being a long-term reduction in phosphorus for the period 1984-1998. This reduction probably reflects the results of the regulatory requirements for the improved treatment of point and non-point discharges from phosphate mining areas in the Peace River Basin.

- The data suggest that the unusually heavy rains of 1995 and the 1997/1998 El Niño event may have resulted in the observed statistically significant increases in color and corresponding declines in turbidity at a majority of the isohalines.

5. Phytoplankton

- As of result of salinity differences, there are distinct spatial gradients in the major taxonomic distributions of phytoplankton taxa within the Lower Peace River/Upper Charlotte Harbor Estuarine System.

- Different taxanomic groups are seasonally important within each of the four isohalines studied.

- Trend analyses suggest that the high freshwater inflows during 1995 and the 1997/1998 EL Niño resulted in: 1) an unexpected increase in green algae at higher salinities; and 2) significant declines in the numbers and kinds of flagellates.

6. Vegetation

- District GIS vegetation data analyzed in conjunction with the morphometric analyses indicates fairly distinctive spatial breaks among several of the major vegetative associations along the Lower Peace River.

- Long-term comparisons of first and last occurrences of selected indicator plant species along the Lower Peace River indicate that the distribution of most species has varied very little whereas the distribution of some species has fluctuated upstream and downstream over time.

- Graphical analyses demonstrate the difficulty of determining meaningful relationships between freshwater inflow and the long-term distributions of key indicator vegetation taxa.

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Chapter V

Evaluation of Potential Impacts of Peace River Facility Withdrawals

This chapter assesses the significance of past and future potential impacts of the permitted freshwater withdrawals by the Peace River Facility. It is important to evaluate such impacts relative to both the timing and magnitude of withdrawals in relationship to the natural spatial and temporal variability of rainfall and flow that have occurred in the watershed during the recent historic period.

5.1 Rainfall

The first step in assessing the basic hydrological conditions that influence the Lower Peace River/Upper Charlotte Harbor estuary is to evaluate whether there have been significant changes in either rainfall and/or flow-to-rainfall relationships within the Upper Peace River Basin Watershed. Table 5.1 presents the summary results of trend analyses conducted of rainfall, and the ratio of gaged flow to area rainfall, over both the recent historic period (1966 to 1998) and for the duration of the HBMP (1976-1998). Although both rainfall and flow records extend back a number of decades, there were several reasons for selecting the interval 1966 to 1998 to characterize recent historical conditions:

- A number of investigations of the Upper Peace River Basin (see reviews in *Summary of Historical Information Relevant to the Hydrobiological Monitoring of the Lower Peace River and Upper Charlotte Harbor Estuarine System*, 1999) have indicated that conditions in the 30s, 40s and early 50s were characteristically wetter with significantly higher freshwater inflows. This period was followed by natural and induced declines in flows throughout much of the Peace River basin that continued through the later part of the 1960s.

- The major tributaries contributing to total flow at the mouth of the river include: the Peace River; Horse Creek; Joshua Creek; and Shell Creek. The year 1966 marks the beginning when complete daily flow records are available for all of these sources of freshwater inflows to the HBMP study area.

Comprehensive statistical results (Tau, P-Value and Slope) of these trend analyses of rainfall and flow relationships in the Upper Peace River basin (see **Figure 5.1**) are presented in **Tables 5.2**, **5.3** and **5.4**. Thorough discussions of both the graphical and statistical methodologies presented in these tables are provided in **Chapter IV** and **Appendix A**. It should be noted that some care should be given in interpreting the results

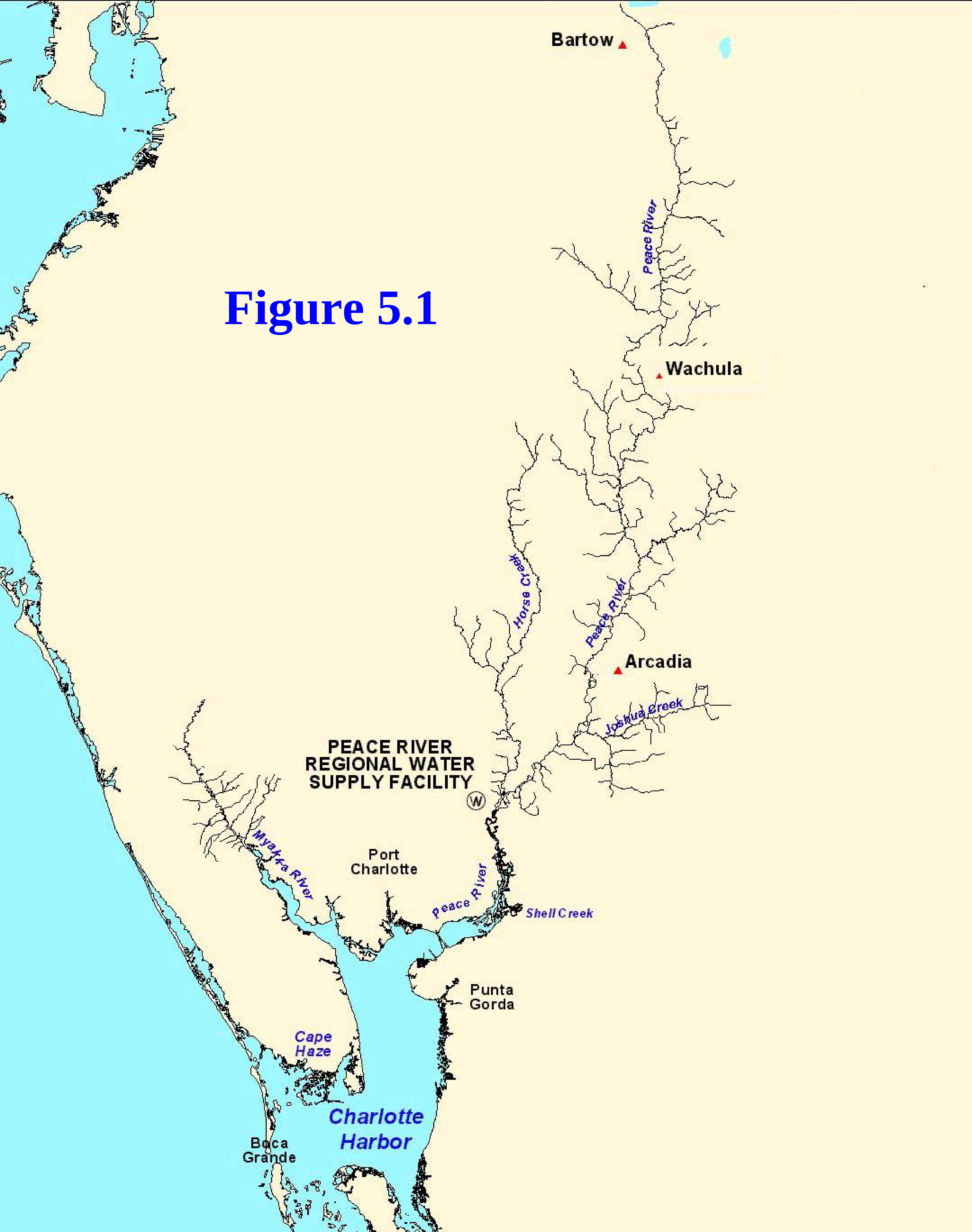


Figure 5.1
Bartow
Peace River
Wachula
Horse Creek
Peace River
Arcadia
Joshua Creek
PEACE RIVER
REGIONAL WATER
SUPPLY FACILITY
W
Myakka River
Port
Charlotte
Peace River
Shell Creek
Punta
Gorda
Cape
Haze
Charlotte
Harbor
Boca
Grande

Table 5.2 Trends in Rainfall (inches) over Recent Historical Periods in the Upper Peace River Basin					
Time Period Location	**Tau Statistic**	**P-Value without Serial Correlation**	**P-Value with Serial Correlation**	**Slope Statistic**	**Trend**
1966-1998					
Rainfall @ Arcadia	0.000	0.988	0.990	0.000	
Rainfall @ Wauchula	0.061	0.083	0.093	0.020	▲
Rainfall @ Bartow	0.023	0.513	0.501	0.008	
1976-1998					
Rainfall @ Arcadia	0.006	0.888	0.907	0.001	
Rainfall @ Wauchula	0.059	0.181	0.190	0.026	
Rainfall @ Bartow	0.038	0.379	0.391	0.015	
1984-1998					
Rainfall @ Arcadia	0.016	0.800	0.807	0.012	
Rainfall @ Wauchula	0.096	**0.107**	0.053	0.056	▲
Rainfall @ Bartow	0.128	**0.027**	0.023	0.090	▲

Table 5.3 Ratio of Flow (cfs) to Rainfall (inches) at Arcadia over Recent Historical Periods

Time Period Location	Tau Statistic	P-Value without Serial Correlation	P-Value with Serial Correlation	Slope Statistic	Trend
1966-1998					
Ratio Gauged Flow at Arcadia to Rainfall at Arcadia	-0.021	0.566	0.678	-0.385	
1976-1998					
Ratio Gauged Flow at Arcadia to Rainfall at Arcadia	0.099	**0.031**	0.134	2.946	▲
1984-1998					
Ratio Gauged Flow at Arcadia to Rainfall at Arcadia	0.253	0.000	0.010	7.885	▲

Table 5.4 Ratio of Flow (cfs) to Rainfall (inches) at (Arcadia+Wauchula+Bartow) over the Recent Historical Periods

Time Period Location	Tau Statistic	P-Value without Serial Correlation	P-Value with Serial Correlation	Slope Statistic	Trend
1966-1998					
Ratio Gauged Flow at Arcadia to. Rainfall at Arcadia + Wauchula + Bartow	-0.098	**0.007**	0.052	-0.519	▼
1976-1998					
Ratio Gauged Flow at Arcadia to Rainfall at Arcadia + Wauchula + Bartow	0.038	0.416	0.536	0.200	
1984-1998					
Ratio Gauged Flow at Arcadia to Rainfall at Arcadia + Wauchula + Bartow	0.168	**0.006**	0.054	1.457	▲

of trend analyses of flow to rainfall ratios presented in Tables 5.1 and **5.3**, since the relationships between these two measurements are not linear (i.e. depending on antecedent conditions small differences in rainfall can result in substantially differing amounts of runoff).

Table 5.1 Trends of Basin Rainfall and Comparisons with Arcadia Flows

Time Period Location	Trend	Time Series	Box Plot	Correl-ogram		Measurement	Trend	Time Series	Box Plot	Correl-Ogram
Period 1966 to 1998										
Rainfall at Arcadia	N.S	C-001	C-002	C-003		Ratio of Flow at Arcadia to Rainfall at Arcadia	N.S	C-010	C-011	C-012
Rainfall at Wauchula	▲	C-004	C-005	C-006		Ratio of Flow at Arcadia to Rainfall at Arcadia + Wauchula +Bartow	▼	C-013	C-014	C-015
Rainfall at Bartow	N.S	C-007	C-008	C-009						
Period 1976 to 1998										
Rainfall at Arcadia	N.S	C-016	C-017	C-018		Ratio of Flow at Arcadia to Rainfall at Arcadia	▲	C-025	C-026	C-027
Rainfall at Wauchula	N.S	C-019	C-020	C-021		Ratio of Flow at Arcadia to Rainfall at Arcadia + Wauchula +Bartow	N.S	C-028	C-029	C-030
Rainfall at Bartow	N.S	C-022	C-023	C-024						

The data indicate that there was a statistically significant increase in rainfall at the Wauchula gage during the period 1966 to 1998. This pattern however was not apparent at either the Arcadia or Bartow gages. Thus the results indicate that overall, rainfall patterns in the watershed were not consistently changing on a regional basis during either of the two time periods tested. **Table 5.5** shows the results of regression analyses among monthly measurements at the Arcadia, Wauchula and Bartow rainfall gages. Although long-term seasonal rainfall patterns within these different areas of the Upper Peace River Watershed are quite similar (see Box Plots), month-to-month comparisons indicate only moderate correlations (R-Squares 0.52 to 0.64) when linear fits are attempted. This lack of fit probably results from the combined influences of: 1) differences in the size and characteristics of the watersheds; and 2) localized variations in regional rainfall patterns.

5.2 Freshwater Inflows

Table 5.6 presents the trend analyses summary results of flows for each of the four gaged freshwater inflows and cumulatively at two points along the Lower Peace River: 1) at the Peace River Facility; and 2) upstream of the US 41 Bridge. Seasonal Kendal Tau tests for trends were analyzed for three periods:

1. The recent historical period 1966-1998 – This period was selected to provide a long-term basis of comparison with the analysis of rainfall data (sections 5.1 and 5.3).

2. The period covering Peace River Facility withdrawals 1980-1998 – This time period was chosen to correspond both with the trend analyses of withdrawals (section 5.4) and also with the period of data collection used to develop statistical models of the potential influence of withdrawals on salinity gradients (section 5.5).

Table 5.5 Comparison of Monthly Mean Rainfalls and Flows in the Peace River Basins - 1966 to 1998				
Comparison (Y parameter versus X Parameter)		**Intercept**	**Slope**	**R-Square**
(Y)	**(X)**	**(a)**	**(b)**	
Equation (Y = a + bX)				
Rainfall				
Arcadia	Bartow	0.924	0.778	0.52
Arcadia	Wauchula	0.846	0.795	0.58
Bartow	Wauchula	0.974	0.769	0.64
Rainfalls and Arcadia Flow				
Flow at Arcadia	Arcadia rainfall	281.4	148.8	0.25
Flow at Arcadia	Wauchula rainfall	206.2	157.1	0.27
Flow at Arcadia	Bartow rainfall	262.2	149.0	0.22
Flow at Arcadia	sum of rainfalls	127.3	59.6	0.29
Gauged Flows				
Horse Creek	Peace River at Arcadia	-28.2	0.224	0.81
Joshua Creek	Peace River at Arcadia	-2.1	0.117	0.74
Shell Creek	Peace River at Arcadia	53.6	0.325	0.66
Horse Creek	Joshua Creek	9.6	1.600	0.76
Horse Creek	Shell Creek	-0.1	0.503	0.65
Joshua Creek	Shell Creek	-2.0	0.302	0.79

3. The most recent eight years 1990-1998 – The final time period was selected to answer a specific question. There has been a general impression that flows in the Peace River Basin have increased during the 1990s. Trend analyses were conducted to determine whether such increases actually have occurred in each of the major tributaries, and if these patterns are statistically significant. The eight year period 1990-1998 was selected since it approximates the minimum length of time over which Seasonal Kendal Trend Procedures can accurately be applied.

Complete statistical results are provided in **Table 5.7**.

The results indicate that, during roughly the last thirty years, freshwater inflows from all the major tributaries of the lower Peace River have either been stable or increasing, as in the case of Joshua and Shell creeks. The results indicate that there has been a general disposition toward increasing flows throughout the period during which the Peace River Facility has been withdrawing water. Measurements of flow are highly autocorrelated (see correlograms) and only the flows of Joshua and Shell Creeks, and combined freshwater inflows upstream of the US 41 Bridge, meet the strict statistical criteria of significance after correction. The Time Series Plots indicate, that except for Shell Creek, a great deal of the observed upward disposition can be attributed to the unusually long wet periods in both 1995 and 1997.

These differences are further reflected in comparisons among the monthly box plots. The influences of the high winter/spring rainfalls during the 1997/1998 El Niño event are evident in comparisons of seasonal distribution of flows between the 1966-1998 and 1990-1998 periods.

Table 5.6 Trends in Gaged Flows over the Recent Historical Period

Time Period Location	Trend	Time Series	Box Plot	Correl-ogram	Time Period Location	Trend	Time Series	Box Plot	Correl-ogram
Flows over the Period 1966 to 1998									
Peace at Arcadia	N.S.	C-031	C-032	C-033	Total at Facility	N.S	C-040	C-041	C-042
Horse Creek	N.S	C-034	C-035	C-036	Shell Creek	▲	C-043	C-044	C-045
Joshua Creek	▲	C-037	C-038	C-039	Total at US 41 Bridge	N.S	C-046	C-047	C-048
Flows over the Period 1980 to 1998									
Peace at Arcadia	N.S	C-049	C-050	C-051	Total at Facility	N.S	C-058	C-059	C-060
Horse Creek	N.S	C-052	C-053	C-054	Shell Creek	▲	C-061	C-062	C-063
Joshua Creek	▲	C-055	C-056	C-057	Total at US 41 Bridge	▲	C-064	C-065	C-066
Flows over the Period 1990 to 1998									
Peace at Arcadia	N.S	C-067	C-068	C-069	Total at Facility	N.S	C-076	C-077	C-078
Horse Creek	N.S	C-070	C-071	C-072	Shell Creek	N.S	C-079	C-080	C-081
Joshua Creek	▲	C-073	C-074	C-075	Total at US 41 Bridge	N.S	C-082	C-083	C-084

The relationships among freshwater inflows from the four gaged sources: 1) Peace at Arcadia; 2) Horse Creek near Arcadia; 3) Joshua Creek near Nocatee; and 4) Shell Creek near Punta Gorda, are shown in **Table 5.8**. This table shows the comparative results from regression analyses among these four tributaries both for the period of the HBMP (1976-

Table 5.7 Historical Gauged Flows (cfs) by Location for Recent Periods

Time Period Location	Tau Statistic	P-Value without Serial Correlation	P-Value with Serial Correlation	Slope Statistic	Trend
1966-1998					
Peace at Arcadia	-0.021	0.551	0.738	-0.933	
Horse Creek	0.048	0.173	0.424	0.236	
Joshua Creek	0.180	0.000	0.003	0.766	▲
Total at Treatment Facility	0.002	0.939	0.965	0.234	
Shell Creek	0.114	0.001	**0.076**	2.025	▲
Total Gauged at US 41	0.026	0.450	0.663	2.651	
1980-1998					
Peace at Arcadia	0.133	0.006	**0.149**	10.955	
Horse Creek	0.082	0.087	0.316	0.930	
Joshua Creek	0.237	0.000	0.004	2.017	▲
Total at Treatment Facility	0.130	0.007	**0.141**	15.12	
Shell Creek	0.210	0.000	0.027	6.242	▲
Total Gauged at US 41	0.160	0.001	**0.071**	22.23	▲
1990-1998					
Peace at Arcadia	0.181	0.020	**0.125**	36.754	
Horse Creek	0.129	0.097	**0.181**	4.334	
Joshua Creek	0.176	0.024	**0.087**	2.963	▲
Total at Treatment Facility	0.171	0.028	**0.145**	49.75	
Shell Creek	0.065	0.416	0.662	3.573	
Total Gauged at US 41	0.167	0.032	**0.179**	53.86	

Table 5.8 Comparison of Monthly Mean Flows Among Tributaries in the Peace River Basins - 1976 to 1998				
Comparison (Y parameter versus X parameter)		Intercept	Slope	R-Square
(Y)	(X)	(a)	(b)	
Equation (Y = a + bX)				
Overall				
Horse Creek	Peace River at Arcadia	-27.8	0.229	0.83
Joshua Creek	Peace River at Arcadia	2.6	0.113	0.72
Shell Creek	Peace River at Arcadia	75.8	0.306	0.63
Horse Creek	Joshua Creek	-0.6	1.704	0.82
Horse Creek	Shell Creek	-10.8	0.534	0.67
Joshua Creek	Shell Creek	-4.5	0.309	0.79
Wet- Season (July through September)				
Horse Creek	Peace River at Arcadia	-32.7	0.227	0.86
Joshua Creek	Peace River at Arcadia	4.2	0.101	0.66
Shell Creek	Peace River at Arcadia	67.0	0.256	0.56
Horse Creek	Joshua Creek	-6.0	1.747	0.79
Horse Creek	Shell Creek	-14.2	0.561	0.61
Joshua Creek	Shell Creek	-5.7	0.325	0.80
Dry-Season (October through June)				
Horse Creek	Peace River at Arcadia	1.1	0.222	0.72
Joshua Creek	Peace River at Arcadia	5.4	0.124	0.74
Shell Creek	Peace River at Arcadia	173.7	0.326	0.65
Horse Creek	Joshua Creek	23.2	1.617	0.80
Horse Creek	Shell Creek	-7.4	0.515	0.64
Joshua Creek	Shell Creek	-8.4	0.302	0.72

1998), as well as on both a wet- and dry-season basis. These analyses indicate that flows in Shell Creek, with its more coastal watershed, were less correlated than comparisons among the other three more inland subbasin watersheds. The relationships among the four tributaries indicated only slight differences between seasons.

Further statistical comparisons of flows among these four primary tributaries are presented in **Tables 5.9** and **5.10**. The first table indicates the statistical distribution of flows (mean, median and percentiles) for the recent historical period (1966-1998) and during each of the three periods: 1) 1980-1987; 2) 1987-1995; and 3) 1996-1998, when different permitted withdrawal schedules were in effect (see **Chapter I**). The relative magnitudes and importance of each of these freshwater sources to the combined freshwater inflow to the Upper Harbor are further shown in the second of these tables. **Table 5.10** indicates the minimum, maximum and average percentage of total flow contributed by each of these four tributaries. Percentages are shown calculated both on a daily and monthly basis. The Peace River (Arcadia) is typically the major source of freshwater to the lower river, averaging above 60% of total flow, followed by Shell Creek above 20%, and Horse and Joshua creeks both of which usually contribute less than 10%. However, as this table indicates, localized differences in rainfall within these subbasin watersheds can result in dramatic daily, and even monthly differences in their relative contribution of freshwater inflows to the upper estuary.

During the long-term period 1966 through 1998 the total gaged flow at the Arcadia gage equaled 76.4 % of the total gaged flow upstream of the Peace River Water Treatment Facility.

5.3 Rainfall/Flow Relationships

A method of analyses previously used by the US Geological Survey (Hammett, 1990) to evaluate long-term changes in rainfall/flow relationships in the Upper Peace River basin is to develop "double mass" curves. This procedure plots cumulative daily gaged flows against cumulative measured precipitation, by year, over the entire period of interest. The underlying assumption is that significant long-term changes in the amount of flow, per unit of rainfall, will be demonstrated by a corresponding marked change in the slope of the line resulting from the "double mass" curve.

Such "double mass" curves were developed for the recent historic period (1966-1998) using rainfall at Arcadia and gaged flows for: 1) the Peace River at Arcadia; 2) Horse Creek near Arcadia; and 3) Joshua Creek near Nocatee (**Figures 5.2**, **5.3** and **5.4**). The relationships between flow and rainfall for each of these three tributaries were very similar during this thirty-three year period, and can be summarized as follows.

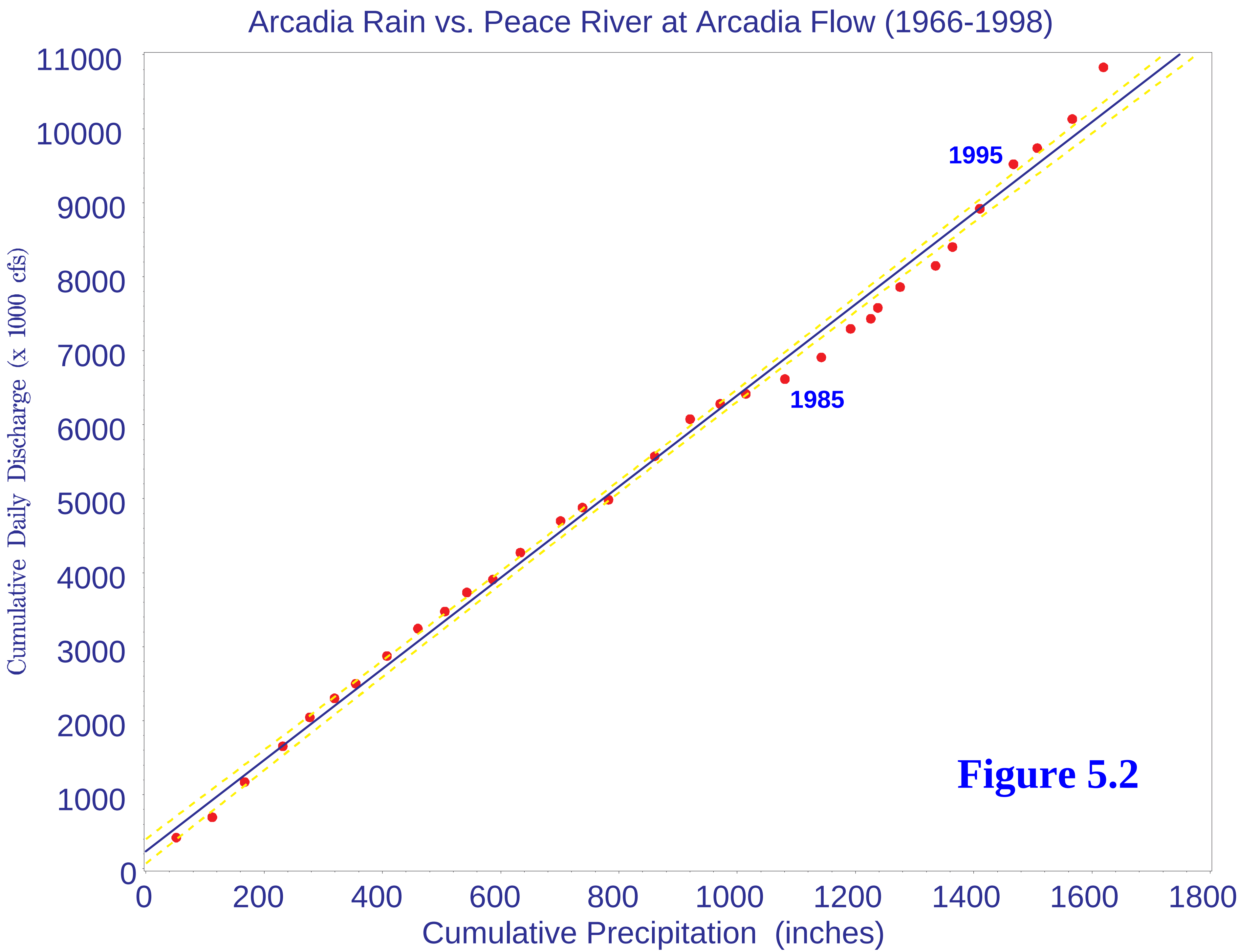
- During the extended drought that followed the 1983 El Niño event, flows per unit rainfall for each of the three tributaries were below the 95% confidence limits of the slope for the long-term period. This indicates that, during this unusually dry period, typical runoff/groundwater interactions changed resulting in lower than average stream flows for comparable levels of basin rainfall.

Table 5.9 Comparisons of Freshwater Inflows Over the Recent Historic Period and During Differing Withdrawal Schedules

Time Period Gauge Location	Mean	Median		Percentiles			
				5th	25th (Q1)	75th (Q3)	95
1976-1998 (Recent Period)							
Peace River @ Arcadia	898	401		92	198	1060	3310
Horse Creek	160	36		1	8	155	738
Joshua Creek	103	304		4	12	94	443
Shell Creek	357	156		8	65	370	1337
1980-1987 (1st Schedule)							
Peace River @ Arcadia	756	357		67	155	896	2700
Horse Creek	160	45		3	11	162	661
Joshua Creek	91	24		5	11	78	362
Shell Creek	313	126		6	43	299	1310
1988-1995 (2nd Schedule)							
Peace River @ Arcadia	895	407		105	200	1020	3210
Horse Creek	188	48		4	13	162	822
Joshua Creek	116	41		11	24	105	452
Shell Creek	408	204		57	107	431	1361
1996-1998 (3rd Schedule)							
Peace River @ Arcadia	1190	518		98	209	1135	4840
Horse Creek	227	50		3	12	186	935
Joshua Creek	122	44		15	26	139	474
Shell Creek	334	152		29	81	396	1250

Table 5.10(a) Percent of Total Gauge Daily Flow at US 41 Bridge												
Time Periods	**Peace @ Arcadia Gauge**			**Horse Creek Gauge**			**Joshua Creek Gauge**			**Shell Creek Gauge**		
	Mean	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
1966-1998	**63.8**	10.3	99.5	**7.7**	0	67.0	**5.6**	0	57.2	**22.9**	0	85.0
1966-1979	**68.3**	12.3	99.5	**7.0**	0	44.7	**4.3**	0	45.5	**20.4**	0	77.3
1980-1987	**63.2**	10.3	97.1	**9.0**	0.2	67.0	**6.0**	0.6	57.2	**21.7**	0	85.0
1988-1995	**57.0**	10.8	91.2	**7.6**	0.1	37.4	**6.8**	1.2	41.9	**28.6**	0	75.4
1996-1998	**61.2**	20.0	87.6	**7.6**	0.3	39.6	**8.3**	0.8	75.3	**23.0**	0.5	72.5

Table 5.10(b) Percent of Total Gauge Monthly Flow at US 41 Bridge												
Time Periods	**Peace @ Arcadia Gauge**			**Horse Creek Gauge**			**Joshua Creek Gauge**			**Shell Creek Gauge**		
	Mean	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
1966-1998	**62.6**	23.1	98.8	**8.4**	0.1	36.4	**6.1**	0.5	26.4	**23.3**	0	53.4
1966-1979	**66.9**	34.1	98.8	**7.7**	0.1	34.3	**4.9**	0.5	15.1	**20.6**	0	43.5
1980-1987	**61.7**	31.8	91.9	**9.6**	0.4	36.4	**6.5**	1.3	26.4	**22.2**	0	45.5
1988-1995	**56.4**	23.1	76.3	**8.3**	0.5	23.6	**7.1**	3.2	17.7	**28.1**	11.9	51.2
1996-1998	**60.0**	34.2	82.7	**8.4**	1.3	21.8	**8.6**	2.4	31.4	**23.1**	2.8	53.4



Arcadia Rain vs. Peace River at Arcadia Flow (1966-1998)
Cumulative Daily Discharge (x 1000 cfs)
Cumulative Precipitation (inches)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
0
200
400
600
800
1000
1200
1400
1600
1800
1995
1985
Figure 5.2

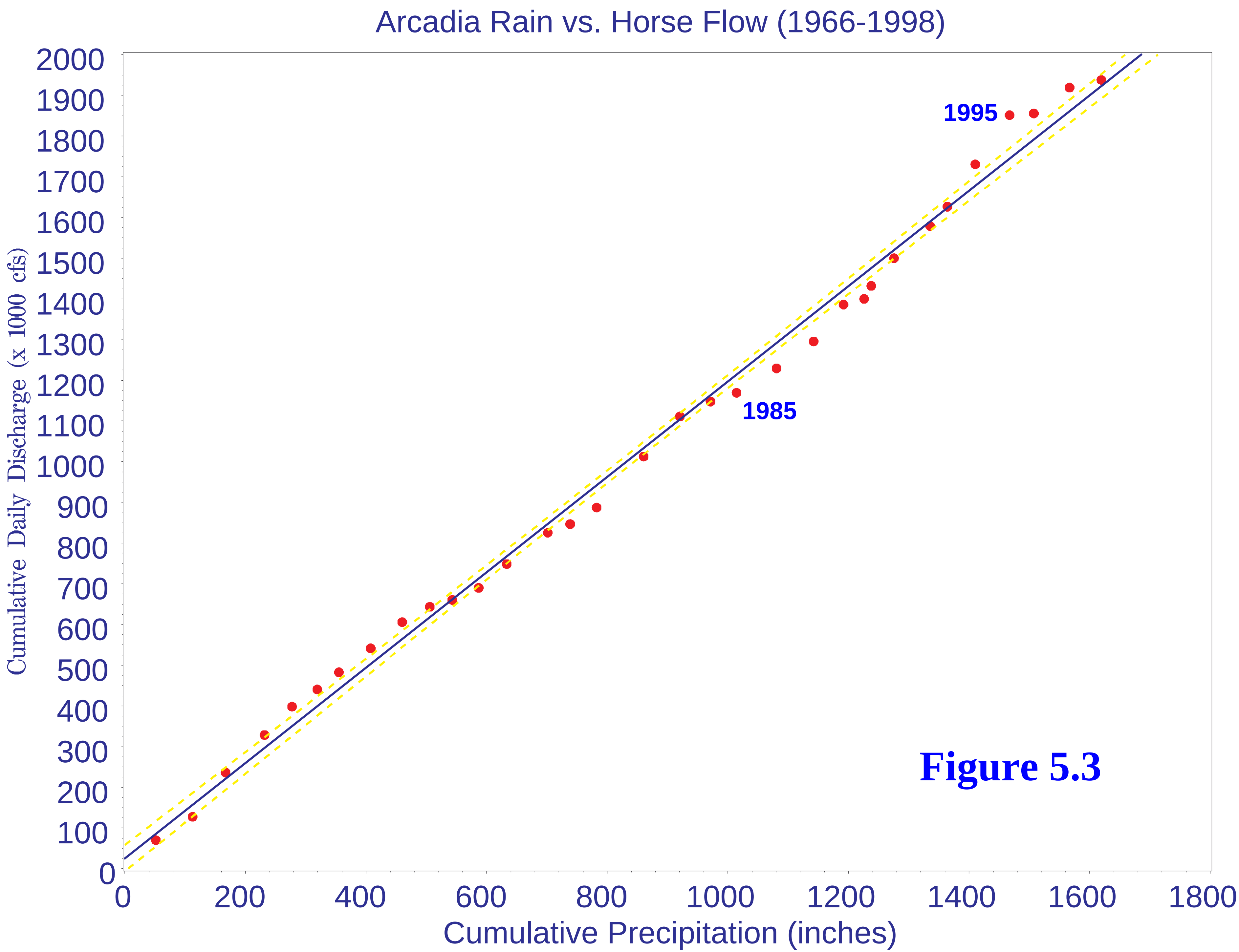
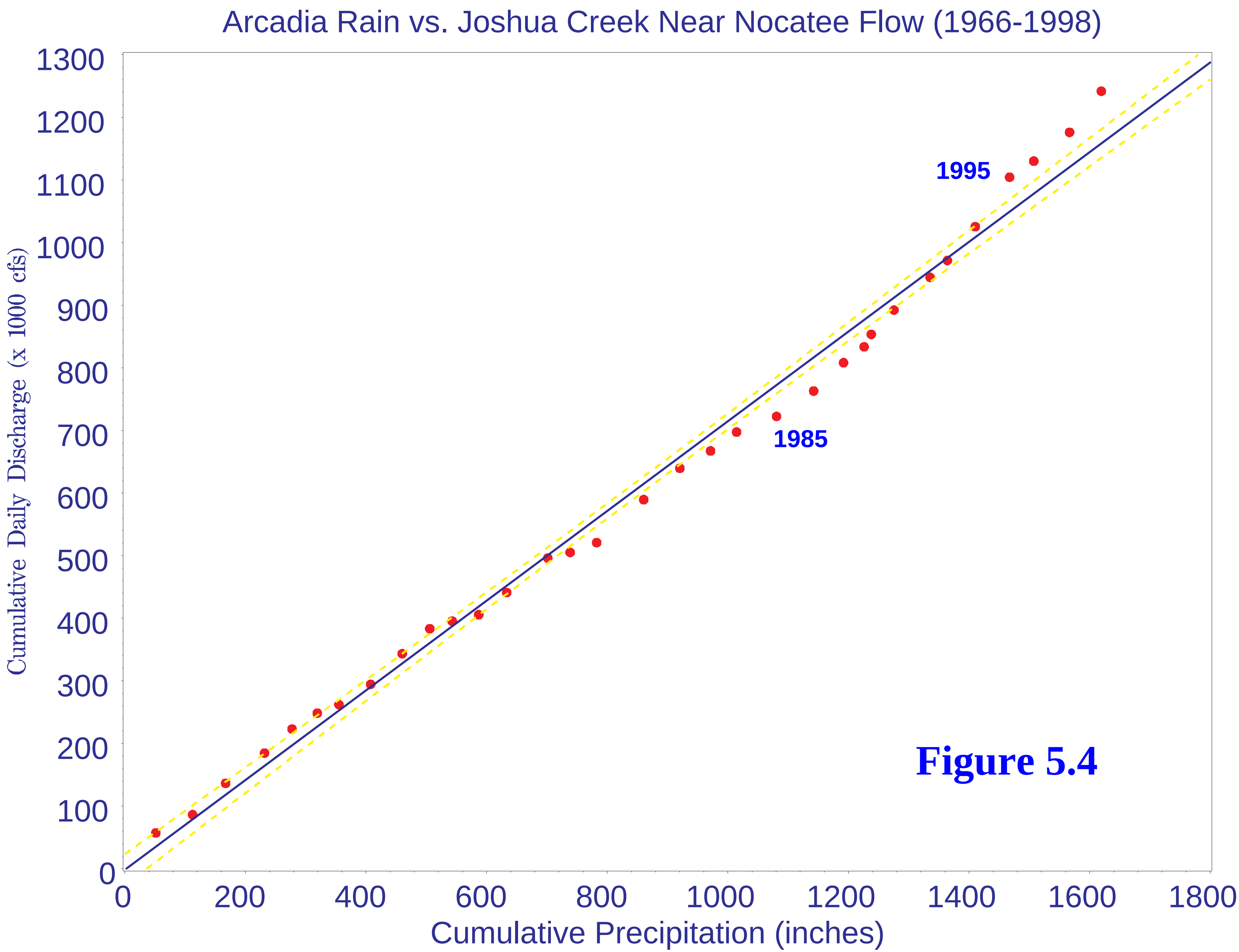

Arcadia Rain vs. Horse Flow (1966-1998)
Cumulative Daily Discharge (x 1000 cfs)
Cumulative Precipitation (inches)
1995
1985
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
0
200
400
600
800
1000
1200
1400
1600
1800

Figure 5.3


Arcadia Rain vs. Joshua Creek Near Nocatee Flow (1966-1998)
Cumulative Daily Discharge (x 1000 cfs)
Cumulative Precipitation (inches)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
0
200
400
600
800
1000
1200
1400
1600
1800
1995
1985
Figure 5.4

- In a similar manner, the unusually high and extended rainfalls of 1995 and during the 1997/1998 El Niño resulted in slightly higher flows per unit rainfall for each of the three tributaries than the long-term average.

- Since 1966 there have not been any marked significant, conspicuous changes in the general relationships between rainfall and flow in any of these three sub-basins, although some small differences have occurred during extended wet and dry periods.

5.4 Withdrawals

Figure 5a indicates the total monthly amount of freshwater withdrawal at the Peace River Treatment Facility as a percent of the total monthly gaged flow at Arcadia since consumptive use began in 1980. This figure shows that prior to the adoption of a 10% upper limit, the original permit schedule based on average monthly maximums resulted in instances when as much as 25% of the gaged Arcadia flow were withdrawn. The figure also strongly suggests that overall, withdrawals have increased as a percent of Arcadia flow as demand has increased. **Figure 5b** depicts the seasonal distribution of withdrawals relative to Arcadia flow. As indicated, the highest percentages of flow occur during the period January through May, when flows are typically low and demand is high.

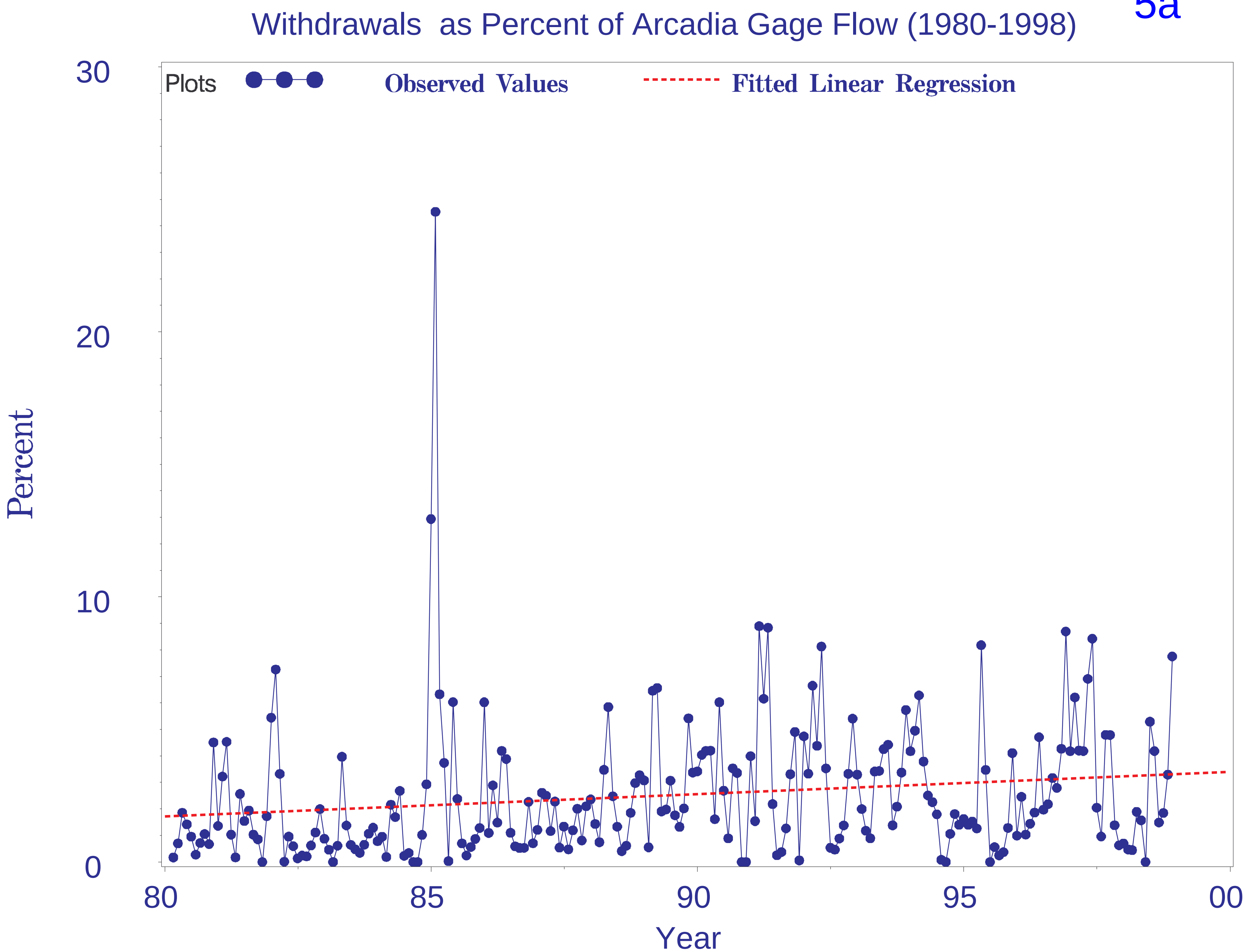
Table 5.11 presents the results of trend analysis of Peace River Facility withdrawals since the beginning of operation in 1980. Corresponding analyses were conducted over the same period of both combined gaged flows upstream of the Peace River Facility, and immediately downstream after adjusting for daily withdrawals. Complete statistical results are provided in **Table 5.12**. Not unexpectedly, the results clearly show the steady progressive increase in withdrawals as capacity and demand have increased. However, these results show that withdrawals have had negligible change in statistical patterns (Box Plots) and measures of trends in flow at the Peace River Facility. Of particular note are comparisons of the differences in magnitudes and seasonal patterns of withdrawals and flows. The box plots clearly indicate that the magnitude and variation in withdrawals is extremely small when compared to the natural seasonal variability in total flows upstream of the Peace River Facility.

Table 5.11 Trends in Withdrawals and Flows at the Peace River Facility Over the Period of Operation (1980-1998)

Measurement in cubic ft/sec	Trend	Time Series	Box Plot	Correlogram
Withdrawals	▲	C-085	C-086	C-087
Gaged Upstream Flow (Peace+Horse+Joshua)	N.S	C-088	C-089	C-090
Upstream Flow minus Withdrawals	N.S	C-091	C-092	C-093

Table 5.13 provides a further analysis of changes in withdrawals under each of the three permit schedules. Average daily withdrawals have more than doubled since the Peace River Facility began operation. However, the total amount still averages less than 1% of gaged flow measured upstream of the Peace River Facility.

5a



Withdrawals as Percent of Arcadia Gage Flow (1980-1998)
Plots
Observed Values
Fitted Linear Regression
Percent
30
20
10
0
80
85
90
95
00
Year

Withdrawals as Percent of Arcadia Gaged Flows
Monthly Boxplots 1980-1998

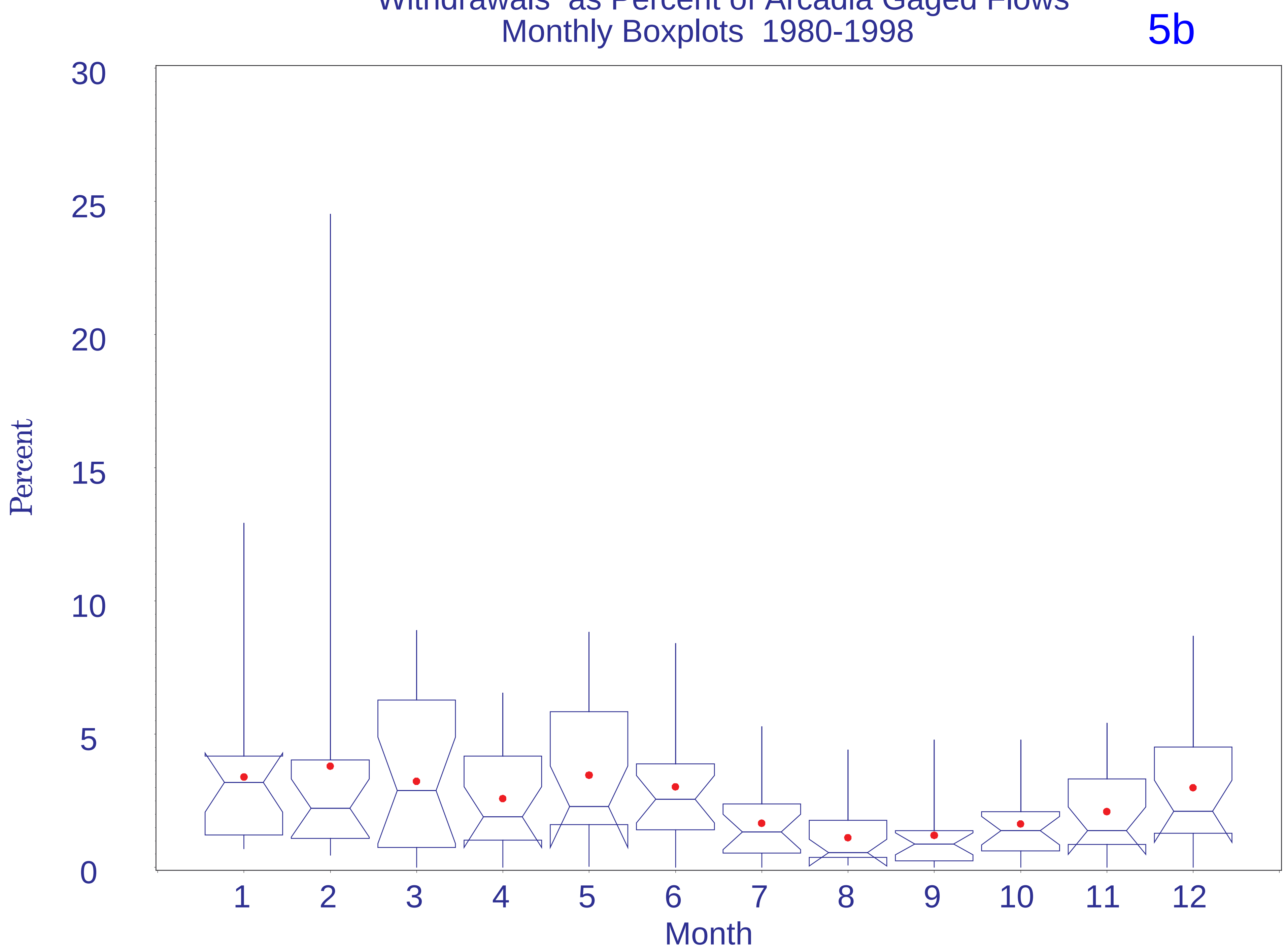


Table 5.12 Flows (cfs) and Withdrawals (cfs) during Period of Facility Operation (1980-1998)					
Time Period Location	**Tau Statistic**	**P-Value without Serial Correlation**	**P-Value with Serial Correlation**	**Slope Statistic**	**Trend**
Facility Freshwater Withdrawals	0.410	0.000	0.000	0.623	▲
Total @ Treatment Facility Before Withdrawals	0.130	0.007	**0.141**	15.121	
Total @ Treatment Facility Accounting for Withdrawals	0.134	0.005	**0.113**	15.223	

Table 5.13 Comparisons of Freshwater Withdrawals (cfs) and Relations to Flow (cfs)									
Time Period	Daily Freshwater Withdrawals (cfs)		Percentiles of Daily Freshwater Withdrawals (cfs)				Withdrawal as Percent of Total Gauged Flow		Percent of Days with No Withdrawal
	Mean	Median	5th	25th	75th	95th	Above Facility	Above US 41	
1980-1987	5.84	3.36	0	0	8.00	27.88	0.6%	0.4 %	47.3 %
1988-1995	10.43	10.89	0	0	14.41	28.13	0.9 %	0.6 %	27.4 %
1996-1998	13.33	15.34	0	0	17.46	31.08	1.0 %	0.8 %	29.4 %

5.5 Potential Impacts of Withdrawals on Salinity

Many of the concerns, regarding freshwater withdrawals from the Peace River, center on the potential for both direct and indirect effects (see **Chapter III**). These effects can potentially result in alterations to the spatial and temporal salinity gradients in the estuary's upper reaches. Many of the existing "Health of the Harbor" elements of the HBMP (see **Chapter II**) are being conducted in large part to assess the variability of these biotic communities to natural seasonal fluctuations in salinity gradients. An understanding of such responses to natural variability in freshwater inflows should provide a better understanding the potential magnitude of any effects that might be associated with withdrawals.

5.5.1 Modeling of Salinity Gradients

The following series of analyses were conducted to quantify the magnitude of past and future permitted withdrawals on the salinity structure along the lower river downstream of the Peace River Facility. The first step was to use the extensive long-term water column profile data, collected as part of various HBMP elements. These data were used to develop statistical models of the relationships between gaged freshwater inflows, withdrawals and salinity in the areas of the river between the point of withdrawal (RK 30.2) and the US 41 Bridge (RK 6.6). The assumptions and criteria used in the development of these models included the following.

- The range of data used was limited to gaged Arcadia flows between 100 and 1000 cfs. The lower 100 cfs limit was set to match the minimum permitted flow criteria established between 1988 and 1996. The upper 1000 cfs limit reflects approximately the level beyond which surface salinities throughout much of the area of interest decline to near zero.

- Based on a review of the data and the river's morphometery, different statistical models were developed for two areas: 1) a lower segment between river kilometers 6 and 16; and 2) an upper segment between river kilometers 15 and 30 (see **Figure 2.1**).

- The models used three "flow-classes" of gaged Arcadia flow to develop both interactions with the flow and distance terms (see below). The classes used were:
  1. flows between 100 and 160 cfs (low flow conditions);
  2. flows between 160 and 400 cfs (median Arcadia flow (1976-1998) ≅ 401 cfs); and
  3. flows between 400 and 1000 cfs (75th Percentile Arcadia flow (1976-1998) ≅ 1060 cfs).

- Seasonal terms were used, defining the wet-season as the three months July-September and the dry-season as the remaining months.

- Long-term mean monthly salinities at Marker #1 (RK –2.4) were used to establish some indication of background conditions and "resident memory" within the upper estuary.

- The flows of Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek near Nocatee were combined to determine the flow term used in the upper river segment. Correspondingly, Shell Creek flows near Punta Gorda were added to establish modeled flows in lower river segment.

- Actual daily withdrawals were subtracted from the above cumulative flows for each observation.

- Logs of the flow term were used in the upper river segment models to account for the curvilinear nature of the salinity data, while linear, non-transformed flows were used in the lower river segment models.

Independent models using the same form were developed for surface and bottom salinities in the upper and lower river segments using the following formula:

$$Salinity = \beta_{0i} + (\beta_{1j} \times RKm) + (\beta_{2} \times Harbor\ Salinity) + (\beta_{3j} \times Flow)$$

where:

β_{0i} = dry or wet season specific intercepts

β_{1j} = "flow-class" specific slopes for river kilometer

β_{2} = slope for background upper harbor salinity

β_{3j} = "flow-class" specific slopes for flow

The relationships between predicted and actual observed salinities (relative fit) of each of these four models are graphically presented in Table 5.14. The R-Square values for the models are indicated on each corresponding graphic.

Table 5.14 Estimated Salinity Predicted by the Model vs. Actual Observed Salinity

Depth	Upper River Segment Facility to Harbour Heights	Lower River Segment Harbour Heights to US 41 Bridge
Surface	C-94	C-96
Bottom	C-95	C-97

The fit between predicted and actual observed salinities was better for the lower river segment models (R-Square 0.86) where the field data included a wide range of salinities as responses to a variety of changing flows. By comparison, the fit of the upper river segment models was less (R-Square 0.61) since, even under moderate levels of flow, a large proportion of observed salinities (and associated variability) were near zero. Complete statistical summaries of parameter estimates and probabilities are provided for each of the four salinity models in **Table 5.15**. As this table indicates, each of the

Table 5.15 Parameter Estimates and Probabilities for Salinity Models for River Segments									
Model Parameter		**Upper Segment Surface**		**Upper Segment Bottom**		**Lower Segment Surface**		**Lower Segment Bottom**	
		Estimate	**Probability**	**Estimate**	**Probability**	**Estimate**	**Probability**	**Estimate**	**Probability**
Season	**Dry**	9.937	.006	10.993	.003	34.494	<.0001	30.293	<.0001
	Wet	9.236	.012	10.719	.005	34.938	<.0001	31.165	<.0001
Distance	**Flow Class 1**	-0.438	<.0001	-0.465	<.0001	-1.507	<.0001	-1.640	<.0001
	Flow Class 2	-0.369	<.0001	-0.416	<.0001	-1.598	<.0001	-1.735	<.0001
	Flow Class 3	-0.324	<.0001	-0.302	<.0001	-1.535	<.0001	-2.046	<.0001
Salinity	**RKm -2.4**	0.379	<.0001	0.352	<.0001	0.607	<.0001	0.690	<.0001
Flow *	**Flow Class 1**	-2.151	.005	-2.083	.009	-3.556	<.0001	-2.477	<.0001
	Flow Class 2	-2.274	<.0001	-2.127	.0004	-3.309	<.0001	-2.307	<.0001
	Flow Class 3	-2.586	<.0001	-2.794	<.0001	-3.401	<.0001	-1.927	.0004

* The log of flow was used in the Upper River Segment

parameters used to construct these predictive models were highly significant in accounting for observed variability in salinity.

Once these models had been developed, they were then used to answer the question: What would have been the average differences in salinities along the Lower Peace River if freshwater withdrawals had not taken place? To do this, daily salinities were calculated by river kilometer downstream of the Peace River Facility, at the surface and bottom, both with and without actual withdrawals using gaged flows for each of the four major tributaries. Comparative plots of predicted mean salinities are listed in Table 5.16 for each of three historic periods during which there were different permit withdrawal schedules.

Table 5.16 Predicted Mean Salinity by River Kilometer With and Without Withdrawals During Each Different Withdrawal Schedule				
Permit Period	Facility to Harbour Heights		Harbour Heights to US 41 Bridge	
	Surface	Bottom	Surface	Bottom
1980-1987	C-98	C-99	C-100	C-101
1988-1995	C-102	C-103	C-104	C-105
1996-1998	C-106	C-107	C-108	C-109

These figures show the magnitude of mean predicted changes in salinity in relation to average ambient levels by river kilometer in each of the two river segments. The statistical models for the upper and lower river segments were developed independently in order to provide the best estimates of the influences of withdrawals within each area of the river. This resulted in differences in the predicted salinities of the river where the models join. For this reason, the absolute results of models for each of the segments should be evaluated independently.

However, the overall results of all of these models indicated that, on average, the influences of withdrawals on the salinity structure of the Peace River between the US 41 Bridge and the Peace River Facility has historically resulted in changes of less than 0.3 ppt. In addition, the largest predicted changes resulting from withdrawals have occurred in the region of the river between river kilometers 14 and 18.

5.5.2 Changes in Salinity Under Maximum Withdrawals

Using the same models developed above for the upper and lower river segments, a second question was then asked: What would the predicted changes in salinities be downstream of the Peace River Facility under the maximum withdrawals allowed under the current permit? In order to answer this question, maximum daily withdrawals were applied over a range of projected conditions based on Arcadia flows between 200 and 1000 cfs, using the following criteria:

- Corresponding flows in each of the other three major tributaries (Horse, Joshua and Shell creeks) were estimated using the regressions developed in **Table 5.8**.

- Maximum daily withdrawals were based on 10% of Arcadia flow, maintaining a minimum of 130 cfs and a rate never exceeding 139.2 cfs (90 mgd, the permitted maximum daily Peace River Facility withdrawal).

Projected salinities were calculated by river kilometer downstream of the Peace River Facility, at the surface and bottom, both with and without maximum daily withdrawals for each of four differing levels of flow at the Arcadia gage. Graphical results of these analyses are listed in Table 5.17.

Table 5.17 Predicted Salinity by River Kilometer Based on Current Permit Conditions With and Without Maximum Daily Withdrawals Under Different Freshwater Inflows (Arcadia)

Arcadia Flows	Facility to Harbour Heights		Harbour Heights to US 41 Bridge	
	Surface	Bottom	Surface	Bottom
200 cfs	C-110	C-111	C-112	C-113
400 cfs	C-114	C-115	C-116	C-117
800 cfs	C-118	C-119	C-120	C-121
1000 cfs	C-122	C-123	C-124	C-125

Using the model results from above, further graphical analyses are presented in Table 5.18 for the same levels of river flow indicating the predicted changes in salinity due to maximum withdrawals relative to both river kilometer and the calculated salinity gradient downstream of the Peace River Facility.

Table 5.18 Estimated Salinity and Predicted Change by River Kilometer Under Maximum Permitted Daily Withdrawal

Depth	During Different Rates of Flows at Arcadia				Summary
	200 cfs	400 cfs	800 cfs	1000 cfs	
Surface	C-126	C-128	C-130	C-132	C-134
Bottom	C-127	C-129	C-131	C-133	C-135

The results of these analyses indicate the following.

- The maximum changes in salinity predicted to result from permitted maximum daily withdrawals at any point downstream of the Peace River Facility are less than 0.5 ppt. Such changes are far less than either the natural seasonal (see **Chapter IV**) or daily variability in salinity that occur along the gradient.

- The predicted differences due to withdrawals are greater at the surface than in the slightly higher saline waters near the bottom.

- The models predict that there should be little difference in either the magnitude or area of influence under conditions of Arcadia flows between 400 and 1000 cfs. However, under lower levels of flow, the results suggest that small changes in salinity (< .5 ppt) will occur further upstream.

5.6 Statistical Models of Other Parameters and Relationships with Flow

In order to assess particular elements of the current HBMP design (see **Chapter VI**) in relation to potential Peace River Facility impacts, statistical models were developed for a number of parameters (Table 5.18) using protocols and procedures analogous to those described above for salinity. The key questions these analyses were designed to answer included:

- Do these parameters exhibit spatial, temporal or other patterns within the area of the Lower Peace River between the US 41 Bridge and the Peace River Facility that can be described using a statistical model?

- Is variability in flow a statistically significant component of the resulting "Best Fit" model?

The first step employed in answering these questions was simply to plot each variable, for each of the two same river segments used in the salinity models, versus gaged Arcadia flows. The resulting graphics, indicating the different time periods over which each parameter was collected, are listed in Table 5.19.

Table 5.19 Parameter/Flow Relationships

Parameter	Graphic of Relationship with Flow	R-Square of Best Fit Model by River Segment		Correlated With Flow?
		Downstream	Upstream	
Chemical				
Alkalinity	C-136	.61	.62	Yes
Chlorides	C-137	.70	.56	Yes
Dissolved Inorganic Nitrogen	C-138	.25	.16	Yes
Total Phosphorus	C-139	.26	.10	Yes
Silica	C-140	.35	.26	Yes
Inorganic Carbon	C-141	.48	.44	Yes
Dissolved Organic Carbon	C-142	.15	.12	No
Total Organic Carbon	C-143	.22	.20	No
Physical				
Turbidity	C-144	.06	.05	No
Extinction Coefficient	C-145	.46	.51	Yes
Biological				
Carbon Uptake	C-146	.06	.16	Yes
Chlorophyll *a* (> 20 µm)	C-147	.04	.09	No
Chlorophyll *a* (< 20 µm & > 5 µm)	C-148	.03	.05	No
Chlorophyll *a* (< 5 µm)	C-149	.10	.07	Yes
Percent Blue-green Algae	C-150	.05	.05	No
Percent Flagellates	C-151	.02	.03	No
Percent Dinoflagellates	C-152	.02	.10	No
Percent Diatoms	C-153	.13	.10	No
Percent Green Algae	C-154	.30	.34	Yes

Next a series of statistical models were developed for each parameter in order to determine if a "best fit" model could be established. Various groups and combinations of seasonal, distance and flow terms, similar to those used in the development of the salinity models, were applied to test for possible relationships using both transformed and non-transformed data. The relative degrees of fit for each of the best resulting upstream and downstream models for each parameter are indicated in Table 5.19. The last column in the table answers the question of whether these models contained a statistically significant term relating changes in river flow with the observed variability of the parameter.

These results indicate that for parameters, such as alkalinity and chlorides, statistical models incorporating flow could be used to explain more than half of the observed variation in the data. In comparison, barely any of the measured variability in turbidity or size fractionated chlorophyll *a* in the lower river could be explained by the statistical models.

5.7 Chapter V Summary

1. Rainfall

- Over both the recent historic period (1966-1998) and the history of the HBMP (1976-1998) there have not been any consistent increasing or decreasing rainfall patterns in the Upper Peace River watershed.

2. Flows

- During the period of approximately the last thirty years, freshwater flows in all of the gaged major Peace River tributaries have been either stable or increasing.

- The Peace River (Arcadia) is typically the major source of freshwater to the lower river, averaging over 60% of total flow. Shell Creek is the next largest source averaging more than 20% of total flow, while Horse and Joshua Creeks each usually contribute less than 10%. However, localized differences in rainfall within each of the four major sub-basin watersheds can result in dramatic daily, and even monthly differences in their relative contributions to the total freshwater inflow to the Lower Peace River estuary.

3. Flow to Rainfall Relationship

- Since 1966 there have not been any conspicuous changes in the general relationships between flow and rainfall in Peace River basin or any of the three tributary sub-basins, although some small differences have occurred during extended wet and dry periods.

4. Withdrawals

- Peace River Facility withdrawals have steadily and progressively increased since their start in 1980. However, the magnitude of withdrawals has been extremely small when compared to the natural seasonal variability, and currently comprises less than 1% of total freshwater inflow at the mouth of the river.

5. Potential Impacts of Withdrawals on Salinity

- Statistical models were developed with the objective of establishing a predictive relationship between flow and salinity in the Lower Peace River, and for discerning the incremental effect of past and future permitted withdrawals on the salinity structure estuary downstream of the Peace River Facility.

- Model results indicated that, on average, the influences of past withdrawals on the salinity structure of the Lower Peace River between the U.S. 41 Bridge and the Peace River Facility has historically resulted in maximum changes of less than 0.3 ppt. These model results also indicated that the largest changes resulting from past withdrawals have occurred between river kilometers 14 and 18 in the Lower Peace River.

- Statistical models were also used to predict what the potential magnitude of salinity changes might be under the maximum permitted daily withdrawals during Arcadia flows between 200 and 1,000 cfs. Model results predict that a maximum salinity change of < 0.5 ppt would occur between river kilometers 14 and 18 when Arcadia flows range between 400 and 1000 cfs. With Arcadia flows of 200 cfs, the results predict that similar changes in salinity (< 0.5 ppt) would occur further upstream.

- The models indicate that the response (incremental change) of salinity to changes in flow is not linear. In general, withdrawals result in incrementally greater changes in salinity during low flows, lesser at high flows, and proportionally smaller changes in salinity during high flows.

- The models also indicate that the effects of withdrawals on salinity tend to be greater upstream than downstream; however, there is a portion of the river below the Peace River Facility that is always fresh and never impacted by withdrawals.

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Chapter VI

Assessment of HBMP Design

Based on the information and analyses presented in the preceding chapters, the primary focus of this chapter is to assess a select number of variables currently being measured by elements of the HBMP. That assessment is to determine, whether these parameters are still applicable elements to the program's overall management goal of addressing resource management issues relative to Peace River Facility operations. These assessments are then used as a basis for the development of a series of proposed revisions (deletions) and potential spatial modifications to specific elements of the HBMP.

6.1 Resource Criteria

The initial step to objectively assessing the relevancy of these selected parameters was to evaluate each with regard to five fundamental questions:

1. Is the parameter a measure of an important component of the Conceptual Model (see Chapter III) of the Lower Peace River estuarine system?

Freshwater inflow to the estuarine system influences the water quality characteristics (gradients) and the numbers, kinds, and spatial distribution of organisms through the combined influences of both direct and indirect effects. Direct effects would include changes in salinity that excludes certain benthic invertebrates from a given area of estuary. An indirect effect, by comparison, could result from a reduction in flow, reducing available nutrients, leading to lower phytoplankton biomass, causing a reduction in zooplankton, and ultimately resulting in fewer juvenile fishes. The conceptual model illustrates both direct and indirect effects of changes in freshwater inflow. However, since Peace River Facility withdrawals take only a very small percent of total freshwater inflows to the estuary, those HBMP variables that measure direct effects have a very much higher probability of detecting any potential impacts associated with withdrawals. Correspondingly, the ability to associate changes due to withdrawals dramatically decreases as the number of mediating steps between freshwater inflow and the measured variable increases.

2. Is the parameter non-redundant?

This question addresses whether or not there is another component or parameter of the HBMP measuring essentially the same thing. For example, outside of the freshwater reaches of the lower river, chlorides can be used to chemically measure salinity. However, *in situ* conductivity measurements can also be used to directly measure salinity.

3. **Is the observed variability of the measured parameter in the lower river directly related to changes in flow (see Chapter V)?**

   The results of the statistical models (see Table 5.19 in **Chapter V**) were used to determine the degree of relationship of each parameter with flow. Only those parameters for which regression models had R-Square values greater than 0.4, and for which flow accounted for a significant portion of the observed variability, were determined to be directly related to flow.

4. **Do the long-term data for this parameter indicate the presence of statistically significant temporal trends within the lower portions of the river downstream of the Peace River Facility?**

   One of the primary goals of the "Health of the Harbor" elements of the HBMP has been to determine whether there have been systematic long-term changes occurring in selected physical/chemical/biological characteristics (**Chapter IV)** in the Lower Peace River/Upper Charlotte Harbor estuarine system. If significant changes have occurred, the next step is to determine if, conceptually, mechanisms associated with either the direct or indirect effects of flow might be involved. These conclusions will further determine whether specific actions, additional analyses, or increased data collections are warranted.

5. **Does the measurement exhibit a distinct spatial pattern or gradient (see Chapter IV) between the mouth of the river and the Peace River Facility?**

   Estuarine systems characteristically exhibit distinct spatial gradients resulting from the combined direct and indirect influences of freshwater inputs. As a result, parameters that fail to exhibit spatial gradients within the estuary can be expected to provide limited utility in evaluating the potential impacts of withdrawals.

The answers to these specific questions are summarized in Table 6.1.

Table 6.1 Variables vs. Criteria for Developing Resource Management Goals

Parameter	Important Component of Conceptual Model?	Direct / Indirect Effect	Is it Non-Redundant?	Is It Related to Flow?	Is There a Temporal Trend?	Is There a Spatial Gradient ?
Chemical						
Alkalinity	No	N/A	Yes	Yes	No	Yes
Chlorides	No	N/A	No	Yes	N/a	Yes
Dissolved Inorganic Nitrogen	Yes	Direct	Yes	No	No	Yes
Total Phosphorus	No	N/A	Yes	No	Yes	Yes
Silica	No	N/A	Yes	No	No	Yes
Inorganic Carbon	No	N/A	Yes	Yes	Yes	Yes
Dissolved Organic Carbon	Yes	Indirect	Yes	No	No	Yes
Total Organic Carbon	Yes	Indirect	Yes	No	No	Yes

Table 6.1 Variables vs. Criteria for Developing Resource Management Goals						
Parameter	**Important Component of Conceptual Model?**	**Direct / Indirect Effect**	**Is it Non-Redundant?**	**Is It Related to Flow?**	**Is There a Temporal Trend?**	**Is There a Spatial Gradient ?**
Physical						
Turbidity	**No**	**N/A**	**Yes**	**No**	**Yes**	**Yes**
Extinction Coefficient	**Yes**	**Direct**	**No**	**Yes**	**Yes**	**Yes**
Biological						
Carbon Uptake	**Yes**	**Indirect**	**No**	**No**	**No**	**Yes**
Chlorophyll *a* size fractions	**No**	**N/A**	**No**	**No**	**No**	**Yes**
Phytoplankton Counts	**Yes**	**Direct/Indirect**	**Yes**	**No**	**No**	**Yes**
Vegetation Transects	**Yes**	**Direct**	**Yes**	**No ****	**No**	**Yes**

****** No quantifiable, consistent changes in indicator species can be attributed to long-term patterns in flow during the recent historic period.

Using the answers to these fundamental questions as a basis for comparison, the next step was to assess the continuing relevance of each selected component to overall goals of the HBMP and recommend deletion, modification or continuance.

- **Alkalinity** – This parameter measures a unique water quality characteristic whose spatial distribution along the Lower Peace River is directly related to flow. However, it was initially added to the list of water chemistry parameters collected at the moving stations as a backup method of calculating inorganic carbon (which was needed to calculate carbon uptake rates). By itself, alkalinity is not a key element of the conceptual model and no longer serves a useful purpose now that carbon uptake rates have been deleted from the program (see below). It is recommended that alkalinity be deleted from both the fixed and moving station HBMP water chemistry studies.

- **Chlorides** – This parameter was originally added to the "moving station" element of the HBMP as a "chemical check" on the accuracy of the field crews in locating each of the four isohalines based on refractometer and conductivity meter readings. Chloride concentrations in the lower river are directly related to freshwater inflows. However, salinity can more easily be directly calculated from *in situ* conductivity measurements in the brackish reaches of the estuary. Since chlorides are a redundant measure it is recommended that this parameter be deleted from both the fixed and moving station HBMP water chemistry studies.

- **Dissolved Inorganic Nitrogen** – Other than conditions when highly colored river water limits the penetration of light into the water column, the availability of nitrogen is the dominant factor limiting primary production in the Charlotte Harbor estuarine system. As such, nitrogen is a key component of the conceptual model and total nitrogen loadings to the Harbor are directly related to flow. However, as indicated by the observed spatial and temporal patterns, ambient concentrations towards the mouth of the river show marked influences of biological processes. Chemical values of dissolved inorganic nitrogen are calculated from combining individual measurements for nitrate/nitrite-nitrogen and ammonia/ammonium-nitrogen. However, both the very high proportion of observations below detection limit, and the occasional very high levels has always complicated the interpretation of ammonia/ammonium-nitrogen results. Field observations have noted that high readings have often been associated with instances of: 1) large numbers of birds on overhead power lines; 2) extensive rafts of ducks over-wintering in the upper harbor; 3) very high abundances of zooplankton; and 4) the fall turn-over of the water column. However, in a great many instances individual high ammonia/ammonium-nitrogen levels remain unexplained. For these reasons, it is recommended that nitrate/nitrite-nitrogen be retained as a "Health of the Harbor" assessment tool, but that ammonia/ammonium-nitrogen be deleted from both the fixed and moving station HBMP water chemistry studies.

- **Total Phosphorus** – This macronutrient meets each of the five key criteria set forth in Table 6.1. However, the Peace River Basin contains extensive natural phosphate deposits, and ambient concentrations in the Lower Peace River are extremely high in comparison to estuarine systems outside of Southwest Florida. There are no data to suggest that the availability of phosphorus ever limits production in the Peace River estuarine system. Orthophosphorus is the biologically available form and comprises over 92% of total measured phosphorus in the Lower Peace River. It is recommended that total phosphorus be deleted from both the fixed and moving station HBMP water chemistry studies, but that orthophosphorus be retained in assessing the "Health of the Harbor" and changes in mining practices in the watershed.

- **Silica** – As a chemical water quality parameter, silica meets four of the five important criteria established for comparison in Table 6.1. It was initially added to the isohaline based "moving" stations to provide potential information regarding competition between major phytoplankton groups. Diatoms require silica for the formation of the frustuals surrounding the cell, and studies have shown these algae to be at a competitive disadvantage under conditions of low ambient silica. However, since it is being recommended (see below) that phytoplankton species identification be deleted from the current monitoring program, it is also proposed that silica be deleted from the moving and fixed chemistry parameters.

- **Inorganic Carbon** – This chemical constituent does not meet the primary key criteria of being an important component of the conceptual model for the Lower River/Upper Harbor estuarine system. It was originally added to the HBMP since it was necessary to measure phytoplankton carbon uptake rates. Primary production has been dropped from the HBMP (see below). Thus measures of inorganic carbon are no longer necessary and it is strongly recommended that this parameter be deleted.

- **Dissolved Organic Carbon –** There is a considerable amount of literature and speculation concerning the potential role of dissolved organic carbon as an important component of production in estuarine systems. However, the pathways, mechanisms, and confounding influences associated with the reliance of bacterial based food chains on estuarine dissolved organic carbon loadings are very poorly understood. While this parameter may be an important "Health of the Harbor" measure, the magnitudes of current permitted withdrawals are far below that which might reasonably be expected to result in measurable changes. Since this parameter can neither be related to flow (see **Chapter V**), nor were statistically significant trends observed, it is recommended that this parameter be deleted from the HBMP water chemistry list. The measurement of dissolved organic carbon could, however, potentially be continued as part of the District's Charlotte Harbor Surface Water Improvement Monitoring (SWIM) Program.

- **Total Organic Carbon** – This water quality parameter measures both dissolved organic carbon (see above) as well as any particulate organic material in the water column, including both phytoplankton and zooplankton. While total organic carbon is an important component of the estuarine conceptual model, its relationships with flow are mediated through a variety of highly temporal pathways. As a result, any interactions with flow are obscured. Therefore, it is recommended that the measurement of total organic carbon be deleted from both the fixed and moving station HBMP water chemistry studies. The measurement of this parameter could, however, potentially be continued as part of the District's Charlotte Harbor Surface Water Improvement Monitoring (SWIM) Program.

- **Turbidity** – Statistical models for the Lower Peace River (see **Chapter V**) failed to demonstrate any consistent relationships of observed turbidity with season, distance, or freshwater inflows. Field observations in the Lower Peace River have indicated increased turbidity resulting from factors such as: 1) flocculent organic material; 2) plankton; and 3) suspended organic sediments caused by wind stress across shallow areas. The potential for any correlation of turbidity with Peace River Facility withdrawals is extremely doubtful, and it is recommended that this parameter be deleted from the HBMP water quality monitoring.

- **Extinction Coefficient** – This parameter is a measure of the rate at which light is absorbed and scattered as it passes through water. In the Upper Charlotte Harbor estuary, this *in situ* physical measurement is influenced (in order of importance) by: 1) color; 2) plankton; and 3) turbidity. As a result of the characteristically high color levels, submerged aquatic vegetation (SAV) along the Lower Peace River is not extensive and limited to very shallow areas. Theoretically reducing water color through very large freshwater withdrawals could benefit SAV communities in the upper estuary, while at the same time enhancing phytoplankton production by increasing the depth of the photic zone. However, the permitted rates of withdrawal are far below those that could significantly influence this measure. Monitoring of the extinction coefficient may potentially be useful in developing relationships between flow and chlorophyll *a*. Since it also meets all but one of the criteria established in Table 6.1, it is recommended that the extinction coefficient continue to be measured as part of the HBMP in conjunction with other "Health of the Harbor" parameters.

- **Carbon Uptake** – This parameter is an instantaneous measure of the potential rate of phytoplankton growth. Chlorophyll *a*, by comparison, can be interpreted as a measure of phytoplankton biomass, integrating past growth. An extensive base of information on carbon uptake rates at each of four isohalines (see **Chapter IV**) was developed as part of the HBMP during the eighteen-year period between June 1983 and June 2000. In consultation with the District, carbon uptake was deleted from the monitoring program after June 2000.

- **Chlorophyll *a* Size Fractions** – Information regarding chlorophyll *a* size fractions can provide important information concerning phytoplankton community structure and potential patterns of energy flow to primary consumers. The relative size distribution of chlorophyll *a* meets only one (Table 6.1) of the key criteria: exhibiting a distinct spatial gradient. The attempt to develop statistical models (see **Chapter V**) for chlorophyll *a* size fractions along Lower Peace River failed to show clear relationships with either flow or distance. Therefore it is recommended that the size fractioning of chlorophyll *a* be eliminated from the HBMP studies.

- **Phytoplankton Counts** - Phytoplankton biomass and production are important components of the overall conceptual model for the Charlotte Harbor estuarine system. Furthermore, the phytoplankton taxonomic data collected since 1989 at the four "moving" isohalines have provided a great deal of "Health of the Harbor" information regarding the seasonal and spatial distributions/abundances of individual and taxonomic groups of algae. However, attempts failed (see **Chapter V**) to statistically relate the relative occurrence of five major algal groups to distance and flow in the area of the river between the US 41 Bridge and the Peace River Facility. The data indicated that the taxonomic composition within specific isohalines is strongly influenced by seasonal factors. Therefore, it is recommended that this "Health of the Harbor" component of the HBMP be discontinued, and that the Year Five Report contain further summary analyses to quantify seasonal and temporal taxonomic variability within each of the four isohalines.

- **Vegetation** – In the status and trends section of this document (see **Chapter IV**) a series of graphical analyses were presented indicating observed long-term changes in the first and last occurrences of selected indicator plant species. The long-term upstream and downstream changes in the occurrences of these taxa were compared with median flows over the period 1975-1998. These graphics clearly indicate that it is difficult to document any meaningful relationships between freshwater inflows and the long-term distributions of the selected indicator plant taxa. Based on this finding, it is doubtful that any further utility can be gained from continuing the collection of first and last plant indicator species data under the current permitted withdrawal schedule. However, since this element of the HBMP is not scheduled to be conducted again until after the Year Five Report has been submitted, it is recommended that any final decision regarding the deletion of the vegetation elements be based on comprehensive analyses conducted as part of the Year Five Report. These analyses should include the analysis of first and last occurrences presented in this report; 2) the findings presented in the upcoming *HBMP Historical Aerial Photographic Interpretation Report*; and, 3) long-term vegetation information being developed by the District.

6.2 Special Studies

Meetings and discussions have been held between the Authority and District to discuss the potential implementation of an experimental "pump test" to determine the relative degree of accuracy of the existing predictive models (see **Chapter V**). The scope and timing of any such potential experimental test to withdraw water and simultaneously evaluate the magnitude and spatial extent of changes in salinity are currently being evaluated.

6.3 HBMP Sampling Design

One of the key aspects of an effective monitoring program design is the adequacy of the design to allow examination of the major sources of variation in the data collected. As shown in Chapter IV, there is significant spatial and temporal variation in the water quality data of the Lower Peace River. The following examines the ability of the existing HBMP to address these questions in a robust and technically defensible manner.

6.3.1 Temporal Variation

The monthly sampling frequency is apparently adequate to allow detection of temporal trends in the water quality of the Lower Peace River, given the significant within year variation in many of the water quality indicators. However, it is uncertain whether short-term variation, such as due to tidal stage, is potentially contributing bias to the current water quality data. The current temporal design does not incorporate any means of randomization that would provide greater assurance that such bias is not significant.

The overall goals of the HBMP are to assess the potential impacts of the Peace River Facility on the Lower Peace River and to assess the overall health of the Lower Peace River. Without a more specific statement regarding the desired temporal frame within which the assessment of either the withdrawal effects or the river's health should be made, it is not possible to make any statements about the adequacy of the existing sample size to allow such an assessment.

6.3.2 Spatial Variation

As described above, the current HBMP design includes three spatial sampling frames:

- Fixed, continuous sampling at two stations and two depths,
- Fixed, monthly sampling at seventeen stations, and
- "Moving station" monthly sampling at four isohalines.

Table 6.2 presents the spatial coverage of the current sampling effort. The numbers in each column represent the number of samples collected in each calendar month during the period1997 and 1998. Clearly, there is unequal representation of the lower river by the existing program. This table represents all hydrolab data and the number of total samples collected in four very general areas of the lower river based on long-term average salinity locations. The river mouth to just downstream of the US 41 Bridge (RK 6.5) had 82 samples, RK 6.5 up stream to near Harbor Heights had 178, from Harbour Heights (RK 15.5) to RK 21.1 (just downstream of the Liverpool area) had 107, and from RK 21.1 to Horse Creek had 240 samples (see **Figure 6.1**). The salinity models developed in Chapter V predicted that greatest salinity changes due to withdrawals would occur in the river between RK 15.3 (near Harbour Heights) and RK 21.1 (near Liverpool). However, the distribution of samples indicates that this is not the most heavily sampled area under the current HBMP design and suggests that the sampling design may need changing in order to focus more effort into the area of the river having the highest predicted salinity changes resulting from withdrawals

Table 6.2 Summary Of The Spatial Coverage Of The Current HBMP Design

Month	< RK 6.5	RK 6.5-15.3	RK 15.3-21.1	> RK 21.1
January	7	14	10	20
February	7	15	9	20
March	7	15	9	18
April	7	15	9	20
May	6	16	8	21
June	6	15	9	21
July	6	16	9	20
August	8	15	8	20
September	6	13	9	20
October	8	14	10	19
November	7	15	8	22
December	7	15	9	19
Total	**82**	**178**	**107**	**240**

It should also be recognized that the existing sampling design depends upon a combination of a fixed spatial sampling frame and one that is based on the downstream most occurrence of four salinities (0, 6, 12, and 20 ppt). This second spatial sampling frame can result in a significant bias towards lower portions of the river during the wet-season, when during the wetter months of the year the isohaline sampling effort can completely omit the areas of the river upstream of RK 15.

Figure 6.2 further depicts the spatial distribution of all the HBMP physical water column profile measurements historically taken between 1975 and 1998, indicated by two-kilometer intervals, extending from four kilometers downstream of the river's mouth to four kilometers upstream of the Water Treatment Facility. Analogous plots of these data are also provided indicating the long-term distributions of these sampling events during both the predominantly dry months (October through May - **Figure 6.3**) and wet-season (June through September - **Figure 6.4**). These figures likewise suggest that some modification of the existing sampling strategies could provide an increased benefit by enhancing the frequency of sampling in the region of the lower Peace River predicted by the models developed in **Chapter V** to have the greatest potential of detecting salinity changes resulting from maximum freshwater withdrawals.

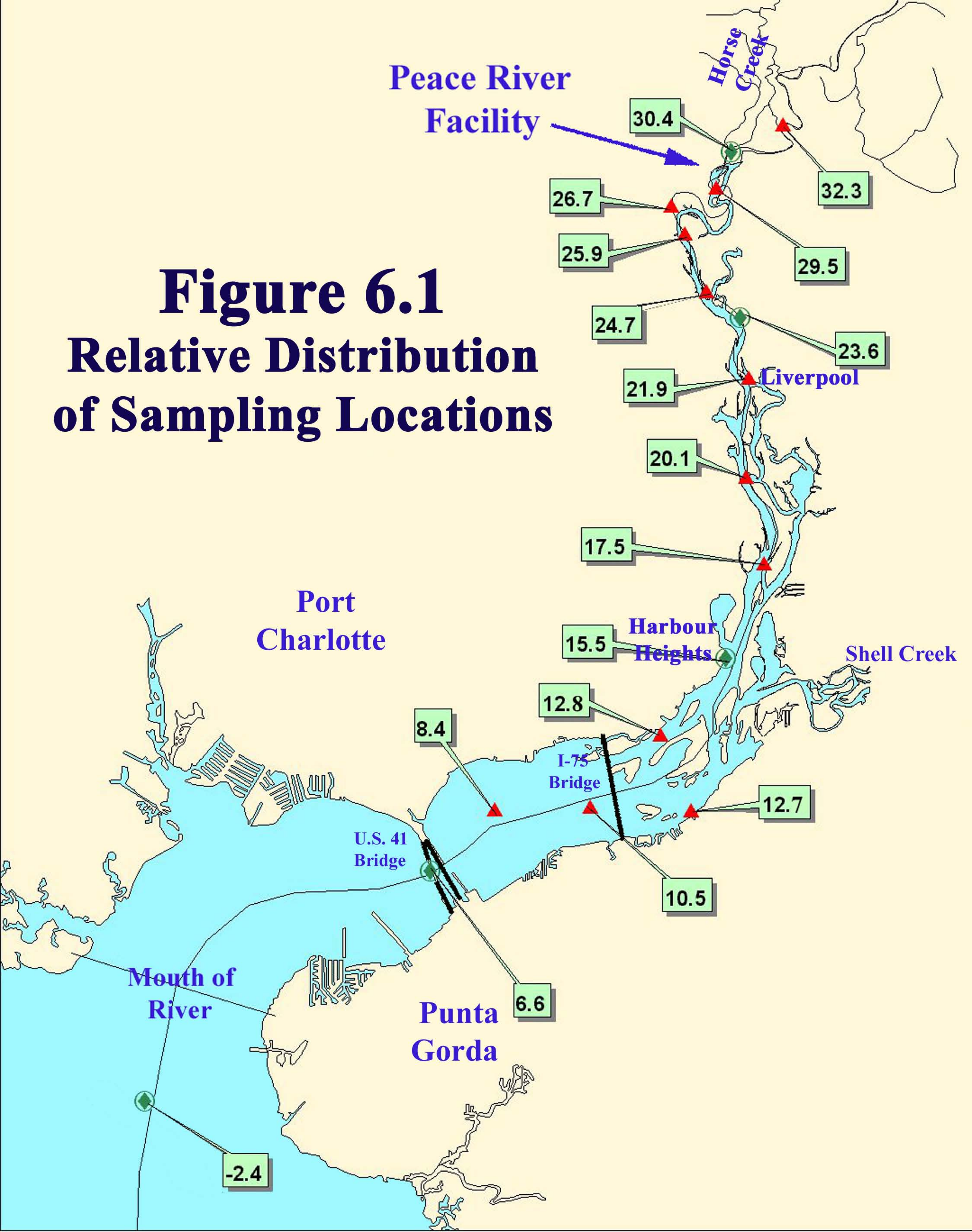
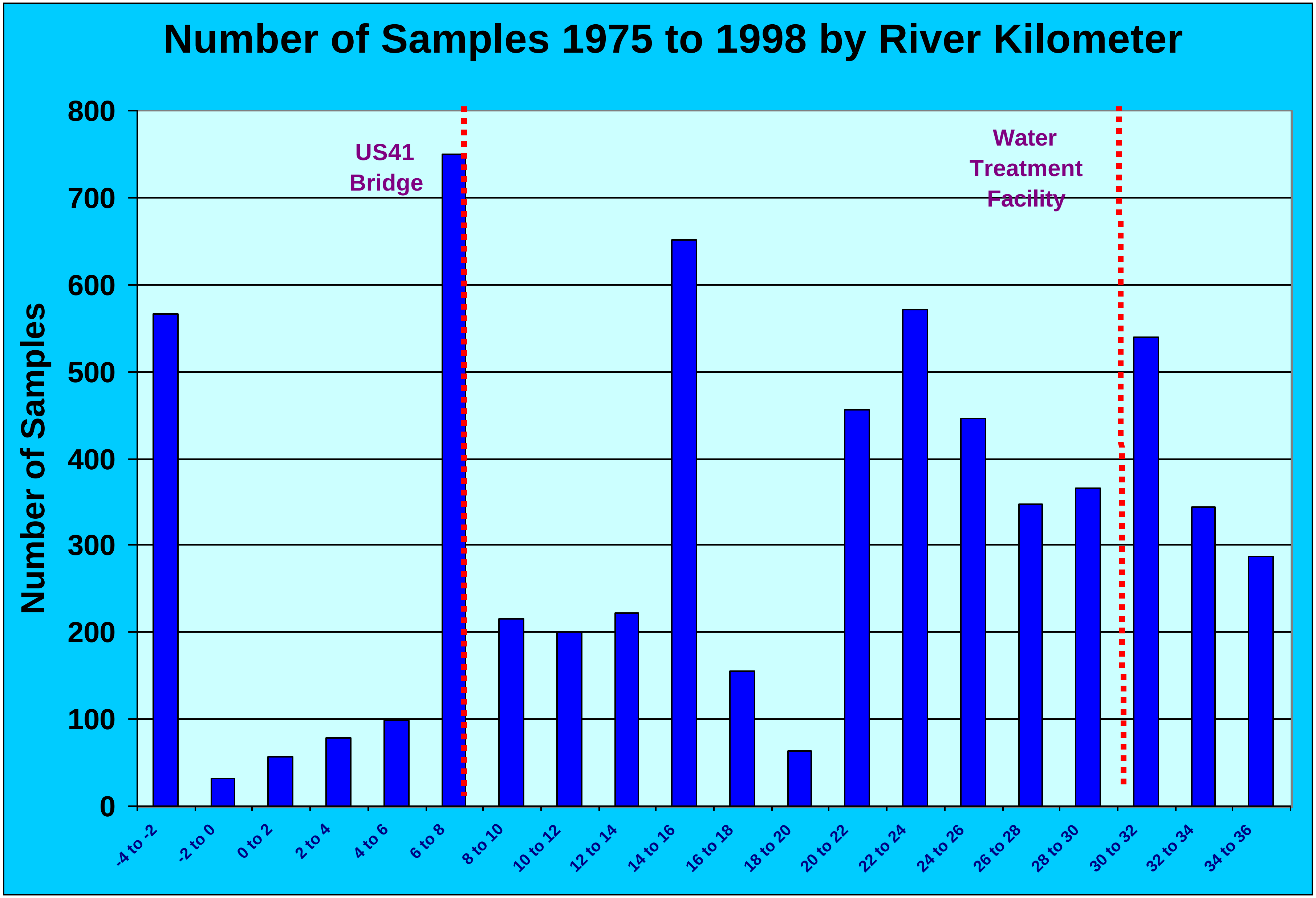


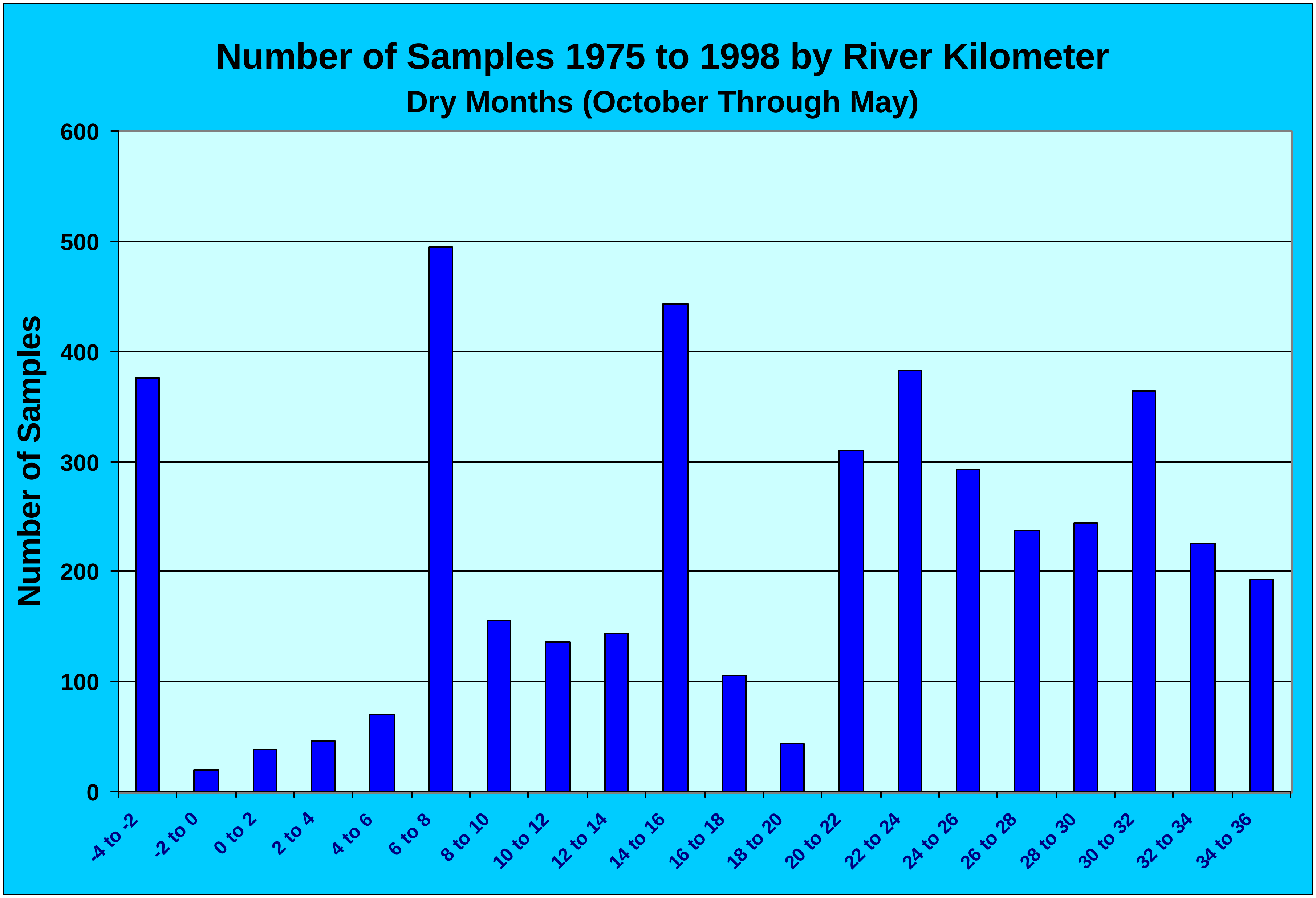
Figure 6.1
Relative Distribution
of Sampling Locations
Peace River
Facility
Horse
Creek
30.4
32.3
26.7
29.5
25.9
24.7
23.6
21.9
Liverpool
20.1
17.5
Port
Charlotte
Harbour
Heights
15.5
Shell Creek
12.8
8.4
I-75
Bridge
12.7
U.S. 41
Bridge
10.5
Mouth of
River
6.6
Punta
Gorda
-2.4

Figure 6.2



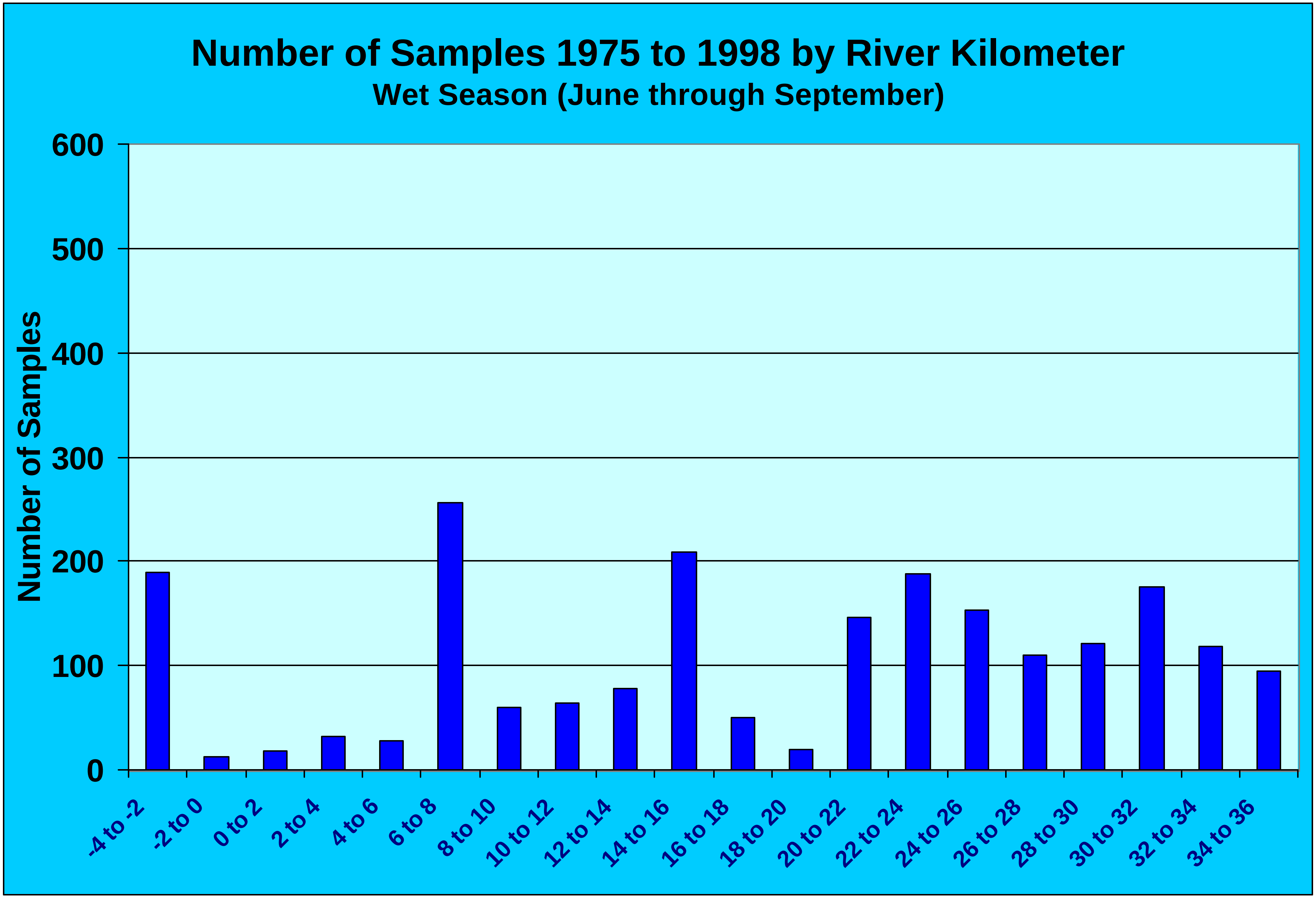
Number of Samples 1975 to 1998 by River Kilometer
Number of Samples
800
700
600
500
400
300
200
100
0
US41
Bridge
Water
Treatment
Facility
-4 to -2
-2 to 0
0 to 2
2 to 4
4 to 6
6 to 8
8 to 10
10 to 12
12 to 14
14 to 16
16 to 18
18 to 20
20 to 22
22 to 24
24 to 26
26 to 28
28 to 30
30 to 32
32 to 34
34 to 36

Figure 6.3



Number of Samples 1975 to 1998 by River Kilometer
Dry Months (October Through May)
Number of Samples
600
500
400
300
200
100
0
-4 to -2
-2 to 0
0 to 2
2 to 4
4 to 6
6 to 8
8 to 10
10 to 12
12 to 14
14 to 16
16 to 18
18 to 20
20 to 22
22 to 24
24 to 26
26 to 28
28 to 30
30 to 32
32 to 34
34 to 36

Figure 6.4



Number of Samples 1975 to 1998 by River Kilometer
Wet Season (June through September)
Number of Samples
600
500
400
300
200
100
0
-4 to -2
-2 to 0
0 to 2
2 to 4
4 to 6
6 to 8
8 to 10
10 to 12
12 to 14
14 to 16
16 to 18
18 to 20
20 to 22
22 to 24
24 to 26
26 to 28
28 to 30
30 to 32
32 to 34
34 to 36

It is suggested that such a sampling design should provide an effective and technically sound practical method for collecting the data needed to obtain unbiased population and subpopulation estimates, as well as unbiased variance estimates for the population and subpopulation estimates.

Sampling theory is typically employed to determine the best design for a sampling strategy. There are basically two common types of sampling strategies:

- **Probability Sampling** - Employing this approach requires a definition of the set of distinct samples, which the sampling program is capable of sampling if applied to a specific population. Each possible sample must have a known probability of selection. The samples are selected by a random process in which each sample receives its appropriate probability of being selected.

- **Nonprobability Sampling** - There are some common types: sampling a restricted portion of the population that is readily accessible (e.g., fixed station sampling of salinity from a bridge); haphazard sample selection without conscious planning; and a selection of "typical" or "representative" sample units that are close to the samplers impression of the average of the target population.

If the conditions are right, each of the methods can provide useful results. However, the only way to verify if an estimate is unbiased is to compare it with the actual population values or an estimate derived from a probability sampling approach.

Unbiased variance estimates provide a measure of the uncertainty of population and/or subpopulation estimates. In order to ensure that variance estimates are unbiased, it is recommended that any modifications to the HBMP sampling design be evaluated following the basic rules for probability sampling and variance estimation. Thus, for all such elements of the sampling design, at least two samples must be collected from each subpopulation for which an unbiased estimate of variance is required, and each sampling unit in the subpopulation must have a known, non-zero probability of inclusion in the sample. In addition, the pairwise inclusion probabilities of all possible combinations of the two samples must be known and non-zero. Logistical constraints may require that some sampling units have a lower inclusion probability than others, and can be incorporated into the sampling design, if necessary. The inclusion probabilities used to select sampling units will be specified quantitatively, introduced as weights in all computations of estimates and associated variances, and hence allow all estimates to be unbiased.

Since most HBMP elements currently employ "Nonprobability Sampling", it is recommended that the Year Five Report comprehensively review and evaluate the existing sampling designs specifically with regard to the issues of the spatial and temporal adequacy of the sampling designs.

6.4 Summary of Chapter VI

1. Several physical, chemical, and biological parameters of the existing HBMP were evaluated with respect to their continued relevance to the objectives of the program. Table 6.3 summarizes the recommendations regarding the deletion or further evaluation of each of the variables considered.

2. The monthly sampling frequency of the existing HBMP is apparently adequate to allow detection of temporal trends in the water quality of the Lower Peace River, given the significant with-in year variation in many of the water quality indicators. However, it is uncertain whether short-term variation, such as due to tidal stage, is potentially contributing bias to the current water quality data. The current temporal design does not incorporate any means of randomization that would provide greater assurance that such bias is not significant.

3. The current HBMP design includes three spatial sampling frames: 1) fixed, continuous sampling at two stations and two depths; 2) fixed, monthly sampling at seventeen stations, and 3) "moving station" monthly sampling at four isohalines.

Table 6.3 Summary of Recommendations Regarding Selected Parameters

Parameters Recommended for Deletion from the HBMP	Parameters Recommended for Continuation or Further Evaluation
Physical	**Physical**
Turbidity	Extinction Coefficient
Chemical	**Biological**
Alkalinity	Vegetation
Chlorides	
Ammonia/Ammonium	
Total Phosphorus	
Silica	
Inorganic Carbon	
Dissolved Organic Carbon	
Total Organic Carbon	
Biological	
Phytoplankton Species Counts	
Carbon Uptake	
Chlorophyll *a* Size Fractions	

4. Under the spatial sampling frames of the current HBMP design, there is clearly an unequal representation of the lower river. Specifically, the portion of the river between RK 15.3 and RK 21.1, which includes the major portion of the river where the relationship between river flow, withdrawals, and salinity are most pronounced, is characterized by far fewer samples than the portion of the river above RK 21.1.

5. It is recommended that further examination of the existing sampling program be pursued in the Year Five Report to more definitively address the issues of the spatial and temporal adequacy of the existing HBMP design.

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Chapter VII

Summary & Recommendations

Water Use Permit No 2010420.02, issued by the Southwest Florida Water Management District (District) to the Peace River/Manasota Regional Water Supply Authority on March 26, 1996, specified the continuation of the Hydrobiological Monitoring Program (HBMP) for the Lower Peace River/Upper Charlotte Harbor estuary. The required HBMP was to build upon the monitoring activities that have been ongoing since 1975. The overall goal of the HBMP is to provide the District with sufficient information to determine whether the biological communities of the Lower Peace River/Upper Charlotte Harbor estuarine system are significantly adversely impacted by permitted freshwater withdrawals at the Peace River/Manasota Regional Water Supply Authority's water treatment facility.

The HBMP has sought to accomplish this goal through two primary objectives:

1. The first objective has been to determine both the magnitude and extent of direct impacts associated with permitted withdrawals. This effort has primarily focused on assessing direct impacts associated with the relative alterations of the spatial distribution of the salinity gradient downstream of the Peace River Facility under differing levels of freshwater inflows. The primary area of focus for the HBMP along the lower Peace River extends from the typically freshwater area just upstream of the Authority's Peace River Facility to the river's mouth nearly 7 kilometers downstream of the US 41 Bridge. The freshwater upstream HBMP study areas characteristically only experiences estuarine salinities during periods of extreme drought, while near the river's mouth only surface salinities decline to near freshwater conditions during periods of high river flow. In between these two extremes, the braided reaches of the lower Peace River (see **Figure 2.1**) are tidally and seasonally characterized by distinctive salinity gradients.

2. The second objective has been to assess both seasonal and long-term patterns of variables associated with the heath of the Lower Peace River/Upper Charlotte Harbor estuarine system. The water quality and biological elements of the HBMP provide mechanisms to determine the potential influences of the indirect effects of freshwater withdrawals.

The permit also specifies reporting requirements with respect to data collected under the HBMP including annual data reports, as well as mid-term (Year Three) and final (Year

Five) interpretive reports. This report constitutes the first required *Year Three Report*, and fulfills the minimum scope of work specified in the permit for the mid-term interpretive report; including a description of monitoring progress and observed changes in streamflow, salinity and other selected variables. In addition, this report addresses other issues, as suggested by the Scientific Review Panel, related to the efficacy of the current HBMP design in meeting the stated program objectives. As such, recommendations are made regarding the potential deletion of certain variables from the current HBMP design, as well as the evaluation of other variables for continuation and/or modification.

The major findings and conclusions presented in the Year Three Report are summarized below.

7.1 Conceptual Model

1. Estuaries are ecosystems that are, to a large degree, dominated by physical and chemical processes. Furthermore, river discharge, or fresh water flow, is one of the most important variables determining the spatial limits of, and the physical and chemical interactions within, an estuary. Therefore, the volume and timing of fresh water discharges from rivers is often the most critical factor driving the biological functions of estuaries.

2. Energy flow through estuarine ecosystems is extremely complex involving numerous physical, chemical and biological processes and interactions. The estuarine food web is made up of both grazing and detritus food chain components.

3. Largely in response to widely variable water chemistry, including substantial fluctuations in salinity and dissolved oxygen concentrations, organisms that live in estuaries have evolved to tolerate the associated physiological stress. Consequently, most estuarine plants and animals can persist and flourish within a broad range of salinity. However, despite their tolerance for wide fluctuations in salinity, the distribution and abundance of estuarine plants and animals still tend to segregate across a salinity gradient, indicating that most species have optimal salinity ranges with respect to environmental physiology and ecological competition.

4. The conceptual model illustrates that variations in river discharge, whether from fresh water withdrawals or natural climatic variability, can affect the structure and function of the estuary in the following ways:

    - Salinity alone is a major determining factor controlling the distribution, abundance and species composition of all biotic communities in the estuary. The primary mode of action on plants and animals is ionic and osmoregulatory adaptations to particular salinity regimes.

    - The interactions between the physical, chemical and biological processes and the biological components of the estuarine ecosystem are exceedingly complex. Most of the effects of changes in fresh water flow on trophic energy flow in the estuary are mediated and modulated by numerous steps and feedback loops.

- Changes in fresh water flows generally result in a horizontal shift in the location of the estuarine mixing zone along the river axis. Greater fresh water flows cause a downstream shift, whereas lesser flows cause and an upstream shift.

- The physical, chemical and biological processes, and trophic energy flows, that take place in the estuarine mixing zone (e.g., adsorption, flocculation, assimilation, and regeneration) are translocated upstream or downstream corresponding to changes in the horizontal location and areal extent of the mixing zone.

- The distribution of the planktonic (drifting) and nektonic (swimming) communities, including phytoplankton, zooplankton, and fishes, and the trophic interactions between these communities, are translocated upstream or downstream primarily in response to changes in salinity over short time scales (e.g., hours, days).

- The distribution of the benthic (bottom) communities - including rooted macrophytes, sediment microbes, and benthic invertebrates - and the trophic interactions between these communities, are translocated upstream or downstream primarily in response to changes in salinity over long time scales (e.g., months, years, decades).

- If the magnitude and duration of variations in river discharge are large enough, spatial discontinuities can be created between the stationary and non-stationary variables of the estuarine ecosystem. For example, if fresh water flows were to be reduced such that there was a substantial upstream shift in the long-term average position of the bottom isohalines, a discontinuity would exist between the stationary biological resources, such as rooted macrophytes and benthic invertebrates, and the overlying water column. That is, the stationary living resources would no longer be spatially distributed within the zone of their "preferred" salinity range, potentially leading to extirpations and shifts in species composition.

- Strong gravitational circulation patterns can develop in shallow partially-mixed estuaries under high flow and low turbulence conditions, especially during summer months when water temperatures are highest. Persistent water column stratification often leads to hypoxia, and even anoxia, which can significantly alter the distribution and abundance of planktonic, nektonic and benthic plants and animals. Periodic hypoxia/anoxia has been well documented in the Peace River estuary during periods of high flow.

5. In defining the variables that have the highest probability of detecting hydrobiological change specifically in response to changes in fresh water flow, it is apparent that

those variables that are most directly linked to flow variations, with the fewest number of mediating steps and feedback loops, will be most efficacious. For this purpose, salinity is perhaps the most useful variable in that it is conservative, and its distribution directly affects other critical physical and chemical processes, as well as the spatial distribution of biological communities. Other useful variables include those that are directly affected by changes in freshwater flow (e.g., nitrogen concentrations, color), as well as those that are closely associated with the directly affected variables (e.g., chlorophyll *a* as measure of nutrient assimilation).

6. Variables that are related to, but not directly or solely driven by, fresh water flows provide little insight into potential hydrobiological impacts of withdrawals. For example, while variations in fresh water flows do affect the delivery of total organic carbon, it is unlikely that these sources of carbon are ever limiting with respect to the detritus food chain in the Peace River Estuary where autochthonous sources may be more important. In addition, any potential impacts associated with changes in riverine organic carbon inputs to the estuary would likely be expressed in some change in biological productivity which would be mediated by a vast number steps and processes, and confounded by numerous other interacting factors. Consequently, the interpretation of data for variables that are far removed from the direct effects of withdrawals is often speculative at best.

7.2 Status and Trends

1. Rainfall/Flows

- Largely as a result of the unusually heavy rains of 1995 and the 1997/1998 El Niño event, both rainfall and river flow significantly increased in the Peace River watershed over the fifteen year period (1984-1998), during which the isohaline based monitoring element of the HBMP has been conducted.

2. Salinity

- Salinity concentrations generally increase from the Peace River Facility, where the river is almost always fresh, downstream towards the mouth of the river. The upstream movement of higher salinity waters has been observed both seasonally and during extended dry periods, such as occurred during the mid 1980s.

- In addition to this horizontal gradient, the water column in the lower Peace River and upper Charlotte Harbor often becomes stratified when more saline waters are overlain by fresher water at the surface.

- The largest seasonal variations in salinity occur in the surface waters near the mouth of the river; however, the greatest relative percent changes take place upstream along the bottom.

- Even with the effects of the 1997/1998 El Niño, the median spatial distribution of salinity along the Lower Peace River during the most recent three year period (1996-1998) was not substantially different than the longer-term average.

- Trend analyses at the fixed stations for the long-term period 1976-1989 (the last few years of which included a series of very dry years) were only able to identify a significant increase in salinity at the most upstream location.

- By comparison, trend analyses (1984-1998) of the monthly locations of the four isohalines show significant downstream movements, indicating the influence of the unusually wet series of years during the 1990s.

3. Dissolved Oxygen

- On average dissolved oxygen concentration along the Lower Peace River between the Peace River Facility and the mouth of the river are above the State Class III standard of 5.0 mg/l.

- Surface dissolved oxygen concentrations tend to increase from the Peace River Facility downstream towards the mouth of the river.

- The occurrence of hypoxic bottom waters downstream of the US 41 Bridge is not uncommon, with many observations indicating near anoxic conditions. However, hypoxic bottom waters have not been observed upstream of river kilometer 10.8 (I-75 Bridge).

- Long-term trend analyses (1976-1998) indicate widespread significant declines in dissolved oxygen concentrations along the Lower Peace River. This trend is caused primarily by a marked decline in the very high dissolved oxygen concentrations associated with extensive blue-green algae blooms that have also declined in the river since the latter part of the 1970s and early 1980s.

4. Water Quality

- Except for slightly elevated levels of phosphorus and color, many of the water quality characteristics of the Lower Peace River are similar to those of other Southwest Florida rivers despite the fact that the watershed area of the Peace River is substantially larger than that of most comparable rivers. The higher phosphorus concentrations are due to both naturally high phosphate deposits in local soils and historically to the extensive phosphate mining that occurs in the basin. The higher color concentrations are due to the large area of riparian forested wetlands in the basin.

- Except for salinity and dissolved oxygen, the current HBMP design does not allow for the analysis of temporal trends at fixed points in the river. The analysis of temporal trends from the moving station data is complicated by the fact that the isohalines are typically spatially biased towards the lower part of the river.

- For the majority of the water quality variables analyzed, strong seasonal trends and spatial gradients are evident, with nitrogen being the most notable. Other variables, such as turbidity show little or no temporal trends or spatial gradients.

- Recent water quality characteristics of the Lower Peace River indicate only small differences when compared to the longer-term averages (1976-1998), with the most notable exception being a long-term reduction in phosphorus for the period 1984-1998. This reduction probably reflects the results of the regulatory requirements that have resulted in significant reductions in both point and non-point discharges associated with phosphate mining in the upper Peace River watershed.

- The data suggest that the unusually heavy rains of 1995, and the 1997/1998 El Niño event, have resulted in statistically significant increases in color and declines in turbidity at a majority of the isohalines.

5. Phytoplankton

- As of result of salinity differences, there are distinct spatial gradients in the major taxonomic distributions of phytoplankton taxa within the Lower Peace River/Upper Charlotte Harbor Estuarine System.

- Different taxonomic groups are seasonally important within each of the four isohalines studied.

- Trend analyses suggest that the high freshwater inflows during 1995 and the 1997/1998 EL Niño resulted in: 1) an unexpected increase in green algae at higher salinities; and 2) significant declines in the numbers and kinds of flagellates.

6. Vegetation

- District GIS vegetation data analyzed in conjunction with the morphometric analyses indicates fairly distinctive spatial breaks among several of the major vegetative associations along the Lower Peace River.

- Long-term comparisons of first and last occurrences of selected indicator plant species along the Lower Peace River indicate that the distribution of most species has varied very little whereas the distribution of some species has fluctuated upstream and downstream over time.

- Graphical analyses demonstrate the difficulty of determining meaningful relationships between freshwater inflow and the long-term distributions of key indicator vegetation taxa.

7.3 Evaluation of Potential Impacts of Facility Withdrawals

1. Rainfall

- A number of studies have documented long-term declines in rainfall in the upper Peace River watershed since the 1930s. However, over both the shorter recent historic period (1966-1998) and the duration of the HBMP (1976-1998) there have not been any consistent increasing or decreasing rainfall patterns in the Peace River watershed.

2. Flows

- During the period of approximately the last thirty years, freshwater flows in all of the gaged major lower Peace River tributaries have been either stable or increasing.

- The Peace River (Arcadia) is typically the major source of freshwater to the lower river, averaging over 60% of total flow. Shell Creek is the next largest source averaging more than 20% of total flow, while Horse and Joshua Creeks each usually contribute less than 10%. However, localized differences in rainfall within each of the four major sub-basin watersheds can result in dramatic daily, and even monthly differences in their relative contributions to the total fresh water inflow to the Lower Peace River estuary.

3. Flow to Rainfall Relationship

- Since 1966 there have not been any conspicuous changes in the general relationships between annual flow and annual rainfall in the Peace River basin or any of the three tributary sub-basins (Horse, Joshua and Shell Creeks), although some small differences have occurred during extended wet and dry periods. However, other analyses have indicated significant increases in flows in a number of these sub-basins during typically dry periods. These results strongly suggest that augmentation of normal dry-season flows is occurring within these watersheds associated with increasing agricultural development.

4. Withdrawals

- Peace River Facility withdrawals have steadily and progressively increased since their start in 1980. However, the magnitude of withdrawals has been extremely small when compared to the natural seasonal variability, and currently comprises less than 1% of total freshwater flow at the mouth of the river.

5. **Potential Impacts of Withdrawals on Salinity**

- Statistical models were developed with the objective of establishing a predictive relationship between flow and salinity in the Lower Peace River, and for discerning the incremental effect of past and future permitted withdrawals on the salinity structure of the estuary downstream of the Peace River Facility.

- Model results indicated that, on average, the influences of past withdrawals on the salinity structure of the Lower Peace River between the U.S. 41 Bridge and the Peace River Facility has historically resulted in maximum changes of less than 0.3 ppt. These model results also indicated that the largest changes resulting from past withdrawals have occurred between river kilometers 14 and 18 in the Lower Peace River.

- Statistical models were also used to predict what the potential magnitude of salinity changes might be under the maximum permitted daily withdrawals during Arcadia flows between 200 and 1,000 cfs. Model results predict that a maximum salinity change of < 0.5 ppt would occur between river kilometers 14 and 18 when Arcadia flows range between 400 and 1000 cfs. With Arcadia flows of 200 cfs, the results predict that similar changes in salinity (< 0.5 ppt) would occur further upstream.

- The models show generally that the response of salinity to changes in flow (e.g. incremental change in salinity vs. change in flow) is not linear. In general withdrawals result in incrementally greater changes in salinity during low flows, and incrementally lesser changes in salinity during high flows.

- The models also indicate that the effects of withdrawals on salinity tend to be greater upstream than downstream. However, when flows are above 130 cfs at Arcadia there is a portion of the river below the Peace River Facility that is always freshwater and therefore never experiences changes in salinities due to withdrawals. As flows and maximum withdrawals increase, potential changes in salinity are predicted to be shifted further downstream.

7.4 Assessment of HBMP Design

1. As part of the Year Three Report analysis, several physical, chemical, and biological parameters of the existing HBMP were evaluated with respect to their continued relevance to the objectives of the program. It is recommended that the following variables be discontinued from future HBMP studies: *turbidity; alkalinity, chlorides, ammonia/ammonium, total phosphorus; silica; inorganic carbon; dissolved organic carbon; total organic carbon; phytoplankton species counts; carbon uptake;* and *chlorophyll a size fractions*. It is also recommended that two other variables, *extinction coefficient* and *vegetation*, be further evaluated for continued inclusion in the HBMP design.

2. The monthly sampling frequency of the existing HBMP is apparently adequate to allow detection of temporal trends in the water quality of the Lower Peace River, given the significant with-in year variation in many of the water quality indicators. However, it is uncertain whether short-term variation, such as due to tidal stage, is potentially contributing bias to the current water quality data. The current temporal design does not incorporate any means of randomization that would provide greater assurance that such bias is not significant.

3. The current HBMP design includes three spatial sampling frames: 1) fixed, continuous sampling at two stations and two depths; 2) fixed, monthly sampling at seventeen stations, and 3) “moving station” monthly sampling at four isohalines.

4. Under the spatial sampling frames of the current HBMP design, there is clearly an unequal representation of the lower river. Specifically, the portion of the river between RK 15.3 and RK 21.1. This area includes the major portion of the river where the relationship between river flow, withdrawals, and salinity are most pronounced and is characterized by far fewer samples than the portion of the river above RK 21.1.

5. It is recommended that further examination of the existing sampling program be pursued in the Year Five Report to more definitively address the issues of the spatial and temporal adequacy of the existing HBMP design.

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