PEACE RIVER MANASOTA REGIONAL WATER SUPPLY AUTHORITY

PBS&J

April 2008
(Revised December 2009)

2006 HBMP Comprehensive Summary Report

2009 Revisions to Original April 2008 Submittal

The original version of the 2006 HBMP Comprehensive Summary Report was submitted to the Southwest Water Management District in April 2008 as a condition of the Peace River Manasota Regional Water Supply Authority's Peace River Facility's Water Use Permit. Subsequently, copies of this document were also provided to each member of the HBMP Scientific Review Panel for their review and comment. All written comments received are provided in **Appendix B**.

Overall the comments received from members of the HBMP Scientific Review Panel generally indicated that they found the historical background information presented in the report regarding a number of HBMP related topics useful.

- The history of Facility permits and expansions
- Previous and ongoing HBMP program elements
- Recent related studies and publications
- The status and trends in hydrological patterns and Facility withdrawals
- Patterns of long-term water quality changes in the lower Peace River and upper Charlotte Harbor
- The observed pattern of increasing dry-season conductivity from the freshwater sources upstream of the Facility

In addition, their comments were supportive of the analytical methods employed and conclusions drawn regarding both the relationships between freshwater inflows, Facility withdrawals, and the daily and seasonal salinity structure of the estuary downstream of the Facility's intake structure.

The panel members however also provided a number of pertinent and useful comments regarding both additional topics they believed should be addressed, as well as suggesting additional analyses that would provide further useful information relative to assessing future projected increases in Facility withdrawals.

Some of the panel's specific comments have been incorporated into the appropriate sections of the document's updated executive summary. However, for the most part the panel's specific suggestions regarding additional information and analyses will be addressed in subsequent HBMP documents, either analogous to the focused, recently completed "HBMP Pump Test Report", or in conjunction with future HBMP Summary Reports. Determinations of the specific methods to be used relative to addressing the panel member's general comments and suggestions will be a topic of discussion at the upcoming HBMP Scientific Review Panel meeting tentatively scheduled for early 2010.

The report made several recommendations regarding modifications to the HBMP and reports. The report's recommendation to install additional continuous conductivity recorders along the HBMP monitoring transect in the lower Peace River was actually initiated in mid-2008 in response to the Panel's suggestions and verbal support at its last meeting (December 2007). Based on the written comments received, implementation of the recommendation to add enhanced determinations of spatial and temporal chlorophyll responses to seasonal changes in freshwater inflows has been delayed until after further discussions at the next panel meeting. Finally, the Panel's comments strongly supported the recommendation that the HBMP continue to provide "Annual Data Reports" enhanced beyond that required under the permit conditions, as well as detailed "Comprehensive Summary Reports" at approximately five year intervals. The Panel also agreed that the current permit requirement for "Year Three Reports" might better be replaced by much shorter, more focused reports designed to address specific issues that might arise and/or explicit questions raised by the Panel at more regularly scheduled meetings.

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Report Summary

An extensive Hydrobiological Monitoring Program (HBMP) was initially established in 1975, five years prior to Peace River withdrawals and completion of the Peace River Facility, to assess the potential effects of freshwater withdrawals on the estuarine communities of the lower Peace River/upper Charlotte Harbor estuarine system. The findings and conclusions presented in this report support past and ongoing modeling efforts. These modeling efforts have indicated that the predicted influences of freshwater withdrawals under the Facility's existing withdrawal schedule typically impacts the daily average salinity along the lower river in the range of 0.1-0.3 ppt. To date, these efforts have suggested that any Facility salinity impacts probably could not easily be detected, other than by using continuous recorders, given the normal distributions and daily tidal ranges of salinity along the lower Peace River/upper Charlotte Harbor HBMP monitoring transect. Given the far greater natural daily and seasonal ranges of salinity variation in the lower Peace River/upper Charlotte Harbor estuary and the lack of information regarding the potential consequences of such small salinity changes on tidal estuarine processes, the ecological consequences of these small but predictable changes are exceptionally difficult to evaluate and predict. Thus, while withdrawals have resulted in predictable changes in salinity, the normal daily and seasonal variability in estuarine salinity distributions indicate that the changes due to Facility withdrawals do not appear to be of a magnitude likely to be easily measured directly. This suggests that evaluating and predicting the effects of withdrawals on the salinity distributions within the lower Peace River/upper Charlotte Harbor estuarine system may ultimately best be accomplished using hydrographic and statistical modeling approaches in assessing, comparing and quantifying the potential for significant adverse harm.

Chapter 1 – Introduction

This introductory chapter provides readers unfamiliar with the history of the Peace River Regional Water Supply Facility (Facility) and the Southwest Florida Water Management District's (District) permit criteria a brief overview of the Peace River Manasota Regional Water Supply Authority's (Authority) Water Use Permit (WUP) for the Facility and those conditions of the permit that have been associated with the thirty-one year history of the Hydrobiological Monitoring Program. The chapter reviews the history of the Facility, its series of water use permits (Table 1.1), and describes the major HBMP study elements that have been associated with specific conditions of these permits. The introduction also provides an overview of the report's general organization and the primary objectives of each of its major sections.

Table 1.1
Historic Summary of Facility Permits

Year	Dec 1975	March 1979	May 1982	Oct 1988	March 1996
Water Use Permit Number	27500016	27602923	202923	2010420	2010420.02
Average Permitted River Withdrawal (mgd)	5.0	5.0	8.2	10.7	32.7
Maximum Permitted River Withdrawal (mgd)	12 & 18	12 & 18	22	22	90
Diversion Schedule Low Flow Cut off (cfs)	91 – 664	91 – 664	100 – 664	100 & 130	130
Maximum Percent Withdrawal of River Flow	5	5	n/a	10	10

Overview of Water Use Permit

The permit contained specific conditions for the continuation and enhancement of the HBMP for the lower Peace River/upper Charlotte Harbor Estuary. The HBMP study elements specified in the 1996 permit were designed to build upon and add to the background and HBMP monitoring activities that have been ongoing since 1975 and predate the 1980 Facility completion and initiation of consumptive river withdrawals. The initial background and HBMP monitoring conducted prior to Facility operations provided a basis for pre-withdrawal conditions against which later comparisons were made.

Overall, the primary goal of the prescribed HBMP study elements has been 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, are being, or may be adversely impacted by permitted freshwater withdrawals by the Authority's water treatment facility. The expanding base of ecological information regarding the lower Peace River and upper Charlotte Harbor resulting from the ongoing HBMP has further been used to periodically evaluate the effectiveness of the withdrawal schedule with regard to its preventing significant adverse estuarine impacts.

Although the Peace River Facility has only been operated by the Authority since 1991, the initial system was constructed by General Development Utilities and has been withdrawing water from the Peace River since 1980. The Facility's initial storage capacity was 625 million gallons in the form of an 85 acre off-stream, surface reservoir. Additional storage capacity was added in 1985 with the development of a series of Aquifer Storage Recovery (ASR) wells. These initial ASR wells added a further 1,080 million gallons of storage capacity by 1988. An additional expansion of ASR wells in 1989 further increased the Facility's total combined storage capacity to 2,785 million gallons. The storage capacity was again increased in 1995 by further expansion of ASR wells, providing a total combined storage capacity of approximately 3,865 million gallons. The storage capacity was again expanded in 2002 by the further addition of 12 new wells providing a total storage capacity of approximately 7,500 million gallons.

The Facility presently has the capacity to treat up to 24 mgd (37.1 cfs). The Facility's existing raw water river diversion station is comprised of four pumps having a combined maximum capacity of 44 mgd (68.0 cfs). In comparison, the long-term average annual daily total gaged river freshwater flow upstream of the Peace River Facility since 1976 has been approximately 796 mgd (1233 cfs). During periods of high river flow, raw river water is stored in the off-stream surface reservoir and any excess treated water is stored in the system's ASR wells. Conversely, when water is unavailable from the Peace River due to the established low flow cutoff of 130 cfs, water can be pumped from the raw off-stream surface water reservoir to the Peace River Facility for treatment, and/or previously treated water can also be recovered from the ASR well system to meet the water supply demands of the Authority's service area.

In order to meet growing regional water demand, the Authority has started another expansion of the Facility. This expansion includes an increase to the river pumping capacity to 90 mgd, which is currently the upper limit of the 1996 permit. This expansion will also double the Facility's treatment capacity to 48 mgd. A larger new regional 640 acre off-stream reservoir with a capacity of 6 billion gallons is also under construction, and the existing transmission piping networks will also be gradually expanded to optimize regional water delivery. Completion of the ongoing physical expansion of the Facility's capacity and the new reservoir are scheduled for 2009.

HBMP Monitoring Program

An extensive HBMP was initially established in 1975, five years prior to completion of construction and actual Peace River Facility withdrawals, to assess the potential for harmful effects of freshwater withdrawals on the estuarine communities of the lower Peace River/upper Charlotte Harbor estuarine system. A number of statistical modeling efforts have been undertaken in conjunction with continuing efforts to refine the HBMP's ability to quantitatively predict the magnitude of potential Facility withdrawal impacts on both the lower river's salinity structure and movement of the freshwater/saltwater interface. A series of statistical models were developed in the late 1980s, 1990s and as part of *2002 Peace River HBMP Comprehensive Summary Report.* These models tested the relationships of lower river salinities and isohaline locations to both Peace River flows and Facility withdrawal using HBMP data from the series of long-term "fixed" monitoring sites along the lower Peace River. The District has also funded additional updated statistical salinity/flow withdrawal models developed at these fixed sampling sites along the original HBMP monitoring transect. The conclusions reached by these different modeling efforts have similarly suggested that the predicted influences of Facility freshwater withdrawals on salinity along the lower river are typically in the range of 0.1 - 0.5 ppt. To date, these efforts have suggested that any Facility salinity impacts could not easily be detected given the normal distributions or daily tidal ranges of salinity along the lower Peace River/upper Charlotte Harbor HBMP monitoring transect, and that the Facility has not significantly affected the seasonal or annual salinity structure of the estuarine reach of the lower Peace River. Thus, the detected and predicted changes in salinity and/or spatial locations of isohalines resulting from Facility freshwater withdrawals have not been found to date to be associated with pronounced or systematic changes in the salinity structure, water quality, or biological integrity of the affected estuarine communities of the lower Peace River/upper Charlotte Harbor estuarine system.

The HBMP has incorporated a wide variety of study elements since its initial inception. The HBMP was not conceived to be 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.

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 because, 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) 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 structure and production 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 estuary" and the influences of naturally occurring extended periods of drought and flood conditions. Two of the most recent short-term HBMP program elements, the benthic invertebrate studies and the fish nursery investigation, were also not designed to directly measure the influences of withdrawals, but rather were designed to investigate the response of biological communities to natural variations in freshwater inflows.

Based on the results of the 1993 and 1995 Summary HBMP Reports and additional analyses requested by District staff during the permit renewal process, an expanded HBMP was approved by the District in March 1996 as part of the current Water Use Permit for implementation in 1996 and subsequent years. An explicit element of the updated HBMP was the development of standardized station descriptors to be applied across all program elements. As part of a required morphometric study, the "mouth" of the Peace River was defined using U. S. Geological Survey (USGS) standardized protocols as an imaginary line extending from Punta Gorda Point to Hog Island.

Modifications have been made to the HBMP throughout its history, and study elements have been added and deleted in order to enhance the overall knowledge base of the lower Peace River/upper Charlotte Harbor estuarine system. Historically, those major monitoring elements aimed at assessing direct relationships with variations in freshwater inflow have had the longest histories (vegetation and water quality). Other program elements, primarily those focused on assessing indirect biological indicators, have extended over a number of years and then ended once a sufficient baseline level of information had been accumulated.

2006 HBMP Comprehensive Summary Report

This *2006 HBMP Comprehensive Summary Report* follows and extends the summarization and interpretation of long-term HBMP data submitted in both the *2002 HBMP Comprehensive Summary Report* and the *2004 Midterm Interpretive Report*. Its primary goals and objectives are to provide the District with sufficient analyses to:

- Evaluate key relationships between ecological characteristics and freshwater inflows, and determine whether the biological health and productivity of the estuary are showing signs of stress related to natural periods of low freshwater inflow or potential negative influences of Facility withdrawals.

- Assess the presence or absence of long-term trends for important HBMP variables.
- Assess the presence or absence of adverse ecological impacts and determine the influence Facility withdrawals may have contributed to such impacts.
- Evaluate the potential environmental impacts that may be associated with additional future increased withdrawals from the river and the feasibility of increased water supplies.
- Assess and evaluate the effectiveness of the withdrawal schedule for preventing adverse environmental impacts.
- Evaluate the overall HBMP design and make recommendations regarding implementing modifications.

Chapter 2 – Summaries of Recent Relevant Reports

The *HBMP 2002 Comprehensive Summary Report* (September 2004) provided brief overviews of major studies related to the lower Peace River/upper Charlotte Harbor estuary system completed between 1996 and 2002. This chapter continues these reviews by providing overviews of the following major reports and studies.

- *Upper Peace River: An Analysis of Minimum Flows and Levels* (SWFWMD, 2002)
- A Review of "Upper Peace River: An Analysis of Minimum Flows and Levels" (Gore *et al.* 2002)
- *Effects of Phosphate Mining and Other Land Uses on Peace River Flows* (Ardaman & Associates 2002)
- *Cumulative Risk of Decreasing Stream Flows in the Peace River Watershed* (SDI Environmental Services, Inc. 2003)
- *Predicted Change in Hydrologic Conditions along the Upper Peace River due to a Reduction in Ground-Water Withdrawals* (Basso 2003)
- *Long-term Variation in Rainfall and its Effect on Peace River Flow in West-Central Florida* (SWFWMD July 2003)
- *Water Quality Data Analysis and Report for the Charlotte Harbor National Estuary Program* (Janicki Environmental, Inc. 2003)
- *An Evaluation of Stream Flow Loss during Low Flow Conditions in the Upper Peace River* (draft, Basso, 2004)
- *Development of Hydrologic Model to Assess Phosphate Mining on the Ona Fort Green Extension* (SDI Environmental Services, Inc. 2004)

- *2003 HBMP Annual Data Report* (PBS&J August 2004)
- *Florida River Flow Patterns and the Atlantic Multidecadal Oscillation* (draft, SWFWMD 2004)
- *Shell Creek and Prairie Creek Watersheds Management Plan – Reasonable Assurance Documentation* (Shell, Prairie, and Joshua Creeks Watershed Management Plan Stakeholders Group 2004)
- *Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia* (Kelly et al. 2005)
- *2004 HBMP Annual Data Report* (PBS&J May 2005)
- Impact of Phosphate Mining on Streamflow (Schreuder et al. 2006)
- *2005 HBMP Annual Data Report* (PBS&J August 2006)
- *Assessment of Potential Shell Creek Impacts Resulting from Changes in City of Punta Gorda Facility Withdrawals* (PBSJ August 2006)
- *Peace River Cumulative Impact Study* (PBSJ 2007)
- *2006 HBMP Annual Data Report* (PBS&J 2007)

Chapter 3 – Status and Trends in Regional Rainfall, Flows and Facility Withdrawals

This chapter updates information presented in previous summary HBMP reports and provides analyses of data collected through 2006 regarding both the status and trends of key hydrological elements associated with the Peace River Hydrobiological Monitoring Program (HBMP). Analyses and discussions are presented in relation to the current status and historic trends in the following specific hydrologically related HBMP study elements.

- Status and trends in watershed rainfall patterns.
- Status and trends in gaged watershed freshwater inflows.
- Status and trends in rainfall/flow interactions.
- History, status and trends in withdrawals.

The presented analyses and summary graphics provide overviews of the current hydrological status within the Peace River watershed and lower Peace River/upper Charlotte Harbor estuarine system, and illustrate comparisons with historic longer-term patterns and characteristics. Also described are the important hydrological influences of more infrequent episodic occurrences such as extended periods of extreme drought, the periodic occurrences of unusually wet winter/spring El Niño climatic events, and differences in summer wet-season rainfall/flows due to variations in the frequency of tropical cyclonic patterns.

Hydrologic Setting

The Peace River watershed (Figure 3.1) covers approximately 1.4 million acres (2,188 square miles), with most of the watershed located in Polk, Hardee, DeSoto and northern Charlotte counties, although smaller portions extend into Highlands, Manatee and Sarasota counties. The main channel of the Peace River begins northeast of Bartow, in Polk County, at the confluence of Peace Creek Drainage Canal and Saddle Creek, and extends approximately 105 miles south to Charlotte Harbor. Previous studies have divided the watershed into eight major drainage basins based on the locations of USGS long-term flow gaging stations and included an additional ungaged coastal lower Peace River basin downstream of Arcadia to the tidal river mouth.

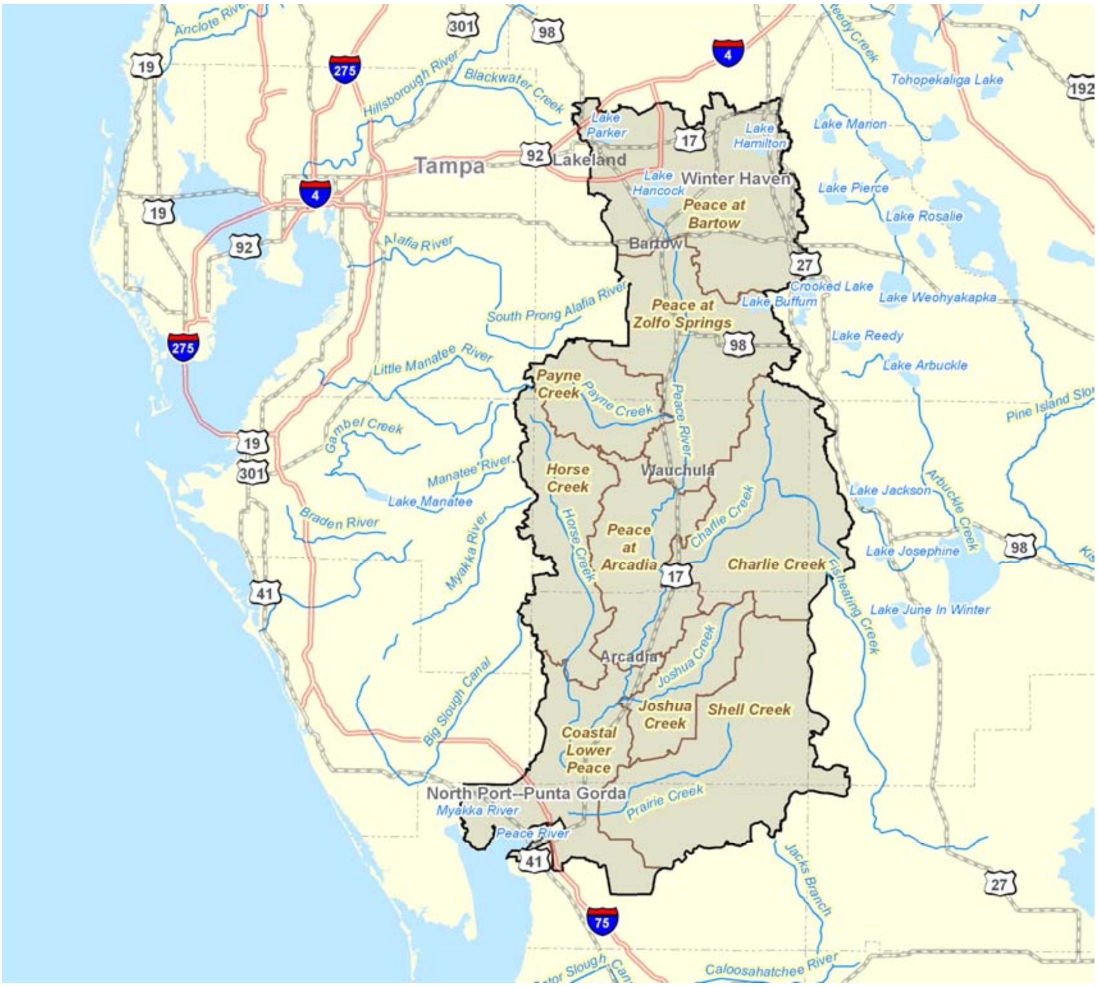


Figure 3.1 Location of the Peace River Watershed in Southwest Florida

Kissengen Spring near Bartow was a significant source of historic base flow to the upper Peace River with average annual estimated flows prior to the mid-1930s of approximately 30 cubic feet per second (cfs). Cessation of flow from the spring circa 1950 has been attributed to the decline in the potentiometric surface of the confined aquifers (Intermediate Artesian and Upper Floridan aquifers) caused by the excessive development of the ground water resource, primarily associated with the early expansion of phosphate mining in the upper watershed. The potentiometric surface of the confined aquifers, previously observed above the riverbed, have generally been tens of feet below the riverbed since the early-1960s (Figure 3.2).

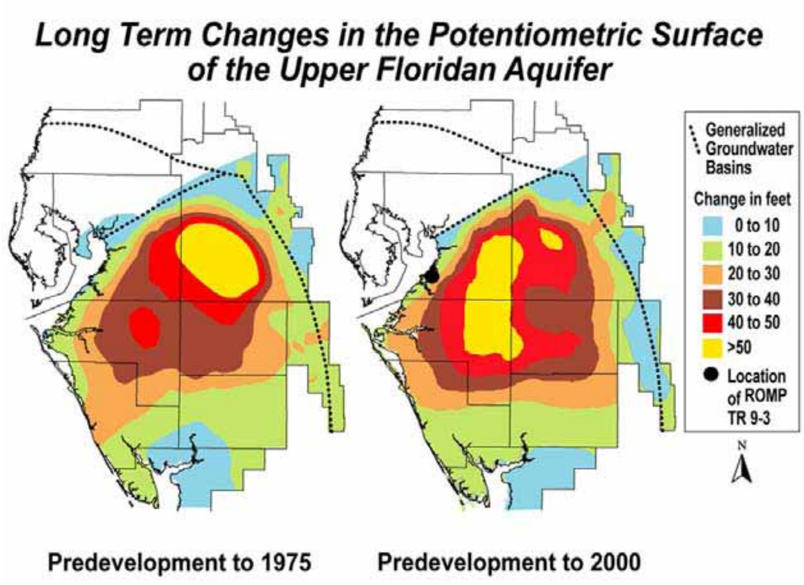


Figure 3.2 Estimated changes in the potentiometric surface of the Upper Floridan Aquifer (SWFWMD, based on USGS data)

Hydrologic Alterations

This historic loss of flows from springs and seeps has been one of the factors that has affected base flow to the upper portion of the river. However, base flow in the upper Peace River has also been affected by changes in discharges and drainage alterations associated with urbanization, phosphate mining, and agriculture. Phosphate mining and domestic waste discharges to the river have gradually declined since the mid-1980s. Historically these anthropogenic discharges augmented dry-season base flow and until recently obscured much of the historic declines and cessation of spring flows in the upper watershed. Other hydrologic alterations in some mined and reclaimed areas in the upper regions of the watershed have included diversions of surface waters that historically flowed to the river to storage for mining activities and/or seasonal impoundments resulting from disconnected surface depressions. Surface flows in some mined areas may also have been altered subsequent to mining due to increased recharge, as rainwater readily infiltrates the resulting disturbed soil structure, and recharge to the intermediate aquifer increases following loss of the upper confining layers associated with extraction of the phosphate matrix.

The Peace River watershed basins south of phosphate mining influences have also experienced historic increasing ground water demands and extensive hydrologic alterations. These changes are reflected in the cumulative loss of wetland and native upland habitats, and increasing dry-season augmentation of base flow in many tributaries as agriculture in these southern basins has progressively changed from predominantly unimproved pasture to improved pasture and subsequently to increasing areas of more intense farming. Agricultural runoff has contributed to increased base flow in the Joshua Creek, Horse Creek and Prairie/Shell Creek basins.

The Peace River watershed predominantly lays within the National Weather Service (NWS) Florida South-Central Region Four, which is characterized by a summer wet-season that accounts for approximately 60 percent of total average annual precipitation of 52 inches (1915-2006). During this summer wet-season, rainfall patterns are influenced by both frequent localized convective thunderstorm activity and periodic, widespread heavy rains associated with more infrequent tropical cyclonic events. In contrast, the remainder of the year is characterized by rainfall patterns predominantly associated with frontal systems moving down and across the Florida peninsula from the northwest.

The four month wet-season extends from June through September, with June on average having the highest annual average rainfall of 8.2 inches (Figure 3.3). Conversely, November through January typically comprise the three driest months of the year, with rainfall in November only averaging 1.8 inches. October characterizes the transition from the convection based summer wet-season rainfall pattern to the frontal dry-season rainfall pattern.

Seasonal influences of rainfall on watershed hydrology and surface flows are therefore directly linked to the preceding hydrologic conditions. At the beginning of the summer wet-season, a large proportion of rainfall is incorporated into filling surface and ground water storage. Conversely, later toward the end of the summer wet-season, soil moisture content is high, ground water levels are near the surface, wetlands and lakes are full, and a large proportion of rainfall contributes directly to runoff. Under such conditions, relatively small increases in rainfall can result in substantial increases in surface flows.

While the described seasonal patterns in the annual hydrologic conditions are typical, there are wide degrees of both seasonal and annual variability in both rainfall and resulting river flow patterns. Deviations from the normal pattern can span periods of months up to several years. Intense El Niño/Southern Oscillation (ENSO) events, such as occurred in 1982/1983 and 1997/1998, result in atypical extended periods of heavy rainfall during the usually drier winter/spring months and dramatically alter the annual watershed hydroperiod. In both instances, these unusually wet El Niño periods were subsequently followed by La Niña events and associated periods of extended drought. While short-term extremes of high and low flows influence the water budget in a watershed over periods of years, superimposed over these may be larger cyclic periods that can cover a number of decades.

Climate researchers have suggested that natural climate cycles or phases can persist over multiple decades. One of these cycles, the Atlantic Multidecadal Oscillation (AMO) refers to long-term cool and warm phase differences of only about 1°F (0.6°C) in North Atlantic average sea surface temperatures. An analysis of Atlantic sea surface temperatures suggests that warm AMO phases occurred during 1869-1893, 1926-1969, and from 1995 to date, while cooler phases occurred predominantly during the 1894-1925 and 1970-1994 time periods. It has been suggested that slight increases in average sea surface temperature in the Atlantic and Caribbean seas during warmer AMO periods produce more summer rainfall across southern Florida, while cooler AMO phases result in decreased summer rainfall.

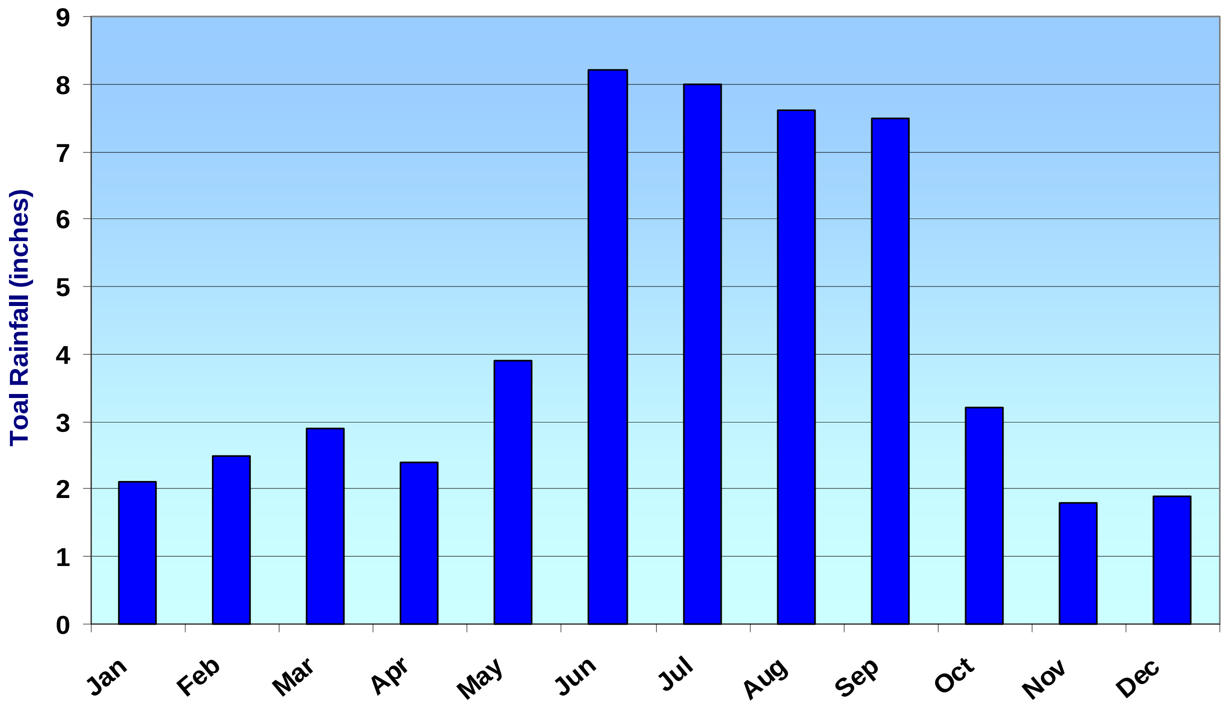


Figure 3.3 Average Monthly Peace River Basin Rainfall (1915-2006)

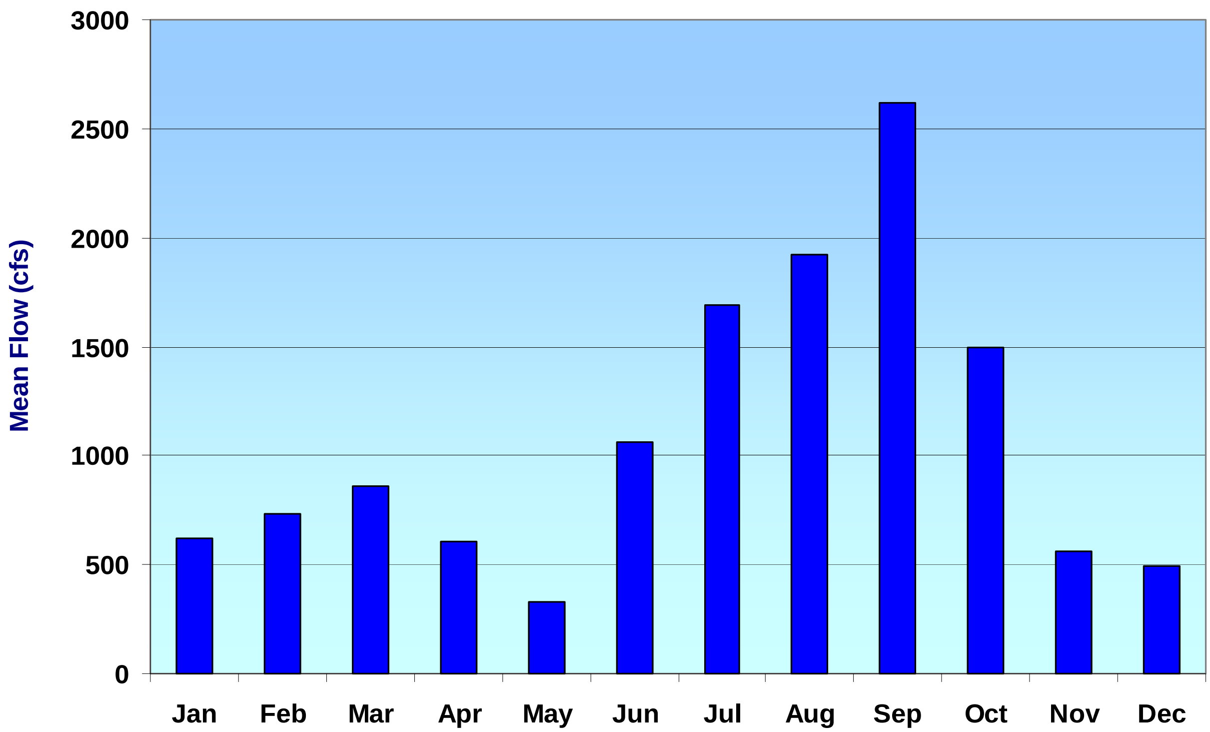


Figure 3.4 Mean monthly flow at the Peace River at Arcadia USGS gage (1932-2006)

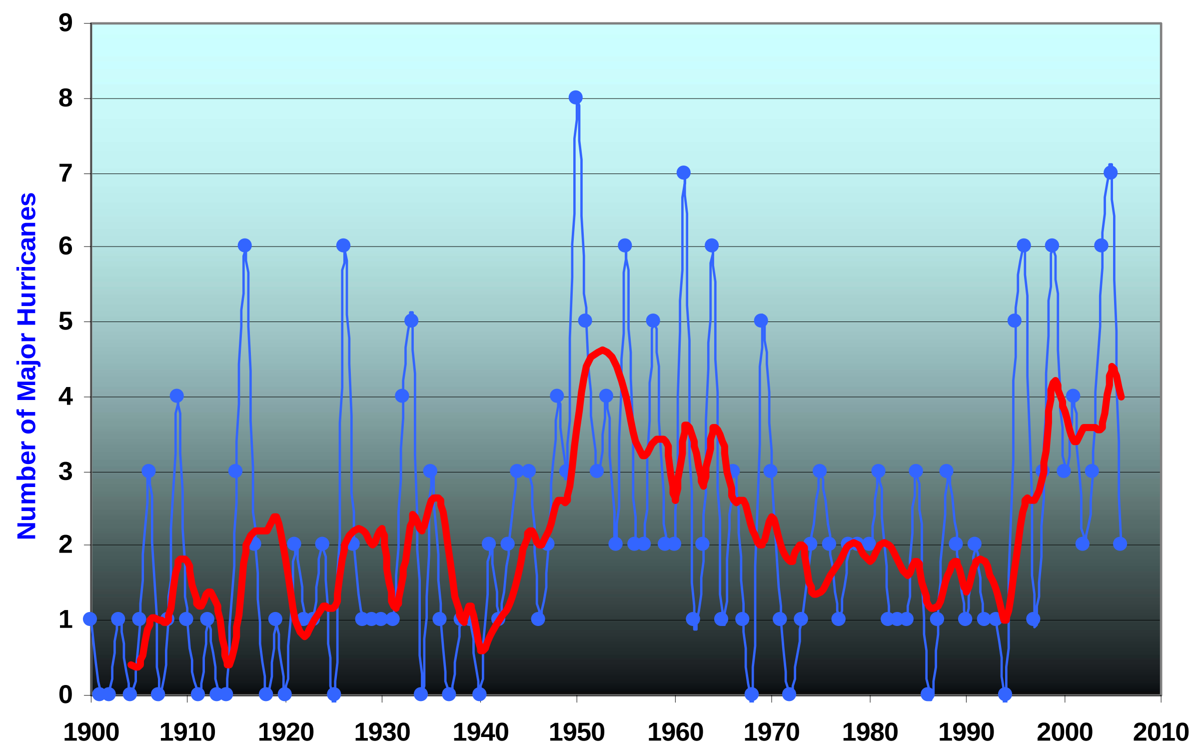


Figure 3.5 Major Atlantic Hurricanes 1900-2006

During the warmer AMO phase (1930-1969), 33 tropical storm events affected the Peace River basin, while during the subsequent cooler 1970-1994 AMO period, only 10 tropical systems impacted the watershed. Figure 3.5 shows the number of major (category 2 or above) Atlantic Hurricanes since 1900, while the red line represents a smoothed moving average. Since 1995, when the AMO shifted from the preceding approximately 26-year cooler period (1969-1994) to a warmer phase, the frequency of major hurricanes has again increased. Based on the typical duration of alternating AMO phases, the current warm phase may persist from 10-30 more years. To date, models capable of predicting the AMO shifts from one phase to another are unavailable. However, the occurrences of 1999-2001 and recent (starting in 2006) droughts emphasize the point that such warm/wet AMO phases only describe long-term average conditions, and that very dry intervals can (and do) occur during what might be a wetter than average longer time period, and that correspondingly very wet years have occurred during cooler/dry AMO phases.

Status and Trends in Watershed Rainfall Patterns

Historic period-of-record rainfall data for three representative long-term Peace River watershed basin rainfall gaging stations and a representative gage in the nearby Myakka River watershed were obtained as an initial step in evaluating the status and trends of hydrologic conditions in the Peace River watershed.

- Long-term total monthly rainfall patterns were similar among the selected rainfall gages.
- The variability in total monthly rainfall is sufficient to obscure changes and patterns when the long-term rainfall data are analyzed on a monthly basis.
- Results of the analyses suggest generally higher monthly rainfall at the more coastal Punta Gorda and Myakka State Park gages than at the two more interior Peace River watershed basin gages.
- When the long-term rainfall data for the Peace River watershed are analyzed as annual totals, the results clearly show both increased variations among the gages and greater indications of both historical wetter and drier intervals (Figure 3.14).

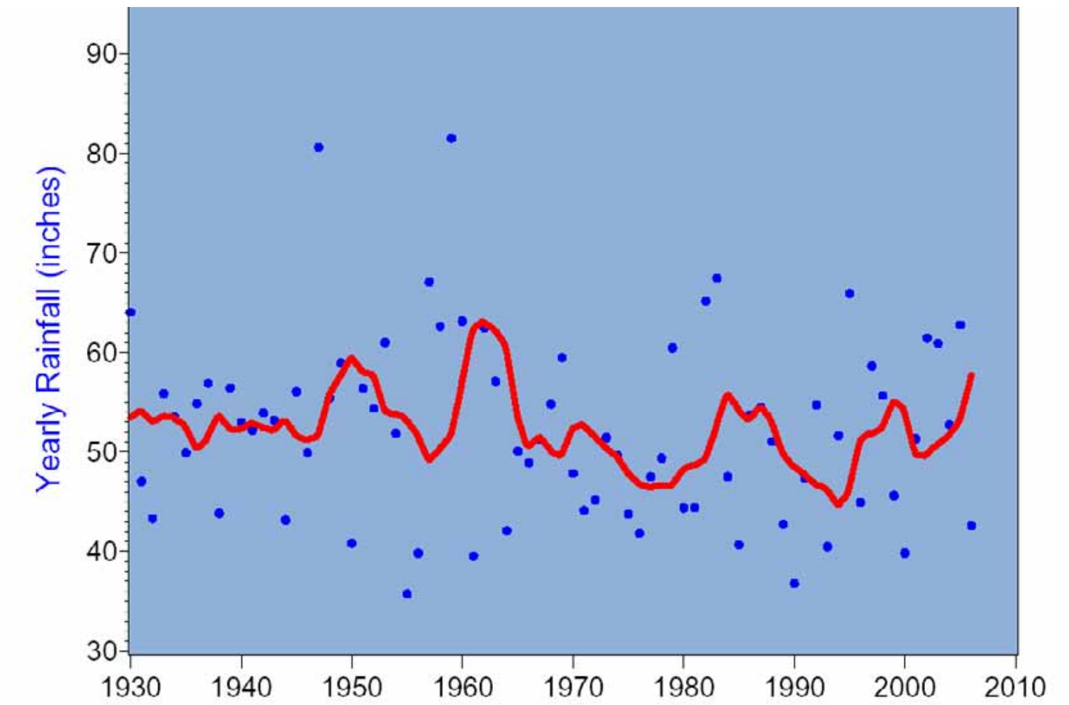


Figure 3.14 Yearly total and 5-year moving average rainfall for the average of the three Peace River watershed basin gages, 1932-2006

- Total annual average Peace River watershed rainfall levels at the Bartow and Arcadia gages were slightly higher prior to the 1960s when compared with the period from the late 1960s to the mid 1990s. The data indicate that between the mid 1990s and 2006 annual total rainfall levels at these two interior Peace River watershed locations increased.
- Annual average wet-season (June-September) rainfall in the Peace River watershed was generally higher during the 1930s through the mid-1960s when compared with the interval from the late 1960s through the early 1990s. Since approximately 1994 there has been a notable increase in wet-season rainfall.

- No similar long-term patterns were apparent with regard to dry-season (January-May and October-December) rainfall, although periodic high annual totals were observed corresponding to El Niño events.

- The plots of yearly annual deviations from the average rainfall further supported the conclusions that total annual rainfall during the 1940s and 1950s was above the long-term average of 52 inches per year, and generally below this average during much of the 1970s and 1980s.

- Similar analyses of annual deviations conducted after dividing yearly rainfall totals into wet-season (June through September) and dry-season (October through December and January through May) indicated slightly higher wet-season rainfall during the earlier time periods. In contrast, dry-season rainfall varied randomly around the long-term average over time.

Status and Trends in Gaged Watershed Freshwater Inflows

A number of recent studies have shown long-term patterns in the Peace River watershed flows corresponding with the previously discussed cyclical AMO rainfall phases (Figure 3.100). Other analyses however have also revealed distinctly different long-term patterns in base flows (lower monthly percentiles) in different regions of the Peace River watershed. Base flows in the upper portions of the watershed show marked declines that can be directly linked to ground water withdrawals and historic reductions in ground water levels and spring flows. In the southern Peace River watershed basins base flows in the Peace River tributaries have been distinctly augmented by agricultural discharges. A number of streams and creeks that were previously seasonally dry now often have some flow throughout the year due to anthropogenic discharges.

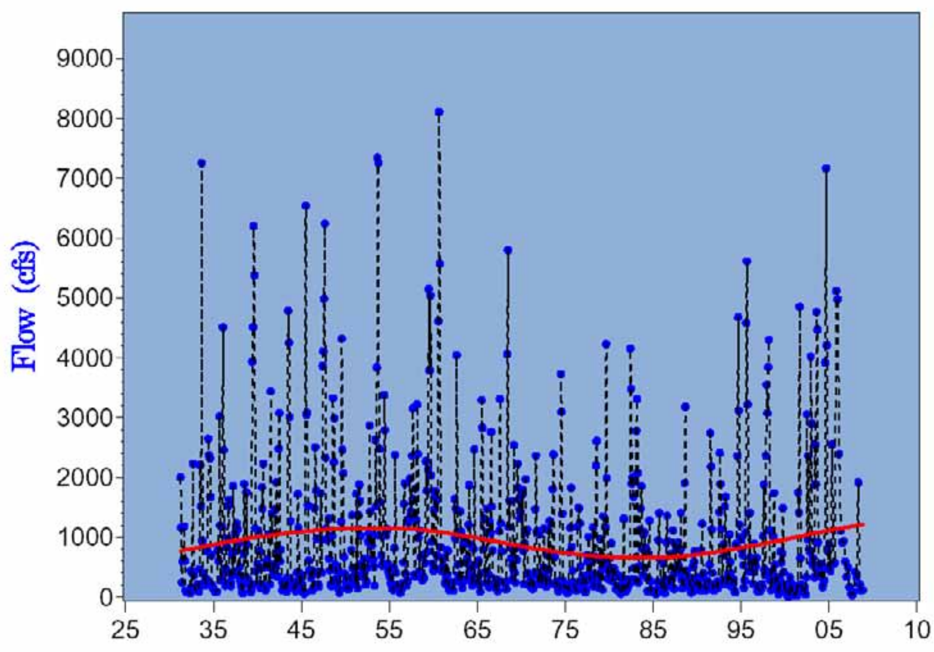


Figure 3.100 Monthly P50 (median) flow at long-term Peace River at Arcadia (2296750) gage (1931-2006)

Graphical and statistical analyses were conducted using a wide variety of monthly flow metrics for flows over the available period-of-records for each of the major long-term USGS gages in the Peace River Watershed.

- P0 Percentile – the minimum or lowest monthly value
- P10 Percentile – low flow value that was exceeded ninety percent of the time
- P25 Percentile – low flow value that was exceeded seventy-five percent of the time
- P50 Percentile – or median value, half of the monthly values were both greater and less
- P75 Percentile – high flow value that was exceeded only twenty-five percent of the time
- P90 Percentile – high flow value that was exceeded only ten percent of the time
- P100 Percentile – the maximum or highest monthly value
- Mean- this average monthly value is usually above the median when evaluating flow data

The following summarizes the findings of these analyses.

- The trend analyses indicate that there have been long-term statistically significant declines in flows in the upper reaches of the watershed at both Bartow (since 1940) and Zolfo Springs (since 1934).

- Peace River at Arcadia flows show statistically significant declines in a number of flow metrics over the 75-year period-of-record.

- In the southern tributaries of the Peace River watershed, by comparison, flows have increased over their periods-of-record (which are of shorter duration than the northern gages). Shell Creek flow data indicate statistically significant increases in the lowest flow percentiles (base flows), while there have been increasing trends in Prairie Creek at all percentiles between the monthly minimum and median values, and all percentiles of flow at the Joshua Creek gage have increased over time.

- Even with such agriculturally augmented dry-season flows in many of the southern watershed basins, combined total gaged flows upstream of the Facility still show statistically significant declines over the 1951 to 2006 interval for all monthly percentiles below the median flow.

- There were no statistically significant trends in flows at any of the USGS gages along the main stem of the Peace River during the period of HBMP monitoring between 1976 and 2006.

- All of the analyzed flow metrics (percentiles) at the Joshua Creek gaging location showed statistically significant increases over the 1976-2006 time interval. The results indicate the relative magnitude of agricultural development that has occurred in the Joshua Creek basin during this time interval.

- In comparison, the trend test results show that only median and those flows below have been augmented by agricultural development in the Horse Creek and Prairie Creek basins.

- The observed differences in trends may indicate that not only have all three of these southern Peace River watershed basins seen augmented dry-season stream flows due to agricultural ground water pumping, but that the degree of land use and drainage changes that have occurred in the Joshua Creek watershed have also resulted in structural changes that have fundamentally altered hydrologic surface flows in the basin.

Overview of Ground Water and Surface Withdrawals

The following provides an overview describing historic and recent patterns of consumptive water use in the Peace River watershed. The magnitude and seasonal timing of Peace River Facility withdrawals are further compared with the corresponding downstream City of Punta Gorda consumptive use that additionally influences Shell Creek flows to the lower river and upper Charlotte Harbor.

Historically, ground water has provided the vast majority of the municipal, industrial, and agricultural consumptive use throughout most of the Peace River watershed. From the 1940s through the 1970s, the dominant ground water use in the upper watershed was associated with phosphate mining. However, in the late 1970s, the phosphate industry implemented a series of practices to reduce ground water consumption, including a greater reliance on capturing and recycling surface waters from mining areas. By the late 1990s, agriculture accounted for approximately 40 percent of the annual ground water use in Polk County, while domestic and industrial uses each accounted for just less than 30 percent of use. In the southern Peace River watershed basins, the majority of ground water withdrawals have been and remain associated with agricultural uses.

Table 3.34 provides estimates of both historical and recent anthropogenic ground water uses within each of the primary Peace River watershed basins. Agricultural practices throughout the Peace River watershed primarily rely on upper Floridan aquifer groundwater, rather than on surface water or the less reliable surficial/intermediate aquifers. Consequently, the conversion of undeveloped and range lands to more intensive forms of agricultural use has resulted in increased irrigation and subsequent increases in annual dry-season base flows, especially in the southern watershed tributaries, such as Joshua Creek, Horse Creek and the Prairie/Shell Creek systems.

Table 3.34
Estimated Peace River Watershed Ground Water Use (mgd) by Basin and Selected Reference Periods

Peace River Watershed Basin	1941-1943	1976-1978	1989-1991	1997-1999
Peace River at Bartow	63	176	156	151
Peace River at Zolfo Springs	34	102	100	95
Payne Creek	7	24	24	24
Charlie Creek	11	49	57	62
Peace River at Arcadia	7	30	37	40
Horse Creek	6	27	34	37
Joshua Creek	9	27	33	36
Shell Creek	13	44	54	55
Lower Coastal	5	20	25	26

Figure 3.370 depicts recent available District information on the number, spatial distribution, relative amount, and use of permitted surface and ground water withdrawals throughout the Peace River watershed. This figure clearly shows the relative scale of consumptive uses throughout the watershed and the potential importance of agricultural discharges relative to augmentation of dry-season flows in each of the watershed tributaries.

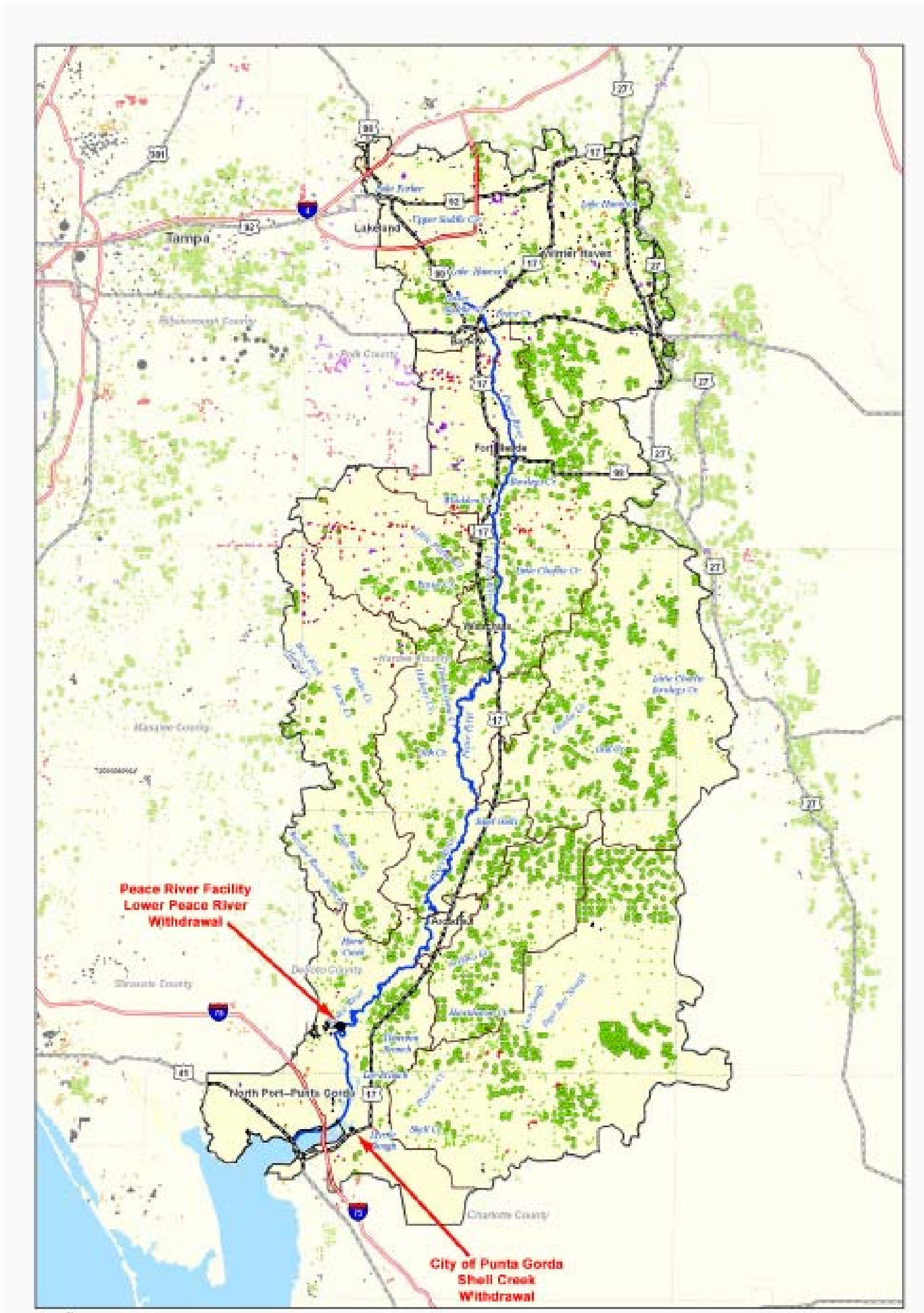


Figure 3.370 District water use permits in the Peace River watershed. Green dot are agricultural permits, red dots are mining permits and black dots are public water supply.

The two current major withdrawals of surface water for urban uses occur in southern DeSoto County, where the Authority withdraws water from the Peace River to provide potable supplies for the City of North Port, Charlotte, DeSoto, and Sarasota counties, and the City of Punta Gorda operates a smaller water treatment facility that withdraws surface water from behind the Hendrickson Dam on Shell Creek (3.378).

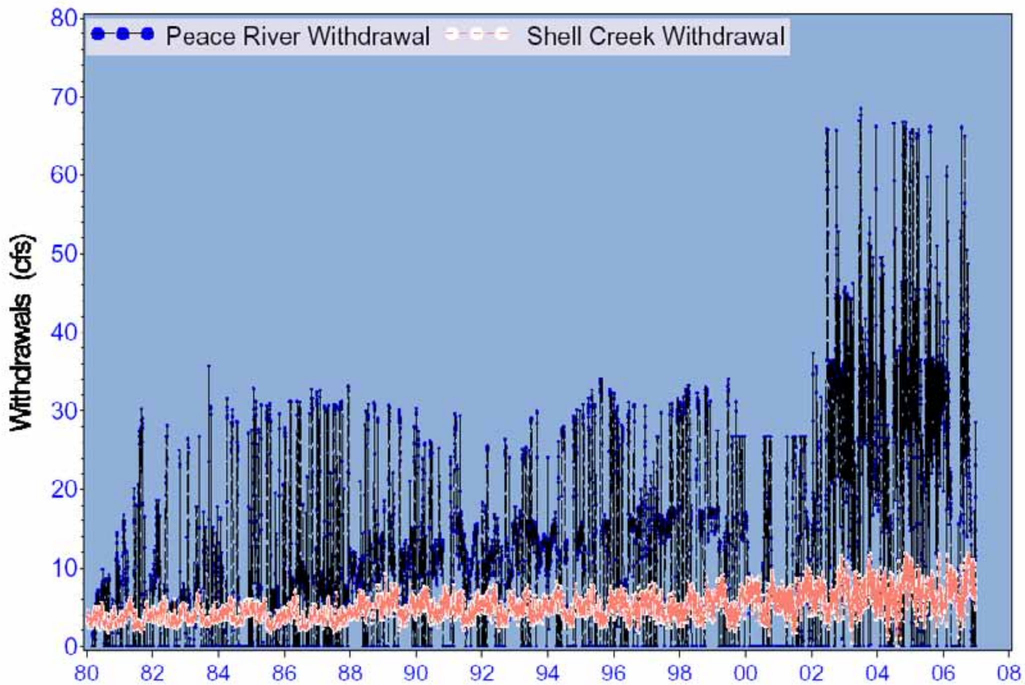


Figure 3.378 Daily Peace River and Shell Creek water treatment facility withdrawals (1980-2006)

Since the issuance in 1996 of the District's newest Facility water use permit, the average daily theoretical maximum permitted quantity of water available from the river based on the Peace River at Arcadia preceding day's flow has been 58.9 cfs, while actual average daily withdrawals over this eleven-year period have been only 17.0 cfs. Available permitted quantities are a direct function of flow, and thus when flows are high, available quantities are relatively high, and vice versa. Actual withdrawals, by comparison, are dependent on a number of factors including pumping capacity, available storage, and demand. The interactions between the availability of flow and the Facility's capacity for withdrawals are indicated by comparisons of withdrawals during the 2000 drought (mean annual withdrawal of 5.7 cfs), and withdrawals during the characteristically wet years such as 2003 and 2005, which had mean annual withdrawals of 26.1 and 29.1 cfs, respectively. Through 2006, the facility was able to meet demands operating within the limits set by the water use permit and the Facility's physical capacity. However, during both the recent very dry 1999-2001 La Niña event and the 2006 drought, the Facility's stored water reserves were drawn down to very low levels. While the stored reserves proved adequate during these recent events, once the additional expanded capacity and storage that are currently being implemented are added, the severity of similar future occurrences should be limited. As demand for potable water supplied from the Facility increases, the timing of flows potentially available for withdrawal relative to timing of peak demands may continue to cause some supply issues during extended dry periods. When flows are low, but still above the 130 cfs low flow cutoff, the Facility typically withdraws water at, or very near, the maximum permitted levels. However, historically, the Facility has withdrawn water well below the maximum permitted amount during periods of high flow. It is expected that as additional off-stream storage and withdrawal pumping capacity are added, actual quantities of water withdrawn from the river will move closer to quantities theoretically available under the existing permit conditions.

The following observations and conclusions regarding the status and long-term patterns and trends in Facility freshwater withdrawals can be drawn from the presented graphical analyses.

- Prior to 1988 when flows were not based on a percent of flow, much larger percentages of low flows were initially taken under the District's original monthly based withdrawal schedule.

- Time-series plots plainly show the relatively steady increases in the amounts of freshwater withdrawals by the Facility during the past twenty-seven years due to increasing water demands. Also clearly evident is the noticeable increase in maximum Facility withdrawals following completion of the Facility's 2001 expansion, which resulted in the Authority's increased ability to treat and store larger daily amounts of freshwater.

- Comparisons indicate that other than during the warm/dry months of April and May when the Facility is often not withdrawing water from the Peace River due to the 130 cfs cutoff, Facility withdrawals have been fairly uniform throughout most of the year, differing primarily between changes in the permits and differences in Facility capacities.

- The low flow cutoffs based on flows at the USGS Peace River at Arcadia gage have often resulted in periods each year when the Facility does not withdraw water from the river. During 2000 the Facility did not withdraw any water from the Peace River for a total of 248 days, and relied solely on stored reserves another 219 days during 2001.

- Facility withdrawals have periodically exceeded the ten percent criteria since it was established in 1988. The primary reason for these discrepancies stems from the way that stage/flow data are gathered. The Authority uses "provisional" preceding day flow data from the water level recorder at the USGS gaging station on the Peace River at Arcadia. Currently, these data are taken directly from the USGS Tampa office's website. However, after the fact, the USGS checks and evaluates the data from the stage recorder and validates the river cross section a number of times each year. Thus, the daily values used by the Authority are only "provisional" and are occasionally changed by the USGS weeks or months after the fact. It is not uncommon for subsequent determinations of percent withdrawals, based on revised USGS calculations of daily flows, to conclude that daily Facility withdrawals, based on provisional flow information, in fact exceeded the established ten percent criteria. Such differences also result in instance when the Authority actual takes less than the permitted ten percent. The Authority and the USGS Tampa office staff have continued to work to reduce such instances to the greatest possible extent.

- Figure 3.386 indicates that differences in the annual average hydrograph of total gaged flows upstream of the Facility or have been very small regardless of season. This is especially true given the fairly large degree of natural variability inherent both between years and over longer decadal periods.

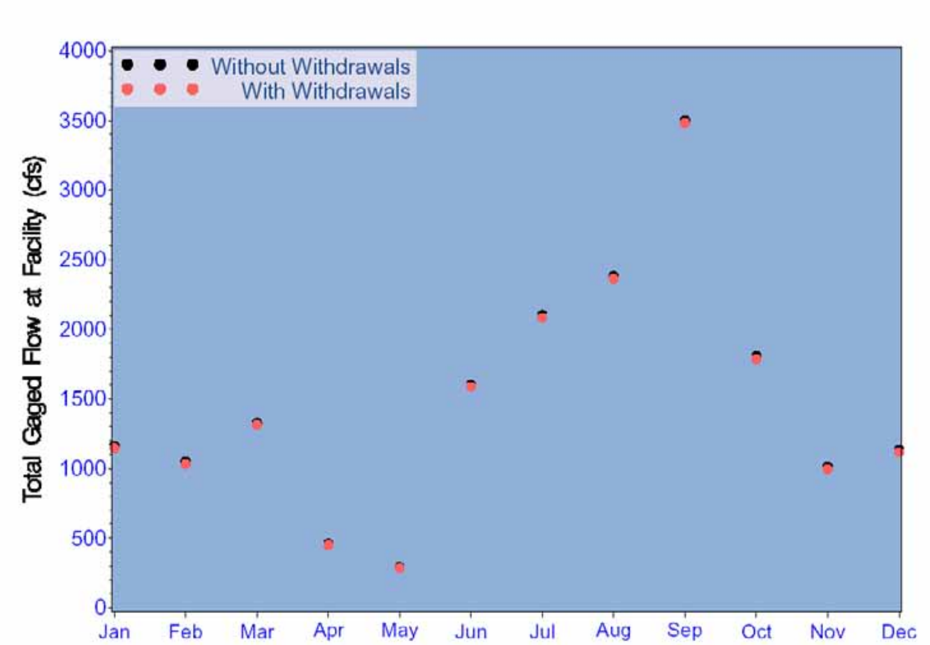


Figure 3.386 Average monthly flow upsteam of the Facility with and without withdrawals (1996-2006)

Chapter 4 – Status and Trends in Hydrobiological Water Quality Indicators in the Lower Peace River/Upper Charlotte Harbor Estuarine System

This chapter provides overviews and analyses of the status and trends in water quality in the lower Peace River/upper Charlotte Harbor estuarine system over the 1976-2006 time interval of HBMP monitoring. The following analyses are included.

- An overview and summary of historical changes in water quality in the upper Peace River and its major tributaries relative to influences of long-term changes in water quality in the lower Peace River and the upper harbor.

- Analyses of the status and trends in water quality at the long-term “fixed” HBMP monitoring stations over the interval from 1976 through 2006.

- Analyses of the status and trends in water quality at the long-term “moving” ishohaline-based HBMP salinity zones over the period between 1984 and 2006.

Overview of Historical Patterns of Water Quality Changes in the Peace River Watershed

Historically, water quality in the upper Peace River watershed has been affected by a number of anthropogenic activities. These have included point and nonpoint source discharges from phosphate mining and processing, point source municipal/industrial effluents, and nonpoint runoff from both expanding urban and intense agricultural land uses. Agricultural land uses in many areas of the Peace River watershed have undergone marked conversions from unimproved grazing pasture to improved pasture and increasingly to citrus and row cops. Some of the largest conversions to more intense agricultural uses have occurred in the southern basins and have been associated with increased discharges of highly mineralized ground water and nonpoint source nutrient loadings (nitrogen).

Both the quantity and quality of water in the Peace River watershed have also been influenced by historic losses throughout the watershed of 342.7 miles of stream channels and their associated habitats. Natural stream channel losses have been associated with phosphate mining, agriculture, and urban land use activities, which have included channeling, filling, grading, and otherwise altering natural streams. Such alterations, combined with corresponding changes in associated land uses, have combined to result in the observed long-term changes in water quality within specific watershed drainages**.**

Until recently, Lake Hancock, a hypereutrophic lake at the Peace River headwaters, received nutrient laden effluent directly from a number of industrial and municipal sources. It has been estimated that there is in excess of 12,000 acre-feet of unconsolidated, deep organic muck currently covering the lake bottom. As a result, the water leaving Lake Hancock is typically characterized by: 1) very high concentrations of blue green algae, 2) high turbidity, and 3) elevated organic content that lead to high biological oxygen demand (BOD) and associated low dissolved oxygen concentrations. Studies have observed that degraded water quality is both more frequent and severe in the upstream reaches of the river toward Lake Hancock and have suggested that dilution from less impacted tributaries in the middle/lower river might be responsible for improved water quality in the lower Peace River watershed

Phosphate mining and processing activities have historically had adverse effects on water quality in the Peace River. Geologically, extensive regions of the Peace River watershed contain Miocene deposits rich in phosphate ore. Historical phosphate mining activities resulted in both degraded water quality and periodic catastrophic fish kills associated with substantial accidental discharges of materials from clay settling areas. Increasing strict environmental regulations implemented by state and federal governments in the late 1970s dramatically reduced both the occurrence and the severity of these events, and significantly reduced the inputs of phosphorous rich waters directly into the upper Peace River. While dissolved inorganic phosphorus concentrations in the Peace River and upper Charlotte Harbor are extremely high relative to most other rivers and estuaries, peak levels have declined by as much as an order of magnitude since the early 1980s.

The following summarizes a number of the key findings relative to the differing water quality characteristics and historical pattern changes that have been observed in the Peace River watershed.

- Lake Hancock water quality has been characterized as “poor,” based on the Florida Trophic State Index. Florida Department of Environmental Protection (FDEP) has verified the impaired condition of the lake and levels of total nitrogen, total phosphorus, and biological oxygen demand all exceeded the state threshold screening values by considerable amounts.

- Instances of low dissolved oxygen concentrations are conspicuous in the upstream portions of the Peace River, and both the frequency and downstream extent of low dissolved oxygen levels increase as discharges from Lake Hancock increase. Flows from the lake via Saddle Creek are characteristically high in total suspended solids, total Kjeldahl nitrogen, total organic carbon, and chlorophyll *a*. The high chlorophyll concentrations (algae) and organic material associated with these discharges result in both the very high and low dissolved oxygen levels in the upper Peace River. During periods of high rainfall, discharges from the lake increase, and the low dissolved oxygen conditions are exacerbated.

- Values for a number of other water quality parameters in the upper Peace River have improved noticeably since the 1960s and 1970s following implementation of regulatory measures and changes in phosphate mining practices that eliminated direct processing discharges and reduced other mining related discharges to surface waters. These changes resulted in decreased levels of specific conductivity, total dissolved solids (TDS), calcium, magnesium, sulfate, silica, total phosphorus, ortho-phosphate, fluoride and strontium in the upper river.

- Analyses of water quality data suggest that historically high ground water withdrawals and subsequent discharges from mining activities substantially augmented river base flows, and masked the decline of natural spring discharges that followed reductions in ground water levels. Ground water discharges were historically so large that when they were reduced, there was a commensurate increase in the average water color in the upper reaches of the river.

- The tributary basins of the Peace River watershed all show water quality changes attributable to mineralized ground water discharges to surface waters.

- Depending on the basin, long-term increases are apparent in conductivity, pH, total dissolved solids, calcium, magnesium, sodium, potassium, chloride, silica, and sulfate. Concentrations of many of these water quality parameters were at or near historical highs during the recent 1999-2001 drought. The basins were ranked relative to the magnitude of change in water quality and are listed from largest to smallest changes.

    1. Joshua Creek
    2. Shell Creek (Prairie Creek and Shell Creek)
    3. Horse Creek
    4. Payne Creek
    5. Charlie Creek

- Ground water discharges in the Payne Creek basin are associated with phosphate mining, electrical power facilities and agriculture. In the other basins, increasing areas of agricultural lands have been transformed to more intensive uses over the past few decades. These intense agricultural uses often rely heavily on ground water for both irrigation and freeze protection. Water in the upper Floridan aquifer is generally more mineralized moving from the northern region of the Peace River watershed toward the south and west. Consequently, relatively similar volumes of Upper Floridan ground water discharged to receiving surface waters in the southern watershed basins can have a greater effect on surface water quality characteristics when compared to discharges in the northern watershed The observed characteristically high conductivity levels (and other water quality constituents) in these southern agricultural dominated basins directly reflect the results of highly mineralized Upper Floridan ground water being discharged into these creeks.

- Water quality in a number of the tributary watershed basins that have undergone land use changes to more intense agriculture also show recent increases in inorganic nitrite+nitrate nitrogen concentrations.

- Dissolved inorganic phosphorus concentrations in the lower Peace River/upper Charlotte Harbor Estuary are extremely high when compared to other estuarine systems. However, measured phosphorus levels in the estuary have declined by as much as an order of magnitude since the early 1980s.

- Except for statistically significant long-term declines in phosphorus levels and recent significant increases in silica concentrations, the water quality of the lower Peace River and upper Charlotte Harbor has remained relatively unchanged over the past quarter century.

- There are, however, distinct seasonal differences in a number of water quality characteristics in the lower river and estuary (including salinity, dissolved oxygen, water color, turbidity, phosphorus, nitrogen, organic carbon and chlorophyll *a*) related to differences in flow and/or temperature.

- Phytoplankton levels in the Peace River and Charlotte Harbor during periods of low to moderate freshwater flow are limited by the availability of inorganic nitrogen. However, as flows increase, water color levels correspondingly increase and phytoplankton production in the river and upper harbor are increasingly limited by the ability of light to penetrate the water column.

- Dissolved oxygen concentrations in the lower Peace River/upper Charlotte Harbor Estuary show clear seasonal cycles in response to higher freshwater flows during the summer wet-season. The duration and magnitude of periods of low dissolved oxygen concentrations increase toward the river mouth and harbor as higher bottom salinities establish greater vertical stratification in the water column during high flows. Bottom dissolved oxygen concentrations in upper Charlotte Harbor are characterized by hypoxic (less than 2.0 mg/L) and even anoxic (less than 0.2 mg/L) conditions during extended periods of high flows during the summer wet-season.

Status and Trends in "Fixed" HBMP Station Water Quality Parameters

The HBMP water quality monitoring design has included the monthly collection of *in situ* physical measurements and chemical water characteristics at a number of fixed station locations along the lower Peace River and in upper Charlotte Harbor. These data were used to describe the present status as well as statistically test for the presence of long-term changes in the water quality characteristics at these specific selected locations along the lower Peace River HBMP monitoring transect. The following summarizes the results and findings of these analyses for a number of key water quality parameters.

- **Salinity –** There is a strong, distinct spatial salinity gradient along the lower Peace River monitoring transect. The greatest inter-annual variability in salinity generally occurs in the surface waters near the mouth of the river in the upper harbor where seasonal differences may reach 35 parts per thousand (or practical salinity units) between extended periods of low and high freshwater inflow. The influences of the recent high freshwater inflows during 1997/1998 El Niño event and the extended 1999-2001 drought are evident in the time-series plots (Figure 4.51). The long-term HBMP monitoring site at RK 23.6 is located approximately a kilometer downstream of Navigator Marina (Figure 1.5).

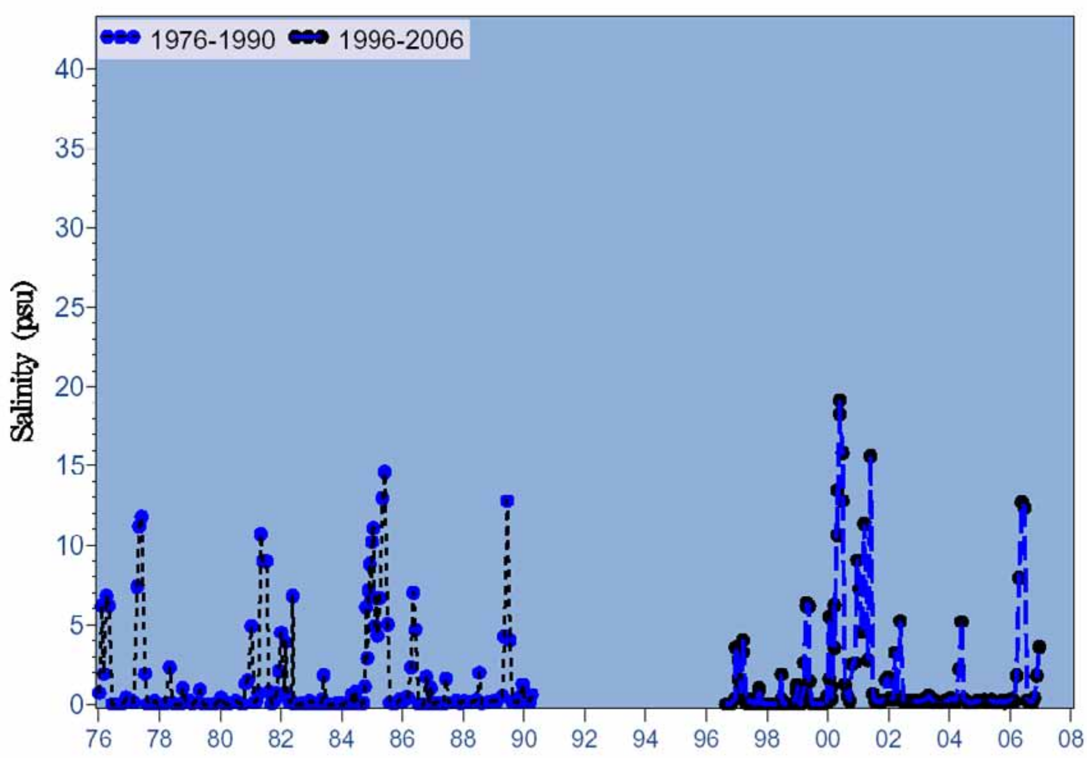
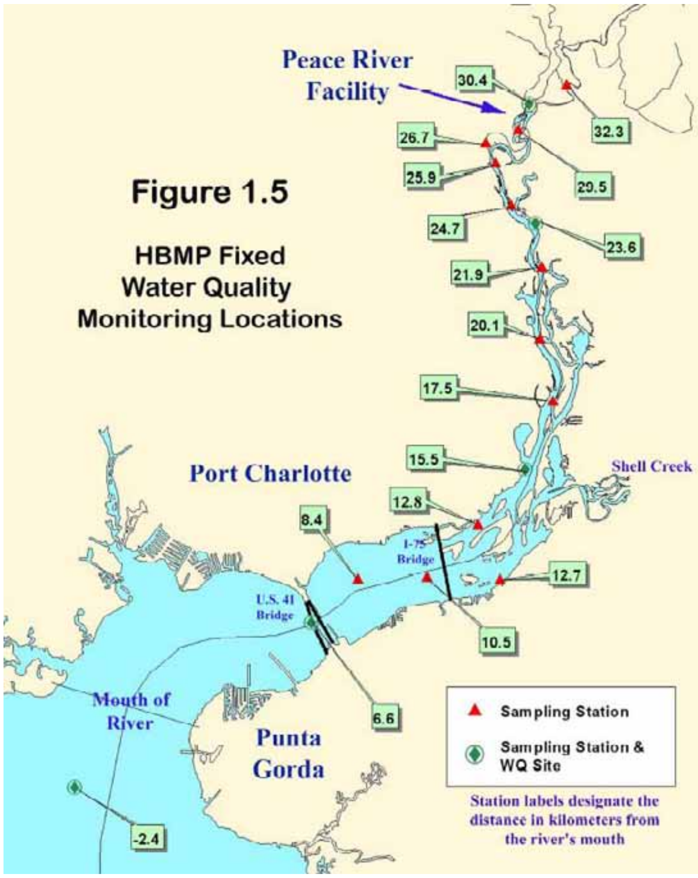


Figure 4.51 Long-term bottom salinity at river kilometer 23.6



- **Dissolved Oxygen –** Near-bottom dissolved oxygen concentrations show clear seasonal cycles in response to higher freshwater flows during the summer wet-season. The duration and magnitude of periods of very low dissolved oxygen concentrations increase toward the river mouth as higher bottom salinities establish greater vertical stratification in the water column during high flows. Other studies have noted apparent declines in dissolved oxygen concentrations in the lower river over time, but have been unable to clearly identify any cause. The current analyses, based on a somewhat longer data set than these previous analyses, generally finds similar surface and bottom annual average dissolved oxygen concentrations along the HBMP monitoring transect when comparing the 1976-1989 and 1996-2006 time periods.

- **Water Color –** Humic compounds derived from the breakdown and subsequent leaching of vegetation into surface waters are the source of the high water color that characterizes the blackwater river systems of southwest Florida. Color levels in the estuary temporally increase quickly in response to increased freshwater inflow, with very high color levels extending well into the harbor during extended periods of high freshwater flows such as occurred during the 1997/1998 El Niño or recently during the extremely high flows that occurred during 2001, 2003, 2004 and 2005. Statistical analyses indicated significant differences between the average annual surface color levels at the two most downstream monitoring locations (River Kilometer (RK) -2.3 and 6.6) between the 1976-1989 and 1996-200 sampling periods. These differences reflect the higher recent inflows of dark colored water farther down the river and into the upper harbor during the recent period of high flows.

- **Nitrite+Nitrate Nitrogen –** Concentration levels and seasonal patterns of dissolved inorganic nitrite+nitrate nitrogen differ along the lower river/upper harbor HBMP monitoring transect. The time-series plots indicate that inorganic nitrite+nitrate nitrogen levels at the most downstream fixed sampling station (located near the arbitrarily defined river mouth) are typically near or at method detection limits. Salinities are typically high in this region of the estuary and, except during periods of very high river flow, phytoplankton primary production is limited by the availability of inorganic nitrogen. Conversely, during extended periods of high freshwater river flows, surface salinities decline, bringing increased nutrient loading and higher levels of water color that limit the penetration of light into the water column and subsequently reduces phytoplankton growth and nitrogen uptake. By comparison, inorganic nitrogen levels progressively increase moving upstream along the HBMP sampling transect, as dilution by low nutrient/high salinity harbor water declines and higher water color increasingly limits phytoplankton nitrogen uptake. Only during periods of extended low freshwater flow, such as during the spring dry-season, are ambient inorganic nitrogen levels low at the upstream river sampling sites. The observed statistically significant increase in inorganic nitrogen concentrations in the upper harbor (RK -2.4) matches with the corresponding increase in water color and supports the previous observations that these increases reflect higher inflows of darker (nitrogen rich) freshwater farther downstream into the upper harbor during the recent period of characteristically higher river flows.

- **Total Kjeldahl Nitrogen –** While this gross measurement of combined inorganic ammonia and organic water column nitrogen shows distinct seasonal patterns, spatially levels at all the monitoring locations were observed to be relatively similar. Statistical tests found no significant differences when comparing the 1976-1989 and 1996-2006 time periods.

- **Ortho-Phosphorus –** Probably the most dramatic long-term change in water quality in the lower Peace River has been the marked, observed statistically significant long-term decline in dissolved inorganic (and total) phosphorus concentrations. Phosphorus concentrations generally reflect both the spatial and temporal variation in Peace River freshwater inputs. The highest phosphorus concentrations are typically associated with seasonal low river flow, when the influences of ground water are more pronounced. Long-term temporal patterns indicate rapid declines in both the magnitude and variability in phosphorus levels when compared with the first six years of HBMP monitoring. Comparisons of the average annual mean phosphorus concentrations between the 1976-1989 and 1996-2006 time periods indicate a continued decline at the HBMP river stations, even though the largest changes occurred prior to 1984. Of particular note however are more recent observations, which show phosphorus levels throughout the lower Peace River/upper Charlotte Harbor Estuary have dramatically increased following Hurricanes Charley, Francis and Jeanne in August and September of 2004 (Figure 4.57). It is apparent that the historically high flows that occurred in the upper Peace River watershed following this unusual series of events has at least temporarily increased phosphorus concentrations throughout the system to levels not seen for over twenty years.

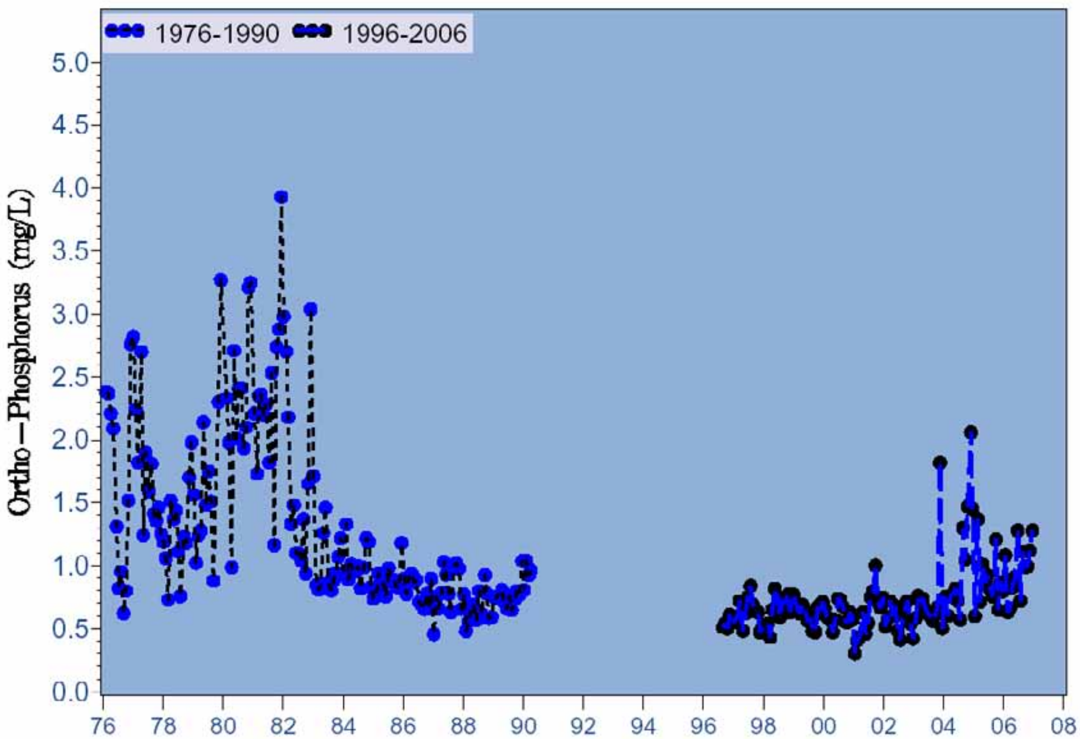


Figure 4.57 Long-term surface ortho-phosphorus at river kilometer 23.6

- **Silica –** Both the long-term time-series plots and the statistical comparisons of mean annual average reactive silica concentrations indicate that silica levels have recently dramatically increased along the entire length of the lower Peace River monitoring transect (Figure 4.58). During the most recent eleven years of HBMP monitoring, silica concentrations at all five fixed sampling sites have increased and the range of variability has increased when compared with similar data from the 1976-1989 period. It may be that the observed increases in ambient reactive silica levels in the Peace River estuarine system reflect the cumulative influences of increased ground water use and the expansion of water intense agriculture in the Peace River watershed, or it may be associated with other land use changes occurring upstream in the watershed. The Authority is currently collecting additional dry- and wet-season data at a number of locations throughout the upper watershed in order to be able to better identify potential sources of both apparent increasing silica and phosphorus concentrations.

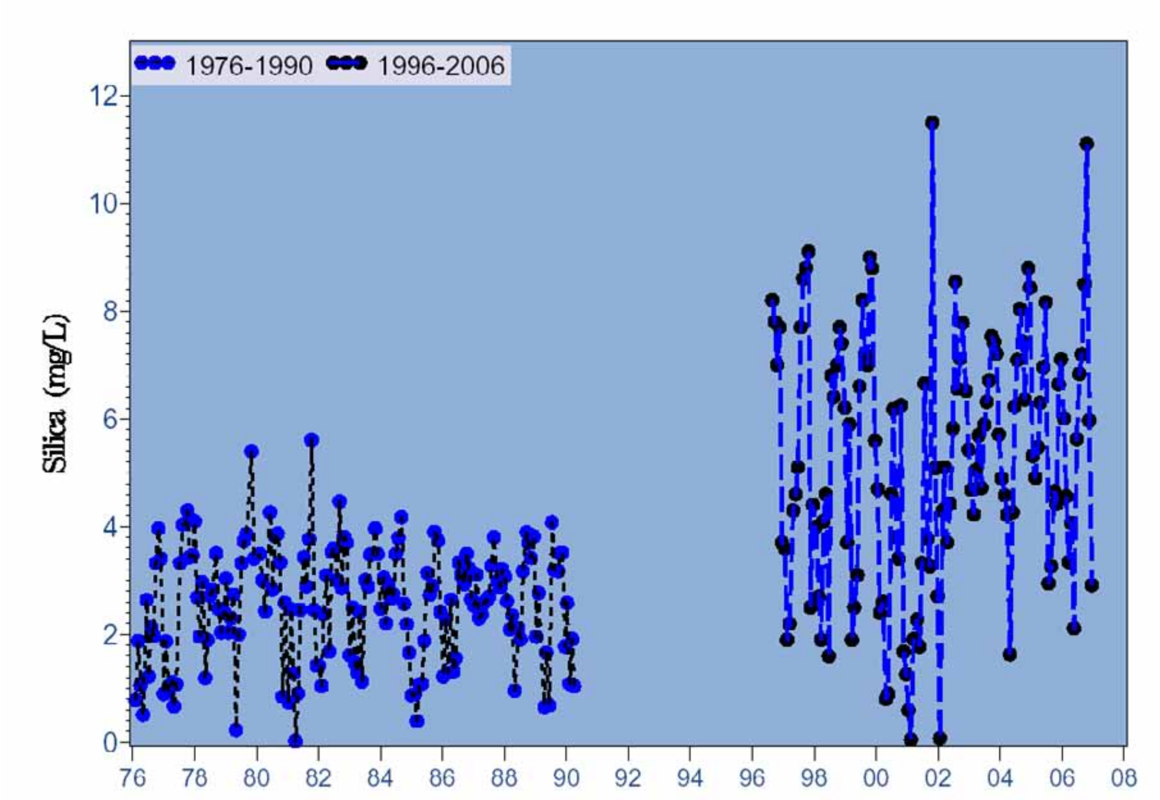


Figure 4.58 Long-term surface silica at river kilometer 23.6

- **Chlorophyll *a* –** Previous studies observed marked declines in the periodic very high chlorophyll *a* concentrations or phytoplankton "blooms" that commonly occurred in the surface waters throughout the lower Peace River/upper Charlotte Harbor estuarine system during the late 1970s and early 1980s. However, the current examination of the data, which extends similar analyses through 2006 indicates that since 2004 chlorophyll *a* levels in the lower river and upper harbor have uniformly shown increases to annual average levels not seen in over twenty years (Figure 4.59). Following Hurricanes Charley, Francis and Jeanne in August and September of 2004, as previously discussed, water quality data from the lower river show marked increases in ortho-phosphorus levels that correspond with the observed increases in chlorophyll *a*. Since phosphorus levels in the lower Peace River/upper Charlotte Harbor Estuary are naturally high, and nutrient additions have shown local estuarine phytoplankton populations are seasonally nitrogen and not phosphorus limited, it is doubtful that the observed increases in phosphorus levels are directly the ultimate cause of the observed increases in chlorophyll *a* concentrations. More likely, is that that other water quality constituents not monitored by the HBMP, but having the same source as the observed phosphorus increases, are responsible for the observed increases in phytoplankton levels. Overall, the result of the observed historic declines, combined with the recent observed increases, is that there are no statistically significant differences in average annual seasonally weighted mean chlorophyll *a* concentrations between the 1976-1989 and 1996-2006 time intervals at any of the fixed HBMP monitoring locations. This result demonstrates the inherent difficulty in using most commonly applied statistical trend procedures when evaluating long-term changes in water quality parameters having multiple non-seasonal increasing and decreasing patterns.

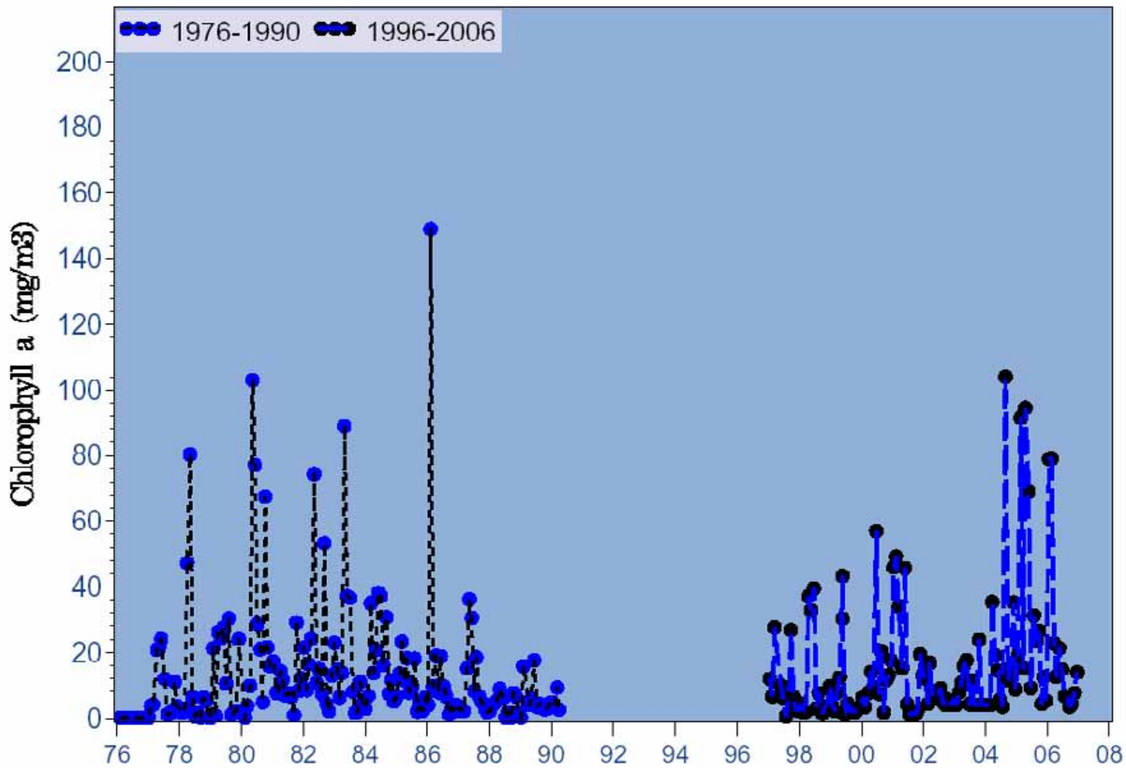


Figure 4.59 Long-term surface chlorophyll a at river kilometer 23.6

A number of graphical methods were used to depict spatial variations of ambient water quality characteristics under different flow regimes at each of the five fixed HBMP Peace River monitoring locations. The following patterns were apparent in the observed responses of the water quality parameters to seasonal changes in freshwater inflows.

- **Salinity (psu) –** The graphical analyses clearly depict the progressive changes that occur along the sampling transect as flows increase. Under the lowest flow conditions, brackish water conditions extend upstream well beyond the point of Facility water withdrawals. Conversely, freshwater at the surface can extend downstream to near the river's mouth under conditions of extended periods of freshwater inflow. There are distinct inverse relationships between measured surface salinities and increases in flow. However, these relationships increasingly break down further upstream with increasing flows as salinities along the HBMP lower river monitoring transect change from being tidally brackish to always being characteristically freshwater under conditions of increasing freshwater flows.

- **Dissolved Oxygen (mg/L) –** The results generally show that surface dissolved oxygen concentrations along the monitoring transect initially increase under increasing low to moderately levels of flow. However, above some level, further increases in flow tend to progressively depress ambient surface dissolved oxygen levels at each of the fixed locations along the monitoring transect. Initially increased flows result in nitrogen stimulation of phytoplankton production within the lower Peace River estuarine system. However, at some level additional increases in water color associated with higher flows result in marked reductions in light penetration of the water column and the phytoplankton compensation depth, resulting in reduced dissolved oxygen production. The relationship between dissolved oxygen concentrations and flow is further confounded by the combined influences of seasonal changes in water temperature and salinity.

- **Water Color (Pt-Co Units) –** The presented graphics clearly depict the distinct patterns and marked changes that occur in water color as freshwater flows increase. Water color levels at the downstream fixed monitoring sites show steady increases in color levels under ever higher rates of freshwater inflow. Further upstream, however, at some point additional increases in flow do not correspond to higher levels in ambient water color. Under conditions of extremely high flows, color levels actually in some regions of the lower river begin to decline as the contact time of sheet flow is reduced and previous built up humic compounds are increasingly flushed from the watershed.

- **Nitrite+Nitrate Nitrogen (mg/L) –** The spatial relationships between dissolved inorganic nitrogen concentration and rates of freshwater inflow are complex. As flows gradually increase following the typical spring dry-season, increasing nitrogen loadings stimulate estuarine phytoplankton production and ambient inorganic nitrogen levels often remain near or at detection limits throughout much of the lower Peace River estuarine system. However, as flows further increase, upstream phytoplankton primary production becomes color rather than nitrogen limited and inorganic nitrogen levels rapidly rise with increasing flows. A third condition then occurs at the upstream HBMP sampling locations as both water color and nutrient levels start to decline with further increases in flow. Such changes again reflect seasonal changes in the water quality characteristic of sheet flow to the watershed's major tributaries following longer (and/or higher) amounts of rainfall.

- **Ortho-phosphorus (mg/L) –** Concentrations in the downstream more marine areas of the upper harbor generally show steady increasing levels with higher flows. However upstream, in the more freshwater reaches of the river, phosphorus concentrations are typically very high and then rapidly decline as freshwater flows increase and surface water runoff rather than ground water steadily provides an ever greater percentage of total river flow.

- **Silica (mg/L) –** Silica levels in the higher salinity waters of the upper harbor under low flows are often very low. Ambient concentrations initially rapidly rise throughout the lower river/upper harbor estuarine system as freshwater inflows increase. Following this marked initial rise however, silica concentrations then remain relatively similar as flows further increase.

- **Chlorophyll *a* (mg/m^3)** – Initially higher flows increase inorganic nitrogen loading, which stimulates phytoplankton production both in the lower river and upper harbor. However, further higher flows also increase color levels in the estuary reducing the ability of light to penetrate the water column, thus simultaneously diminishing phytoplankton growth rates. Residence time is also reduced as flows increase resulting in phytoplankton (chlorophyll) increasingly being "flushed out" of the lower river.

Status and Trends in "Moving" Isohaline-Based Station Water Quality Parameters

The HBMP has also incorporated monthly water quality monitoring at four salinity-based "moving" isohalines. The selection of the salinity-based sampling zones was established based on a literature review of known spatial estuarine differences among the major plankton groups.

- Oligohaline Conditions = 0 psu (defined as upstream of 500 us/cm conductivity
- Lower Mesohaline = 5-7 psu
- Upper Mesohaline = 11-13 psu
- Upper Brackish = 20-22 psu

The four sampling locations represent non-fixed surface salinity zones, such that the relative monthly spatial location of each isohaline sampling site along the HBMP monitoring transect is largely dependent upon the preceding amounts of freshwater Peace River inflow. Table 4.27 summarizes the historical statistical distributions of the four isohalines along the HBMP Peace River monitoring transect.

Table 4.27
Summary Statistics of the Four Isohaline Locations (River Kilometers) from the Peace River's Mouth for the Period 1983-2006

Isohaline	Minimum (Downstream)	Maximum (Upstream)	Mean	Median
0 psu	0.6	37.6	21.5	20.5
6 psu	-16.3	28.3	12.3	12.1
12 psu	-30.1	25.0	7.3	8.7
20 psu	-36.3	21.0	-0.1	2.7

The Peace River Water Treatment Facility is located at approximately RK 29.9. To date, the most upstream occurrence of the 0 psu isohaline sampling location has been just over a quarter mile upstream of the point were Horse Creek joins the Peace River during June 2000. The most downstream occurrence of the 20 psu isohaline sampling location has been in the Gulf of Mexico just off Boca Grande during September 1988.

Time-series plots such as Figure 4.291 show the monthly long-term relative locations of the "moving" isohaline salinity zones relative to the HBMP monitoring transect, and clearly indicate the large degree of both inter-annual and seasonal variability that has occurred in the relative locations of the monitored isohalines. As shown in Table 4.27, seasonal and long-term extreme differences in estuarine freshwater inflows have resulted in variations as much as 35 to 55 kilometers in the relative spatial distributions of the four isohalines. The extended 1999-2002 drought affected rainfalls and river flows throughout southwest Florida, and the influences of this drought are evident in the observed changes in the relative locations of the HBMP isohalines during this interval. The long-term pattern of relatively high summer flows during the past decade has also resulted in some indication of an overall downstream movement in the 6 and 12 psu intermediate salinities. However, the results of the trend tests fail to find statistically significant pattern of progressive change in the relative long-term spatial distributions of any of the four isohaline locations along the HBMP monitoring transect.

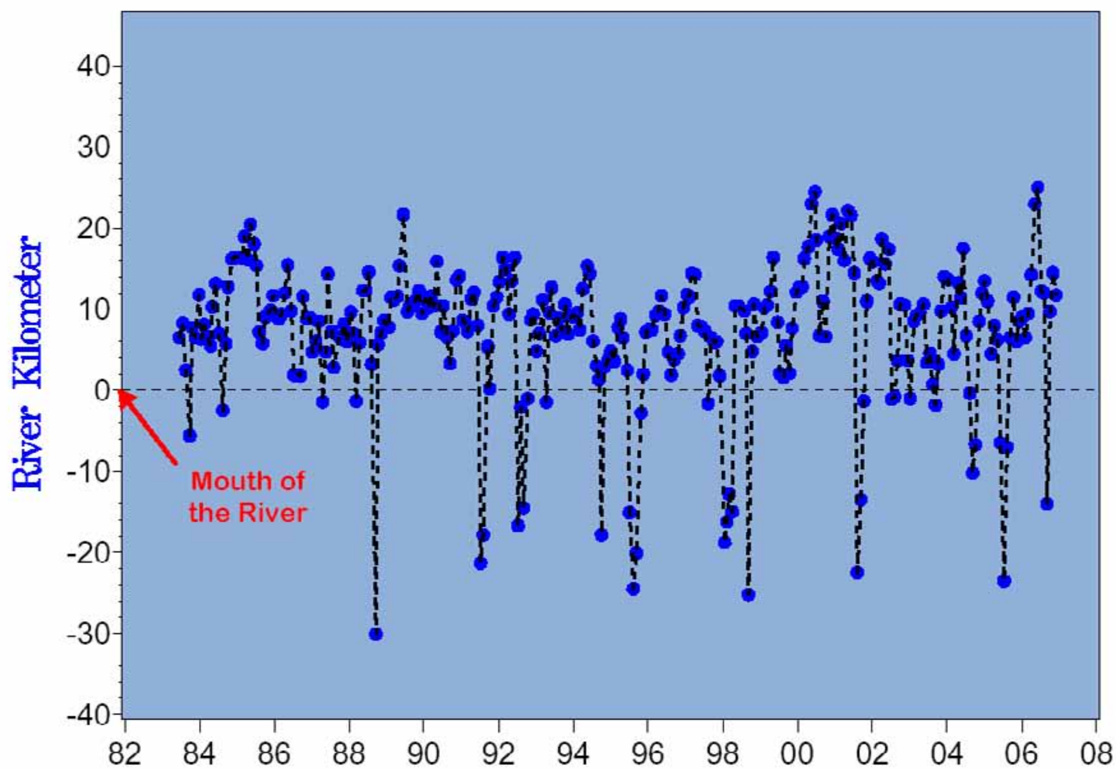


Figure 4.291 Monthly location along the HBMP monitoring transect of the 12 psu isohaline (1983-2006)

Time-series plots and statistical trend analyses were conducted on long-term water quality data collected at each of the four moving isohaline based monitoring locations. The results provide overviews of the seasonal ranges and long-term patterns for the measured water quality parameters. Table 4.36 depicts the summary results of statistical trend tests analyzed both on yearly averages and individual monthly values.

Table 4.36
Summary of Trend Tests of Surface Water Quality Parameters
HBMP Moving Isohaline-Based Monthly Monitoring (1984-2006)

Parameter	Salinity Zone							
	0 psu		6 psu		12 psu		20 psu	
	Yearly	Monthly	Yearly	Monthly	Yearly	Monthly	Yearly	Monthly
River Kilometer	▲ (blue)							
Dissolved Oxygen	▲ (red)	▲ (red)	▲ (blue)	▲ (red)	▲ (red)		▲ (red)	
Color	▲ (red)	▲ (blue)	▲ (red)	▲ (red)	▲ (red)	▲ (red)	▲ (red)	▲ (red)
Nitrite + Nitrate Nitrogen				▼ (red)				▲ (red)
Total Kjeldahl Nitrogen	▲ (blue)							
Total Phosphorus								
Silica	▲ (red)	▲ (red)	▲ (red)	▲ (red)	▲ (red)	▲ (red)	▲ (red)	▲ (red)
Chlorophyll *a*						▲ (blue)		▲ (red)

* Red ▲ denotes significance at the 0.05 level
* Blue ▲ denotes significance at the 0.10 level

The following briefly summarizes the results and primary conclusions drawn from the observed annual, inter-annual and long-term patterns within the four estuarine salinity zones for key selected water quality parameters.

- **Dissolved Oxygen (mg/L) –** Dissolved oxygen levels in the lower Peace River estuarine system show distinct seasonal patterns, with the lowest levels typically occurring during the summer wet-season. Even near the top of the water column dissolved oxygen concentrations are often below State of Florida standards (5 mg/L for freshwater and 4 mg/L for predominantly estuarine/marine). Measured levels are generally higher during cooler months, due to lower water temperatures (that increase the ability of the water to hold more dissolved gases) and seasonally increasing wind stress and mixing. Higher daytime values are also often associated with increases in phytoplankton production (chlorophyll *a*) and typically account for many of the unusually high observed values. Unlike the dissolved oxygen data from the fixed HBMP monitoring stations, observations from the moving, isohaline-based sites indicate that measured dissolved oxygen levels have actually progressively increased over time. A potential mechanism that might explain these apparent increases may be related to the previously discussed higher summer freshwater inflows. Increases in summer flows result in higher average nutrient (inorganic and organic) loadings to the estuarine system. Increased loading may subsequently stimulate phytoplankton production, leading to an increase in higher dissolved oxygen levels. Unfortunately, any such relationship is confounded by a number of factors that include light inhibition resulting from increased water color, and periods of lag related to internal temperature dependent nutrient recycling.

- **Water Color (Pt-Co Units) –** Gaged freshwater inflows over the 23-year period of the moving, salinity based HBMP monitoring have shown statistically significant increases in average annual flows primarily associated with higher periods of summer rainfall. The two applied statistical trend test procedures indicate that these increases in wet-season flows have resulted in statistically significant increases in ambient water color within all four of the HBMP salinity zones.

- **Nitrite+Nitrate Nitrogen (mg/L) –** Graphical analyses show distinct spatial and seasonal differences in dissolved inorganic nitrite+nitrate nitrogen concentrations among the four moving lower Peace River/upper Charlotte Harbor salinity zones. Inorganic nitrogen concentrations are typically at or near detection limits in the highest salinity reaches of the estuary throughout most of the spring and summer when light levels are high and phytoplankton production is greatest. Concentrations are conversely greater at all four measured isohalines during the fall and winter months. Overall, ambient inorganic nitrogen levels progressively increase moving upstream from high to low salinities. Inorganic nitrogen concentrations also increase under higher freshwater inputs, which results in increases in water color that limit the penetration of light into the water column and subsequently reduce phytoplankton production (nitrogen uptake). The results of the Seasonal Kendall Tau trend tests found that inorganic nitrite+nitrate concentrations within the most downstream 20 psu salinity zone have slightly statistically significantly increased over time. This result corresponds with both the observed statistically significant increases in flow (primarily during the summer wet-season) and the measured increased color levels

- **Total Kjeldahl Nitrogen (mg/L) –** Combined inorganic ammonia and organic nitrogen concentrations measured as total Kjeldahl nitrogen show distinct seasonal patterns within the lower Peace River/upper Charlotte Harbor Estuary. The highest levels are typically observed throughout the estuarine system each fall following the summer wet-season. Total Kjeldahl nitrogen concentrations increase spatially from higher to lower salinities within the lower river/upper harbor estuarine system, directly reflecting the influences of freshwater inputs. However, even though average annual flows have increased due to slightly higher average summer wet-season rainfalls, the applied statistical trend procedures did not indicate that total Kjeldahl nitrogen levels have correspondingly also increased over the 1984-2006 monitoring interval.

- **Ortho-Phosphorus (mg/L) –** The most dramatic historic changes in the lower Peace River/upper Charlotte Harbor ambient dissolved (and total) phosphorus concentrations occurred prior to the 1983 start of primary production and water quality monitoring at the four HBMP isohaline-based salinity zones. The presented graphical analyses for each of the four moving isohalines show that phosphorus levels continued to decline during the 1980s and 1990s. However, they also indicate that following the series of hurricanes that passed over the Peace River watershed during the summer of 2004, there has been an ongoing increase in measured phosphorus levels within each of the estuarine salinity zones. The observed declines in ambient phosphorus concentrations from the 1980s through the early 2000s in the lower river and upper harbor, followed by the recent marked increases, have resulted in the applied statistical trend tests showing no significant changes over the entire 1984-2006 time period. There are, however, two distinct patterns, neither of which is indicated by analyzing for trends over the entire historical time interval. It is readily apparent that the recent increases in phosphorus concentrations directly followed the historically high flows that resulted following the 2004 series of hurricane events.

- **Silica (mg/L) –** The presented analyses clearly show that there have been marked increases in reactive silica concentrations in the surface water of the Charlotte Harbor estuarine system. The initial increases probably began in the late 1990s, but were interrupted as a result of the very low flows during the 1999-2001 drought. Following the drought, levels in 2002 were markedly higher and have been steadily increasing through 2006. It is suspected that the observed increases in ambient reactive silica levels in the Peace River estuarine system reflect recent anthropogenic changes in the Peace River watershed. Again the sources have yet to be identified and the Authority is conducting low and high flow water quality monitoring at a number of locations in the upper watershed to help discover potential sources.

- **Chlorophyll *a* -** Previous summary HBMP reports have noted apparent declines in the frequency of phytoplankton blooms commonly observed during the early 1980s in the upper reaches of the lower Peace River. The current analyses, however suggest chlorophyll *a* phytoplankton levels have actually increased over the 1984-2006 time interval. These changes are shown to have been statistically significant within the two higher salinity zones. Higher chlorophyll levels are a reflection of the corresponding observed significant higher flows and color levels (that can serve as a proxy for nutrient loadings) that have, on average, characterized the proposed warmer AMO phase since 1995. Spatially, the highest chlorophyll *a* levels occur within the two intermediate salinity zones. During the spring, high levels of phytoplankton biomass often are observed within the 6 psu isohaline, which characterizes the zone of the estuary where nutrient rich freshwater first mixes with low nutrient harbor water. A second, often smaller peak in phytoplankton chlorophyll *a* usually occurs within the 6 psu salinity zone during the fall, as water color (inflow) decreases. Conversely, an opposite seasonal pattern occurs in the more saline 12 psu salinity zone, where nutrients (nitrogen) are more limited and the spring phytoplankton bloom is smaller, and the fall increase in response to the reduction in light limitations is more pronounced. In the reaches of the estuary characterized by the 20 psu isohaline, phytoplankton production is reduced and shows less seasonal variability, with the highest concentrations often occurring at the end of the summer wet-season.

Water quality characteristics among the four HBMP isohalines were also analyzed to determine responses to differing flow conditions. Large degrees of variation often occur at a given flow depending on the history of flows over both the immediate and longer-term preceding periods. Water color at an isohaline for example can differ dramatically at intermediate levels of gage freshwater inflow depending on whether the sampling occurred early in the summer wet-season as flows were increasing or at the end of the summer/fall period as flows were decreasing. The following briefly summarizes a number of the observed patterns and primary conclusions resulting from the presented graphical and statistical comparisons made between freshwater inflows and the measured downstream variability of water quality characteristics within the four salinity zones.

- **Isohaline Location (River Kilometer) –** The relative locations of each of the four HBMP isohalines along the lower river/upper harbor monitoring transect show strong inverse relationships with freshwater inflows. Under very low flow conditions, the highest 20 psu salinity zone often extends up into the lower river. The freshwater/saltwater interface (0 psu), by comparison, can extend well downstream towards the mouth of the river during extended periods of high river flow. These relationships are confounded due to the importance of both short- and long-term preceding conditions, as well as the often increasing physical stratification of the water column under conditions of higher flows.

- **Dissolved Oxygen (mg/L) –** The presented graphics indicate that as flows increase, dissolved oxygen concentrations near the freshwater/saltwater interface (0 psu) become depressed. Increasing flows result in higher water color, which reduces light levels in the water column and reduces phytoplankton growth leading to lower oxygen production. Within each of the three more brackish estuarine salinity zones, dissolved oxygen levels initially increase with flow due to higher nutrient levels and then decrease at higher flows as higher water color limits phytoplankton production. These interactions between nutrient stimulation and color inhibition mediated by flow, combined with both the physical decrease in dissolved oxygen saturation and enhanced bacterial respiration rates with higher summer temperatures, result in the observed changes in surface dissolved oxygen levels along the Peace River HBMP transect.

- **Water Color (Pt-Co Units) –** Measured color levels within the four salinity zones are significantly positively correlated with increasing flows. However, there are distinct differences in the relative patterns between color and freshwater inflow both among the isohalines and categorized flows. The strongest relationships between water color and freshwater inflows occur within the lower two salinity zones over low to intermediate ranges of flows. The relationships between color and flow within the 12 and 20 psu isohalines by comparison are somewhat less pronounced due to the greater dilution by low color/higher salinity waters. Color levels within all four isohalines typically become asymptotic, and then begin to decline with higher flows as color levels in the freshwater inflows from the watershed begin to decline under high flow conditions.

- **Nitrite+Nitrate Nitrogen (mg/L) –** The relationships between dissolved inorganic nitrogen concentrations and freshwater inflow at the four estuarine isohalines are complex. Under low to moderate levels of flow, nitrogen stimulates phytoplankton production and ambient levels can be near detection limits throughout much of the lower Peace River/upper Charlotte Harbor estuarine system. However, as flows increase and the river estuarine phytoplankton primary production becomes color rather than nitrogen limited, ambient inorganic nitrogen levels increase with increasing flow. However, measured inorganic nitrogen concentrations often decline again as river flows further increase. Higher levels of accumulated nitrogen are often associated with the initial periods of seasonal runoff from the watershed. Increased volumes and rates of surface water runoff (sheetflow) also limit contact time, further reducing both color and inorganic nitrogen concentrations.

- **Total Kjeldahl Nitrogen (mg/L) – Total** Kjeldahl nitrogen measures both organic nitrogen and inorganic ammonia/ammonium. Concentrations within the 0, 6 and 12 psu isohalines initially increases in response to higher freshwater inflows, and then quickly level off. Total Kjeldahl nitrogen levels within the 20 psu isohaline by comparison do not show any distinct patterns with regard to changes in river flows.

- **Ortho-Phosphorus (mg/L) –** Concentrations within each of the four isohalines progressively decline as flows increase. Phosphorus concentrations within the lower river and upper harbor seasonally decline as rainfall increases and the relative importance of ground water inputs versus surface flows declines.

- **Silica (mg/L) –** Concentrations within the 0, 6 and 12 psu isohalines initially increase in response to higher freshwater inflows, and then quickly become asymptotic, while concentrations within the 20 psu isohaline do not show any distinct, consistent patterns with changes in river flows.

- **Chlorophyll *a* (mg/m^3) –** Higher flows result in a number of interacting confounding factors that ultimately affect resultant phytoplankton biomass (chlorophyll *a* concentrations) within the estuarine system. Higher rates of freshwater inflow increase inorganic nitrogen loading that stimulates phytoplankton production, while at the same time higher color levels simultaneously reduce the ability of light to penetrate the water column and reduces phytoplankton production. Higher rates of flow also reduce the physical hydraulic residence time within the lower river and effectively "flushes" phytoplankton populations further downstream, in effect limiting the buildup of higher chlorophyll concentrations. Chlorophyll concentrations within the 0 and 6 psu isohalines both show higher levels in response to low to moderate increases in inflows and higher nitrogen inputs. However, measured chlorophyll *a* concentrations then decline as factors such as color and residence time become increasingly important. The direct relationships between chlorophyll *a* concentrations and flow are less distinct at the higher two salinity zones.

Chapter 5 – Influences of Increasing Conductivity in the Lower Peace River Watershed

Recently studies have identified anthropogenically driven trends of increasing specific conductance within a number of the major lower Peace River tributaries. These changes over recent decades have been primarily associated with increasing land conversions from less to more intense forms of agriculture that increasingly rely on irrigation using higher conductivity water pumped from the upper Floridan aquifer. This chapter evaluated patterns and historical trends in specific conductance and associated water quality characteristics measured at the Peace River at Arcadia gage, and within both the Joshua and Horse creek tributaries located upstream of the Peace River Facility. Historic changes in conductivity and other allied constituents at these locations are compared and contrasted with long-term data collected at the HBMP fixed sampling site at River Kilometer (RK) 30.4, which is located immediately upstream of the Peace River Facility. It is logical to infer that during seasonally dry periods, when low flows in both the Horse and Joshua creek systems are being artificially augmented by high conductivity ground water, downstream conductivities at the Facility may also have been progressively affected over time. The results of the presented series of analyses are discussed relative to their potential influences on Facility operations.

Historical data collected in conjunction with USGS and District long-term surface water monitoring programs, and the HBMP were combined for these analyses. These data were divided into dry-season (November through June) and wet-season (July through October) subsets in order to provide comparative analyses among the selected station locations.

Peace River at Arcadia

The following summarizes the findings for the Peace River at Arcadia site.

- Measured specific conductance values (Figure 5.5) have ranged from a low of only 22 uS/cm (July 1, 1966) to a high of 645 uS/cm (June 7, 2000).

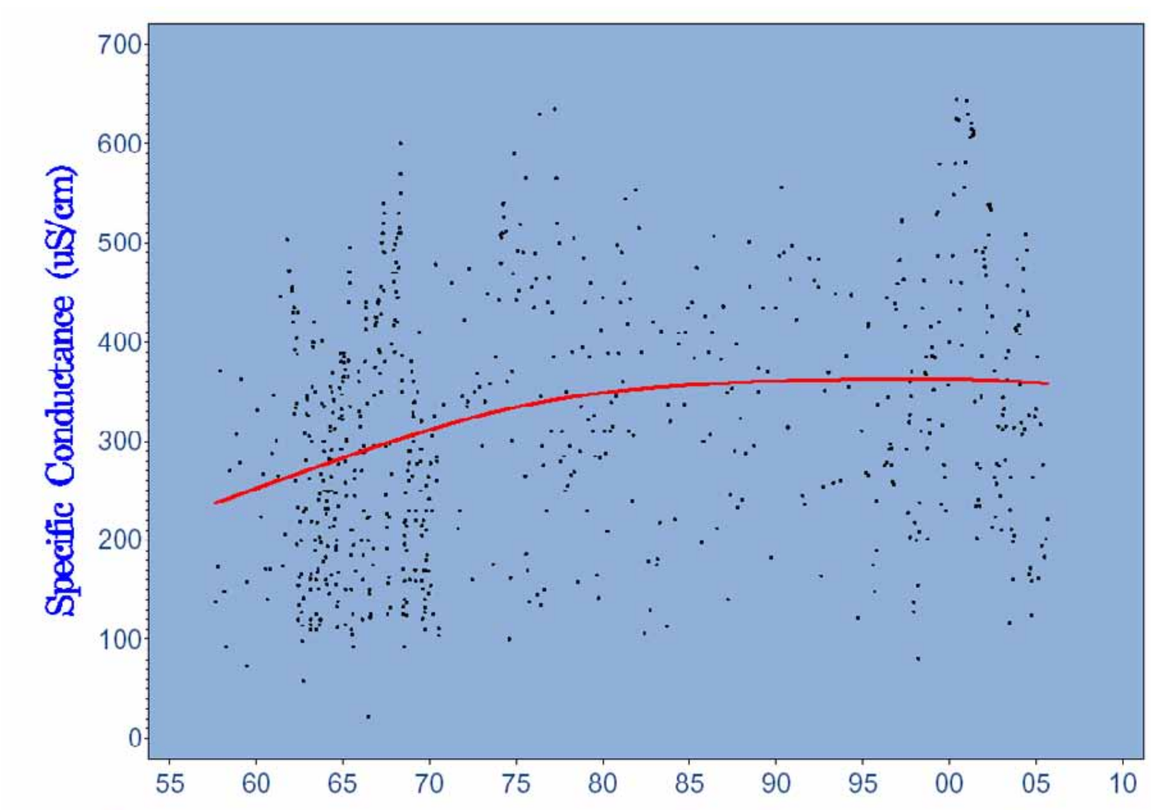


Figure 5.5 Specific conductance over time in the Peace River at Arcadia (all flows)

- Seasonal analyses of the data indicate that the highest mean and median specific conductance values occur in May following the typically spring dry-season, while the lowest mean and median levels are observed in August during the summer wet-season.

- The data however clearly indicate that both specific conductance and chloride concentrations have both increased over time during periods of low flow, and that the largest increases occurred from the 1960s to the early 1980s. This corresponds with the time period of relatively large phosphate mining discharges to the upper river.

- Time-series figures of specific conductance and chloride levels under all flow conditions clearly indicate that concentrations of these two water quality parameters measured at the Peace River at Arcadia gage have steadily increased over time, plainly indicating increasing seasonal contributions of higher conductivity ground water into the middle portions of the Peace River.

Joshua Creek at Nocatee

Land use in this basin has historically changed from predominantly native habitats and unimproved pasture to extensive areas of improved pasture and more intense forms of agriculture such as citrus and row crops. These changes to more intense forms of agriculture are reflected in the historic changes in the water chemistry of Joshua Creek, which over recent decades has seen large increases in concentrations of both specific conductance and total dissolved solids. The augmentation of flow over the past two decades resulting from agricultural groundwater discharges is particularly apparent during seasonal low flow periods, when irrigation is vital to agriculture. The District's *Shell Creek and Prairie Creek Watersheds Management Plan* addressed specific water quality issues in Joshua Creek, acknowledging that agricultural irrigation is the primary contributing factor to the observed water quality degradation.

The following summarizes the findings for the Joshua Creek at Nocatee site.

- It was unusual before the 1990s for measured specific conductance levels at the Joshua Creek gage to exceed 775 uS/cm, and prior to the extended 1999-2001 drought no measurements had exceeded 1275 uS/cm.

- However, since 1999 approximately half of the measured specific conductance values have been over 775 uS/cm, and seven percent of all values have been above the higher 1275 uS/cm standard.

- Time-series plots of specific conductance under low and all flow conditions clearly indicate that specific conductance has been increasing in Joshua Creek over time (Figure 5.9). The highest concentrations were observed during the 1999-2001 drought, while the recent dip reflects the much wetter than usual conditions that characterized both 2004 and 2005.

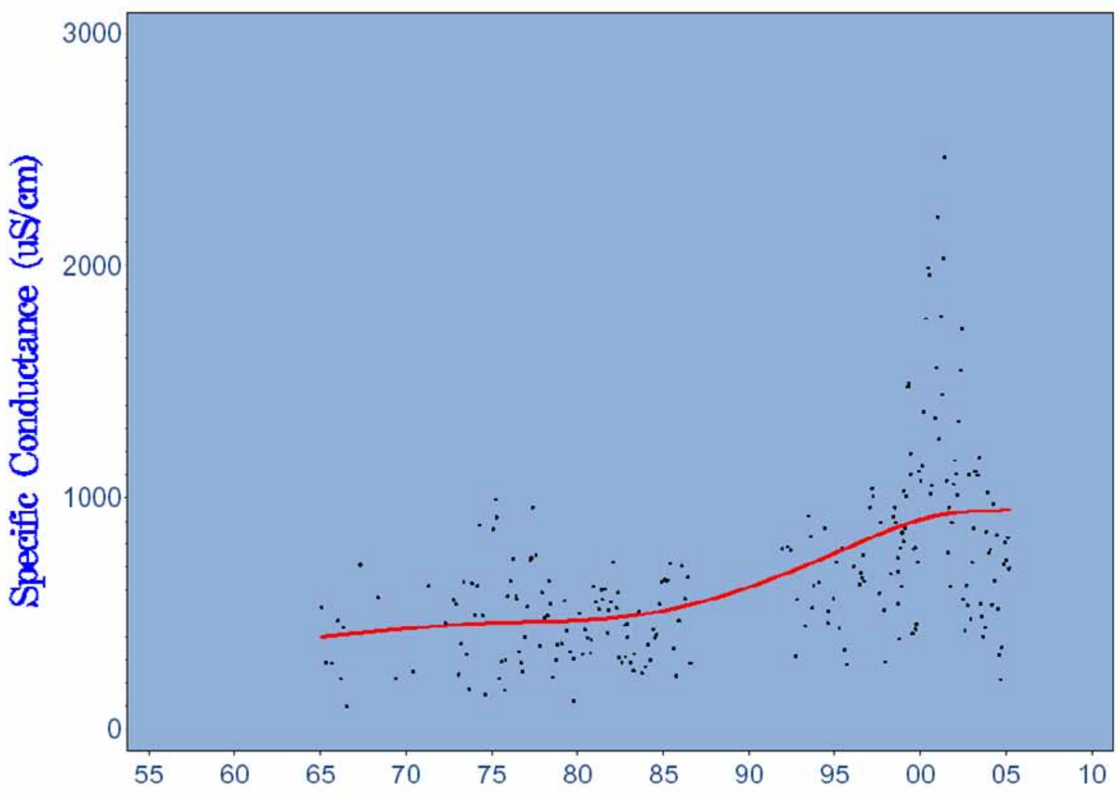


Figure 5.9 Specific conductance over time in Joshua Creek (all flows)

Horse Creek near Arcadia

There have been a number of land use changes in the Horse Creek basin that have influenced basin flows. Phosphate mining has moved south from the Payne Creek basin and continues to expand into the adjoining northern areas of the Horse Creek basin. Agriculture and urban development have both at the same time expanded in the more southern portions of the basin. Horse Creek base flows have been increasing since the early 1980s, and again are directly attributable to increasing rates of agricultural ground water discharges.

The following summarizes the findings for the Horse Creek near Arcadia site.

- Time-series plots indicate that specific conductance levels have steadily been increasing at the lower Horse Creek station over an extended period of time (Figure 5.14).

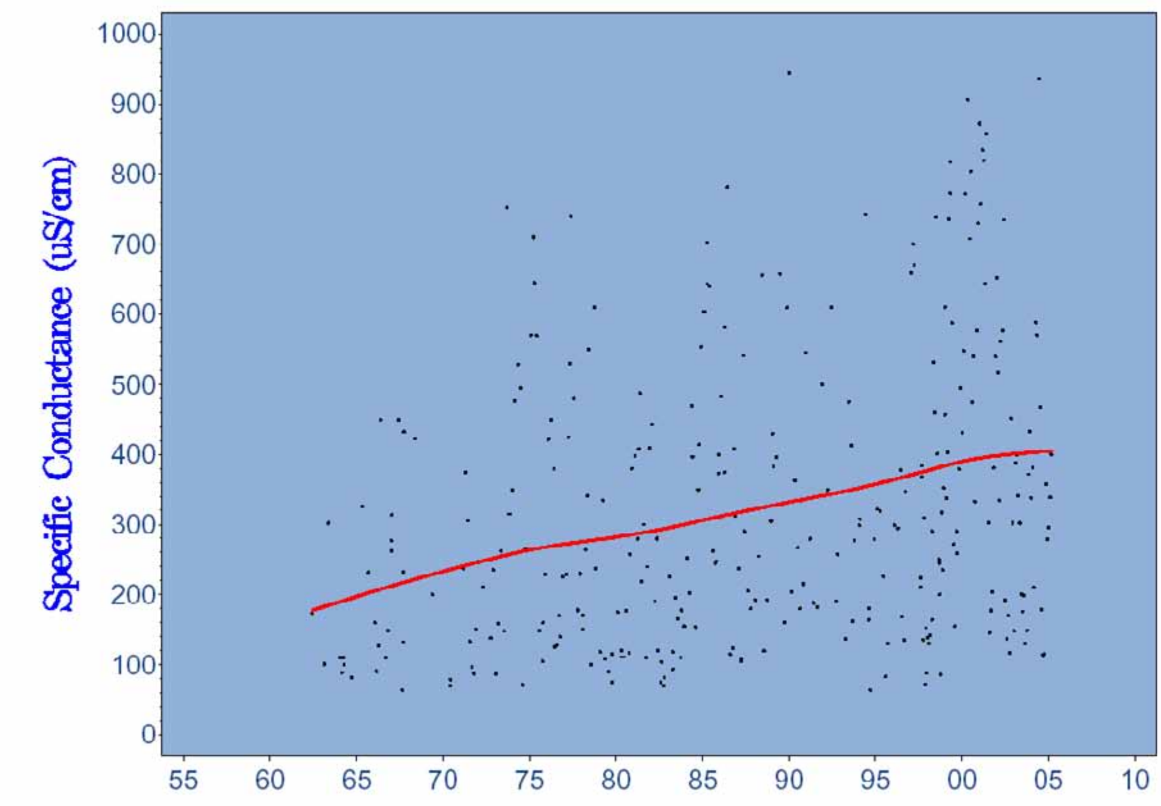


Figure 5.14 Specific conductance over time in Horse Creek (all flows)

- Concentrations are generally the highest during the seasonally dry spring and other periods of low flow, such as during the 1999-2001 drought.
- The data indicate that specific conductance and chloride have been increasing in Horse Creek, primarily due to augmented base flow by surface discharges of highly mineralized deep aquifer ground water. Specific conductance concentrations during dry periods however have exceeded the protective levels set forth by the District in the *Shell Creek and Prairie Creek Watersheds Management Plan.*

Peace River Kilometer 30.4

Monthly samples have been taken as part of the fixed station HBMP water quality monitoring program just upstream of the Peace River Facility at RK 30.4. When the Peace River at Arcadia flows are low (90-110 cfs) over an extended period of time, the reach of the lower Peace River near the Facility is often tidally subject to intrusions of brackish waters. However, beyond such low flow occurrences, the primary seasonal influences on specific conductance (and other associated water quality parameters) measured immediately upstream of the Facility are constituents contained in combined flows moving downstream from the Peace River at Arcadia, Joshua Creek at Nocatee, and Horse Creek near Arcadia stations. In order to characterize potential trends in specific conductance at RK 30.4, sampling events were removed from the data when Peace River at Arcadia flows were less than 130 cfs to assure that measured conductivities were not actually influenced by unusual tidal and/or wind driven conditions. The resulting data were then split into wet- and dry-season subsets and analyzed separately.

The following summarizes the findings for the Peace River Kilometer 30.4.

- When the wet- and dry-season specific conductance measurements are compared, there are not large differences in the slopes of the averaged fitted lines over time.
- The results show that both conductance and chlorides have been progressively increasing over time (Figures 5.18).

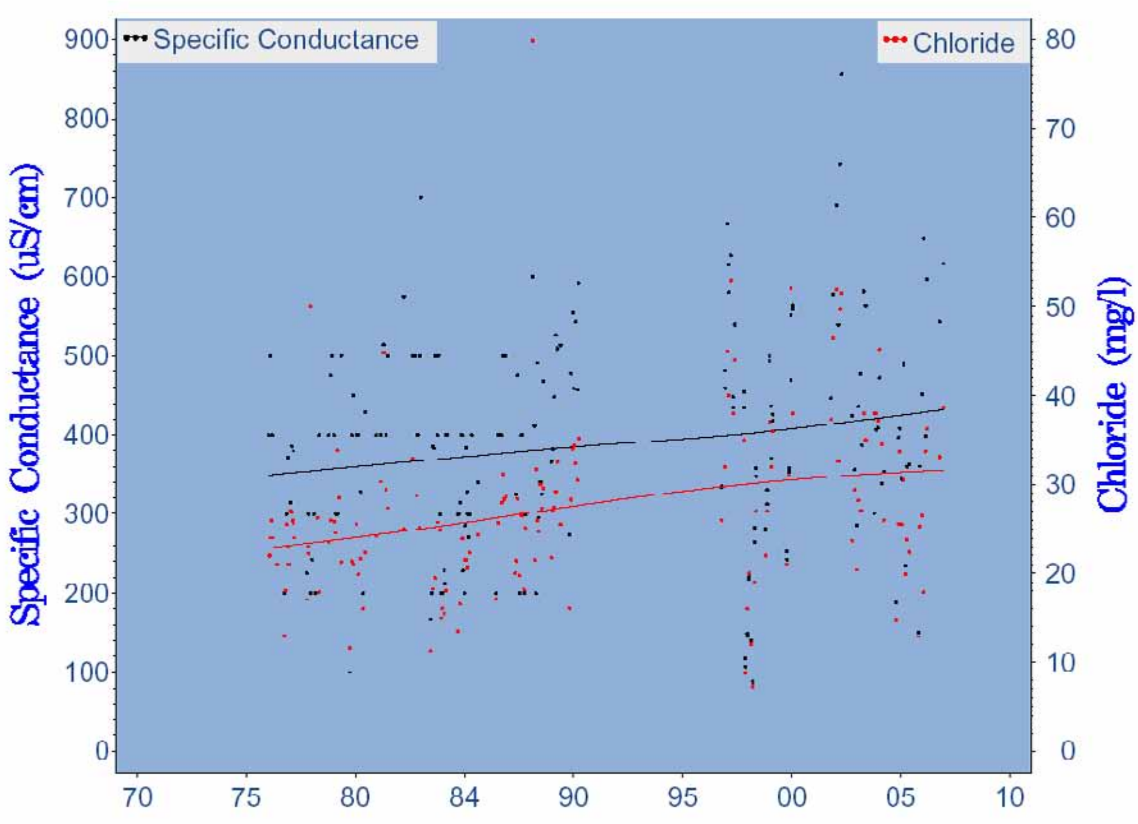


Figure 5.18 Dry Season(Oct-May) specific conductance and chloride over time at RK 30.4
Low flow (<130 cfs) data removed from RK 30.4 dataset

- When specific conductance or chloride concentrations are plotted alongside corresponding measurements from the upstream Peace River at Arcadia, Joshua Creek, and Horse Creek stations, it is evident that Joshua Creek consistently has much higher measured concentrations than any of the other locations.
- Analyses of the relative annual flow contributions of the upstream gages to total gaged flows at the Facility indicate that over time the proportion from the Peace River at Arcadia station has been decreasing, while the relative contributions from Horse and Joshua Creeks have been increasing. The proportion of flow coming from Horse and Joshua Creeks during drought years increased dramatically.

- The increasing relative importance of Joshua Creek flows during dry periods has resulted from a decoupling of rainfall and basin flow due to agricultural augmentation of flow.

Potential Impacts on Peace River Facility Operations

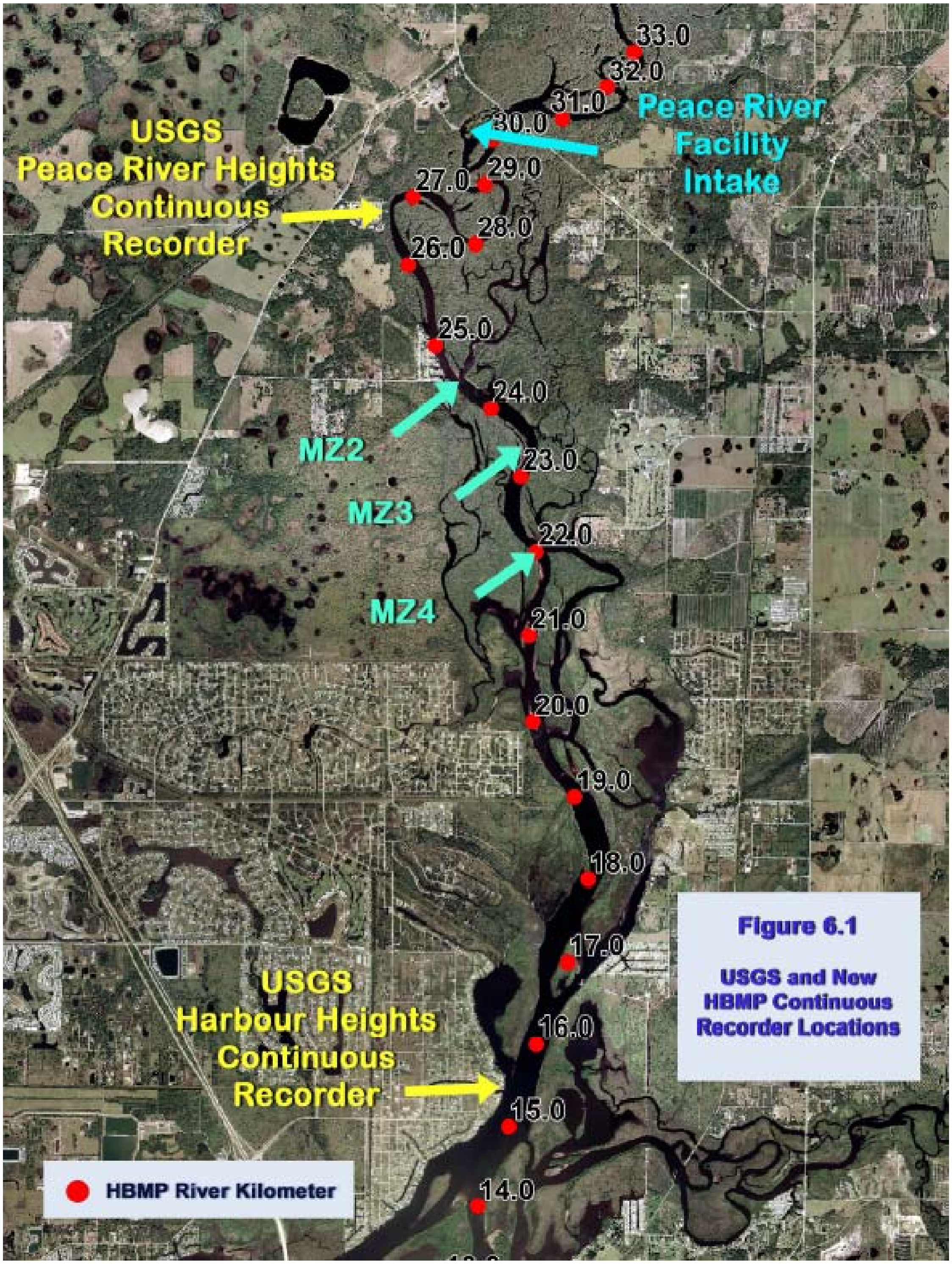
The 775 uS/cm specific conductance value is important, since it represents the level above which the Facility finds it difficult to process water using its currently available treatment methods. High specific conductance and TDS levels originating from upriver agricultural discharges during the dry-season have yet to be a serious hindrance to water supply. This is not to say that specific conductance and TDS from upstream sites may not become a problem in the future. If specific conductance and TDS continue to increase in the contributing upstream basins, it is possible that at some point high conductivity levels may affect the functioning of the Facility, particularly during low flow conditions

Brackish water moving upstream has typically only been a problem when there are not adequate river flows. Prior to the temporary emergency exception in December 2006, the water use permit did not allow water withdrawals when measured flows at the Peace River at Arcadia gage were less than 130 cfs. This level of flow adequately removed the likelihood, except under very rare instances, that salt water intrusion due to low flows would affect Facility operations.

To a great extent the historic declines in base flow due to the anthropogenic losses of spring flows in the upper Peace River watershed have subsequently been replaced by agricultural discharges in the southern watershed basins. Future reductions of these artificially augmented flows without corresponding restoration of upper watershed base flows may have the unintended consequence of shifting the salt wedge further upriver and increasing the frequency of time during which the Facility is unable to withdraw water during low flow conditions. It is important to realize that these issues are particularly pertinent seasonally towards the end of the spring dry-season, or during periods of droughts when there are anthropogenically increased TDS loads from the immediate upstream basins, combined with the upstream movement of the estuarine salt wedge.

Chapter 6 – Salinity/Flow/Withdrawal Relationships at the Continuous Recorders

Previous HBMP Mid-Term and Comprehensive Summary reports have included the development of both fixed station locations and spatial statistical models. These models were used as predictive tools to assess the magnitude of potential salinity changes due to both historic actual and potential maximum permitted Facility withdrawals The objective of this chapter is to determine enhanced statistical relationships between flows, tide stage, and withdrawals at both the two long-term (1996-2006) fixed USGS continuous gages, and the three newly installed (2006) HBMP continuous recorders (Figure 6.1). The additional series of the three HBMP continuous conductivity recorders, when combined with the two existing long-term USGS sites, were specifically designed to determine salinity changes during Facility withdrawals within the reach of the river characterized by the movement of the freshwater/saltwater interface at flows immediately above (or below) the 130 cfs threshold. The modeled salinity increases resulting from Facility withdrawals predicted by these new, enhanced models were compared and contrasted with the results of other previous salinity models, as well as those directly observed during the recently completed series of “pump tests.”



Summaries and Comparisons of the Spatial and Temporal Characteristics Measured at the Continuous Recorders

Seasonal and longer-term temporal variabilities in salinity have been recorded over approximately ten years of data collection at the two USGS continuous recorders, while only a single full year of data are currently available from the three HBMP recorders, which were installed in December 2005. Annual summary statistics (mean, median, minimum and maximum) were analyzed for gage height, and surface and bottom salinities for the USGS continuous recorders at Harbour Heights (RK 15.5) and Peace River Heights (RK 26.5). The following summarizes differences and patterns at these two locations.

- Minimum and maximum gage heights (water levels) indicate that the extremes between the highest and lowest annual levels can be as great as six to eight feet. Actual daily differences however are typically far lower. Differences between daily high and low water levels over the ten years of monitoring at Harbour Heights have averaged only 2.15 feet, while the greatest measured daily difference over the same period was just 5.03 feet.

- Annual mean and median gage heights at the downstream Harbour Heights recorder are much more uniform than corresponding measurements upstream at the Peace River Heights location. The results indicate that water levels further upstream are much more heavily influenced by higher flows during wet years, such as occurred during the interval between 2003 and 2005, than are corresponding measured gage heights further down stream. The implications of such observations are that seasonal differences in gage height need to be taken into account when developing statistical salinity models that rely on the interactions of flows and gage height. Higher gage heights during low river flows result in salinity tidally moving upstream, while higher gage heights with increasing flows reflect the combined influences of tide and the increasing resistance to downstream flow.

- Mean and median annual salinities at both USGS recorders were much higher during the extended 1999-2001 drought. The largest relative observed differences were in the maximum salinities measured at the Peace River Heights site. Peak salinities measured at this upstream site during the drought years were at least four to six times higher than the maximum annual salinity levels observed during wetter years.

- Bottom salinity measurements were systematically higher than corresponding surface measurements, and as expected the differences were greater at the downstream Harbour Heights recorder location.

Table 6.3 provides summary comparisons of surface salinities between the two USGS recorders during 2005 (a relatively wet year) and 2006 (a relatively dry year). Table 6.4 in comparison presents summary statistics that provide spatial comparisons of seasonal salinity differences in 2006, which was the first year that data were available at all five recorder locations. The average daily salinity range is shown to progressively decline moving upstream. Somewhat surprising are the relatively large daily changes in surface salinities that occur even well upstream given the right combinations of river flow, tides and wind.

Table 6.3
Comparisons of Annual Average Surface Salinity between Wet and Dry Years

River Kilometer	Mean Salinity (psu)	Median Salinity (psu)	Minimum Salinity (psu)	Maximum Salinity(psu)
2005 (Wet Year)				
RK 15.5	2.1	0.5	0.1	20.0
RK 26.7	0.1	0.1	0.1	3.3
2006 (Dry Year)				
RK 15.5	8.1	7.6	0.1	24.7
RK 26.7	1.1	0.3	0.1	14.1

Table 6.4
Seasonal and Daily Ranges of Salinity at the Two USGS and Three HBMP Continuous Recorders during 2006

Location	Annual Salinity Statistics				Daily Variability (Δ) of Salinity Statistics			
	Mean Salinity (psu)	Median Salinity (psu)	Minimum Salinity (psu)	Maximum Salinity (psu)	Mean Salinity Change (psu)	Median Salinity Change (psu)	Minimum Salinity Change (psu)	Maximum Salinity Change (psu)
RK 15.5	8.1	7.6	0.1	24.7	6.0	6.0	0	14.3
RK 21.9	2.7	0.9	0.1	18.6	3.4	3.1	0	13.7
RK 23.4	2.0	0.5	0.1	18.3	3.1	2.3	0	14.1
RK 24.5)	1.6	0.4	0.1	16.5	2.8	1.9	0	13.3
RK 26.7	1.1	0.3	0.1	14.1	1.6	1.0	0	10.4

Statistical Models of Flow versus Salinity Relationships at the Five Continuous Recorder Locations

A series of analyses were conducted to update and determine statistical relationships between the measured salinity variability at each of the established five recorder locations along the lower Peace River HBMP monitoring transect. Specific ranges of flow were applied at each location to increase the resulting model's ability to be used specifically to assess salinity changes due to existing and currently permitted maximum withdrawals. The developed statistical models initially utilized the following generalized form. Each model was then specifically modified to include only those significant terms that directly increase the overall fit using statistically significant terms. Only a single term was selected and applied to represent multiple significant terms that were themselves highly autocorrelated.

$$Salinity = \beta_{\alpha} + (\beta_1 x\ Flow1) + (\beta_2 \times Flow2) + (\beta_3 xStage) + (\beta_4 x(Stage / Flow))$$

where:

β_{α} = specific intercept

β_1 = "short-term" flow slopes (linear and/or non-linear)

β_2 = "long-term" flow slopes (linear and/or non-linear)

β_3 = gage height specific slope

β_4 = gage height/flow interaction specific slope

The developed statistical models for each of the five recorder locations were then used to predict average hour salinities over the period 1998 through 2006. Calculated mean, median, minimum and maximum predicted salinity differences between the "Actual Withdrawals/No Withdrawal" and the "Maximum Withdrawal/No Withdrawal" scenarios at each of the five recorder location were then determined. The following conclusions can be drawn from theses salinity comparisons.

- The results of the analyses emphasize the very high degrees of seasonal and inter-annual variability in salinity that naturally occurs along the lower Peace River. These differences are especially dramatic when relative comparisons are made among wet years (such as 1998, 2003, 2004, and 2005) and periods of comparatively much lower flows (such as 2000, 2001, and 2006).

- The results generally indicate higher salinity increases occurring under the maximum withdrawals allowed by the 1996 water use permit, when compared with modeled salinity changes resulting from actual Facility withdrawals. These differences are shown to have narrowed slightly following the recent 2002 Facility expansion, and thus might be expected to narrow further following the expected 2009 completion of the ongoing next expansion.

- The annual average (mean) differences in salinities due to withdrawal were the greatest at the most downstream Harbour Heights location (RK 15.5) and became progressively smaller moving upstream, being the lowest at the Peace River Heights location (RK 26.7). This result is as expected, since as flows increase the reaches of the river near and immediately below the Facility become less and less influenced by higher salinity water moving tidally upstream. Facility withdrawals can only influence those segments of the lower river that are still tidally influenced by saltwater, and thus the further a location is downstream, the greater the percent of time that salinities can be influenced by withdrawals.

- The observation that almost all the calculated median differences were zero indicates that at least half the time Facility withdrawals have limited (if any) influence on the salinities. Obviously the Facility cannot affect salinity during the period of time when gage flows at Peace River at Arcadia are below the District's low flow threshold. Conversely, when flows are high enough that a particular reach of the river is always characterized by freshwater conditions, Facility withdrawals also do not affect salinity in that portion of the lower river. A somewhat less intuitive finding of the recently completed series of "pump tests" was the observation that Facility withdrawals of ten percent or more even during low to moderate flows, primarily only resulted in higher observed salinities during incoming tides. Withdrawals seemed to have very little directly measurable influence on salinities during the outgoing and low phases of the daily tidal cycle. Since the results presented in this report were based on hourly estimates (versus daily estimates), it is therefore not surprising that more than half the observations did not predict any differences in salinities with and without withdrawals.

- The mean differences indicate that the largest changes in annual salinity occurred during the 2006 drought following the 2002 expansion. The annual average salinity changes due to actual Facility withdrawals ranged from approximately 0.1 psu upstream to 0.4 psu downstream.

- Predicted maximum "hourly" salinity differences due to Facility withdrawals are shown to typically range from approximately 0.6 psu to 1.5 psu, with the largest predicted salinity increases occurring not at the most downstream Harbour Heights recorder location, but rather spatially further upstream at the intermediate recorder locations along the HBMP monitoring transect. Again, these results are similar to the physical observations recorded during the recently completed HBMP Facility "pump tests." These results showed measurable salinity changes of similar magnitudes due to withdrawals that were temporally confined to the top end of incoming tides. Spatially, the maximum observed salinity changes during the "pump tests" were determined by the relative location of the saltwater/freshwater interface, which is a function of the interactions of both flows and tides. The predicted results of the statistical models based on hourly estimated salinities are, therefore, supported by the observed findings of the Facility "pump tests."

- Previous statistical modeling efforts have generally relied on monthly or "daily" averaged values and did not include "hourly" estimated tidal influences (gage height). These previous modeling efforts suggested that the predicted effects of freshwater withdrawals on salinity were typically between 0.1-0.5 psu along the lower Peace River/upper Charlotte Harbor HBMP monitoring transect. Similar determinations of daily average differences using the current hourly based statistical models support these previous findings.

- These results further support the findings that to date measured and predicted (modeled) temporal and spatial salinity changes resulting from Facility freshwater withdrawals have not been found to cause any pronounced, sustained or systematic changes in the salinity structure of the lower Peace River/upper Charlotte Harbor estuarine system.

Chapter 7 – Evaluation of Existing Withdrawal Schedule and Assessment of Effectiveness in Limiting Potential Impacts

The long-term goal of the combined HBMP study elements are outlined in the District 1996 Water Use Permit conditions and overall objectives, which included the following targets.

- To determine the relative degree and magnitude of effects of Facility withdrawals on ecological changes that may have been observed in the lower Peace River/upper Charlotte Harbor estuarine system.
- To evaluate whether Facility freshwater withdrawals have significantly contributed to naturally occurring ecological impacts to the estuary resulting from extended periods of low freshwater inflows.
- To assess whether the Facility withdrawals have had any significant spatial or temporal effects on the ecology of the estuary.

This chapter summarizes and provides an overview of the effectiveness the Facility's water use permits have had in limiting the potential impacts of withdrawals on the biological resources of the lower Peace River/upper Charlotte Harbor estuarine system.

Prior to the change in October 1988 of using low flow cutoffs combined with a percent reduction approach, the previous water use permit limited annual average withdrawals to 8.2 mgd (12.7 cfs). Maximum daily permitted withdrawals were limited by the Facility's physical ability to withdraw water from the river, which at that time was 22 mgd (34.0 cfs). Individual low flow cutoffs were calculated monthly, based on the previous 20 years of flow data, and ranged from lows of 64.6 mgd (100 cfs) in April and May to a high of 429.2 mgd (664 cfs) in September.

The October 1988 water use permit renewal limited withdrawals to ten percent of the previous day flow as measured at the USGS Peace River at Arcadia gage, up to the limit of 34.0 cfs per day (which still matched the pumping capacity of the river intake facility). The low flow cutoffs during the period from 1989 to 1995 were 130 cfs during the months of June through February, and then 100 cfs during the March through May spring dry-season.

The current 20-year 1996 water use permit renewal increased the low flow cutoff to 130 cfs throughout the year, while concurrently raising the maximum withdrawal capacity to 90 mgd (139 cfs). The 1996 permit renewal retained the ten percent withdrawal limit established under the previous October 1988 permit. The Authority's intent was to increase the Facility's treatment capacity to capture a greater portion of the full permitted ten percent withdrawal under higher flow conditions, thus increasing the Facility's ability to withdraw and store excess amounts above actual daily demands.

Potential Criteria for Future Modification of the Existing Withdrawal Schedule

When combined, the predictions from the series of developed statistical models and the results from the recent "pump tests" support the overall conclusion that, to date, measured and predicted (modeled) salinity increases resulting directly from Facility freshwater withdrawals have been relatively small. This is especially true given the much larger magnitudes of salinity variability that naturally occur along the lower river daily due to the effects of tides and winds, or are observed seasonally due to changes in freshwater inflows. Analyses of the HBMP data have not shown that Facility freshwater withdrawals over the past twenty-seven years have caused any pronounced, sustained or systematic temporal and/or spatial changes in either the dynamic or static salinity habitat structure along the lower Peace River/upper Charlotte Harbor estuarine system.

Given the steady increases in withdrawals since the Facility began operations in 1980, the District's permitted withdrawal schedules have been effective in limiting potential impacts. The underlying premise essential to the Facility's withdrawal schedule has been to restrict predicted (and observed) salinity increases due to withdrawals to a small portion of the natural temporal and spatial variability resulting from the combined daily and seasonal influences of tides, wind and flows. The underlying assumption is that by maintaining the basic natural variability of both the dynamic and static estuarine salinity habitat structure downstream of the Facility's withdrawals, the seasonal and annual integrity of the biological communities within and along the lower Peace River/upper Charlotte Harbor system will also be preserved.

The Facility's 1996 permitted withdrawal schedule was based on several simple key assumptions. These include the following premises.

- Increases in salinities, and therefore potential biological response, are increasingly sensitive to withdrawals under lower flow conditions.
- The withdrawal schedule should therefore include a low flow cutoff, below which no further withdrawals should occur.
- The withdrawal schedule should be based on a fixed percent of upstream gaged flows to assure that salinity increases resulting from Facility withdrawals mimic natural short-term and long-term changes in seasonal and annual flow patterns.

The Facility's withdrawal schedule has effectively limited potential impacts over the approximately twenty-year period since the combined "ten percent of flow," and 100-130 cfs low flow cutoff threshold model were adopted by the District for the lower Peace River. Although this withdrawal schedule was initially somewhat controversial, the data gathered over the intervening years in conjunction with the HBMP study elements have shown the effectiveness of the basic underlying assumptions.

However, as regional demands increase in response to future projected growth the question arises whether some changes to the withdrawal schedule can be made that when combined with ongoing and planned expansions in both Facility treatment capacity and storage, provide similar levels of protection to the salinity structure and biological resources of the lower Peace River/upper Charlotte Harbor Estuary. Discussions with the Peace River HBMP Scientific Review Panel have suggested a small number of relatively simple alternative approaches that would provide very similar levels of environmental protection while increasing potential supplies from the river. The following are some of these suggested alternatives.

Base the percent withdrawal on the combined total of the upstream gaged tributaries rather than simply the USGS Peace River at Arcadia gage.

Implement a sliding scale rather than the single fixed percent withdrawal that would allow the Authority to withdraw and store more water under higher flow conditions when resulting salinity increases would be smaller and the lower river/upper harbor estuarine system is less sensitive to potential impacts.

The current 90 mgd maximum withdrawal could be changed to allow increasingly larger volumes of water to be withdrawn and stored in the Facility's new expanded reservoir using the proposed sliding scale methodology.

Consideration should be given to applying different percent flow reduction criteria to initial late spring/early summer flows relative to similar rates of flow occurring during the late summer/fall period of declining flows.

Proposed District Minimum Flows and Levels

In August 2007, the District published an initial draft of its proposed minimum flows and levels (MFLs) for Shell Creek and the lower Peace River. The District has the responsibility to permit the consumptive use of water, while at the same time protecting these water resources from "significant harm." The District is further under legislative mandate to establish MFLs for the streams and rivers within its boundaries (Section 373.042, Florida Statutes). By statute, "the minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area."

The District has proposed using seasonal blocks corresponding to periods of low, medium, and high flows, similar to those previously defined during development of MFLs for the middle Peace River. The underlying concept of utilizing seasonal flow related time "blocks" in establishing MFLs is to get the "right flow at the right time." The proposed MFLs for each system were based on limiting changes in selected criteria to a 15 percent change.

The proposed MFL for Shell Creek was defined extending downstream from the City of Punta Gorda dam to the confluence of Shell Creek with the lower Peace River. In developing the MFL the District's selected criterion was a salinity of 2 psu, which was selected as biologically-relevant in maintaining the integrity of fish and benthic community structures. Applying this criterion, draft minimum Shell Creek flows were defined for each block and flow condition as the percentage of the Shell Creek dam flow that could be withdrawn.

The proposed MFL for the lower Peace River was defined as the segment of the river downstream from the USGS Peace River at Arcadia gage, including the total combined inflows from the Peace River at Arcadia, Joshua Creek at Nocatee, and Horse Creek near Arcadia gages. The selected salinity criteria for the lower Peace River were 2, 5, and 15 psu, which were determined as biologically-relevant in maintaining the biological integrity of fish, benthic, and vegetation community structures in the lower river. In addition, a more spatially-specific assessment of salinity within a portion of the lower river was also determined to be critical.

The Peace River HBMP Scientific Review Panel (Panel) met in December 2007. The District made a presentation outlining the proposed MFLs for the lower Peace River and Shell Creek systems, and members of the Panel have provided the District with written comments and questions. The District has forwarded these comments to its own Peer Review Panel, which is expected to provide written comments to the District in the early spring of 2008.

Recommended Actions

The District's draft proposed approach to establishing MFLs for the lower Peace River represents a systematic shift away from the previous underlying approach that has been historically used to evaluate and limit the potential salinity impacts of Facility withdrawals. Historically, the HBMP has evaluated actual and potential maximum salinity changes due to withdrawals using statistical models developed from measured fixed and moving station data. These statistical models have typically been used to determine the relative daily magnitude of salinity increases due to withdrawals at these fixed locations. The underlying assumption has been that as long as predicted and observed salinity increases due to withdrawals remain small relative to the natural daily (or seasonal) variability at theses locations, that any associated biological changes will also be limited.

The District's draft MFL approach, by comparison, is based on application of a hydrodynamic model to predict the reduction in flow needed to change the volume, area or shoreline falling under a cumulative distribution function (CDF) curve by more than 15 percent using adjusted flows over the 1996-1999 time period, which was used to approximate a historic baseline condition. Following any revision made after the District receives comments from its Peer Review Panel, it is recommended that finalized MFL criteria be applied to a select number of the statistical models developed in conjunction with the HBMP to determine relative temporal and spatial differences in predicted salinity changes under the current permitted withdrawal schedule and the final MFL scenarios. These comparisons will then be available to the HBMP Scientific Review Panel to aid in suggesting possible future changes and modifications of the Authority's HBMP program.

The Authority's current ongoing Facility expansion and construction of the new six billion gallon reservoir are projected to be completed during 2009. It is recommended that the Peace River Scientific Review Panel meet again in the later part of 2008 to discuss and make suggestions regarding potential revisions to the Facility's withdrawal schedule and HBMP monitoring programs in light of the District's revised and finalized MFLs for the lower Peace River and Shell Creek systems.

Chapter 8 – Peace River Morphometric Analysis

The objective of this section was to reproduce the earlier Peace River Morphometric Study using improved data and methods. The first report was produced in 1998 using transect surveys and geometric calculations. The number of Graphical Information System (GIS) tools available at that time was relatively limited. The presented updated results were developed using detailed bathymetric data and current advanced GIS tools. Recent enhanced bathymetry data gathered for development of the District's mechanistic hydrodynamic model for the lower Peace River/Shell Creek MFLs were used to perform this morphometric analysis (Figure 8.2 and 8.3). Raw data were collected. Complete details of the procedures used in developing the updated bathymetric data are contained in the *Bathymetric Survey in Charlotte Harbor Area* report submitted to the District by Ping Wang from the Department of Geology at the University of South Florida.

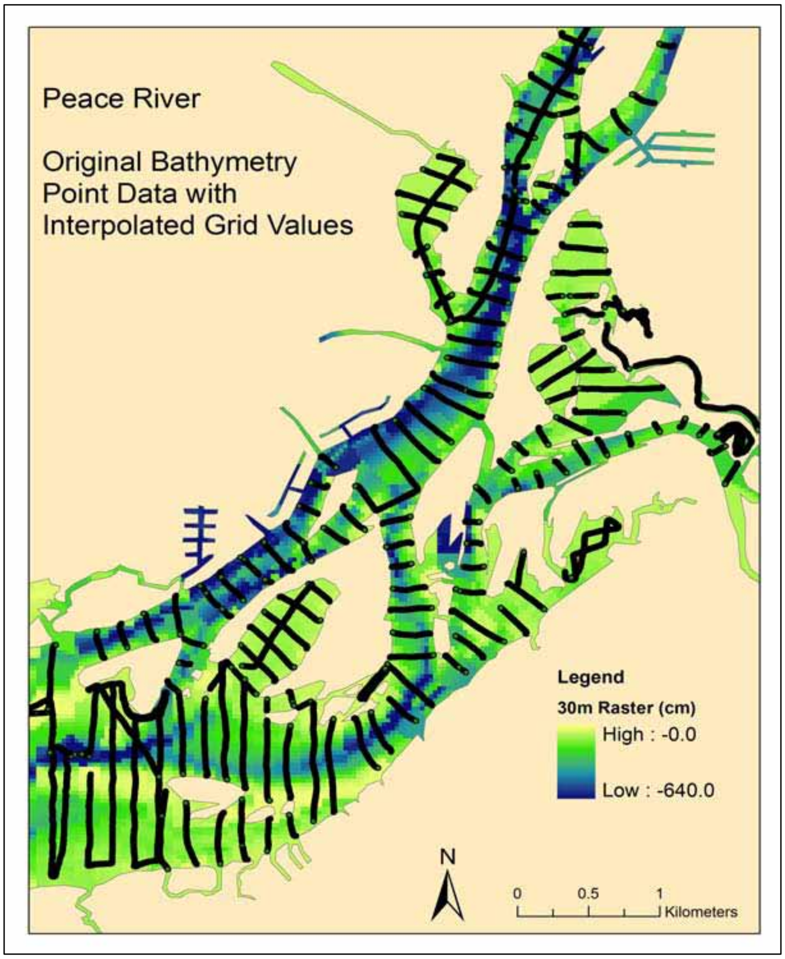


Figure 8.2. Interpolated depth values with original bathymetry points. Dark blue are deepest areas.

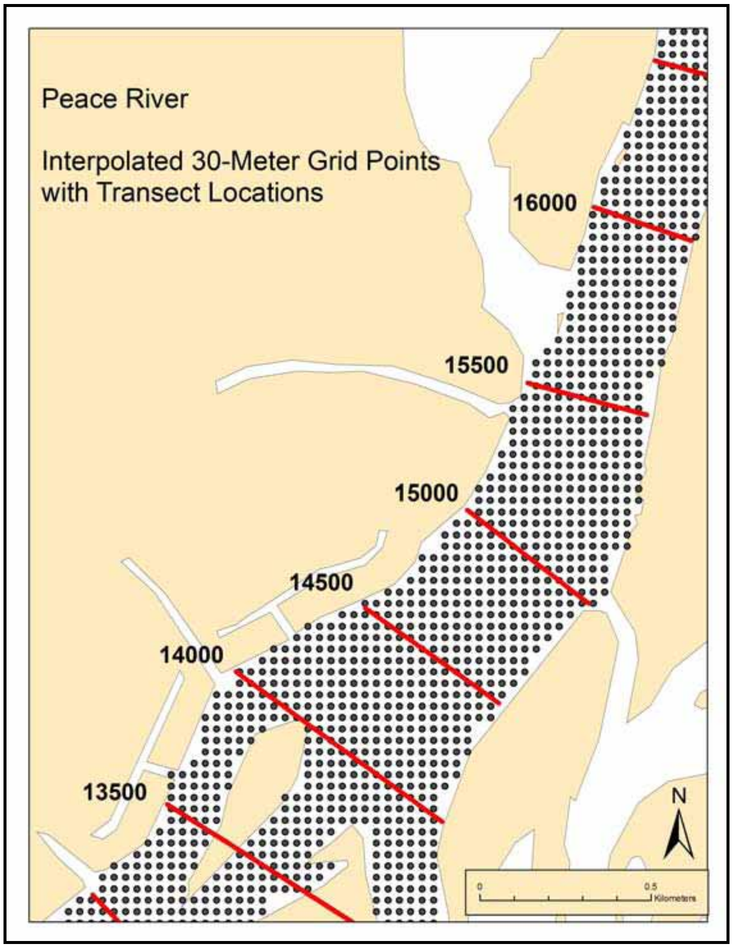


Figure 8.3. Grid values represented as points with new transect results

These data were used to calculate and depict both typical cross-sections at 0.5 kilometer intervals along the HBMP monitoring transect, as well as the following morphometric parameters for each transect and segment.

- Transect bottom length
- Transect top length (calculated)
- Transect top length (measured)
- Transect cross section area
- Transect mean depth
- Transect maximum depth
- Segment shoreline length
- Segment surface area
- Segment volume

The calculated and measured profiles are shown to have a relatively good fit between the older measured and currently calculated results providing assurance that the primary conclusions drawn in the older document should be transferable. It is however recommended that at some point in the future both river bathymetry and vegetation data may need to be evaluated again in a follow-up study, since portions of the lower Peace River morphometry could have been significantly disturbed by Hurricane Charley in August of 2004 and Hurricanes Frances and Jeanne that also impacted the Peace River watershed to a much lesser extent in the same year.

Chapter 9 – Significant Environmental Change

An approach for determining whether permitted surface withdrawals have or are causing adverse environmental changes in the estuary utilizing HBMP data was initially proposed in the *2002 HBMP Comprehensive Summary Report*. The current chapter summarizes the hierarchy of management actions proposed to be implemented in response to detected changes that could forewarn of potential future changes that would constitute an adverse change.

Regulatory Basis of Review

The District's *Basis of Review* has established a specific series of performance standards for water use permits associated with withdrawals from natural surface waterbodies.

- *Flow rates shall not deviate from the normal rate and range of fluctuation to the extent that water quality, vegetation, and animal populations are adversely impacted in streams and estuaries.*

- *Flow rates shall not be reduced from the existing level of flow to the extent that salinity distributions in tidal streams and estuaries are significantly altered as a result of withdrawals.*

- *Flow rates shall not deviate from the normal rate and range of fluctuation to the extent that recreational use or aesthetic qualities of the water resource are adversely impacted.*

An adverse environmental impact can be defined from a technical standpoint using a wide range of metrics that quantify deviations from the pre-withdrawal salinity patterns, water quality conditions, and the distribution and abundance of biological communities. The Peace River HBMP Scientific Review Panel (Panel) has been established primarily to assist District and Authority staff in assessing the continued technical efficacy and ability of the HBMP to detect potential adverse impacts caused by the Facility, and secondarily to assist in the interpretation of analysis of HBMP data.

Inherent in the District rules is the recognition that surface water withdrawals are linked to potential changes in salinity, associated water quality constituents and biological communities. Freshwater withdrawals have a direct and instantaneous physical affect on salinity, while the effects of freshwater withdrawals on other water quality constituents, and biological communities in particular, are typically indirect and more complex. Such indirect impacts are mediated by physical and chemical processes, and are typically manifested on slower time scales (weeks, months, or seasons).

The term *adverse impact*, which is included in the Authority's water use permit, has a distinct legal meaning in the context of water use permitting. The HBMP Scientific Review Panel expressed a concern that delaying action until this regulatory threshold had been cross limited the ability to avoid perceived potential impacts. Therefore, based on consultation with the HBMP Scientific Review Panel and District staff, the *2002 Peace River Comprehensive Summary Report* proposed that the less restrictive term *significant environmental change* be used by the Authority as a lower threshold criterion for assessing the findings of the HBMP.

Significant Environmental Change

A detected change, supported by statistical inference or a preponderance of evidence, in the normal or previous abundance, distribution, species composition, or species richness of biological communities of interest in the lower Peace River and upper Charlotte Harbor that is directly attributable to reductions in freshwater inflows caused by permitted surface water withdrawals.

Authority's Management Response Plan (MRP) to a Potential Observed Significant Environmental Change

Waiting until an adverse environmental impact has occurred to initiate appropriate management actions or remedial measures reduces the opportunity to adequately protect resources that may be at risk. The Authority has therefore adopted a MRP that is a proactive approach to protecting the resources of concern in the lower Peace River estuarine system.

The plan recommends that salinity deviations be used as the primary indicator of significant environmental change that could lead to potential adverse environmental impact. In addition, salinity deviations would be used as the triggering mechanism for a range of management responses aimed at reversing or minimizing the change to prevent potential adverse environmental impact. Salinity deviations from the target distribution will be evaluated in terms of magnitude, spatial extent, and/or temporal duration to develop a decision tree that is linked to alternative management actions (Figure 9.3).

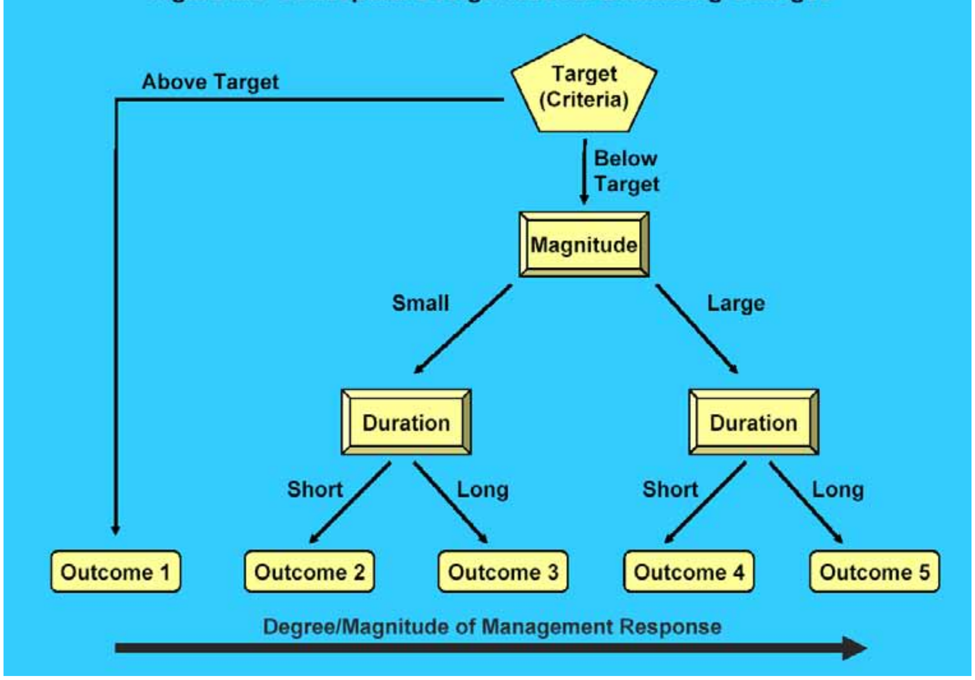


Figure 9.3 Conceptual Design Tree for Evaluating Changes

The objective of implementing a management response is the prevention of an “adverse impact”. Any hydrobiological change must always be framed within the degree of certainty that the detected change is real, and not solely due to chance. Therefore, the intensity of the management response should be tied not only to the magnitude or severity of the hydrobiological change, but also to the degree of certainty that the detected change is real, and whether it is caused by Authority withdrawals. Table 9.1 presents a conceptual matrix approach that integrates the magnitude of the detected change and the probability that the change is due to chance alone.

Table 9.1
Conceptual Decision Matrix For Determining An Appropriate Management Response To Detected Hydrobiological Change

Probability of Making a Type I Error	Magnitude of Detected Hydrobiological Change		
Alpha	Small	Moderate	Large
0.20	Data Comparison	Scientific Review Panel Meeting	Redirected Sampling
0.10	Scientific Review Panel Meeting	Redirected Sampling	Determination of Significant Change
0.05	Redirected Sampling	Determination of Significant Change	Regulatory Summit Meeting

If the detected change is relatively large, but the degree of certainty is low then a less intense management response would be appropriate. If, on the other hand, the detected change is considered to be moderate, but the degree of certainty is high, then a more intense management response would be indicated. The approach of the selected management response would also depend on whether the observed change was found to be attributable directly to Facility withdrawals or potentially to anthropogenic upstream activities.

Chapter 10 – Proposed Monitoring Design Modifications to the Existing Long-term HBMP Elements

The primary objectives of this final chapter are to review the effectiveness and address potential modifications of the current HBMP study elements based on the results of the analyses and conclusions presented in this *2006 HBMP Comprehensive Summary Report.*

HBMP Monitoring Objectives

The combined elements of the program’s design need to meet the specific expectations and objectives set forth in the permit as well as provide sufficient long-term information on which to base the development of answers to potential future questions that might be expected to arise. The overall goal of the HBMP continues to be to provide the District with sufficient information to determine whether the water quality characteristics and biological communities of the lower Peace River/upper Charlotte Harbor estuarine system have been, are being, or may be significantly adversely impacted by permitted facility withdrawals.

HBMP Design Criteria

In order to effectively meet these goals and objectives, the integrated design of HBMP elements should incorporate the following criteria.

- The program needs to identify those appropriate physical and biological indicators, and specific mechanisms of action, potentially subject to significant changes resulting from permitted freshwater withdrawals from the lower Peace River/upper Charlotte Harbor estuarine system.

- The program should determine and predominantly focus its efforts in those geographical regions of the lower river where naturally occurring and Facility induced changes in flows would be expected to result in the greatest potential observed changes in identified key estuarine characteristics.

- The design of the HBMP monitoring element should include sufficient spatial and temporal intensity to assure detection of measurable changes in selected physical/chemical/biological parameters resulting from changes in freshwater inflows.

It is important that each HBMP study element, as well as the overall program, have specific clearly stated goals and objectives to cost-effectively meet the design criteria needed to accomplish the monitoring program's multiple expectations. These goals and objectives need to clearly establish the scientific basis needed to provide sufficient information to meet the District's criteria for required reasonable assurance, as well as provide meaningful information to both the public and the members of the HBMP Scientific Review Panel. It is also essential that the HBMP study elements delineate the types and amounts of monitoring data necessary to construct, calibrate, and verify the quantitative predictive models needed to evaluate both current as well as possible future alternative withdrawal strategies.

It is also important that the HBMP design criteria provide for opportunities, where feasible, to include the incorporation of short-term, intensive monitoring elements needed to provide answers to specific questions or issues that may arise periodically during the review process. The HBMP design elements further need to be sufficiently flexible to allow incorporation of modifications when and where changes in conditions, or new gathered information, suggest the need for specific monitoring program changes.

Indicators of Environmental Change

Possible monitoring parameters can generally be divided into three primary categories relative to their degree of overall importance in assessing the potential impacts of Facility withdrawals on the lower Peace River/upper Charlotte Harbor estuarine system.

- Those ***critical*** to the overall success of the monitoring program
- Parameters that would provide ***desirable*** additional information
- Indicators that may have some ***potential*** future application

The HBMP monitoring design needs to focus on identifying and incorporating those *critical indicators* known to exhibit marked direct responses to variations in freshwater inflow, since it is these parameter measurements that present the greatest probability of both detecting and assessing the principle underlying causative factor(s) to observed environmental changes.

Since the initiation of HBMP monitoring in 1976, the program has incorporated a number of differing physical, chemical, and biological study elements. Modifications have been made to the elements of the HBMP throughout its history. Historically, those major monitoring elements aimed at assessing direct relationships with variations in freshwater inflow have had the longest histories. Other program elements, primarily those focused on assessing indirect biological indicators, have extended over a number of years and then ended once a sufficient baseline basis of information had been accumulated.

Proposed HBMP Sampling Design Modifications

The following series of proposed modifications are presented based on the results presented in this *2006 HBMP Comprehensive Summary Report*, and recent recommendations and suggestions made by the HBMP Scientific Review Panel.

Additional Continuous Recorders

The HBMP study design includes continuous (fifteen-minute interval) measurements of subsurface and near bottom water column conductivities at two fixed USGS monitoring gages located at River Kilometers 15.5 and 26.7. The downstream gage was installed in 1996 and the upstream gage was added the following year. In December 2005, the Authority installed three new HBMP continuous recorders measuring surface conductivities at River Kilometers 21.9, 23.4 and 24.5. The locations of these additional gages were specifically selected to determine salinity increases directly due to Facility withdrawals within the reach of the river characterized by the movement of the freshwater/saltwater interface at flows immediately above (or below) the 130 cfs threshold.

Based on the ongoing analyses of the data collected from these five continuous recorder locations, the Peace River HBMP Scientific Review Panel recently recommended that the Authority consider expanding the current array of continuous recorders to include instruments placed near and upstream of the Facility. In response, the Authority has purchased additional continuous recorders and selected several potential new sites for their deployment.

Chlorophyll *a* Phytoplankton Biomass Measurement

Both the "fixed" and "moving" HBMP water quality study elements currently include monthly monitoring of chlorophyll *a* levels along the lower river/upper harbor monitoring transect. However, advances in fluorescence technology have resulted in the recent capability of semi-quantitatively measuring of *in situ* phytoplankton chlorophyll *a* estimates, without having to employ extensive filtering and expensive laboratory chemical extraction and analyses. *In situ* fluorometer chlorophyll *a* measurement procedures also present the potential utility of particularly near-real-time data acquisition in synoptically identifying spatial phytoplankton biomass patterns along the lower river salinity gradient. Ongoing work by University of South

Florida researches have recently provided insight into correcting *in situ* fluorometer chlorophyll levels in highly colored waters such as the Peace River estuarine system.

Previously reported results, from both the “fixed” and “moving” HBMP study elements, have indicated the existence of a distinct, seasonally-variable chlorophyll *a* maxima along the lower Peace River/upper Charlotte Harbor monitoring transect. Including a new HBMP study element employing *in situ* fluorometer chlorophyll *a* methodology could provide the fine-grained spatial information needed to accurately define on a monthly basis both the magnitude and spatial extent of variations in chlorophyll *a* patterns within the lower Peace River/upper Charlotte Harbor Estuary. Accurate spatial determinations of the relative intensity and location of monthly chlorophyll *a* maxima patterns would provide additional information regarding the known seasonal interactions between changes in freshwater flow (relative to additions of both nutrients and color) and the seasonal movement of important estuarine zones of primary (and secondary) production.

Scope and Frequency of Major HBMP Reports

The 1996 permit renewal required that the HBMP program submit “Midterm Interpretive Reports” the end of each third year and “Comprehensive Summary Reports” approximately at the end of the fifth year within each of the five-year intervals of the overall 20-year life of the permit. The permit also required the Authority to provide “Data Reports” to the District during the 1st, 2nd and 4th years of each five-year cycle. The following summarizes the relative differences, and levels of information and analyses originally envisioned regarding each of these three types of reports in the 1996 permit conditions.

- **Annual Data Reports –** These reports were simply to contain all raw data collected during the previous year (typically delivered to the District as SAS data sets covering the entire cumulative period-of-record), with summary data submitted in tabular form and accompanying text limited to an explanation of variable names and descriptions of any problems encountered or important observations made during the preceding interval.

- **Year Three Midterm Reports –** These expanded reports were to contain basic figures, tables and statistical summaries of the data for the entire period-of-record for selected variables, as well as providing the District with all data. The interpretative text contained within the midterm reports was to be restricted to descriptions of the monitoring progress, and observed changes in stream flow, salinity and other selected variables.

- **Year Five Reports –** The overall objective of these comprehensive, interpretive reports was to provide complete analyses of all the continuing data collected to date. These reports were to determine whether long-term patterns or trends could be identified in key selected variables, and identify relationships between ecological characteristics and freshwater flows. The reports were to further analyze the data to determine the status of the lower river/upper harbor estuarine system with regard to changes in freshwater inflows, and determine if the biological health and productivity of the estuary were under stress due to natural periods of low inflows and potentially associated influences of Facility withdrawals. The proportions of the freshwater estuarine flow budget reduced by withdrawals were to be determined relative to the magnitude of the overall effects on the ecology of the estuary.

The HBMP design was to be reviewed and re-evaluated within these year five reports, and modifications proposed as necessary. These comprehensive summary reports were envisioned as the District's primary tools for evaluating the presence or absence of adverse ecological impacts, determining the relative significance of withdrawals to any such observed impacts, and assessing environmental considerations regarding further increased river withdrawals. The effectiveness of the existing withdrawal schedule was to be evaluated in preventing adverse environmental impacts, and potential environmental factors related to the feasibility of expanded diversions and additional storage to increase potential water supplies were to be determined.

In response to the high degree of public interest and concerns regarding the overall status and health of the lower Peace River/Charlotte Harbor estuarine system, the Authority has voluntarily provided expanded reports beyond those basics stated in the 1996 permit requirements. The Authority has continued to submit Annual Data Reports to the District yearly. These annual reports go far beyond simply providing tabular summaries of the previous year's data and "limited" text. In addition, the Authority has submitted Midterm Interpretive Reports covering monitoring through 2000 and 2004, and a previous Comprehensive Summary Report preceded this current document summarizing information through 2002.

It is recommended that the Authority continue to submit Annual Data Reports to the District following the currently expanded format that has been provided to the District. These reports actually meet or exceed the basic requirements set forth in the permit for the Year Three Midterm Reports. It is recommended that the Authority also continue to submit Comprehensive Summary Reports to the District and HBMP Scientific Review Panel following the current approximate five-year intervals. It is, however proposed that the Authority drop the separate Year Three Midterm Reports, since the information is highly repetitive to that currently contained in the Annual Data Reports and the Comprehensive Summary Reports. It is recommended that the Authority continue to provide specific, focused reports such as the recently submitted "Facility Pump Test Report" on an as-needed basis in response to specific requests made by the HBMP Scientific Review Panel following consultation with District staff.

2006 HBMP Comprehensive Summary Report

Required by

Southwest Florida Water Management District
Water Use Permit 20010420.0004

Prepared for

Peace River Regional Water Supply Facility

Peace River Manasota Regional
Water Supply Authority

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Submitted: April 2008

(Revised: December 2009)

Acknowledgments

Members of the HBMP Scientific Review Panel have previously expressed the desire that the major summary reports should include not only simply updated information and new analyses, but also provide comprehensive overviews of the Facility's operations, current and projected future water demands, the historical and current monitoring components, and summaries of the key findings and conclusions presented in previous HBMP documents. A goal of this report therefore is to provide an updated single document containing the necessary background information for those not familiar with the long-term history of the HBMP program and related watershed/estuarine issues.

We would like to thank the staff of Janicki Environmental and especially Ravic Nijbroek for providing the analyses and write-up of the results presented in the revised "Peace River Morphometric Analysis" presented in Chapter 8. We would also like to acknowledge the efforts of Sam Stone and Mike Coates with the Authority for providing information, and their review and comments.

The long-term historic and current data summarized in this report have been gathered and compiled from a number of sources that are specifically identified within the report. Additional detailed information regarding these data can be found in the Annual Data Reports submitted to the District.

The following summarizes the major contributions of the members of the current HBMP project team.

- EarthBalance – provides all *in situ* water column physical measurements and the collection of water chemistry samples for both the "fixed" and "moving" station elements of the HBMP.

- Benchmark Laboratory – conducts all HBMP water chemistry analyses.

- U.S. Geological Survey (Tampa Office) – provides information from the two conductivity / temperature / water depth gages located in the lower Peace River that continuously collect data at 15 minute intervals. USGS also collects daily stream flow data at a wide number of gaging locations throughout southwest Florida.

    - Peace River at Bartow (02294650)
    - Peace River at Fort Meade (02294898)
    - Peace River at Zolfo Springs (02295637)
    - Peace River at Arcadia (02296750)
    - Joshua Creek at Nocatee (02297100)
    - Horse Creek near Arcadia (02297310)
    - Prairie Creek near Fort Ogden (02298123)
    - Shell Creek near Punta Gorda (02298202)
    - Myakka River near Sarasota (02298830)

- Big Slough near North Port (02299450)

- PBS&J (Tampa Office) – is responsible for all data collected at the three Authority HBMP recorders located in the lower Peace River that continuously collect data at 15-minute intervals. Measurements at each of the three gaging locations include surface conductivity and water temperature.

- Peace River Manasota Regional Water Supply Authority – provided measurements of daily withdrawals by the facility.

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1.0 Introduction

This introductory section provides a brief overview of the water use permit history (issued by the Southwest Florida Water Management District (District)) of the Peace River Manasota Regional Water Supply Authority's (Authority) Peace River Regional Water Supply Facility. Also described are the major study elements of the Hydrobiological Monitoring Program (HBMP) that have been associated with specific conditions of these permits. This introduction further summarizes the report's general organization and overall primary objectives.

1.1 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). Projected population estimates at the time suggested that the number of new residents in these planned communities could well exceed a quarter of a million by the year 2020. The primary goal of GDU 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 (Charlotte, Sarasota, and DeSoto) county areas where GDC communities were being constructed or planned for development.

General Development Corporation determined that an assessment study was needed to evaluate the feasibility of locating a regional water supply system on the Peace River in Desoto County near State Road No. 761. Staff from the Rosenstiel School of Marine and Atmospheric Science at University of Miami were contracted to assess the potential environmental impacts to the lower Peace River and upper Charlotte Harbor of projected future freshwater withdrawals.

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 (Michel *et al.* 1975). 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 these initial 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 developed to predict changes in salinity at sites extending from near the mouth of the river upstream to the planned future location 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.

On December 10, 1975, the Consumptive Use Permit #7500016 for the Peace River Regional Water Supply Facility was signed between General Development Utilities, Inc. and the Southwest Florida Water Management District. Specific conditions of the District's 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 seasonal, long-term, and withdrawal related changes in Peace River flow. The long-term HBMP study elements have specifically been designed to evaluate the consequences and significance of natural changes in salinity, water quality and biological characteristics inherently associated with seasonal variations in freshwater input. In particular, a number of monitoring program 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 lower Peace River/upper Charlotte Harbor Estuary. A history of the HBMP and descriptions of its major historic study elements are described below.

Construction of the Peace River Facility was completed and withdrawals began in the spring of 1980. As part of the initial construction, a relatively small off-stream surface water reservoir was constructed and soon thereafter construction began on a series of Aquifer Storage Recovery (ASR) wells. Adequate storage was identified as an important component early in the initial evaluation and planning for the Peace River Facility. Unlike many other water treatment facilities 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. The District mandated as an initial permit condition that no withdrawals could be made below certain river flow levels. As a result the Peace River Facility has always relied on off-stream storage to maintain supplies during the dry season and/or drought conditions.

The first permit renewal occurred in 1982. Withdrawals had recently begun and only a limited number of changes were made to the HBMP monitoring design. By the second permit renewal in 1988, extensive amounts of data had been collected as part of the ongoing HBMP studies and these data were used to make significant modifications to both the monitoring efforts and withdrawal schedule (Table 1.1).

Prior to 1988, the regulatory limit for maximum daily withdrawals from the Peace River was 22 mgd (34.0 cfs) which could be withdrawn as long as the measured stream flow at the Arcadia gage was above the regulatory minimum flow for each month. 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 records of the previous twenty years of stream flow 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 the USGS Peace River at Arcadia gage) by as much as 25 percent on some days. 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 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 GDU agreed that the withdrawal schedule should be modified. A minimum criterion was established with no withdrawals when flows at Arcadia were below 100 cfs during the three typically dry spring months (March through May) and 130 cfs during the remainder of the year. Beyond that, withdrawals could equal up to 10 percent of the daily measured gaged flow at Arcadia, up to a maximum not to exceed 22.0 mgd (34 cfs). This schedule allowed withdrawals to more closely follow the natural variability of rainfall and flow.

In 1990 General Develop Utilities parent company GDC filed for bankruptcy protection. Charlotte County took control of GDU facilities within Charlotte County, and ownership of the Peace River Regional Water Supply Facility was transferred to the newly formed Peace River Manasota Regional Water Supply Authority in mid 1991. The Authority was formed and functions through agreements made among Charlotte, Desoto, Manatee, and Sarasota counties. As owners of the Peace River Facility, the Authority soon began making plans for expansion of the treatment facilities to both increase reliability and provide additional water to the region beyond that originally envisioned by GDU. 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. In 2002, the Authority completed a major expansion of the Peace River Facility and its interconnection with the Carlton Water Treatment Facility in Sarasota County as the first step toward this long-term goal.

The current twenty-year renewal of the Facility's Water Use Permit (No. 20010420.0004) was issued by the District to the Authority in March 1996 (a summary of the history of the Facility's District Water Use permits is presented in Table 1.1). The permit contained specific conditions for the continuation and enhancement of specific study elements of the ongoing lower Peace River/upper Charlotte Harbor Estuary HBMP and established a series of maximum withdrawal quantities. This permit increased the minimum flows measured at the upstream Arcadia gage, under which no withdrawal can occur, to 130 cfs during all months of the year. Beyond that, withdrawals can still not exceed ten percent of the preceding day average daily Peace River at Arcadia gaged flow. The existing 20 year permit encourages the Authority to withdraw, treat and store more river water under high flows while limiting withdrawals to ten percent, and not exceeding 90 mgd (139 cfs).

Table 1.1
Historic Summary of Facility Permits

Year	Dec 1975	March 1979	May 1982	Oct 1988	March 1996
Water Use Permit Number	27500016	27602923	202923	2010420	2010420.02
Average Permitted River Withdrawal (mgd)	5.0	5.0	8.2	10.7	32.7
Maximum Permitted River Withdrawal (mgd)	12 & 18	12 & 18	22	22	90
Diversion Schedule Low Flow Cut off (cfs)	91 – 664	91 – 664	100 – 664	100 & 130	130
Maximum Percent Withdrawal of River Flow	5	5	n/a	10	10

It should be noted that the District's permitted withdrawals to date for the Peace River Facility have been more conservative and well below the "safe" levels originally proposed by the University of Miami Study. The magnitudes of the observed and predicted changes in salinity and isohalines due to Facility freshwater withdrawals have indicated that the predicted influences of freshwater withdrawals under the Facility's existing withdrawal schedule typically impact the daily average salinity along the lower river in the range of 0.1-0.3 ppt. To date, these efforts have suggested that any Facility salinity impacts probably could not easily be detected, other than by using continuous recorders, given the normal distributions and daily tidal ranges of salinity along the lower Peace River/upper Charlotte Harbor HBMP monitoring transect. Given the far greater natural daily and seasonal ranges of salinity variation in the lower Peace River/upper Charlotte Harbor estuary and the lack of information regarding the potential consequences of such small salinity changes on tidal estuarine processes, the ecological consequences of these small but predictable changes are exceptionally difficult to evaluate and predict. Thus, while withdrawals have resulted in predictable changes in salinity, the normal daily and seasonal variability in estuarine salinity distributions indicate that the changes due to Facility withdrawals do not appear to be of a magnitude likely to be easily measured directly. This suggests that evaluating and predicting the effects of withdrawals on the salinity distributions within the lower Peace River/upper Charlotte Harbor estuarine system may ultimately best be accomplished using hydrographic and statistical modeling approaches in assessing, comparing and quantifying the potential for significant adverse harm to the mechanisms by which Facility withdrawals might lead to significant adverse impacts.

1.2 Long-term Water Demand and Supply Projection

The purpose of this section is to provide a synopsis of historical demand in the region receiving water from the Peace River, and the related withdrawals from the Peace River. Included are a review of historical demand and projected demand, and comparisons of actual river withdrawals, permitted river withdrawals, and the capacity of the Facility.

1.2.1 Major Facility Physical Expansions and Capabilities

In order to meet increasing regional demand (see below) the Authority has expanded the Facility to increase its supply potential. The ability of the Facility to pump river water from 1980 to 1989 was limited to 34.0 cfs. The initial actual treatment capacity of the Facility, between 1980 through 1988 was just 6 mgd (9.3 cfs). In 1989 the treatment capacity of the Facility was doubled from 6 to 12 mgd (18.6 cfs).

The Facility's initial storage capacity was 625 million gallons in the form of an 85 acre off-stream, surface reservoir. Additional storage capacity was added in 1985 with the development of a series of Aquifer Storage Recovery (ASR) wells. The initial ASR wells added a further 1,080 million gallons of storage capacity by 1988, to give the Facility a total combined storage capacity of 1,705 million gallons. An additional expansion of ASR wells in 1989 again increased the Facility's total storage capacity to 2,785 million gallons. The storage capacity was again increased in 1995 by further expansion of ASR wells, providing for a total combined Facility storage capacity of approximately 3,865 million gallons.

The most recent expansion of the Facility capacity became operational in December 2001. This expansion consisted of doubling the Facility's previous existing treatment capacity from 12 mgd to 24 mgd, as well as adding an additional twelve ASR wells to the system's existing, previously nine ASR wells, giving the Facility a total storage capacity of approximately 7,500 million gallons. At the same time a total of 27 miles of new water transmission lines were completed wells in order to provide additional potable water supply to Charlotte, DeSoto and Sarasota Counties as well as the City of North Port.

The Facility presently has the capacity to treat up to 24 mgd is equivalent to withdrawals from the river of 37.1 cfs. The Facility's existing raw water river diversion station is comprised of four pumps having a combined maximum capacity of 44 mgd (68.0 cfs). In comparison, the long-term average annual daily total gaged river freshwater flow upstream of the Peace River Facility since 1976 has been approximately 796 mgd (1233 cfs). During periods of high river flow, raw river water is stored in an off-stream surface reservoir and any excess treated water is stored in the system's ASR wells. Conversely, when water is unavailable from the Peace River due to the established low flow cutoff of 130 cfs, water can be pumped from the raw off-stream surface water reservoir to the Peace River Facility for treatment, and/or previously treated water can also be recovered from the ASR well system to meet the water supply demands of the Authority's service area.

In order to meet the growing demand, the Authority has started another expansion of the Facility. The current expansion includes an increase to the river pumping capacity of the Facility river pump station to 90 mgd, which is the current permit limit. The current ongoing Facility expansion includes a doubling of treatment capacity to 48 mgd. A much larger new regional 640 acre off-stream reservoir with a capacity of 6 billion gallons is also under construction, and the existing transmission piping networks will also be gradually expanded to optimize regional water delivery. Completion of the ongoing physical expansion of the Facility's capacity and the new reservoir under the current Water Use Permit are scheduled for 2009.

1.2.2 Regional Demand for Water

Demand is a direct function of (among other things) population. Since 1970, population levels have steadily increased in each of the four counties (Charlotte, De Soto, Manatee, and Sarasota) serviced by the Authority (**Figure 1.1**). The City of North Port, which also receives water from the Peace River Facility, is included in the Sarasota County census. The projected regional population (according to the Florida Office of Economic and Demographic Research) is expected to reach approximately 1.29 million by the year 2030. Such projections may ultimately be revised upward or downward depending on economic conditions. However, such a projected increase would suggest an expected approximate increase of about one million people from 1970, with the greatest absolute increase expected to occur in Sarasota County (**Table 1.2**).

Demands for water supplies from the Peace River Facility have progressively increased since it began operation in 1980 (**Figure 1.2).** There was a rapid increase in regional demands from the Facility following completion of recent expansion in December 2001. The relative magnitude of the resulting annual increase is indicated by the non-overlapping notches around the annual medians. When mean monthly river withdrawals and mean monthly demands are compared (**Figure 1.3**) it is clear that river withdrawals have generally exceeded demands, except seasonally during the typical dry spring months and during periods of extended drought such as occurred between 1999 and 2002. During both the annual spring dry season months and/or during drought conditions, the permit's low flow cutoff of 130 cfs based on the Peace River at Arcadia gage often mandates little to no Facility river water withdrawals. Monthly demands under these seasonally fairly frequent conditions far exceed permitted river water withdrawals, and the difference is made up from either available surface storage from the reservoir or by previously treated and stored groundwater from the ASR wells.

The Authority has developed projected estimated future demands based on available information from its member governments and other regional sources. When evaluating these demands it is important to note that the total water supplies for Charlotte, DeSoto and Sarasota counties (and the city of North Port) come from a variety of additional sources. Only those portions of the total regional demand that are expected to be met by Peace River withdrawals are presented. The estimates of future demands are based on the projected available supply, in compliance with the current existing permit conditions (i.e. an average annual withdrawal and delivery of 32.7 mgd). Thus, the estimated Facility demands are based on projected seasonal flows from the available historic record and existing permitted quantities, rather than projected population increases. The total projected Facility water demands through 2011 are projected to continue to be the greatest from Charlotte County and the lowest from DeSoto County (**Figure 1.4).** However, the largest projected increases in demands over this period and potentially into the future are expected to occur from Sarasota County.

1.3 Authority's Master Water Supply Plan and Alternate Source Studies

Currently, the Authority serves Charlotte, DeSoto, Sarasota counties and the city of North Port through water production, storage, treatment, delivery and ancillary facilities. By 2014, the Authority will also be responsible for providing additional water supplies to Manatee County. A draft version of the *Integrated Regional Water Supply Master Plan* (Master Plan) was released by the Authority in March 2006. This document was produced to ensure the Authority's mission statement "to provide the region with a sufficient high quality, safe drinking water supply that is reliable, sustainable and protective of our natural resources now and into the future" can be maintained. The Master Plan discusses the current Facility and planned future expansions proposed to continue to meet the required water supplies for its customers. A detailed Regional System Reliability Model (RSRM) was developed for the Authority to quantify current and future water supply, storage, treatment and delivery systems. This model was a key component of the Master Plan, which provides multiple scenarios allowing the Authority to select the most cost-effective and dependable mechanisms to develop water supplies to meet future projected demands.

The Master Plan presents and summarizes 20 year projections for both potential available additional water supplies and projected future needs. These projections have indicated that additional water supplies and further storage sources need to be investigated. Using the Master Plan, the Authority has identified and ranked a series of possible scenarios to provide projected minimum water demands while providing needed regional system reliability. Six potential water supply sources were initially identified and approved by the Authority board for further consideration and study.

1. Carlton Wellfield expansion
2. Dona Bay/Cow Pen Slough restoration
3. Flatford Swamp restoration
4. Myakkahatchee Creek/Cocoplum Waterway
5. Peace River
6. Shell Creek (including Tippen Bay and Long Island Marsh) restoration

In addition to the initially identified six potential additional water sources, the Regional System Reliability Model also included a series of further recommendations to provide increased water supplies and storage, increase overall reliability to at least 95 percent, and meet estimated demands through 2024.

- **Fiscal Year 2007 –** The plan identified an additional 2 mgd of water potentially regionally available from the Carlton Wellfield, with an additional 3 mgd available through re-rating of the Peace River Facility. However, even with these enhancements the expected system reliability was calculated to be less than the recommended 95 percent.

  Due to the current ongoing drought, the Authority obtained in December 2006 temporary approval from the District to modify the Facility's withdrawal schedule to allow regional diversions up to 10 percent when Peace River at Arcadia flow was above 90 cfs, rather than the 130 cfs established under the 1996 Water Use Permit. This increased the system's regional reliability to about 96 percent. A more detailed evaluation of an environmentally appropriate withdrawal schedule was recommended given the observed increase in regional reliability.

  It was recommended that source feasibility studies be undertaken for Shell Creek, Dona Bay/Cow Pen Slough, and Flatford Swamp systems, and that a feasibility study also be assessed for the Myakkahatchee Creek system.

- **Fiscal Year 2008 –** The Phase I Loop Interconnect project between the Peace River Facility and the City of Punta Gorda's Facility would increase regional reliability. It was recommended that the results of the feasibility studies be used as a basis to begin initiation of the project(s) that demonstrate the greatest opportunity for improved regional reliability in the most cost-effective manner.

- **Fiscal Year 2009 –** The current Peace River Facility expansion is projected to be completed and will provide an additional regional 24 mgd. An additional 2 mgd should become available from new wells at the Carlton Wellfield. However, even with these additional supplies the Regional System Reliability Model simulations indicate that the regional reliability may be less than 95 percent. It was suggested that other measures, such as modification of the Facility's Peace River withdrawal schedule may need to be considered to obtain required minimum regional reliability.

- **Fiscal Years 2010 through 2012 –** The Peace River Facility's new 6 billion gallon off-stream reservoir will dramatically increase system reliability. The Regional System Reliability Model predicts regional reliability will exceed 95 percent through 2012, assuming use of the permitted 130 cfs low Peace River at Arcadia cut off.

- **Fiscal Year 2013 –** The Master Plan suggested that a new source will be needed and that an off-stream reservoir and water treatment facility in the Shell/Prairie Creek basin may provide the highest reliability based on observed consistent and generally large quantities of surface water available within the system.

- **Fiscal Years 2014 through 2024 –** Assuming the Master Plan's recommendation that a Shell Creek supply is incorporated into the regional system during 2013, the Regional System Reliability Model indicates that a second additional new supply and associated treatment capacity will be needed by 2019. A Dona Bay alternative could include a 6 billion gallon off-stream reservoir and a 20 mgd water treatment facility. Such a system configuration would provide the projected minimum regional reliability through at least 2023. A Flatford Swamp source could include a 4 billion gallon reservoir supporting a 15 mgd water treatment facility to further meet projected demands and reliability requirements.

The Authority and District are currently funding an initial study to assess the feasibility and relative costs of providing additional water supply resources through joint restoration projects within the Dona Bay/Cow Pen Slough, Flatford Swamp and Prairie/Shell Creek watershed basins. The results of these preliminary investigations and initial relative cost estimates will be available by the late summer of 2008.

1.4 HBMP Study Elements and Studies

In 1976 the initial monitoring elements of the HBMP were designed in coordination with District staff to provide answers to specific questions raised during the original permitting process. These questions raised concerns regarding the potential for negative impacts potentially associated with salinity changes in the lower Peace River/upper Charlotte Harbor estuarine system resulting from Facility freshwater withdrawals. The HBMP has incorporated a wide variety of study elements since its initial inception, while a number of modifications have been made to the HBMP throughout its history. While the overall level of effort of the monitoring program has remained relatively constant, study elements have been added and deleted in order to enhance the overall knowledge base of the lower Peace River/upper Charlotte Harbor estuarine system. Historically, those major monitoring elements aimed at assessing direct relationships with variations in freshwater inflow have had the longest histories. Other program elements, primarily those focused on assessing indirect biological indicators, have extended over a number of years and then ended once a sufficient baseline level of information had been accumulated. A summary of the time-lines for each of the major historical HBMP components is presented in **Table 1.3**.

Between 1976 and 1996, the staff of the Environmental Quality Laboratory, Inc. (EQL) conducted all elements of the HBMP. Since the expansion of the permit requirements in 1996, the individual programs have been divided during different periods among a number of researchers, including:

- U.S. Geological Survey
- ASCI Laboratory
- Benchmark Laboratory
- EarthBalance (Florida Environmental)
- PBS&J
- University of South Florida
- Mote Marine Laboratory

The HBMP was never conceived to be a rigid monitoring program. Rather it has historically incorporated a flexible study design (adaptive management) that could be periodically restructured based on updated findings and identified research needs. When the first discussion began with District staff in 1975 about what might be included within the initial monitoring 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 substantial freshwater diversions. Much of the beginning effort under the initial HBMP study design was therefore directed toward developing sufficient data to statistically describe the spatial distribution and temporal seasonal variability among selected physical and chemical indicators within this estuarine system. The ultimate goal was to determine potential relationships of these selected indicators with natural seasonally occurring variation in freshwater inflows. The initial 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 from upstream of the Facility to near Boca Grande Pass.

In addition, initial attempts were begun to determine if key indicator species or biological communities could be identified to further assess responses to natural variations in freshwater inflows. Determining the presence of such long-term relationships was thought to be especially important because, with only a small percentage of total flow being initially diverted, the direct effects of Facility withdrawals were projected to be extremely small in comparison to natural variation. The original HBMP elements included a number of biological studies.

- An initial long-term study of the seasonal pattern of juvenile fishes in the upper harbor.
- Studies of benthic indicator species.
- An investigation of the seasonal distribution of sea stars in the harbor and lower river.
- A long-term vegetation study of first and last occurrence of selected plant taxa along the lower Peace River.
- Periodic aerial photographic documentation of potential changes in the spatial distribution of riparian vegetation along the banks of the lower river.

Analysis of data from pre- and post-water treatment plant operation, presented in the August 1982 Summary Report, indicated the need to revise the monitoring program to better evaluate changes in the Charlotte Harbor system due to both natural seasonal and longer-term variations in freshwater inflows, given the relative magnitude and timing of changes due to Facility withdrawals. Further modifications and refinements to the HBMP were further made in 1985 and again in conjunction with the renewal of the Water Use Permit in November 1988.

In the 1980s, studies of zooplankton and phytoplankton community structure and primary production 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 estuary" and the influences of naturally occurring extended periods of drought and flood conditions on key initial components of the estuarine food-chain. The short-term benthic invertebrate study and the fish nursery investigation conducted in the late 1990s were again not designed to measure the influences of withdrawal directly, but rather were intended to investigate the spatial responses of biological communities to natural variations in freshwater inflows.

Based on the results of the 1993 and 1995 Summary HBMP Reports and additional analyses requested by District staff during the permit renewal process, an expanded HBMP was approved by the District in March 1996 as part of the Facility's current 20 year Water Use Permit. An explicit element of the updated HBMP was the development of standardized station descriptors to be applied across all program elements. As part of a required morphometric study, the "mouth" of the Peace River was defined using U. S. Geological Survey (USGS) standardized protocols as an imaginary line extending from Punta Gorda Point to Hog Island. Since the morphometric study, all new and previous on-going study elements monitoring locations have been cross-referenced to this "River Kilometer" identification system. **Figure 1.5** and **Table 1.4** provide a summary of the locations of all of the ongoing long-term fixed study elements and a cross-reference to previous station identifications.

As defined by the District 1996 Water Use Permit conditions, the primary focus and overall objective of the HBMP is to assess the following key issues.

- Monitor river withdrawals from the Peace River by the Facility and evaluate gaged tributary flows from Joshua, Horse and Shell creeks, as well as the primary Peace River flows measured at Arcadia and direct rainfall to the lower Peace River.

- Evaluate relationships between the ecology of the lower Peace River/upper Charlotte Harbor Estuary and freshwater inflows.

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

- Determine the relative degree and magnitude of effects of Peace River withdrawals by the Facility on ecological changes that may be observed in the lower Peace River/upper Charlotte Harbor estuarine system.

- Evaluate whether consumptive freshwater withdrawals significantly contribute to any adverse ecological impacts to the estuary resulting from extended periods of low freshwater inflows.

- Evaluate whether the withdrawals have had any significant effects on the ecology of the estuary, based on related information such as nutrient loadings, fish abundance, or seagrass distribution data collected by other studies conducted by the District or other parties.

The outside Peace River HBMP Scientific Review Panel (Panel), implemented in conjunction with the 1996 Water Use Permit renewal, met in November 2002 and reviewed the monitoring program modifications recommended in the *1998 Mid-term Interpretive Report*. The Panel recommended a number of changes to the monitoring program study elements. The Panel agreed that both the "fixed" and "moving" water quality monitoring programs were important, and that if a water chemistry parameter was not providing useful information relative to seasonal variations in freshwater inflows and potential Facility impacts, it should be deleted from the HBMP.

Other suggestions and recommendations made by the Scientific Review Panel regarding the monitoring program included:

- Continue collecting non-size fractioned phytoplankton biomass estimates at both the "fixed" and "moving" physical/chemical water quality monitoring locations.

- Continue enumeration of phytoplankton taxonomic composition at the "moving" isohalines for at least major taxonomic groupings (blue greens, diatoms, flagellates, dinoflagellates, etc.).

- Determine if either the benthic invertebrate/mollusk investigations conducted by Mote Marine Laboratory, or the juvenile fish/zooplankton study undertaken by the University of South Florida should be incorporated in part into HBMP study elements.

- Evaluate the need to continue monitoring at the existing spatial and temporal intensity.

Overall the Panel recommended that the HBMP should focus monitoring primarily on assessing long-term trends in key physical, chemical and biological characteristic directly related to the Facility's potential influences and less on "health of the estuary" issues that should be the task of other District monitoring efforts.

The Peace River HBMP Scientific Review Panel met again in September 2004 to review and make additional recommendations based on the *2002 Peace River HBMP Comprehensive Summary Report*. The Panel at that time made a series of further recommendations to the District and Authority with regard to needed changes to the monitoring program's study elements.

Recommended Deletions to the Existing Monitoring Program – the Scientific Review Panel recommended in 2004 that a number of the study elements be deleted from further study.

- Data had been collected since the inception of the HBMP program with regard to the first and last occurrence of riparian vegetation along the lower Peace River. Extensive analysis of the data over the 1976-2002 time interval found that although there had been extended periods of both high and low river flows' the relative spatial distributions of the major vegetation communities had remained virtually unchanged. Based on these finding the review Panel recommended deletion of this HBMP study element.

- Aerial photography of vegetation along the lower river had also been taken at periodic intervals since 1976. Analyses failed to indicate any systematic spatial changes in the major communities that could be tied to known changes in river flows, and the panel again recommended that this element of the HBMP be discontinued.

- Vegetation data had further been collected since 1979 at selected fixed transitional vegetation sites along the lower river and the Panel recommended that this monitoring also be deleted.

- Expansion of the HBMP monitoring program had included the collection by USGS of 15-minute tide stage near Boca Grande pass. However, subsequent discussions with USGS staff revealed that the location of this gage was inappropriate for its intended use of determining potential long-term changes in sea levels. All parties recommended that this gage be deleted from the array of HBMP continuous recorders and the Panel agreed.

- Monthly phytoplankton taxonomy had been conducted in conjunction with measurements of chlorophyll *a* biomass at the moving isohaline-based monitoring locations. The Scientific Review Panel recommended that chlorophyll *a* concentrations continue to be measured monthly at these locations, while phytoplankton species composition should be deleted from further consideration.

Recommended Additions to the Monitoring Program – the Scientific Review Panel recommended several additional sources of information be added to the HBMP.

- The Panel recommended that the Authority investigate adding wind velocity to the data being collected, in order to provide a possible source of data to further explain flow/salinity relationships being developed from the 15-minute conductivity data being collected at the two USGS recorders in the lower Peace River.

- The Panel also recommended that the Authority look into installing a series of additional continuous recorders between the two initially established in 1996 by the USGS as part of the expanded HBMP program under the District's permit renewal.

- The Panel suggested that the Authority evaluate and report back on the technical merit of implementing monthly *in situ* chlorophyll *a* monitoring along the HBMP monitoring transect to determine potential spatial peaks in chlorophyll biomass relative to seasonal changes in freshwater inflows.

- The Panel supported the Authority's intention to run a series of "pump tests" using data from the continuous recorders to experimentally determine the relative spatial magnitude of Facility withdrawals on salinities over a number of tidal cycles given different flow conditions.

Proposed Additions not Recommended – the *2002 Peace River HBMP Comprehensive Summary Report* suggested several additional potentially new study elements for the program. The Scientific Review Panel felt that given the already available existing information and the relative added costs, three of these proposed additional studies should be deleted from consideration at the current time.

1. Addition of a limited stratified random monitoring design for *in situ* water quality parameters.

2. Additional dry and wet season larval fish sampling.

3. A continued limited ongoing benthic mollusk study.

The most recent meeting of the Peace River HBMP Scientific Review Panel was held in December 2007 to review the findings in the draft Authority report on the initial series of Facility "pump tests" run between December 2006 and April 2007. At this meeting the Panel also reviewed and provided comments to the District on its proposed draft Minimum Flows and Levels (MFL) for both the lower Peace River and Shell Creek.

- The Panel recommended that the Authority install at least two more continuous recorders above the most current upstream USGS recorder (**Figure 1.6**). The Authority is currently in the process of installing such additional continuous recorders at two locations upstream of the Facility and at a third location downstream near the mouth of Shell Creek.

- Based on the findings of the initial series of pump tests conducted by the Authority, the panel recommended that no further tests be conducted until after the upcoming Facility expansion is completed.

1.4.1 Ongoing Study Elements of the HBMP

The 1996 Water Use Permit renewal specifies reporting requirements with respect to data collected and interpreted under the HBMP. In addition to Annual Data Reports, the permit requires limited Mid-term Reports and much more extensive Comprehensive Summary Reports be submitted to the District approximately after the third and fifth years of each five-year interval over the duration of the twenty-year permit. Due to increased public concerns regarding long-term hydrologic alterations of freshwater flows in the Peace River watershed, the Authority has expanded the level of data analysis in all of the HBMP Reports beyond that originally envisioned during the 1996 permit renewal. The primary focus of these additional increased statistical analyses and evaluations have been specifically directed toward further assessing both the magnitude and temporal and spatial distribution of potential impacts resulting from both current and projected future Facility withdrawals under the 1996 permit. The following briefly summarizes both the ongoing and some of the major recently deleted program elements from the HBMP.

1.4.2 USGS Continuous Recorders

This element of the HBMP allows for 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 flows, and withdrawals can be used to develop detailed spatial and temporal relationships. A secondary goal of this HBMP element is to assess potential long-term changes in river salinity, which might be explained by predicted increases in sea level.

Historically, the HBMP has utilized three USGS automated 15-minute interval water level recorders in the study area. The first, installed in 1996, was at Boca Grande, which is the estuary's largest opening to the Gulf of Mexico. This gaging site was discontinued after 2004 subsequent to comments by the HBMP Scientific Review Panel during their September 2004 meeting. The second, also installed in 1996, is 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. The third recorder, installed in November of 1997, is at approximately River Kilometer (RK) 26.7 just downstream of the Peace River Facility. This gage measures water level as well as surface and bottom conductivity at 15-minute intervals. The relative locations of the active USGS gages are depicted in **Figure 1.6**.

1.4.3 Additional HBMP Continuous Recorders

During 2005, the Authority evaluated a number of both possible alternative sites and deployment methodologies to be utilized in the establishment of additional continuous conductivity monitoring devices downstream of the Facility. The objective was to deploy additional continuous conductivity recorders at other monitoring sites to be used as part of an expanded HBMP study element directed specifically toward measuring Facility withdrawal impacts under lower flow conditions. The Authority received permission from the U.S. Fish and Wildlife Service to establish continuous recorders at three Manatee Speed Zone markers, the locations of which are indicated by the light-green arrows in **Figure 1.6**. Analyses of conductivity data from these new monitoring locations are utilized to extend the graphical and statistical results previously conducted and presented as part of the 2002 HBMP Comprehensive Summary Report with regard to directly measuring the salinity changes due to withdrawals.

1.4.4 Water Chemistry and Water Column Physical Profiles

These study elements involve the measurement of physical and chemical water quality over time and track the overall "health of the estuary." 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 whether 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.

1. During the first week of each month, water quality measurements (physical and chemical) are conducted at four "moving" salinity based isohaline locations (0, 6, 12 and 20 psu) along a River Kilometer center-line running from the imaginary "mouth" of the Peace River upstream to above its junction with Horse Creek, and downstream to Boca Grande Pass. The relative monthly location of each sampling is based on the first occurrence of these specific isohalines (± 0.5 psu), with freshwater being defined as the first occurrence of conductivities less than 500 us/cm. The isohaline sampling effort was undertaken in conjunction with the long-term phytoplankton elements of the HBMP.

2. Approximately two weeks after the collection of the "moving" isohalines, water column physical profiles are conducted, near high tide, at sixteen fixed locations along a transect running from just below the river's mouth upstream to a point just above the Peace River Facility (see **Figure 1.5** and **Table 1.4**). In addition, chemical water quality samples are taken at five of these locations.

Both of these water quality HBMP study elements include physical *in situ* water column profile measurements of characteristic parameters (temperature, dissolved oxygen, pH, conductivity and salinity) at 0.5-meter intervals from the surface to the bottom. In addition both efforts measure the penetration of photosynthetically active radiation (PAR) to determine ambient extinction coefficients at specific sampling locations. Both studies also include the analyses of an extensive list of chemical water quality parameters. The only difference is that at the "fixed" sampling stations both sub-surface and near-bottom samples are collected at each of the five sites, while only sub-surface water chemistry samples are taken as part of "moving" isohaline phytoplankton production study element.

The HBMP Scientific Review Panel agreed during it's November 2002 meeting that both the "fixed" and "moving" water quality monitoring programs were important, but that certain water chemistry parameters could be omitted from the sampling regime. The Scientific Review Panel recommended that the District accept the suggested chemical parameter revisions with the caveat that chlorides and silica continue as HBMP parameters. Based on these recommendations, the District agreed to the revised HBMP water chemistry parameter list (**Table 1.5**) starting in January 2003.

1.4.5 Phytoplankton Studies

Sub-surface samples are collected in conjunction with the "moving" isohaline sampling of physical and chemical water quality characteristics described above.

Phytoplankton Primary Production – From June 1983 through December 1999, statistically comparable levels of phytoplankton 14C fixation rates were measured monthly at each of the four salinity-based isohaline locations. In addition to overall estimates of phytoplankton production, carbon uptake rates were determined for three separate size fractions: 1) greater than 20 microns; 2) 5 to 20 microns; and 3) less than 5 microns. The results of this long-term HBMP study clearly showed the quick response of phytoplankton production to brief pulses of relatively nitrogen rich freshwater into the estuary during the early spring. These results further supported the extreme importance to other components of the estuarine food-web of early spring/summer flows to the estuary during the start of the typical summer wet-season. Based on the extensive nature of the database gathered, further *in situ* carbon uptake measurements were deleted from the HBMP in 2000.

Species Composition - A second element of the HBMP phytoplankton study, conducted monthly between 1989 and 2004, sought to quantify the specific responses of major phytoplankton taxonomic groups to variations in the periodicity of freshwater inflow. The developed monthly phytoplankton taxonomic information included: 1) raw counts of the relative taxonomic structure; 2) percent composition of key major taxonomic groups; and 3) summary species diversity and evenness index estimates. This monitoring effort was deleted following 2004 based on the recommendations of the Peace River HBMP Scientific Review Panel.

Phytoplankton Biomass Estimates – Although direct *in situ* measurements of carbon uptake rates and enumerations of phytoplankton taxonomic structure are no longer conducted, the HBMP isohaline based monitoring study element continues to collect monthly information of phytoplankton biomass (chlorophyll *a*), in relation to seasonal and flow related variations in physical parameters, water column light profiles, and the major chemical constituents associated with phytoplankton growth.

1.4.6 HBMP Study of Long-Term Changes in Vegetation

At selected intervals between 1976 and 2004, three different HBMP study elements were conducted to assess variations in emergent and riparian vegetation along the lower Peace River. The overall objective of these monitoring programs was to determine the magnitude of annual and longer term changes caused by natural river flow differences between extended wet and dry periods, and then using this information to assess the potential magnitude of changes that might be expected to occur due to current and projected Facility withdrawals.

The vegetative monitoring elements of the HBMP provided information for determining relationships between vegetation patterns and freshwater flows 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 could be an indication that withdrawals were impacting the river corridor wetlands, as long as natural variability (drought) or other man-made causes could be eliminated.

HBMP studies of long-term changes in vegetation consisted of three elements. Photo-interpretation began in 1976. Initially aerial infra-red photography of the vegetative communities along the lower Peace River was taken yearly, 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 continued to be conducted at two-year intervals. All post-1996 aerial photography was taken in a corrected, GIS compatible format, thus allowing for accurate quantification of any observed changes. Photo-interpretation of these images, in conjunction with field observations, will periodically be used to develop maps of the river's vegetation associations. Both qualitative and quantitative data are being used to assess potential changes associated with extended natural periods of both low and high freshwater inflows.

Since 1976, at approximately two year intervals, 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 were made, identifying the first and last occurrences of individual and substantial populations of key indicator species. These data were used in conjunction with the aerial photography to assess the influences of long-term natural variations in river flow.

Detailed monitoring of plant communities along the river's banks at fixed locations began in 1979 and was expanded under later permits. The vegetative communities at three permanent transect sites were sampled at two-year intervals. At each monitoring location, three transects from the top of the bank to the water's edge were surveyed. The vegetation one meter to each side of the transects was identified, and the location and density recorded. These long-term data were to be used to further assess the response of the riverine vegetative communities to natural variations in freshwater flows.

Complete and thorough analyses of the long-term results of these vegetation studies were presented in both the *2002 HBMP Comprehensive Summary Report* and the *2004 HBMP Annual Data Report*. These analyses indicated that vegetation patterns along the lower tidal Peace River have remained relatively stable over long periods of time, and show little in the way of consistent responses to natural periods of either high or low freshwater river flow. As a result, based on discussions with both the Scientific Review Panel and District staff, it was determined to suspend the vegetation monitoring elements with the exception of photo-interpretation. Following 2004 this monitoring element will continue at approximately five year intervals.

1.4.7 Special Studies Associated with the HBMP

In addition to the monitoring elements of the HBMP summarized 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 research questions.

Comprehensive summaries of these special HBMP studies as well as other recent relevant reports by other research programs in the lower Peace River/upper Charlotte Harbor estuarine system were presented in the *2002 Comprehensive Summary Report*. Similar summaries of additional studies completed since that time are presented in **Chapter 2**.

1.4.8 Assessing Significant Environmental Change

Since its inception in 1976 the HBMP has incorporated numerous physical, chemical, and biological study elements directed toward assessing both the overall "health of the estuary" as well as direct and indirect adverse impacts potentially associated with Facility withdrawals. To date none of the extensive HBMP analyses have found or suggested any significant long-term physical, chemical or biological changes in the lower Peace River/upper Charlotte Harbor estuarine system, resulting from either current or historic water withdrawals by the Facility.

The *2002 HBMP Comprehensive Report* proposed an initial approach for determining from the HBMP data whether permitted surface water withdrawals are causing or have caused adverse environmental changes in the lower Peace River estuarine system. In addition, a hierarchy of management actions was proposed to be implemented in response to detected changes that could forewarn of potential future changes that would constitute an adverse change. **Chapter 9** of this report provides a more detailed discussion of the conceptual HBMP process developed for evaluating key water quality and biological estuarine components, and assessing potential adverse estuarine impacts from current permitted withdrawals.

1.5 Report Organization and Primary Objectives

The following briefly summarizes the organization and primary objectives of each of the following chapters of the *2006 HBMP Comprehensive Summary Report*.

- **Chapter 2.0** - **Summaries of Recent HBMP Reports and Primary Conclusions –** This chapter provides brief overviews of each of the major studies and reports related to the Peace River watershed, lower Peace River and upper Charlotte Harbor that were prepared since those previously summarized in the *2002 Peace River Comprehensive Summary Report*. Its primary focus is to provide concise overviews of the purpose and major conclusions of each study.

- **Chapter 3.0** - **Status and Trends in Regional Rainfall and Flows, and Facility Withdrawals –** The purpose of this chapter is to provide updated graphical plots and trend analyses of rainfall and flows in the Peace and Myakka River watersheds over multiple time scales. Recent and historical unusual occurrences (such as extended droughts and unusually wet intervals) are documented and compared to the long-term average statistical characteristics at each of the major tributary gaging locations in the Peace River watershed.

- **Chapter 4.0** - **Status and Trends of Hydrobiological Water Quality Indicators in the Lower Peace River/Upper Charlotte Harbor Estuarine System –** The purpose of this chapter is to provide updated trend analyses of selected water quality hydrobiological variables. Unusual occurrences, such as periods of extended drought, are documented and compared to the long-term statistical water quality characteristics.

- **Chapter 5.0 – Influences of Increasing Conductivity in the Lower Peace River Watershed** – The recent Peace River Cumulative Impact Study (CIS) identified anthropogenic increasing trends in the dry season conductivity of many of the major tributaries in the lower Peace River watershed. The primary objective of this chapter is to further evaluate these trends beyond the period covered by the CIS (which ended in 2004) and determine the duration and potential magnitude such increases may be having on the dry season conductivity of lower Peace River immediately upstream of the Facility's point of withdrawal.

- **Chapter 6.0 - Salinity/Flow/Withdrawal Relationships at the Continuous USGS Recorders –** Previous HBMP Mid-term (year three) and Summary (year five) Reports have developed both fixed location and spatial statistical models, which were used as predictive tools in assessing the magnitude of potential salinity changes due to both historic and potential maximum freshwater withdrawals under the existing permit conditions. The primary objective of this chapter is to determine statistical relationships between flows, tide stage, and withdrawals at both the two long-term (1996-2006) fixed USGS continuous gages, and the three new (2006) HBMP continuous recorders. The results of these analyses are compared and contrasted with the results of other previous salinity models.

- **Chapter 7.0 – Evaluation of Existing Withdrawal Schedule and Assessment of Effectiveness in Limiting Potential Impacts -** The primary objective of the analyses presented in this chapter is to briefly summarize and contrast the results of the recent hydrodynamic model developed by the District for use in establishing minimum flows and levels, with those presented in Chapter 6. Existing empirical salinity models are used to assess the effectiveness of the Authority's withdrawal schedule for preventing impacts to the natural resources of the lower Peace River/ upper Charlotte Harbor estuary.

- **Chapter 8.0 - Analyses of Updated Morphometry**- Recently developed river morphometric information from the District is used to update key components of the older (2000) *Morphometric Habitat Analysis of the Lower Peace River.*

- **Chapter 9.0 - Evaluation of the Presence or Absence of Adverse Ecological Impacts and Appropriate Indicators** – This chapter provides a generalized discussion of the appropriate measurable criteria that can be linked to freshwater withdrawals and provides reasonable assurance for determining the potential for, or occurrence of, environmental change. The primary objective of this chapter is to describe the methodology and criteria used by the HBMP to determine if previous, existing and permitted Facility withdrawals have or are likely to cause significant environmental changes to the lower Peace River/ upper Charlotte Harbor estuarine system.

- **Chapter 10.0 - Proposed Monitoring Design Modifications to the Existing Long-Term HBMP Elements –** Based on the overall preceding conclusions of the report, this chapter extends the discussions raised in previous Summary Reports, and recommends possible reductions and/or eliminations of specific parameters and elements within the current HBMP, as well as the potential implementation of new long-term study elements.

1.6 Summary

The purpose of this introductory section is to provide readers unfamiliar with the history of the Peace River Regional Water Supply Facility and the District's permit criteria a brief overview of the Authority's Water Use Permit (WUP) for the Facility and those conditions of the permit requiring the major study elements that have been associated with the thirty-one year history of the HBMP.

- The primary goal of the combined HBMP study elements 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, are being, or may be adversely impacted by permitted freshwater withdrawals by the Authority's water treatment facility.

- The continually expanding base of ecological information developed by the HBMP will also be used to periodically evaluate the effectiveness of the withdrawal schedule with regard to assuring the prevention of significant adverse estuarine impacts.

- The existing twenty-year Water Use Permit issued by the District in 1996 sets a maximum withdrawal quantity. Under the permit, no withdrawals can occur until there is a minimum flow of 130 cfs at the Peace River at Arcadia gage, which is located approximately thirty-six miles upstream. Beyond 130 cfs, withdrawals cannot exceed 10 percent of the average daily Arcadia flow and cannot exceeding 90 mgd (139 cfs) on any day. (Note: Special exceptions have temporarily been issued by the District since December 2006 due to the severity of the ongoing drought, which has severely impacted available stored reserves.)

- The Facility presently has the capacity to treat up to 24 million gallons per day (mgd), which is equivalent to withdrawals from the river of 37.2 cubic feet per second (cfs). The existing raw water river diversion structure has four pumps with a combined maximum capacity of 44 mgd (68.0 cfs). In comparison, the long-term average annual daily total gaged river freshwater flow upstream of the Peace River Facility since 1976 has been approximately 796 mgd (1233 cfs).

- During periods of high river flow, raw river water is stored in the system's off-stream reservoir, while excess treated water is stored in the existing twenty-one 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 service area.

This *2006 HBMP Comprehensive Summary Report* follows and extends the summarization and interpretation of long-term HBMP data submitted in both the *2002 HBMP Comprehensive Summary Report* and the *2004 Midterm Interpretive Report*. Its primary goals and objectives are to provide the District with sufficient analyses to:

- Evaluate key relationships between ecological characteristics and freshwater inflows, and determine whether the biological health and productivity of the estuary are showing signs of stress related to natural periods of low freshwater inflow or potential negative influences of Facility withdrawals.
- Assess the presence or absence of long-term trends for important HBMP variables.
- Evaluate the overall HBMP design and make recommendations regarding implementing modifications.
- Assess the presence or absence of adverse ecological impacts and determine the influence Facility withdrawals may have contributed to such impacts.
- Evaluate the potential environmental impacts that may be associated with additional future increased withdrawals from the river and the feasibility of increased water supplies.
- Assess and evaluate the effectiveness of the withdrawal schedule for preventing adverse environmental impacts.

None of the detailed analyses of HBMP data presented in previous HBMP reports have shown that Facility withdrawals have had, or are expected to cause, significant physical or biological adverse impacts within the lower Peace River/upper Charlotte Harbor estuarine system. A key objective of this report is to provide the District with sufficient analyses of the HBMP data to date to assure that the withdrawal schedule is providing adequate continuing resource protection.

2.0 Summaries of Recent Relevant Reports

The *HBMP 2002 Comprehensive Summary Report* (September 2004) provided brief overviews of major studies related to the lower Peace River/upper Charlotte Harbor estuary system completed between 1996 and 2002. This chapter continues this review by providing brief overviews of major reports and studies related to the estuary since those previously summarized in the 2002 Comprehensive Summary Report. Concise overviews of the purpose and major conclusions of these studies are provided.

2.1 Upper Peace River: An Analysis of Minimum Flows and Levels (SWFWMD, 2002)

This report was published as a draft in August 2002. It was subsequently used to develop a provisional minimum flows and levels (MFL) for the upper Peace River (from the Zolfo Springs gage to the Bartow gage located immediately downstream from the Lake Hancock discharge) which was adopted by the Southwest Florida Water Management District (District) Governing Board. The document was peer reviewed by a Scientific Peer Review Panel (Panel) established by the District (see Gore et al. below).

This document was the first produced by the District to articulate the concept that the protection of a river's ecology is dependent on maintaining minimum flows across the entire flow regime not just a low flow threshold. Furthermore, this document outlined both a general methodological and policy approach to MFL evaluations.

The determination of minimum flows for the upper Peace River first involved an assessment of the historic and current flow regime and the factors that have shaped flow regimes. The upper Peace River has experienced declining baseflows over the past three decades. It has been hypothesized that phosphate mining and agricultural irrigation are the primary anthropogenic causes. In recent years, climate change, specifically the Atlantic Multi-decadal Oscillation, has been shown to have a significant effect on flows in Florida rivers. The District utilized various statistical and hydrologic modeling tools to conduct flow analyses including various trend analysis techniques and the Index of Hydrologic Alteration developed by the Nature Conservancy Sustainable Waters Program.

This was followed by a consideration of the absolute minimum instream flow needs, or the flow which historically has been most often equated with the idea of a "minimum flow." In the case of the upper Peace River, this flow was the lowest acceptable flow under the lowest anticipated flow conditions. A flow that would ensure fish passage or maintain the desirable wetted perimeter was considered the lowest acceptable minimum flow.

Certain instream habitats ("snags and roots") provide substrate for the development and colonization of food organisms, and cover for various aquatic species, but occur at elevations above that which would allow for fish passage and a minimum acceptable wetted perimeter. It was therefore considered desirable to evaluate how often these habitats are inundated each year in an effort to determine when significant harm will occur to the resource.

It is expected that riparian hardwood and cypress swamp systems require flooding on at least a seasonal basis to maintain their biological integrity, and if historic flow records indicate a fairly sustained period of inundation, their flow needs can be assessed on the basis of the inundation requirements of certain associated biota (e.g. frog life histories).

To quantify the flow requirements of both instream and floodplain habitats, topographic survey transects were conducted at various locations perpendicular to the river channel to determine the elevations of desirable habitats. Then the USGS hydrologic model HEC-RAS was used to determine what flows would be necessary to ensure the desired inundation period of those habitats.

In summary, the resource management goals established for the upper Peace River included the following:

- Maintain minimum depths for fish passage and canoeing in the upper river
- Maintain depths above the inflection point in the wetted perimeter of the stream bottom
- Inundate woody habitats in the stream channel
- Meet the hydrologic requirements of floodplain biological communities

Following the completion of the MFL evaluation, DISTRICT staff recommended the adoption of only a minimum low flow at each of the three gage locations covering this segment based solely on the fish passage and wetted perimeter criteria. It was recommended that the minimum low flow, as a 95 percent annual exceedance value, not be allowed to go below 17 cfs at Bartow, 27 cfs at Ft. Meade, and 45 cfs at Zolfo Springs.

Furthermore, it was concluded that the flow regime in the upper Peace River was such that medium and high flows were not adequate to protect ecological resources (e.g. riparian swamps) across the entire flow regime. Because District staff could not adequately partition among the various controlling factors (rainfall, structural alterations and changes, withdrawals) the causes for the altered flow regime, no medium and high minimum flow criteria were proposed for adoption.

Two management standards were proposed for consideration that, if met, would provide some measure of improvement to the riverine ecosystem in the medium to medium-high flow range. To ensure that exposed root habitat in the uppermost reaches of the river (upstream of Ft. Meade) is inundated so that the habitat can be used long enough for dominant macroinvertebrates (dipterans, predominately chironomids) to colonize and reach maturity, it was recommended that the highest root indicator site measured in the upper river be inundated to its mean elevation for a minimum of 45 consecutive days annually. In order for the majority of anuran (frogs and toads) species expected to occur in association with the river and its floodplain to have access to and reproduce in riverine wetlands, it was proposed that periods of 90 consecutive days of inundation are needed in lower floodplain habitats at a three-year average recurrence interval.

The findings for habitats requiring medium and high flows were considered to be applicable to other District strategies to restore the full flow regime in the upper river through a combination of physical, regulatory, and management approaches. As such, the District is pursuing a recovery strategy for the upper Peace River.

2.2 A Review of "Upper Peace River: An Analysis of Minimum Flows and Levels" (Gore *et al*. 2002)

As stated above, the District convened a panel of experts – referred to as the MFL Scientific Peer Review Panel - to provide a peer review of the upper Peace River MFL evaluation report. The panel report was published in November 2002. The objectives of the panel review were to: 1) provide a critical review of the methods, data, and conclusions of the District with regard to the upper Peace River MFL; and 2) recommend improvements and guidelines for future decisions on the restoration and/or rehabilitation of the upper Peace River. The findings and conclusions of the MFL Scientific Peer Review Panel can be summarized as follows.

- The proposed MFLs for the upper Peace River are a good first step in the management process but cannot be the only step.

- The resource management goals represent a reasonable subset of potential goals for an improved biotic community in the degraded upper basin. The rationale for choosing these goals was clearly presented and scientifically justified.

- In general, the wetted perimeter approach does an adequate job to predict levels that will address the management goals, as described. As an initial step, maintaining fish passage, or the hydrologic connectivity of the system, is a necessary goal. The assumption of a desired elevation of the channel at its deepest point being 0.6 feet above minimum elevation for fish passage is reasonable. The application of the HEC-RAS model to generate a wetted perimeter versus flow plot for each transect also is a justifiable scientific approach.

- In order to complete an effective program of rehabilitation of the upper Peace River, the current management goals may not adequately address the linkages between instream flow-related (hydraulic) habitat requirements of resident biota and discharge conditions over the range of life-stages and functions of various species within the community. Future efforts to enhance the integrity of the upper Peace River may require that these linkages be established.

- The District should frequently revisit this study and view the establishment of MFLs and rehabilitation goals as a dynamic process that results in improved flow criteria as new data and techniques are acquired.

- The approach the District adopted to investigate the relationship between floodplain systems and hydrologic patterns were reasonable and appropriate, based on the relationships presented in most of the published literature. However, in this system, the methods and analyses were not adequate to produce information that could be used to formulate recommendations regarding medium and high flow regimes on those surfaces. The District was, therefore, correct in declining to recommend specific flow criteria for that purpose. Recommendations for future studies of this nature include collection of more detailed data and the adoption of a broader perspective regarding options for ecosystem management and restoration, including actions other than flow regulation.

- No specific quality assurance measures are described in the report. In hindsight, it might have been a good idea to apply the "peer review panel" concept to the study plan development phase. This might have produced a more streamlined and more narrowly focused study plan.

- The District completed a comprehensive data set for application to the wetted perimeter method for minimum flow analysis. However, the question of "best available data to establish minimum flows" cannot be entirely evaluated. There are many alternative techniques for predicting or analyzing minimum flows in fluvial systems. Some of these techniques would require more comprehensive instream physical data than reported in this study.

- One of the weaknesses of the District report is the ability to link maintenance of medium and high flows to the maintenance of riparian floodplains. This linkage is a critical component for the maintenance of the integrity of the upper Peace River basin. We suggest that the ultimate goal for restoration of that integrity will necessarily be the recreation of the medium and high flows that establish these linkages.

The panel reviewed several techniques that it considered to be alternatives to the evaluation procedures employed by the District. All of these techniques would require a greater effort in data collection and analysis; however, the panel felt that such an analysis would lead to more sound management strategies to maintain the integrity of riverine ecosystems. Specifically, the panel suggested that the instream flow incremental approach be considered as the next management step as a means of connecting physical habitat requirements and availability to MFLs already established.

The panel further stated that instream flow analysts consider a loss of more than 15 percent of the habitat of a particular population or assemblage, as compared to the undisturbed or current conditions, to be a significant impact on that population or assemblage. In addition, the panel recommended that the District utilize a so-called building block approach in future MFL evaluations.

2.3 Effects of Phosphate Mining and Other Land Uses on Peace River Flows (Ardaman & Associates 2002)

The objective of this study was to assess the potential impact of phosphate mining on observed reductions in flows in the lower Peace River. Addressed issues included reductions in base flow, decreased stream flow at Arcadia, the lower potentiometric surface in the Floridan aquifer, and changes in evapotranspiration (ET) rates. Average annual water budgets were developed for the Peace River above Arcadia for the two periods 1934-1963 and 1969-1988 shown below.

Average Annual Water Budgets for Peace River above Arcadia

Parameter	Quantity (in/year)	
	1934 - 1963	1969 - 1998
Rainfall	54.75	50.90
Evapotranspiration	38.8	37.8
Deep recharge	3.37	6.3
Return Flow	0.5	1.95
Δ Storage	0.0	0.0
Stream flow	13.08	8.75

The results of the study attributed most of the observed reduction following 1963 in Peace River flows at the USGS Arcadia gage to natural changes in rainfall, with smaller contributions caused by the lowering of potentiometric ground water surfaces, and changes in evapotranspiration. Overall, the report suggested that phosphate mining has had relatively minimal impacts on Peace River flows, concluding that:

- 88 percent of the reduction in Peace River flows at Arcadia after 1963 was caused by lower natural rainfall.
- That only 8.5 percent of the 45-foot drawdown of the Floridan aquifer potentiometric surface at Kissengen Spring south of Bartow was related to phosphate mining.
- That higher evapotranspiration rates on the order of 0.5–1.0 inch/year in mined versus unmined areas due to increased evapotranspiration from wetlands, lakes and clay settling areas (CSAs) resulting from mining and reclamation.
- The study found that approximately 89 percent (387 out of 436 cfs) of the observed Peace River at Arcadia flow reductions can be attributed to rainfall declines and that phosphate mining is responsible for a relatively small fraction of the remaining 11 percent. Specifically, the study attributes a flow loss due to phosphate mining at 8.5–17 cfs (~1 percent).
- The reduction in stream flow from increased evapotranspiration rates is more than offset by the increased runoff, estimated at 160 cfs, resulting from urban development.
- Mining has not significantly reduced base flow to the Peace River; and that evidence suggests that base flow may be higher in tributary basins that have been mined.

2.4 Cumulative Risk of Decreasing Stream Flows in the Peace River Watershed (SDI Environmental Services, Inc. 2003)

This report presents an analysis of the impacts of phosphate mining on stream flows in the Peace River and predictions of future stream flow reductions based on projected increases of mined areas. The analysis is based on a statistical regression between monthly rainfall and stream flow for the period of 1933 – 1962. Rainfall was the average of rainfall records at Bartow, Wauchula and Arcadia, and the stream flow data was taken from the Arcadia gage. Having developed the regression model, the authors then applied it to estimate how much of the observed stream flow reductions from 1963 onward can be attributed to anthropogenic factors (i.e. land uses changes), versus climatic factors (i.e. reductions in rainfall). In order to separate mining impacts from other land use changes, the study examined stream flow reductions in the South Prong Alafia watershed. This watershed was primarily impacted by mining, with minimal impacts from other land use changes. The study used South Prong data for the periods 1963-1977 and 1978-2000 to develop a relationship between the mined area fraction of the watershed and stream flow reductions. Extrapolation of this relationship to the Peace River watershed allowed the authors to estimate how much of the stream flow reduction above Arcadia could be attributed to mining as compared to other land use changes. The same methodology was also used to estimate future stream flow reductions resulting from expansion of the area mined in the Peace River watershed. Findings from this study are:

- Average annual rainfall in the Peace River watershed for 1963 – 2002 decreased by 8 percent (55.48 to 51.02 inches) compared to the 1933 – 1962 period.
- Average annual stream flow decreased by 34 percent (13.25 to 8.78 inches) over the same time periods.
- Primary contributing factors to the stream flow reductions are: rainfall (55.3 percent), mining (17.5 percent), and other anthropogenic (27.2 percent).
- The unit rate of stream flow (inches of stream flow per unit area of watershed) under ‘natural’ conditions is 2.13 times higher than the unit stream flow for mined areas.
- Mining impacts on stream flow are similar for reclaimed areas as they are for active mining areas.

The conclusions of this study regarding the contribution of mining to Peace River stream flow reductions contradict findings in the 2002 report of Ardaman and Associates on “*Effects of Phosphate Mining and Other Land Uses on Peace River Flows.*” Ardaman and Associates argue that 89 percent (387 out of 436 cfs) of the observed stream flow reductions above Arcadia can be attributed to rainfall reductions and that phosphate mining is responsible for a relatively small fraction of the remaining 11 percent. Specifically, Ardaman and Associates attribute a flow loss of 8.5 – 17 cfs (~ 1 percent of the pre-1963 flow at Arcadia) to increased evapotranspiration from wetlands, lakes and CSAs resulting from mining and reclamation.

The rainfall – stream flow regression model developed in this study provides a way to separate natural and anthropogenic influences on observed Peace River stream flow reductions. In applying their mining analysis to the South Prong Alafia River watershed, the authors assumed that all factors other than the area mined (i.e. including average rainfall) remained constant during the period of 1963 – 2000. The study is based on a statistical analysis of stream flow data, and does not address the mechanisms through which mining impacts stream flow. As a result, the projections of future impacts are based on the tacit assumption that mining and reclamation practices that cause the stream flow reductions have and will remain the same. For example, this study does not address how changes in water use by mines (historically based on ground water pumping, but currently based on capture of stormwater) impact Peace River flows.

2.5 Predicted Change in Hydrologic Conditions along the Upper Peace River due to a Reduction in Ground-Water Withdrawals (Basso, SWFWMD 2003)

This study examined the interaction between the Peace River and surrounding groundwater from Lake Hancock to the Zolfo Springs gage station. Decreases in Peace River flow due to the effect of groundwater pumpage have been discussed in the literature since the 1950s. Surface drainage to the upper portion of the river is largely phosphate mine releases and reclaimed stream channels. There are 25 facilities with Florida Department of Environmental Protection (FDEP) permits to discharge effluent, the total volume of which is about 20 mgd.

The major groundwater users have traditionally been the phosphate mining industry and agriculture. Current groundwater withdrawals average between 300-400 mgd from Hardee and Polk counties.

Kissengen Spring is the only major spring in the upper Peace River basin. This spring, which had averaged ~19 mgd of discharge ceased continuous discharge in 1950, and has not flowed at all since 1960. Peek (1951) attributed the cessation in flow largely to a decline in the potentiometric surface of the intermediate and Upper Floridan (UF) aquifers. This attribution is supported by analysis of estimated (by regression) and observed data from the late 1940s to 1975. These data indicate that the decline in water level of the UF aquifer removed the potential for discharge at Kissengen Spring.

There are very few groundwater monitoring sites with data that predate 1970. Thus models have been produced to estimate the impact of groundwater withdrawals on the potentiometric surface of the Upper Floridan aquifer. These estimates generally show a steep decline in potentiometric surface from about 1960 to the mid-1970s, after which a more gradual increase has occurred. These analyses indicate that as of 2000 the potentiometric surface is still much lower than the pre-1960 condition.

The two major contributing factors to changes in potentiometric surface are groundwater withdrawals and rainfall. In periods of high rainfall water is naturally available and irrigation needs decrease (both agricultural and residential), allowing for a decrease in groundwater withdrawal. In dry periods this feedback loop reverses, as irrigation needs increase.

In addition to the loss of flow from Kissengen Spring, there have been several documented sinks/subsidences between Bartow and Ft. Meade, which may have caused a loss of as much as 11 mgd of river flow. Despite these losses baseflow can still provide a positive input to the upper

Peace River from the surficial aquifer and possibly a unit of the intermediate aquifer system (IAS) below Ft. Meade.

Groundwater Reduction Scenarios

In order to restore positive flow at Kissengen Spring during the spring dry season it is estimated that groundwater withdrawals in Polk County and the surrounding area would have to be reduced by 60 percent. In order to increase Kissengen Spring flow to near 15 cfs, withdrawals would have to be reduced by more than 80 percent. Overall, reducing dry season withdrawal by 20 percent should increase upward flow along 5 additional river miles. Reducing withdrawal by 40 percent allows for upward flow along 10 additional river miles, and an 80 percent reduction should create upward flow along an additional 30 river miles, in conjunction with initiating positive flow from Kissengen Spring.

A second modeled approach was to reduce withdrawals in the 676 square mile region surrounding Kissengen Springs. In this scenario a 50 percent withdrawal reduction was estimated to create upward flow over an additional 8.5 river miles, but flow would not be initiated at Kissengen Spring. A 100 percent cessation of withdrawals in this region would create upward flow over an additional 28 miles of the river, and initiate flow from Kissengen Spring.

2.6 Long-term Variation in Rainfall and its Effect on Peace River Flow in West-Central Florida (Basso and Schultz, SWFWMD 2003)

Flow reductions in the Peace River have been largely attributed to anthropogenic factors, however the role of long-term, multi-decadal variation in rainfall toward flow changes has only recently received close attention. This report examines long-term changes in rainfall, focusing on decadal variations and its impacts on streamflow. Various analytical methods and models are utilized to demonstrate the hydrologic significance of these changes.

Data from 27 long-term rainfall stations in central Florida were examined, with six of these stations considered within the Peace River basin specifically. Based on simple linear regression of annual rainfall data, five-year running mean rainfall, and median rainfall by decade, the report indicates that regional multi-decadal cycles of above-or-below average rainfall appear to closely follow the Atlantic Multidecadal Oscillation (AMO).

Averaging the six stations within the Peace River basin indicated that the change in rainfall was about five inches per year between 30-year periods (partitioned at either 1965 or 1970, ± 30 years). Additionally, the five-year running average rainfall for the six Peace River basin stations was similar to the 27-station average for the region. Cumulative departure analyses also indicated that the 1930s to 1960s were wetter than the more recent three decades.

Based on monthly averages over the period of record from the six Peace River basin stations, about 80 percent of the 5 inches/year change between 30 year periods was due to a decline in wet season rainfall. Single mass plots and running 5-year means of wet season rainfall illustrate that the change in wet season rainfall emanated around 1970. Single mass analysis and 5-year running mean of dry season rainfall indicate a slight decline in dry season rainfall beginning in the mid-to-late 1960s.

The AMO is strongly associated with variation in tropical cyclone activity. The report questions whether the AMO cooler mode from 1970-1994 leading to a lull in tropical cyclone activity compared to the previous 45 years accounts for all of the decline in annual rainfall between the two periods. The frequency of cyclones was greater during the warmer AMO phase than the cooler AMO phase. Additionally, tropical cyclone mean rainfall declined between 30 year periods. Tropical cyclone frequency was found to account for up to one-third of the 5 inch/year decline in rainfall.

In general, statistical tests of significant differences (two-sample t-test, Wilcoxon Rank Sum) between two 30 year periods support the hypothesis that the post-1965 period was drier than the pre-1965 period. The authors note that statistical significance does not necessarily equate to physical significance (in terms of aquifer recharge or streamflow).

Empirical and surface water model results were utilized to calculate estimates of streamflow decline due to rainfall changes. The estimated minimum annual rainfall values needed for the Peace River to remain a perennial system differed between methods, and the magnitude of flow decline associated with a 5 inch/ year rainfall change varied from 22 to 35 percent, expressed as a percentage of mean flow. Single mass plots combined with regression analyses of empirical data indicated that 75 to 90 percent of observed streamflow decline can be related to long-term changes in rainfall.

The authors note that a warmer ocean phase of the AMO mode began in 1995 and the wetter cycle is expected to last another 20 to 50 years.

2.7 Water Quality Data Analysis and Report for the Charlotte Harbor National Estuary Program (Janicki Environmental, Inc. 2003)

The results of the status and trends analysis of surface water quality indicated that although there have been many areas of unchanging or improving water quality in the Peace River watershed, there have also been declines in some water quality parameters in a number of basins. Relatively consistent problems regarding selected water quality constituents were found across much of the Charlotte Harbor study area. Florida surface water standards were frequently exceeded in many basins for both dissolved oxygen (instantaneous and daily average) and ammonia, and to a lesser extent for chlorophyll *a* and bacteria.

Similar results were observed for the 1996 to 2000 status period with the approach being applied by FDEP for the Florida Impaired Waters Rule (FAC 62-303.100). The results of the comparison of current water quality conditions to three candidate nutrient criteria suggested that these criteria may not be appropriate for all of the basins in the study area. Nutrient criteria were frequently exceeded for chlorophyll, phosphorus, and nitrogen. The Secchi disk depth criterion was also exceeded in a number of basins, while the turbidity criterion was only rarely exceeded.

Overall, it was suggested that the presented results of the integrated status and trend analyses provide useful information to the Charlotte Harbor National Estuary Program in addressing watershed goals. Brief descriptions of the water quality analysis for each basin are provided here.

- **Peace River at Bartow –** Significant declines in ammonia, total nitrogen, and total phosphorus were observed at several locations and concentrations exceeded five percent of the median value for a station per year. Significant, but smaller, declines were also detected for Total Kjeldahl Nitrogen (TKN) and nitrogen at several stations. Both increasing and decreasing trends in Secchi disk depth trends were identified. With respect to surface water quality standards, water quality at stations in this basin frequently exceeded the standard for ammonia, and some stations frequently exceeded the chlorophyll *a*, total coliform bacteria, and dissolved oxygen standards. With respect to the Impaired Water Rule (IWR) criteria, this basin indicated unacceptable conditions for dissolved oxygen, ammonia, and chlorophyll *a*.

- **Payne Creek –** The Payne Creek basin is relatively small and drains to the Peace River upstream of the USGS Zolfo Springs gage. Streams in this basin were ranked high among the groups of stations with respect to total phosphorus and dissolved oxygen, and were ranked low with respect to Secchi disk depth, chlorophyll *a*, and turbidity. With respect to water quality standards, ammonia and total coliform bacteria criteria were frequently exceeded. Application of the IWR criteria identified acceptable conditions for dissolved oxygen, chlorophyll *a*, and fluoride, and unacceptable conditions for ammonia.

- **Peace River at Zolfo Springs –** This basin receives direct discharge upstream at its confluence with Payne Creek. Significant declines in Secchi disk depths (deteriorating water clarity) at a rate of greater than five percent of the median value per year were observed at 12 stations in the basin. Significant increases in total nitrogen and total phosphorus concentrations were also observed at a number of locations. State surface water quality standards at sampling stations were frequently exceeded for ammonia, dissolved oxygen, total coliform bacteria, and annual chlorophyll *a*. Relative to IWR criteria, total coliform bacteria and fluoride conditions were acceptable, while dissolved oxygen, ammonia, and chlorophyll *a* annual means were not.

- **Charlie Creek –** The Charlie Creek basin is one of the larger basins and discharges freshwater into the Peace River upstream of the USGS Peace River at Arcadia gage and downstream of the Zolfo Springs gage. No differences in water quality were found in comparisons between historical and current time periods. Water quality at basin stations were ranked among the best for Secchi disk conditions, total phosphorus, turbidity, and total nitrogen values. With respect to IWR criteria, this basin was also identified as having unacceptable conditions for ammonia. The EPA nutrient criteria for total phosphorus and total nitrogen were frequently exceeded at some stations, although the EPA criteria for chlorophyll *a*, Secchi disk depth, and turbidity were not.

- **Peace River at Arcadia –** The Peace River at Arcadia basin receives flow from below the Peace River at Zolfo Springs USGS stream flow gage and receives additional flows from the upstream confluence with Charlie Creek. A trend of increasing nitrite+nitrate at a rate greater than five percent of the median value per year was reported. A decreasing trend of similar magnitude was detected for total phosphorus. The stream stations in the Peace River at Arcadia basin were ranked highest with respect to color, total phosphorus, ammonia and nitrite+nitrate. The stations were ranked among the lowest with respect to conductivity, pH, turbidity, and Secchi disk depth. Florida standards for ammonia and dissolved oxygen standards were frequently exceeded. Chloride, annual chlorophyll *a*, and conductivity standards were not found to be frequently exceeded. With respect to the IWR criteria, the basin has acceptable conditions for dissolved oxygen, total coliform bacteria, and mean annual chlorophyll *a* values. Unacceptable conditions occurred for ammonia. EPA nutrient criteria were frequently exceeded for all parameters except Secchi depth and turbidity.

- **Joshua Creek –** This relatively small basin discharges freshwater into the Coastal Lower Peace basin upstream of the confluences of the Peace River with Horse Creek. Significant increasing trends were observed for nitrite+nitrate, chloride, and sulfate. The stream stations in the basin were ranked high with respect to the median nitrite+nitrate value, and ranked among the lowest stations for turbidity. State standards for ammonia, dissolved oxygen and total coliform bacteria were exceeded. Relative to IWR criteria, water quality was acceptable for dissolved oxygen and fluoride, and unacceptable for ammonia.

- **Horse Creek –** This relatively large basin discharges freshwater into the tidal area of the Coastal Lower Peace basin downstream of the Peace River at Arcadia gage. Two Horse Creek stations frequently exhibited exceedances of the state ammonia standard and IWR criteria. EPA phosphorus criteria were also frequently exceeded.

- **Shell Creek –** This basin discharges to the tidal Coastal Lower Peace River watershed and is characterized by an extensive estuary at its confluence with the Peace River estuary. Significant trends in increasing conductivity were observed at the HBMP Prairie Creek monitoring site upstream of the City's reservoir. Since 1991, this trend appears to be influenced by a recent shift towards slightly higher values. Higher TKN values were also detected in comparisons of historical and current time periods. Overall, observed water quality was relatively good in comparison to the other basins. However, with respect to surface water quality standards, there were frequent exceedances of ammonia and dissolved oxygen. Relative to IWR standards, the basin was identified as having acceptable conditions for fluoride and mean annual chlorophyll *a*, and unacceptable conditions for dissolved oxygen and ammonia.

- **Coastal Lower Peace –** The basin includes the Peace River watershed, beginning downstream of the Arcadia USGS gage, and continuing to the wider, tidal portions of the Peace River at its confluence with Charlotte Harbor. A number of significant water quality trends were detected for the stations in the Coastal Lower Peace basin. Notably Total Suspended Solids (TSS) trends were detected for five stations at rates of increase of greater than five percent of median values per year, and slight, significant trends in pH were detected for 20 stations. The pH trends appear to be gradual rather than sudden, which might be expected if the change was due to a change in a metering device. Ammonia, chlorophyll *a*, and dissolved oxygen values frequently exceeded water quality standards. Relative to IWR criteria, fecal coliform bacteria, total coliform bacteria, and annual chlorophyll *a* means in the stream stations were acceptable, while dissolved oxygen, ammonia, and annual chlorophyll *a* means for estuary stations were not.

2.8 An Evaluation of Stream Flow Loss during Low Flow Conditions in the Upper Peace River (draft, Basso, SWFWMD 2004)

Prior to significant groundwater withdrawals (predevelopment), the potentiometric surface of the Upper Floridan aquifer was much higher than the stage of the Peace River throughout its entire length. Increasing groundwater withdrawals for phosphate mining, agriculture, and public supply use has resulted in a 30 to 40 foot decline of the potentiometric surface of the Upper Floridan aquifer since predevelopment in the upper Peace River Basin. This long-term decline has reversed the hydraulic gradient between the Peace River and the underlying aquifers, resulting in occasional loss of perennial flow between Bartow and Homeland during the spring dry season. At the time of this study, the United States Geological Survey (USGS) was engaged in a cooperative study with the District to map karst features in the riverbed and adjacent floodplain and determine stream flow loss to the underlying aquifer(s). For the planning stages of the District water resource development projects, however, an immediate estimate of stream flow loss was needed so that potential augmentation quantities could be established. This paper examines the flow history between the Bartow and Ft. Meade stations and uses statistical analysis to provide an estimate of anticipated augmentation quantities necessary to overcome losses between the two stations. It was intended to be a preliminary analysis until more quantitative results could be obtained by the USGS.

The stream flow record from the Bartow and Ft Meade stations was examined from 1975 through 2003 to summarize hydrologic conditions and determine durations of flow that fell below the proposed minimum flows and levels. To assess river leakage during the dry part of the year, statistics were generated on the difference in daily flow between each station when Ft. Meade was at or below its recommended MFL.

The study concluded that during low flow conditions, defined as 27 cfs or lower at Ft. Meade, the average daily stream flow loss between Bartow and Ft. Meade was about 7 cfs, and less than 16 cfs, 95 percent of the time. This estimate assumes that the runoff characteristics are the same for the watershed between Ft. Meade and Bartow as they are for the watershed above Bartow. The report acknowledges the uncertainty in the estimated loss by not accounting for permitted mining discharges. Based on further examination of stream flow records at Homeland, located in between Bartow and Ft. Meade, the study concluded that nearly all of the in-stream leakage to the ground water system occurs along the river segment between Bartow and Homeland.

The study provided conservative estimates of augmentation quantities to meet MFLs. Expected augmentation schedules were derived based on regressions of historical flow differences and taking into account flow history at Ft. Meade over a 29 year period. The maximum projected capacity for in-stream augmentation to meet the MFL was 52 cfs (MFL at Ft. Meade plus 25 cfs). This capacity was required to assure that the MFL be met 99 percent of the time. The author stressed that the augmentation schedules should be considered preliminary and subject to revision until the detailed assessment conducted by the USGS could be completed.

2.9 Development of Hydrologic Model to Assess Phosphate Mining on the Ona Fort Green Extension (SDI Environmental Services, Inc. 2004)

This study was conducted in support of the administrative hearing process for the proposed Ona Mine extension in the Horse Creek basin. It involved the development of an integrated hydrologic model to evaluate the proposed reclamation technique and design that was part of the permit application. The model was first calibrated against stream flow and surficial aquifer water level data for the period 1978 – 1988, and was then applied to compare post-reclamation to pre-mining conditions in terms of various hydrologic watershed characteristics, including stream flow quantities, flow duration curves, and wetland hydroperiod. The study also provided an average water budget for Horse Creek for the 1978-1988 period. The average annual water budget had the following components:

- Rainfall + irrigation = 49.8 inches
- Evapotranspiration = 36.9 inches
- Stream flow (runoff+base flow) = 9.8 inches
- Net ground water recharge = 3.1 inches

2.10 2003 HBMP Annual Data Report (PBS&J 2004)

Between 1979 and 2003, an ongoing series of individual reports have been submitted to the District, documenting the results of the HBMP during the period from January 1976 through December 2002. This data report represents the fourteenth year of data collection for the Peace River/Manasota Regional Water Supply Authority (Authority), the owner/operator of the Peace River Regional Water Supply Facility.

This report compares data collected during 2003 with similar average values for key parameters previously compiled during various elements of the ongoing long-term monitoring programs. In making comparisons of the 2003 data with averages of similar data collected over the preceding twenty-year period (1983-2002), it should be noted that the very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced southwest Florida and the entire Peace River watershed between 1999 and mid-2002. A weaker El Niño at the end of 2002 and a wetter than average wet-season resulted in freshwater flows during 2003 being well above average.

- **Flows** – Overall, gaged Peace River at Arcadia freshwater inflows during 2003 were approximately double the average daily flow for the preceding long-term period 1976-2002. The sum of average daily flows from the Peace River at Arcadia, Horse Creek, Joshua Creek, and Shell Creek during 2003 was roughly one hundred and ninety percent of the average daily flows for the period 1976-2002.

- **Withdrawals** – Facility withdrawals only reached levels of ten percent of the gaged Peace River at Arcadia flows (those over 130 cfs) on three percent of the days of the year. Facility withdrawals during 2003 comprised 1.41 percent of the annual Arcadia gaged flow, and 0.89 percent of the combined lower Peace River gaged flow (Peace River at Arcadia, Horse Creek, Joshua Creek and Shell Creek). During 2003, the facility did not withdraw any water approximately eleven percent of the time. Maximum withdrawals increased notably during the later half of 2002 due to the recently completed facility expansion, which resulted in an increase in the Authority's ability to treat larger daily amounts of freshwater when river flows are within the existing permit schedule.

- **Temperature –** Average water temperatures throughout most of the year were generally above the long-term annual averages, even though surface water temperatures during the summer months were slightly below recent years (probably reflecting increased wet-season rainfall). Water temperatures at the end of the year (November and December 2003) were much warmer than average. As in previous years, during the summer wet-season (June through October), water temperatures in the freshwater isohaline were slightly below those observed at the other three monitored salinity zones.

- **Water Color –** The average color levels throughout the estuary were markedly different than those recently observed during the preceding years of drought. Color levels were well above the long-term averages as a result of the higher than average flows during much of 2003. Comparatively, the greatest difference in color levels during 2003 when compared to the long-term averages occurred within the higher salinity reaches of the estuary.

- **Extinction Coefficient –** Comparisons among the mean 2003 extinction values indicated divergent patterns. Light extinction coefficients within the freshwater reaches of the lower river were below historical annual averages, while at the same time extinction coefficients were at or above average within the higher estuarine salinity zones. It is suggested that the higher than average flows that occurred through the first half of 2003 suppressed normal spring levels of phytoplankton production (chlorophyll *a*), resulting in lower than average measurements of extinction coefficients within the lower river.

- **Nitrite/Nitrate Nitrogen** - During 2003, the average concentrations of this major inorganic form of nitrogen were similar to the long-term averages in the lower river, and slightly above average in the higher salinity reaches of the estuary. Spatially concentrations typically decreased rapidly with increasing salinity, while temporally ambient inorganic nitrogen concentrations in the estuary usually declined to their lowest levels during the relatively drier, late spring as phytoplankton populations responded to increasing water temperatures and light, and increased primary production removed available inorganic nitrogen.

- **Ortho-phosphorus** - Average inorganic phosphorus concentrations during 2003 were generally lower than the long-term averages (1983-2002). Since ambient inorganic phosphorus concentrations are heavily influenced by the unusually "very" high natural levels found in the Peace River watershed, the observed differences in concentrations among the four monitored HBMP isohalines simply reflect conservative dilution by Gulf waters. Unlike inorganic nitrogen, observed changes in phosphorus concentrations are for the most part unaffected by biological uptake. Ambient inorganic phosphorus concentrations entering the estuary system from the Peace River watershed are typically lower during wetter periods, when a higher proportion of flow results from surface flow (rather than coming from groundwater, which is naturally richer in phosphorus). Since the late 1970s there has been a marked decline in inorganic phosphorus levels in the lower Peace River/upper Charlotte Harbor estuarine system due to declines in the influences of phosphate mining in the upper reaches of the basin.

- **Nitrogen to Phosphorus Atomic Ratios** – Calculated atomic inorganic nitrogen to phosphorus ratios for ambient measured concentrations showed nitrogen to always be the inorganic macronutrient limiting phytoplankton production within the lower Peace River/upper Charlotte Harbor estuarine system.

- **Silica** - Concentrations during 2003 reflected a continuation of the previously noted increasing pattern of higher dissolved silica concentrations. This increasing pattern was slightly interrupted by the recent extended drought, but average reactive silica concentrations during 2003 were more than double the long-term means throughout the lower river and upper harbor.

- **Chlorophyll *a*** – The pattern of freshwater inflows during 2003 reflected the influences of the much wetter than usual 2002/2003 winter, followed by wetter than average conditions during the typically very dry spring, and a wetter than average summer wet-season. The result was both higher than average inputs of inorganic nutrients, and higher than average ambient water color (low light). This was fairly typical of relatively lower levels of phytoplankton production in the more highly color-influenced lower salinity reaches of the estuary, combined with higher than average phytoplankton production (chlorophyll *a*) within the higher salinity zones. The 2003 data indicated the occurrences of a number of instances of high phytoplankton chlorophyll *a* biomass. Corresponding species identifications found that either increases in dinoflagellates or diatoms often characterized these "blooms."

The graphical and summary analyses presented in this document do not indicate any substantial changes, or atypical events in either the physical or biological data collected during 2003, other than those previously noted. These include:

- Higher than usual winter freshwater inflows associated with the winter 2002/2003 El Niño event.

- A wetter than average summer wet-season.

- A resumption of the previously noted long-term increase in reactive silica concentrations in the lower Peace River.

These "limited" analyses also do not suggest that there have been any long-term changes resulting from either current or historic water withdrawals by the Peace River Regional Water Supply Facility.

2.11 Florida River Flow Patterns and the Atlantic Multidecadal Oscillation (Kelley, SWFWMD 2004)

The purpose of this paper was to discuss the influence of the Atlantic Multidecadal Oscillation (AMO) on stream flow patterns throughout Florida, including the Peace River. This broader climatic influence was placed in the context of geographic and seasonal differences in rainfall patterns in Florida, and a number of waterbodies are specifically examined. There is a seasonal/geographic divergence in rainfall pattern within the state of Florida. North Florida receives its highest rainfall in the spring, while South Florida receives the majority of its rainfall through the summer monsoon. The Wacasassa and Steinhatchee Rivers are located in a range that is influenced by both rainfall patterns. These rivers exhibit a seasonally bimodal flow pattern (summer and winter peaks in flow). The AMO is now widely accepted among climatologists. There has been an assumption that the long term rainfall and flow are distributed in a random independent and identical manner. The presence of predictable periodic changes in rainfall counters this assumption. Due to the affect of the AMO on rainfall, and the relationship between rainfall and stream flow, the author believes that there should be a distinct step trend, rather than a monotonic trend, in temporal flow evaluations.

The relationship between mean annual flow and total annual rainfall was developed further to examine seasonal and monthly flow and rainfall relationships. In doing so, median daily flows were normalized by creating a ratio of flow per unit area of drainage basin. Flow conditions in many Florida Rivers changed sometime around 1970, the time of an AMO shift. Prior to 1970 the flow peaks in South Florida were larger, and flow peaks in North Florida were smaller. The rivers with bimodal flow distribution exhibited these changes as apparent shifts in seasonal rainfall volume. In the Peace River Basin, despite the impact of the regional lowering of the potentiometric surface of the Upper Floridan Aquifer it is believed that the recent decline in flow is attributable to natural variation in climatic condition (the AMO) rather than anthropogenic sources. This attribution is based on the similarity in flow trend between the Peace River and Charlie and Horse Creeks, despite the fact that Charlie and Horse Creeks have not undergone anthropogenic landscape alteration to the extent of the Peace River.

2.12 Shell Creek and Prairie Creek Watersheds Management Plan – Reasonable Assurance Documentation (Shell, Prairie, and Joshua Creeks Watershed Management Plan Stakeholders Group 2004)

The Shell, Prairie, and Joshua creek watersheds account for 20 percent of the Peace River basin. Shell and Prairie creeks are designated Class I waterways, while Joshua Creek is a Class III waterway. Currently three of the eight waterbody identifications (WBIDs) that comprise the Shell and Prairie creek watersheds are classified as impaired. WBID #1962 in the Prairie Creek watershed is impaired for specific conductance and total dissolved solids (TDS). WBIDs #2040 and #2041 in the Shell Creek watershed are impaired for specific conductance, TDS, and chloride. The identified predominant source of these pollutants is mineralized groundwater withdrawn for agricultural use. The presence of these contaminants affects the ability of the City of Punta Gorda to meet secondary drinking water standards.

The goal of the reasonable assurance plan is to improve the water quality of the Praire and Shell creek waterbodies to meet Class I Standards at all times. The Joshua Creek watershed is included because of its proximity to Shell and Prairie creeks and due to identification of similar water quality issues.

A number of management activities, including but not limited to well back plugging, well construction and water use permitting, Facilitating Agricultural Resource Management Systems (FARMS) projects, land acquisition, and best management practices manuals will be utilized to reduce pollutant loads to the impaired waterbodies. The results of these management activities will be monitored by:

- Specific Conductance Reconnaissance Network (SWFWMD)
- In-Stream Data Sonde – Conductance Logging Network (SWFWMD and USGS)
- SPJC – Water Quality Monitoring Networks
- Pre- and Post- Back Plug Well Monitoring Network (SWFWMD)
- Surface Water Quality Monitoring Networks (SWFWMD and FDEP)
- Habitat Assessment and Stream Condition Index Monitoring (SWFWMD and FDEP)
- Coastal Ground Water Quality Monitoring Network (SWFWMD)
- Water Use Permitting Ground Water Quality Monitoring Network (SWFWMD)
- Shell Creek Hydrobiological Monitoring Program (City of Punta Gorda)

As the cause of impairment is a known point source of highly mineralized groundwater used for agricultural purpose, it is believed that no corrective action will be needed beyond controlling this point source. It is acknowledged that, due to the buildup of salts in the sediments, it may be some time before the full benefit of the corrective actions is recognized. While it is believed that a ten year time period will be sufficient, additional time may be necessary to achieve the Class I waterway standards.

2.13 Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia (Kelly *et al*. 2005)

This report was published as a draft in February 2005. The methods used in this MFL evaluation were significantly more sophisticated than those employed in the upper Peace River evaluation, largely following the recommendations of the MFL Scientific Peer Review Panel. The report was subsequently used to develop MFLs for the middle Peace River which were adopted by the District Governing Board.

The middle segment of the Peace River is defined as the stretch of the river from the USGS gage sites at Zolfo Springs and at Arcadia (approximately 35 km, not tidally influenced). The watershed of this segment of the Peace River is relatively unimpacted by mining activities and urban development compared to the upper Peace River. The intake for the Peace River/Manasota Regional Water Supply Authority potable water supply is located approximately twenty-five kilometers downstream from the Arcadia gage.

Building on the approach used for the upper Peace River segment, an analysis of historic versus current flow conditions was conducted to assess the extent withdrawals or other anthropogenic factors have affected flows. The District assessed for the first time the effects of climatic oscillations on regional river flows, and identified two benchmark periods for evaluating flows in the middle segment of the Peace River. Furthermore, they concluded that "…flow declines in the middle Peace River which have been ascribed to human causes by some investigators, are largely a function of climatic variation."

For development of the MFLs, the District identified three seasonal blocks corresponding to periods of low, medium and high flows. Short-term minimum flow compliance standards for the Zolfo Springs and Arcadia gage sites were developed for each of these seasonal periods using a "building block" approach recommended by the Panel. Prescribed flow reductions were based on limiting potential changes in aquatic and wetland habitat availability that may be associated with seasonal changes in flow. Low flow thresholds were based on fish passage depth and wetted perimeter inflection points, and were also incorporated into the short-term compliance standards. The low flow threshold was defined to be a flow that serves to limit withdrawals, with no withdrawals permitted unless the threshold is exceeded.

A prescribed flow reduction for the low flow period (Block 1, April 20 - June 24) was based on review of limiting factors developed using the Physical Habitat Simulation Model (PHABSIM) to model potential changes in habitat availability for several fish species and macroinvertebrate diversity. Simulated reductions in historic flows greater than 10 percent resulted in more than a 15 percent loss of available habitat as sites upstream from the Arcadia and the Zolfo Springs gages. Using this limiting factor, the prescribed flow reduction for both gage sites during the low flow period was defined as a 10 percent reduction in flow, with the exception that withdrawals should not be allowed to reduce the flow to less than 45 cfs at the Zolfo Springs site and 67 cfs at the Arcadia site.

For the high flow season of the year (Block 3, June 25 - October 27), prescribed flow reduction was based on review of limiting factors developed using the HEC-RAS floodplain model and frequency statistical analyses to evaluate percent of flow reductions associated with changes in the number of days of inundation of floodplain features. It was determined that a stepped flow reduction of 13 percent and 8 percent of historic flows, with the step occurring at the 25 percent exceedance flow (1,362 cfs) resulted in a decrease of 15 percent or more in the number of days that flows would inundate floodplain features at the Arcadia gage. A stepped flow reduction of 11 percent and 8 percent of historic flows, with the step occurring at the 25 percent exceedance flow (783 cfs) was established at the Zolfo Springs gage. Using these limiting factors, prescribed flow reductions consistent with the stepped flow reductions described above were established, with the exception that withdrawals should not be allowed to reduce the flow to less than 45 and 67 cfs at the Zolfo Springs and Arcadia gage sites, respectively.

For the medium flow period (Block 2, October 28 - April 19), both PHABSIM and HEC-RAS were utilized to evaluate prescribed flow reductions. PHABSIM was deemed to be the more conservative approach for both gages and was utilized to define the percent flow reduction. It was determined that more then 15 percent of historically available habitat would be lost for specific species life-stages if flows were reduced by more than 18 percent at Arcadia or more the 10 percent at Zolfo Springs during the medium flow period. Thus, prescribed flow reductions during the medium flow period were set at these levels, with the exception that withdrawals would not be allowed to reduce flow at the Zolfo Springs site below 45 cfs.

Because minimum flows are intended to protect the water resources or ecology of an area, and because climatic variation can influence river flow regimes, the District developed long-term compliance standards for the middle Peace River gage sites at Arcadia and Zolfo Springs. The standards are hydrologic statistics that represent flows that may be expected to occur during long-term periods when short term-compliance standards are being met. The long-term compliance standards were generated using gage-specific historic flow records and the short-term compliance standards. For the analyses, the entire flow record for each site was altered by the maximum allowable flow reductions in accordance with the prescribed flow reductions and the low flow threshold. Hydrologic statistics for the resulting altered flow data sets, including five and ten-year mean and median flows were determined and identified as long-term compliance standards. Because these long-term compliance standards were developed using the short-term compliance standards and the historic flow records, it may be expected that the long-term standards will be met if compliance with short-term standards is achieved.

Collectively, the short and long-term compliance standards proposed for the USGS gage sites at Zolfo Springs and Arcadia comprised the District's proposed minimum flows and levels for the middle segment of the Peace River. The standards are intended to prevent significant harm to the water resources or ecology of the river that may result from water use. The building block approach and resulting compliance standards encompass the full flow regime for this segment, and are substantially more comprehensive than the low flow threshold developed for the upper Peace River segment.

2.14 2004 HBMP Annual Data Report (PBS& J 2005)

This data report represents the fifteenth year of data collection for the Peace River/Manasota Regional Water Supply Authority (Authority), the owner/operator of the Peace River Regional Water Supply Facility. The report compares data collected during 2004 with similar average values for key parameters previously compiled during various elements of the ongoing long-term monitoring programs. In making comparisons of the 2004 data with averages of similar data collected over the preceding twenty-one year period, it should be noted that the very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced the entire Peace River watershed between 1999 and mid-2002. A weaker El Niño occurred at the end of 2002, and freshwater flows during both 2003and 2004 were well above average.

- **Flows –** Overall, gaged Peace River at Arcadia freshwater inflows during 2004 were approximately one hundred and ninety-five percent the average daily flow for the preceding long-term period 1976-2003. The sum of average daily flows from the Peace River at Arcadia, Horse Creek, Joshua Creek, and Shell Creek during 2004 was roughly one hundred and eighty-two percent of the average daily flows for the period 1976-2003.

- **Withdrawals –** Overall withdrawals comprised 1.39 percent of the annual Arcadia gaged flow, and 0.87 percent of the combined lower Peace River gaged flow (Peace River at Arcadia, Horse Creek, Joshua Creek and Shell Creek). Facility withdrawals exceeded ten percent of the gaged Peace River at Arcadia flows approximately four and a half percent of the time. Such ascendances result from subsequent revisions by USGS of the provisional daily flow information available to the Authority at the time of actual withdrawals. During 2004, the facility did not withdraw any water approximately twenty percent of the time.

- **Temperature –** Median water temperatures during 2004 were slightly lower than corresponding values measured over the preceding twenty-one year period. Such results may reflect differences in cloud cover resulting from the overall wetter than usual conditions and three hurricanes that passed near (or over) the area. Measured water temperatures in the freshwater isohaline during the spring of 2004 were slightly higher than those observed at the other three monitored salinity zones, possibly reflecting the increased heating of the more highly colored water. The water temperatures measured during December 2004 were the warmest December values measured during the 1983-2004 period.

- **Water Color –** Color levels, as in 2003, were well above the long-term averages as a result of the higher than average freshwater inflows during much of 2004.

- **Extinction Coefficient –** The rates of measured light attenuation reflect both ambient color and phytoplankton biomass. Comparisons among the mean 2004 extinction values indicate that even though water color throughout the estuary was slightly higher than average during 2004, light extinction coefficients were below historical annual averages. It is possible that higher than average freshwater inflows resulted in higher than average water color, which in turn suppressed normal spring levels of phytoplankton production (chlorophyll *a*), resulting in lower than average measurements of extinction coefficients.

- **Nitrite/Nitrate Nitrogen** - During 2004, the average concentrations of this major inorganic form of nitrogen were slightly lower than the long-term historical annual averages. Monthly comparisons show unusual marked declines in the freshwater flows entering the estuary following the hurricanes in August and September. Typically, monthly comparisons indicate nitrite/nitrate inorganic nitrogen concentrations in the lower Peace River/upper Charlotte Harbor Estuary are characterized by a distinct spatial gradient. Concentrations typically decrease rapidly with increasing salinity, with inorganic nitrogen levels within the 20 o/oo isohaline being near method detection limits throughout much of the year. Normally, estuarine inorganic nitrogen concentrations usually decline to their lowest levels during the relatively drier, late spring as phytoplankton populations respond to increasing water temperatures and light, and increased primary production removes available inorganic nitrogen. However, the higher than normal freshwater flows during the spring of 2004 also resulted in differences in the characteristic annual patterns of inorganic nitrogen concentrations in the upper reaches of the estuary.

- **Ortho-phosphorus** - Estuarine inorganic phosphorus concentrations in the lower Peace River and upper Charlotte Harbor are heavily influenced by the unusually "very" high natural levels found in the Peace River watershed. As a result, the observed differences in concentrations among the four isohalines simply reflect conservative dilution by Gulf waters. Unlike inorganic nitrogen, seasonal observed changes in phosphorus concentrations in the estuary are for the most part unaffected by biological uptake. Since the late 1970s there has been marked historical declines in inorganic phosphorus levels in the lower Peace River/upper Charlotte Harbor estuarine system due to declines in the influences of phosphate mining in the upper reaches of the basin. Inorganic phosphorus concentrations entering the estuary system from the Peace River watershed are typically lower during wetter periods, when a higher proportion of flow results from surface flow (rather than coming from groundwater, which is naturally richer in phosphorus). However, average concentrations during 2004 were higher than the long-term averages. This was the result of unusually high phosphorus levels in the freshwater entering the estuary following Hurricanes Charley Frances and Jeanne.

- **Nitrogen to Phosphorus Atomic Ratios** – Calculated atomic inorganic nitrogen to phosphorus ratios for ambient measured concentrations in 2004, as indicated by the long-term averages, show nitrogen to always be the limiting macronutrient at each of four isohalines sampled.

- **Silica** – Measured concentrations of dissolved reactive silica in the lower Peace River/upper Charlotte Harbor estuarine system during 2004 reflected a continuation of the previously noted increasing pattern of higher values. Comparisons of long-term annual average silica concentrations indicated that 2004 levels were approximately double the long-term historic levels.

- **Chlorophyll *a*** – The seasonal patterns of freshwater inflows during 2004 were influenced by both much wetter than average conditions during the typically very dry early spring, and a wetter than average late summer wet-season. The resulting seasonal flow patterns combined to produce both higher than average inputs of inorganic nutrients, as well as higher than average levels of water color (resulting in greater light attenuation). Overall, phytoplankton production (chlorophyll *a*) levels in the lower Peace River/upper Charlotte Harbor Estuary were slightly above the long-term (1983-2003) averages within each of the four salinity zones. Phytoplankton blooms within both the 6 and 12 o/oo isohalines occurred periodically during 2004.

The analyses presented in this document do not indicate any substantial changes, or atypical events in either the physical or biological data collected during 2004, other than those previously noted. These include:

- A series of somewhat unusual periods of increased freshwater inflow during the typically dry early spring.

- High late summer/fall freshwater inflows following the rainfall events associated with Hurricane Charlie in August and Frances, Ivan and Jeanne in September.

- A continuation of the previously noted long-term increase in reactive silica concentrations in the lower Peace River.

- Marked increases in inorganic phosphorus concentrations in the freshwater entering the estuary following the hurricanes.

These "limited" analyses also do not suggest that there have been any long-term changes resulting from either current or historic water withdrawals by the Peace River Regional Water Supply Facility.

2.15 Impact of Phosphate Mining on Streamflow (Schreuder *et al*. 2006)

This study combined analyses of both double-mass rainfall/flow plots and best-fit trend lines to assess the potential impacts of phosphate mining on stream flow. Double-mass rainfall/flow plots were developed for the Peace River and its tributaries: Bowlegs, Charlie, Joshua, Payne and Horse creeks, as well as the South Prong of the Alafia River, the Alafia at Lithia, the Little Manatee River at Wimauma, the Manatee River at Myakka Head, the Myakka River near Sarasota, and the Withlacoochee River at Holder. Annual low flow (P10), median flow (P50) and high flow (P90) exceedance values for each of these systems were plotted against cumulative annual rainfall. The conclusions of the study based on these analyses indicated:

- Approximately 70 percent of the Payne Creek basin has been impacted by phosphate mining. However, results indicated that total stream flow from the Payne Creek basin was higher than from the similarly sized Joshua Creek basin.

- Overall, standardized (flow per unit area) mean stream flow was found to be consistently higher from basins in the Alafia River and Peace River watersheds where phosphate mining is a dominant land use.

- In the Southern Water Use Caution Area (SWUCA), agricultural irrigation pumpage from the Floridan aquifer has caused a significant decline in the potentiometric surface of the Floridan aquifer. This decline represents the transfer of large volumes of ground water from the deeper Floridan aquifer to the shallow surficial aquifer that is in direct contact with surface water streams.

- As a result, mean stream flow was found to be higher in the coastal river basins than either the Alafia or the Peace River watersheds.

- Stream flows from Payne Creek were found to significantly increase the unit mean flow in the Peace River from 0.40 cfs/m at the Ft. Meade gaging station to 0.58 cfs/m at the Zolfo Springs gage. The study concluded that this demonstrates that additional surface water flow from tributary basins, where pumpage from the underlying confined aquifer system(s) or salvage of evapotranspiration losses is taking place, augments the surface water flow in the Peace River.

- Polynomial trendlines of the double-mass plots of area standardized mean stream flow versus rainfall for the 20 year period from 1980 through 2000 indicate increased stream flow in the studied streams, with the exceptions of upper Horse Creek, Bowlegs Creek and the Withlacoochee River.

- The results of the double-mass analyses indicated that stream flows from predominantly mined/reclaimed areas have not been declining, but during the 1980-2000 period have been increasing at rates greater than unmined areas with irrigated agricultural land uses..

- There was a distinctly different distribution of stream flows between the mined (reclaimed) basins and other basins. The analyses indicated mined areas tend to retain flood flows (P90) for later release as median (Q50) and base flows (P10).

- The magnitude and seasonal distribution of stream flow were observed to be similar among the mined basins, but distinctly different from unmined agriculture-dominated basins. Gains in streamflow resulting from phosphate mining were related to reduced evapotranspiration (ET) losses associated with vegetation changes on reclaimed land compared to more mature pre-mining vegetation. In agriculture-dominated basins, gains in stream flow were due to ground water pumpage from the underlying confined aquifer and subsequent discharges to surface waters.

2.16 2005 HBMP Annual Data Report (PBS&J 2006)

This data report represents the sixteenth year of data collection for the Peace River/Manasota Regional Water Supply Authority (Authority), the owner/operator of the Peace River Regional Water Supply Facility and the tenth Annual Data Report submitted under the expanded Hydrobiological Monitoring Program (HBMP) initiated in 1996.

The report summarizes and compares data collected during 2005 with similar HBMP information previously compiled during various elements of the ongoing long-term monitoring programs. In making comparisons of the 2005 data with averages of similar data collected over the preceding twenty-two year period (1983-2004), it should be noted that the very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced southwest Florida and the entire Peace River watershed between 1999 and mid-2002. A weaker El Niño occurred at the end of 2002, and freshwater flows during 2003, 2004 and 2005 were generally above average.

- **Flows –** Overall, gaged Peace River at Arcadia freshwater mean flows during 2005 were approximately two hundred and two percent the average daily flow for the preceding long-term period 1976-2004. The sum of average daily flows from the Peace River at Arcadia, Horse Creek, Joshua Creek, and Shell Creek during 2005 was roughly one hundred and eighty-seven percent of the average daily flows for the period 1976-2004.

- **Withdrawals –** Overall withdrawals comprised 1.01 percent of the annual Arcadia gaged flow, and 0.64 percent of the combined lower Peace River gaged flow (Peace River at Arcadia, Horse Creek, Joshua Creek and Shell Creek). Facility withdrawals during 2005 never exceeded ten percent of the gaged Peace River at Arcadia flows. During 2005, the facility did not withdraw any water approximately nine percent of the time.

- **Temperature –** Median water temperatures at each of the three higher salinity isohalines were slightly greater than corresponding values measured over the preceding twenty-two year period. The warm water temperatures in the freshwater isohaline during the spring of 2005 were slightly higher than those observed at the other three salinity zones, possibly reflecting the increased heating of the more highly colored water. Water temperatures measured in January and December 2005 were much warmer than usual.

- **Water Color –** Color levels in 2005 were well above the long-term averages as a result of the higher than average freshwater inflows. The peak very high color levels typically observed during the summer wet-season within the freshwater isohaline was not observed during 2005. This may reflect the higher than usual flows during both the winter and spring of 2005 and that the washout of tannins from uplands and wetlands were distributed over a much longer period.

- **Extinction Coefficient –** The rates of measured light attenuation reflect both ambient color and phytoplankton biomass. Comparisons among the mean 2005 extinction values indicate that even though water color throughout the estuary was higher than average during 2005 due to greater than average freshwater inflows, light extinction coefficients were below historical annual averages. It is possible that in 2003 - 2005 higher than average inflows resulted in higher than average water color, which in turn suppressed normal spring levels of phytoplankton production, yielding lower than average extinction coefficients.

- **Nitrite/Nitrate Nitrogen** - During 2005, average concentrations of this major inorganic form of nitrogen were lower in the upper freshwater reach of the estuary than the long-term, historical annual average and higher at the three higher salinity isohalines. This is unlike the typical spatial gradient where concentrations decrease rapidly with increasing salinity, with inorganic nitrogen levels within the 20 o/oo isohaline often being near method detection limits. Normally, estuarine inorganic nitrogen concentrations usually decline to their lowest levels during the relatively drier, late spring as phytoplankton populations increase. However, the higher than normal freshwater flows during winter and spring of 2005 resulted in differences in the characteristic annual patterns of inorganic nitrogen concentrations in the estuary.

- **Ortho-phosphorus** - Estuarine inorganic phosphorus concentrations are heavily influenced by the unusually "very" high natural levels found in the Peace River watershed. As a result, the observed differences in concentrations among isohalines simply reflect conservative dilution by Gulf waters. Seasonal observed changes in phosphorus concentrations in the estuary are for the most part unaffected by biological uptake. Inorganic phosphorus concentrations entering the estuary system from the Peace River watershed are typically lower during wetter periods, when a higher proportion of flow results from surface flow (rather than coming from groundwater, which is naturally richer in phosphorus). Average inorganic phosphorus concentrations during 2005 were higher than the long-term averages, reflecting the overall results of higher than average freshwater inflows.

- **Nitrogen to Phosphorus Atomic Ratios –** Calculated atomic inorganic nitrogen to phosphorus ratios for ambient measured concentrations in 2005, as indicated by the long-term averages, show nitrogen to always be the limiting macronutrient at each of the four isohalines.

- **Silica –** Although the observed seasonal peaks of dissolved reactive silica in the lower Peace River/upper Charlotte Harbor estuarine system during 2005 were below those observed in 2003 and 2004, overall concentrations reflected a continuation of the previously noted increasing pattern of higher values at all four isohalines.

- **Chlorophyll *a*** – The seasonal patterns of freshwater inflows to the estuary during 2005 reflect both much wetter than average conditions during the typically dry winter/spring and wetter than average conditions both during the early and late summer wet-season. The resulting seasonal flow patterns combined to produce both higher than average inputs of inorganic nutrients, as well as higher than average levels of water color (resulting in greater light attenuation). Overall, phytoplankton production (chlorophyll *a*) levels in the lower Peace River/upper Charlotte Harbor Estuary were above the long-term averages within each of the four salinity zones. As in previous years, phytoplankton blooms were more common within the intermediate (6 and 12 o/oo) isohalines. Somewhat surprisingly, the highest chlorophyll level ever recorded by any of the HBMP monitoring programs occurred during October 2005 at the 12 o/oo isohaline. The actual recorded value was based on a calculation using a very high dilution and therefore represents only a relative estimate. However, this isolated unusual estimated level was nearly double the previous highest measurement.

The graphical and summary analyses presented in this document do not indicate any substantial changes, or atypical events in either the physical or biological data collected during 2005, other than those previously noted. These include:

- Freshwater inflows during 2005 were characterized by much wetter than normal flows during the winter (January and February), unusually high flows during the typical spring dry-season (especially during March and May), much higher than normal flow through the first part of the summer wet-season (June, July and August), and seasonally very high flows from the end of October through mid-November.

- A continuation of the previously noted long-term increase in reactive silica concentrations in the lower Peace River.

- Some indications that inorganic phosphorus concentrations in the freshwater entering the estuary has increased slightly in recent years, following decades of major declines that began in the late 1970s.

The "limited" analyses presented in the annual data report do not suggest that there have been any long-term changes resulting from either current or historic water withdrawals by the Peace River Regional Water Supply Facility. To date, none of the conducted HBMP data analyses have shown that facility withdrawals have had, or are expected to cause, measurable negative physical or biological adverse impacts within the lower Peace River estuarine system.

2.17 Assessment of Potential Shell Creek Impacts Resulting from Changes in City of Punta Gorda Facility Withdrawals (PBSJ 2006)

The Authority and the City of Punta Gorda (City) submitted a conjunctive water use permit application to the Southwest Florida Water Management District, including a request to increase the permitted maximum monthly Shell Creek Reservoir water withdrawals from 8 to 10 million gallons per day (mgd) to accommodate a projected "gap" between water supply demands and permitted withdrawals. This document was prepared to provide data and analyses requested by the District in order to evaluate whether the biological communities of the Shell Creek/lower Peace River estuarine system might be adversely impacted as a result of the proposed increased permitted freshwater withdrawals.

Data sources for the report included seasonal and long-term water quality data from the Shell Creek Hydrobiological Monitoring Program (HBMP) which began in 1991. Additionally, information from a number of other sources was utilized including USGS flow data, rainfall data from the District and water quality data from the USGS and City monitoring programs.

A number of technical analyses and summaries of existing available information were undertaken in conjunction with evaluating potential impacts of the proposed "Gap" increase in withdrawals from the Shell Creek Reservoir.

Characterization of Historical Shell Creek Flow Regime

Daily USGS flow data for the period 1966-2004 were used to develop a comprehensive overview of both annual and seasonal variability in Shell Creek freshwater flows.

Graphical analyses indicated freshwater flows over the Hendrickson Dam (Dam) vary seasonally and annually. Flows during the drier and cooler historic AMO period (1966-1994) were lower when compared with a wetter and warmer recent AMO period (1995-2004). Higher flows occurred primarily in wet-season months.

Results of the USGS Seasonal Kendall Tau analysis were consistent with other studies, indicating that long-term increases in base flows in Shell Creek during winter/spring flows are a result of agricultural groundwater augmentation. However, analyses of variance (ANOVA) results indicated no significant differences in flows between the previously described AMO periods.

Influences of Withdrawals on Flow Characteristics

The greatest changes in flows were predicted during the lowest monthly flows, and changes decreased in magnitude as flows increased. Differences between the current maximum capacity and alternative withdrawals indicate that the proposed "Gap" permit increase from 8 to 10 mgd would result in relatively small changes in the range, minimum, maximum, and other statistics associated with flows. While changes in flows due to withdrawals are most conspicuous during the spring dry season, withdrawals could potentially reduce flows significantly on a percentage basis during any month as a result of the wide seasonal variability.

Influences of Flow on Salinity, Dissolved Oxygen, and Chlorophyll *a*

Under no-flow conditions, surface salinities near the dam can reach nearly 15 psu. As flows increase, salinities can decrease to zero, although the effect of flow on salinity decreases downstream. Variability increases in the salinity flow relationship moving downstream as a result of the combined effects of tidal volume and Peace River flows. Unusually high tides or extended periods of southerly winds may move higher salinity water upstream increasing salinities beyond those predicted using typical salinity/flow relationships.

Bottom Dissolved Oxygen (DO) values are generally lower than surface values, although differences become less distinct under very high flows. DO levels at the dam are low at low flows, but differences are less apparent downstream. A pattern of declining DO values with high flows occurs during the summer, and may be related to higher water temperatures.

Data analyses indicate that chlorophyll *a* levels decline with decreasing flows. This is probably due to the combined influences of increases in water color and a decrease in residence time.

Analyses were performed to evaluate spatial and temporal differences in salinity, DO and chlorophyll *a* along the Shell Creek monitoring transect. Results indicate spatial gradients in surface and bottom salinity levels, but not DO or chlorophyll *a*. Temporal differences are apparent from salinity data in the tidal portion of Shell Creek.

Potential Influences of Facility Freshwater Withdrawals on Salinity

Modeling and analyses indicated that potential increases in surface and bottom salinities along Shell Creek due to a proposed increase in withdrawals from 8 to 10 mgd would be very small when compared to both the short and longer term seasonal variations occurring naturally in this reach of the creek.

Comparisons of Flows with and without Proposed Withdrawals

Log-Pearson Type III distributions were utilized to assess potential changes in flow-duration and lowest mean-discharges for various consecutive-day periods. The results of these analyses indicated only small differences between the current maximum 8 mgd withdrawal and the proposed "Gap" increase to 10 mgd.

Characterization of Major Freshwater Ions

Relevant long-term monitoring data from a number of sources were utilized to characterize trends in water quality characteristics and major ion constituents of Shell and Prairie creeks, as well as within the City of Punta Gorda's reservoir. While most of the analyses indicate no significant trends in water quality, some changes were likely associated with increases in groundwater use and "tail water" agricultural discharges to natural surface waters. For example, there has been an increase in chloride levels over time at both Prairie Creek and Shell Creek sites. Data for a Prairie Creek site indicate increases in specific conductance, hardness, total dissolved solids, and chlorides. Shell Creek Reservoir data indicate increases in specific conductance, hardness, chloride, sulfate and silica levels over time. Increases in surface DO levels also suggest that the reservoir may be more eutrophic due to increased agricultural development in the upstream watersheds.

Within the reservoir, concentrations of most parameters, including specific conductance, hardness, DO, pH, total dissolved solids, total Kjeldahl nitrogen, total phosphorus, ortho-phosphorus, total organic carbon, and alkalinity increased with increasing flows, while color, sulfate, and chloride decreased.

Riparian Vegetation

The spatial distribution of riparian vegetation along estuarine Shell Creek below the Dam was evaluated and compared with previous GIS vegetation information developed by Florida Marine Research Institute (FMRI) for the District from field verified 1994 aerials. Vegetation along the creek transitions downstream from a larger mix of low-salinity and freshwater species, to fewer species tolerant of a larger range in salinities, to species such as mangroves and needle rush, which are tolerant of salinities much greater than that of sea water.

Within a given salinity regime, other factors become more important in affecting marsh species distributions. For example, under freshwater conditions, species competition influences distributions. Under higher salinity conditions, elevation becomes more important, as does proximity to wave energy.

Mapping data from 1994 (FMRI 1998) and this 2006 “Gap” report indicate a spatial shift to a larger number of freshwater species, specifically giant cutgrass, upstream of the Myrtle Slough confluence. In addition, the distribution of at least one species, bulrush, appears to have increased along the river channel since 1994. Salinity data indicate lower salinities during 2002 – 2004, compared with 1991 – 2001, and changes in salinity could cause a slow shift to larger numbers of more typically freshwater species. Bulrushes are tolerant of a wide range of salinities and may easily expand into gaps where other species are absent.

However, the resolution of the digital orthophoto quadrangle (DOQQs) used may limit the ability to make this comparison and, as noted by the authors of the FMRI report, better resolution photographs would have been helpful in making more accurate observations. Finally, although not addressed in this study, the impact of recent hurricanes cannot be disregarded when considering possible spatial and temporal changes in vegetation along Shell Creek.

Evaluation of Information of Flow Influences on Biological Community Structure

Biological information gathered as part of the Peace River HBMP and the District minimum flow studies were evaluated and summarized in order to provide a general overview of the relationships between historical seasonal and long-term variations in Shell Creek flow and the structure and composition of biological communities in the Shell Creek/lower Peace River estuarine system. The information, graphics and conclusions contained in previous studies conducted for the District were reviewed and summarized as part of this report with regard to evaluating the salinity tolerances of key groups of estuarine species and assessing potential responses to predicted levels of salinity increase potentially resulting from proposed “Gap” withdrawals.

2.18 Peace River Cumulative Impact Study (PBSJ 2007)

Changes in both land and water uses in the Peace River watershed have cumulatively impacted both the hydrology and ecology of the watershed. In recognition of these impacts, the Florida

Legislature enacted Senate Bill 18-E during the 2003 legislative session. The bill directed the Florida Department of Environmental Protection to conduct a Cumulative Impact Study (CIS) and prepare a Resource Management Plan for the Peace River watershed. The purpose of this study was to conduct an objective assessment of the individual and cumulative impacts of certain anthropogenic and natural stressors in the Peace River watershed with respect to historical changes in stream flow, ambient water quality, and various ecological indicators.

The Resource Management Plan prepared by FDEP will identify regulatory and non-regulatory means to minimize future impacts and mitigate past impacts to the Peace River watershed. In support of the Resource Management Plan, the primary goal and specific task of the CIS was to document and evaluate the historic hydrologic and land use changes in the Peace River watershed. The CIS objectives presented below were established to evaluate the potential cumulative impacts of the observed changes on the natural resources of the watershed and downstream estuarine system.

- Assess historical changes in the watershed with respect to the following indicators:
    1. Acres of wetlands lost
    2. Acres of native upland habitats lost
    3. Miles of streambed lost
    4. Changes in rainfall
    5. Changes in stream flows
    6. Changes in ground water elevations
    7. Changes in the concentrations of indicator water quality constituents
    8. Changes in the abundance, distribution, and diversity of indicator fish communities.
- Discern, and quantify where possible, the relative and absolute contribution of each of the four stressors to documented historical changes in each of the nine major basins in the Peace River watershed.
- Develop a scientific foundation for the subsequent preparation and adoption of a Resource Management Plan for the Peace River watershed.

A variety of analytical techniques were used to determine and quantify, where feasible, the relative cause and effect relationships between the primary stressors and key indicators. Temporal changes in land uses and cover types associated with the anthropogenic stressors were directly assessed and quantified using various GIS spatial analytical methods. Temporal changes in hydrology attributable to the anthropogenic stressors and recent climate variability were assessed and quantified where possible using appropriate multivariate statistical procedures and modeling techniques.

A historical timeline of policy and regulatory programs implemented in the Peace River watershed from the benchmark period to the present was prepared. An attempt was made to relate historical changes in state and water management district policy and regulatory programs with documented temporal changes in key watershed indicators. From this analysis, inferences were developed regarding the effectiveness of current policy and regulatory programs. In addition, proposed changes to current regulatory and management programs were developed to reduce or reverse documented cumulative impacts.

The goal of the CIS report was to summarize the major findings of the study in a manner that provides a comprehensive overview to a wide audience. The general findings and conclusions presented in the report were then supported through a series of technical appendices constructed around specific project tasks.

2.19 2006 HBMP Annual Data Report (PBS&J 2007)

This document represents the eleventh Annual Data Report submitted under the expanded Hydrobiological Monitoring Program (HBMP) initiated in 1996. The report compares data collected during 2006 with similar average values for key parameters previously compiled during various elements of the ongoing long-term monitoring programs. In making comparisons of the 2006 data with averages of similar data collected over the preceding twenty-three year period (1983-2005), it should be noted that the very wet winter/spring El Niño of 1997/1998 was followed by very dry La Niña conditions that influenced southwest Florida and the entire Peace River watershed between 1999 and early 2002. A weaker El Niño occurred at the end of 2002, and freshwater flows during 2003, 2004 and 2005 were generally above average. Rainfall in the Peace River watershed during 2006 by comparison was well below average, especially during the usually wet summer months. The summer 2006 wet-season was often characterized by afternoon summer thunder storms building along the coast rather than inland, and few tropical storms in comparison to the recent preceding years.

- **Flows –** Overall, gaged Peace River at Arcadia freshwater mean flow (376 cfs) during 2006 was approximately forty percent of the average daily flow for the preceding long-term period 1976-2005. In comparison, the sum of average daily flows from the Peace River at Arcadia, Horse Creek, Joshua Creek, and Shell Creek during 2006 was roughly fifty-one percent of the average daily flows over the longer term 1976-2005 HBMP monitoring period.

- **Withdrawals –** Combined total freshwater withdrawals by the Peace River and the City of Punta Gorda facilities accounted for approximately 3.2 percent of total freshwater flows to the estuary. In comparison with previous years, there were a number of days during 2006 when Peace River Facility withdrawals exceeded ten percent of the gaged Peace River at Arcadia flows. Such exceedances of the permitted ten percent withdrawals result from subsequent revisions by USGS of the provisional daily flow information available to the Authority at the time of actual withdrawals. During 2006, the facility did not withdraw any water from the river approximately thirty-two percent of the time.

- **Salinity Spatial Distribution –** The influences of the much drier than usual conditions that characterized 2006 were reflected in the seasonal and average spatial distributions of each of four sampled, moving isohalines along the HBMP monitoring transect. Overall, the relative spatial distributions of each of the isohalines during 2006 reflected upstream movements of 4-7 kilometers when compared with their previous long-term 1983-2005 averages.

- **Temperature –** Mean water temperatures during 2006 at each of the salinity isohalines were similar to one another, as well as to corresponding values measured over the preceding twenty-thee year period (1983-2005). It should, however, be noted that the water temperatures measured during both January and December 2006 were, as during the previous three years (2003-2005), much warmer than usual in comparison to values measured over the longer term period-of-record.

- **Water Color –** Color levels in 2006 were below long-term averages as a result of the lower than average freshwater inflows. Somewhat surprisingly was the very high peak in color level observed within the most upstream freshwater isohaline toward the end of the summer wet-season in September 2006 following tropical storm Ernesto. This unusually high peak in color level may have reflected higher flows following the storm event washing-out tannins and humic compounds from uplands and wetlands that had accumulated over the much drier than usual summer period.

- **Extinction Coefficient –** Comparisons among the mean 2006 extinction values indicate that lower than average freshwater inflows resulted in diminished water color throughout the estuary during most of 2006. This combined with fairly typical chlorophyll *a* phytoplankton biomass levels resulted in light extinction coefficients being well below long-term historical annual averages. As with color, light extinction coefficients seasonally peaked during September-October as a result of the high flows following tropical storm Ernesto.

- **Nitrite/Nitrate Nitrogen** - During 2006, average concentrations of this major inorganic form of nitrogen were much lower when compared with the long-term, historical annual averages. Monthly comparisons among the isohalines indicate concentrations typically decrease rapidly with increasing salinity, with inorganic nitrogen levels within the 20 psu isohaline often being near or at method detection limits over much of the year. Normally, estuarine inorganic nitrogen concentrations decline to their lowest levels during the relatively drier spring as phytoplankton populations respond to increasing water temperatures and light, and increased primary production removes available inorganic nitrogen. However, during 2006 there was a marked decline to near detection limits of inorganic nitrogen in the most upstream freshwater isohaline during March. This somewhat unusual event was associated with a corresponding early peak in phytoplankton chlorophyll *a* biomass upstream of the freshwater/saltwater interface.

- **Ortho-phosphorus** - Estuarine inorganic phosphorus concentrations in the lower Peace River and upper Charlotte Harbor are heavily influenced by the characteristically "very" high natural levels found in the Peace River watershed. As a result, the observed difference in concentrations among the four isohalines primarily reflects conservative dilution by Gulf waters. Seasonal observed changes in phosphorus concentrations in the estuary are for the most part unaffected by biological uptake. Inorganic phosphorus concentrations entering the estuary system from the Peace River watershed are typically lower during wetter periods, when a higher proportion of flow results from surface flow (rather than coming from groundwater, which is naturally richer in phosphorus). Historically, since the late 1970s, there had been marked declines in inorganic phosphorus levels in the lower Peace River/upper Charlotte Harbor estuarine system due to declines in the combined influences of phosphate mining and processing in the upper reaches of the basin. However, following Hurricane Charley and the subsequent influences of Hurricanes Francis and Jean during the late summer of 2004, inorganic phosphorus concentrations have dramatically increased throughout the lower Peace River/upper Charlotte Harbor estuarine system. Ortho-phosphorus concentrations during 2006 were well above both historic and recent levels. Currently, the direct cause for these increased levels remains unclear.

- **Nitrogen to Phosphorus Atomic Ratios –** Calculated atomic inorganic nitrogen to phosphorus ratios for ambient measured concentrations in 2006, as indicated by the long-term averages, show nitrogen to always be the limiting macronutrient at each of the four isohalines.

- **Silica –** Seasonally, silica levels in the lower Peace River/upper Charlotte Harbor estuarine system typically peak following periods of high freshwater inflows. Although silica levels also seem to be positively correlated with higher water temperatures (possibly reflecting recycling from riverine/estuarine sediments), historically lower silica concentrations in higher salinity zones of the estuary have often occurred during corresponding periods of combined low spring freshwater inflow and spring increases in phytoplankton diatom numbers. Between 1983 and the late 1990s these seasonal patterns of increasing and decreasing reactive silica concentrations remained relatively stable with no indications of any consistent systematic changes over time. However, as discussed in previous HBMP reports, silica levels started showing increasing concentrations during the late 1990s. Then, as flows declined during the 1999-2002 extended drought, silica levels also declined. However, following the return of higher than average flows during 2003-2005 measured silica levels in the estuary again began rapidly increasing. Even though flows during 2006 were below normal, silica levels throughout the lower river/upper harbor estuary reached historically high levels during the summer wet-season. The immediate cause of these fairly recent increases is unknown. However, studies in other areas have found that increases in dissolved silica concentrations have been associated with land use changes and clearing of natural vegetation. In many of these systems, changes in silica concentrations have also been found to be associated with changes in both calcium and magnesium levels.

- **Chlorophyll *a* –** The seasonal patterns of freshwater inflows to the estuary during 2006 were characterized by much drier than average conditions. Seasonally, there was an unusually high peak in flow during February, and then conditions were unusually dry until the much higher peak in flows during September following tropical storm Ernesto.

> Such periods of high seasonal flows combine to produce both higher than average inputs of limiting inorganic nutrients (nitrogen), as well as higher than average levels of water color (resulting in greater light attenuation). The early high flows in February were followed in March by a spike in chlorophyll *a* levels in the upper freshwater reach of the estuary, while the high flows in the late summer were followed by increases in phytoplankton biomass in November in the 6 psu zone, and then in the downstream 12 psu in December. Overall, phytoplankton production (chlorophyll *a*) levels in the lower Peace River/upper Charlotte Estuary were similar to the long-term (1983-2005) averages within the three higher salinity zones. The relatively low flows and reduced water color during 2006 resulted in chlorophyll *a* levels in the upper freshwater reach of the estuary being higher than the corresponding long-term average. As in previous years, phytoplankton levels were generally higher within the intermediate (6 and 12 psu) isohalines, reflecting a balance between stimulation due to increased nitrogen inputs, and light inhibition resulting from higher water color.

The graphical and summary analyses presented in this document do not indicate any substantial changes, or atypical events in either the physical or biological data collected during 2006, other than those previously noted. These include:

- Freshwater inflows during 2006 were characterized by a much drier than normal flows, especially during the normal summer wet-season.
- There has been a continuation of the previously noted long-term increase in reactive silica concentrations in the lower Peace River.
- There are strong indications that inorganic phosphorus concentrations in the freshwater entering the estuary has increased in recent years, following decades of major declines that began in the late 1970s.

The "limited" analyses presented in the Annual Data Report do not suggest that there have been any long-term changes resulting from either current or historic water withdrawals by the Peace River Regional Water Supply Facility.

3.0 Chapter 3 – Status and Trends in Regional Rainfall, Flows and Facility Withdrawals

The purpose and focus of this chapter are to update information presented in previous summary HBMP reports, and provide analyses of data collected through 2006 regarding both the status and trends of key hydrological elements associated with the Peace River Hydrobiological Monitoring Program (HBMP). Analyses and discussions are presented in relation to the current status and historic trends in the following specific hydrologically related HBMP study elements:

- Status and trends in watershed rainfall patterns.
- Status and trends in gaged watershed freshwater inflows.
- Status and trends in rainfall/flow interactions.
- History, status and trends in withdrawals.

The primary objectives of the presented analyses and summary graphics associated with each of these HBMP elements are to provide an overview of the current hydrological status within the Peace River watershed and lower Peace River/upper Charlotte Harbor estuarine system, and illustrate comparisons with historic longer-term patterns and characteristics. A corollary goal is to describe the important hydrological influences of more infrequent episodic occurrences such as extended periods of extreme drought, the periodic occurrences of unusually wet winter/spring El Niño climatic events, and differences in summer wet-season rainfall/flows due to variations in the frequency of tropical cyclonic patterns.

3.1 Hydrologic Setting

The Peace River watershed (Figure 3.1) covers approximately 1.4 million acres (2,188 square miles) and can be divided into nine major drainage basins within six counties. Most of the watershed is located in Polk, Hardee, DeSoto and northern Charlotte counties, although smaller portions extend into Highlands, Manatee and Sarasota counties. The main channel of the Peace River begins northeast of Bartow, in Polk County, at the confluence of Peace Creek Drainage Canal and Saddle Creek, and extends approximately 105 miles south to Charlotte Harbor. Previous studies (PBS&J and W.D. Bender 1999) divided the watershed into eight drainage basins based on the locations of USGS long-term flow gaging stations and included an additional ungaged coastal lower Peace River basin downstream of Arcadia to the tidal river mouth (defined by USGS, McPherson et al. 1997).

These nine basins are listed below.

- Peace River at Bartow
- Peace River at Zolfo Springs
- Payne Creek
- Peace River at Arcadia
- Charlie Creek
- Joshua Creek
- Horse Creek
- Shell Creek (including Prairie Creek)
- Coastal Lower Peace River

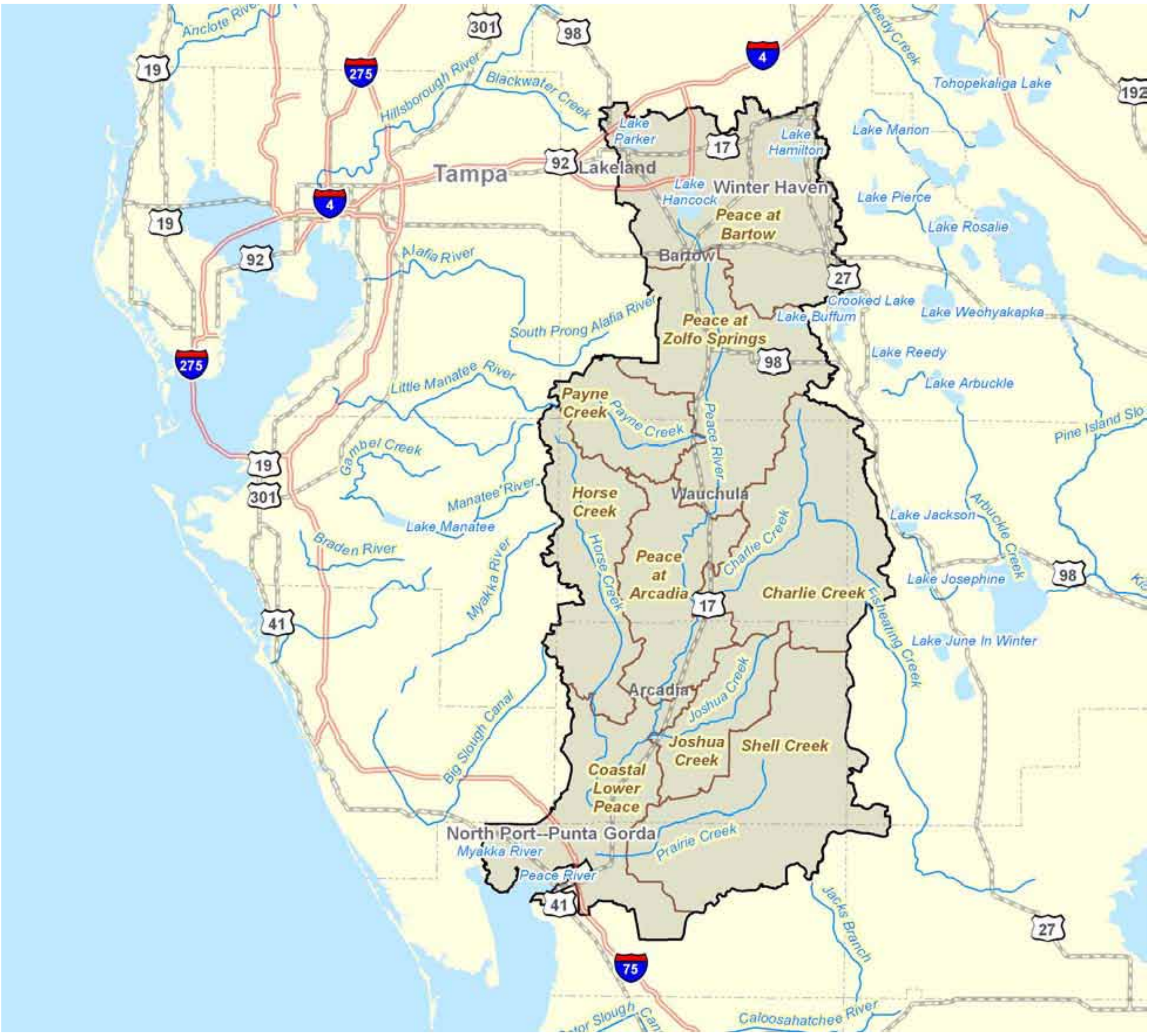

Figure 3.1 Location of the Peace River Watershed in Southwest Florida

The five largest basins in the watershed include the Peace River at Bartow, Peace River at Zolfo Springs, Charlie Creek, Shell Creek, and the Coastal Lower Peace. Each of these basins individually makes up between 12 and 17 percent of the watershed and combined, they comprise roughly 70 percent of the overall watershed area. The remaining four smaller basins, the Peace at Arcadia, Payne Creek, Joshua Creek, and Horse Creek individually comprise between six and nine percent of the remaining watershed area. Historically, the landscape features and hydrological drainage patterns of these watershed basins have to varying extents been modified by anthropogenic influences, including the expansions of more intense agriculture, urbanization and phosphate mining activities (PBS&J 2007). Hydrologically, such historic and ongoing landform changes have significantly altered both surface water runoff and infiltration rates within broad areas of the Peace River watershed.

3.1.1 Hydrogeology

The Peace River watershed is underlain by three aquifer systems. The uppermost system primarily associated with surface flows is the unconfined surficial aquifer system, which consists of unconsolidated quartz sand, silt, and clayey sand. The depth of the surficial aquifer system varies from only a few feet in some areas to well over a hundred feet in the sand hill ridge areas. Underlying the surficial aquifer system is the confined intermediate aquifer system, consisting of thin, inter-bedded limestones, sands, and phosphatic clays of generally low permeability. The intermediate aquifer system is relatively thin in the upper reaches of the Peace River watershed and thickens to the south. Underlying the intermediate aquifer system, the confined Floridan aquifer system consists of limestone and dolostone formations. The Floridan aquifer system is the principal water supply source for most anthropogenic activities accounting for 85 to 90 percent of all anthropogenic ground water use in the Peace River watershed. The depth to the lower Floridan aquifer and its relatively much poorer water quality currently preclude any extensive use of this last aquifer system as a water supply.

Upstream of Ft. Meade, in the vicinity of the Peace River proper, the terrain and geology are karst in origin, resulting in large sinks and solution features in the river's floodplain. Kissengen Spring near Bartow was a significant source of historic base flow to the upper Peace River with average annual estimated flows prior to the mid-1930s of approximately 30 cubic feet per second (cfs). Cessation of flow from the spring circa 1950 has been attributed (Peek 1951, Steward 1966, Hammett 1990, Basso 2003, PBS&J 2007) to the decline in the potentiometric surface of the confined aquifers (Intermediate Artesian and Upper Floridan aquifers) caused by the excessive development of the ground water resource, primarily associated with the early expansion of phosphate mining in the upper watershed. The potentiometric surface of the confined aquifers, previously observed above the riverbed, has generally been tens of feet below the riverbed since the early-1960s (Figure 3.2).

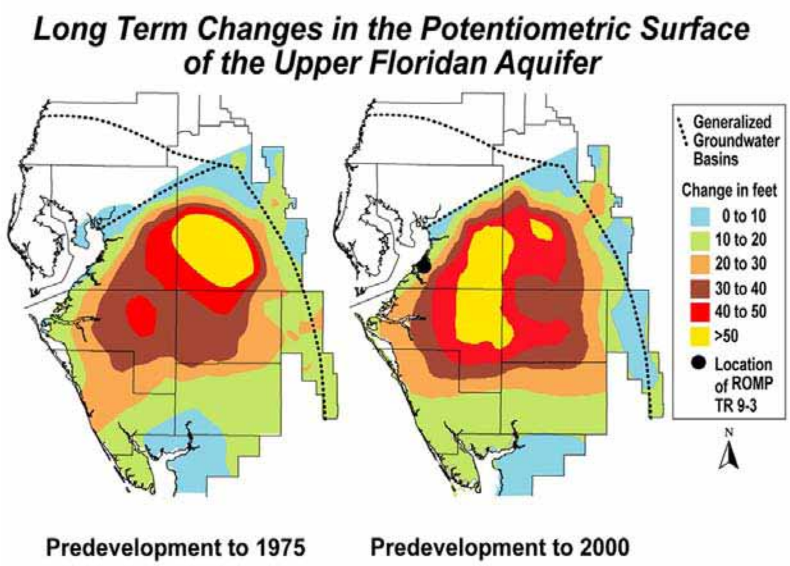

Figure 3.2 Estimated changes in the potentiometric surface of the Upper Florida Aquifer (SWFWMD, based on USGS data)

3.1.2 Hydrologic Alterations

This historic loss of flows from springs and seeps has been one of the factors that have affected base flow to the upper portion of the river. However, base flow in the upper Peace River has also been affected by changes in discharges and drainage alterations associated with urbanization, phosphate mining, and agriculture. Phosphate mining and domestic waste discharges to the river have gradually declined since the mid-1980s (SWFWMD 2002). Historically these anthropogenic discharges augmented dry-season base flow and until recently obscured much of the historic declines and cessation of spring flows in the upper watershed. As a result, during recent periods portions of low flows in the Peace River between USGS Bartow and Ft. Meade gages actually run into the numerous crevices of the streambed and floodplain resulting in a loss of flows on a significant number of days each year within this upper reach of the river.

Other hydrologic alterations in some mined and reclaimed areas in the upper regions of the watershed have included diversions of surface waters that historically flowed to the river to storage for mining activities and/or seasonal impoundments resulting from disconnected surface depressions. Surface flows in some mined areas may also have been altered subsequent to mining due to increased recharge, as rainwater readily infiltrates the resulting disturbed soil structure, and recharge to the intermediate aquifer increases following loss of the upper confining layers associated with extraction of the phosphate matrix.

The Peace River watershed basins south of phosphate mining influences have also experienced historic increasing ground water demands and extensive hydrologic alterations. These changes are reflected in the cumulative loss of wetland and native upland habitats, and increasing dry-season augmentation of base flow in many tributaries as agriculture in these southern basins has progressively changed from predominantly unimproved pasture to improved pasture and subsequently to increasing areas of more intense farming (citrus and row crops). Agricultural runoff has contributed to increased base flow in the Joshua Creek, Horse Creek and Prairie/Shell Creek basins. In addition, urban land uses in the northern and southern areas of the Peace River watershed have increased impervious surface areas, altered natural hydroperiods, and reduced stream stability, which resulted in the loss of in-stream habitat and degraded water quality, and led to reductions in biological diversity (Arnold and Gibbons 1996, Brant 1999, Shaver and Maxted 1996).

3.1.3 Climate

The climate in the Peace River watershed is subtropical with an annual average temperature of approximately 73 degrees Fahrenheit. The Peace River watershed predominantly lays within the National Weather Service (NWS) Florida South-Central Region Four, which is characterized by a summer wet-season that accounts for approximately 60 percent of total average annual precipitation of 52 inches (1915-2006). During this summer wet-season, rainfall patterns are influenced by both frequent localized convective thunderstorm activity and periodic, widespread heavy rains associated with more infrequent tropical cyclonic events. In contrast, the remainder of the year is characterized by rainfall patterns predominantly associated with frontal systems moving down and across the Florida peninsula from the northwest.

The four month wet-season extends from June through September, with June on average having the highest annual average rainfall of 8.2 inches (Figure 3.3). Conversely, November through January typically comprise the three driest months of the year, with rainfall in November only averaging 1.8 inches. October characterizes the transition from the convection based summer wet-season rainfall pattern to the frontal dry-season rainfall pattern.

Low precipitation, combined with higher temperatures and evapotranspiration proceed the dry spring months and, as a result, streams, wetlands and surficial ground water levels are typically at their lowest during May just prior to the beginning of the four month summer wet-season (Figure 3.4) Conversely, during September and October, at the end of the summer wet-season, hydrologic systems and surface flows are usually near or at their annual peaks.

Seasonal influences of rainfall on watershed hydrology and surface flows are therefore directly linked to the preceding hydrologic conditions. At the beginning of the summer wet-season, a large proportion of rainfall is incorporated into filling surface and ground water storage (Basso and Schultz 2003.) Conversely, later toward the end of the summer wet-season, soil moisture content is high, ground water levels are near the surface, wetlands and lakes are full, and a large proportion of rainfall contributes directly to runoff (Ross et al. 2001). Under such conditions, relatively small increases in rainfall can result in substantial increases in surface flows (PBS&J 2007).

While the described seasonal patterns in the annual hydrologic conditions are typical, there are wide degrees of both seasonal and annual variability in both rainfall and resulting river flow patterns. Deviations from the normal pattern can span periods of months up to several years. Intense El Niño/Southern Oscillation (ENSO) events, such as occurred in 1982/1983 and 1997/1998, result in atypical extended periods of heavy rainfall during the usually drier winter/spring months and dramatically alter the annual watershed hydroperiod. In both instances, these unusually wet El Niño periods were subsequently followed by La Niña events and associated periods of extended drought (Coley and Waylen 2006). While short-term extremes of high and low flows influence the water budget in a watershed over periods of years, superimposed over these may be larger cyclic periods that can cover a number of decades (Kelly 2004). An understanding of the underlying causes affecting the duration and magnitude of long-term regional rainfall cycles is therefore important to assessing historic natural and anthropogenic hydrologic changes in both stream flows and ground water levels in the Peace River watershed (Basso and Schultz 2003.)

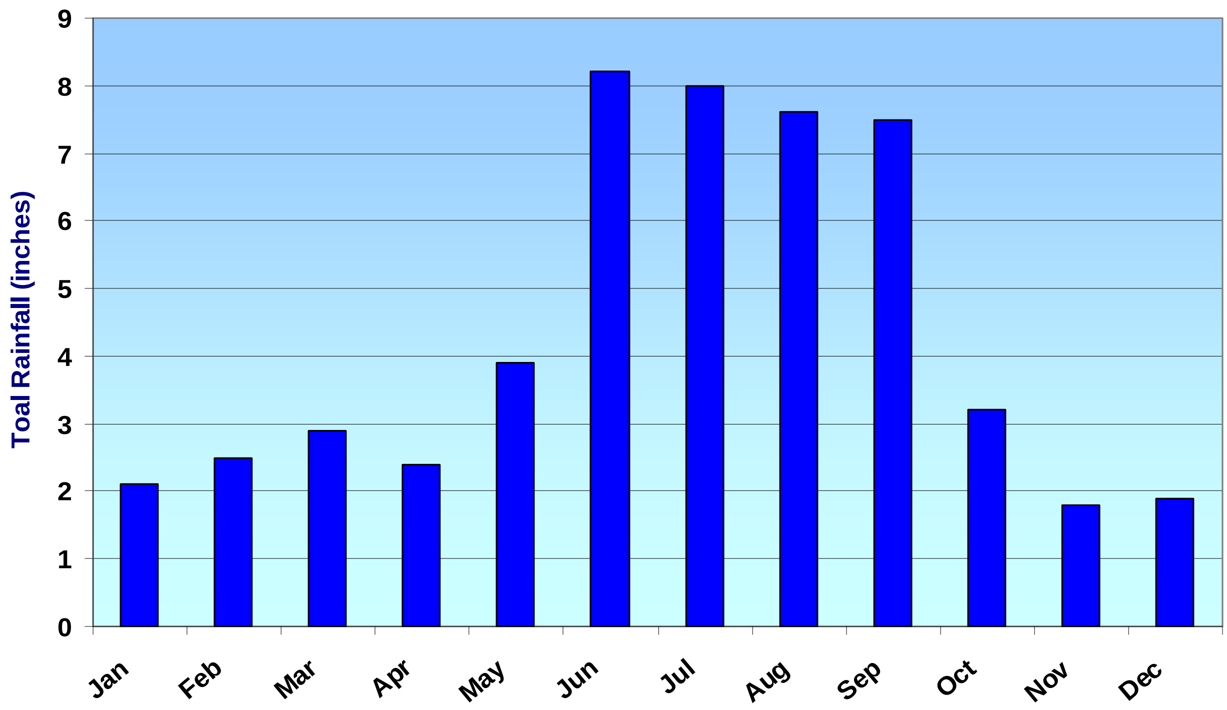

Figure 3.3 Average Monthly Peace River Basin Rainfall (1915-2006)

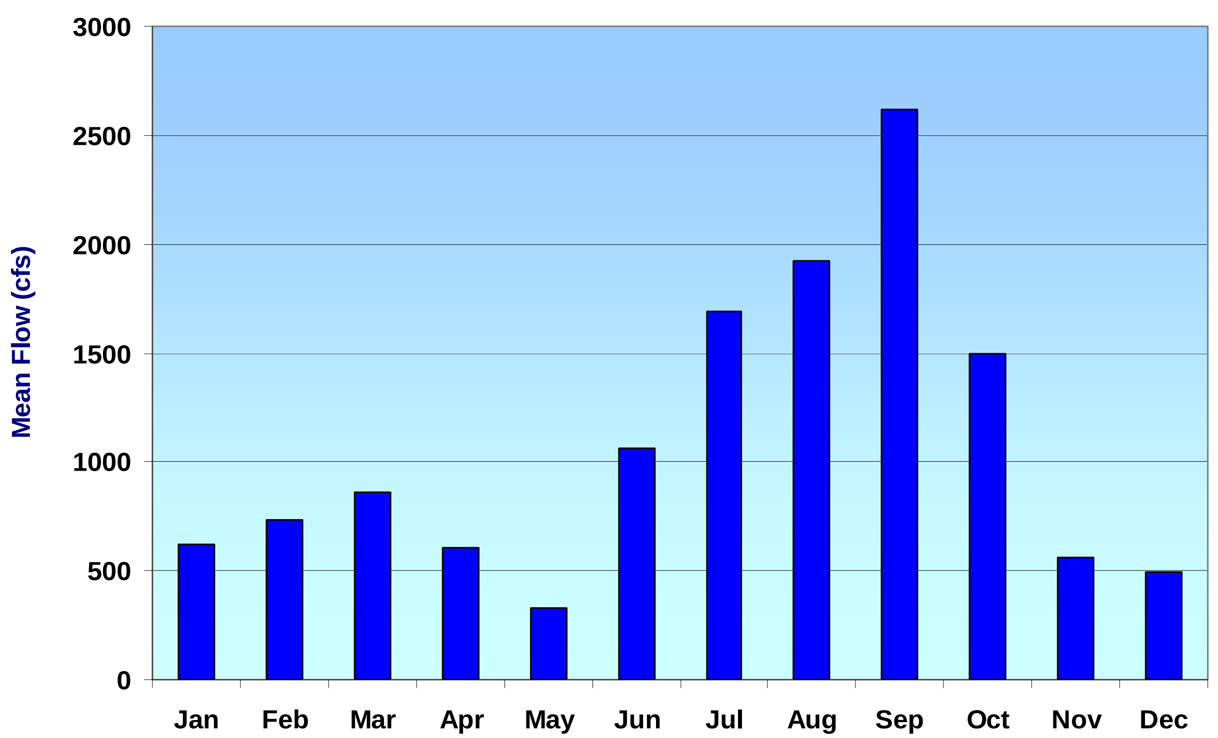

Figure 3.4 Mean monthly flow at the Peace River at Arcadia USGS gage (1932-2006)

Climate researchers (Gray et al. 1997, Enfield et al. 2001) have suggested that natural climate cycles or phases can persist over multiple decades. One of these cycles, the Atlantic Multidecadal Oscillation (AMO) refers to long-term cool and warm phase differences of only about 1°F (0.6°C) in North Atlantic average sea surface temperatures. An analysis of Atlantic sea surface temperatures suggests that warm AMO phases occurred during 1869-1893, 1926-1969, and from 1995 to date, while cooler phases occurred predominantly during the 1894-1925 and 1970-1994 time periods (Landsea et al. 1999). Climatological data indicate that differences between relatively warm and cool AMO periods affect both air temperature and rainfall patterns over North America and Europe (Gray et al. 1997, Enfield et al. 2001). It has been suggested that slight increases in average sea surface temperature in the Atlantic and Caribbean seas during warmer AMO periods produce more summer rainfall across southern Florida, while cooler AMO phases result in decreased summer rainfall (Enfield et al. 2001, Basso and Schultz 2003, Kelly 2004).

Studies of paleoclimate proxies, including tree rings and ice cores, indicate that oscillations similar to those measured from Atlantic sea surface temperatures have commonly occurred over 15-60 year intervals for at least the last thousand years. These changes predate the modern era of anthropogenic climate influences and indicate that the AMO phases are likely natural climate oscillations. It has also been suggested that during the 20th century, cyclical AMO climate changes have alternately camouflaged or exaggerated the potential effects of global warming making it more difficult to ascertain any confounding influences.

Climatological information indicates that differences between relatively warm and cool AMO periods particularly affect air temperatures and rainfall patterns over North America and Europe (Gray et al. 1997, Enfield et al. 2001). Research suggests that past warm AMO cycles have corresponded with major droughts in the Midwest and the southwest regions of the U.S, while in cooler AMO phases, rainfall has been more plentiful. Two of the most severe droughts of the 20th century in the western U.S., including the Dust Bowl of the 1930s, occurred during the extended warm AMO phase between 1925 and 1965. Conversely, rainfall patterns in both south Florida and along the northwest Pacific Coast indicate exactly the opposite patterns, with higher wet-season rainfall during warmer AMO periods.

Small increases in average sea surface temperature in the Atlantic and Caribbean during warmer AMO periods result in increased wet-season rainfall across south Florida, while cooler AMO phases correspond to decreased summer rainfall (Enfield et al. 2001, Basso and Schultz 2003, Kelly 2004). During warm AMO phases, general Atlantic/Caribbean atmospheric circulation patterns predominantly flow from the southeast across the southern Florida peninsula, increasing summer afternoon convective thunderstorm activity and resulting in slightly enhanced wet-season rainfall levels. At the same time, higher North Atlantic sea surface temperatures also result in atmospheric circulation patterns that tend to both increase the frequency and intensity of tropical storms, including those originating in the Sahel region of northwest Africa, while also decreasing high level wind shear in the tropical Atlantic Ocean. During warm AMOs, these factors result in a higher frequency (Figure 3.5) and duration of major tropical cyclones in the Gulf of Mexico, Atlantic and Caribbean Basins (Gray et al. 1997, Landsea et al. 1999). These tropical systems can produce extremely high rainfall events as they move near (or across) Florida and a single storm event can account for as much as a third of the normal total annual wet-season rainfall. Since these storm events are more frequent toward the end of the summer wet-season in August and September, soils in the watershed may be saturated, rivers and lakes are often at high flows and/or levels, and the hurricane associated rainfall events can dramatically influence annual flows and patterns in the watershed.

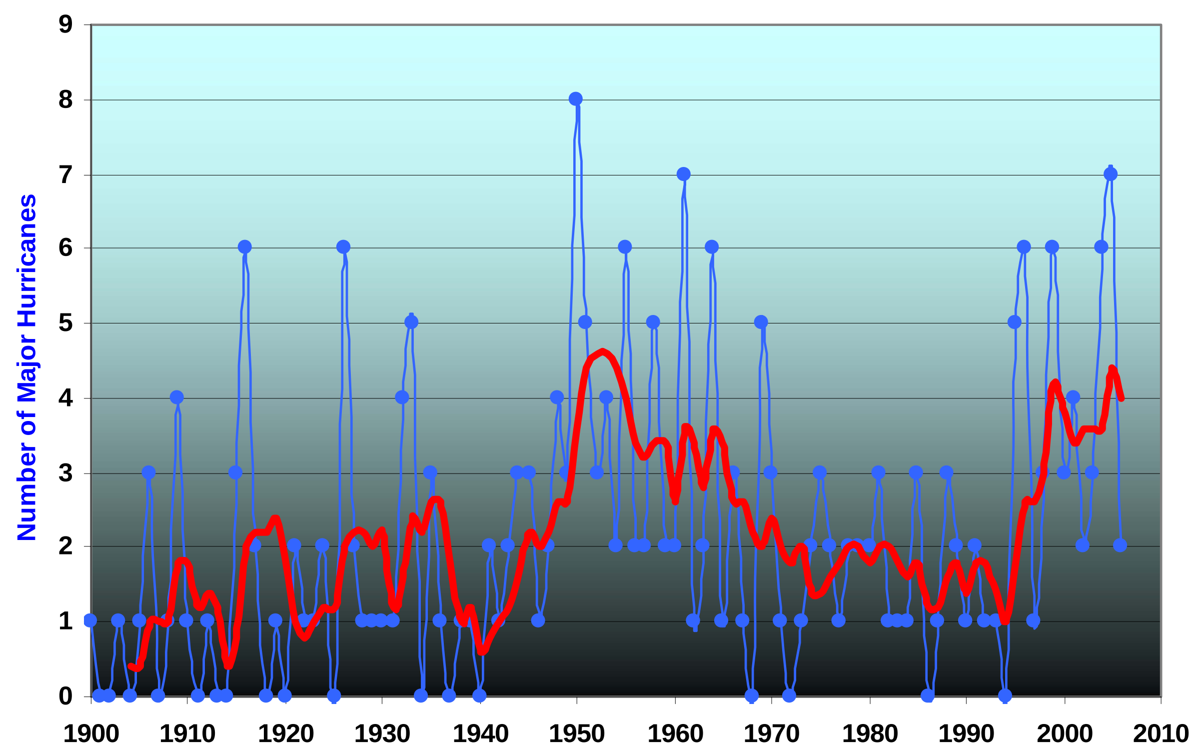

Figure 3.5 Major Atlantic Hurricanes 1900-2006

Several studies (Hickey 1998, Basso and Schultz 2003, Kelly 2004) have recently expanded upon previous work (Hammett 1990) in which changes in rainfall and/or stream flow patterns and relationships in the Peace River watershed were examined. Hickey (1998) attributed observed declines in rainfall and flows to a reduction in the frequency of tropical storms events prior to and following 1970. Basso and Schultz (2003) found that while annual rainfall has not significantly changed over the last century, partitioning the data into shorter intervals revealed cyclical decadal periods of above or below average rainfall. Using graphical and statistical analytical methods, including 5-year moving averages mean and median statistics, cumulative departure analyses, single mass techniques, and time-series plots, they were able to demonstrate that the decades between the 1930s and 1960s were wetter than recent periods. Mean and median rainfall values at six gaging locations within the Peace River watershed indicated average declines of 4.5 and 5.5 inches/year between the two 30-year periods 1936-1965 and 1966-1995. Changes in wet-season rainfall, primarily linked to the AMO, were found to account for approximately eighty percent of the observed differences between the two periods. An analysis of rainfall changes associated with an observed decline in tropical cyclone activity during 1970-1994 found that approximately one-third of the measured decline in wet-season rainfall was associated with the observed decrease in these storms events. A total of 47 documented tropical cyclones (includes subtropical systems, depressions, tropical storms, and hurricanes) impacted the Peace River watershed during the period 1930-2001. During the warmer AMO phase (1930-1969), 33 tropical storm events affected the basin. In comparison, during the subsequent cooler 1970-1994 AMO period, only 10 tropical systems impacted the watershed. This analysis indicated that the frequency of such intense rainfall storm events influencing the Peace River watershed during the warm AMO phase was approximately double of that which occurred during the cooler period.

During warm AMO phases, the average number of tropical storms that become major hurricanes is significantly greater (at least double) when compared with cooler periods. Since 1995, when the AMO shifted from the preceding approximately 26-year cooler period (1969-1994) to a warmer phase, the frequency of major hurricanes (category 3 or above on the Saffir-Simpson scale) has again increased. Based on the typical duration of alternating AMO phases, the current warm phase may persist from 10-30 more years. To date, models capable of predicting the AMO shifts from one phase to another are unavailable. However, it is possible to determine the probability that a change in the AMO cycle will occur within a given future time frame (Enfield and Cid-Serrano 2005.) Such probability-based projections may be useful with regard to long-term water management planning since the availability of potential surface water supplies can vary considerably between warmer and cooler AMO periods. However, the occurrences of 1999-2001 and recent (starting in 2006) droughts emphasize the point that such warm/wet AMO phases only describe long-term average conditions, and that very dry intervals can (and do) occur during what might be a wetter than average longer time period, and that correspondingly very wet years have occurred during cooler/dry AMO phases.

3.2 Status and Trends in Watershed Rainfall Patterns

Historic period-of-record rainfall data for three representative long-term Peace River watershed basin rainfall gaging stations and a representative gage in the nearby Myakka River watershed were obtained as an initial step in evaluating the status and trends of hydrologic conditions in the Peace River watershed. Table 3.1 provides summary information regarding each of the four selected rainfall gages.

- Rainfall gage name
- Gage SWFWMD (District) identification
- National Oceanographic and Atmospheric Administration (NOAA) identification
- Location (latitude & longitude)
- Historical period-of-record interval of data

The sites were selected based both on the need to provide a broad spatial range of geographical coverage and the availability of a reliable long-term historical data record.

- **Bartow –** This gage was selected as representative of the northern/upper Peace River watershed, with daily long-term rainfall data having been collected at this site since 1902. The gage is designated ATM0009 in the NOAA rainfall monitoring network, and this same location is designated as R142 in the Southwest Florida Water Management District's (District) web-based data acquisition system.

- **Arcadia** – Historical data from this monitoring site were chosen to characterize rainfall patterns in the central regions of the Peace River watershed. The daily, long-term rainfall record at this location extends back historically to 1908. The Arcadia gage is designated as site ATM0003 in the NOAA monitoring network and as R148 by the District.

- **Punta Gorda** – The data from this monitoring gage were used to assess seasonal and long-term rainfall patterns in the lower/coastal region of the lower Peace River watershed, and existing daily records at this gaging site extend back to 1915. This rainfall monitoring gage is designated ATM0117 in the NOAA network and as R255 by the District.

- **Myakka State Park –** This final monitoring gage was selected to provide additional information and assess potential differences in rainfall patterns between the interior Peace River watershed locations and the more coastal Myakka River watershed. The existing daily records at this site only extend back to 1943, and the rainfall gage is designated as ATM0101 in the NOAA network and as R336 by the District.

Table 3.1
Selected Rainfall Gages

Gage Name	SWFWMD Site ID	NOAA Site ID	Latitude	Longitude	Data Record
Peace River Watershed					
Bartow	R142	ATM0009	27°53'59.08"	81°50'34.27"	1908-2006
Arcadia	R148	ATM0003	27°13'44.17"	81°51'27.28"	1907-2006
Punta Gorda	R255	ATM0117	26°55'10.22"	82°00'21.30"	1914-2006
Additional Reference Gage					
Myakka State Park	R336	ATM0101	27°14'32.17"	82°10'27.31"	1943-2006

While all the selected gages had relatively complete periods-of-record, in some instance data from a particular site may have been missing for a number of consecutive days for periods of weeks and/or months. In these instances, missing data were substituted using additional available information from the District's rainfall monitoring network using the average values from the two nearest rainfall gages that also had the highest long-term correlations with data from the station with the missing values (PBS&J 2007).

3.2.1 Time-series Plots

Monthly and annual total rainfall values were graphically analyzed for each of the four selected watershed rainfall gages using several alternative methods. The organization of the rainfall time-series analyses are presented in Table 3.2. Summary conclusions based on the results of these alternative graphical analyses of historic rainfall patterns are presented below.

Table 3.2
Time-series Plots of Watershed Rainfall

Long-Term Rainfall Gage	Time Interval	Total Monthly Rainfall	Annual Total Rainfall		
			Overall	Wet-Season	Dry-season
Peace River Watershed					
Bartow	1932-2006	Figure 3.6	Figure 3.11	Figure 3.16	Figure 3.21
Arcadia	1932-2006	Figure 3.7	Figure 3.12	Figure 3.17	Figure 3.22
Punta Gorda	1932-2006	Figure 3.8	Figure 3.13	Figure 3.18	Figure 3.23
Watershed Average	1932-2006	Figure 3.9	Figure 3.14	Figure 3.19	Figure 3.24
Additional Reference Gage					
Myakka State Park	1943-2006	Figure 3.10	Figure 3.15	Figure 3.20	Figure 3.25

Total Monthly Rainfall – **Figures 3.6** through **3.10** illustrate time-series plots of total monthly rainfall data from the selected gaging locations. Values were plotted for the years 1932-2004 (corresponding to the longest record of gaged flows in the watershed) or the period-of-record for locations with shorter long-term records. These graphics include both monthly total rainfall and a fitted, smoothed line (this line was calculated using the Statistical Analysis Software (SAS) cubic spline method that minimizes the linear combination of the sums of squares of the residuals of the fit as well as the integral of the square of the second derivative). The following summary conclusions are based on these analyses.

- Long-term total monthly rainfall patterns were similar among the selected rainfall gages.
- The variability in total monthly rainfall is sufficient to obscure small changes that may (or may not) have occurred, and there are no indications of any consistent larger changes (or patterns) when the long-term rainfall data are analyzed on a monthly basis.
- Results of the analyses suggest that total monthly rainfall at the more coastal Punta Gorda and Myakka State Park gages are in general slightly greater than at the two more interior Peace River watershed basin gages.

Annual Total Rainfall – Similar time-series plots of annual total rainfalls at the same rainfall monitoring locations were evaluated for the 1932-2006 interval for the three Peace River watershed sites and over the 1943-2006 periods-of-record for the Myakka River watershed location. These graphics include a line representing a smoothed five-year moving average, which provides a general indication of long-term patterns after having reduced some of the occurring annual variation.

- When the long-term rainfall data for the Peace River watershed locations are viewed as annual totals, the results clearly show both increased variations among the watershed gages and greater indications of both historical wetter and drier intervals. The calculated five-year moving averages, which further reduces short-term background "noise," also indicated relatively longer wet and dry intervals over the selected recent historic periods.

- Total annual average Peace River watershed rainfall levels at the Bartow and Arcadia gages were slightly higher prior to the 1960s when compared with the period from the late 1960s to the mid 1990s. The data indicate that between the mid 1990s and 2006 annual total rainfall levels at these two interior Peace River watershed locations increased.

- These long-term patterns were far less pronounced for annual total rainfall levels at the more coastal Punta Gorda and Myakka State Park monitoring sites.

Wet-season and Dry-season Total Annual Rainfall – To evaluate possible long-term differences in seasonal rainfall patterns, time-series plots similar to those developed for annual total rainfall (above) were developed for total annual rainfall for the four month wet-season (June-September) and for the eight drier months (January-May and October-December). Time-series plots of total annual wet-season rainfall data at each of the four selected rainfall monitoring locations are presented in **Figures 3.16** through **3.20**, while corresponding graphics for total annual dry-season rainfall levels are presented in **Figures 3.21** through **3.25**. These graphics also include a statistically smoothed line of the five-year moving average. In evaluating these analyses, it should be noted that the terms wet-season and dry-season are applied relative to the long-term annual average hydrograph for southwest Florida (**Figure 3.3**). The following summary conclusions are based on these analyses.

- Annual average wet-season (June-September) rainfall in the Peace River watershed was, in general, slightly higher during the 1930s through the mid-1960s when compared with the interval from the late 1960s through the early 1990s (**Figure 3.19**). Since approximately 1994 there has been a notable increase in wet-season rainfall.

- The long-term patterns in wet-season rainfall at the more coastal Myakka River State Park site are again different than those observed within the Peace River watershed.

- No similar long-term patterns were apparent at any of the selected monitoring stations with regard to dry-season (January-May and October-December) rainfall, although periodic high annual totals were observed corresponding to El Niño events.

3.2.2 Longer Historical Rainfall Patterns in the Peace River Watershed

In order to further evaluate potential longer historic changes in Peace River watershed rainfall patterns, a series of analyses were conducted using the available long-term 1915-2005 data from the Bartow, Arcadia and Punta Gorda rainfall monitoring stations.

- The first technique was to plot each annual rainfall value after subtracting it from the basin-specific long-term average for the entire 1915-2006 period. This long-term average was then used as a zero value, against which each annual total was sequentially plotted above or below. A smoothed, five-year moving average was then fitted to the resulting calculated points.

- The second method also used the differences between the total annual rainfall and the long-term basin averages. However, in this instance, a year-by-year cumulative sum of the yearly difference was plotted over time. The calculated value for each year therefore represented the running sum of the yearly differences (positive or negative) from the historic 1915-2006 basin average annual rainfall.

The results of these graphical analyses are presented in Table 3.3 using both overall annual rainfall totals, as well as separately for just the typical four summer wet-season months (June-September) and the remaining eight drier season months.

Table 3.3
Historic 1915-2006 Long-term Watershed Rainfall Patterns

Rainfall Gage District ID	Overall		Wet-season		Dry-season	
	Annual & 5-Year Moving Average	Cumulative Deviation from Average	Annual & 5-Year Moving Average	Cumulative Deviation from Average	Annual & 5-Year Moving Average	Cumulative Deviation from Average
Peace River Watershed						
Bartow – (R142)	Figure 3.26	Figure 3.31	Figure 3.36	Figure 3.41	Figure 3.46	Figure 3.51
Arcadia – (R148)	Figure 3.27	Figure 3.32	Figure 3.37	Figure 3.42	Figure 3.47	Figure 3.52
Punta Gorda – (R255)	Figure 3.28	Figure 3.33	Figure 3.38	Figure 3.43	Figure 3.48	Figure 3.53
Watershed Average	Figure 3.29	Figure 3.34	Figure 3.39	Figure 3.44	Figure 3.49	Figure 3.54
Additional Reference Gage						
Myakka State Park – (R336)	Figure 3.30	Figure 3.35	Figure 3.40	Figure 3.45	Figure 3.50	Figure 3.55

* Note: Period-of-record for the Myakka rainfall monitoring site extends back only to 1943.

These methods were used to distinguish random variations in average annual rainfall levels from distinct longer-term rainfall patterns in the Peace River watershed. The following conclusions summarize some of the principal findings of these historical rainfall analyses.

- The plots of yearly annual deviations from the average rainfall (**Figure 3.34**) further supported the previous conclusions that total annual rainfall in the watershed during the 1940s and 1950s was above the long-term average of 52 inches per year, and generally below this average during much of the 1970s and 1980s.

- Similar analyses of annual deviations conducted after dividing yearly rainfall totals into wet-season (June through September) and dry-season (October through December and January through May) indicated slightly higher wet-season rainfall during the earlier time periods. In contrast, dry-season rainfall varied randomly around the long-term average over time.

- Graphical analyses of cumulative: 1) overall; 2) wet-season; 3) and dry-season rainfall deviations from long-term averages clearly indicate historical differences in watershed rainfall patterns. Although there were differences among the three Peace River watershed rainfall gages, when averaged, annual rainfall levels were generally above average from the early 1920s through approximately the early 1960s and then were below average until the early 1990s.

- The plots of cumulative wet and dry-season rainfall deviations for the three Peace River watershed gages again demonstrated that annual wet-season rainfall levels from the mid-1960s through the early 1990s were lower than the long-term 1915-2006 average.

3.2.3 Seasonal Kendall Tau Trend Analyses of Rainfall

The inherent natural unevenness in southwest Florida rainfall results in high temporal and spatial variability in fixed station rainfall data at both small and larger scales. The objective of the Seasonal Kendall Tau analyses was to determine if this method of statistical trend analysis could be applied to further describe observed long-term changes in rainfall patterns. The term "trends" is used here to refer to progressive changes over time in a metric (such as the monthly or annual total rainfall), while "seasonal" and shorter term oscillating patterns are due to repeating natural processes. This method differs from that used by others (Basso and Schultz 2003, Kelly 2004) in which significant differences in rainfall between historic and more recent periods were evaluated by comparing average differences among decadal (or longer) annual total rainfall levels. The Seasonal Kendal Tau statistic differs in that it estimates the slope, or rate, of change over time and determines if the measured rate of change is statistically significant.

Researchers have proposed a number of parametric and nonparametric (distribution-free) statistical methods for determining the presence or absence of trends, some of which are more robust, than others (see below for definition). The objective of these tests is to separate a pattern (trend) from the “noise” of repeating seasonal and/or random “unexplained noise” in the data. The ability to detect and quantify, or determine the absence of, progressive changes over time is imperative to developing a framework and basis for future management decisions.

- **Parametric versus Nonparametric Methods**. A basic assumption of most parametric statistical tests is that the data distribution is approximately normally distributed (or that it can be transformed to be so). The general overall robustness of parametric tests is dependent on this underlying assumption and provides resistance to the influence of outlier data. However, environmental data in general, and rainfall and flow data in particular, often violate this key underlying assumption of the most commonly applied parametric procedures. Therefore, nonparametric tests are usually considered more robust when analyzing many kinds of environmental data.

- **Robustness, Resistance, and Influence**. "Robustness" refers to the insensitivity to violations of the basic assumptions of a particular statistical procedure. The term "resistance" by comparison is used to refer to the insensitivity to outliers, while the word "influence" is used to describe the effect of extreme observations on summary measures.

Kendall Tau and the Seasonal Kendall Tau tests are nonparametric statistical tests widely used to analyze data for trends where normality cannot be assumed. These methods can be used to determine whether data values are increasing, declining, or remaining relatively level over time. This is accomplished by computing a statistic (Tau) based on the differences among all possible data pairs, thus representing the net direction of movement of the time-series data. The number of positive differences minus the number of negative differences is then determined and this is used to calculate the Mann-Kendall Tau statistic. If the time-series data are systematically increasing (or decreasing) over time, then the Tau statistic will be a relatively large positive (or negative) value. If, however, the change over time is negligible, then the number of positive pairs and the number of negative pairs will be approximately equal, and the Tau statistic will be small. The Tau statistic can thus be viewed as an estimate of the median slope of the set of slopes estimated for the lines connecting all possible pairs of data.

The Seasonal Kendall Tau test incorporates an additional factor to account for seasonal variation. When analyzing monthly data, each month is viewed as a "season" and this method is therefore directly applicable to flow and rainfall data, which are characterized by strong seasonal patterns. As in parametric tests, hypothesis testing for a trend is based on the null hypothesis that "there is no trend." The null hypothesis can only be rejected if the Tau statistic is sufficiently large at a given level of probability (p-value).

Statistical tests were conducted using SAS programming code developed by the U.S. Environmental Protection Agency (USEPA) for nonparametric analysis of water quality and other environmental data. The USEPA SAS code was based on Seasonal Kendall Tau program code originally developed by the USGS to test for trends in flows and water quality data. This SAS code provides two alternative methods for determining if data exhibit a statistically significant trend at a given level of probability. The first method assumes that the seasonal data are independent, while the second method corrects (or detrends) for "serial autocorrelations" within the data. Monthly rainfall (and flow) data are often serially correlated (the values in many months are similar to either the preceding or following months). Therefore, statistical Seasonal Kendall Tau probabilities corrected for serial correlations were used for tests of trends in monthly values over selected time intervals.

Rainfall data at each of the four long-term gages were tested for statistically significant trends first using monthly totals (**Table 3.4**) and then alternatively based on annual levels (**Table 3.5**). The initial test for trends was conducted over the 1932-2006 time period (corresponding to the longest record of gaged historic flows) for the three Peace River watershed sites, and over the somewhat shorter 1943-2006 period-of-record for the Myakka River watershed gage. These same analyses were then again repeated over the 1976-2006 time period, which corresponds with the interval of HBMP monitoring. The sign and magnitude of the calculated Seasonal Kendall Tau statistic, and the slope indicate direction and degree of change, while the probability values indicate the likelihood that the change is statistically significant. Since monthly rainfall totals are seasonally autocorrelated, the probabilities for these monthly based tests should be corrected for serial correlations.

Overall, the results presented in the graphical and statistical analyses of historic rainfall patterns extend and support findings previously described both in the *2002 Peace River HBMP Comprehensive Summary Report* (PBS&J 2004) and the *Peace River Cumulative Impact Study* (PBS&J 2007). The following summarize the key findings regarding the long-term variability of seasonal rainfall patterns in southwest Florida.

- The average annual rainfall pattern for the Peace River watershed (**Figure 3.3**) shows that more than half of the total annual rainfall typically falls within the four month summer wet-season between June and September.

- However, the results of the time-series plots (see **Table 3.3**) clearly show that over the thirty-one year period of HBMP monitoring (1976-2006) there has been considerable unevenness in seasonal and annual rainfall levels. The sources of such variability can often be directly linked with influences of major climatic events such as unusually wet winter/spring El Niño periods (1982-1983 and 1997-1998) that were subsequently followed by La Niña influenced extended drought conditions (1985-1990 and 1999-2002), or periodic tropical events such as those that occurred in 2004 when three hurricanes (Charley, Frances and Jeanne) all directly impacted the Peace River watershed.

- When annual and seasonal rainfall patterns are analyzed over longer historic time intervals, such as 1932-2006 or 1915-2006, more distinctive decadal patterns become apparent.

- Graphical analyses using cumulative differences of historical changes in rainfall patterns indicate that such decadal changes have been small relative to both monthly and annual variations, and that the observed changes in historical rainfall levels have been primarily associated with small changes during the four month summer wet-season.

- The data also suggest that during the historically slightly wetter summer periods from the 1930s to the 1960s rainfall levels in both May and June were somewhat higher than during the drier summers between 1969 and 1994.

- Trend tests of both monthly and annual rainfall levels at the three long-term Peace River locations over the period 1932-2006 were however not statistically significant (**Tables 3.4** and **3.5**). These results indicate that the high annual variability inherent in the fixed station rainfall data, relative to the small wet-season changes, limits the effectiveness of typical statistical trend analysis in assessing long-term patterns.

- Overall, analyses of the rainfall data show apparent differences between the two inland rainfall gages (Bartow and Arcadia), and the more coastal Punta Gorda and Myakka River recording sites. The two more coastal rainfall gages have generally had slightly higher rainfall levels, and the long-term patterns at these more coastal locations show neither the distinct wet-season declines following the 1960s nor the recovery following the early 1990s apparent from rainfall measurements at the two inland Peace River watershed gages.

- Such differences are further emphasized by the fact that trend tests using both monthly and annual total rainfall levels show statistically significant increases over the 1943-2006 period-of-record at the Myakka River State Park location. This is in direct contrast to trend tests for the other three Peace River watershed locations that showed no significant trends over the longer 1932-2006 time interval.

- There were no significant trends in either monthly or annual total rainfall levels over the 1976-2006 HBMP monitoring program period at any of the four tested rainfall locations.

3.3 Status and Trends in Gaged Watershed Freshwater Inflows

A number of studies in recent years have evaluated historic flow trends and patterns in portions of the Peace River watershed and addressed potential causes relative to observed changes in seasonal and longer term flow patterns. The following lists some of these key studies.

- Peek (1951)
- Hammett (1990, 1992, 1998)
- Lewelling and Wylie (1993)
- Coastal Environmental (1996)
- Hickey (1998)
- Lewelling, Tihansky, and Kindinger (1998)
- Flannery and Barcelo (1998)
- Ardaman & Associates (2002)
- Basso and Schultz (2003)
- SDI (2003)
- Basso (2004)
- Kelly (2004)
- Kelly, Munson, and Leeper (2005)
- PBS&J (1999, 2006, 2007)

Peek (1951) was one of the first to show a relationship between the loss of flow from Kissengen Spring and the lowering of the potentiometric surface in the Floridan aquifer system resulting from ground water pumping primarily associated with the expansion of phosphate mining in the upper Peace River watershed. Hammett (1990) subsequently identified statistically significant declines in long-term annual mean discharges at the Peace River at Bartow, Zolfo Springs, and the Arcadia USGS gaging stations over the period between the 1930s and 1984. Hammett also suggested that such observed declines in Peace River flows were probably related to the declines in the water levels in the underlying aquifer systems resulting from ground water withdrawals. Her analyses indicated that the largest declines in river flows were in the northern and eastern parts of the watershed where the greatest reductions in the potentiometric ground water surface had occurred. Lewelling et al. (1998) updated and extended this analysis by including the subsequent 10 years of gaged river flows and found the same declining trends when flows were analyzed over the interval from the 1930s to 1994. Recent studies (Kelly 2004, Basso 2004 and Kelly et al. 2005) have indicated that there are long-term patterns in the Peace River watershed flows that can be related to the previously discussed cyclical Atlantic Multidecadal Oscillation (AMO) rainfall phases. These studies found decadal differences in mean and median flows that closely match the wet 1932-1969, dry 1969- 1994 and again wet 1994-present AMO phases, and indicated that such changes were primarily associated with decadal differences in summer wet-season flows. Additional analyses based on USGS flow records through 2004 (PBS&J 2007) found similar historic flow patterns relative to mean and median monthly flows at long-term USGS gages both within the Peace River and other nearby watersheds. The PBS&J analyses however also revealed distinctly different long-term patterns in base flows (lower monthly percentiles) in different regions of the Peace River watershed. Base flows at the USGS gages in those basins found in the upper portions of the watershed show marked declines that can be directly linked to ground water withdrawals and historic reductions in ground water levels and spring flows. Historically, loss of the potentiometric surface in the Floridan aquifer system can be traced to the expansion of phosphate mining in the northern watershed. However, over more recent decades ground water withdrawals associated with mining have declined and been replaced by increases in agricultural demands and potable uses. Agricultural ground water use in the southern Peace River watershed basins have increased to such an extent that base flows in these Peace River tributaries have been distinctly augmented. There are some streams and creeks that were previously seasonally dry that now often have some flow throughout the year due to agricultural discharges.

The gaged flow records for ten long-term USGS stream flow monitoring sites in the Peace River watershed and the Myakka River near Sarasota gage were obtained from the USGS Tampa website. Since USGS flow data are periodically updated from "provisional" data or corrected based on revised information, new period-of-record flow data for each gage were obtained and reviewed from the USGS website rather than simply updating previous HBMP information.

Summary information for each of the analyzed long-term USGS stream flow gaging locations is presented in Table 3.6.

- USGS gage ID number
- Gage identification name
- Location (latitude & longitude)
- Elevation of gaging site
- Basin/watershed area upstream of the gaging location (drainage area)
- Historical period-of-record interval of data (start through 2006)

Table 3.6
Selected USGS Flow Gages

USGS ID	Gages Within Study Area	Latitude	Longitude	Elevation NGDV29 (meters)	Basin Area (square miles)	Start of Flow Record
Peace River Watershed						
2294650	Peace River at Bartow	27°54'07"	81°49'03"	87.56	390.0	10/01/39
2294898	Peace River at Fort Meade	27°45'04"	81°46'56"	0.00	480.0	06/01/74
2295420	Payne Creek near Bowling Green	27°37'13"	81°49'33"	51.06	121.0	10/01/63
2295637	Peace River at Zolfo Springs	27°30'15"	81°48'04"	30.20	826.0	09/01/33
2296500	Charlie Creek near Gardner	27°22'29"	81°47'48"	21.66	330.0	05/01/50
2296750	Peace River at Arcadia	27°13'19"	81°52'34"	6.00	1367.0	04/01/31
2297100	Joshua Creek at Nocatee	27°09'59"	81°52'47"	3.94	132.0	05/01/50
2297310	Horse Creek near Arcadia	27°11'57"	81°59'19"	10.96	218.0	05/01/50
2298123	Prairie Creek near Fort Ogden	27°03'06"	81°47'05"	25.00	233.0	10/01/63
2298202	Shell Creek near Punta Gorda	26°59'04"	81°56'09"	0.00	373.0	01/01/15
Additional Reference Gage						
2298830	Myakka River near Sarasota	27°14'25"	82°18'50"	7.92	229.0	09/1/36

3.3.1 Time-Series Plots

Time-series plots of monthly flow values were plotted for the period-of-record for each of these long-term USGS gaging sites. The organization of these plots within this document is presented in **Table 3.7**. Monthly summary flow statistics were plotted to facilitate evaluation of potential differences among a number of statistics commonly applied to flow metrics.

The graphs include monthly flow metric values as well as a fitted, smoothed line, which was plotted using a SAS cubic spline method that minimizes both the linear combination of the sums of squares of the residuals of the fit as well as the integral of the square of the second derivative. The statistical metrics used included seven monthly flow percentiles, including minimum and maximum values, as well as the monthly mean.

- P0 Percentile – the minimum or lowest monthly value
- P10 Percentile – low flow value that was exceeded ninety percent of the time
- P25 Percentile – low flow value that was exceeded seventy-five percent of the time
- P50 Percentile – or median value, half of the monthly values were both greater and less
- P75 Percentile – high flow value that was exceeded only twenty-five percent of the time
- P90 Percentile – high flow value that was exceeded only ten percent of the time
- P100 Percentile – the maximum or highest monthly value
- Mean- this average monthly value is usually above the median when evaluating flow data

Among the presented graphics (**Figure 3.56** through **Figure 3.159**), variable scales were selected to provide the context of the full range of data being presented. While the use of such variable scales allows viewing greater detail within individual plots, care needs to be taken when making comparisons among plots. As an example, due to changes in scale, what may appear to be large changes in minimum monthly flows would probably completely disappear when evaluating changes in the maximum monthly values over time.

Similar graphics over the thirty-one year period of HBMP monitoring (1976-2006) were also plotted in order to be able to provide uniform comparisons with other HBMP monitoring elements. The organization of these additional plots is presented in **Table 3.8**.

3.3.2 Seasonal Kendall Tau Analyses for Trends in Flows, Period-of-Record

Watershed flows can vary both spatially and temporally over both small and large scales due to natural variations in rainfall, as well as anthropogenic influences associated with urbanization, mining, and agricultural practices. The term "trends" is used here to refer to progressive changes over time in a flow metric (such as the monthly mean level), while "seasonal" and shorter term oscillating patterns are normally due to repeating natural processes. The Seasonal Kendall Tau test is a nonparametric statistical test often used to analyze data for trends where normality cannot be assumed. This statistical procedure can be used to determine whether data values are increasing, declining, or remaining relatively level over time. This is accomplished by computing a statistic (Tau) based on the differences among all possible data pairs, thus representing the net direction of movement of the time-series data. The number of positive differences minus the number of negative differences is then determined and this is used to calculate the Mann-Kendall Tau statistic. If the time-series data are systematically increasing (or decreasing) over time, then the resulting computed Tau statistic will be a relatively large positive (or negative) value. If, however, the change over time is negligible, then the number of positive pairs and the number of negative pairs will be approximately equal, and the Tau statistic will be small. The Tau statistic can thus be viewed as an estimate of the median slope of the set of slopes estimated for the lines connecting all possible pairs of data.

The Seasonal Kendall Tau test incorporates an additional factor to account for seasonal variation. When analyzing monthly data, each month is viewed as a "season" and this method is therefore directly applicable to southwest Florida’s strong seasonal flow patterns (**Figure 3.4**). As in parametric tests, hypothesis testing using the Seasonal Kendall Tau for a trend is based on the null hypothesis that “there is no trend.” The null hypothesis can only be rejected if the Tau statistic is sufficiently large at a given statistical level of probability (p-value).

Statistical tests were conducted using SAS programming code developed by the USEPA for nonparametric analysis of water quality and other environmental data (see previous discussion above in Section 3.2.3). **Tables 3.9** through **3.16** provide summary results of Seasonal Kendall Tau tests for trends in flows over the period-of-record for each of the previously discussed time-series plots (**Figure 3.56** through **Figure 3.159**.) In these analyses, trends in flows were tested over the period-of-record for each of the 10 long-term Peace River watershed USGS stream flow gaging sites and the Myakka River near Sarasota gage. Table 3.17 summarizes the tabular organizations of the presented Seasonal Kendall Tau statistical trends of monthly based flow metrics tests analyzed for each of the long-term series at the selected locations.

Table 3.17
Summary of Results of Seasonal Kendall Trend Analyses
(Long-term Period-of-Record)

Flow Metric	Figure Number	Flow Metric	Figure Number
P0 Percentile (Minimum)	**Table 3.9**	P75 Percentile	**Table 3.13**
P10 Percentile	**Table 3.10**	P90 Percentile	**Table 3.14**
P25 Percentile	**Table 3.11**	P100Percentile (Maximum)	**Table 3.15**
P 50 Percentile (Median)	**Table 3.12**	Mean	**Table 3.16**

The specific information presented in these summary tables is listed below.

- The station identification (USGS ID and gage name).
- The time period designating the first complete year of annual flow data (trends were tested from this period through 2006).
- The number of years over which the trend test was conducted.
- The Tau statistic, for which positive values indicate an increasing trend over time, negative values indicate a declining trend, and larger absolute values indicates larger changes.
- P-values without correction for serial correlations (not used in these analyses).
- P-values statistically corrected to account for serial correlations (values used).
- The slope, which indicates the magnitude of the relative rate of change, and the sign indicates an increasing or decreasing change over time (trend).

The overall results of Seasonal Kendall Tau trends tests presented in **Tables 3.9** through **3.16** are graphically summarized in **Table 3.18**. Arrows depict significant increasing or decreasing trends, by USGS gaging site and flow percentile. Red arrows denote statistically significant trends over the period-of-record at the P=0.05 level, while blue arrows indicate significant trends at a lesser P=0.10 level. Empty cells indicate no significant trends in flows based on the Seasonal Kendall Tau test results corrected for serial correlations. The following summarizes the observed trends in flows at the USGS gaging sites over the individual periods-of-record.

- The trend analyses indicate that there have been long-term statistically significant declines in flows at the USGS main Peace River stream gages in the upper reaches of the watershed at both Bartow (since 1940) and Zolfo Springs (since 1934).

- Main channel flows in the middle portion of the Peace River watershed, characterized by the Peace River at Arcadia, show statistically significant declines in a number of flow metrics over the 75-year period-of-record.

- In the southern tributaries of the Peace River watershed, by comparison, flows have increased over their periods-of-record (which are of shorter duration than the northern gages). Shell Creek flow data indicate statistically significant increases in the lowest flow percentiles (base flows), while there have been increasing trends in Prairie Creek at all percentiles between the monthly minimum and median values, and all percentiles of flow at the Joshua Creek gage have increased over time.

- The increased flows at the Joshua Creek gaging station are similar to those observed outside the Peace River watershed at the Myakka River near Sarasota gage, which has also historically experienced anthropogenically augmented flows.

- Even with such agriculturally augmented dry-season flows in many of the southern watershed basins, combined total gaged flows upstream of the Facility still show statistically significant declines over the 1951 to 2006 interval for all monthly percentiles below the median flow.

The interpretation of such trend comparisons among basins over different time intervals can only be fairly general, since the results of trend analyses can differ significantly depending on the time intervals tested. An alternative approach was therefore applied to identify the time periods over which the trends occurred, and subsequently provide direct comparisons among the various gaging sites in the Peace River watershed basins. A series of Seasonal Kendall Tau trend tests were run for each of the USGS gaging sites using standardized five-year intervals, such that the number of intervals tested for each gage differed depending on the length of the gage's particular period-of-record. The Peace River at Zolfo Springs gage, for example, has a relatively long historic record so trend tests were run in five-year intervals starting in 1935 (1935-2006, 1940-2006, 1945-2006, 1950-2006, etc.). Since it usually requires six to eight years of monthly data to determine statistical significant trends in highly seasonal data, the last interval used for all gages was 1995-2006. In order to facilitate the comparisons among gages, trend tests were conducted for three selected monthly flow metrics (listed below).

- The low flow P10 Percentile, which is exceeded ninety percent of the time.
- The median flow P50 Percentile, which is greater and less that half the monthly flows.
- The high flow P90 Percentile, which is exceeded only ten percent of the time.

The results of Seasonal Kendall Tau test for trends among comparable intervals for each of the ten long-term USGS flow gaging stations in the Peace River watershed and the Myakka River near Sarasota gage are summarized graphically in **Table 3.19**. As in **Table 3.18**, the directions of the arrows denote statistically significant increasing or decreasing trends. Red arrows indicate trends between each date and 2006 at the P=0.05 level, while blue arrows indicate significant trends at a lower P=0.10 level. Empty cells indicate an absence of trends based on the Seasonal Kendall Tau results corrected for serial correlations, while dashes indicate that the gaged period-of-record did not include data for that interval. The following flow trends and generalized patterns are evident in **Table 3.19**.

- In general, the high degree of both seasonal and yearly variability in flows requires a lengthy record of monthly flow values to ascertain whether changes over time are statistically significant when correcting for serial correlations. Only low flow changes in Joshua and Prairie creeks were large enough to be statistically significantly over the 22 year interval 1985-2006.

- Low, median, and higher flows at the three Peace River gages in the main channel (Bartow, Zolfo Springs, and Arcadia) show significant declines over longer time intervals beginning in the 1930s, 1940s and 1950s. However, there have not been any statistically significant changes in the tested flow percentiles at any of these three locations since 1975 (32 years).

- Increased flows in Joshua Creek are conspicuous, since the increases occur over most of the gaged period-of-record for all three flow percentiles (low, median and high).

- Similar increases in Prairie Creek flows also stand out, although the gaged period-of-record is much shorter. These results indicate that increases in the Prairie Creek flows have occurred much more rapidly than in Joshua Creek since the 1980s.

- Horse Creek flows, by comparison, only show increases over the longer 1965-2006, 1970-2006 and 1975-2006 periods, and do not show the same degree of recent rapid increases apparent at the Prairie and Joshua Creek gages.

- The effects of anthropogenic flow augmentations in the Myakka River near Sarasota are also substantiated by the observed statistically significant increases in flows over all periods up to 1975.

3.3.3 Seasonal Kendall Tau Analyses for Trends in Flows, 1976-2006

Analogous Seasonal Kendall Tau trend test procedures were next used to analyze monthly flow metrics at each of the previously used USGS gaging sites over the 1976-2006 period, which corresponds with the historic interval of lower Peace River/upper Charlotte HBMP monitoring. The overall results of Seasonal Kendall Tau trends tests presented in **Tables 3.20** through **3.27** are graphically summarized in **Table 3.28**.

Table 3.29 summarizes the organization of the Seasonal Kendall Tau statistical trend test results of monthly based flow metrics from the series of selected locations over the 1976-2006 period.

Table 3.29
Summary of Results of Seasonal Kendall Trend Analyses
(1976-2006 Period)

Flow Metric	Figure Number	Flow Metric	Figure Number
P0 Percentile (Minimum)	**Table 3.20**	P75 Percentile	**Table 3.24**
P10 Percentile	**Table 3.21**	P90 Percentile	**Table 3.25**
P25 Percentile	**Table 3.22**	P100 Percentile (Maximum)	**Table 3.26**
P50 Percentile (Median)	**Table 3.23**	Mean	**Table 3.27**

The following summarizes the results presented in **Table 3.28** relative to the trend analyses of Peace River watershed flows over the 1976-2006 time interval.

- There were no statistically significant trends in flows at any of the USGS gages along the main stem of the Peace River between 1976 and 2006.

- Increasing trends in flows were however observed at the USGS gaging sites in a number of the southern Peace River watershed basins. These basins have experienced extensive expansion and changes from less to more intense agricultural development during the past several decades (PBS&J 2007). Expanded agricultural development has resulted in both increases in surface drainage and ditching, as well as large discharges of ground water to receiving surface waters.

- All of the analyzed flow metrics (percentiles) at the USGS Joshua Creek at Nocatee gaging location showed statistically significant increases over the 1976-2006 time interval. The results indicate the relative magnitude of agricultural development that has occurred in the Joshua Creek basin during this time interval.

- In comparison, the trend test results show that only median and those flows below have been augmented by agricultural development in the Horse Creek and Prairie Creek basins.

- The observed differences in trends may indicate that not only have all three of these southern Peace River watershed basins seen augmented dry-season stream flows due to agricultural ground water pumping, but that the degree of land use and drainage changes that have occurred in the Joshua Creek watershed have also resulted in structural changes that have fundamentally altered hydrologic surface flows in the basin.

- These observed increases in base flow in the Peace River tributaries upstream of the Facility will become an important consideration later in **Chapter 5**, relative to historic changes in water quality and potential influences on the Facility during lower spring dry-season flows.

3.4 Additional Analyses and Comparisons of USGS Gaged Flows in Peace River Watershed

Several alternative analytical methods were used to further investigate and evaluate historical natural and anthropogenic changes in USGS gaged Peace River basins flows, and provide comparisons with long-term changes in regional rainfall patterns. In many instances, these additional analytical procedures are similar to those applied in previous studies of patterns and changes in Peace River watershed flows and rainfall, listed above in **Section 3.3**.

3.4.1 Comparisons of Flows among Atlantic Multidecadal Oscillation Periods

Graphical and statistical analytical methods were used to evaluate whether the proposed Atlantic Multidecadal Oscillation (AMO) events might account for previously observed patterns of higher flows that occurred during the 1930-1960 time interval, the observed declines in flows during the 1960s and early 1970s, and the subsequent signs of increasing flows in the mid 1990s. The three AMO periods evaluated included the warmer wet phase prior to 1969, the cooler dry interval between 1969 and 1994, and the recent warmer wet period since 1995. A limitation to these analyses was that the differences in periods-of-record among gaging stations made uniform comparisons among the three AMO phases for all of the flow gaging locations impossible.

Comparisons of Average Monthly Flows

This initial method utilized monthly average flows standardized by watershed basin areas and grouped by each of the three AMO periods. Flows were standardized relative to the upstream area (square miles) of each USGS gaging site (see **Table 3.6**) in order to also provide estimates of the relative differences in contributing flows per unit area among the Peace River watershed basins. The resulting values were then plotted to evaluate variability and potential differences in average annual hydrographs among the three proposed recent historical AMO phases. Flow statistics using four different flow metrics were calculated for each of the selected Peace River gaging stations and the Myakka River near Sarasota basin to assess potential basin and seasonal differences in AMO influences.

- P10 Percentile – low flow value that was exceeded ninety percent of the time.
- P50 Percentile – or median value, half of the monthly values was both greater and less.
- P90 Percentile – high flow value that was exceeded only ten percent of the time.
- Mean – the average monthly value (usually above the median for flow data).

Table 3.30 identifies time intervals associated with flow data for each USGS gaging site and indicates the way in which the individual hydrograph figures for each of the gaging locations have been organized (**Figures 3.264** through **3.315**). Several distinct differences in the annual average hydrographs among the proposed AMO phases are apparent from these figures.

- The historical flow data for several USGS gaging sites (Peace River at Bartow, Peace River at Zolfo Springs and the Peace Rivera at Arcadia; Charlie, Joshua and Horse creeks; and the Myakka River near Sarasota) include information from both the proposed warmer "wet" AMO phases prior to 1969 and the more recent period since 1995, as well as what is believed to have been the cooler "dry" phase between 1969-1994.

- Wet-season (June-September) summer flows were distinctly higher for the high (P90), mean and median (P50) flows at all of these gages (including the Peace River at Arcadia) during the two warmer "wet" AMO periods when compared to the cooler "dry" 1969-1994 phase.

- There were not any similar consistent differences among the three AMO periods for the other eight drier months of the year at any of the selected USGS gaging sites.

- Higher low flows (P10) were also readily apparent during the four month summer wet-season at a number of locations for the historic warmer (wetter) AMO period prior to 1969, when compared to the two later AMO phases. Higher flows in this lower monthly percentile occurred at the Peace River at Bartow, and the Peace River at Zolfo Springs, the Peace River at Arcadia USGS gages, as well as for combined gaged freshwater inflows upstream of the Facility and entering upper Charlotte Harbor.

- Consistent with the results of the previous trend analyses, low (P10) and median (P50) flows throughout the entire annual hydrograph have been distinctly higher since 1995 than during either of the two previous AMO phases, again indicating the differences localized anthropogenic influences can have on regional hydrology.

Table3.30
Summary of Seasonal Differences Among Three Historical AMO Periods at Long-term USGS Gages

USGS ID	Gage Identification	Time Period of Data	P10	P50 (Median)	P90	Mean
Peace River Watershed						
2294650	Peace River At Bartow	1940-2006	Figure 3.264	Figure 3.277	Figure 3.290	Figure 3.303
2294898	Peace River At Fort Meade	1975-2006	Figure 3.265	Figure 3.278	Figure 3.291	Figure 3.304
2295420	Payne Creek Near Bowling Green	1980-2006	Figure 3.266	Figure 3.279	Figure 3.292	Figure 3.305
2295637	Peace River At Zolfo Springs	1934-2006	Figure 3.267	Figure 3.280	Figure 3.293	Figure 3.306
2296500	Charlie Creek Near Gardner	1951-2006	Figure 3.268	Figure 3.281	Figure 3.294	Figure 3.307
2296750	Peace River At Arcadia	1932-2006	Figure 3.269	Figure 3.282	Figure 3.295	Figure 3.308

Table3.30
Summary of Seasonal Differences Among Three Historical AMO Periods at Long-term USGS Gages

USGS ID	Gage Identification	Time Period of Data	P10	P50 (Median)	P90	Mean
2297100	Joshua Creek At Nocatee	1951-2006	Figure 3.270	Figure 3.283	Figure 3.296	Figure 3.309
2297310	Horse Creek Near Arcadia	1951-2006	Figure 3.271	Figure 3.284	Figure 3.297	Figure 3.310
	Total Gaged Flow at Facility	1951-2006	Figure 3.272	Figure 3.285	Figure 3.298	Figure 3.311
2298123	Prairie Creek Near Fort Ogden	1978-2006	Figure 3.273	Figure 3.286	Figure 3.299	Figure 3.312
2298202	Shell Creek Near Punta Gorda	1965-2006	Figure 3.274	Figure 3.287	Figure 3.300	Figure 3.313
	Total Gaged Flow to Harbor	1965-2006	Figure 3.275	Figure 3.288	Figure 3.301	Figure 3.314
Reference Basin						
2298830	Myakka River near Sarasota	1937-2006	Figure 3.276	Figure 3.289	Figure 3.302	Figure 3.315

Differences in Cumulative Distributions

Cumulative Distribution Function (CDF) plots were also used to examine potential differences in gaged watershed flows among the three AMO periods. CDF plots are a graphical method often used to evaluate potential differences in frequency distributions among data sets with large numbers of observations. In simple terms, a CDF plot indicates the probability that a measured variable (in this case a basin area standardized daily flow) is less than or equal to x, and can be expressed by the equation that follows.

$$F(x) = \Pr(X < x) = \alpha$$

The expression for variables with continuous distributions can be calculated using the following formula.

$$F(x) = \int_{\infty}^{x} f(u)du$$

Where F(x) is the estimated accumulated probability of the integrated change in the continuous variable (flow).

CDFs were plotted for the three AMO periods: 1) on an overall annual basis; 2) for the four month summer wet-season (June-September) only, and 3) for the remaining eight drier months

(October-May). Plots are presented in **Figures 3.316** through **3.354** and summarized in Table 3.31. AMO periods with higher flows have statistical distributions (CDF lines) shifted to the right compared with CDF lines for the drier periods, which are comparatively shifted to the left. The results of the CDF analyses further support the previous conclusions that flows measured at the USGS sites during the 1969-1994 cool "drier" AMO phase were generally lower when compared with flows recorded during the two warmer "wetter" AMO periods (prior to 1969 and following 1994.) The statistical distributions also indicate that differences in the summer wet-season (June-September) flows between the warm and cool AMO periods were generally greater than during the rest of the year (October-May).

Table 3.31
CDF Comparisons Among AMO Periods

USGS ID	Gage Identification	Initial Year of Data	Overall	Wet-season June-October	Dry-season November-May
Peace River Watershed					
2294650	Peace River At Bartow	1940	**Figure 3.316**	**Figure 3.329**	**Figure 3.342**
2294898	Peace River At Fort Meade	1975	**Figure 3.317**	**Figure 3.330**	**Figure 3.343**
2295420	Payne Creek near Bowling Green	1980	**Figure 3.318**	**Figure 3.331**	**Figure 3.344**
2295637	Peace River At Zolfo Springs	1934	**Figure 3.319**	**Figure 3.332**	**Figure 3.345**
2296500	Charlie Creek Near Gardner	1951	**Figure 3.320**	**Figure 3.333**	**Figure 3.346**
2296750	Peace River At Arcadia	1932	**Figure 3.321**	**Figure 3.334**	**Figure 3.347**
2297100	Joshua Creek At Nocatee	1951	**Figure 3.322**	**Figure 3.335**	**Figure 3.348**
2297310	Horse Creek Near Arcadia	1951	**Figure 3.323**	**Figure 3.336**	**Figure 3.349**
	Total Gaged Flow Upstream of the Facility	1951	**Figure 3.324**	**Figure 3.337**	**Figure 3.350**
2298123	Prairie Creek Near Fort Ogden	1978	**Figure 3.325**	**Figure 3.338**	**Figure 3.351**
2298202	Shell Creek Near Punta Gorda	1965	**Figure 3.326**	**Figure 3.339**	**Figure 3.352**
	Total Gaged Peace River Flow to Harbor	1965	**Figure 3.327**	**Figure 3.340**	**Figure 3.353**
Other Reference Basins					
2298830	Myakka River near Sarasota	1937	**Figure 3.328**	**Figure 3.341**	**Figure 3.354**

3.4.2 Cumulative Differences in Flows in the Peace River

The preceding analyses (see **Table 3.3** above) of cumulative rainfall differences indicated that during the 1940s and 1950s rainfall was generally above the long-term rainfall average, while during the 1970s and 1980s annual total rainfall was below average. A similar analysis of the cumulative deviation from average of total annual Peace River flow at the Arcadia gage is presented for comparison in **Figures 3.355**. As expected, when plotted as cumulative deviations from the long-term average overall, the observed differences in historic patterns are similar to those previously described for rainfall (**Figure 3.12**). Similar cumulative deviations in flows were also developed for the four month wet-season (**Figure 3.356**) and the eight drier months (**Figure 3.357**). The 75-year plots of both overall and wet-season cumulative Peace River at Arcadia flow deviations exhibit nearly identical patterns. In contrast, the cumulative deviation plot of Peace River at Arcadia dry-season flows indicates declining flows occurred between the middle 1930s and the middle 1950s. This same pattern is also apparent in the comparable dry-season cumulative rainfall deviation plots.

Table 3.32
Comparisons of Cumulative Differences in Rainfall and Flow at the Peace River at Arcadia

Rainfall Period	Cumulative Difference in Rainfall	Cumulative Difference in Flow
Total Annual Rainfall	**Figure 3.12**	**Figure 3.355**
Total Annual Wet-season Rainfall	**Figure 3.17**	**Figure 3.356**
Total Annual Dry-season Rainfall	**Figure 3.22**	**Figure 3.357**

3.4.3 Analyses of Cumulative Flow and Rainfall Relationships

A method used by others (Hammett 1988 and 1990, Hicky 1998, Basso 2002, PBS&J 2007) to evaluate potential historical changes in watershed flows has been to graph cumulative annual flows over time (sometimes referred to as "single mass plots"). Changes in flow patterns can be evaluated based on changes in the slopes of lines graphically fitted to the cumulative annual flows over time. When "breaks" in the slopes of these fitted lines occur, the corresponding years (along the X-axis) have been interpreted as reflecting periods when natural or anthropogenic influences have changed annual average flows. Similarly, graphical analysis of cumulative annual rainfall totals has been used to detect natural variations in long-term rainfall patterns. An additional application of this method has been to evaluate the relationships between changes in rainfall and flows by graphing cumulative total annual gaged flows against cumulative annual measured basin rainfall (sometimes referred to as "double mass plots"). Breaks in the slopes of fitted lines can be interpreted as indicating changes in the relationships between rainfall and flow during different time intervals. In these plots, the data points represent consecutive years (**Figures 3.360**, **3.363**, **3.366** and **3.369**), which allows specific time periods to be associated with any observed changes in the relationships between rainfall and flow.

Cumulative time-series plots of rainfall and flow (single mass), and flow versus rainfall (double mass) were developed using data from five long-term USGS gages in the Peace River watershed and one outside reference site (Table 3.33). Moving downstream, the three gages along the river's main stem (Peace River at Bartow, Zolfo Springs and Arcadia) progressively include increasing larger upstream watershed areas. The Myakka River basin was selected for comparison, since it represents a more coastal watershed and the Myakka River also flows into upper Charlotte Harbor. The graphics summarized in Table 3.33 illustrate relationships between flows and rainfall. Annual sums are represented as individual blue dots, the red dashed line is a regression line fitted over the entire period, and the yellow dashed lines represent upper and lower ninety-five percent confidence intervals.

Table 3.33
Summary of Plots Comparing Cumulative Plots of Rainfall and Flow Over Historic Periods and Cumulative Mass Plots of Rainfall / Flow Relationships

Rainfall / Flow Gages	First Year of Data Used through 2006	Summary of Total (Mass) Rainfall Over Time	Summary of Total (Mass) Flow Over Time	Double Mass Rainfall / Flow
Peace River Watershed				
Bartow / Peace River at Bartow	1940	Figure 3. 358	Figure 3. 359	Figure 3.360
Wachula / Peace River at Zolfo Springs	1934	Figure 3. 361	Figure 3. 362	Figure 3. 363
Arcadia / Peace River at Arcadia	1932	Figure 3. 364	Figure 3. 365	Figure 3. 366
Reference Watershed				
Myakka / Myakka at State Park	1943	Figure 3. 367	Figure 3. 368	Figure 3. 369

The following results summarize the observed relative historical changes in patterns of rainfall and flow, and between their relationships.

- Graphics of data from the three main channel USGS gages indicated similar long-term flow patterns.
- The plots of cumulative annual rainfall over time (single mass) indicate only slight variations (oscillation) in rainfall above and below the long-term fitted line, but suggest differences (or breaks) in slopes before the 1960s and again in the early 1990s.
- In comparison, cumulative time-series plots of annual flows indicate distinct long-term patterns when compared to the overall regression line. These plots show marked breaks approximately in both 1960 and 1994.
- Plots of cumulative annual flow versus cumulative annual rainfall (double mass) indicate distinct changes in the relationships between rainfall and flow following two "breaks," one in the early 1960s and the other in the 1990s.

- These breaks in the relationships between cumulative long-term river flow and rainfall generally coincide with the proposed AMO wet and dry southwest Florida rainfall periods (see previous AMO discussions).

- Breaks in cumulative flows and cumulative rainfall relationships are evident in data from all three of the main channel Peace River USGS gaging stations (Peace River at Bartow, Zolfo Springs and Arcadia). However, the differences increase moving upstream. These differences among the gaging locations probably reflect differences in areas of the upstream basins, and the greater influence of anthropogenic ground water impacts on changes in base flow at the more upstream gages.

- Most of the variation and patterns in annual total flow, rainfall and their relationships apparent in the Peace River watershed coincide with similar long term changes at the referenced Myakka River USGS gaging station (**Figure 3.369**). This suggests that most of the variation in total annual flow at these gages is due to natural long term variations in rainfall in southwest Florida (Kelly 2004). As previously described, the Myakka River watershed is more coastal and has historically had slightly higher and different rainfall patterns than the more interior gaging locations in the Peace River watershed.

3.5 History, Status and Changes in Withdrawals

The primary objective of the following is to provide a brief overview describing historic and recent patterns of consumptive water use in the Peace River watershed, and specifically detail freshwater surface withdrawals from the lower river by the Peace River Facility. The magnitude and seasonal timing of Peace River Facility withdrawals are further compared with the corresponding downstream City of Punta Gorda consumptive use that additionally influences Shell Creek flows to the lower river and upper Charlotte Harbor. A much more comprehensive summary and overview of the history of Peace River Facility and estimated regional demands for potable supplies were previously presented and detailed in **Chapter 1**.

3.5.1 Overview of History and Status of Water Use in the Peace River Watershed

Historically, ground water has provided the vast majority of the municipal, industrial, and agricultural consumptive use throughout most of the Peace River watershed. From the 1940s through the 1970s, the dominant ground water use in the upper watershed was associated with phosphate mining. However, in the late 1970s, the phosphate industry implemented a series of practices to reduce ground water consumption, including a greater reliance on capturing and recycling surface waters from mining areas. By the late 1990s, agriculture accounted for approximately 40 percent of the annual ground water use in Polk County, while domestic and industrial uses each accounted for just less than 30 percent of use (SWFWMD 2004). In the southern Peace River watershed basins, the majority of ground water withdrawals have been and remain associated with agricultural uses.

Table 3.34, developed as part of the recent Peace River Cumulative Impact Study (PBS&J 2007), provides estimates of both historical and recent anthropogenic ground water uses within each of the primary Peace River watershed basins (see **Figure 1.1**). Agricultural practices throughout the Peace River watershed primarily rely on upper Floridan aquifer ground water, rather than on surface water or the less reliable surficial/intermediate aquifers. Consequently, the conversion of undeveloped and range lands to more intensive forms of agricultural has resulted in increased irrigation and subsequent increases in annual dry-season base flows, especially in the southern watershed tributaries, such as Joshua Creek, Horse Creek and the Prairie/Shell Creek systems (see previous trend results and discussions in **Section 3.3** above).

Table 3.34
Estimated Peace River Watershed Ground Water Use (mgd)
by Basin and Selected Reference Periods

Peace River Watershed Basin	1941-1943	1976-1978	1989-1991	1997-1999
Peace River at Bartow	63	176	156	151
Peace River at Zolfo Springs	34	102	100	95
Payne Creek	7	24	24	24
Charlie Creek	11	49	57	62
Peace River at Arcadia	7	30	37	40
Horse Creek	6	27	34	37
Joshua Creek	9	27	33	36
Shell Creek	13	44	54	55
Lower Coastal	5	20	25	26

Figure 3.370 depicts recent available District information on the number, spatial distribution, relative amount, and use of permitted surface and ground water withdrawals throughout the Peace River watershed. This figure clearly shows the relative scale of consumptive uses throughout the watershed and the potential importance of agricultural discharges relative to augmentation of dry-season flows in each of the watershed tributaries.

The two current major withdrawals of surface water for urban uses occur in southern DeSoto County, where the Peace River/Manasota Regional Water Supply Authority (Authority) withdraws water from the Peace River to provide potable supplies for the City of North Port, Charlotte, DeSoto, and Sarasota counties, and the City of Punta Gorda operates a smaller water treatment facility that withdraws surface water from behind the Hendrickson Dam on Shell Creek (**Figure 3.370**).

3.5.2 Peace River Facility Overview

The Authority's Peace River Facility is located on a side-branch adjacent to the main stem of the lower Peace River (**Figure 3.371**). The Peace River Facility has been operating and withdrawing water from the Peace River since 1980, although the system has only been operated by the Authority since 1991. The Facility presently has the capacity to treat up to 24 million gallons per day (mgd), which is equivalent to withdrawals from the river of 37.2 cubic feet per second (cfs). The existing raw water river diversion station has four pumps having a combined maximum capacity of 44 mgd (68.0 cfs). During periods of high river flow (or periods where permitted withdrawal exceeds demand), raw river water is stored in an off-stream surface reservoir and any excess treated water is stored in the system's twenty-one Aquifer Storage Recovery (ASR) wells. Conversely, when water is unavailable from the Peace River due to the established low flow 130 cfs cutoff (or when demand exceeds permitted withdrawals), 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 well system to meet the water supply demands of the Authority's service area. Table 3.35 summarizes the history of major modifications of the Facility's District operating permits (the first of which preceded actual operations).

Table 3.35
Historic Summary of Facility Permits

Year	December 1975	March 1979	May 1982	October 1988	March 1996
Water Use Permit Number	27500016	27602923	202923	2010420	2010420.02
Average Permitted River Withdrawal (mgd)	5.0	5.0	8.2	10.7	32.7
Maximum Permitted River Withdrawal (mgd)	12 & 18	12 & 18	22	22	90
Diversion Schedule Low Flow Cut off (cfs)	91 – 664	91 – 664	100 – 664	100 & 130	130
Maximum Percent Withdrawal of River Flow (%)	5	5	n/a	10	10

Facility Withdrawal Permit between 1980 and 1988

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 lower river as long as the measured stream flow at the Peace River Arcadia gage was above the established minimum regulatory 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. The formula applied by the District used the previous twenty years of stream flow records for the USGS Peace River at Arcadia flow gage to establish separate minimum flows for each calendar month. The monthly minimum flows for the Peace River at Arcadia that were used to establish the freshwater withdrawal schedule used between 1980 and 1988 ranged from a low of 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. Conversely, the District's water withdrawal schedule during September didn't allow withdrawals from the river until gaged flows at the USGS Peace River at Arcadia gage exceeded 664 cfs.

It should be noted that use of the USGS Peace River at Arcadia gage for establishing minimum flows for Facility withdrawals was originally based on available late 1970s technology needed to easily "census" the preceding day's provisional estimated flows from the gage via a phone connection. While only approximately seventy-five percent of the annual average total gaged flow at the Facility is measured at the Arcadia gage (Table 3.36), inclusion of additional flows from the other two gaged major tributaries (Joshua Creek and Horse Creek) that join the Peace River between Arcadia and the Facility was determined to be cost prohibitive at the time.

Table 3.36
Percent Flows and Withdrawal at the Facility and to the Upper Harbor (1980-2006)

Total Gaged Flow at:	Relative Percent of USGS Gaged Flows				Percent Facility Withdrawals
	Arcadia	Joshua Creek	Horse Creek	Shell Creek	
The Facility	75.0	9.2	15.8	NA	0.9
The US 41 Bridge	57.8	7.1	12.2	22.9	0.7

Facility Withdrawal Permit between 1988 and 1996

When the permit was renewed in 1988, General Development Utilities' consulting scientists and the District agreed that the previous 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, District staff and General Development Utilities agreed that the withdrawal schedule should be modified. A minimum criterion was established with 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 (Table 3.35). Beyond that, withdrawals could equal up to ten percent of the preceding daily measured Peace River at Arcadia flow, with a daily maximum not to exceed 22.0 mgd (34 cfs). This schedule allowed withdrawals to more closely follow the natural variability of rainfall and flow.

Facility Withdrawal Permits from 1996 to Present

The District's 1996 twenty-year renewal of the Facility's Water Use Permit (WUP) established a series of maximum withdrawal quantities. 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 of the year. Beyond that, withdrawals were still not to exceed ten percent of the preceding day's average daily Peace River at Arcadia gaged flow, while the upper daily limit was expanded from 22 to 90 mgd. This revision to the existing permit allows the Authority to withdraw, treat and store more water from the river under high flow conditions.

Overview of the History of Facility Expansions

The physical ability of the Facility to pump water from the river between 1980 and 1989 was initially limited to 22 mgd (34.0 cfs). The Facility's actual treatment capacity from 1980 through 1988 was only 6 mgd (9.3 cfs). In 1989 the Facility treatment capacity was doubled to 12 mgd (18.6 cfs). The initial storage capacity was 625 million gallons in the form of the Facility's off-stream, surface reservoir. Additional storage capacity was added in 1985 with the development of a series of Aquifer Storage Recovery (ASR) wells. By 1988, these new ASR wells had added an additional 1,080 million gallons of storage capacity giving the Facility a total combined storage capacity with the reservoir of 1,705 million gallons. Additional ASR wells completed in 1989 further increased the Facility's total storage capacity to 2,785 million gallons. Further expansion of ASR wells in 1995 again increased the Facility's total combined storage capacity to 3,865 million gallons.

The most recent expansion of the Facility became operational in December 2001. This expansion consisted of doubling the Facility's previous existing treatment capacity from 12 mgd to 24 mgd, and expanding the pumping capacity from the river from 22 to 44 mgd (68.1 cfs). An additional twelve ASR wells were added to the system's existing nine wells. A total of 27 miles of new water transmission piping was also added in order to provide additional water to DeSoto and Charlotte counties, as well as to Sarasota County's Carlton Water Treatment Facility.

Current ongoing expansion plans are to further increase the Facility's river pumping capacity to 90 mgd, which is the current upper permit limit. These plans also include expanding the Facility to treat 48 mgd, or a doubling of the Facility's current treatment capacity. A second, new regional off-stream reservoir with an added storage capacity of 6 billion gallons is to be constructed, along with the extended pipe networks to optimize water delivery. Completion of this next expansion under the current Water Use Permit is currently envisioned for completion during 2009.

Table 3.37 provides a yearly summary of the history (1980-2006) of the Facility's permitted quantities, capacities, demands and withdrawals.

3.5.3 Peace River Facility Withdrawals

Since the beginning of Facility withdrawals from the river in March of 1980, average (mean) daily withdrawals have been 11.8 cfs, while median withdrawals have been slightly lower (9.3 cfs). In comparison, since the issuance in 1996 of the District's newest Facility water use permit, the average daily theoretical maximum permitted quantity of water available from the river based on the Peace River at Arcadia preceding day's flow has been 58.9 cfs, while actual average daily withdrawals over this eleven-year period have been only 17.0 cfs. This means that on an average daily basis since 1996, approximately 28.9 percent of the actual maximum permitted quantities of potential water available from the river have actually been utilized. Available permitted quantities are a direct function of flow, and thus when flows are high, available quantities will be relatively high, and vice versa. Actual withdrawals, by comparison, are dependent on a number of factors including pumping capacity, available storage, and demand (**Table 3.37**). Annually, the highest potential availability of water under the permit typically occurs during August and September, while the lowest levels typically occur during May (**Figure 3.4**). The interactions between the availability of flow and the Facility's capacity for withdrawals are indicated by comparisons of withdrawals during the 2000 drought (mean annual withdrawal of 5.7 cfs), and withdrawals during the characteristically wet years such as 2003 and 2005, which had mean annual withdrawals of 26.1 and 29.1 cfs, respectively (**Table 3.38**) following the recent expansion of the Facility. Currently, the ability to quickly refill storage after a similar sustained drought is limited by the Facility's existing 44 mgd (68 cfs) pumping capacity from the river and ultimately by the permit's 90 mgd (139 cfs) maximum cap on daily withdrawals.

As discussed, beyond the Facility's permitted low flow cutoff of 130 cfs at the Peace River at Arcadia USGS gage and the 90 mgd (139 cfs) maximum daily withdrawal cap, there are a number of additional factors that limit actual daily withdrawals. These include normal Facility maintenance and operations, the Facility's physical capacity to pump water from the river, the capacity of the Facility to store/treat water, and historically the seasonal demands. Combined, these have resulted in the Facility not withdrawing the maximum amount of water allotted under any of the historical permit conditions. Over time modifications of the District's water use permits (see Table 3.35 above) and increases in Facility capacity have resulted in changes needed to better meet the demands (**Table 3.37**) of the communities serviced by the Facility. The demand for water is generally the highest in the spring dry-season months when flows are characteristically at seasonal low levels, meaning that sufficient water must be withdrawn and stored when it is available, primarily during the summer wet-season months. Past and planned future expansions of the Facility to allow pumping up to the permitted 90 mgd maximum, in combination with increased storage capacity in the Facility's ASR wells and an upcoming expanded off-stream reservoir will allow the Facility to utilize higher flows when they are available in the future. The 1988 change in the Facility's water use permit to a flow based withdrawal schedule, rather than a fixed predetermined monthly schedule, also increased the potential to allow greater withdrawals when sufficient water above the low flow cutoff was available. As a result, observed increases in withdrawal relative to maximum permitted amounts under the permit have not been as large as the actual absolute increase in withdrawals (**Figure 3.372**).

Through 2006, the facility was able to meet demands operating within the limits set by the water use permit and the Facility's physical capacity. However, during both the recent very dry 1999-2001 La Niña event and the 2006 drought, the Facility's stored water reserves were drawn very low. While the stored reserves proved adequate during these recent events, once the additional expanded capacity and storage that are currently being implemented are added, the severity of similar future occurrences should be limited. Comparisons of potential relative impacts of current and future projected levels of withdrawal relative to Peace River flows vary depending on where flows are being measured. Peace River Facility withdrawals have never exceeded 4.9 percent of the annual gaged flow at Arcadia, 3.4 percent of the total gaged flow upstream of the Facility, or 2.2 percent of the total annual lower Peace River gaged flow to upper Charlotte Harbor (**Table 3.38**). As demand for potable water supplied from the Facility increases in the future, the timing of flows potentially available for withdrawal relative to timing of peak demands may cause some supply issues, especially during extended dry periods. During periods when flows are low, but still above the 130 cfs low flow cutoff, the Facility typically withdraws water at, or very near, the maximum permitted levels. However, historically, the Facility has withdrawn water well below the maximum permitted amount during periods of high flow (**Figure 3.380**). It is expected that as demands from the Facility continue to grow, and new expanded facilities are added, the difference between plotted lines for permitted and actual withdrawals under higher flows will become similar (**Figure 3.382)**. Facility expansions have historically occurred incrementally, in response to projected demands balanced against the construction costs of adding both needed and future capacity. It is expected that over time, as additional off-stream storage and pumping capacity from the river are added, actual quantities of water withdrawn from the river will move closer to those quantities theoretically available under the existing permit conditions. Stated another way the Facility will be able to more frequently utilize all available water under the permit with the addition of more pumping and storage capacity.

A series of graphical and statistical analyses were conducted in order to provide a comprehensive overview of the current status as well as long-term patterns and trends in freshwater withdrawals by the Facility since it became operational in 1980. An overview of the graphical analyses is presented in Table 3.39

Table 3.39
Summary Graphics of Facility Freshwater Withdrawals 1980-2006

Figure	Description
Figure 3.372	Daily water treatment facility withdrawals (1980-2006)
Figure 3.373	Monthly mean water treatment facility withdrawals (1980-2006)
Figure 3.374	Peace River flows at Arcadia vs. water treatment facility withdrawals
Figure 3.375	Peace River flows at Arcadia vs. water treatment facility withdrawals
Figure 3.376	Peace River flows at Arcadia vs. % water treatment facility withdrawals
Figure 3.377	Peace River flows at Arcadia vs. % water treatment facility withdrawals
Figure 3.378	Daily Peace River and Shell Creek water treatment facility withdrawals (1980-2006)
Figure 3.379	Average monthly maximum permitted and actual Facility withdrawals (1996-2006)
Figure 3.380	Average monthly maximum permitted and actual Facility withdrawals (1996-2002)
Figure 3.381	Average monthly maximum permitted and actual Facility withdrawals (2002-2006)

The following observations and conclusions regarding the status and long-term patterns and trends in Facility freshwater withdrawals can be drawn from the presented graphical analyses.

- The time-series plots presented in **Figures 3.372** and **3.373** indicate a number of patterns. The low flow cutoffs based on flows at the USGS Peace River at Arcadia gage have often resulted in periods each year when the Facility does not withdraw water from the river. The effects of the recent extended 2000-2001 drought on Facility water withdrawals are clearly evident in both figures. During 2000 the Facility did not withdraw any water from the Peace River 248 days during the year, and relied solely on stored reserves another 219 days during 2001.

- These time-series plots also plainly show the relatively steady increases in the amounts of freshwater withdrawals by the Facility during the past twenty-seven years due to increasing water demands. Also clearly evident is the noticeable increase in maximum Facility withdrawals during the later half of 2002 due to the completed Facility expansion of 2001, which resulted in the Authority's increased ability to treat and store larger daily amounts of freshwater.

- Comparisons of **Figures 3.374 and 3.379** indicate that other than during the warm/dry months of April and May when the Facility is often not withdrawing water from the Peace River due to the 130 cfs cutoff, Facility withdrawals have been fairly uniform throughout most of the year, differing primarily between changes in the permits and differences in Facility capacities.

- **Figures 3.374** and **3.375** indicate that once flows exceed the 130 cfs cutoff, withdrawals by the Facility are more dependent on demand and capacity rather than supply, since as indicated, very similar amounts of water have been withdrawn over a wide range of flows.

- **Figure 3.375** also shows that much larger amounts and percentages of flow were initially taken during low flows under the District's original monthly based withdrawal schedule.

- **Figures 3.376** and **3.377** indicate withdrawals as percentages over the 1980-2006 time period in relation to "finalized" daily USGS Peace River at Arcadia flows. As indicated, prior to implementation of the ten percent criteria in 1988, the Facility routinely withdrew fairly large percentages of the Arcadia gaged flow during dry periods.

- These figures also show that Facility withdrawals have periodically exceeded the ten percent criteria since it was established in 1988. The primary reason for these discrepancies stems from the way that stage/flow data are gathered. The Authority uses "provisional" preceding day flow data from the water level recorder at the USGS gaging station on the Peace River at Arcadia. Currently, these data are taken directly from the USGS Tampa office's website. However, after the fact, the USGS checks and evaluates the data from the stage recorder and validates the river cross section a number of times each year. Thus, the daily values used by the Authority are only "provisional" and are occasionally changed by the USGS weeks or months after the fact. It is not uncommon for subsequent determinations of percent withdrawals, based on revised USGS calculations of daily flows, to conclude that daily Facility withdrawals, based on provisional flow information, in fact exceeded the established ten percent criteria. Similarly, there are also times when upward revisions would have meant that the Authority could have theoretically withdrawn additional amounts. The Authority and the USGS Tampa office staff have continued to work to reduce such instances to the greatest possible extent.

- As **Figure 3.374** indicates, Facility withdrawals are not directly related to flows (outside of the 130 cfs cutoff, and then ten percent maximum of Arcadia flow up to a maximum single day withdrawal of 139 cfs). Therefore, as expected, withdrawals and average total monthly watershed rainfall (**Figure 3.9**) also fail to show any direct relationships, outside of the general seasonal and marked differences that occur between extended periods of lower and higher than average rainfall and the corresponding influences on resulting flows.

An alternative method of evaluating the relative potential magnitude of impacts from Facility withdrawals on the hydrology of the lower Peace River estuarine system is to compare the seasonal structure of the average annual hydrograph with and without withdrawals. Table 3.40 summaries graphical comparison of the annual average hydrographs of total upstream gaged flow with and without freshwater withdrawals at two locations along the lower Peace River. The first location is at the Peace River Facility and compares average seasonal gaged flows with and after actual daily withdrawals have been subtracted. The second selected location along the lower river is at the US 41 Bridge and includes Shell Creek flows and additional surface withdrawals by the City of Punta Gorda.

Graphical comparisons of differences in the annual average hydrographs for three different time intervals are presented. Each of the three selected time periods are characteristic of major differences in the Facility's District water use permit criteria and/or Facility capacity (see **Table 3.35** above).

Table 3.40
Differences in Annual Average Hydrographs With and Without Withdrawals

Location	1980-1988	1989-1995	1996-2006
Lower Peace River at Facility	**Figure 3.382**	**Figure 3.384**	**Figure 3.386**
Lower Peace River at US41 Bridge	**Figure 3.383**	**Figure 3.385**	**Figure 3.387**

These analyses show that differences in the annual average hydrograph resulting from actual Facility withdrawals have, to date, been very small regardless of season. This is especially true given the fairly large degree of natural variability inherent both between years and over longer decadal periods (see AMO discussion in **Section 3.4.1**).

3.6 Summary

This chapter updates information presented in previous summary HBMP reports, and provides analyses of data collected through 2006 regarding both the status and trends of key hydrological elements associated with the Peace River Hydrobiological Monitoring Program (HBMP). Analyses and discussions are presented in relation to the current status and historic trends in the following specific hydrologically related HBMP study elements:

- Status and trends in watershed rainfall patterns.
- Status and trends in gaged watershed freshwater inflows.
- Status and trends in rainfall/flow interactions.
- History, status and trends in withdrawals.

The presented analyses and summary graphics provide overviews of the current hydrological status within the Peace River watershed and lower Peace River/upper Charlotte Harbor estuarine system, and illustrate comparisons with historic longer-term patterns and characteristics. Also described are the important hydrological influences of more infrequent episodic occurrences such as extended periods of extreme drought, the periodic occurrences of unusually wet winter/spring El Niño climatic events, and differences in summer wet-season rainfall/flows due to variations in the frequency of tropical cyclonic patterns.

3.6.1 Hydrologic Setting

The Peace River watershed covers approximately 1.4 million acres (2,188 square miles), and the main channel of the Peace River begins northeast of Bartow, in Polk County, at the confluence of Peace Creek Drainage Canal and Saddle Creek, and extends approximately 105 miles south to Charlotte Harbor. Kissengen Spring near Bartow was a significant source of historic base flow to the upper Peace River with average annual estimated flows prior to the mid-1930s of approximately 30 cubic feet per second (cfs). Cessation of flow from the spring circa 1950 has been attributed to the decline in the hydraulic potential of the confined aquifers caused by the excessive development of the ground water resource, primarily associated with the early expansion of phosphate mining in the upper watershed. The hydraulic potentials of the confined aquifers, previously observed above the riverbed, have generally been tens of feet below the riverbed since the early-1960s. This historic loss of flows from springs and seeps has been one of the factors that have affected base flow to the upper portion of the river. However, base flow in the upper Peace River has also been affected by changes in discharges and drainage alterations associated with urbanization, phosphate mining, and agriculture. Other hydrologic alterations in some mined and reclaimed areas in the upper regions of the watershed have included diversions of surface waters that historically flowed to the river to storage for mining activities and/or seasonal impoundments resulting from disconnected surface depressions. Surface flows in some mined areas may also have been altered subsequent to mining due to increased recharge, as rainwater readily infiltrates the resulting disturbed soil structure, and recharge to the intermediate aquifer increases following loss of the upper confining layers associated with extraction of the phosphate matrix. The Peace River watershed basins south of phosphate mining influences have also experienced historic increasing ground water demands and extensive hydrologic alterations. These changes are reflected in the cumulative loss of wetland and native upland habitats, and increasing dry-season augmentation of base flow in many tributaries as agriculture in these southern basins has progressively changed from predominantly unimproved pasture to improved pasture and subsequently to increasing areas of more intense farming. Agricultural runoff has contributed to increased base flow in the Joshua Creek, Horse Creek and Prairie/Shell Creek basins.

The Peace River watershed predominantly lays within the National Weather Service (NWS) Florida South-Central Region Four, which is characterized by a summer wet-season that accounts for approximately 60 percent of total average annual precipitation of 52 inches (1915-2006). The four month wet-season extends from June through September, with June on average having the highest annual average rainfall of 8.2 inches. Conversely, November through January typically comprise the three driest months of the year, with rainfall in November only averaging 1.8 inches. October characterizes the transition from the convection based summer wet-season rainfall pattern to the frontal dry-season rainfall pattern.

While the described seasonal patterns in the annual hydrologic conditions are typical, there are wide degrees of both seasonal and annual variability in both rainfall and resulting river flow patterns. Deviations from the normal pattern can span periods of months up to several years. Intense El Niño/Southern Oscillation (ENSO) events, such as occurred in 1982/1983 and 1997/1998, result in atypical extended periods of heavy rainfall during the usually drier winter/spring months and dramatically alter the annual watershed hydroperiod. In both instances, these unusually wet El Niño periods were subsequently following by La Niña events and associated periods of extended drought. While short-term extremes of high and low flows influence the water budget in a watershed over periods of years, superimposed over these may be larger cyclic periods that can cover a number of decades.

Climate researchers have suggested that natural climate cycles or phases can persist over multiple decades. One of these cycles, the Atlantic Multidecadal Oscillation (AMO) refers to long-term cool and warm phase differences of only about 1°F (0.6°C) in North Atlantic average sea surface temperatures. An analysis of Atlantic sea surface temperatures suggests that warm AMO phases occurred during 1869-1893, 1926-1969, and from 1995 to date, while cooler phases occurred predominantly during the 1894-1925 and 1970-1994 time periods. It has been suggested that slight increases in average sea surface temperature in the Atlantic and Caribbean seas during warmer AMO periods produce more summer rainfall across southern Florida, while cooler AMO phases result in decreased summer rainfall.

3.6.2 Status and Trends in Watershed Rainfall Patterns

Historic period-of-record rainfall data for three representative long-term Peace River watershed basin rainfall gaging stations and a representative gage in the nearby Myakka River watershed were obtained as an initial step in evaluating the status and trends of hydrologic conditions in the Peace River watershed.

- Long-term total monthly rainfall patterns were similar among the selected rainfall gages.
- The variability in total monthly rainfall is sufficient to obscure changes and patterns when the long-term rainfall data are analyzed on a monthly basis.
- Results of the analyses suggest generally higher monthly rainfall at the more coastal Punta Gorda and Myakka State Park gages than at the two more interior Peace River watershed basin gages.
- When the long-term rainfall data for the Peace River watershed are analyzed as annual totals, the results clearly show both increased variations among the gages and greater indications of both historical wetter and drier intervals (Figure 3.14)
- Total annual average Peace River watershed rainfall levels at the Bartow and Arcadia gages were slightly higher prior to the 1960s when compared with the period from the late 1960s to the mid 1990s. The data indicate that between the mid 1990s and 2006 annual total rainfall levels at these two interior Peace River watershed locations increased.

- Annual average wet-season (June-September) rainfall in the Peace River watershed was generally higher during the 1930s through the mid-1960s when compared with the interval from the late 1960s through the early 1990s. Since approximately 1994 there has been a notable increase in wet-season rainfall.

- No similar long-term patterns were apparent with regard to dry-season (January-May and October-December) rainfall, although periodic high annual totals were observed corresponding to El Niño events.

- The plots of yearly annual deviations from the average rainfall further supported the conclusions that total annual rainfall during the 1940s and 1950s was above the long-term average of 52 inches per year, and generally below this average during much of the 1970s and 1980s.

- Similar analyses of annual deviations conducted after dividing yearly rainfall totals into wet-season (June through September) and dry-season (October through December and January through May) indicated slightly higher wet-season rainfall during the earlier time periods. In contrast, dry-season rainfall varied randomly around the long-term average over time.

3.6.3 Status and Trends in Gaged Watershed Freshwater Inflows

A number of recent studies have shown long-term patterns in the Peace River watershed flows corresponding with the previously discussed cyclical AMO rainfall phases. Other analyses however have also revealed distinctly different long-term patterns in base flows (lower monthly percentiles) in different regions of the Peace River watershed. Base flows in the upper portions of the watershed show marked declines that can be directly linked to ground water withdrawals and historic reductions in ground water levels and spring flows. In the southern Peace River watershed basins base flows in the Peace River tributaries have been distinctly augmented by agricultural discharges. A number of streams and creeks that were previously seasonally dry now often have some flow throughout the year due to anthropogenic discharges.

Graphical and statistical analyses were conducted using a wide variety of monthly flow metrics for flows over the available period-of-records for each of the major long-term USGS gages in the Peace River Watershed.

- P0 Percentile – the minimum or lowest monthly value
- P10 Percentile – low flow value that was exceeded ninety percent of the time
- P25 Percentile – low flow value that was exceeded seventy-five percent of the time
- P50 Percentile – or median value, half of the monthly values were both greater and less
- P75 Percentile – high flow value that was exceeded only twenty-five percent of the time
- P90 Percentile – high flow value that was exceeded only ten percent of the time
- P100 Percentile – the maximum or highest monthly value
- Mean- this average monthly value is usually above the median when evaluating flow data

The following summarizes the findings of these analyses.

- The trend analyses indicate that there have been long-term statistically significant declines in flows in the upper reaches of the watershed at both Bartow (since 1940) and Zolfo Springs (since 1934).

- Peace River at Arcadia flows show statistically significant declines in a number of flow metrics over the 75-year period-of-record.

- In the southern tributaries of the Peace River watershed, by comparison, flows have increased over their periods-of-record (which are of shorter duration than the northern gages). Shell Creek flow data indicate statistically significant increases in the lowest flow percentiles (base flows), while there have been increasing trends in Prairie Creek at all percentiles between the monthly minimum and median values, and all percentiles of flow at the Joshua Creek gage have increased over time.

- Even with such agriculturally augmented dry-season flows in many of the southern watershed basins, combined total gaged flows upstream of the Facility still show statistically significant declines over the 1951 to 2006 interval for all monthly percentiles below the median flow.

- There were no statistically significant trends in flows at any of the USGS gages along the main stem of the Peace River during the period of HBMP monitoring between 1976 and 2006.

- All of the analyzed flow metrics (percentiles) at the Joshua Creek gaging location showed statistically significant increases over the 1976-2006 time interval. The results indicate the relative magnitude of agricultural development that has occurred in the Joshua Creek basin during this time interval.

- In comparison, the trend test results show that only median and those flows below have been augmented by agricultural development in the Horse Creek and Prairie Creek basins.

- The observed differences in trends may indicate that not only have all three of these southern Peace River watershed basins seen augmented dry-season stream flows due to agricultural ground water pumping, but that the degree of land use and drainage changes that have occurred in the Joshua Creek watershed have also resulted in structural changes that have fundamentally altered hydrologic surface flows in the basin.

3.6.4 Overview of Groundwater and Surface Withdrawals

Historically, ground water has provided the vast majority of the municipal, industrial, and agricultural consumptive use throughout most of the Peace River watershed. From the 1940s through the 1970s, the dominant ground water use in the upper watershed was associated with phosphate mining. However, in the late 1970s, the phosphate industry implemented a series of practices to reduce ground water consumption, including a greater reliance on capturing and recycling surface waters from mining areas. By the late 1990s, agriculture accounted for approximately 40 percent of the annual ground water use in Polk County, while domestic and industrial uses each accounted for just less than 30 percent of use. In the southern Peace River watershed basins, the majority of ground water withdrawals have been and remain associated with agricultural uses.

The two current major withdrawals of surface water for urban uses occur in southern DeSoto County, where the Peace Authority withdraws water from the Peace River to provide potable supplies for the City of North Port, Charlotte, DeSoto, and Sarasota counties, and the City of Punta Gorda operates a smaller water treatment facility that withdraws surface water from behind the Hendrickson Dam on Shell Creek.

Since the issuance in 1996 of the District's newest Peace River Facility water use permit, the average daily theoretical maximum permitted quantity of water available from the river based on the preceding day's flow has been 58.9 cfs, while actual average daily withdrawals over this eleven-year period have been only 17.0 cfs. Available permitted quantities are a direct function of flow, and thus when flows are typically high, available quantities are relatively high, and vice versa. Actual withdrawals, by comparison, are dependent on a number of factors including pumping capacity, available storage, and demand. The interactions between the availability of flow and the Facility's capacity for withdrawals are indicated by comparisons of withdrawals during the 2000 drought (mean annual withdrawal of 5.7 cfs), and withdrawals during the characteristically wet years such as 2003 and 2005, which had mean annual withdrawals of 26.1 and 29.1 cfs, respectively. Through 2006, the facility was able to meet demands operating within the limits set by the water use permit and the Facility's physical capacity. However, during both the recent very dry 1999-2001 La Niña event and the 2006 drought, the Facility's stored water reserves were drawn down to very low levels. While the stored reserves proved adequate during these recent events, once the additional expanded capacity and storage that are currently being implemented are added, the severity of similar future occurrences should be limited. As demand for potable water supplied from the Facility increases, the timing of flows potentially available for withdrawal relative to timing of peak demands may continue to cause some supply issues during extended dry periods. When flows are low, but still above the 130 cfs low flow cutoff, the Facility typically withdraws water at, or very near, the maximum permitted levels. However, historically, the Facility has withdrawn water well below the maximum permitted amount during periods of high flow. It is expected that as additional off-stream storage and withdrawal pumping capacity are added, actual quantities of water withdrawn from the river will increasingly become similar to those quantities available under the existing permit conditions.

The following observations and conclusions regarding the status and long-term patterns and trends in Facility freshwater withdrawals can be drawn from the presented graphical analyses.

- Prior to 1988 when flows were not based on a percent of flow, much larger percentages of low flows were initially taken under the District's original monthly based withdrawal schedule.

- Time-series plots plainly show the relatively steady increases in the amounts of freshwater withdrawals by the Facility during the past twenty-seven years due to increasing water demands. Also clearly evident is the noticeable increase in maximum Facility withdrawals following completion of the Facility's 2001 expansion, which resulted in the Authority's increased ability to treat and store larger daily amounts of freshwater.

- Comparisons indicate that other than during the warm/dry months of April and May when the Facility is often not withdrawing water from the Peace River due to the 130 cfs cutoff, Facility withdrawals have been fairly uniform throughout most of the year, differing primarily between changes in the permits and differences in Facility capacities.

- The low flow cutoffs based on flows at the USGS Peace River at Arcadia gage have often resulted in periods each year when the Facility does not withdraw water from the river. During 2000 the Facility did not withdraw any water from the Peace River for a total of 248 days, and relied solely on stored reserves another 219 days during 2001.

- Facility withdrawals have periodically exceeded the ten percent criteria since it was established in 1988. The primary reason for these discrepancies stems from the way that stage/flow data are gathered. The Authority uses "provisional" preceding day flow data from the water level recorder at the USGS gaging station on the Peace River at Arcadia. Currently, these data are taken directly from the USGS Tampa office's website. However, after the fact, the USGS checks and evaluates the data from the stage recorder and validates the river cross section a number of times each year. Thus, the daily values used by the Authority are only "provisional" and are often changed by the USGS weeks or months after the fact. It is not uncommon for subsequent determinations of percent withdrawals, based on revised USGS calculations of daily flows, to conclude that daily Facility withdrawals, based on provisional flow information, in fact exceeded the established ten percent criteria. The Authority and the USGS Tampa office staff have continued to work to reduce such instances to the greatest possible extent.

- Comparisons of the annual average hydrographs of total gaged flows upstream of the Facility with and without withdrawals have been very small regardless of season. This is especially true given the fairly large degree of natural variability inherent both between years and over longer decadal periods.

4.0 Status and Trends of Hydrobiological Water Quality Indicators in the Lower Peace River/Upper Charlotte Harbor Estuarine System

The primary objectives of this section are to provide overviews and analyses of the status and trends in water quality in the lower Peace River/upper Charlotte Harbor estuarine system over the 1976-2006 time interval of HBMP monitoring. The following initially provides a general overview and summary of the major causes of historical changes in water quality in the Peace River watershed and the influences that ultimately have affected downstream water quality characteristics in the lower Peace River/upper Charlotte Harbor estuary. These upstream influences are then related to the seasonal patterns and longer term changes observed in the characteristics of the water quality data collected over the long-term interval of HBMP monitoring. Included in this section are:

- An overview and summary of historical changes in water quality in the upper Peace River and its major tributaries relative to influences of long-term changes in water quality in the lower Peace River and the upper harbor.
- Analyses of the status and trends in water quality at the long-term "fixed" HBMP monitoring stations over the interval from 1976 through 2006.
- Analyses of the status and trends in water quality at the long-term "moving" ishohaline based HBMP salinity zones over the period between 1984 and 2006.

4.1 Overview of Historical Patterns of Water Quality Changes in the Peace River Watershed

Historically, water quality in the upper Peace River watershed has been affected by a number of anthropogenic activities. These have included point and nonpoint source discharges from phosphate mining and processing, point source municipal/industrial effluents, and nonpoint runoff from both expanding urban and intense agricultural land uses. A number of studies over the past two decades have evaluated the influences of the watershed on water quality in the lower Peace River/upper Charlotte Harbor estuarine system.

- Fraser, T.H., 1986. *Long-term water-quality characteristics of Charlotte Harbor, Florida:* U.S. Geological Survey Water-Resources Investigations Report 86-4180, 43 p
- Hammett, K.M., 1990. *Land use, water use, streamflow characteristics, and water-quality characteristics of the Charlotte Harbor inflow area, Florida*: U.S. Geological Survey Water-Supply Paper 2359-A.
- Montgomery, R.T., B.F. McPherson, and E.E. Emmons. 1991. *Effects of nitrogen and phosphorous additions on phytoplankton productivity and* chlorophyll *a in a subtropical estuary, Charlotte Harbor, Florida:* U.S. Geological Survey Water-Resources Investigations Report 91-4077.

- Coastal Environmental. 1995. Estimates of Total Nitrogen, Total Phosphorus, and Total Suspended Solids Loadings to Charlotte Harbor, Florida. Southwest Florida Water Management District SWIM Department.

- Coastal Environmental. 1996. Review and Analyses of Meteorological, Tributary Flow, and Water Quality Data from the Charlotte Harbor Estuarine System. Southwest Florida Water Management District SWIM Department.

- McPherson, B.F., R.L. Miller, and Stoker, Y.E. 1996. Physical, chemical, and biological characteristics of the Charlotte Harbor basin and estuarine system in southwestern Florida - A summary of the 1982-90 U.S. Geological Survey Charlotte Harbor Assessment and other studies. U.S. Geological Survey Water-Supply Paper 2486.

- Camp Dresser & McKee, Inc. 1998. The Study of Seasonal and Spatial Patterns of Hypoxia in Upper Charlotte Harbor. Southwest Florida Water Management District SWIM Department.

- PBS&J and W. Dexter Bender. 1999. Synthesis of Technical Information. Volumes 1 and 2. Charlotte Harbor National Estuary Program Technical Report No. 99-02

- Janicki Environmental. 2002. Regression Analysis of Salinity-Streamflow Relationships in the Lower Peace River/Upper Charlotte Harbor Estuary. Southwest Florida Water Management District.

- PBS&J. 2004. Peace River Hydrobiological Monitoring Program 2002 Comprehensive Summary Report. Peace River Manasota Regional Water Supply Authority.

- PBS&J. 2007. Peace River Cumulative Impact Study. Florida Department of Environmental Protection.

Summaries of these and other studies relative to the hydrological, biological and water quality characteristics of the lower river and upper harbor are presented in **Chapter II**.

4.1.1 Changes in Land Use

In addition to increases in mining and urban development, over the past several decades, agricultural land uses in many areas of the Peace River watershed have undergone marked conversions from unimproved grazing pasture to improved pasture and increasingly to citrus and row cops. Some of the largest conversions to more intense agricultural uses have occurred in the southern basins and have been associated with increased discharges of highly mineralized ground water and nonpoint source nutrient loadings (nitrogen). The series of figures summarized in Table 4.1 provide comparisons of differences in undeveloped and developed land uses in the Peace River watershed. These comparisons show changes in major land use categories based on SWFWMD (District) graphical information systems (GIS) information from 1979 and 1999, which represent the two currently available GIS layers corresponding with the period of HBMP monitoring. These land use changes in the Peace River watershed are further summarized relative to changes in both acreages and percent cover in Table 4.2.

Table 4.1
Overview of Historical Land Use Changes in the Peace River Watershed during the Period of HBMP Monitoring

Type of Land Use	1979	1999
Undeveloped Land Uses	Figure 4.1	Figure 4.2
Developed Land Uses	Figure 4.3	Figure 4.4

Table 4.2
Land Use in the Peace River Watershed
1979 – 1999

Land Use	Acres (Percent) in Land Use Class	
	1979	1999
Developed		
Improved Pasture	356,925 (25.6)	379,346 (27.2)
Intense Agriculture	191,496 (13.7)	229,832 (16.5)
Mined lands	64,437 (4.6)	143,487 (10.3)
Urban Land Use	73,049 (5.2)	133,571 (9.6)
Undeveloped		
Native Upland Habitat	419,449 (30.0)	242,849 (17.4)
Wetlands	249,255 (17.8)	218,232 (15.6)
Water		
Lakes and open water	35,432 (2.5)	43,027 (3.1)
Other Water	6,641 (0.5)	6,338 (0.5)
Total	**1,396,683 (100)**	**1,396,683 (100)**

4.1.2 Losses of Historic Stream Channels and Habitats

Both the quantity (see **Chapter 3**) and quality of water in the Peace River watershed have also been influenced by historic losses throughout the watershed of stream channels and their associated habitats (PBS&J 2007). The documented losses of natural stream channels in the Peace River watershed (**Table 4.3**) have potentially altered surface water flows and runoff, surface water storage, aquifer recharge and evapotranspiration, and specifically eliminated fish and wildlife habitats. Natural stream channel losses have been associated with phosphate mining, agriculture, and urban land use activities, which have included channeling, filling, grading, and otherwise altering natural streams. Natural stream channels eliminated due to anthropogenic activities may be replaced by ditching, native upland habitats, wetlands, or lakes as a result of subsequent reclamation to another land use. Such alterations, combined with corresponding changes in associated land uses have combined to result in the observed long-term changes in water quality within specific watershed drainages.

Stream losses in the Peace River watershed between the 1940s and 1999 totaled 342.7 miles (**Table 4.3**). The largest losses from developed land uses were associated with phosphate mining (101.2 miles), followed by agriculture (64.5 miles), and urban (37.5 miles) land uses. Losses of natural streams were limited primarily to the smaller first and second order streams, rather than the main river channel (third order), although a portion of the Peace River just south of Lake Hancock has been channeled extensively. The greatest loss of natural stream channels occurred in the Lower Coastal Peace basin (77.5 miles), followed by Payne Creek (66.9 miles), Peace River at Bartow (57.8 miles), and Peace River at Zolfo Springs (49.4 miles) (see **Figure 3.1**). Phosphate mining was the largest single land use that occurred in place of former natural stream channels, and accounted for 105.2 miles (29.5 percent) of the absent or channeled stream segments. Phosphate mining accounted for 82 percent and 64 percent, respectively, where stream losses occurred in the Peace River at Zolfo Springs and Payne Creek basins. The largest change of natural stream channels to phosphate mining was in the Payne Creek (54.8 miles) and the Peace River at Zolfo Springs (31.6 miles) basins.

Loss of natural stream channels in now urban land use areas totaled 37.5 miles and made up about 11 percent of the loss. Urban land uses in the place of former natural stream channels was greatest in the Coastal Lower Peace (24.8 miles) basin. Urban land uses replaced 24.8 miles of natural stream channels in the Lower Coastal Peace basin and 8.9 miles in the Peace at Bartow basin, compared with a total of 3.9 miles in the remaining seven basins. Agriculture accounted for 64.5 miles, or 18.8 percent of the natural stream channels lost between the 1940s and 1999, and this replacement ranged from 4.0 acres in the Joshua Creek basin to 9.8 acres in the Peace River at Bartow basin.

4.1.3 Direct Primary Influences on Watershed Water Quality

The two direct primary influences on water quality in the Peace River watershed have historically been attributed to: 1) nutrient inputs and the eutrophication of Lake Hancock and subsequent increased nitrogen loadings to the upper river; and 2) discharges to the river from phosphate mining and processing associated with extensive mining of large tracts of land in the upper basins (PBS&J 1999, Janicki Environmental 2003, PBS&J 2007). More recently increases in ground water discharges from agricultural practices in the southern basins have resulted in increases in both conductivity and associated water quality characteristics (SWFWMD 2004, PBS&J 2007), and nitrogen levels (Janicki Environmental 2003, PBS&J 2007).

Until recently, Lake Hancock, a hypereutrophic lake at the Peace River headwaters (**Figure 3.1**), received nutrient laden effluent directly from a number of industrial and municipal sources. It has been estimated that there is in excess of 12,000 acre-feet of unconsolidated, deep organic muck currently covering the lake bottom. As a result, the water leaving Lake Hancock is typically characterized by: 1) very high concentrations of blue green algae, 2) high turbidity, and 3) elevated organic content that lead to high biological oxygen demand (BOD) and associated low dissolved oxygen concentrations. Champeau (1990) suggested that the degraded water quality of Lake Hancock influences both the diversity and abundance of fishes in the upper reaches of the Peace River. Champeau (1988) observed that degraded water quality is both more frequent and severe in the upstream reaches of the river toward Lake Hancock and suggested that dilution from less impacted tributaries in the middle/lower river might be responsible for improved water quality and resulting increases in fish species richness and diversity in the lower Peace River watershed. He hypothesized that the higher water quality (lower nutrients, lower phytoplankton biomass, and more stable dissolved oxygen conditions) in these tributaries provides habitat for these species that is unavailable along the main stem of the Peace River.

Phosphate mining and processing activities have historically had adverse effects on water quality in the Peace River. Geologically, extensive regions of the Peace River watershed contain Miocene deposits rich in phosphate ore. During the late 1800s, large areas of the river bottom in the northern watershed were directly mined for phosphate ore, followed in the early 1900s by expanded strip mining over areas of the northern Peace River watershed. Much of the early phosphate strip mining occurred in the Hillsborough and Alafia River watersheds, and historically expanded into the upper Peace River watershed during the 1940s. Over time, phosphate mining has continued to move south as the ore reserves in the upper portion of the watershed were reduced (**Figures 4.3** and **4.4**). Historical phosphate mining activities resulted in both degraded water quality and periodic catastrophic fish kills associated with substantial accidental discharges of materials from clay settling areas (**Table 4.4**). However, increasing strict environmental regulations implemented by state and federal governments in the late 1970s dramatically reduced both the occurrence and the severity of these events, and significantly reduced the inputs of phosphorous rich waters directly into the upper Peace River. As a result, while dissolved inorganic phosphorus concentrations in the Peace River and upper Charlotte Harbor are extremely high relative to most other rivers and estuaries, peak levels have declined by as much as an order of magnitude since the early 1980s.

As part of the recent *Peace River Cumulative Impact Study* (PBS&J 2007), time-series and trend analyses were conducted using historically available water quality data collected at a series of long-term monitoring locations (**Table 4.5**) throughout the Peace River watershed by a number of federal, state and local governmental agencies, including the Peace River/Manasota Regional Water Supply Authority. The following tables graphically summarize and compare observed long-term patterns of change over the individual periods-of-record of key water quality characteristic at selected locations throughout the watershed.

- **Table 4.6** – Saddle Creek and Peace River at Bartow
- **Table 4.7** – Peace River at Fort Meade and Zolfo Springs, and Bowlegs Creek
- **Table 4.8** – Payne and Charlie Creeks and Peace River at Arcadia
- **Table 4.9** – Joshua and Horse Creeks
- **Table 4.10** – Prairie and Shell Creeks

Summary – the following summarizes a number of the key findings relative to the differing water quality characteristics and historical pattern changes that have been observed in the Peace River watershed.

- Lake Hancock water quality has been characterized as "poor," based on the Florida Trophic State Index, since at least 1970, and water quality in the lake has been a concern as far back as the 1950s. Florida Department of Environmental Protection (FDEP) has verified the impaired condition of the lake and levels of total nitrogen, total phosphorus, and biological oxygen demand all exceeded the state threshold screening values by considerable amounts. In addition:

1. Inorganic nitrogen is the nutrient that limits algae production in Lake Hancock.

2. Lake sediments are a sink for nitrogen rather than a source.

3. A large portion of the organic nitrogen exported from the lake is a result of nitrogen-fixation by high levels of bluegreen algae concentrations.

- Instances of low dissolved oxygen concentrations are conspicuous in the upstream portions of the Peace River, and both the frequency and downstream extent of low dissolved oxygen levels increase as discharges from Lake Hancock increase. Flows from the lake via Saddle Creek are characteristically high in total suspended solids, total Kjeldahl nitrogen, total organic carbon, and chlorophyll *a*. The high chlorophyll concentrations (algae) and organic material associated with these discharges result in both the very high and low dissolved oxygen levels in the upper Peace River. During periods of high rainfall, discharges from the lake increase, and the low dissolved oxygen conditions are exacerbated.

- Values for a number of other water quality parameters in the upper Peace River have improved noticeably since the 1960s and 1970s following implementation of regulatory measures and changes in phosphate mining practices that eliminated direct processing discharges and reduced other mining related discharges to surface waters. These changes resulted in decreased levels of specific conductivity, total dissolved solids, calcium, magnesium, sulfate, silica, total phosphorus, ortho-phosphate, fluoride and strontium in the upper river.

- Analyses of water quality data suggest that historically high ground water withdrawals and subsequent discharges from mining activities substantially augmented river base flows, and masked the decline of natural spring discharges that followed reductions in ground water levels. Ground water discharges were historically so large that when they were reduced, there was a commensurate increase in the average water color in the upper reaches of the river. Increases in water color may have subsequently reduced the distribution of the submerged aquatic plant *Vallisneria americana* (Tape grass) in the upper river, thereby reducing the availability of this unique fish habitat.

- The tributary basins of the Peace River watershed all show water quality changes attributable to mineralized ground water discharges to surface waters.

- Depending on the basin (and available data), long-term increases are apparent in conductivity, pH, total dissolved solids, calcium, magnesium, sodium, potassium, chloride, silica, and sulfate. Concentrations of many of these water quality parameters were at or near historical highs during the recent 1999-2001 drought. The basins were ranked relative to the magnitude of change in water quality and are listed from largest to smallest changes.

1. Joshua Creek
2. Shell Creek (Prairie Creek and Shell Creek)
3. Horse Creek
4. Payne Creek
5. Charlie Creek

- Ground water discharges in the Payne Creek basin are associated with phosphate mining, electrical power facilities and agriculture. In the other basins, increasing areas of agricultural lands have been transformed to more intensive uses over the past few decades. These intense agricultural uses often rely heavily on ground water for both irrigation and freeze protection. Water in the upper Floridan aquifer is generally more mineralized moving from the northern region of the Peace River watershed toward the south and west. Consequently, relatively similar volumes of Upper Floridan ground water discharged to receiving surface waters in the southern watershed basins can have a greater effect on surface water quality characteristics when compared to discharges in the northern watershed The observed characteristically high conductivity levels (and other water quality constituents) in these southern agricultural dominated basins directly reflect the results of highly mineralized upper Floridan ground water being discharged into these creeks.

- Water quality in a number of the tributary watershed basins that have undergone land use changes to more intense agriculture also show recent increases in inorganic nitrite+nitrate nitrogen concentrations.

- Dissolved inorganic phosphorus concentrations in the lower Peace River/upper Charlotte Harbor Estuary are extremely high when compared to other estuarine systems. However, measured phosphorus levels in the estuary have declined by as much as an order of magnitude since the early 1980s.

- Except for statistically significant long-term declines in phosphorus levels and recent significant increases in silica concentrations, the water quality of the lower Peace River and upper Charlotte Harbor has remain relatively unchanged over the past quarter century.

- There are, however, distinct seasonal differences in a number of water quality characteristics in the lower river and estuary (including salinity, dissolved oxygen, water color, turbidity, phosphorus, nitrogen, organic carbon and chlorophyll *a*) related to differences in flow and/or temperature.

- Phytoplankton levels in the Peace River and Charlotte Harbor during periods of low to moderate freshwater flow are limited by the availability of inorganic nitrogen. However, as flows increase, water color levels correspondingly increase and phytoplankton production in the river and upper harbor are increasingly limited by the ability of light to penetrate the water column.

- Dissolved oxygen concentrations in the lower Peace River/upper Charlotte Harbor Estuary show clear seasonal cycles in response to higher freshwater flows during the summer wet-season. The duration and magnitude of periods of low dissolved oxygen concentrations increase toward the river mouth and harbor as higher bottom salinities establish greater vertical stratification in the water column during high flows. Bottom dissolved oxygen concentrations in upper Charlotte Harbor are characterized by hypoxic (less than 2.0 mg/L) and even anoxic (less than 0.2 mg/L) conditions during extended periods of high flows during the summer wet-season.

4.2 Status and Trends in "Fixed" HBMP Station Water Quality Parameters

Historically, between 1976 and 1987, the HBMP water quality monitoring design included the monthly collection of *in situ* physical measurements of water column profile characteristics at a number of fixed station locations along the lower Peace River and in upper Charlotte Harbor. Under the 1996 water use permit's expansion of the monitoring program, monthly surface and bottom water chemistry data collections were initiated at five fixed sampling locations along an established transect from near the mouth of the river to upstream of the Facility. In addition to these five water quality monitoring sites, i*n situ* physical water column profile sampling was also resumed at an additional ten fixed sampling locations. These water quality sampling and *in situ* water column profile measurements of the HBMP program elements were initiated using sampling sites formerly (1976-1990) utilized by General Development's Environmental Quality Laboratory (EQL) as part of their long-term Peace River/Charlotte Harbor background monitoring program. An additional fixed monthly sampling site was added in 1998 to correspond to the location of the third USGS tide gage that was installed in 1997 at river kilometer (RK) 26.7. The relative locations of these fixed sampling locations were previously described in Chapter 1 (**Figure 1.5)**. **Table 1.4** further provides both the currently used river kilometer centerline designations as well as both the previously used EQL station numbers and USGS sample river mile designations.

Combining the historic EQL background and older HBMP water quality monitoring data with the more recent HBMP monitoring information gathered since 1996 provides both physical *in situ* water column profile information and sub-surface and near-bottom water chemistry data for the complete periods 1976-1989 and 1996-2006 at the five current fixed HBMP water quality sampling locations. These combined data were used in this section to describe the present status as well as statistically test for the presence of long-term changes in the water quality characteristics at these specific selected locations along the lower Peace River HBMP monitoring transect (**Figure 1.5**). Statistical tests for significant trends in mean annual water quality conditions for these fixed lower Peace River sampling locations were analyzed using methods developed by Coastal Environmental (1996) for the Florida Department of Environmental Protection using seasonally weighted yearly averages. In this instance the procedure was used to examine statistical differences (trends) between the two disjunct periods of record.

4.2.1 Gaged Peace River Flow 1976-1989 and 1996-2006

The following analyses were conducted in order to provide comparisons of freshwater inflows over the same two time intervals for which physical and water chemistry are available from the lower river fixed HBMP monitoring locations. Graphical depictions presented in Table 4.11 of differences in daily, monthly mean, and monthly median gaged Peace River flows at three different river locations were selected to incorporate and account for cumulative differences in the major gaged river tributaries. A more extensive discussion of seasonal and long-term hydrological patterns in rainfall and flow were previously presented in **Chapter 3**.

Table 4.11
Gaged Peace River Flow

Gaged Peace River Flow	Daily	Monthly Mean	Monthly Median
Peace River at Arcadia	Figure 4.5	Figure 4.6	Figure 4.7
Total Gaged Flow Upstream of Facility	Figure 4.8	Figure 4.9	Figure 4.10
Total Gaged Flow Upstream of US 41 Bridge	Figure 4.11	Figure 4.12	Figure 4.13

Statistical tests were used to determine seasonally adjusted annual mean and median differences in total gaged flow at each of the three selected Peace River locations over the 1976-1989 and 1996-2006 time intervals. These results are summarized in Table 4.12, and clearly indicate increases in annual mean an median flows at these locations of approximately 300-500 cfs during the recent eleven-year 1996-2006 time period. Annual mean and median flows in each instance were statistically significantly higher during this most recent time interval when compared with the previous 1976-1989 fourteen-year period. Both of the 1976-1989 and 1996-2006 time intervals where characterized by highly variable seasonal and yearly differences in gaged freshwater inflows having extended periods of very high flows during El Niño climatic events, followed by extended unusually dry La Niña rainfall conditions. The major differences in flows between these two time intervals however, as previously discussed in **Chapter 3.4**, seems to correspond with the proposed Atlantic Multidecadal Oscillation (AMO) theory of differences in average summer rainfall resulting from small cycling differences in average surface temperatures in the Atlantic Ocean. The 1976-1990 interval is within the AMO cool/dry phase that is proposed to have extended from 1969 to 1994, while the 1996-2006 interval lies totally within the recent, ongoing warm/wet AMO phase proposed to have initially begun in 1995.

Table 4.12
Trend Tests Gaged Peace River Flow (1976-1990 & 1996-2006)

Gaged Peace River Flow	Monthly Mean	Diff. Means	P Value of Diff.	Monthly Median	Diff. Means	P Value of Diff.
Peace River at Arcadia	Figure 4.14	362.5	0.029	Figure 4.15	336.4	0.022
Total Gaged Flow at Facility	Figure 4.16	430.5	0.043	Figure 4.17	394.1	0.038
Total Gaged Flow at US 41 Bridge	Figure 4.18	536.6	0.043	Figure 4.19	454.5	0.044

* All tests were statistically significant at the 0.05 level

4.2.2 Water Quality Comparisons between 1976-1989 and 1996-2006

Table 4.13 (containing links to Figures 4.20 through 4.119) summarizes both the time-series plots as well as the results of the statistical tests used to determine seasonally adjusted mean annual differences in selected water quality parameters from samples collected monthly at each of the five "fixed" HBMP monitoring locations between the 1976-1989 and 1996-2006 time periods. The results of these analyses indicate both observed short-term seasonal patterns as well as longer-term variations between the two temporal monitoring periods for each of the selected water quality parameters. It should be noted that all of the water quality data over the 1976-1989 time period were analyzed by EQL, while that from the most recent eleven years were sequentially analyzed by the USGS, EQL and Benchmark Laboratories (PBS&J 2004). The time-series and trend test summarized in Table 4.13 were conducted only for those ongoing water quality parameters included through 2006 as part of the existing HBMP. Not included in these analyses were those additional water quality characteristics that had previously been deleted from the monitoring program after consultation with District staff and the Scientific Review Panel. Previous parameters deleted from these ongoing analyses include Turbidity, Total Phosphorus, Total Suspended Solids (TSS), Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC) and Total Inorganic Carbon (IOC).

Table 4.13
Time-Series and Trend Tests
Peace River HBMP Estuary Sites Water Quality (1976-1989 and 1996-2006)

River Kilometer Parameter	Subsurface Values				
	Time-Series	Trend Test	Diff. Means	P Value of Diff.	Change
River Kilometer –2.4					
Salinity (Surface)	Figure 4.20	Figure 4.70	0.44	0.664	
Salinity (Bottom)	Figure 4.21	Figure 4.71	3.27	0.028	▲
Dissolved Oxygen (Surface)	Figure 4.22	Figure 4.72	-0.06	0.754	
Dissolved Oxygen (Bottom)	Figure 4.23	Figure 4.73	-0.23	0.232	
Color	Figure 4.24	Figure 4.74	15.8	0.012	▲
Nitrite + Nitrate Nitrogen	Figure 4.25	Figure 4.75	0.02	0.030	▲
Total Kjeldahl Nitrogen	Figure 4.26	Figure 4.76	-0.03	0.544	
Ortho-Phosphorus	Figure 4.27	Figure 4.77	-0.01	0.781	
Silica	Figure 4.28	Figure 4.78	1.18	0.001	▲
Chlorophyll a	Figure 4.29	Figure 4.79	3.50	0.330	
River Kilometer 6.6					
Salinity (Surface)	Figure 4.30	Figure 4.80	-1.35	0.250	
Salinity (Bottom)	Figure 4.31	Figure 4.81	0.87	0.373	
Dissolved Oxygen (Surface)	Figure 4.32	Figure 4.82	-0.01	0.963	

Table 4.13
Time-Series and Trend Tests
Peace River HBMP Estuary Sites Water Quality (1976-1989 and 1996-2006)

River Kilometer Parameter	Subsurface Values				
	Time-Series	Trend Test	Diff. Means	P Value of Diff.	Change
Dissolved Oxygen (Bottom)	Figure 4.33	Figure 4.83	-0.34	**0.066**	▼
Color	Figure 4.34	Figure 4.84	24.1	0.011	▲
Nitrite + Nitrate Nitrogen	Figure 4.35	Figure 4.85	0.01	0.814	
Total Kjeldahl Nitrogen	Figure 4.36	Figure 4.86	-0.08	0.243	
Ortho-Phosphorus	Figure 4.37	Figure 4.87	-0.11	**0.001**	▼
Silica	Figure 4.38	Figure 4.88	1.54	**0.001**	▲
Chlorophyll *a*	Figure 4.39	Figure 4.89	-1.61	0.547	
River Kilometer 15.5					
Salinity (Surface)	Figure 4.40	Figure 4.90	0.17	0.841	
Salinity (Bottom)	Figure 4.41	Figure 4.91	0.64	0.514	
Dissolved Oxygen (Surface)	Figure 4.42	Figure 4.92	-0.10	0.615	
Dissolved Oxygen (Bottom)	Figure 4.43	Figure 4.93	-0.25	0.188	
Color	Figure 4.44	Figure 4.94	10.14	0.308	
Nitrite + Nitrate Nitrogen	Figure 4.45	Figure 4.95	-0.02	0.418	
Total Kjeldahl Nitrogen	Figure 4.46	Figure 4.96	0.04	0.543	
Ortho-Phosphorus	Figure 4.47	Figure 4.97	-0.417	**0.001**	▼
Silica	Figure 4.48	Figure 4.98	2.19	**0.001**	▲
Chlorophyll *a*	Figure 4.49	Figure 4.99	9.51	0.302	
River Kilometer 23.6					
Salinity (Surface)	Figure 4.50	Figure 4.100	0.24	0.523	
Salinity (Bottom)	Figure 4.51	Figure 4.101	0.19	0.676	
Dissolved Oxygen (Surface)	Figure 4.52	Figure 4.102	0.08	0.764	
Dissolved Oxygen (Bottom)	Figure 4.53	Figure 4.103	0.07	0.763	
Color	Figure 4.54	Figure 4.104	10.64	0.270	
Nitrite + Nitrate Nitrogen	Figure 4.55	Figure 4.105	-0.03	0.555	
Total Kjeldahl Nitrogen	Figure 4.56	Figure 4.106	-0.19	0.169	
Ortho-Phosphorus	Figure 4.57	Figure 4.107	-0.61	**0.001**	▼
Silica	Figure 4.58	Figure 4.108	2.51	**0.001**	▲
Chlorophyll *a*	Figure 4.59	Figure 4.109	1.34	0.606	
River Kilometer 30.4					
Salinity (Surface)	Figure 4.60	Figure 4.110	0.15	**0.029**	▲

Table 4.13
Time-Series and Trend Tests
Peace River HBMP Estuary Sites Water Quality (1976-1989 and 1996-2006)

River Kilometer Parameter	Subsurface Values				
	Time-Series	Trend Test	Diff. Means	P Value of Diff.	Change
Salinity (Bottom)	**Figure 4.61**	**Figure 4.111**	0.17	**0.034**	▲
Dissolved Oxygen (Surface)	**Figure 4.62**	**Figure 4.112**	-0.06	0.792	
Dissolved Oxygen (Bottom)	**Figure 4.63**	**Figure 4.113**	-0.18	0.366	
Color	**Figure 4.64**	**Figure 4.114**	11.4	0.269	
Nitrite + Nitrate Nitrogen	**Figure 4.65**	**Figure 4.115**	-0.07	**0.051**	▼
Total Kjeldahl Nitrogen	**Figure 4.66**	**Figure 4.116**	-0.04	0.400	
Ortho-Phosphorus	**Figure 4.67**	**Figure 4.117**	-0.72	**0.001**	▼
Silica	**Figure 4.68**	**Figure 4.118**	2.58	**0.001**	▲
Chlorophyll *a*	**Figure 4.69**	**Figure 4.119**	2.10	0.436	

* Red ▼ denotes significance at the 0.05 level
* Blue ▼ denotes significance at the 0.10 level

Table 4.14 further summarizes the results of the trend tests presented in Table 4.13 by parameter and location (river kilometer) along the HBMP monitoring transect (**Figure 1.5**). Brief descriptions of the overall results of the graphical and trend analyses for each of the water quality parameters currently monitored in the lower river and upper harbor are additionally presented below.

Table 4.14
Trend Tests Peace River HBMP Estuary Sites Water Quality
(1976-1989 and 1996-2006)

Parameter	River Kilometer				
	-2.3	6.6	15.5	23.6	30.4
Salinity (Surface)					▲
Salinity (Bottom)	▲				▲
Dissolved Oxygen (Surface)					
Dissolved Oxygen (Bottom)		▼			
Color	▲	▲			
Nitrite + Nitrate Nitrogen	▲				▼
Total Kjeldahl Nitrogen					
Total Phosphorus		▼	▼	▼	▼

Table 4.14
Trend Tests Peace River HBMP Estuary Sites Water Quality
(1976-1989 and 1996-2006)

Parameter	River Kilometer				
	-2.3	6.6	15.5	23.6	30.4
Silica	▲	▲	▲	▲	▲
Chlorophyll *a*					

* Red ▲ denotes significance at the 0.05 level
* Blue ▲ denotes significance at the 0.10 level

Salinity (psu) – There is a strong, distinct spatial salinity gradient along the lower Peace River monitoring transect. Salinity levels are much higher (often near Gulf water conditions) in the vicinity of the river mouth and are typically near freshwater levels just upstream of the Water Treatment Facility. The greatest inter-annual variability in salinity generally occurs in the surface waters at the most downstream monitoring sites where seasonal differences may reach 35 parts per thousand between extended periods of low and high freshwater inflow. However, even bottom salinity levels in the area of the US 41 Bridge (RK 6.6) exhibit similar large inter-annual variation. The influences of the recent high freshwater inflows during 1997/1998 El Niño event and the extended 1999-2001 drought are evident in the time-series plots. The graphical and trend analyses show that as a result of the extended periods of low flows during the 1999-2001 and recent 2006 droughts, bottom salinities near the rivers mouth and both surface and bottom salinities near the Facility were on an average annual basis significantly higher during the 1996-2006 interval than between the 1976-1989 sampling period. These results emphasize the influence of such intense seasonal drought conditions, since average annual flows during the more recent eleven year period were significantly higher (see Table 4.12 above).

Dissolved Oxygen (mg/L) – Near-bottom dissolved oxygen concentrations show clear seasonal cycles in response to higher freshwater flows during the summer wet-season. The duration and magnitude of periods of low dissolved oxygen concentrations increase toward the river mouth as higher bottom salinities establish greater vertical stratification in the water column during high flows. Bottom dissolved oxygen concentrations at the two most downstream monitoring stations, located at RK –2.4 and 6.6, are characterized by hypoxic (less than 2.0 mg/L) and even anoxic (less than 0.2 mg/L) conditions during extended periods of high flows during the summer wet-season. Other studies (CHNEP 1999, 2003 and PBS&J 2007) have noted apparent declines in dissolved oxygen concentrations in the lower river over time, but have been unable to clearly identify any cause. Proposed explanations have included: declines in the very high chlorophyll *a* concentrations that were frequently observed during the 1970s and 1980s; influences of higher average flows during more recent time periods; and potentially progressive changes associated with *in situ* dissolved membrane technology and measuring precision. The current analyses, based on a somewhat longer data set than these previous analyses, generally finds similar surface and bottom annual average dissolved oxygen concentrations along the HBMP monitoring transect when comparing the 1976-1989 and 1996-2006 time periods.

Water Color (Pt-Co Units) – Humic compounds derived from the breakdown and subsequent leaching of vegetation into surface waters are the source of the high water color that characterizes the blackwater river systems of southwest Florida. Time-series graphs indicate that color levels temporally increase quickly in response to increased freshwater inflow. Water color concentrations are typically higher farther upstream than near the mouth of the river. Very high color levels, however, can extend well into the harbor during extended periods of high freshwater flows such as occurred during the 1997/1998 El Niño or recently during the extremely high flows that occurred during 2001, 2003, 2004 and 2005. Statistical analyses indicated significant differences between the average annual surface color levels at the two most downstream monitoring locations (RK -2.3 and 6.6) between the 1976-1989 and 1996-200 sampling periods. These differences reflect the higher recent inflows of dark colored water farther down the river and into the upper harbor during the recent period of high flows

Nitrite+Nitrate Nitrogen (mg/L) – Concentration levels and seasonal patterns of dissolved inorganic nitrite+nitrate nitrogen are spatially different among the five HBMP lower Peace River monitoring locations. The time-series plots indicate that inorganic nitrite+nitrate nitrogen levels at the most downstream fixed sampling station (located near the arbitrarily defined river mouth) are typically near or at method detection limits. Salinities are typically high in this region of the estuary and, except during periods of very high river flow, phytoplankton primary production is limited by the availability of inorganic nitrogen (Montgomery et al. 1991). Conversely, during extended periods of high freshwater river flows, surface salinities decline, bringing increased nutrient loading and higher levels of water color that limit the penetration of light into the water column and subsequently reduces phytoplankton growth and nitrogen uptake. By comparison, inorganic nitrogen levels progressively increase moving upstream along the HBMP sampling transect, as dilution by low nutrient/high salinity harbor water declines and higher water color increasingly limits phytoplankton nitrogen uptake. Only during periods of extended low freshwater flow, such as during the spring dry-season, are ambient inorganic nitrogen levels low at the upstream river sampling sites. Differences between the average annual surface dissolved inorganic nitrite+nitrate nitrogen concentrations at four of the five monitoring locations were not statistically significant in comparisons made between the 1976-1989 and 1996-2006 sampling periods. The statistically significant increase in the upper harbor at RK -2.4 matches with the corresponding increase in water color and supports the previous observations that these increases reflect higher inflows of darker (nitrogen rich) freshwater farther downstream into the upper harbor during the recent period of characteristically higher river flows.

Total Kjeldahl Nitrogen (mg/L) – While this gross measurement of combined inorganic ammonia and organic water column nitrogen shows distinct seasonal patterns, spatially the time-series graphics show total Kjeldahl nitrogen levels at all five lower Peace River monitoring locations to be relatively similar. Further, the different applied statistical tests indicated no significant differences between the average annual surface and bottom water column concentrations at any of the five monitoring sites when comparing the 1976-1989 and 1996-2006 time periods.

Ortho-Phosphorus (mg/L) – Probably the most dramatic long-term change in water quality in the lower Peace River is the marked, observed statistically significant long-term decline in dissolved inorganic (and total) phosphorus concentrations (CHNEP 1999, 2003 and PBS&J

1999, 2004, 2007). The lower Peace River/upper Charlotte Harbor estuarine system is naturally high in phosphorus due to the extensive natural phosphate deposits in a number of the major upstream watershed basins. Phosphorus concentrations generally reflect both the spatial and temporal variation in Peace River freshwater inputs. The highest phosphorus concentrations are typically associated with seasonal low river flow, when the influences of ground water are more pronounced. Long-term temporal patterns indicate rapid declines in both the magnitude and variability in phosphorus levels when compared with the first six years of HBMP monitoring. This decline followed implementation in the late 1970s of stricter regulations and subsequent decreases of both point and nonpoint discharges to surface waters from phosphate mining and processing. However, comparisons of the average annual mean phosphorus concentrations between the 1976-1989 and 1996-2006 time periods indicate a continued decline at the HBMP river stations, even though the largest changes occurred prior to 1984. Of particular note however are the results of the presented graphical analyses, which show phosphorus levels throughout the lower Peace River/upper Charlotte Harbor Estuary have dramatically increased following Hurricanes Charley, Francis and Jeanne in August and September of 2004. It is apparent that the historically high flows that occurred in the upper Peace River watershed following this unusual series of events has at least temporarily increased phosphorus concentrations throughout the system to levels not seen for over twenty years.

Silica (mg/L) – Both the long-term time-series plots and the statistical comparisons of mean annual average reactive silica concentrations indicate that silica levels have dramatically increased along the entire length of the lower Peace River monitoring transect between the earlier and later time periods. During the most recent eleven years of HBMP monitoring, silica concentrations at each of the five fixed sampling sites have increased and the range of variability has increased when compared with similar data from the 1976-1989 period. Silica concentrations among the lower river sampling sites also spatially increase upstream. It may be that the observed increases in ambient reactive silica levels in the Peace River estuarine system reflect the cumulative influences of increased ground water use and the expansion of water intense agriculture in the Peace River watershed, or it may be associated with other land use changes occurring upstream in the watershed. The Authority is currently collecting additional dry- and wet-season data at a number of locations throughout the upper watershed in order to be able to better identify potential sources of both apparent increasing silica and phosphorus concentrations.

Chlorophyll *a* (ug/L) – Previous studies (CHNEP 1999, 2003 and PBS&J 1999, 2004, 2007) observed marked declines in the periodic very high chlorophyll *a* concentrations or phytoplankton "blooms" that commonly occurred in the surface waters throughout the lower Peace River/upper Charlotte Harbor estuarine system during the late 1970s and early 1980s. However, the current examination of the data, which extends similar analyses through 2006 indicates that since 2004 chlorophyll *a* levels in the lower river and upper harbor have uniformly shown increases to annual average levels not seen in over twenty years. Following Hurricanes Charley, Francis and Jeanne in August and September of 2004, as previously discussed, water quality data from the lower river show marked increases in ortho-phosphorus levels that correspond with the observed increases in chlorophyll *a*. Since phosphorus levels in the lower Peace River/upper Charlotte Harbor Estuary are naturally high, and nutrient additions (Montgomery et al. 1991) have shown local estuarine phytoplankton populations are seasonally nitrogen and not phosphorus limited, it is doubtful that the observed increases in phosphorus levels are directly the ultimate cause of the observed increases in chlorophyll *a* concentrations. It is more likely that other water quality constituents not monitored by the HBMP, but having the same source as the observed phosphorus increases, are responsible for the observed increases in phytoplankton levels. Overall, the result of the observed historic declines, combined with the recent observed increases, is that there are no statistically significant differences in average annual seasonally weighted mean chlorophyll *a* concentrations between the 1976-1989 and 1996-2006 time intervals at any of the five fixed river kilometer based HBMP monitoring locations. This result demonstrates the inherent difficulty in using most commonly applied statistical trend procedures when evaluating long-term changes in water quality parameters having multiple non-seasonal increasing and decreasing patterns.

4.2.3 Spatial Response of Water Quality Parameters to Levels of Freshwater Inflows

Box and whisker graphical plots were used to depict spatial variations under different flow regimes of ambient sub-surface water quality characteristics at each of the five fixed HBMP Peace River monitoring locations. Univariate plots of selected water quality parameters were compared by river kilometer among the sampling sites under a series of percentile flow based ranges of the preceding seven day average gaged flow (as measured by the USGS Peace River at Arcadia USGS site).

- **Very Low Flows** (0 to 94 cfs) – representative of the lowest ten percent (P10) of river flows during the 1976-2006 time period.
- **Low Flows** (94-171 cfs) – or flows within the P10 to P25 interval.
- **Normal Low Flows** (171-399 cfs) – or flows characteristic of the long-term P25 to P50 (median) range.
- **Normal High Flows** (399 to 1000 cfs) – representative of Peace River Arcadia flows within the P50 (median) to P75 statistical interval.
- **High Flows** (1000 to 3173 cfs) – characterizing river flows in the P75 to P90 range.
- **Very High Flows** (above 3173 cfs) – or the upper ten percent (P90) of all observed flows during the 1976-2006 time period.
- **All Flows –** this final series of univariate box and whisker plots depicts the overall spatial differences and the range of observed variation in each of the water quality parameters without regard to flow.

The graphical results of these analyses are summarized in Table 4.15. The presented flow-based graphics include analyses for some HBMP water quality parameters that were dropped from the monitoring program in 2004 following the finalized recommendations included in the *2002 HBMP Comprehensive Summary Report*.

Table 4.15
Univariate Plots Of Water Quality Parameters Under Differing Flow Categories

Water Quality Parameter	Flow Category – Range in Cubic Feet/Second						
	0 to 94 cfs	94 to 71 cfs	171 to 399 cfs	399 to 1000 cfs	1000 to 3173 cfs	> 3173 cfs	All Flows
Salinity	Figure 4.120	Figure 4.121	Figure 4.122	Figure 4.123	Figure 4.124	Figure 4.125	Figure 4.126
Dissolved Oxygen	Figure 4.127	Figure 4.128	Figure 4.129	Figure 4.130	Figure 4.131	Figure 4.132	Figure 4.133
Water Color	Figure 4.134	Figure 4.135	Figure 4.136	Figure 4.137	Figure 4.138	Figure 4.139	Figure 4.140
Turbidity	Figure 4.141	Figure 4.142	Figure 4.143	Figure 4.144	Figure 4.145	Figure 4.146	Figure 4.147
Nitrite+Nitrate Nitrogen	Figure 4.148	Figure 4.149	Figure 4.150	Figure 4.151	Figure 4.152	Figure 4.153	Figure 4.154
Ammonia/Ammonium Nitrogen	Figure 4.155	Figure 4.156	Figure 4.157	Figure 4.158	Figure 4.159	Figure 4.160	Figure 4.161
Total Kjeldahl Nitrogen	Figure 4.162	Figure 4.163	Figure 4.164	Figure 4.165	Figure 4.166	Figure 4.167	Figure 4.168
Total Phosphorus	Figure 4.169	Figure 4.170	Figure 4.171	Figure 4.172	Figure 4.173	Figure 4.174	Figure 4.175
Silica	Figure 4.176	Figure 4.177	Figure 4.178	Figure 4.179	Figure 4.180	Figure 4.181	Figure 4.182
Total Organic Carbon	Figure 4.183	Figure 4.184	Figure 4.185	Figure 4.186	Figure 4.187	Figure 4.188	Figure 4.189
Dissolved Organic Carbon	Figure 4.190	Figure 4.191	Figure 4.192	Figure 4.193	Figure 4.194	Figure 4.195	Figure 4.196
Chlorophyll *a*	Figure 4.197	Figure 4.198	Figure 4.199	Figure 4.200	Figure 4.201	Figure 4.202	Figure 4.203

Overall, the following patterns and observations can be drawn from the series of graphics presented in Table 4.14 for each of the selected water quality characteristics.

Salinity (psu) – The series of figures clearly depict the progressive changes that occur along the river kilometer based lower Peace River sampling transect as flows increase. Under the lowest flow conditions, brackish water conditions extend upstream well beyond the point of Facility water withdrawals. Conversely, freshwater at the surface can extend downstream to near the river's mouth under conditions of extended periods of freshwater inflow.

Dissolved Oxygen (mg/L) – The plots suggest that as flows increase, upstream surface water dissolved oxygen concentrations may be depressed. As previously discussed, increasing freshwater inflows result in higher ambient water color, which results in reduced penetration of light into the water column and slows phytoplankton growth and consequently the production of oxygen. In addition, water column density stratification increases with increasing flow, especially in the lower reaches of the river. These phenomena, combined with the physical decrease in saturation levels with increasing summer wet-season temperatures, results in the observed changes in surface dissolved oxygen levels with increasing flows in the upper areas of the lower Peace River HBMP transect.

Water Color (Pt-Co Units) – The presented series of graphics clearly depict the distinct patterns and marked changes that occur in water color as freshwater flows increase. The graphics indicate that under low Peace River flows much of the water coming from the watershed originates from sources having low color levels, such as surficial base flows and discharges of deeper aquifer waters associated with agricultural pumping. Color levels under such low flow conditions are the highest near the reach of the lower river where drainage from the Lettuce Lake system enters the Peace River from the east, suggesting localized ungaged drainage may be an important source of color in this reach of the river when flows are low. The series of figures show that as flows increase, typical southwest Florida “blackwater” river inflows are a major influence on the lower Peace River/upper Charlotte Harbor estuarine system.

Turbidity (NTU) – As indicated, lower Peace River turbidity levels are generally low and levels do not increase in response to higher levels of freshwater flows, since the relatively slow moving major blackwater Peace River watershed tributaries do not carry large amounts of either silt or clay. The data do show indications of a turbidity maxima generally within the middle reach of the lower river approximately between river kilometers five and fifteen, coinciding with the region of the lower river where the chlorophyll *a* maxima is often observed.

Nitrite+Nitrate Nitrogen (mg/L) – The observed changes in the spatial patterns of inorganic dissolved nitrite+nitrate nitrogen clearly show that initially higher ambient concentrations occur in the upper river under conditions of increasing levels of freshwater inflow. However, concentrations actually decline during periods of very high river flow, when ground water levels are near the surface causing surface water runoff (sheetflow) to rapidly move water into the watershed’s tributaries. These figures also show that dissolved inorganic nitrogen concentrations in the downstream more saline reaches of the monitoring transect are at or near detection limits except during periods of very highest freshwater inflow.

Ammonia/Ammonium Nitrogen (mg/L) – Ammonia/ammonium nitrogen concentrations spatially increase and high spikes occur at the downstream HBMP monitoring sites during periods of high river flow, probably reflecting salinity stratification induced development of hypoxic/anoxic bottom water conditions.

Total Kjeldahl Nitrogen (mg/L) – Spatially total Kjeldahl nitrogen concentrations (which measures both organic nitrogen and inorganic ammonia) along the HBMP fixed station monitoring transect generally show increasing patterns both moving upstream and with increasing levels of freshwater inflow.

Ortho-Phosphorus (mg/L) – The observed patterns and response of ortho-phosphorus to increasing flows in the lower Peace River estuarine system is very similar to that exhibited by inorganic nitrite+nitrate nitrogen. Concentrations progressively increase upstream towards the freshwater source, and initially rise in response to higher levels of freshwater inflow. However, as freshwater flows increase further and surface water runoff begins to provide an ever greater percentage of total river flow, the actual concentration of ortho-phosphorus (which is usually more than ninety percent total phosphorus) declines.

Silica (mg/L) – The observed spatial pattern of reactive silica within the lower Peace River estuarine system reflects the influences of freshwater inflows. Seasonally, as freshwater inflows become greater, ambient reactive silica concentrations are shown to both increase and move further downstream into the upper Harbor.

Dissolved and Total Organic Carbon (mg/L) – The series of box and whisker plots of both dissolved and total organic carbon concentrations show very similar spatial patterns and responses to changes in levels of freshwater inflow. On average organic carbon levels generally increase both upstream and in response to higher levels of freshwater inflow.

Chlorophyll *a* (mg/m^3) – Other studies (PBS&J 1999, 2002, 2004) have shown that chlorophyll *a* along the lower Peace River HBMP monitoring transect exhibits distinct spring and fall increases that are influenced by both the timing and amounts of freshwater inflow into the river estuarine system. The presented box and whisker plots indicate that normally there is a distinct chlorophyll *a* phytoplankton maxima that spatially occurs along the monitoring transect. The location of this maximum generally moves downstream as river flow increases. These seasonal patterns are the combined result of a number of factors associated with increasing freshwater flows. Higher flows reduce residence time and increase inorganic nitrogen loading that simulates phytoplankton production, while at the same time higher color levels simultaneously reduce the ability of light to penetrate the water column and diminishes phytoplankton growth.

4.2.3.1 Response of Water Quality Parameters by Sampling Site to Changes in Freshwater Flows

Plots of sub-surface measurements of the selected water quality parameters versus the preceding seven day average gaged Peace River at Arcadia flow (0 to 3000 cfs) are presented in Table 4.16. These graphical analyses provide additional support to the previously described responses of the selected water quality parameters to seasonal changes in freshwater inflow at each of the fixed sampling locations along the long-term HBMP monitoring transect (**Figure 1.5**).

Table 4.16
Water Quality Parameters Versus Flow

Water Quality Parameter	Monitoring Station River Kilometer				
	-2.2	6.6	15.5	23.6	30.4
Salinity	Figure 4.204	Figure 4.205	Figure 4.206	Figure 4.207	Figure 4.208
Dissolved Oxygen	Figure 4.209	Figure 4.210	Figure 4.211	Figure 4.212	Figure 4.213
Water Color	Figure 4.214	Figure 4.215	Figure 4.216	Figure 4.217	Figure 4.218
Turbidity	Figure 4.219	Figure 4.220	Figure 4.221	Figure 4.222	Figure 4.223
Nitrite+Nitrate Nitrogen	Figure 4.224	Figure 4.225	Figure 4.226	Figure 4.227	Figure 4.228
Ammonia Nitrogen	Figure 4.229	Figure 4.230	Figure 4.231	Figure 4.232	Figure 4.233
Total Kjeldahl Nitrogen	Figure 4.234	Figure 4.235	Figure 4.236	Figure 4.237	Figure 4.238
Total Phosphorus	Figure 4.239	Figure 4.240	Figure 4.241	Figure 4.242	Figure 4.243
Silica	Figure 4.244	Figure 4.245	Figure 4.246	Figure 4.247	Figure 2.248
Total Organic Carbon	Figure 4.249	Figure 4.250	Figure 4.251	Figure 4.252	Figure 4.253
Dissolved Organic Carbon	Figure 4.254	Figure 4.255	Figure 4.256	Figure 4.257	Figure 4.258
Chlorophyll *a*	Figure 4.259	Figure 4.260	Figure 4.261	Figure 4.262	Figure 4.263

Correlations were further used to assess potential statistical differences in the relationships between differing rates of seven day average gaged flow (Peace River at Arcadia) and the selected surface water quality characteristics at each of the five fixed HBMP sampling sites spatially distributed along the lower river monitoring transect. The same seven statistically based river flow groupings described above in Section 4.3.3 were used to test for differences in correlations, and the summary results are presented in the following series of summary tables. Presented in these tables, for each location and flow category, are the number of available observations (N), the resulting correlation coefficient (R value), and the level of significance (P). In evaluating these results, it should be remembered that the relative degree of variability (percent) explained for each water quality parameter (the dependent variable) by changes in flow (the independent variable) is actually the correlation coefficient squared or R^2.

- **Table 4.17** (River Kilometer –2.2)
- **Table 4.18** (River Kilometer 6.6)
- **Table 4.19** (River Kilometer 15.5)
- **Table 4.20** (River Kilometer 23.6)
- **Table 4.21** (River Kilometer 30.4)

The following briefly summarizes some of the apparent patterns and primary conclusions resulting from the presented analytical comparisons between the measured variability of water quality characteristics in the lower river/upper harbor estuarine system and Peace River at Arcadia gaged freshwater inflows.

Salinity (psu) – There is a distinct inverse relationship between measured surface salinities and increases in gaged flow up to 3000 cfs at the most downstream fixed sampling site, located near the river's mouth. However, similar relationships increasingly break down further upstream with increasing flows as salinities along the HBMP lower river monitoring transect change from being tidally brackish to always being characteristically freshwater under conditions of increasing freshwater flows.

Dissolved Oxygen (mg/L) – The results generally show that surface dissolved oxygen concentrations along the monitoring transect initially increase under increasing low to moderately levels of flow. However, above some level, further increases in flow tend to progressively depress ambient surface dissolved oxygen levels at each of the fixed locations along the HBMP monitoring transect. As previously discussed, initially increased flows result in nitrogen stimulation of phytoplankton production within the lower Peace River estuarine system. However, at some level additional increases in water color associated with higher flows result in marked reductions in light penetration of the water column and the phytoplankton compensation depth, resulting in reduced dissolved oxygen production. The relationship between dissolved oxygen concentrations and flow is further confounded by the combined influences of seasonal changes in water temperature and salinity as shown in **Figure 4.264**.

Water Color (Pt-Co Units) – Somewhat analogous to the previously described spatially divergent responses of surface salinities to increases in freshwater flows, levels of water color at the downstream fixed monitoring sites show steady increases in color levels under ever higher rates of freshwater inflow. Further upstream, however, at some point additional increases in flow do not correspond to higher levels in ambient water color. Under conditions of extremely high flows, color levels actually in some regions of the lower river begin to decline as the contact time of sheet flow is reduced and previous built up humic compounds are increasingly flushed from the watershed.

Nitrite+Nitrate Nitrogen (mg/L) – The spatial relationships between dissolved inorganic nitrogen concentration and rates of freshwater inflow are complex, as shown in **Figures 4.224** through **4.228**. As flows gradually increase following the typical spring dry-season, increasing nitrogen loadings stimulate estuarine phytoplankton production and ambient inorganic nitrogen levels often remain near or at detection limits throughout much of the lower Peace River estuarine system. However, as flows further increase, upstream phytoplankton primary production become color rather than nitrogen limited and inorganic nitrogen levels rapidly rise with increasing flows. A third condition then occurs at the upstream HBMP sampling locations as both water color and nutrient levels start to decline with further increases in flow. Such changes again reflect seasonal changes in the water quality characteristic of sheet flow to the watershed's major tributaries following longer (and/or higher) amounts of rainfall.

Ortho-phosphorus (mg/L) – Concentrations in the downstream more marine areas of the upper harbor generally show steady increasing levels with higher flows. However upstream, in the more freshwater reaches of the river, phosphorus concentrations are typically very high and then rapidly decline as freshwater flows increase and surface water runoff rather than ground water steadily provides an ever greater percentage of total river flow.

Silica (mg/L) – Silica levels in the higher salinity waters of the upper harbor under low flows are often very low. Ambient concentrations initially rapidly rise throughout the lower river/upper harbor estuarine system as freshwater inflows increase. Following this marked initial rise however, silica concentrations then remain relatively similar as flows further increase.

Chlorophyll *a* (mg/m^3) – Initially higher flows increase inorganic nitrogen loading, which simulates phytoplankton production both in the lower river and upper harbor. However, further higher flows also increase color levels in the estuary reducing the ability of light to penetrate the water column, thus simultaneously diminishing phytoplankton growth rates. Residence time is also reduced as flows increase resulting in phytoplankton (chlorophyll) increasingly being "flushed out" of the lower river.

4.2.4 Spatial Correlations among Water Quality Characteristics

A second series of correlation analyses were conducted to test for potential relationships among the previously selected water quality parameters at each of the five fixed spatial HBMP sampling locations along the lower Peace River monitoring transect. Matrices of the results of these correlation tests are presented in the following series of summary tables. The first value for each comparison indicates the available number of observations. The second value is the correlation coefficient (R), while the final value indicates the level of significance (P). Caution should be used interpreting these correlation results since two parameters may show a significant correlation only because they are both highly related to a third (such as salinity), which as discussed may have varying responses to seasonal changes in freshwater inflows. Also, as a result of the high number of observations, the correlation analyses can indicate a high level of statistical significance for relationships with very small correlation. Again, the relative degree of variability (percent) explained for each water quality parameter (the dependent variable) by changes in flow (the independent variable) is actually the correlation coefficient squared or R^2.

- **Table 4.22** (River Kilometer –2.2)
- **Table 4.23** (River Kilometer 6.6)
- **Table 4.24** (River Kilometer 15.5)
- **Table 4.25** (River Kilometer 23.6)
- **Table 4.26** (River Kilometer 30.4)

4.3 Status and Trends in "Moving" Isohaline-Based Station Water Quality Parameters

The initial 1976 HBMP monitoring design incorporated *in situ* water column profiles at a series of twenty "fixed" sampling site locations, extending from near the mouth of Charlotte Harbor (**Figure 4.265**) to upstream on the lower Peace River, past the Facility, to the point where Horse Creek flows into the lower Peace River (**Figure 4.266**). In 1983, the Environmental Quality Laboratory undertook monthly monitoring of phytoplankton primary productivity and water quality measurements at four salinity-based "moving" isohalines in addition to General Development's lower Peace River/Charlotte Harbor general background monitoring programs. The selection of the salinity-based sampling zones was originally established on a literature review of known spatial estuarine differences among the major plankton groups.

- Oligohaline Conditions = 0 psu (defined as upstream of 500 us/cm conductivity
- Lower Mesohaline = 5-7 psu
- Upper Mesohaline = 11-13 psu
- Upper Brackish = 20-22 psu

This moving station, salinity-based water quality sampling program element was subsequently added to the HBMP in 1987 in conjunction with other program modifications made during renewal of the water use permit. The monthly moving isohaline based sampling has been included as part of the HBMP since that time, thus complete, continuous data are available over the 1983-2006 time interval. The initial objective of the isohaline based monitoring HBMP program element was to develop a thorough understanding of the processes controlling phytoplankton production within Charlotte Harbor in order to quantify the estuary's immediate and long-term responses to both seasonal and long-term changes in freshwater flows and nutrient inputs. Phytoplankton production generally represents an immediately available food resource, and is the largest single component of primary production directly accessible to grazing, filtering and detrital feeding organisms. Phytoplankton production and composition, due to the short generation times involved, have been shown to be effective in demonstrating seasonal and long-term changes in water quality, and have been used to provide information on both direct and predictive secondary impacts of external influences such as freshwater withdrawals.

Statistically comparable levels of phytoplankton ^{14}C fixation rates were measured monthly at each of the four salinity-based isohaline locations between June 1983 and December 1999. Although, direct *in situ* measurements of phytoplankton carbon uptake rates are no longer being measured, monthly determinations continue to be made at the four isohaline locations for phytoplankton biomass (chlorophyll *a*), physical water quality parameters, water column light extinction, and near surface measurements for the same series of chemical constituents used in the fixed station HBMP design. The four sampling locations in this study represent non-fixed surface salinity zones, such that the relative monthly spatial location of each isohaline sampling site along the HBMP monitoring transect (**Figure 1.5**) is largely dependent upon the preceding amounts of freshwater Peace River inflow. Table 4.27 summarizes the historical statistical distributions of the four isohalines along the HBMP Peace River monitoring transect.

Table 4.27
Summary Statistics of the Four Isohaline Locations (River Kilometers) from the Peace River's Mouth for the Period 1983-2006

Isohaline	Minimum (Downstream)	Maximum (Upstream)	Mean	Median
0 psu	0.6	37.6	21.5	20.5
6 psu	-16.3	28.3	12.3	12.1
12 psu	-30.1	25.0	7.3	8.7
20 psu	-36.3	21.0	-0.1	2.7

Note: previous HBMP reports have used the units "o/oo", however, equivalent practical salinity units (psu) are currently used to distinguish between salinity determined by *in situ* conductivity rather than wet chemistry.

The Peace River Water Treatment Facility is located at approximately RK 29.9. To date, the most upstream occurrence of the 0 psu isohaline sampling location has been just over a quarter mile upstream of the point were Horse Creek joins the Peace River during June 2000. The most downstream occurrence of the 20 psu isohaline sampling location has been in the Gulf of Mexico just off Boca Grande during September 1988 (**Figure 4.267**).

4.3.1 Gaged Peace River Flow 1983-2006

Time-series plots of daily and monthly mean and median Peace River flows over the 1983-2006 HBMP isohaline-based monitoring period are presented in Table 4.28 at three locations that account for the differing contributions of the river's major downstream tributaries (see **Chapter 3**). Box plots are also presented depicting the average annual monthly hydrograph of mean and median gaged flows for each of these three points along the river.

Table 4.28
Gaged Peace River Flow

Combined Peace River Gaged Flows	Time-Series Plots			Seasonal Box Plots	
	Daily	Monthly Mean	Monthly Median	Monthly Mean	Monthly Median
Peace River at Arcadia	Figure 4.268	Figure 4.269	Figure 4.270	Figure 4.271	Figure 4.272
Total Gaged Flow at Facility	Figure 4.273	Figure 4.274	Figure 4.275	Figure 4.276	Figure 4.277
Total Gaged Flow at US 41 Bridge	Figure 4.278	Figure 4.279	Figure 4.280	Figure 4.281	Figure 4.282

Two different statistical methods were used to test for the potential presence of systematic changes (trends) in gaged flows at each of these three Peace River locations over the 1983-2006 time interval. The initial statistical method applied was that developed by Coastal Environmental (see previous fixed station HBMP analysis). These statistical procedures were used to determine potential significant trends in seasonally adjusted mean annual total gaged flows at each of these points along the Peace River between 1983 and 2006.

Long-term continuous historical daily records are available for each of the major gaged lower Peace River tributaries (**Chapter 3**). Therefore, the more commonly used nonparametric, distribution-free Seasonal Kendall Tau statistical procedure was also used to test for the presence of significant trends in seasonally adjusted monthly gaged river flows at these locations over the twenty-three years of HBMP isohaline-based monitoring. This Seasonal Kendall Tau statistic is based on the differences among all possible seasonal (monthly) data pairs, thus representing the net direction of movement of the time-series data. The number of positive differences minus the number of negative differences is then determined and used to determine the Mann-Kendall Tau test statistic. If the time-series data are systematically increasing (decreasing), then the test statistic will be a positive (negative) number. However, if differences over time are negligible, then the number of positive pairs and the number of negative pairs will be approximately equal, and the test statistic will be small in absolute value. The Tau estimator can thus be viewed as an estimate of the median slope from the set of slopes estimated for the lines connecting all possible pairs of data. This statistical procedure is particularly applicable to data (such as flows and water quality in southwest Florida) that are characterized by strong seasonal patterns.

The results of these statistical trend procedures using mean annual and monthly flows are summarized in Table 4.29, while Table 4.30 presents analogous trend tests results using median monthly gage flows at each of the three selected locations. Probability (P) values calculated both unadjusted and adjusted for serial autocorrelations are presented for the Seasonal Kendall Tau results.

Table 4.29
Trend Tests of Gaged Annual Monthly Mean Peace River Flow 1983-2006

Gaged Peace River Flow Locations	Seasonally Adjusted Annual Means			Seasonal Kendall Tau of Monthly Means			
	Monthly Mean	Slope	P Value	Tau Value	Un- Adj. P	Adjusted P	Slope
Peace River at Arcadia	Figure 4.283	27.9	0.003	0.06	0.163	0.518	4.89
Total Gaged Flow at Facility	Figure 4.284	35.6	0.005	0.06	0.146	0.493	6.73
Total Gaged Flow at US 41 Bridge	Figure 4.285	41.4	0.012	0.06	0.127	0.460	7.59

Table 4.30
Trend Tests of Gaged Monthly Median Peace River Flow 1983-2006

Gaged Peace River Flow Locations	Seasonally Adjusted Annual Medians			Seasonal Kendall Tau of Monthly Medians			
	Monthly Median	Slope	P Value	Tau Value	Un- Adj. P	Adjusted P	Slope
Peace River at Arcadia	Figure 4.286	25.7	0.004	0.05	0.237	0.585	3.00
Total Gaged Flow at Facility	Figure 4.287	31.9	0.007	0.05	0.197	0.544	4.60
Total Gaged Flow at US 41 Bridge	Figure 4.288	36.2	0.018	0.05	0.210	0.543	5.81

The two differing trend testing procedures, the Coastal Environmental (1996) method that utilizes seasonally adjusted "annual" determinations, and the Seasonal Kendall Tau procedure that is based on paired comparisons of seasonally adjusted "monthly" values, indicate somewhat differing results over the twenty-four year interval between 1983 and 2006. Both methods indicate relatively similar increasing slopes calculated on either an annual or monthly basis. However, these changes were found to be statistically significant when evaluated annually, but not so when calculated monthly. These divergent findings are not too surprising given the previous results presented in **Chapter 3** that indicated that the higher annual flows since 1995 have primarily resulted from differences during the typical four month summer wet-season, while flows during the other eight months of the year have remained relatively unchanged. Thus it might be expected that the Seasonal Kendall Tau procedure based monthly levels and looking for overall comparisons for progressive changes (accounting for seasonal variations) might not be as sensitive to the observed annual increases primarily limited to only a few months.

The important factor to be remembered is that over the 1983-2006 period of the isohaline-based HBMP monitoring program, there has been a pattern of increasing summer wet-season flows. This long-term pattern needs to be incorporated in assessing any corresponding potential changes in observed water quality measurements along the lower Peace River/upper Charlotte Harbor monitoring transect.

4.3.2 Relative Isohaline Location

Time-series plots of the monthly long-term relative locations of each of the four monitored "moving" isohaline HBMP salinity zones are presented in Table 4.31. Corresponding box and whisker plots depicting the seasonal monthly variability of each of these salinity zones are also included. These figures clearly indicate the large degree of both inter-annual and seasonal variability that has occurred in the relative locations of the monitored isohalines along the established lower Peace River/upper Charlotte Harbor river kilometer transect. As shown above in Table 4.27, seasonal and long-term extreme variations in estuarine freshwater inflows have resulted in variations as much as 35 to 55 kilometers in the relative spatial distributions of the four isohalines.

Table 4.31
Long-term and Seasonal Variability of Estuarine Isohaline Zones

Isohaline	Time-Series Plot	Box Plot of the Monthly Variability
0 psu Salinity - First Upstream Occurrence	Figure 4.289	Figure 4.293
6 psu Salinity – First Downstream Occurrence	Figure 4.290	Figure 4.294
12 psu Salinity – First Downstream Occurrence	Figure 4.291	Figure 4.295
20 psu Salinity – First Downstream Occurrence	Figure 4.292	Figure 4.296

The statistical Coastal Environmental method of testing seasonally adjusted annual averages and the monthly Seasonal Kendall Tau statistical procedure were used to test for potential trends in the locations of each of the four monitored "moving" isohaline-based HBMP monitored salinity zones between 1984 and 2006. Summary results of these trend analyses are presented Table 4.32.

(Note: The presented time-series plots for the moving isohaline-based salinity zones start in June 1983 coinciding with the beginning of monitoring, while January 1984 was used as the starting point for all statistical trend analyses. The initial seven months in 1983 were not included in order to incorporate twelve months of data having equal numbers of seasons within each of the subsequent twenty-three years analyzed.)

Table 4.32
Trend Tests of Isohaline Locations 1984-2006

Salinity-Based Isohaline Location	Seasonally Adjusted Annual Means			Seasonal Kendall Tau of Monthly Means			
	Monthly Mean	Slope	P Value	Tau Value	Un- Adj. P	Adjusted P	Slope
0 psu Salinity - First Upstream Occurrence	Figure 4.297	0.09	0.100	0.05	0.260	0.602	0.07
6 psu Salinity – First Downstream Occurrence	Figure 4.298	-0.05	0.221	-0.03	0.502	0.744	-0.03
12 psu Salinity – First Downstream Occurrence	Figure 4.299	-0.05	0.387	-0.01	0.813	0.907	-0.01
20 psu Salinity – First Downstream Occurrence	Figure 4.300	-0.02	0.771	0.02	0.620	0.811	0.03

The results of the trend tests using both the Coastal Environmental seasonally adjusted annual means and the Seasonal Annual Kendall Tau monthly means procedures fail to find statistically significant pattern of progressive change between 1984 and 2006 in the relative spatial distributions of any of the four isohaline locations along the HBMP monitoring transect. The extended 1999-2002 drought affected rainfalls and river flows throughout southwest Florida, and the influences of this drought are evident in the observed changes in the relative locations of the HBMP isohalines during this interval. The relative overall degree of upstream movement of the freshwater/saltwater interface (0 psu) is especially noticeable in **Figure 4.297**. The long-term pattern of relatively high summer flows (see above and **Chapter 3**) during the past decade has also resulted in some indication (although not statistically significant) of an overall downstream movement in the 6 and 12 psu intermediate salinities.

4.3.3 Water Quality Characteristics

Time-series plots of monthly water quality parameters collected from sub-surface samples at each of the four moving HBMP monitoring locations between 1983 and 2006 are presented in Table 4.33. Box and whisker plots showing annual monthly seasonal differences are summarized in Table 4.34. These graphical procedures provide overviews of the seasonal ranges and long-term patterns for each of the ongoing HBMP isohaline-based water quality parameters. The presented figures depict the relative degrees of both annual and inter-annual variability observed over the twenty-four years within each of the four selected salinity zones along the lower Peace River/upper Charlotte Harbor estuarine monitoring transect. All water quality data from 1983 through 2001 were analyzed by EQL, while water chemistry data since then have been analyzed by Benchmark Laboratories.

Table 4.33
Time-Series Plots of Surface Water Quality Parameters at Isohaline-Based "Moving" HBMP Monitoring Salinity Zones

Water Quality Parameter	0 psu Salinity First Upstream Occurrence	6 psu Salinity First Downstream Occurrence	12 psu Salinity First Downstream Occurrence	20 psu Salinity First Downstream Occurrence
Dissolved Oxygen	Figure 4.301	Figure 4.302	Figure 4.303	Figure 4.304
Water Color	Figure 4.305	Figure 4.306	Figure 4.307	Figure 4.308
Nitrite+Nitrate	Figure 4.309	Figure 4.310	Figure 4.311	Figure 4.312
Total Kjeldahl Nitrogen	Figure 4.313	Figure 4.314	Figure 4.315	Figure 4.316
Ortho-phosphorus	Figure 4.317	Figure 4.318	Figure 4.319	Figure 4.320
Silica	Figure 4.321	Figure 4.322	Figure 4.323	Figure 4.324
Chlorophyll *a*	Figure 4.325	Figure 4.326	Figure 4.327	Figure 4.328

Table 4.34
Box Plots of Annual Monthly Seasonal Patterns of Surface Water Quality Parameters at each of the Isohaline Monitoring Locations

Water Quality Parameter	0 psu Salinity First Upstream Occurrence	6 psu Salinity First Downstream Occurrence	12 psu Salinity First Downstream Occurrence	20 psu Salinity First Downstream Occurrence
Dissolved Oxygen	Figure 4.329	Figure 4.330	Figure 4.331	Figure 4.332
Water Color	Figure 4.333	Figure 4.334	Figure 4.335	Figure 4.336
Nitrite+Nitrate	Figure 4.337	Figure 4.338	Figure 4.339	Figure 4.340
Total Kjeldahl Nitrogen	Figure 4.341	Figure 4.342	Figure 4.343	Figure 4.344
Ortho-phosphorus	Figure 4.345	Figure 4.346	Figure 4.347	Figure 4.348
Silica	Figure 4.349	Figure 4.350	Figure 4.351	Figure 4.352
Chlorophyll *a*	Figure 4.353	Figure 4.354	Figure 4.355	Figure 4.356

The two previously applied Coastal Environmental and Seasonal Kendall Tau statistical procedures, which are respectively based on annual and monthly variability, were again used to test for the potential presence of long-term systematic changes in these selected water quality characteristics at each estuarine isohaline location. Detailed results are presented in Table 4.35, while Table 3.36 graphically summarizes and contrasts the overall results among the four HBMP salinity based isohalines.

Table 4.35
Trend Tests of Isohaline Water Quality Characteristics

Salinity Based Isohaline Location	Seasonally Adjusted Annual Means			Seasonal Kendall Tau of Monthly Means			
	Yearly Mean	Slope	P Value	Tau Value	Un- Adj. P	Adjusted P	Slope
0 psu Salinity First Upstream Occurrence							
Dissolved Oxygen	Figure 4.357	0.15	0.001	0.16	0.001	0.001	0.04
Water Color	Figure 4.358	1.90	0.002	0.12	0.004	0.062	1.50
Nitrite + Nitrate	Figure 4.359	-0.01	0.502	-0.07	0.116	0.249	0.01
Total Kjeldahl Nitrogen	Figure 4.360	0.01	0.067	0.06	0.200	0.519	0.01
Ortho-phosphorus	Figure 4.361	-0.01	0.206	-0.13	0.003	0.153	-0.01
Silica	Figure 4.362	0.15	0.001	0.34	0.001	0.001	0.12
Chlorophyll *a*	Figure 4.363	0.06	0.501	0.03	0.549	0.746	0.02
6 psu Salinity First Upstream Occurrence							
Dissolved Oxygen	Figure 4.364	0.03	0.066	0.11	0.008	0.042	0.03
Water Color	Figure 4.365	1.98	0.001	0.18	0.001	0.015	1.67
Nitrite+Nitrate	Figure 4.366	-0.01	0.191	-0.14	0.002	0.016	0.01
Total Kjeldahl Nitrogen	Figure 4.367	-0.01	0.852	0.04	0.368	0.626	0.01
Ortho-phosphorus	Figure 4.368	-0.01	0.661	-0.13	0.002	0.150	0.01
Silica	Figure 4.369	0.12	0.001	0.35	0.001	0.001	0.09
Chlorophyll *a*	Figure 4.370	0.06	0.791	0.05	0.230	0.267	0.12
12 psu Salinity First Upstream Occurrence							
Dissolved Oxygen	Figure 4.371	0.04	0.038	0.08	0.078	0.250	0.03
Water Color	Figure 4.372	2.19	0.001	0.29	0.001	0.001	1.69
Nitrite+Nitrate	Figure 4.373	-0.01	0.768	-0.02	0.675	0.729	0.01

Table 4.35
Trend Tests of Isohaline Water Quality Characteristics

Salinity Based Isohaline Location	Seasonally Adjusted Annual Means			Seasonal Kendall Tau of Monthly Means			
	Yearly Mean	Slope	P Value	Tau Value	Un- Adj. P	Adjusted P	Slope
Total Kjeldahl Nitrogen	Figure 4.374	0.01	0.776	0.03	0.542	0.731	0.01
Ortho-phosphorus	Figure 4.375	-0.01	0.535	-0.11	0.008	0.231	0.01
Silica	Figure 4.376	0.10	0.001	0.37	0.001	0.001	0.08
Chlorophyll *a*	Figure 4.377	1.00	0.159	0.09	0.033	0.104	0.20
20 psu Salinity First Upstream Occurrence							
Dissolved Oxygen	Figure 4.378	0.02	0.048	0.02	0.608	0.732	0.01
Water Color	Figure 4.379	1.76	0.001	0.34	0.001	0.001	1.29
Nitrite+Nitrate	Figure 4.380	0.01	0.358	0.19	0.001	0.012	0.01
Total Kjeldahl Nitrogen	Figure 4.381	-0.01	0.275	-0.04	0.356	0.663	0.01
Ortho-phosphorus	Figure 4.382	0.01	0.115	-0.01	0.831	0.930	0.01
Silica	Figure 4.383	0.10	0.001	0.38	0.001	0.001	0.07
Chlorophyll *a*	Figure 4.384	0.21	0.181	0.14	0.002	0.036	0.19

Table 4.36
Summary of Trend Tests of Surface Water Quality Parameters
HBMP Moving Isohaline-Based Monthly Monitoring (1984-2006)

Parameter	Salinity Zone							
	0 psu		6 psu		12 psu		20 psu	
	Yearly	Monthly	Yearly	Monthly	Yearly	Monthly	Yearly	Monthly
River Kilometer	▲ (blue)							
Dissolved Oxygen	▲ (red)	▲ (red)	▲ (blue)	▲ (red)	▲ (red)		▲ (red)	
Color	▲ (red)	▲ (blue)	▲ (red)	▲ (red)	▲ (red)	▲ (red)	▲ (red)	▲ (red)
Nitrite + Nitrate Nitrogen				▼ (red)				▲ (red)
Total Kjeldahl Nitrogen	▲ (blue)							

Table 4.36
Summary of Trend Tests of Surface Water Quality Parameters
HBMP Moving Isohaline-Based Monthly Monitoring (1984-2006)

Parameter	Salinity Zone							
	0 psu		6 psu		12 psu		20 psu	
	Yearly	Monthly	Yearly	Monthly	Yearly	Monthly	Yearly	Monthly
Total Phosphorus								
Silica	▲ (red)	▲ (red)	▲ (red)	▲ (red)	▲ (red)	▲ (red)	▲ (red)	▲ (red)
Chlorophyll *a*						▲ (blue)		▲ (red)

* Red ▲ denotes significance at the 0.05 level
* Blue ▲ denotes significance at the 0.10 level

The following briefly summarizes the results and primary conclusions that can be drawn from the observed annual, inter-annual and long-term patterns over the extended period of monitoring for each of the selected water quality parameters within the four salinity zones selected along the lower Peace River/upper Charlotte Harbor estuarine system.

Dissolved Oxygen (mg/L) – Dissolved oxygen levels in the lower Peace River estuarine system show distinct seasonal patterns, with the lowest levels typically occurring during the summer wet-season. Even near the top of the water column dissolved oxygen concentrations are often below State of Florida standards (5 mg/L for freshwater and 4 mg/L for predominantly estuarine/marine). Measured levels are generally higher during cooler months, due to lower water temperatures (that increase the ability of the water to hold more dissolved gases) and seasonally increasing wind stress and mixing. Higher daytime values are also often associated with increases in phytoplankton production (chlorophyll *a*) and typically account for many of the unusually high observed values. Unlike the dissolved oxygen data from the fixed HBMP monitoring stations, observations from the moving, isohaline-based sites indicate that measured dissolved oxygen levels have actually progressively increased over time. A potential mechanism that might explain these apparent increases may be related to the previously discussed higher summer freshwater inflows. Increases in summer flows result in higher average nutrient (inorganic and organic) loadings to the estuarine system. Increased loading may subsequently stimulate phytoplankton production, leading to an increase in higher dissolved oxygen levels. Unfortunately, any such relationship is confounded by a number of factors that include light inhibition resulting from increased water color, and periods of lag related to internal temperature dependent nutrient recycling.

Water Color (Pt-Co Units) – The blackwater systems of southwest Florida are characterized by humic compounds associated with the breakdown and leaching from decaying vegetation. Both the presented time-series, and box and whisker graphics indicate that color levels in the freshwater and estuarine salinity zones rapidly increase throughout the lower Peace River/upper Charlotte Harbor system in response to higher seasonal summer freshwater inflows. Moderate to higher flows result in the strong spatial color gradients depicted among the four Charlotte Harbor salinity zones. Gaged freshwater inflows over the twenty-three years of the moving, salinity based HBMP monitoring have shown statistically significant increases in average annual flows primarily associated with higher periods of summer rainfall. The two applied statistical trend test procedures indicate that these increases in wet-season flows have resulted in statistically significant increases in ambient water color within all four of the HBMP salinity zones over the 1984 through 2006 time interval.

Nitrite+Nitrate Nitrogen (mg/L) – Both the time-series, and box and whisker plots show distinct spatial and seasonal differences in dissolved inorganic nitrite+nitrate nitrogen concentrations among the four moving lower Peace River/upper Charlotte Harbor salinity zones. These graphics indicate that ambient inorganic nitrogen concentrations are typically at or near detection limits in the highest salinity reaches of the estuary throughout most of the spring and summer when light levels are high and phytoplankton production is greatest. Concentrations are conversely greater at all four measured isohalines during the fall and winter months. Overall, ambient inorganic nitrogen levels progressively increase moving upstream from high to low salinities. Inorganic nitrogen concentrations also increase under higher freshwater inputs, which results in increases in water color that limit the penetration of light into the water column and subsequently reduce phytoplankton production (nitrogen uptake). The results of the Seasonal Kendall Tau trend tests found that inorganic nitrite+nitrate concentrations within the most downstream 20 psu salinity zone have slightly statistically significantly increased over time. This result corresponds with both the observed statistically significant increases in flow (primarily during the summer wet-season) and the measured increased color levels. The apparent decline in inorganic nitrite+nitrate nitrogen concentrations at the 6 psu salinity zone given the corresponding simultaneous observed increase in color is however more difficult to explain, and may reflect other more localized influences.

Total Kjeldahl Nitrogen (mg/L) – Combined inorganic ammonia and organic nitrogen concentrations measured as total Kjeldahl nitrogen show distinct seasonal patterns within the lower Peace River/upper Charlotte Harbor Estuary. The highest levels are typically observed throughout the estuarine system each fall following the summer wet-season. The presented time-series, and box and whisker graphics indicate that measured total Kjeldahl nitrogen concentrations increase spatially from higher to lower salinities within the lower river/upper harbor estuarine system, directly reflecting the influences of freshwater inputs. However, even though average annual flows have increased due to slightly higher average summer wet-season rainfalls, the applied statistical trend procedures did not indicate that total Kjeldahl nitrogen levels have correspondingly also increased over the 1984-2006 monitoring interval.

Ortho-Phosphorus (mg/L) – The most dramatic historic changes in lower Peace River/upper Charlotte Harbor ambient dissolved (and total) phosphorus concentrations occurred prior to the 1983 start of primary production and water quality monitoring at the four HBMP isohaline-based salinity zones (PBS&J 1999, 2002, 2004). The relative magnitude of the historic changes in typical phosphorus concentrations throughout the estuarine system during the late 1970s and early 1980s is evident in the time-series plots previously presented for each of the fixed HBMP sampling locations (see **Section 4.3**). The time-series and box and whisker plots presented for each of the four moving isohalines show that phosphorus levels continued to decline during the 1980s and 1990s. However, they also indicate that following the series of hurricanes that passed over the Peace River watershed during the summer of 2004, there has been an ongoing increase in measured phosphorus levels within each of the estuarine salinity zones. The result has been that measured phosphorus concentrations within each of the estuarine salinities were actually, on average, higher in both 2005 and 2006 than they were at the initial start of the moving station monitoring in the early 1980s. The observed declines in ambient phosphorus concentrations from the 1980s through the early 2000s in the lower river and upper harbor, followed by the recent marked increases, have resulted in the applied statistical trend tests showing no significant changes over the entire 1984-2006 time period. There are however, two distinct patterns, neither of which is indicated by analyzing for trends over the entire historical time interval. It is readily apparent that the recent increases in phosphorus concentrations directly followed the historically high flows that resulted following the 2004 series of hurricane events. The ultimate responsible change in the watershed, however, currently remains unknown, and the Authority is conducting a series sampling events throughout the upper watershed during low and high flows to help identify potential sources. Seasonally, the box and whisker plots clearly show that the highest phosphorus concentrations within each of the four salinity zones occur during the late spring during periods of lower river flow, when the influences of ground water are more pronounced. The time-series and box and whisker graphics both indicate that phosphorus concentrations increase from higher to lower salinity waters, directly reflecting the influences of freshwater inputs.

Silica (mg/L) – The time-series plots clearly show that there have been marked increases in reactive silica concentrations in the surface water of the Charlotte Harbor estuarine system. The time-series plots indicated that the initial increases probably began in the late 1990s, but were interrupted as a result of the very low flows during the 1999-2001 drought. Following the drought, levels in 2002 were markedly higher and have been steadily increasing through 2006. Trend tests using both annual seasonally adjusted averages and monthly variability methods show that there have been highly statistically significant increases at all four salinity zones. The time-series and box and whisker plots indicate that reactive silica levels spatially increase progressively upstream and that ambient concentrations are typically seasonally highest following the summer period of high freshwater inflows. It is suspected that the observed increases in ambient reactive silica levels in the Peace River estuarine system reflect recent anthropogenic changes in the Peace River watershed. Again the sources have yet to be identified and the Authority is conducting low and high flow water quality monitoring at a number of locations in the upper watershed to help discover potential sources.

Chlorophyll *a* - Previous summary HBMP reports (PBS&J 1999, 2002, 2004) noted apparent declines in the frequency of phytoplankton blooms commonly observed during the early 1980s in the upper reaches of the lower Peace River. The current long-term time-series plots as well as the applied annual and monthly-based trend procedures, however suggest chlorophyll *a* phytoplankton levels have actually increased over the 1984-2006 time interval. These changes are shown to have been statistically significant within the two higher salinity zones. Higher chlorophyll levels are a reflection of the corresponding observed significant higher flows and color levels (that can serve as a proxy for nutrient loadings) that have, on average, characterized the proposed warmer AMO phase since 1995. Spatially, the highest chlorophyll *a* levels occur within the two intermediate salinity zones. During the spring, high levels of phytoplankton biomass often are observed within the 6 psu isohaline, which characterizes the zone of the estuary where nutrient rich freshwater first mixes with low nutrient harbor water. A second, often smaller peak in phytoplankton chlorophyll *a* usually occurs within the 6 psu salinity zone during the fall, as water color (inflow) decreases. Conversely, an opposite seasonal pattern occurs in the more saline 12 psu salinity zone, where nutrients (nitrogen) are more limited and the spring phytoplankton bloom is smaller, and the fall increase in response to the reduction in light limitations is more pronounced. In the reaches of the estuary characterized by the 20 psu isohaline, phytoplankton production is reduced and shows less seasonal variability, with the highest concentrations often occurring at the end of the summer wet-season.

4.3.4 Response of Water Quality Parameters to Differing Levels of Freshwater Inflow within the Isohalines

The objective of the following section was to graphically depict spatial differences in measured sub-surface water quality characteristics among the four HBMP monitored lower Peace River/upper Charlotte Harbor Estuary isohalines under differing flow conditions. Box and whisker univariate plots were used to depict and compare selected water quality parameters among the four estuarine salinity zones under a series of flow ranges (measured at the USGS Peace River at Arcadia gaging site).

- **Very Low Flows** (0 to 94 cfs) – representative of the lowest ten percent (P10) of river flows during the 1976-2006 time period.
- **Low Flows** (94-171 cfs) – or flows within the P10 to P25 interval.
- **Normal Low Flows** (171-399 cfs) – or flows characteristic of the long-term P25 to P50 (median) range.
- **Normal High Flows** (399 to 1000 cfs) – representative of Peace River Arcadia flows within the P50 (median) to P75 statistical interval.
- **High Flows** (1000 to 3173 cfs) – characterizing river flows in the P75 to P90 range.
- **Very High Flows** (above 3173 cfs) – or the upper ten percent (P90) of all observed flows during the 1976-2006 time period.
- **All Flows –** this final series of univariate box and whisker plots depicts the overall spatial differences and the range of observed variation in each of the water quality parameters without regard to flow.

The graphical results of these analyses are summarized in Table 4.37. Following the previous format applied for the fixed HBMP monitoring stations, the presented flow based graphics for the isohaline locations include analyses for some HBMP water quality parameters that were dropped from the monitoring program in 2004 following the finalized recommendations included in the *2002 HBMP Comprehensive Summary Report*.

Table 4.37
Univariate Plots Of Water Quality Parameters Under Differing Flow Categories

Water Quality Parameter	Flow Category – Range in Cubic Feet/Second						
	0-94 cfs	94-171	171-399	399-1000	1000-3173	>31730	All Flows
River Kilometer	Figure 4.385	Figure 4.386	Figure 4.387	Figure 4.388	Figure 4.389	Figure 4.390	Figure 4.391
Dissolved Oxygen	Figure 4.392	Figure 4.393	Figure 4.394	Figure 4.395	Figure 4.396	Figure 4.397	Figure 4.398
Water Color	Figure 4.399	Figure 4.400	Figure 4.401	Figure 4.402	Figure 4.403	Figure 4.404	Figure 4.405
Turbidity	Figure 4.406	Figure 4.407	Figure 4.408	Figure 4.409	Figure 4.410	Figure 4.411	Figure 4.412
Nitrite+Nitrate Nitrogen	Figure 4.413	Figure 4.414	Figure 4.415	Figure 4.416	Figure 4.417	Figure 4.418	Figure 4.419
Ammonia/Ammonium Nitrogen	Figure 4.420	Figure 4.421	Figure 4.422	Figure 4.423	Figure 4.424	Figure 4.425	Figure 4.426
Total Kjeldahl Nitrogen	Figure 4.427	Figure 4.428	Figure 4.429	Figure 4.430	Figure 4.431	Figure 4.432	Figure 4.433
Total Phosphorus	Figure 4.434	Figure 4.435	Figure 4.436	Figure 4.437	Figure 4.438	Figure 4.439	Figure 4.440
Silica	Figure 4.441	Figure 4.442	Figure 4.443	Figure 4.444	Figure 4.445	Figure 4.446	Figure 4.447
Total Organic Carbon	Figure 4.448	Figure 4.449	Figure 4.450	Figure 4.451	Figure 4.452	Figure 4.453	Figure 4.454
Dissolved Organic Carbon	Figure 4.455	Figure 4.456	Figure 4.457	Figure 4.458	Figure 4.459	Figure 4.460	Figure 4.461
Chlorophyll *a*	Figure 4.462	Figure 4.463	Figure 4.464	Figure 4.465	Figure 4.566	Figure 4.467	Figure 4.468

The following patterns and observations can be drawn from the presented figures.

Isohaline Location (River Kilometer) – The series of plots indicate the effects of increased freshwater on the relative locations of each of the four HBMP isohalines along the lower Peace River/Charlotte Harbor monitoring transect. The presented series of figures show that under low flow conditions, all four isohalines are confined over limited ranges within the lower river. The spatial pattern of the locations of the isohalines changes with increasing flows. The relative spatial locations of each of the four isohaline-based salinity zones move more downstream and become much more variable as flows increase. This is especially true with regard to the relative spatial locations of the two highest salinity zones, since under high flows the positions of these isohalines are to a great extent dependent upon the length of the preceding period of high flows. Overall, the variability of the relative locations of the four isohalines increases with salinity.

Water Color (Pt-Co Units) – Under conditions of lower flows, the presented series of graphics indicate that the intermediate salinities often have higher ambient color than the lowest or highest salinities. This suggests that during periods when ground water comprises the major source of water coming from the Peace River watershed, the wetlands immediately surrounding the lower river are the primary source (ungaged) of water color. However, as gaged freshwater flows from the watershed increase, the presented figures show the influences that "blackwater" river inflows have on the lower Peace River estuarine system. The overall variability of water color among the four isohalines decreases with salinity.

Turbidity (NTU) – Turbidity levels within the Peace River/Charlotte Harbor estuarine system are generally low and do not proportionally increase in response to higher levels of freshwater inflow. The blackwater watershed tributaries throughout southwest Florida typically have relatively slow velocities due to the often very flat terrains. Combined with the typical soil profiles these systems generally do not naturally (outside of anthropogenically generated events) transport large amounts of either silt or clay. The data do show turbidity maxima generally occurring within the intermediate isohalines, which often corresponds with the zone of maximum phytoplankton production. Thus, within the lower Peace River/upper Charlotte Harbor estuarine system, turbidity levels generally reflect phytoplankton biomass or other particulate organic matter, rather than sediment material mechanically being carried from the watershed into the estuary. Important examples of marked exceptions not shown by the HBMP data would include events such as historic spills from phosphate mining clay settling areas and the heavy loads of sand and other sediments transported to the estuary as a result of very high flows such as occurred following the 2004 hurricanes.

Nitrite+Nitrate Nitrogen (mg/L) – The observed changes in the patterns of inorganic dissolved nitrite+nitrate nitrogen concentrations among the four salinity zones clearly show that, initially under conditions of increasing levels of freshwater inflow, inorganic nitrogen levels increase in the lower salinity estuarine waters. However, measured concentrations actually then decline during periods of very high river flow, when ground water levels are near the surface and sheetflow rapidly moves water from the land and into the estuary. These figures also show that dissolved inorganic nitrogen concentrations within the highest salinity zone are typically at or near detection limits except during periods of very highest freshwater inflow.

Ammonia/Ammonium Nitrogen (mg/L) – Ammonia/ammonium nitrogen concentrations increase and high spikes are more frequent during periods of higher freshwater inflow. These observations coincide with the development of strong salinity stratification in the region of the estuary downstream of the US 41 Bridge (river kilometer 6.6) and the development of hypoxic/anoxic bottom water conditions over extensive areas of the lowest reaches of the river and upper harbor.

Total Kjeldahl Nitrogen (mg/L) – Total Kjeldahl nitrogen measures both organic and ammonia/ammonium inorganic forms of nitrogen. Concentrations within the lower Peace River/upper Charlotte Harbor Estuary generally show increasing patterns both moving upstream and with increasing levels of freshwater inflow.

Total Phosphorus (mg/L) – Spatially, concentration patterns among the four monitored HBMP isohalines within the lower river/upper harbor estuarine system act conservatively, with ambient levels reflecting the dilution of high freshwater concentrations by saltwater. Measured phosphorus concentrations within each of the four HBMP isohalines declines during the typical summer wet-season as freshwater flows increase and surface sheetflow provides a greater percentage of total river input relative to ground water contributions.

Silica (mg/L) – Under lower levels of freshwater inflow, the presented series of graphics indicate higher ambient concentrations within the two intermediate isohalines (analogous to the pattern observed for water color). Reactive silica concentrations within each of the estuarine salinity zones increase and the pattern among the isohalines indicates higher concentrations toward the freshwater source as gaged freshwater flows from the watershed increase.

Dissolved and Total Organic Carbon (mg/L) – The series of box and whisker plots of both dissolved and total organic carbon concentrations show very similar patterns of response among the four HBMP isohalines to changes in levels of freshwater inflow. Average organic carbon levels generally increase both upstream and in response to higher levels of freshwater inflow.

Chlorophyll *a* – The presented series of box and whisker plots clearly show that the highest levels of phytoplankton chlorophyll *a* biomass spatially occur in the estuary within the two intermediate salinity zones. Chlorophyll *a* concentrations are typically slightly higher within the 6 psu isohaline as freshwater high in color and inorganic nitrogen mixes with low color, nutrient poor higher salinity water. However under conditions of higher flows the phytoplankton maximum often shifts to the 12 psu isohaline as increasing water color levels limit light levels in the two lower estuarine isohalines.

4.3.5 Response of Water Quality Parameters by Sampling Site to Changes in Freshwater Flows

Plots of the location and sub-surface measurements at each of the four HBMP isohalines versus gaged Peace River at Arcadia flow (0 to 3000 cfs) for each of the selected water quality parameters are presented in Table 4.38. These analyses provide further support for the previously described water quality responses to seasonal changes in freshwater inflow at each of the salinity based sampling locations. As these figures indicate, large degrees of variation often occur at a given flow depending on the history of flows over both the immediate and longer-term preceding periods. Water color at an isohaline for example can differ dramatically at intermediate levels of gage freshwater inflow depending on whether the sampling occurred early in the summer wet-season as flows were increasing or at the end of the summer/fall period as flows were decreasing.

Table 4.38
Water Quality Parameters Versus Flow

Water Quality Parameter	Estuarine Isohaline			
	0 psu	6 psu	12 psu	20 psu
River Kilometer	Figure 4.469	Figure 4.470	Figure 4.471	Figure 4.472
Dissolved Oxygen	Figure 4.473	Figure 4.474	Figure 4.475	Figure 4.476
Water Color	Figure 4.477	Figure 4.478	Figure 4.479	Figure 4.480
Turbidity	Figure 4.481	Figure 4.482	Figure 4.483	Figure 4.484
Nitrite+Nitrate Nitrogen	Figure 4.485	Figure 4.486	Figure 4.487	Figure 4.488
Ammonia/Ammonium Nitrogen	Figure 4.489	Figure 4.490	Figure 4.491	Figure 4.492
Total Kjeldahl Nitrogen	Figure 4.493	Figure 4.494	Figure 4.495	Figure 4.496
Total Phosphorus	Figure 4.497	Figure 4.498	Figure 4.499	Figure 4.500
Silica	Figure 4.501	Figure 4.502	Figure 4.503	Figure 4.504
Total Organic Carbon	Figure 4.505	Figure 4.506	Figure 4.507	Figure 4.508
Dissolved Organic Carbon	Figure 4.509	Figure 4.510	Figure 4.511	Figure 4.512
Chlorophyll *a*	Figure 4.513	Figure 4.514	Figure 4.515	Figure 4.516

Correlations were again further used to assess potential statistical differences in the relationships between differing rates of seven day average gaged flow (Peace River at Arcadia) and the selected surface water quality characteristics at each of the four moving HBMP isohaline-based sampling salinity zones spatially distributed along the lower river monitoring transect. The same seven statistically based river flow groupings described above in Section 4.3.3 were used to test for differences in correlations, and the summary results are present in the following series of summary tables. Presented in these tables, for each location and flow category, are the resulting correlation coefficient (R value), the level of significance (P) and the number of available observations (N). In evaluating these results, it should be remembered that the relative degree of variability (percent) explained for each water quality parameter (the dependent variable) by changes in flow (the independent variable) is actually the correlation coefficient squared or R^2.

- **Table 4.39** (0 psu Isohaline)
- **Table 4.40** (6 psu Isohaline)
- **Table 4.41** (12 psu Isohaline)
- **Table 4.42** (20 psu Isohaline)

The following briefly summarizes a number of the observed patterns and primary conclusions resulting from the presented graphical and statistical comparisons made between Peace River at Arcadia gaged freshwater inflows and the measured downstream variability of water quality characteristics within the four selected salinity zones. Overall, standard correlation analysis can generally only be used to explain small percentages of the observed annual and inter-annual variability between many of the water quality parameters and freshwater inflows within each of the four HBMP isohalines.

Isohaline Location (River Kilometer) – The relative locations of each of the four HBMP isohalines along the lower river/upper harbor monitoring transect show strong inverse relationships with freshwater inflows. Under very low flow conditions, the highest 20 psu salinity zone often extends up into the lower river. The freshwater/saltwater interface (0 psu), by comparison, can extend well downstream towards the mouth of the river during extended periods of high river flow. The graphical and statistical analyses indicate that the relative spatial locations of each of the isohalines initially rapidly move downstream with increasing flows. However, over higher ranges of flows the relative slope of change becomes less as do the relationships between flow and isohaline location along the monitoring transect. The observed relationships are confounded due to the importance of both short and long-term preceding conditions, as well as the often increasing physical stratification of the water column under conditions of higher flows.

Dissolved Oxygen (mg/L) – The presented graphics indicate that as flows increase, dissolved oxygen concentrations near the freshwater/saltwater interface (0 psu) become depressed. Increasing flows result in higher water color, which reduces light levels in the water column and reduces phytoplankton growth leading to lower oxygen production. Within each of the three more brackish estuarine salinity zones, dissolved oxygen levels initially increase with flow due to higher nutrient levels and then decrease at higher flows as higher water color limits phytoplankton production. These interactions between nutrient stimulation and color inhibition mediated by flow, combined with both the physical decrease in dissolved oxygen saturation and enhanced bacterial respiration rates with higher summer temperatures, result in the observed changes in surface dissolved oxygen levels along the Peace River HBMP transect.

Water Color (Pt-Co Units) – Measured color levels within each of the four HBMP salinity zones are significantly positively correlated with increasing flows. However, there are distinct differences in the relative patterns between color and freshwater inflow both among the isohalines and categorized flows. The strongest relationships between water color and freshwater inflows occur within the lower two salinity zones over low to intermediate ranges of flows. The relationships between color and flow within the 12 and 20 psu isohalines by comparison are somewhat less pronounced due to the greater dilution by low color/higher salinity waters. Color levels within all four isohalines typically become asymptotic, and then begin to decline with higher flows as color levels in the freshwater inflows from the watershed begin to decline under high flow conditions.

Turbidity (NTU) – Turbidity levels are generally fairly low throughout the lower river/upper harbor estuarine system. Turbidity levels within each of the four isohalines show indications of initial increases in response to increasing freshwater flows. Since the relatively slow moving waters of the Peace River watershed tributaries do not typically carry large amounts of either silt or clay it is possible that these initial turbidity responses are in fact due to higher chlorophyll *a* concentrations resulting from increasing inputs of inorganic nitrogen. This hypothesis is in part supported by the observations that turbidity levels within each of the four isohalines then quickly decline as residence times decrease and color levels increase.

Nitrite+Nitrate Nitrogen (mg/L) – The observed relationships between dissolved inorganic nitrogen concentrations and rates of freshwater inflow at the four selected estuarine isohalines are complex. Under low to moderate levels of flow, nitrogen stimulates phytoplankton production and ambient levels can be near detection limits throughout much of the lower Peace River/upper Charlotte Harbor estuarine system. However, as flows increase and the river estuarine phytoplankton primary production becomes color rather than nitrogen limited, ambient inorganic nitrogen levels increase with increasing flow. However, measured inorganic nitrogen concentrations often decline again as river flows further increase. Higher levels of accumulated nitrogen are often associated with the initial periods of seasonal runoff from the watershed. Increased volumes and rates of surface water runoff (sheetflow) also limit contact time, further reducing both color and inorganic nitrogen concentrations.

Ammonia/Ammonium Nitrogen (mg/L) – The presented graphical and statistical analyses of ammonia/ammonium nitrogen concentrations within the four estuarine isohalines do not show any clear relationships with seasonal changes in rates of freshwater inflow.

Total Kjeldahl Nitrogen (mg/L) – Total Kjeldahl nitrogen measures both organic nitrogen and inorganic ammonia/ammonium. Concentration within the 0, 6 and 12 psu isohalines initially increase in response to higher freshwater inflows, and then quickly become asymptotic. Total Kjeldahl nitrogen levels within the 20 psu isohaline by comparison do not show any distinct patterns with regard to changes in gaged river flows.

Ortho-Phosphorus (mg/L) – The observed response of ortho-phosphorus concentrations within each of the four selected estuarine isohalines to higher rates of freshwater inflow are very similar. In each instance, measured concentrations progressively decline as flows increase. As previously discussed, this suggests that the highest phosphorus levels throughout the estuary occur when freshwater inflows are predominantly derived within the watershed from surfical ground water base flow. Phosphorus concentrations within the lower river and upper harbor seasonally decline as rainfall increases and the relative importance of ground water inputs versus surface flows declines.

Silica (mg/L) – The response of dissolved reactive silica concentrations within the four HBMP moving station isohalines to increases in gaged Peace River flows is very similar to that of total Kjeldahl nitrogen. Concentration within the 0, 6 and 12 psu isohalines initially increase in response to higher freshwater inflows, and then quickly become asymptotic, while concentrations within the 20 psu isohaline do not show any distinct, consistent patterns with changes in river flows.

Dissolved and Total Organic Carbon (mg/L) – Both dissolved and total organic carbon concentrations show very similar spatial patterns and responses to changes in levels of freshwater inflow. Concentrations near the freshwater/saltwater interface (0 psu) increase rapidly with flow and then quickly become asymptotic. Similar patterns occur within the 6, 12 and 20 psu isohalines, but become increasing less distinct as salinities increase.

Chlorophyll *a* (mg/m^3) – Higher flows result in a number of interacting confounding factors that ultimately affect resultant phytoplankton biomass (chlorophyll *a* concentrations) within the lower river/upper harbor estuarine system. Higher rates of freshwater inflow increase inorganic nitrogen loading that simulates phytoplankton production, while at the same time higher color levels simultaneously reduce the ability of light to penetrate the water column and reduces phytoplankton production. Higher rates of flow also reduce the physical hydraulic residence time within the lower river and effectively "flushes" phytoplankton populations further downstream, in effect limiting the buildup of higher chlorophyll concentrations. Chlorophyll concentrations within the 0 and 6 psu isohalines both show higher levels in response to low to moderate increases in gaged inflows and higher nitrogen inputs. However, as expected, measured chlorophyll *a* concentrations then decline as factors such as color and residence time become increasingly important. The direct relationships between chlorophyll a concentrations and flow are less distinct at the higher two salinity zones. As previously discussed, there are strong seasonal components associated with the interactions between rates of flow and phytoplankton biomass. Similar rates of flow in the spring and fall can have dramatically different influences on stimulating or inhibiting phytoplankton growth within each of the four different moving salinity zones. Chlorophyll *a* concentrations can therefore exhibit an extremely wide range of variability over a given range of flows as indicated by the presented tabular results of correlations.

4.3.6 Spatial Correlations among Water Quality Characteristics

A final series of correlation analyses were conducted to test for potential relationships among the selected water quality parameters at each of the four moving isohaline-based salinity zones along the HBMP monitoring transect. Matrices of the results of these correlation tests are presented in the following series of summary tables. The first value for each comparison indicates the number of available observations, while the second is the correlation coefficient, and the last value presents the level of significance. A great deal of care needs to be taken in interpreting these correlation results since two parameters may show a significant correlation only because they are both highly related to a third, which as discussed, may have varying responses to seasonal changes in freshwater inflows. Also, as a result of the relative high number of observations, correlation analyses can indicate in some instances high levels of statistical significance for relationships that actually have very weak correlations and explain very little of the observed annual and inter-annual variation between these characteristics.

- **Table 4.43** (0 psu Isohaline)
- **Table 4.44** (6 psu Isohaline)
- **Table 4.45** (12 psu Isohaline)
- **Table 4.46** (20 psu Isohaline)

4.4 Summary

This chapter provides overviews and analyses of the status and trends in water quality in the lower Peace River/upper Charlotte Harbor estuarine system over the 1976-2006 time interval of HBMP monitoring. The following analyses are included.

- An overview and summary of historical changes in water quality in the upper Peace River and its major tributaries relative to influences of long-term changes in water quality in the lower Peace River and the upper harbor.

- Analyses of the status and trends in water quality at the long-term "fixed" HBMP monitoring stations over the interval from 1976 through 2006.

- Analyses of the status and trends in water quality at the long-term "moving" ishohaline based HBMP salinity zones over the period between 1984 and 2006.

4.4.1 Overview of Historical Patterns of Water Quality Changes in the Peace River Watershed

Historically, water quality in the upper Peace River watershed has been affected by a number of anthropogenic activities. These have included point and nonpoint source discharges from phosphate mining and processing, point source municipal/industrial effluents, and nonpoint runoff from both expanding urban and intense agricultural land uses. Some of the largest conversions to more intense agricultural uses have occurred in the southern basins and have been associated with increased discharges of highly mineralized ground water and nonpoint source nutrient loadings (nitrogen). The following summarizes a number of the key findings relative to the differing water quality characteristics and historical pattern changes that have been observed in the Peace River watershed.

- Lake Hancock water quality has been characterized as "poor," based on the Florida Trophic State Index. Florida Department of Environmental Protection (FDEP) has verified the impaired condition of the lake and levels of total nitrogen, total phosphorus, and biological oxygen demand all exceeded the state threshold screening values by considerable amounts.

- Instances of low dissolved oxygen concentrations are conspicuous in the upstream portions of the Peace River, and both the frequency and downstream extent of low dissolved oxygen levels increase as discharges from Lake Hancock increase. Flows from the lake via Saddle Creek are characteristically high in total suspended solids, total Kjeldahl nitrogen, total organic carbon, and chlorophyll *a*. The high chlorophyll concentrations (algae) and organic material associated with these discharges result in both the very high and low dissolved oxygen levels in the upper Peace River. During periods of high rainfall, discharges from the lake increase, and the low dissolved oxygen conditions are exacerbated.

- Values for a number of other water quality parameters in the upper Peace River have improved noticeably since the 1960s and 1970s following implementation of regulatory measures and changes in phosphate mining practices that eliminated direct processing discharges and reduced other mining related discharges to surface waters. These changes resulted in decreased levels of specific conductivity, total dissolved solids, calcium, magnesium, sulfate, silica, total phosphorus, ortho-phosphate, fluoride and strontium in the upper river.

- Analyses of water quality data suggest that historically high ground water withdrawals and subsequent discharges from mining activities substantially augmented river base flows, and masked the decline of natural spring discharges that followed reductions in ground water levels. Ground water discharges were historically so large that when they were reduced, there was a commensurate increase in the average water color in the upper reaches of the river.

- The tributary basins of the Peace River watershed all show water quality changes attributable to mineralized ground water discharges to surface waters.

- Depending on the basin, long-term increases are apparent in conductivity, pH, total dissolved solids, calcium, magnesium, sodium, potassium, chloride, silica, and sulfate. Concentrations of many of these water quality parameters were at or near historical highs during the recent 1999-2001 drought. The basins were ranked relative to the magnitude of change in water quality and are listed from largest to smallest changes.

  1. Joshua Creek
  2. Shell Creek (Prairie Creek and Shell Creek)
  3. Horse Creek
  4. Payne Creek
  5. Charlie Creek

- Ground water discharges in the Payne Creek basin are associated with phosphate mining, electrical power facilities and agriculture. In the other basins, increasing areas of agricultural lands have been transformed to more intensive uses over the past few decades. These intense agricultural uses often rely heavily on ground water for both irrigation and freeze protection. Water in the upper Floridan aquifer is generally more mineralized moving from the northern region of the Peace River watershed toward the south and west. Consequently, relatively similar volumes of Upper Floridan ground water discharged to receiving surface waters in the southern watershed basins can have a greater effect on surface water quality characteristics when compared to discharges in the northern watershed The observed characteristically high conductivity levels (and other water quality constituents) in these southern agricultural dominated basins directly reflect the results of highly mineralized upper Floridan ground water being discharged into these creeks.

- Water quality in a number of the tributary watershed basins that have undergone land use changes to more intense agriculture also show recent increases in inorganic nitrite+nitrate nitrogen concentrations.

- Dissolved inorganic phosphorus concentrations in the lower Peace River/upper Charlotte Harbor Estuary are extremely high when compared to other estuarine systems. However, measured phosphorus levels in the estuary have declined by as much as an order of magnitude since the early 1980s.

- Except for statistically significant long-term declines in phosphorus levels and recent significant increases in silica concentrations, the water quality of the lower Peace River and upper Charlotte Harbor has remain relatively unchanged over the past quarter century.

- There are, however, distinct seasonal differences in a number of water quality characteristics in the lower river and estuary (including salinity, dissolved oxygen, water color, turbidity, phosphorus, nitrogen, organic carbon and chlorophyll *a*) related to differences in flow and/or temperature.

- Phytoplankton levels in the Peace River and Charlotte Harbor during periods of low to moderate freshwater flow are limited by the availability of inorganic nitrogen. However, as flows increase, water color levels correspondingly increase and phytoplankton production in the river and upper harbor are increasingly limited by the ability of light to penetrate the water column.

- Dissolved oxygen concentrations in the lower Peace River/upper Charlotte Harbor Estuary show clear seasonal cycles in response to higher freshwater flows during the summer wet-season. The duration and magnitude of periods of low dissolved oxygen concentrations increase toward the river mouth and harbor as higher bottom salinities establish greater vertical stratification in the water column during high flows. Bottom dissolved oxygen concentrations in upper Charlotte Harbor are characterized by hypoxic (less than 2.0 mg/L) and even anoxic (less than 0.2 mg/L) conditions during extended periods of high flows during the summer wet-season.

4.4.2 Status and Trends in "Fixed" HBMP Station Water Quality Parameters

The HBMP water quality monitoring design has included the monthly collection of *in situ* physical measurements and chemical water characteristics at a number of fixed station locations along the lower Peace River and in upper Charlotte Harbor. These data were used to describe the present status as well as statistically test for the presence of long-term changes in the water quality characteristics at these specific selected locations along the lower Peace River HBMP monitoring transect. The following summarizes the results and findings of these analyses for a number of key water quality parameters.

- **Salinity –** There is a strong, distinct spatial salinity gradient along the lower Peace River monitoring transect. The greatest inter-annual variability in salinity generally occurs in the surface waters near the mouth of the river in the upper harbor where seasonal differences may reach 35 parts per thousand between extended periods of low and high freshwater inflow. The influences of the recent high freshwater inflows during 1997/1998 El Niño event and the extended 1999-2001 drought are evident in the time-series plots.

- **Dissolved Oxygen –** Near-bottom dissolved oxygen concentrations show clear seasonal cycles in response to higher freshwater flows during the summer wet-season. The duration and magnitude of periods of very low dissolved oxygen concentrations increase toward the river mouth as higher bottom salinities establish greater vertical stratification in the water column during high flows. Other studies have noted apparent declines in dissolved oxygen concentrations in the lower river over time, but have been unable to clearly identify any cause. The current analyses, based on a somewhat longer data set than these previous analyses, generally finds similar surface and bottom annual average dissolved oxygen concentrations along the HBMP monitoring transect when comparing the 1976-1989 and 1996-2006 time periods.

- **Water Color –** Humic compounds derived from the breakdown and subsequent leaching of vegetation into surface waters are the source of the high water color that characterizes the blackwater river systems of southwest Florida. Color levels in the estuary temporally increase quickly in response to increased freshwater inflow, with very high color levels extending well into the harbor during extended periods of high freshwater flows such as occurred during the 1997/1998 El Niño or recently during the extremely high flows that occurred during 2001, 2003, 2004 and 2005. Statistical analyses indicated significant differences between the average annual surface color levels at the two most downstream monitoring locations (RK -2.3 and 6.6) between the 1976-1989 and 1996-200 sampling periods. These differences reflect the higher recent inflows of dark colored water farther down the river and into the upper harbor during the recent period of high flows

- **Nitrite+Nitrate Nitrogen –** Concentration levels and seasonal patterns of dissolved inorganic nitrite+nitrate nitrogen differ along the lower river/upper harbor HBMP monitoring transect. The time-series plots indicate that inorganic nitrite+nitrate nitrogen levels at the most downstream fixed sampling station (located near the arbitrarily defined river mouth) are typically near or at method detection limits. Salinities are typically high in this region of the estuary and, except during periods of very high river flow, phytoplankton primary production is limited by the availability of inorganic nitrogen. Conversely, during extended periods of high freshwater river flows, surface salinities decline, bringing increased nutrient loading and higher levels of water color that limit the penetration of light into the water column and subsequently reduces phytoplankton growth and nitrogen uptake. By comparison, inorganic nitrogen levels progressively increase moving upstream along the HBMP sampling transect, as dilution by low nutrient/high salinity harbor water declines and higher water color increasingly limits phytoplankton nitrogen uptake. Only during periods of extended low freshwater flow, such as during the spring dry-season, are ambient inorganic nitrogen levels low at the upstream river sampling sites. The observed statistically significant increase in inorganic nitrogen concentrations in the upper harbor (RK -2.4) matches with the corresponding increase in water color and supports the previous observations that these increases reflect higher inflows of darker (nitrogen rich) freshwater farther downstream into the upper harbor during the recent period of characteristically higher river flows.

- **Total Kjeldahl Nitrogen –** While this gross measurement of combined inorganic ammonia and organic water column nitrogen shows distinct seasonal patterns, spatially levels at all the monitoring locations were observed to be relatively similar. Statistical tests found no significant differences when comparing the 1976-1989 and 1996-2006 time periods.

- **Ortho-Phosphorus –** Probably the most dramatic long-term change in water quality in the lower Peace River has been the marked, observed statistically significant long-term decline in dissolved inorganic (and total) phosphorus concentrations. Phosphorus concentrations generally reflect both the spatial and temporal variation in Peace River freshwater inputs. The highest phosphorus concentrations are typically associated with seasonal low river flow, when the influences of ground water are more pronounced. Long-term temporal patterns indicate rapid declines in both the magnitude and variability in phosphorus levels when compared with the first six years of HBMP monitoring. Comparisons of the average annual mean phosphorus concentrations between the 1976-1989 and 1996-2006 time periods indicate a continued decline at the HBMP river stations, even though the largest changes occurred prior to 1984. Of particular note however are more recent observations, which show phosphorus levels throughout the lower Peace River/upper Charlotte Harbor Estuary have dramatically increased following Hurricanes Charley, Francis and Jeanne in August and September of 2004. It is apparent that the historically high flows that occurred in the upper Peace River watershed following this unusual series of events has at least temporarily increased phosphorus concentrations throughout the system to levels not seen for over twenty years.

- **Silica –** Both the long-term time-series plots and the statistical comparisons of mean annual average reactive silica concentrations indicate that silica levels have recently dramatically increased along the entire length of the lower Peace River monitoring transect. During the most recent eleven years of HBMP monitoring, silica concentrations at all five fixed sampling sites have increased and the range of variability has increased when compared with similar data from the 1976-1989 period. It may be that the observed increases in ambient reactive silica levels in the Peace River estuarine system reflect the cumulative influences of increased ground water use and the expansion of water intense agriculture in the Peace River watershed, or it may be associated with other land use changes occurring upstream in the watershed. The Authority is currently collecting additional dry- and wet-season data at a number of locations throughout the upper watershed in order to be able to better identify potential sources of both apparent increasing silica and phosphorus concentrations.

- **Chlorophyll *a* –** Previous studies observed marked declines in the periodic very high chlorophyll *a* concentrations or phytoplankton "blooms" that commonly occurred in the surface waters throughout the lower Peace River/upper Charlotte Harbor estuarine system during the late 1970s and early 1980s. However, the current examination of the data, which extends similar analyses through 2006 indicates that since 2004 chlorophyll *a* levels in the lower river and upper harbor have uniformly shown increases to annual average levels not seen in over twenty years. Following Hurricanes Charley, Francis and Jeanne in August and September of 2004, as previously discussed, water quality data from the lower river show marked increases in ortho-phosphorus levels that correspond with the observed increases in chlorophyll *a*. Since phosphorus levels in the lower Peace River/upper Charlotte Harbor Estuary are naturally high, and nutrient additions have shown local estuarine phytoplankton populations are seasonally nitrogen and not phosphorus limited, it is doubtful if the observed increases in phosphorus levels are directly the ultimate cause of the observed increases in chlorophyll *a* concentrations. It may be more likely that other water quality constituents not monitored by the HBMP, but having the same source as the observed phosphorus increases, are responsible for the observed increases in phytoplankton levels. Overall, the result of the observed historic declines, combined with the recent observed increases, is that there are no statistically significant differences in average annual seasonally weighted mean chlorophyll *a* concentrations between the 1976-1989 and 1996-2006 time intervals at any of the fixed HBMP monitoring locations. This result demonstrates the inherent difficulty in using most commonly applied statistical trend procedures when evaluating long-term changes in water quality parameters having multiple non-seasonal increasing and decreasing patterns.

4.4.3 Spatial Response of Water Quality Parameters to Levels of Freshwater Inflows

A number of graphical methods were used to depict spatial variations of ambient water quality characteristics under different flow regimes at each of the five fixed HBMP Peace River monitoring locations. The following patterns were apparent in the observed responses of the water quality parameters to seasonal changes in freshwater inflows.

- **Salinity (psu) –** The graphical analyses clearly depict the progressive changes that occur along the sampling transect as flows increase. Under the lowest flow conditions, brackish water conditions extend upstream well beyond the point of Facility water withdrawals. Conversely, freshwater at the surface can extend downstream to near the river's mouth under conditions of extended periods of freshwater inflow. There are distinct inverse relationships between measured surface salinities and increases in flow. However, these relationships increasingly break down further upstream with increasing flows as salinities along the HBMP lower river monitoring transect change from being tidally brackish to always being characteristically freshwater under conditions of increasing freshwater flows.

- **Dissolved Oxygen (mg/L) –** The results generally show that surface dissolved oxygen concentrations along the monitoring transect initially increase under increasing low to moderately levels of flow. However, above some level, further increases in flow tend to progressively depress ambient surface dissolved oxygen levels at each of the fixed locations along the monitoring transect. Initially increased flows result in nitrogen stimulation of phytoplankton production within the lower Peace River estuarine system. However, at some level additional increases in water color associated with higher flows result in marked reductions in light penetration of the water column and the phytoplankton compensation depth, resulting in reduced dissolved oxygen production. The relationship between dissolved oxygen concentrations and flow is further confounded by the combined influences of seasonal changes in water temperature and salinity.

- **Water Color (Pt-Co Units) –** The presented graphics clearly depict the distinct patterns and marked changes that occur in water color as freshwater flows increase. Water color levels at the downstream fixed monitoring sites show steady increases in color levels under ever higher rates of freshwater inflow. Further upstream, however, at some point additional increases in flow do not correspond to higher levels in ambient water color. Under conditions of extremely high flows, color levels actually in some regions of the lower river begin to decline as the contact time of sheet flow is reduced and previous built up humic compounds are increasingly flushed from the watershed.

- **Nitrite+Nitrate Nitrogen (mg/L) –** The spatial relationships between dissolved inorganic nitrogen concentration and rates of freshwater inflow are complex. As flows gradually increase following the typical spring dry-season, increasing nitrogen loadings stimulate estuarine phytoplankton production and ambient inorganic nitrogen levels often remain near or at detection limits throughout much of the lower Peace River estuarine system. However, as flows further increase, upstream phytoplankton primary production become color rather than nitrogen limited and inorganic nitrogen levels rapidly rise with increasing flows. A third condition then occurs at the upstream HBMP sampling locations as both water color and nutrient levels start to decline with further increases in flow. Such changes again reflect seasonal changes in the water quality characteristic of sheet flow to the watershed's major tributaries following longer (and/or higher) amounts of rainfall.

- **Ortho-phosphorus (mg/L) –** Concentrations in the downstream more marine areas of the upper harbor generally show steady increasing levels with higher flows. However upstream, in the more freshwater reaches of the river, phosphorus concentrations are typically very high and then rapidly decline as freshwater flows increase and surface water runoff rather than ground water steadily provides an ever greater percentage of total river flow.

- **Silica (mg/L) –** Silica levels in the higher salinity waters of the upper harbor under low flows are often very low. Ambient concentrations initially rapidly rise throughout the lower river/upper harbor estuarine system as freshwater inflows increase. Following this marked initial rise however, silica concentrations then remain relatively similar as flows further increase.

- **Chlorophyll *a* (mg/m^3) –** Initially higher flows increase inorganic nitrogen loading, which simulates phytoplankton production both in the lower river and upper harbor. However, further higher flows also increase color levels in the estuary reducing the ability of light to penetrate the water column, thus simultaneously diminishing phytoplankton growth rates. Residence time is also reduced as flows increase resulting in phytoplankton (chlorophyll) increasingly being "flushed out" of the lower river.

4.4.4 Status and Trends in "Moving" Isohaline-Based Station Water Quality Parameters

The HBMP has also incorporated monthly water quality monitoring at four salinity-based "moving" isohalines.

- Oligohaline Conditions = 0 psu (defined as upstream of 500 us/cm conductivity
- Lower Mesohaline = 5-7 psu
- Upper Mesohaline = 11-13 psu
- Upper Brackish = 20-22 psu

The four sampling locations represent non-fixed surface salinity zones, such that the relative monthly spatial location of each isohaline sampling site along the HBMP monitoring transect is largely dependent upon the preceding amounts of freshwater Peace River inflow. Time-series plots show the monthly long-term relative locations the "moving" isohaline salinity zones relative to the HBMP monitoring transect, and clearly indicate the large degree of both inter-annual and seasonal variability that has occurred in the relative locations of the monitored isohalines. Seasonal and long-term extreme differences in estuarine freshwater inflows have resulted in variations as much as 35 to 55 kilometers in the relative spatial distributions of the four isohalines. The extended 1999-2002 drought affected rainfalls and river flows throughout southwest Florida, and the influences of this drought are evident in the observed changes in the relative locations of the HBMP isohalines during this interval. The long-term pattern of relatively high summer flows during the past decade has also resulted in some indication of an overall downstream movement in the 6 and 12 psu intermediate salinities. However, the results of the trend tests fail to find statistically significant pattern of progressive change in the relative long-term spatial distributions of any of the four isohaline locations along the HBMP monitoring transect.

The following briefly summarizes the results and primary conclusions drawn from the observed annual, inter-annual and long-term patterns within the four estuarine salinity zones for key selected water quality parameters.

- **Dissolved Oxygen (mg/L) –** Dissolved oxygen levels in the lower Peace River estuarine system show distinct seasonal patterns, with the lowest levels typically occurring during the summer wet-season. Even near the top of the water column dissolved oxygen concentrations are often below State of Florida standards (5 mg/L for freshwater and 4 mg/L for predominantly estuarine/marine). Measured levels are generally higher during cooler months, due to lower water temperatures (that increase the ability of the water to hold more dissolved gases) and seasonally increasing wind stress and mixing. Higher daytime values are also often associated with increases in phytoplankton production (chlorophyll *a*) and typically account for many of the unusually high observed values. Unlike the dissolved oxygen data from the fixed HBMP monitoring stations, observations from the moving, isohaline-based sites indicate that measured dissolved oxygen levels have actually progressively increased over time. A potential mechanism that might explain these apparent increases may be related to the previously discussed higher summer freshwater inflows. Increases in summer flows result in higher average nutrient (inorganic and organic) loadings to the estuarine system. Increased loading may subsequently stimulate phytoplankton production, leading to an increase in higher dissolved oxygen levels. Unfortunately, any such relationship is confounded by a number of factors that include light inhibition resulting from increased water color, and periods of lag related to internal temperature dependent nutrient recycling.

- **Water Color (Pt-Co Units) –**Gaged freshwater inflows over the 23-year period of the moving, salinity based HBMP monitoring have shown statistically significant increases in average annual flows primarily associated with higher periods of summer rainfall. The two applied statistical trend test procedures indicate that these increases in wet-season flows have resulted in statistically significant increases in ambient water color within all four of the HBMP salinity zones.

- **Nitrite+Nitrate Nitrogen (mg/L) –** Graphical analyses show distinct spatial and seasonal differences in dissolved inorganic nitrite+nitrate nitrogen concentrations among the four moving lower Peace River/upper Charlotte Harbor salinity zones. Inorganic nitrogen concentrations are typically at or near detection limits in the highest salinity reaches of the estuary throughout most of the spring and summer when light levels are high and phytoplankton production is greatest. Concentrations are conversely greater at all four measured isohalines during the fall and winter months. Overall, ambient inorganic nitrogen levels progressively increase moving upstream from high to low salinities. Inorganic nitrogen concentrations also increase under higher freshwater inputs, which results in increases in water color that limit the penetration of light into the water column and subsequently reduce phytoplankton production (nitrogen uptake). The results of the Seasonal Kendall Tau trend tests found that inorganic nitrite+nitrate concentrations within the most downstream 20 psu salinity zone have slightly statistically significantly increased over time. This result corresponds with both the observed statistically significant increases in flow (primarily during the summer wet-season) and the measured increased color levels

- **Total Kjeldahl Nitrogen (mg/L) –** Combined inorganic ammonia and organic nitrogen concentrations measured as total Kjeldahl nitrogen show distinct seasonal patterns within the lower Peace River/upper Charlotte Harbor Estuary. The highest levels are typically observed throughout the estuarine system each fall following the summer wet-season. Total Kjeldahl nitrogen concentrations increase spatially from higher to lower salinities within the lower river/upper harbor estuarine system, directly reflecting the influences of freshwater inputs. However, even though average annual flows have increased due to slightly higher average summer wet-season rainfalls, the applied statistical trend procedures did not indicate that total Kjeldahl nitrogen levels have correspondingly also increased over the 1984-2006 monitoring interval.

- **Ortho-Phosphorus (mg/L) –** The most dramatic historic changes in lower Peace River/upper Charlotte Harbor ambient dissolved (and total) phosphorus concentrations occurred prior to the 1983 start of primary production and water quality monitoring at the four HBMP isohaline-based salinity zones. The presented graphical analyses for each of the four moving isohalines show that phosphorus levels continued to decline during the 1980s and 1990s. However, they also indicate that following the series of hurricanes that passed over the Peace River watershed during the summer of 2004, there has been an ongoing increase in measured phosphorus levels within each of the estuarine salinity zones. The observed declines in ambient phosphorus concentrations from the 1980s through the early 2000s in the lower river and upper harbor, followed by the recent marked increases, have resulted in the applied statistical trend tests showing no significant changes over the entire 1984-2006 time period. There are however, two distinct patterns, neither of which is indicated by analyzing for trends over the entire historical time interval. It is readily apparent that the recent increases in phosphorus concentrations directly followed the historically high flows that resulted following the 2004 series of hurricane events.

- **Silica (mg/L) –** The presented anlyses clearly show that there have been marked increases in reactive silica concentrations in the surface water of the Charlotte Harbor estuarine system. The initial increases probably began in the late 1990s, but were interrupted as a result of the very low flows during the 1999-2001 drought. Following the drought, levels in 2002 were markedly higher and have been steadily increasing through 2006. It is suspected that the observed increases in ambient reactive silica levels in the Peace River estuarine system reflect recent anthropogenic changes in the Peace River watershed. Again the sources have yet to be identified and the Authority is conducting low and high flow water quality monitoring at a number of locations in the upper watershed to help discover potential sources.

- **Chlorophyll *a* -** Previous summary HBMP reports have noted apparent declines in the frequency of phytoplankton blooms commonly observed during the early 1980s in the upper reaches of the lower Peace River. The current analyses, however suggest chlorophyll *a* phytoplankton levels have actually increased over the 1984-2006 time interval. These changes are shown to have been statistically significant within the two higher salinity zones. Higher chlorophyll levels are a reflection of the corresponding observed significant higher flows and color levels (that can serve as a proxy for nutrient loadings) that have, on average, characterized the proposed warmer AMO phase since 1995. Spatially, the highest chlorophyll *a* levels occur within the two intermediate salinity zones. During the spring, high levels of phytoplankton biomass often are observed within the 6 psu isohaline, which characterizes the zone of the estuary where nutrient rich freshwater first mixes with low nutrient harbor water. A second, often smaller peak in phytoplankton chlorophyll *a* usually occurs within the 6 psu salinity zone during the fall, as water color (inflow) decreases. Conversely, an opposite seasonal pattern occurs in the more saline 12 psu salinity zone, where nutrients (nitrogen) are more limited and the spring phytoplankton bloom is smaller, and the fall increase in response to the reduction in light limitations is more pronounced. In the reaches of the estuary characterized by the 20 psu isohaline, phytoplankton production is reduced and shows less seasonal variability, with the highest concentrations often occurring at the end of the summer wet-season.

Water quality characteristics among the four HBMP isohalines were also analyzed to determine responses to differing flow conditions. The following briefly summarizes a number of the observed patterns and primary conclusions resulting from the presented graphical and statistical comparisons made between freshwater inflows and the measured downstream variability of water quality characteristics within the four salinity zones.

- **Isohaline Location (River Kilometer) –** The relative locations of each of the four HBMP isohalines along the lower river/upper harbor monitoring transect show strong inverse relationships with freshwater inflows. Under very low flow conditions, the highest 20 psu salinity zone often extends up into the lower river. The freshwater/saltwater interface (0 psu), by comparison, can extend well downstream towards the mouth of the river during extended periods of high river flow. These relationships are confounded due to the importance of both short and long-term preceding conditions, as well as the often increasing physical stratification of the water column under conditions of higher flows.

- **Dissolved Oxygen (mg/L) –** The presented graphics indicate that as flows increase, dissolved oxygen concentrations near the freshwater/saltwater interface (0 psu) become depressed. Increasing flows result in higher water color, which reduces light levels in the water column and reduces phytoplankton growth leading to lower oxygen production. Within each of the three more brackish estuarine salinity zones, dissolved oxygen levels initially increase with flow due to higher nutrient levels and then decrease at higher flows as higher water color limits phytoplankton production. These interactions between nutrient stimulation and color inhibition mediated by flow, combined with both the physical decrease in dissolved oxygen saturation and enhanced bacterial respiration rates with higher summer temperatures, result in the observed changes in surface dissolved oxygen levels along the Peace River HBMP transect.

- **Water Color (Pt-Co Units) –** Measured color levels within the four salinity zones are significantly positively correlated with increasing flows. However, there are distinct differences in the relative patterns between color and freshwater inflow both among the isohalines and categorized flows. The strongest relationships between water color and freshwater inflows occur within the lower two salinity zones over low to intermediate ranges of flows. The relationships between color and flow within the 12 and 20 psu isohalines by comparison are somewhat less pronounced due to the greater dilution by low color/higher salinity waters. Color levels within all four isohalines typically become asymptotic, and then begin to decline with higher flows as color levels in the freshwater inflows from the watershed begin to decline under high flow conditions.

- **Nitrite+Nitrate Nitrogen (mg/L) –** The relationships between dissolved inorganic nitrogen concentrations and freshwater inflow at the four estuarine isohalines are complex. Under low to moderate levels of flow, nitrogen stimulates phytoplankton production and ambient levels can be near detection limits throughout much of the lower Peace River/upper Charlotte Harbor estuarine system. However, as flows increase and the river estuarine phytoplankton primary production becomes color rather than nitrogen limited, ambient inorganic nitrogen levels increase with increasing flow. However, measured inorganic nitrogen concentrations often decline again as river flows further increase. Higher levels of accumulated nitrogen are often associated with the initial periods of seasonal runoff from the watershed. Increased volumes and rates of surface water runoff (sheetflow) also limit contact time, further reducing both color and inorganic nitrogen concentrations.

- **Total Kjeldahl Nitrogen (mg/L) –** Total Kjeldahl nitrogen measures both organic nitrogen and inorganic ammonia/ammonium. Concentrations within the 0, 6 and 12 psu isohalines initially increase in response to higher freshwater inflows, and then quickly levels off. Total Kjeldahl nitrogen levels within the 20 psu isohaline by comparison do not show any distinct patterns with regard to changes in river flows.

- **Ortho-Phosphorus (mg/L) –** Concentrations within each of the four isohalines progressively decline as flows increase. Phosphorus concentrations within the lower river and upper harbor seasonally decline as rainfall increases and the relative importance of ground water inputs versus surface flows declines.

- **Silica (mg/L) –** Concentration within the 0, 6 and 12 psu isohalines initially increase in response to higher freshwater inflows, and then quickly become asymptotic, while concentrations within the 20 psu isohaline do not show any distinct, consistent patterns with changes in river flows.

- **Chlorophyll *a* (mg/m^3) –** Higher flows result in a number of interacting confounding factors that ultimately affect resultant phytoplankton biomass (chlorophyll *a* concentrations) within the estuarine system. Higher rates of freshwater inflow increase inorganic nitrogen loading that simulates phytoplankton production, while at the same time higher color levels simultaneously reduce the ability of light to penetrate the water column and reduces phytoplankton production. Higher rates of flow also reduce the physical hydraulic residence time within the lower river and effectively "flushes" phytoplankton populations further downstream, in effect limiting the buildup of higher chlorophyll concentrations. Chlorophyll concentrations within the 0 and 6 psu isohalines both show higher levels in response to low to moderate increases in inflows and higher nitrogen inputs. However, measured chlorophyll *a* concentrations then decline as factors such as color and residence time become increasingly important. The direct relationships between chlorophyll a concentrations and flow are less distinct at the higher two salinity zone.

5.0 Influences of Increasing Conductivity in the Lower Peace River Watershed

The recently completed *Peace River Cumulative Impact Study* (PBS&J, 2007) identified anthropogenically driven trends of increasing specific conductance within some of the major tributaries to the lower Peace River. These changes over recent decades have been primarily associated with increasing land conversions from less to more intense forms of agriculture that increasingly rely on irrigation using higher conductivity water pumped from the upper Floridan aquifer(see **Figures 4.1** through **4.4**). The primary purpose of this chapter is to evaluate patterns and historical trends in specific conductance and associated water quality characteristics measured at the Peace River at Arcadia gage, and within both the Joshua and Horse Creek tributaries located upstream of the Peace River Facility. Historic changes in conductivity and other allied constituents at these locations are compared and contrasted with long-term data collected at the HBMP fixed sampling site at River Kilometer (RK) 30.4 (old EQL Station 18), which is located immediately upstream of the Peace River Facility. It is logical to infer that during seasonally dry periods, when low flows in both the Horse and Joshua Creek systems are being artificially augmented by high conductivity ground water, downstream conductivities at the Facility may also have been progressively affected over time. The results of the presented series of analyses are discussed relative to their potential influences on Facility operations.

The major water quality parameters observed to have been increasing over time in the lower Peace River tributaries are specific conductance and total dissolved solids (TDS). Unfortunately, consistent, long-term TDS information at these locations is not readily available. Chloride levels however are a prevalent component of total dissolved solid measurements, and a much more commonly sampled water quality parameter. Chloride levels can fortunately often serve as a proxy for TDS concentrations due to their strong correlations. Class I waters designated for potable water supplies under Florida Administrative Code rule 62-302.400 are required to meet maximum concentration standards for specific conductance, chloride, and TDS of 1275 uS/cm, 250 mg/l, and 1000 mg/l, respectively. The lower portion of Horse Creek from the northern border of Section 14, T38S, R23E, southward to the Peace River is designated as Class I waters. However, neither the lower Peace River, nor the Joshua Creek tributary, upstream of the Facility are currently classified as Class I waterbodies. The Southwest Florida Water Management District (District), however, was concerned relative due to the history of increasingly elevated levels of chloride, TDS, and specific conductance in the Prairie/Shell Creek and Joshua Creek basins resulting from increased agricultural use of highly mineralized water from the lower intermediate aquifer and upper Floridan aquifer. In response, the District developed the *Shell Creek and Prairie Creek Watersheds Management Plan* (SWFWMD 2004) that also included the Joshua Creek basin. The overall stated goal of this reasonable assurance plan was to reduce specific conductance levels, using such concentrations as surrogate measures for both chloride and TDS concentrations. The District chose to use a specific conductance below 775 uS/cm, based on analysis of historical watershed data, to insure compliance with Class I standards for chloride and TDS levels. The District selected specific conductance goal of 775 uS/cm in these basins equates to chloride concentrations of approximately 150 mg/l and TDS concentrations below 500 mg/l.

Historical data collected in conjunction with U.S. Geological Survey (USGS) and District long-term ambient southwest Florida surface water monitoring programs, and the Peace River HBMP were combined for the following series of analyses. These data were divided into dry-season (November through June) and wet-season (July through October) subsets in order to provide comparative analyses among the selected station locations.

5.1 Peace River at Arcadia

The Peace River at Arcadia basin is approximately 128,186 acres in size and located almost directly at the center of the larger Peace River watershed. It extends north from the USGS Peace River at Arcadia gage north, upstream to just south of Zolfo Springs. The largest portion of the basin is located in Hardee County, while the southern part of the basin between Arcadia and Peace River's confluence with Charlie Creek lies within DeSoto County. Between the mid-1940s and 1999 (the last year for which detailed land use information is currently available), improved pasture lands in the basin increased from less than 5 thousand acres to more than 45 thousand acres, while intense agriculture changed from approximately ten thousand acres to more than 25 thousand acres.

The Peace River at Arcadia USGS gage (2296750) has the longest historic record (1931–present) of any of the gages in the Peace River watershed. It is also the most downstream gage located along the main stem of the river and includes flows not only from the immediate basin, but also from the upstream Bartow and Zolfo Springs watershed basins, as well as the Payne and Charlie Creek tributary basins. Figure 5.1 indicates time-series plots of both the monthly minimum and 10th percentile flows at the Peace River at Arcadia gage over the 1931-2006 time period. Historic losses of flows from springs and seeps have been one of the factors that have affected base flow to the upper portion of the Peace River (see discussions in Chapter 3). Base flows in both the upper and middle Peace River have also been affected by changes in discharges and drainage alterations associated with urbanization, phosphate mining, and more intense forms of agriculture. Statistical trend tests using the Seasonal Kendall Tau procedure summarized in Table 3.19 found that over periods of time from the 1940s and 1950s to present these anthropogenic alterations have resulted in statistically significant declines in minimum and low flows at the Peace River at Arcadia gage.

Specific conductance values historically measured by USGS and more recently by the District at the Peace River at Arcadia gage site have ranged from a low of only 22 uS/cm (July 1, 1966) to a high of 645 uS/cm (June 7, 2000). Seasonal analyses of the data indicate that the highest mean and median specific conductance values occur in May following the typically spring dry-season, while the lowest mean and median levels are observed in August during the summer wet-season. Historically, the lowest measured chloride level at the Peace River at Arcadia was 0.7 mg/l (June 25, 1959) and the highest was 51 mg/l (May 1, 1963). Seasonally, May (20.3) has had the highest average mean chloride concentration, while July (14.8) has had the lowest. The highest median concentration occurred in 1985 (24.5 mg/l).

These values at the Peace River at Arcadia site have to date been below the standards set by the District for the downstream Joshua and Shell Creek tributary basins. The data however clearly indicate that both specific conductance and chloride concentrations have both increased over time during periods of low flow. This is illustrated by plotting the measured specific conductance levels and chloride concentrations during flow conditions in the 10th percentile of any given month (**Figures 5.2** and **5.3**). These graphics show that the largest increases occurred from the 1960s to the early 1980s and levels under low flow conditions have remained relatively stable since. This pattern reflects the natural differences of upper Floridan aquifer water quality characteristics over the Peace River watershed. Aquifer conductivity and chloride levels in the upper and middle portions of the watershed are much lower than those further south and west (**Figure 5.4**) and so maximum concentrations observed at Arcadia are expected to be much lower than those observed in the southern tributaries. Time-series figures of specific conductance and chloride levels under all flow conditions (**Figures 5.5** and **5.6**) clearly indicate that concentrations of these two water quality parameters measured at the Peace River at Arcadia gage have steadily increased over time, plainly indicating increasing seasonal contributions of higher conductivity ground water into the middle portions of the Peace River.

5.2 Joshua Creek at Nocatee

Joshua Creek is located in the southeast portion of the Peace River watershed in Desoto County and is the smallest basin (77,391 acres) in the Peace River watershed. Joshua Creek begins in northeastern DeSoto County and flows southwest to where it joins the Peace River downstream of the Peace River at Arcadia gage at a point slightly upstream from Nocatee in central DeSoto County (Estevez et al. 1984). The basin contains two smaller tributaries, Hawthorne Creek and Hog Bay that flow into the lower reach of Joshua Creek just upstream of its confluence with the Peace River. Further upstream above the town of Joshua, both Lake Slough and Honey Run flow into the creek, although the creek channel is very poorly defined in this area.

Land use in this basin has historically changed from predominantly native habitats and unimproved pasture in the 1940s to extensive areas of improved pasture and more intense forms of agriculture such as citrus and row crops by the late 1990s. Approximately 73 percent of the land use in the Joshua Creek basin by 1999 was in agricultural use (nearly 56 thousand acres), with 29 percent (approximately 24 thousand acres) of the basin being utilized for citrus production (PBS&J 2007). These changes to more intense forms of agriculture are reflected in the historic changes in the water chemistry of Joshua Creek, which over recent decades has seen large increases in concentrations of both specific conductance and total dissolved solids. These increases, as previously described, are associated with surface drainage of agricultural discharges of high conductivity ground water from the upper Floridan aquifer into Joshua Creek.

The flow record for the USGS Joshua Creek near Nocatee gage (02297100) dates back to 1950 (**Table 3.6**). The augmentation of flow over the past two decades resulting from agricultural discharges is most apparent during naturally occurring seasonal low flow periods, when irrigation is vital to agriculture. Minimum and 10th percentile (exceeded 90 percent of the time) flows each month were plotted over the historic period (**Figure 5.7**). The resulting figure clearly indicates distinct patterns of increasing flows at the low ends of the flow range. The results of the Seasonal Kendall Tau trend tests summarized in **Tables 3.18** and **3.19** further indicate that increases in Joshua Creek flows have also been statistically significant at intermediate and higher flows.

The *Shell Creek and Prairie Creek Watersheds Management Plan* (SWFWMD 2004) addressed these specific water quality issues in Joshua Creek, acknowledging that pumping highly mineralized water from the upper Floridan aquifer for agricultural irrigation is the primary contributing factor to the observed water quality degradation in Joshua Creek. Irrigation discharges reach Joshua Creek through both direct runoff and surficial leaching. The watershed management plan proposed basin target levels corresponding to the state standards for Class I (SWFWMD 2004) not to be exceeded at any time by 2014. Continuous specific conductance data recorders were installed in December 2001 to obtain daily average annual measurements as part of the District's enhanced basin monitoring program. The total number of specific conductance samples annually measured prior to this time ranged from 0 to 24.

It was unusual prior to the 1990s for measured specific conductance levels at the Joshua Creek gage to exceed 775 uS/cm, and in fact before the extended 1999-2001 drought no measurements had exceeded 1275 uS/cm (**Table 5.1**). However, since 1999 approximately half of the measured specific conductance values have been over 775 uS/cm, and seven percent of all values have been above the higher 1275 uS/cm standard. Time-series plots of specific conductance under low and all flow conditions clearly indicate that specific conductance has been increasing in Joshua Creek over time (**Figures 5.8** and **5.9**). The highest concentrations were observed during the 1999-2001 droughts, while the recent dip reflects the much wetter than usual conditions that characterized both 2004 and 2005. Similar plots of chloride concentration show increasing changes in concentrations (**Figures 5.10** and **5.11**). Sampling frequency for chloride is lesser than for specific conductance, and there were relatively few samples taken during low flow conditions. It seems clear from **Figure 5.11** that chloride concentrations spiked during the 1999-2001 drought before dropping in the subsequent wet period. The available data indicate that water quality in Joshua Creek has undergone substantial chemical changes over time. These changes in conductivity and related water quality parameters stem from agricultural irrigation practices throughout the basin and have recently been particularly prevalent during drought conditions.

5.3 Horse Creek near Arcadia

The Horse Creek basin is approximately 128,435 acres in size, and drains approximately 241 square miles in the western portion of the Peace River watershed (Lewelling 1997). Horse Creek flows south approximately 43 miles along the southwestern portion of the Peace River watershed, running primarily through Hardee and DeSoto counties, although the western edges of the basin include small portions of Hillsborough, Polk, and Manatee counties. The West Fork of Horse Creek and Brushy Creek both originate in the Polk uplands. These drainage areas have been heavily ditched, resulting in the rapid drainage of surface flows (Lewelling 1997). Other Horse Creek tributaries in the central and southern portions of the basin originate in the DeSoto plains/Gulf coast lowlands. These tributaries include the Elder Branch and Cypress Branch which flow into Horse Creek in Hardee County. The slower, meandering Buzzard Roost Branch and Brandy Branch enter Horse Creek further south near Pine Level in DeSoto County. Ultimately, Horse Creek at its southern end joins the Peace River near Fort Ogden (PBS&J 2007).

The unconfined surficial aquifer in the Horse Creek basin is permeable and contiguous with the land surface, while the intermediate aquifer is primarily recharged with water from the surficial aquifer, sinkholes, and abandoned mine pits that breach the upper confining layers (Lewelling

1997). Both the intermediate and Floridan aquifers are under confined conditions in the Horse Creek basin and may contribute to the artesian flow in portions of the Horse Creek drainage area (Cowherd et al. 1984). Water used in the Horse Creek basin is drawn from the upper Floridan aquifer for use by industrial and agricultural interests (PBS&J 2007).

In the south basin, the head of the intermediate aquifer is higher than that of the surficial aquifer, resulting in intermediate aquifer ground water moving upward into the surficial aquifer and then discharging into the creek (PBS&J 2007). In other portions of the basin, however, ground water use has historically reduced the potentiometeric surface of the lower aquifers and base flow is predominantly due to agricultural ground water discharges. There have been a number of land use changes in the Horse Creek basin that have influenced basin flows. Phosphate mining has moved south from the Payne Creek basin and continues to expand into the adjoining northern areas of the Horse Creek basin. Agriculture and urban development have both at the same time expanded in the more southern portions of the basin. Agriculture in 1999 accounted for just under half of the Horse Creek basin's land use, with ten percent (approximately 12 thousand acres) being in intense forms of agriculture (citrus and row crops).

There are two USGS stream flow gages within the basin. The northern, upstream Horse Creek gage located near Myakka City gage has a continuous flow record extending back to only 1978. The period-of-record for the southern, downstream Horse Creek near Arcadia USGS gage (2297310) in comparison began in 1950. When the monthly minimum and tenth percentile flows are plotted over time several long-term patterns are apparent (**Figure 5.12**). Up to the early 1960s low flows in the lower Horse Creek basin were increasing, and then flows declined until the late 1970s. These patterns roughly correspond with similar historic flow patterns in other Peace River watershed basins and can be directly linked to long-term cyclical rainfall patterns (**Chapter 3**). Horse Creek base flows however have been increasing since the early 1980s (**Table 3.19**). This in direct contrast to the low flow declines observed over the same time period in the upper Peace River watershed basins. The observed increases in Horse Creek base flows, as discussed previously, are directly attributable to increasing rates of agricultural ground water discharges.

Graphical time-series plots indicate that specific conductance levels have steadily been increasing at the lower Horse Creek station over an extended period of time (**Figures 5.13** and **5.14**). Concentrations are generally the highest during the seasonal dry spring and other periods of low flow, such as during the 1999-2001 drought. Measured concentrations have never exceeded 1275 uS/cm, while the District's goal of 775 uS/cm set for nearby basins has been exceeded a number of times. The number of samples annually measured over the period-of-record has ranged from one to seventeen, with highest frequency of samples having been taken during recent years. The highest percentage of exceedances occurred in 2001, when levels above 775 uS/cm were measured during four separate months (**Table 5.2**). Plots of chloride concentration over time (**Figures 5.15** and **5.16**) also indicate that chloride levels have similarly been increasing. Ultimately the data indicate that specific conductance and chloride have been increasing in Horse Creek, primarily due to augmented base flow by surface discharges of highly mineralized deep aquifer ground water. Specific conductance concentrations during dry periods have exceeded the protective levels set forth by the District in the *Shell Creek and Prairie Creek Watersheds Management Plan.*

5.4 Peace River Kilometer 30.4 (Station 18)

Monthly samples have been taken as part of the fixed station HBMP water quality monitoring program just upstream of the Peace River Facility at RK 30.4 or "Station 18." The fixed station monitoring began in 1976, ceased in 1990, and then resumed in 1996 in conjunction with the renewal of the Facility's current water use permit. The data from this location has been of special interest due to its proximity to the Facility. The sampling frequency was therefore increased in 1996 to twice monthly. The overall available data at this site is somewhat less temporally comprehensive than the previously discussed upstream watershed sites due to the 1990-1995 break in data collection.

When the Peace River at Arcadia flows are low (90-110 cfs) over an extended period of time, the reach of the lower Peace River near the Facility is often tidally subject to intrusions of brackish waters. However, beyond such low flow occurrences, the primary seasonal influences on specific conductance (and other associated water quality parameters) measured immediately upstream of the Facility are constituents contained in combined flows moving downstream from the Peace River at Arcadia, Joshua Creek at Nocatee, and Horse Creek near Arcadia stations. In order to characterize potential trends in specific conductance at RK 30.4, sampling events were removed from the data when Peace River at Arcadia flows were less than 130 cfs to assure that measured conductivities were not actually influenced by unusual tidal and/or wind driven conditions. The use of such an exclusion criterion removed a large number of the samples taken between 1999 and 2001, when the region was experiencing an extended drought and flows were consistently low over long intervals. The resulting data were then split into wet (June through September) and dry (October through May) season subsets and analyzed separately.

Interestingly, when the wet- and dry-season specific conductance measurements at RK 30.4 are compared, there are not large differences in the slopes of the averaged fitted lines over time (**Figures 5.17** and **5.18**). The factor that appears to be more influential than seasonal variability is interannual differences in precipitation. The period of 1999 to 2001 was relatively quite dry in comparison to 2002 through 2004, and during the drought measured levels of specific conductance and chloride were moderately higher. The prior removal of extreme low flow conditions from the analyses assured that the observed high levels of specific conductance and chloride did not stem from tidal influences, but rather were the result of the addition of these constituents upstream of the Facility.

When specific conductance or chloride concentrations at RK 30.4 are plotted alongside corresponding measurements from the upstream Peace River at Arcadia, Joshua Creek, and Horse Creek stations (**Figure 5.19** and **5.20**), it is evident that Joshua Creek consistently has much higher measured concentrations than any of the other locations. This result is not surprising given the extent of agricultural use of the highly mineralized upper Floridan ground water in the basin. These graphical results indicate that conductivity concentrations near the Facility are generally between the high Joshua Creek levels, and the somewhat lower concentrations measured in the Peace River at Arcadia and Horse Creek.

Plotted smooth data lines of the relative annual contributions of the upstream gages to flows at the Facility (**Figure 5.21**) indicate that over time the proportion from the Peace River at Arcadia station has been decreasing, while the relative contributions from Horse and Joshua Creeks have increasing. The proportion of flow coming from Horse and Joshua Creeks during drought years has increased dramatically (**Table 5.3**). In 2000 the annual combined mean flow upstream of the Facility was only 221 cfs (median 99 cfs), and the relative contributions of Joshua and Horse Creeks were respectively 24.5 percent and 10.7 percent. The annual average contribution of Joshua Creek prior to 1985 had only exceeded 8 percent on only one occasion, 1958 (10.21 percent). The annual average contribution from Joshua Creek has been higher than 8 percent for 20 of the 22 years between 1985 and 2006. The increasing relative importance of Joshua Creek flows during dry periods has resulted from a decoupling of rainfall and basin flow due to agricultural augmentation of flow. High levels of agricultural ground water pumping during drier periods increases Joshua Creek flows, while correspondingly the Peace River at Arcadia and Horse Creek receive proportionally smaller ground water inputs. Plots of specific conductance and chloride concentration in Joshua Creek clearly illustrate not just an increasing change over time, but considerable interannual variability dependent on rainfall. The median specific conductance of Joshua Creek in 2000, an extremely dry year, was 1344 uS/cm. This is in contrast to 2003, a wetter year, during which median specific conductance in Joshua Creek was 882 uS/cm. Prior to the 1990s median annual specific conductance in Joshua Creek did not exceed 710 uS/cm. Chloride levels in Joshua Creek have been high enough that, even though Joshua Creek does not provide the lion's share of flow, during low flow periods it has provided more than twice the combined chloride load of both Horse Creek and the Peace River at Arcadia. This result supports the conclusion that increasing levels of specific conductance and chloride in Joshua Creek, coupled with an increasing proportion of dry-season flow from Joshua Creek, have acted to increase levels of these constituents at RK 30.4.

5.5 Potential Impacts on Peace River Facility Operations

There are several standards for specific conductance that are worthy of comparison in order to place the observed changes in specific conductance at RK 30.4 into perspective. These include the previously discussed Class I 1275 uS/cm specific conductance and 250 mg/l chloride criteria, and the 775 uS/cm specific conductance value established in the District's *Shell Creek and Prairie Creek Watersheds Management Plan* (SWFWMD 2004). The 775 uS/cm specific conductance value is also important in the lower Peace River, since it represents the level above which the Facility finds it difficult to process water using its currently available treatment methods. When potentially tidally influenced (low flow) conditions are removed from the dataset the specific conductance at RK 30.4, just upstream of the Facility, does not exceed the 900 uS/cm level except for one suspiciously high sample on October 15, 1986 (3450 uS/cm) which had a concurrently measured chloride concentration of just 20 mg/l.

High specific conductance and TDS levels originating from upriver agricultural discharges during the dry-season have yet to be a serious hindrance to water supply. The brackish water wedge moving upstream is only a problem when there are not adequate river flows. Prior to the temporary emergency exception in December 2006, the water use permit did not allow water withdrawals when measured flows at the Peace River at Arcadia gage were less than 130 cfs. This level of flow adequately removes the likelihood, except under very rare instances, that salt water intrusion due to low flows will affect Facility operations. This is not to say that specific conductance and TDS from upstream sites will not become a problem in the future. If specific conductance and TDS continue to increase in the contributing upstream basins, it is possible that at some point high conductivity levels may affect the functioning of the Facility. The potential for this to occur is particularly high during low flow conditions. Reducing agricultural ground water pumping in these upstream basins would effectively decrease such potential impacts to Facility operations, however it would also substantially reduce the total dry-season flows to the Facility. Recall that during recent low flow periods augmented Joshua Creek flows have provided a substantial proportion of the total flow to the Facility. To a great extent the historic declines in base flow due to the anthropogenic losses of spring flows in the upper Peace River watershed have subsequently been replaced by agricultural discharges in the southern watershed basins. Future reductions of these artificially augmented flows without corresponding restoration of upper watershed base flows may have the unintended consequence of shifting the salt wedge further upriver and increasing the frequency of time during which the Facility is unable to withdraw water during low flow conditions. It is important to realize that these issues are particularly pertinent seasonally towards the end of the spring dry-season, or during periods of droughts when there are anthropogenically increased TDS loads from the immediate upstream basins, combined with the movement of the salt wedge upriver.

5.6 Summary

This chapter evaluates patterns and historical trends in specific conductance and associated water quality characteristics measured at the Peace River at Arcadia gage, and within both the Joshua and Horse Creek tributaries located upstream of the Peace River Facility. Historic changes in conductivity and other allied constituents at these locations are compared and contrasted with long-term data collected at the HBMP fixed sampling site at RK 30.4, which is located immediately upstream of the Peace River Facility. It is logical to infer that during seasonally dry periods, when low flows in both the Horse and Joshua Creek systems are being artificially augmented by high conductivity ground water, downstream conductivities at the Facility may also have been progressively affected over time. The results of the presented series of analyses are discussed relative to their potential influences on Facility operations.

5.6.1 Peace River at Arcadia

The following summarizes the findings for the Peace River at Arcadia site.

- Seasonal analyses of the data indicate that the highest mean and median concentrations occur in May following the typically spring dry-season, while the lowest mean and median levels are observed in August during the summer wet-season.

- The data however clearly indicate that both specific conductance and chloride concentrations have both increased over time during periods of low flow, and that the largest increases occurred from the 1960s to the early 1980s. This corresponds with the time period of relatively large phosphate mining discharges to the upper river.

- Time-series figures of specific conductance and chloride levels under all flow conditions clearly indicate that concentrations of these two water quality parameters measured at the Peace River at Arcadia gage have steadily increased over time, plainly indicating increasing seasonal contributions of higher conductivity ground water into the middle portions of the Peace River.

5.6.2 Joshua Creek at Nocatee

The following summarizes the findings for the Joshua Creek at Nocatee site.

- It was unusual before the 1990s for measured specific conductance levels at the Joshua Creek gage to exceed 775 uS/cm, and prior the extended 1999-2001 drought no measurements had exceeded 1275 uS/cm.

- However, since 1999 approximately half of the measured specific conductance values have been over 775 uS/cm, and seven percent of all values have been above the higher 1275 uS/cm standard.

- Time-series plots of specific conductance under low and all flow conditions clearly indicate that specific conductance has been increasing in Joshua Creek over time. The highest concentrations were observed during the 1999-2001 drought, while the recent dip reflects the much wetter than usual conditions that characterized both 2004 and 2005.

5.6.3 Horse Creek near Arcadia

The following summarizes the findings for the Horse Creek near Arcadia site.

- Time-series plots indicate that specific conductance levels have steadily been increasing at the lower Horse Creek station over an extended period of time.

- Concentrations are generally the highest during the seasonal dry spring and other periods of low flow, such as during the 1999-2001 drought.

- The data indicate that specific conductance and chloride have been increasing in Horse Creek, primarily due to augmented base flow by surface discharges of highly mineralized deep aquifer ground water. Specific conductance concentrations during dry periods however have exceeded the protective levels set forth by the District in the *Shell Creek and Prairie Creek Watersheds Management Plan.*

5.6.4 Peace River Kilometer 30.4

The following summarizes the findings for the Peace RK 30.4.

- When the wet- and dry-season specific conductance measurements are compared, there are not large differences in the slopes of the averaged fitted lines over time.

- The results show that both conductance and chlorides have been progressively increasing over time.

- When specific conductance or chloride concentrations are plotted alongside corresponding measurements from the upstream Peace River at Arcadia, Joshua Creek, and Horse Creek stations, it is evident that Joshua Creek consistently has much higher measured concentrations than any of the other locations.

- Analyses of the relative annual flow contributions of the upstream gages to total gaged flows at the Facility indicate that over time the proportion from the Peace River at Arcadia station has been decreasing, while the relative contributions from Horse and Joshua Creeks have increasing. The proportion of flow coming from Horse and Joshua Creeks during drought years increased dramatically.

- The increasing relative importance of Joshua Creek flows during dry periods has resulted from a decoupling of rainfall and basin flow due to agricultural augmentation of flow.

5.6.5 Potential Impacts on Facility Operations

- High specific conductance and TDS levels originating from upriver agricultural discharges during the dry-season have yet to be a serious hindrance to water supply. This is not to say that specific conductance and TDS from upstream sites may not become a problem in the future. If specific conductance and TDS continue to increase in the contributing upstream basins, it is possible that at some point high conductivity levels may affect the functioning of the Facility, particularly during low flow conditions

- Brackish water moving upstream has typically only been problem when there are not adequate river flows. Prior to the temporary emergency exception in December 2006, the water use permit did not allow water withdrawals when measured flows at the Peace River at Arcadia gage were less than 130 cfs. This level of flow adequately removed the likelihood, except under very rare instances, that salt water intrusion would affect Facility operations.

- To a great extent the historic declines in base flow due to the anthropogenic losses of spring flows in the upper Peace River watershed have subsequently been replaced by agricultural discharges in the southern watershed basins. Future reductions of these artificially augmented flows without corresponding restoration of upper watershed base flows may have the unintended consequence of shifting the salt wedge further upriver and increasing the frequency of time during which the Facility is unable to withdraw water during low flow conditions. It is important to realize that these issues are particularly pertinent seasonally towards the end of the spring dry-season, or during periods of droughts when there are anthropogenically increased TDS loads from the immediate upstream basins, combined with the upstream movement of the estuarine salt wedge.

6.0 Salinity/Flow/Withdrawal Relationships at the Continuous Recorders

6.1 Introduction and Overview

Analyses conducted in previous Hydrobiological Monitoring Program (HBMP) *Mid-Term* (year three) and *Comprehensive Summary* (year five) reports have developed both fixed station location and spatial statistical models. These models were subsequently used as predictive tools to assess the magnitude of potential salinity changes due to both historic actual and potential maximum permitted withdrawals by the Peace River/Manasota Regional Water Supply Authority's (Authority) Peace River Facility's water use permit. The primary objective of this chapter is to determine statistical relationships between flows, tide stage, and withdrawals at both the two long-term (1996-2006) fixed U.S. Geological Survey (USGS) continuous gages, and the three newly installed (2006) HBMP continuous recorders. The results of these analyses are then used to predict salinity changes due to Facility withdrawals. These findings are then compared and contrasted with the results of other previous salinity models, setting the stage for Chapter 7. The following summarizes the different analytical procedures presented in this chapter.

- The general temporal characteristics of the data are summarized describing seasonal differences among the information from each of the five available continuous recorder locations.

    1. Period-of-record.

    2. Tidal variations.

    3. Frequency distribution of salinity values (ranges of daily and seasonal variability under differing flow conditions).

- Updated statistical salinity models are presented using freshwater inflows, stage, and withdrawals data through 2006 from the USGS Harbour Heights and Peace River Heights continuous recorders.

- New similar statistical models of surface salinity are developed at each of the three recently installed HBMP recorder locations using freshwater inflows, withdrawals, and estimated stage from the two USGS recorders.

- The resulting statistical models are then applied to determine the predicted magnitudes of both recent and maximum permitted withdrawals under the Facility's current Southwest Florida Water Management District (District) water use permit.

6.1.1 USGS Continuous Recorders

The USGS began a cooperative water quality data collection program with the Authority in August 1996. An initial USGS continuous recorder (15-minute intervals) was installed later that month in the lower river at the end of an exiting private dock at Harbour Heights (River

Kilometer (RK) 15.5). This USGS gaging site (02297460) monitors water level, surface and bottom specific conductance, and temperature.

The USGS added a second continuous recorder at the request of the Authority in November 1997 further upstream (RK 26.7) on a private dock near Peace River Heights (**Figure 6.1**). This USGS site (02297350) also measures water level, surface and bottom specific conductance, and corresponding temperatures at 15-minute intervals.

Water level measurements at these two USGS recording sites are made utilizing a float sensor in a PVC stilling well. USGS combination temperature and specific conductance probes are used to measure near-surface and near-bottom specific conductance and temperature. The near-surface sensors are suspended one-foot below the surface using a float, while the near-bottom sensors are suspended about one-foot from the bottom in the same stilling well. Readings are electronically averaged over two-minute intervals and recorded at 15-minute intervals using a Campbell Scientific CR-10 electronic data logger. Data are retrieved and the sensors are recalibrated at approximately monthly intervals.

The particular locations of the USGS recorders on existing docks were established in part due to the USGS need to be able to have land based access for the ease of routine maintenance and the downloading of data. The influences of tide, wind and antecedent flow conditions can individually and combined result in an extremely wide range of observed variation in daily averaged conductivity measurements at the Harbour Heights gage located at RK 15.5 when compared to corresponding flows at the Peace River at Arcadia gage (**Figures 6.2** and **6.3**). The influences of these confounding affects by comparison are noticeably less at the more upstream USGS Peace River Heights gaging site located at RK 26.7 (**Figures 6.4** and **6.5**).

Table 6.1
Average Daily Conductivity Versus Flow at USGS Continuous Recorders

USGS Gage / River Kilometer	Subsurface Conductivity	Near Bottom Conductivity
Harbour Heights (RK 15.5)	**Figure 6.2**	**Figure 6.3**
Peace River Heights (RK 26.7)	**Figure 6.4**	**Figure 6.5**

The 1996 renewal of the Facility's Water Use Permit set a threshold of 130 cfs at the USGS Peace River at Arcadia gage for the start of freshwater withdrawals (in December 2006 this was reduced to 90 cfs due to extreme drought conditions). However, as shown in Table 6.1, salinity levels are often extremely low in the reach of the river (River Kilometer 26.7) at the Peace River Heights USGS recorder (**Figure 6.1**), which is often characterized by freshwater conditions when flows at Arcadia are 130 cfs or greater. While the physical location of this upstream continuous recorder is appropriate to detect potential long-term systematic shifts in the freshwater/saltwater interface during low levels of freshwater inflow, it is extremely doubtful if the direct influences of the Facility withdrawals can typically be measured at this location when flows are near or above 130 cfs.

Therefore, the *2002 HBMP Comprehensive Report* (finalized in September 2004) recommended that an additional series of continuous conductivity gages be established by the Authority downstream of the USGS Peace River Heights recorder location. The primary objective of installing an additional series of HBMP continuous conductivity recorders, when combined with the two existing long-term USGS sites, was to obtain greater resolution of the direct relationships among freshwater flow, stage height, and conductivity downstream of the Facility during periods of withdrawals. The addition of these gages was specifically designed to determine potential salinity changes during Facility withdrawals within the reach of the river characterized by the movement of the freshwater/saltwater interface at flows immediately above (or below) the 130 cfs threshold. The primary objective of selected locations of these additional gages was, therefore, to assure and enhance the monitoring program's ability to directly measure salinity changes due to Facility withdrawals under lower flow conditions.

6.1.2 Recently Established HBMP Continuous Recorders

A number of possible alternative sites and deployment methodologies were evaluated by the Authority to assure that these monitoring objectives were met by the additional HBMP continuous conductivity recorders. The first step in deploying these instruments was to determine the potential spatial distribution of arraying the recorders downstream of the Facility. Again, the primary objective was to spatially maximize the new recorders' ability to detect salinity changes (impacts) that could be directly attributed to Facility freshwater withdrawals. Existing statistical models and graphical analyses of salinity/flow relationships were reviewed from the long-term HBMP fixed stations and USGS continuous recorders along the lower Peace River HBMP monitoring transect. These results were next evaluated in relationship to potential existing physical structures (docks, pilings, etc.) to which additional continuous recorders might be attached. A series of potential new monitoring sites located between the two existing USGS continuous recorders were selected and evaluated. The recent placement of a large number of Manatee Speed Zone markers along the lower river provided a series of spatially distributed potential sites downstream of the Facility. The Authority received permission from U.S. Fish and Wildlife to establish continuous recorder locations using these Manatee markers.

Three of these Manatee Speed Zone markers were chosen for the initial deployment of the new HBMP continuous recorders, and the locations of these are indicated by the light-green arrows in **Figure 6.1**.

- **MZ4 –**The Manatee Speed Zone Marker located on the Peace River near the Liverpool side channel (RK 21.9).
- **MZ3 –** The Manatee Speed Zone Marker located on the Peace River at RK 23.4.
- **MZ2 –** The Manatee Speed Zone Marker located on the Peace River just downstream of the Navigator Marina (RK 24.5).

The methodologies used for deployment of the three new continuous recorders are depicted in **Figure 6.6** and **Photographs 6.1** through **6.4**.

- **Figure 6.6** – This diagram shows the method used to attach the PVC stilling well to the deep side of the selected Manatee Speed Zone Markers, using a series of stainless steel clamps.

- **Photo 6.1** – The photograph shows actually strapping the PVC stilling well to the inside of one of the Manatee Speed Zone Markers.

- **Photo 6.2** – The method used to attach the YSI conductivity/temperature sonde to the bullet floats is shown in this photograph. The size of the bullet floats was selected based on the weight of the sonde, and the diameter of the stilling well. Unlike the USGS continuous recorders, these YSI units have been deployed to measure conductivity and temperature only just below the surface. The Manatee Speed Zone Markers are located in relatively shallow depths along the sides of the main river channel. These locations are therefore not well suited for measuring differences between surface and bottom values.

- **Photo 6.3** – This photograph shows the YSI conductivity/temperature sonde attached to two bullet floats being readied for placement in the stilling well.

- **Photo 6.4** – This last photograph shows the stilling well (with the locking cap) as seen from the river.

Data from these recorders are retrieved at approximately monthly intervals (or more often as needed). A complete cleaned, calibrated and checked set of sondes are typically deployed each month. However, if this is not possible, then the data are retrieved, the stability of the specific conductance and temperature sensors are checked, and the conductivity probes are cleaned and recalibrated. The factory calibrated temperature is checked against a second instrument, while specific conductance is calibrated against standards with values that bracket the range of expected values in the Peace River. The sensors are considered calibrated if the temperature is within 0.2 °C and specific conductance is within five percent of the standard values.

6.2 Summaries and Comparisons of the Spatial and Temporal Characteristics Measured at the Continuous Recorders

This section provides a general overview of the relative magnitudes of the spatial and temporal salinity differences that have been measured at both the two long-term USGS recorders and at the three recently installed additional HBMP locations. Seasonal and longer-term temporal variabilities in salinity have been recorded over approximately ten years of data collection at the two USGS continuous recorders, while only a single full year of data are currently available from the three HBMP recorders, which were installed in December 2005.

Table 6.2 provides annual summary statistics (mean, median, minimum and maximum) of gage height, and surface and bottom salinities at the downstream USGS continuous recorder at Harbour Heights (RK 15.5) and further upstream at Peace River Heights (RK 26.5). The following summarizes some of the observed differences and patterns shown by the presented comparisons of annual salinity variability at these two locations along the lower river.

- Minimum and maximum gage heights (water levels) indicate that the extremes between the highest and lowest annual levels can be as great as six to eight feet. Actual daily differences however are typically far lower. Differences between daily high and low water levels over the ten years of monitoring at Harbour Heights have averaged only 2.15 feet, while the greatest measured daily difference over the same period was just 5.03 feet.

- Annual mean and median gage heights at the downstream Harbour Heights recorder are much more uniform than corresponding measurements upstream at the Peace River Heights location. The results indicate that water levels further upstream are much more heavily influenced by higher flows during wet years, such as occurred during the interval between 2003 and 2005, than are corresponding measured gage heights further down stream. The implications of such observations are that seasonal differences in gage height need to be taken into account when developing statistical salinity models that rely on the interactions of flows and gage height (see Section 6.3 below). Higher gage heights during low river flows result in salinity tidally moving upstream, while higher gage heights with increasing flows reflect the combined influences of tide and the increasing resistance to downstream flow.

- Mean and median annual salinities at both USGS recorders were much higher during the extended 1999-2001 drought. The largest relative observed differences were in the maximum salinities measured at the Peace River Heights site. Peak salinities measured at this upstream site during the drought years were at least four to six times higher than the maximum annual salinity levels observed during wetter years.

- Bottom salinity measurements were systematically higher than corresponding surface measurements, and as expected the differences were greater at the downstream Harbour Heights recorder location.

Further comparisons of the measured degree of annual variability in surface and bottom salinities at the Harbour Heights and Peace River Heights sites are indicated by the box and whisker univariate plots presented in **Figures 6.7** and **6.8**. The general form of the information presented in these plots is depicted in Diagram 6.1. The "box" shows the range of annual values falling between the 25th and 75th percentiles, while the "whiskers" show the range from the minimum to the maximum values observed each year. Statistically rare events, those more than 1.5 times the range of the "box" are shown as individual points along the whiskers. **Figure 6.7** shows the relatively small annual differences between surface and bottom salinities when compared to the much greater degrees of both seasonal and annual variability at Harbour Heights (RK 15.5). Differences, again, between surface and bottom salinities further upstream at Peace River Heights (RK 26.7) were even smaller, as were the normal annual salinity ranges (from the 25th to 75th percentiles). The high degree of observed

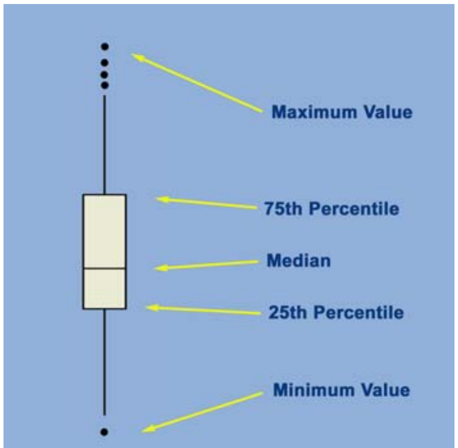

Diagram 6.1 Diagram of box and whisker plot format

annual maximum variability in the typical seasonal range in this upper reach of the river is shown to be in marked contrast to the overall very low annual median salinity levels.

Table 6.3 provides similar statistical summary comparisons of surface salinities between the two USGS recorders during 2005 (a relatively wet year) and 2006 (a relatively dry year). These annual differences between the two USGS recorder locations are further shown in **Figure 6.9**. Table 6.4 in comparison presents summary statistics that provide spatial comparisons of seasonal salinity differences in 2006, which was the first year that data were available at all five recorder locations. The average daily salinity range is shown to progressively decline moving upstream. Somewhat surprising are the relatively large daily changes in surface salinities that occur even well upstream given the right combinations of river flow, tides and wind. The range of seasonal differences among the recorders is further graphically depicted in **Figure 6.10** (annual mean values are shown by the rose colored dots). These comparisons show the relative degree of spatial variability among the recorder locations, and again indicate the large differences between annual average (mean or median) salinity levels and both the normal ranges of variation (25^{th} to 75^{th} percentiles) and more infrequent extremes.

Table 6.3
Comparisons of Annual Average Surface Salinity between Wet and Dry Years

River Kilometer	Mean Salinity (psu)	Median Salinity (psu)	Minimum Salinity (psu)	Maximum Salinity(psu)
2005 (Wet Year)				
RK 15.5	2.1	0.5	0.1	20.0
RK 26.7	0.1	0.1	0.1	3.3
2006 (Dry Year)				
RK 15.5	8.1	7.6	0.1	24.7
RK 26.7	1.1	0.3	0.1	14.1

Table 6.4
Seasonal and Daily Ranges of Salinity at the Two USGS and Three HBMP Continuous Recorders during 2006

Location	Annual Salinity Statistics				Daily Variability (∆) of Salinity Statistics			
	Mean Salinity (psu)	Median Salinity (psu)	Minimum Salinity (psu)	Maximum Salinity (psu)	Mean Salinity Change (psu)	Median Salinity Change (psu)	Minimum Salinity Change (psu)	Maximum Salinity Change (psu)
RK 15.5	8.1	7.6	0.1	24.7	6.0	6.0	0	14.3
RK 21.9	2.7	0.9	0.1	18.6	3.4	3.1	0	13.7
RK 23.4	2.0	0.5	0.1	18.3	3.1	2.3	0	14.1
RK 24.5)	1.6	0.4	0.1	16.5	2.8	1.9	0	13.3
RK 26.7	1.1	0.3	0.1	14.1	1.6	1.0	0	10.4

6.3 Statistical Models of Flow versus Salinity Relationships at the Five Continuous Recorder Locations

The principal objective of the following series of presented analyses was to update and determine statistical relationships between the measured salinity variability at each of the established five recorder locations along the lower Peace River HBMP monitoring transect (Figure 6.1). Specific ranges of flow were applied at each location to increase the resulting model's ability to be used specifically to assess salinity changes due to existing and currently permitted maximum withdrawals. Flows were cutoff at a low of 60 cfs (Peace River at Arcadia) to assure that the statistical models were not unreasonably fitted to the rapidly increasing salinities at very low flows. A similar low flow cutoff was applied in developing the specific low flow models used in the recently submitted draft of the evaluation of 2006-2007 HBMP "pump tests" (PBS&J 2007). The models developed in this report also limited flows at the high end. Unique high flow cutoffs were applied at each location once the reach of the lower river had become predominantly characterized by freshwater conditions (see Figures in Table 6.5). This again reduced the resulting statistical model's likelihood of unduly weighting its fit to lower part of the salinity/flow relationship.

Similar statistical models using the more limited data available at that time, and slightly wider ranges of flows, were previously developed for the two USGS continuous recorders as part of the *2002 HBMP Comprehensive Summary Report* (PBS&J 2004). These earlier models and those produced for the District (Janicki Environmental, 2003), further discussed below (Section 6.4), were subsequently used as predictive tools to assess the spatial extent and magnitude of possible salinity changes due to both historic and future potential maximum freshwater withdrawals under the Facility's 1996 twenty-year permit.

6.3.1 Development of Statistical Models

The presented series of site specific statistical models were developed using averaged hourly data gathered during the periods-of-record for the five continuous recording locations. The data were used to develop statistical models of salinity versus flow relationships using measured sub-surface salinities as the dependent variables, and expressions of gaged freshwater inflows minus withdrawals as well as measured stage (water level) as independent variables. The following assumptions and criteria were applied during the development of the individual statistical models.

- The modeled flow terms were limited to total daily gaged freshwater inflows measured at the Peace River at Arcadia USGS gage. Some enhancement of the models would potentially have resulted from also including corresponding gaged flows from both Horse and Joshua creeks (and for the Harbor Heights recorder location also using Shell Creek). However, these additional inputs were not included since a primary objective of the study was to determine specific relationships relative to the low flow threshold based on gaged river flows at the Arcadia gage.

- Actual daily withdrawals by the Facility were subtracted from the daily average Peace River at Arcadia flow for each observation in order to determine the final resultant flow terms.

- A second lagged, long-term cumulative flow term was then applied to the statistical models to establish some indication of background conditions and the "resident memory" associated with the characteristic of the longer-term salinity gradient within the lower river/upper harbor estuarine system.

- The 15-minute data from the continuous recorder were averaged over one-hour intervals to reduce the influences of short-term random events (such as boat wakes).

- Stage heights corresponding with the same interval of the measured salinity were added to the models to account for the daily variability in the influences of tides/wind on salinity. Water level heights were measured directly at the two USGS recorders at Harbour Heights (RK 15.5) and Peace River Heights (RK 26.7). Corresponding water levels were interpolated for the HBMP recorder locations between these two USGS sites using their relative distances (River Kilometers 21.9, 23.4 and 26.7) and the measured lags in tide stage.

- A final term was tested for each model to account for the interactions of flow with stage and tidal influences. When freshwater inflows are low (such as the spring dry-season), there are very close correlations between tidal stage and the observed daily variability in measured conductivities (salinity). However, as flow increases and overall conductivities decline, the influences of daily tidal variability on observed salinity patterns declines.

- As an initial step in the development of each statistical model, the Statistical Analysis Software (SAS) "Stepwise General Linear Model" and "RSREG" procedures were used to screen the potential significance of a number of possible applied linear, non-linear, and interactive terms. Logs of the flow term were tested to account for the often-observed curvilinear response of salinity to increasing freshwater flow. Conversely, non-transformed variables were used within the models for those independent terms found to have more linear interactions. (All model parameters were tested and met the statistical requirements for normal distributions due to the very large number of observations.)

- Using an iterative process, surface salinity models were developed for each of the continuous recorder sites using the fewest number of independent variables that were both significant at the 0.01 level and added appreciably (at least one percent) to the overall explained error of the model. In developing the statistical models, enhancement of the explained error (R-square) was considered secondary to increasing the relationships between predicted and observed salinities (model fit).

The developed statistical models used to predict salinity levels at each of the continuous recorder locations initially utilized the following generalized form. Each model was then specifically modified to include only those significant terms that directly increase the overall fit using statistically significant terms. Only a single term was selected and applied to represent multiple significant terms that were themselves highly autocorrelated (i.e. one, five and seven day lag flow terms).

$$Salinity = \beta_{\alpha} + (\beta_1 x\ Flow1) + (\beta_2 \times Flow2) + (\beta_3 x Stage) + (\beta_4 x (Stage / Flow))$$

where:

β_{α} = specific intercept

β_1 = "short-term" flow slopes (linear and/or non-linear)

β_2 = "long-term" flow slopes (linear and/or non-linear)

β_3 = gage height specific slope

β_4 = gage height/flow interaction specific slope

6.3.2 Results of Statistical Models

Table 6.5 summarizes each of the various types of analyses undertaken during the development of the statistical models for the five continuous recorder locations.

Table 6.5
Surface Salinities at the Two USGS and Three HBMP Continuous Recorders

Continuous Recorder Location	Salinity vs. Flow (used to established high flow cutoff)	Developed Statistical Model	Predicted vs. Observed Model Fit
Harbour Heights (RK 15.5)	Figure 6.11	Table 6.6	Figure 6.12
MZ4 (RK 21.9)	Figure 6.13	Table 6.7	Figure 6.14
MZ3 (RK 23.4)	Figure 6.15	Table 6.8	Figure 6.16
MZ2 (RK 24.5)	Figure 6.16	Table 6.9	Figure 6.18
Peace River Heights (RK 26.7)	Figure 6.19	Table 6.10	Figure 6.20

Figures 6.11 through **6.19** show plots comparing the different salinity/flow relationships among the recorder locations using gaged Peace River at Arcadia flows for the overall period-of-record for each recorder. These graphics include both average hourly measured salinity values as well as a fitted, smoothed line, plotted using a SAS cubic spline method that minimizes both the linear combination of the sums of squares of the residuals of the fit as well as the integral of the square of the second derivative. These figures clearly show the great degree of variability in salinity that can be observed at locations along the lower river even over a very narrow range of flows. The high degree of observed salinity variability as previously discussed results primarily from the combined influences of normal daily tidal patterns, periodic strong wind's predominantly blowing from either the north or south, and differences in preceding seasonal flow patterns that result in either higher or lower background salinity levels in upper Charlotte Harbor. The vertical lines in these figures represent the selected low flow cutoff (60 cfs at the Peace River at Arcadia gage) and the unique high flow cutoff specifically used in developing the statistical models for each location.

Tables 6.6 through **6.10** provide the detailed results of the best-fit statistical models developed for each of the five monitoring site locations. The resulting models generally ranged from explaining approximately 70 to 75 percent of the observed variation in salinity at the recorder locations. The exception was the most upstream recorder, where the resulting best-fit model explained only approximately 45 percent of the observed hourly variability in salinity due to the indicated extremely wide degree of observed salinity variability over a narrow range of flows. These tables clearly demonstrate the relative dominant importance that both stage height and flows contribute in determining salinity. Further comparisons of the Type I and Type III error terms of each of the resulting best-fit statistical models show the degree of importance of these two dominant variables as well as the interactions other factors have in determining the natural range in salinity variation observed along the lower river HBMP monitoring transect.

The relative degree of fit of the statistical models developed for each recorder location are further shown in **Figures 6.12** through **6.20**, which plots predicted versus observed values. In these figures, the black dashed line represents a regression of predicted versus observed (with the 95 percent confidence interval shown in yellow), while the solid red line shows a relative idealized one-for-one line. Overall, the plots of predicted versus observed salinities indicate that the models slightly over-predict salinities at low levels and correspondingly under-predict at higher levels. However, over the typical range of salinities observed at each of the gaging sites, the developed models provide a good fit and can generally be used to explain most of the observed variation in measured salinities given the inherent variability resulting from the interactions of flows and tides.

The developed statistical models for each of the five recorder locations were then used to predict average hour salinities over the period 1998 through 2006. This corresponds with the interval of available complete annual 15-minute gage height data for the two USGS recorders (**Figure 6.1**). Predicted salinities were made using three separate conditions.

- **No Withdrawals –** this baseline condition applied the individual developed statistical models using measured gage heights at the USGS Harbour Heights and Peace River Heights gages, and calculated gaged heights for the three intermediate HBMP locations based on the measured lags between the two USGS recorders and the relative location of each of the HBMP sites. The applied flow terms used in the models assumed no Facility withdrawals.

- **Actual Withdrawals –** the same model conditions were then run after subtracting actual daily facility withdrawals from the USGS gaged Peace River at Arcadia flows. The Facility often does not withdraw the full amount allowed under the 1996 District permit due to a number of factors that include physical limits to withdrawal capacity, and Facility maintenance and operations. There are however other instances when withdrawals have exceeded the permit’s ten percent limit and/or the established low flow threshold. Historically, the reason for these discrepancies stems from the way that flow data are gathered. The Facility uses “provisional” preceding day flow data from the water level recorder at the USGS gaging station on the Peace River at Arcadia. Such “provisional” real-time data are obtained by the Authority staff a number of times each day directly from the USGS Tampa office’s Web Site. This is accomplished in order to determine an accurate working estimate of the preceding daily Arcadia flow on which to establish the current day’s withdrawal schedule. However, after the fact, the USGS checks and evaluates the data from both the Arcadia gage stage recorder and periodic river cross section measurements collected a number of times each year. Based on such quality assurance checks the USGS may make various revisions to the recent, real-time information before establishing finalized daily flow estimates for the preceding water year. Thus, the daily values used by the Facility are only "provisional" and can and are often changed as a result of ongoing USGS data quality assurance procedures weeks or even months later. It is therefore not uncommon for subsequent determinations of percent withdrawals, based on the finalized, revised USGS calculations of the initial "provisional" daily flows, to sometimes indicate that daily withdrawals, based on initial real-time flow information, exceeded the District's permitted maximum ten percent and/or low flow cutoff.

- **Maximum Permitted Withdrawals** – the models were run again assuming unlimited physical Facility withdrawal, treatment and storage capacity to determine potential salinity levels given the maximum withdrawals allowed under the 1996 District water use permit conditions.

Summary graphical results of the modeled differences among these three alternative withdrawal scenarios are presented on an annual basis over the 1998 to 2006 time interval in Table 6.11. The depicted univariate box and whisker plots (see Section 6.2 above) indicate the predicted annual variability in salinity at each of the five continuous recorder locations under each of the three withdrawal scenarios (annual mean salinities are shown as rose colored dots). Calculated mean, median, minimum and maximum predicted annual salinity differences between the "Actual Withdrawals/No Withdrawal" and the "Maximum Withdrawal/No Withdrawal" scenarios at each of the five recorder location are further presented in **Table 6.12**.

Table 6.11
Box and Whisker Plots of Predicted Differences in Annual Average Salinities at each of the Five Recorder Locations

Year	Predicted Salinities		Predicted Salinities
1998	**Figure 6.21**	2003	**Figure 6.26**
1999	**Figure 6.22**	2004	**Figure 6.27**
2000	**Figure 6.23**	2005	**Figure 6.28**
2001	**Figure 6.24**	2006	**Figure 6.29**
2002	**Figure 6.25**		

The following conclusions can be drawn from the presented salinity comparisons based on the statistical models developed for each of the five continuous recorder locations along the HBMP lower river monitoring transect.

- The presented series of annual graphics emphasize the very high degrees of seasonal and inter-annual variability in salinity that naturally occurs along the lower Peace River. These differences are especially dramatic when relative comparisons are made among wet years (such as 1998, 2003, 2004, and 2005) and periods of comparatively much lower flows (such as 2000, 2001, and 2006).

- The graphical and tabular results generally indicate higher salinity increases occurring under the maximum withdrawals allowed by the 1996 water use permit, when compared with modeled salinity changes resulting from actual Facility withdrawals. These differences are shown to have narrowed slightly following the recent 2002 Facility expansion, and thus might be expected to narrow further following the expected 2009 completion of the ongoing next expansion.

- The annual average (mean) differences in salinities due to withdrawal were the greatest at the most downstream Harbor Heights location (RK 15.5) and became progressively smaller moving upstream, being the lowest at the Peace River Heights location (RK 26.7). This result is as expected, since as flows increase the reaches of the river near and immediately below the Facility become less and less influenced by higher salinity water moving tidally upstream. Facility withdrawals can only influence those segments of the lower river that are still tidally influenced by saltwater, and thus the further a location is downstream, the greater the percent of time that salinities can be influenced by withdrawals.

- The observation that almost all the calculated median differences in **Table 6.12** were zero indicates that at least half the time Facility withdrawals have limited (if any) influence on the salinities. Obviously the Facility cannot affect salinity during the period of time when gage flows at Peace River at Arcadia are below the District's low flow threshold. Conversely, when flows are high enough that a particular reach of the river is always characterized by freshwater conditions (**Figures 6.11**, **6.13**, **6.15**, **6.17** and **6.19**), Facility withdrawals also do not affect salinity in that portion of the lower river. A somewhat less intuitive finding of the recently completed series of "pump tests" (PBS&J 2007) was the observation that Facility withdrawals of ten percent or more even during low to moderate flows, primarily only resulted in higher observed salinities during incoming tides. Withdrawals seemed to have very little directly measurable influence on salinities during the outgoing and low phases of the daily tidal cycle. Since the presented summary statistics were based on hourly estimates (versus daily estimates), it is therefore not surprising that more than half the observations did not predict any differences in salinities with and without withdrawals.

- The mean differences shown in **Table 6.12** indicate that the largest changes in annual salinity occurred during the 2006 drought following the 2002 expansion. The annual average salinity changes due to actual Facility withdrawals ranged from approximately 0.1 psu upstream to 0.4 psu downstream.

- Predicted maximum salinity differences due to Facility withdrawals are shown to typically range from approximately 0.6 psu to 1.5 psu, with the largest predicted salinity increases occurring not at the most downstream Harbour Heights recorder location, but rather spatially further upstream at the intermediate recorder locations along the HBMP monitoring transect. Again, these results are similar to the physical observations recorded during the recently completed HBMP Facility "pump tests." These results showed measurable salinity changes of similar magnitudes due to withdrawals that were temporally confined to the top end of incoming tides. Spatially, the maximum observed salinity changes during the "pump tests" were determined by the relative location of the saltwater/freshwater interface, which is a function of the interactions of both flows and tides. The predicted results of the statistical models based on hourly estimated salinities are, therefore, supported by the observed findings of the Facility "pump tests."

6.4 Comparisons with the Results of Previous Modeling Efforts

The preceding statistical models presented in this section were specifically developed from hourly averaged data gathered over the period-of-record at each of the current five continuous recorder locations along the lower Peace River monitoring transect (**Figure 6.1**). These models were then used to predict salinity changes due to Facility withdrawals using actual measured hourly variations in gage height with daily averaged rates of freshwater inflows and withdrawals. Historically, there have been a number of previous modeling efforts that have similarly attempted to quantify the potential impacts of Peace River Facility withdrawals on both the salinity structure of the lower river as well as the movement of specific isohalines. These previous efforts generally relied on monthly or daily averaged values and typically did not include hourly estimated tidal influences (gage height). These previous modeling efforts suggested that the predicted effects of freshwater withdrawals on salinity would typically be between 0.1-0.5 psu and probably could not easily be detected given the normal distributions or daily tidal ranges of salinity along the lower Peace River/upper Charlotte Harbor HBMP monitoring transect.

The following briefly summarizes the objectives and significant conclusions of each of the historic lower Peace River salinity/isohaline modeling efforts (see **Table 6.13**).

6.4.1 University of Miami

The Rosenstiel School of Marine and Atmospheric Science (University of Miami) (Michel et al. 1975) evaluated potential environmental impacts in conjunction with General Development Corporation's initial assessment of the feasibility of locating a regional water supply system on the Peace River in Desoto County near State Road No. 761. The university research team developed a series of statistical relationships for selected areas of the lower river downstream of the proposed Peace River Facility location using freshwater flow, tide and salinity based on data collected between 1973 and 1974. These data were subsequently used to calibrate the first initial numerical models utilized to characterize the salinity distributions with and without Facility withdrawals under the normal range of variation in flows during both extended wet and dry periods.

Worst-case conditions were modeled assuming freshwater withdrawals during naturally occurring periods of low river flow (50 cfs), which is well below the 1996 permitted Peace River at Arcadia gage 130 cfs low flow threshold. These initially developed models suggested that increased salinities in the range of 1.3 to 3.2 psu would be observed under withdrawals of 30 mgd (46 cfs) during periods when Arcadia gaged Peace River flow was only 100 cfs. 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.

6.4.2 Environmental Quality Laboratory Reports

A series of statistical models were developed based on the long-term accumulation of HBMP fixed station salinity and isohaline information. Statistical models of sub-surface and near-bottom salinity, and/or the relative locations of isohalines, were used to assess the spatial magnitude of seasonal salinity variations in response to annual and long-term patterns in gaged freshwater inflows, as well as projected changes resulting from Facility withdrawals. The results of these modeling efforts were presented in conjunction with previous HBMP summary reports (EQL 1982, 1984, 1989, 1996). The results of these modeling efforts suggested that the predicted salinity increases due to District permitted Facility withdrawals would be less than 0.5 psu, and that the corresponding movement of isohaline locations would be less than 0.4 kilometer. These HBMP Summary Reports concluded that the magnitude of such predicted salinity changes specifically attributable to Facility withdrawals represented only a small fraction of the natural daily salinity variability due to tidal influences. Any salinity changes due to Facility withdrawals therefore would be buried within the much larger natural "noise" of daily and seasonal variability, and would accordingly be very difficult to measure directly.

6.4.3 2000 Midterm Interpretive Report

Further statistical models were also developed as part of the *2000 Midterm Interpretive Report* analyses with the specific objective of establishing "predictive" relationships between gaged inflows and the spatial salinity structure of the lower Peace River. These models were then applied in order to discern the incremental effects of permitted withdrawals on the salinity structure of the estuary downstream of the Facility.

Model results indicated that, on average, the influences of past withdrawals on the spatial distribution of salinity patterns in the lower Peace River had historically resulted in maximum changes of less than 0.3 psu. These model results also indicated that the largest changes resulting from past withdrawals would have been predicted to have occurred between River Kilometers 14 and 18 in the lower Peace River. The developed statistical models were then used to predict the potential magnitude of salinity changes expected under maximum future permitted daily withdrawals under conditions of Peace River at Arcadia flows between 200 and 1,000 cfs. The modeled results predicted maximum salinity increases of < 0.5 psu occurring between River Kilometers 14 and 18 when Arcadia flows range between 400 and 1000 cfs. Under conditions of flows of 200 cfs at Arcadia, the models predicted similar maximum increases in salinity (< 0.5 psu) occurring further upstream.

6.4.4 Janicki Environmental (2003)

The Southwest Florida Water Management District (Janicki Environmental 2003) re-evaluated the regression analyses of salinity/streamflow interactions in the lower Peace River estuarine system in order to further quantify salinity and isohaline location relationships with inflows using updated HBMP data through 1999. The study's primary objective was to assist in review of the HBMP in evaluating the salinity regime of the lower Peace River/upper Charlotte Harbor system, by determining the relative potential magnitude of salinity changes directly associated with Peace River Facility freshwater withdrawals.

Updated salinity models were developed for a series of seven "fixed" sites located along the lower Peace River transect from just downstream of the river's mouth (RK –2.4) upstream to a point (RK 25.9) below the Facility. Best-fit regression models were used to predict salinities at each location, at the four water column profile depths, for incremental percentiles of flow under three differing withdrawal scenarios.

- "No Withdrawals"
- "Actual Historical Withdrawals"
- "Maximum Theoretical Withdrawals" as per the 1996 permit schedule

A corollary task was to develop updated regression models of the predicted spatial locations of the four monitored "moving" isohaline locations (0, 6, 12 and 20 psu) in relation to variations in freshwater inflows under the same three withdrawal scenarios.

The key findings of this study indicated that:

- There is a considerable amount of natural variation in salinity, seemingly independent of flow, observed over a wide range of freshwater inflows.

- The modeled salinity increases predicted as a direct result of Facility withdrawals under the maximum permitted conditions at the "fixed" sampling sites along the lower Peace River ranged from between 0.1 and 0.3 psu.

- The predicted changes in relative spatial distributions of the four HBMP isohalines (**Chapter 4**) due to maximum Facility withdrawals were found to be only 0.1 to 0.3 kilometers.

6.4.5 2002 HBMP Comprehensive Summary Report (2004)

Statistical models were developed as part of this report using the 15-minute conductivity and stage height data from the two lower Peace River USGS continuous recorders (RK 26.7 and 15.5). These models were then used to answer the following questions.

1. What would have been the average differences in salinity at each of these sites if freshwater withdrawals had not taken place?

2. What would the predicted changes in salinity have been at these two locations downstream of the Peace River Facility under the maximum withdrawals allowed under the current permit?

The following conclusions and inferences were drawn from the summary results.

- Facility withdrawals were found to have no effect on salinity approximately thirty to forty percent of the time, due to the combined influences of the 130 cfs permit cutoff criteria, and the fact that Facility withdrawals cannot change salinity when flows are high enough that salinities are zero at the gaging site over the entire range of the daily tidal cycle.

- Overall, the models indicated that the influences of Facility withdrawals are predicted to be small, being less than 0.2 psu more than seventy percent of the time, which is far less than the daily range of variation resulting from the daily tidal cycle.

- Under conditions of maximum permitted withdrawals the models suggested that the greatest differences in salinities at each of the sites would be approximately 0.4 psu. The models indicated that the predicted increases in salinity due to actual withdrawals have exceeded this approximately ten percent of the time.

- The differences in salinity due to withdrawals were predicted to be slightly greater at the downstream gaging site, since salinities are very low (or zero) throughout much of the year at the more upstream gaging site.

- The conclusions of the modeling of continuous recorder data were found to be very similar to those reached by previous modeling efforts using the monthly fixed station HBMP data. If anything, the statistical models based on continuous recorder data predicted slightly lower potential salinity increases due to permitted Facility withdrawals than the results of previous statistical models developed using monthly fixed station data.

6.4.6 Evaluation of Low Flow "Pump Test" Findings (2007)

The primary objective of this study was to graphically and statistically analyze the results from a series of sixteen "pump test" events conducted by the Peace River/Manasota Regional Water Supply Authority during the period between December 2006 and May 2007. The Authority received permission from the District in late November 2006 to temporarily reduce the low flow threshold specified in the 1996 water use permit from 130 cfs to 90 cfs. This temporary reduction in the low flow threshold resulted from the historically very low summer flows that occurred during the 2006 summer wet-season, and the dry conditions projected for the spring of 2007.

The study used graphical and statistical procedures to analyze salinity changes due to withdrawals below the 130 cfs threshold using the information from the five continuous (15-minute interval) conductivity recorders located downstream of the Facility. The following briefly summarizes some of the study's key findings.

- During the period of study between December 1, 2006 and May 1, 2007, Peace River at Arcadia gaged flows were between the previous 130 cfs threshold and the temporary 90 cfs cutoff only approximately twenty-four percent of the time. This and the timing of such occurrences suggest that any salinity changes downstream of the Facility due to the temporary reduction of the low flow cutoff from 130 cfs to 90 cfs would have been limited in both frequency and duration.

- Graphical analyses of the relationships between average hourly gage heights and conductivities showed that under ideal conditions of similar flows and tides, differences attributable to withdrawals were, as expected, relatively small given the normal daily range of variation.

- The graphical analyses of continuous recorder data found that salinity changes due to withdrawals were primarily confined to the peaks of incoming tides when differences in flows might be expected to have the greatest influences.

- The results showed declines in the influences of tidal patterns on salinity moving downstream with increasing flows. Potential changes in salinity resulting from Facility withdrawals were also found to increasingly move further downstream as river flows increased.

- The largest directly observed changes in salinity apparently related to withdrawals occurred during flows below the original 130 cfs threshold. The magnitude of such changes was found to be generally similar over a relatively wide reach of the lower river.

- However, even when withdrawals occurred below the 90 cfs cutoff, the maximum observed differences were found to predominantly occur at the peak height of incoming tides.

- The maximum salinity differences observed from the graphical analyses of the continuous recorder data were well within those limits predicted by previous statistical models. In fact, when averaged over the entire range of the daily tidal cycles, these directly observed daily changes were far less than those estimated from statistical models.

- The graphical analyses visibly point out patterns of increasing salinity and variability upstream as river flows decline, and the relatively large influences that short term differences in tide stages can have on salinities even under relatively similar flow conditions along the entire lower river.

- Low flow statistical models were developed using averaged hourly data gathered during the first four months of 2007 at the five continuous recording sites. The resulting statistical models were found to be relatively accurate (having R-square values between 0.70 and 0.87) in predicting the frequency, duration and magnitude of the observed daily variation in salinity along the HBMP monitoring transect.

- The results of analyses using these specifically developed low flow models were similar to those of previous statistical models that indicated that the magnitude of salinity differences due to Peace River Facility withdrawals were probably between 0.1 and 0.5 psu. The model results indicated that such salinity changes due to Facility withdrawals were relatively small even at flows below the 130 cfs threshold when compared to the normal range of salinity variation observed due to tides and wind.

6.5 Summary and Conclusions

Previous HBMP Mid-Term and Comprehensive Summary reports have included the development of both fixed station location and spatial statistical models. These models were used as predictive tools to assess the magnitude of potential salinity changes due to both historic actual and potential maximum permitted Facility withdrawals The objective of this chapter was to determine enhanced statistical relationships between flows, tide stage, and withdrawals at both the two long-term (1996-2006) fixed USGS continuous gages, and the three newly installed (2006) HBMP continuous recorders. The modeled salinity increases resulting from Facility withdrawals predicted by these new, enhanced models were compared and contrasted with the results of other previous salinity models, as well as those directly observed during the recently completed series of “pump tests”.

6.5.1 Summaries and Comparisons of the Spatial and Temporal Characteristics Measured at the Continuous Recorders

Seasonal and longer-term temporal variabilities in salinity have been recorded over approximately ten years of data collection at the two USGS continuous recorders, while only a single full year of data are currently available from the three HBMP recorders, which were installed in December 2005. Annual summary statistics (mean, median, minimum and maximum) were analyzed for gage height, and surface and bottom salinities the USGS continuous recorders at Harbour Heights (RK 15.5) and Peace River Heights (RK 26.5). The following summarizes differences and patterns at these two locations.

- Minimum and maximum gage heights (water levels) indicate that the extremes between the highest and lowest annual levels can be as great as six to eight feet. Actual daily differences however are typically far lower. Differences between daily high and low water levels over the ten years of monitoring at Harbour Heights have averaged only 2.15 feet, while the greatest measured daily difference over the same period was just 5.03 feet.

- Annual mean and median gage heights at the downstream Harbour Heights recorder are much more uniform than corresponding measurements upstream at the Peace River Heights location. The results indicate that water levels further upstream are much more heavily influenced by higher flows during wet years, such as occurred during the interval between 2003 and 2005, than are corresponding measured gage heights further down stream. The implications of such observations are that seasonal differences in gage height need to be taken into account when developing statistical salinity models that rely on the interactions of flows and gage height. Higher gage heights during low river flows result in salinity tidally moving upstream, while higher gage heights with increasing flows reflect the combined influences of tide and the increasing resistance to downstream flow.

- Mean and median annual salinities at both USGS recorders were much higher during the extended 1999-2001 drought. The largest relative observed differences were in the maximum salinities measured at the Peace River Heights site. Peak salinities measured at this upstream site during the drought years were at least four to six times higher than the maximum annual salinity levels observed during wetter years.

- Bottom salinity measurements were systematically higher than corresponding surface measurements, and as expected the differences were greater at the downstream Harbour Heights recorder location.

6.5.2 Statistical Models of Flow Versus Salinity Relationships at the Five Continuous Recorder Locations

A series of analyses were conducted to update and determine statistical relationships between the measured salinity variability at each of the established five recorder locations along the lower Peace River HBMP monitoring transect. Specific ranges of flow were applied at each location to increase the resulting model's ability to be used specifically to assess salinity changes due to existing and currently permitted maximum withdrawals. The developed statistical models for each of the five recorder locations were then used to predict average hour salinities over the period 1998 through 2006. Calculated mean, median, minimum and maximum predicted salinity differences between the "Actual Withdrawals/No Withdrawal" and the "Maximum Withdrawal/No Withdrawal" scenarios at each of the five recorder location were then determined. The following conclusions can be drawn from theses salinity comparisons.

- The results of the analyses emphasize the very high degrees of seasonal and inter-annual variability in salinity that naturally occurs along the lower Peace River. These differences are especially dramatic when relative comparisons are made among wet years (such as 1998, 2003, 2004, and 2005) and periods of comparatively much lower flows (such as 2000, 2001, and 2006).

- The results generally indicate higher salinity increases occurring under the maximum withdrawals allowed by the 1996 water use permit, when compared with modeled salinity changes resulting from actual Facility withdrawals. These differences are shown to have narrowed slightly following the recent 2002 Facility expansion, and thus might be expected to narrow further following the expected 2009 completion of the ongoing next expansion.

- The annual average (mean) differences in salinities due to withdrawal were the greatest at the most downstream Harbor Heights location (RK 15.5) and became progressively smaller moving upstream, being the lowest at the Peace River Heights location (RK 26.7). This result is as expected, since as flows increase the reaches of the river near and immediately below the Facility become less and less influenced by higher salinity water moving tidally upstream. Facility withdrawals can only influence those segments of the lower river that are still tidally influenced by saltwater, and thus the further a location is downstream, the greater the percent of time that salinities can be influenced by withdrawals.

- The observation that almost all the calculated median differences were zero indicates that at least half the time Facility withdrawals have limited (if any) influence on the salinities. Obviously the Facility cannot affect salinity during the period of time when gage flows at Peace River at Arcadia are below the District's low flow threshold. Conversely, when flows are high enough that a particular reach of the river is always characterized by freshwater conditions, Facility withdrawals also do not affect salinity in that portion of the lower river. A somewhat less intuitive finding of the recently completed series of "pump tests" was the observation that Facility withdrawals of ten percent or more even during low to moderate flows, primarily only resulted in higher observed salinities during incoming tides. Withdrawals seemed to have very little directly measurable influence on salinities during the outgoing and low phases of the daily tidal cycle. Since the results presented in this report were based on hourly estimates (versus daily estimates), it is therefore not surprising that more than half the observations did not predict any differences in salinities with and without withdrawals.

- The mean differences indicate that the largest changes in annual salinity occurred during the 2006 drought following the 2002 expansion. The annual average salinity changes due to actual Facility withdrawals ranged from approximately 0.1 psu upstream to 0.4 psu downstream.

- Predicted maximum salinity differences due to Facility withdrawals are shown to typically range from approximately 0.6 psu to 1.5 psu, with the largest predicted salinity increases occurring not at the most downstream Harbour Heights recorder location, but rather spatially further upstream at the intermediate recorder locations along the HBMP monitoring transect. Again, these results are similar to the physical observations recorded during the recently completed HBMP Facility "pump tests." These results showed measurable salinity changes of similar magnitudes due to withdrawals that were temporally confined to the top end of incoming tides. Spatially, the maximum observed salinity changes during the "pump tests" were determined by the relative location of the saltwater/freshwater interface, which is a function of the interactions of both flows and tides. The predicted results of the statistical models based on hourly estimated salinities are, therefore, supported by the observed findings of the Facility "pump tests."

- Previous statistical modeling efforts have generally relied on monthly or daily averaged values and did not include hourly estimated tidal influences (gage height). These previous modeling efforts suggested that the predicted effects of freshwater withdrawals on salinity were typically be between 0.1-0.5 psu along the lower Peace River/upper Charlotte Harbor HBMP monitoring transect. Similar determinations of daily average differences using the current hourly based statistical models support these previous findings.

- These results further support the findings that to date measured and predicted (modeled) temporal and spatial salinity changes resulting from Facility freshwater withdrawals have not been found to cause any pronounced, sustained or systematic changes in the salinity structure of the lower Peace River/upper Charlotte Harbor estuarine system.

7.0 Evaluation of Existing Withdrawal Schedule and Assessment of Effectiveness in Limiting Potential Impacts

7.1 Introduction and Overview

The long-term goal of the combined Hydrobiological Monitoring Program (HBMP) study elements has been to provide the Southwest Florida Water management District (District) with sufficient information to determine whether the water quality characteristics and biological communities of the lower Peace River/upper Charlotte Harbor estuarine system have been, are being, or may be significantly adversely impacted by permitted withdrawals by the Peace River Regional Water Supply Facility (Facility). As outlined in the District 1996 Water Use Permit conditions, the overall objectives of the HBMP have included the following targets.

- To determine the relative degree and magnitude of effects of Facility withdrawals on ecological changes that may have been observed in the lower Peace River/upper Charlotte Harbor estuarine system.
- To evaluate whether Facility freshwater withdrawals have significantly contributed to naturally occurring ecological impacts to the estuary resulting from extended periods of low freshwater inflows.
- To assess whether the Facility withdrawals have had any significant spatial or temporal effects on the ecology of the estuary.

This chapter summarizes and provides an overview of the effectiveness the Facility's water use permits have had in limiting the potential impacts of withdrawals on the biological resources of the lower Peace River/upper Charlotte Harbor estuarine system. Table 7.1 summarizes the key elements associated with each of the modifications of the Facility's long-term permit conditions.

Table 7.1
Historic Summary of Facility Permits

Year	December 1975	March 1979	May 1982	October 1988	March 1996
Water Use Permit Number	27500016	27602923	202923	2010420	2010420.02
Average Permitted River Withdrawal (mgd)	5.0	5.0	8.2	10.7	32.7
Maximum Permitted River Withdrawal (mgd)	12 & 18	12 & 18	22	22	90
Diversion Schedule Low Flow Cut off (cfs)	91 – 664	91 – 664	100 – 664	100 & 130	130
Maximum Percent Withdrawal of River Flow (%)	5	5	n/a	10	10

- Prior to the change in October 1988 of using low flow cutoffs combined with a percent reduction approach, the previous water use permit limited annual average withdrawals to 8.2 mgd (12.7 cfs). Maximum daily permitted withdrawals were limited by the Facility's physical ability to withdraw water from the river, which at that time was 22 mgd (34.0 cfs). Individual low flow cutoffs were calculated monthly, based on the previous 20 years of flow data, and ranged from lows of 64.6 mgd (100 cfs) in April and May to a high of 429.2 mgd (664 cfs) in September.

- The October 1988 water use permit renewal limited withdrawals to ten percent of the previous day flow as measured at the USGS Peace River at Arcadia gage, up to the limit of 34.0 cfs per day (which still matched the pumping capacity of the river intake facility). The low flow cutoffs during the period from 1989 to 1995 were 130 cfs during the months of June through February, and then 100 cfs during the March through May spring dry-season.

- The current 20-year 1996 water use permit renewal increased the low flow cutoff to 130 cfs throughout the year, while concurrently raising the maximum withdrawal capacity to 90 mgd (139 cfs). The 1996 permit renewal retained the ten percent withdrawal limit established under the previous October 1988 permit. The Authority's intent was to increase the Facility's treatment capacity to capture a greater portion of the full permitted ten percent withdrawal under higher flow conditions, thus increasing the Facility's ability to withdraw and store excess amounts above actual daily demands.

7.2 Overview of Historical Facility Withdrawals

A comprehensive summary of the history, status and changes in the Facility's withdrawals has previously been presented in **Chapter 3.5**. The following briefly summarizes some of the key relevant previously presented specific conclusions.

- The time-series plots presented in **Figures 3.372** and **3.373** show the fairly steady increases in the quantities of freshwater Facility withdrawals from the river over the past twenty-seven years, which correspond with increasing demands (**Table 3.37**). Also clearly evident is the increase in maximum Facility withdrawals following completion of the 2001 expansion, which resulted in the Facility's enhanced ability to treat and store larger amounts of freshwater. The low flow cutoffs often resulted in periods each year when the Facility did not withdraw water from the river. During the recent extended drought the Facility did not withdraw any water from the river for a total of 248 days during 2000, and relied solely on stored reserves another 219 days during 2001.

- The interactions between the permitted availability of water and the Facility's capacity for withdrawals are indicated by comparisons of withdrawals during the 2000 drought (mean annual withdrawal of 5.7 cfs), and withdrawals during the characteristically wet years such as 2003 and 2005, when mean annual withdrawals were 26.1 and 29.1 cfs, respectively (**Table 3.38**). As indicated, Peace River Facility withdrawals have never exceeded 4.9 percent of the annual gaged flow at Arcadia, 3.4 percent of the total gaged flow upstream of the Facility, or 2.2 percent of the total annual lower Peace River gaged flow to upper Charlotte Harbor.

- The average monthly differences between maximum withdrawals under the revised 1996 permit conditions and actual Facility withdrawals over the 1996-2006 time interval are depicted in **Figure 3.379**.

- **Figure 3.386** shows that differences in the annual average hydrograph resulting from actual Facility withdrawals under the current District permit conditions have, to date, been very small regardless of season.

7.3 Estimated Temporal and Spatial Magnitude of the Salinity Changes due to Facility Withdrawals

Historically, a number of efforts using statistical modeling have attempted to quantify the potential temporal and spatial impacts of Peace River Facility withdrawals on both the salinity structure of the lower river as well as the movement of specific isohalines (**Table 6.13**). Thorough discussions of these previous studies as well as additional statistical models developed as part of this report are presented in **Chapter 6**. The following summarizes the major relevant conclusions presented in this previous chapter.

- Previous developed statistical models using HBMP data generally relied on monthly or daily averaged values. The overall results of these models have suggested that the predicted effects of Facility freshwater withdrawals on the salinity structure of the lower Peace River would typically be expected to temporally and spatially vary between 0.1-0.5 psu. These previous historical studies further suggested that given the normal distributions of daily tidal salinity ranges along the lower Peace River/upper Charlotte Harbor HBMP monitoring transect, such predicted increases directly due to Facility withdrawals would probably not be easily detected.

- Between December 2006 and May 2007, the Authority conducted a series of sixteen "pump test" events conducted under relatively low flow conditions. Graphical analyses of the relationships between average hourly gage heights and conductivities at the five continuous recorder locations downstream of the Facility showed that under ideal conditions of similar flows and tides, differences attributable to withdrawals were, as expected, relatively small given the normal daily range of variation. These analyses showed that salinity changes due to withdrawals were primarily confined to the peaks of incoming tides. The maximum salinity differences observed from these graphical analyses were well within those limits predicted by previous statistical models. In fact, when averaged over the entire range of the daily tidal cycles, these directly observed daily salinity changes were far less than those estimated from the previously developed statistical models.

- Enhanced statistical models were further developed as part of **Chapter 6** specifically using hourly averaged data gathered over the period-of-record at each of the current five continuous recorder locations along the lower Peace River monitoring transect (**Figure 6.1**). These models were then used to predict salinity changes due to Facility withdrawals using actual measured hourly variations in gage height with daily averaged rates of freshwater inflows and withdrawals. The resulting annual summary graphics emphasize the very high degree of seasonal and inter-annual variability in salinity that naturally occurs along the lower Peace River. These differences are especially dramatic when relative comparisons are made between dry years (**Figure 6.23**) and periods of comparatively higher flows (**Figure 6.28**). The predicted annual mean differences in salinities due to withdrawal were the greatest at the most downstream Harbor Heights location (River Kilometer (RK) 15.5) and became progressively smaller moving upstream, being the lowest at the Peace River Heights location (RK 26.7). These observed spatial differences are as expected, since as flows increase the reaches of the river near and immediately below the Facility become less and less influenced by higher salinity water moving tidally upstream. Facility withdrawals can only influence those segments of the lower river that are still tidally influenced by saltwater, and thus the further a location is downstream, the greater the percent of time that salinities can be influenced by withdrawals. **Table 6.12** indicates that at least half the time Facility withdrawals have limited (if any) influence on the salinities. Obviously the Facility cannot affect salinity during the period of time when gaged flows at Peace River at Arcadia are below the District's low flow threshold. Conversely, when flows are high enough that a particular reach of the river is always characterized by freshwater conditions, Facility withdrawals also do not affect salinity in that portion of the lower river. The statistical models using the continuous recorder data also show that withdrawals also have much less directly measurable influence on salinities during the outgoing and low phases of the daily tidal cycle. Predicted maximum salinity differences due to Facility withdrawals are shown to typically range from approximately 0.6 psu to 1.5 psu at the peak of incoming tides, with the largest predicted salinity increases occurring not at the most downstream Harbour Heights recorder location, but rather spatially further upstream at the intermediate recorder locations along the HBMP monitoring transect. Spatially, the maximum salinity changes were determined by the relative location of the saltwater/freshwater interface, which is a function of the interactions of both flows and tides

7.4 Potential Criteria for Future Modification of the Existing Withdrawal Schedule

When combined, the predictions from the series of developed statistical models and the results from the recent "pump tests" support the overall conclusion that, to date, measured and predicted (modeled) salinity increases resulting directly from Facility freshwater withdrawals have been relatively small. This is especially true given the much larger magnitudes of salinity variability that naturally occur along the lower river daily due to the effects of tides and winds, or are observed seasonally due to changes in freshwater inflows. Analyses of the HBMP data have not shown that Facility freshwater withdrawals over the past twenty-seven years have caused any pronounced, sustained or systematic temporal and/or spatial changes in either the dynamic or static salinity habitat structure along the lower Peace River/upper Charlotte Harbor estuarine system.

Given the steady increases in withdrawals since the Facility began operations in 1980, the District's permitted withdrawal schedules have been effective in limiting potential impacts. The underlying premise essential to the Facility's withdrawal schedule has been to restrict predicted (and observed) salinity increases due to withdrawals to a small portion of the natural temporal and spatial variability resulting from the combined daily and seasonal influences of tides, wind and flows. The underlying assumption is that by maintaining the basic natural variability of both the dynamic and static estuarine salinity habitat structure downstream of the Facility's withdrawals, the seasonal and annual integrity of the biological communities within and along the lower Peace River/upper Charlotte Harbor system will also be preserved.

The Facility's 1996 permitted withdrawal schedule was based on several simple key assumptions. These include the following premises.

- Increases in salinities, and therefore potential biological response, are increasingly sensitive to withdrawals under lower flow conditions.

- The withdrawal schedule should therefore include a low flow cutoff, below which no further withdrawals should occur.

- The withdrawal schedule should be based on a fixed percent of upstream gaged flows to assure that salinity increases resulting from Facility withdrawals mimic natural short-term and long-term changes in seasonal and annual flow patterns.

The Facility's withdrawal schedule, as summarized above, has effectively limited potential impacts over the approximately twenty-year period since the combined "ten percent of flow," and 100-130 cfs low flow cutoff threshold model were adopted by the District for the lower Peace River. Although this withdrawal schedule was initially somewhat controversial, the data gathered over the intervening years in conjunction with the HBMP study elements have shown the effectiveness of the basic underlying assumptions.

However, as regional demands increase in response to future projected growth (**Figures 1.1** and **1.4**), the question arises whether some changes to the withdrawal schedule can be made that when combined with ongoing and planned expansions in both Facility treatment capacity and storage, provide similar levels of protection to the salinity structure and biological resources of the lower Peace River/upper Charlotte Harbor Estuary. Discussions with the Peace River HBMP Scientific Review Panel (Panel) have suggested a small number of relatively simple alternative approaches that would provide very similar levels of environmental protection while increasing potential supplies from the river. The following are some of these suggested alternatives.

- *Base the percent withdrawal on the combined total of the upstream gaged tributaries rather than simply the USGS Peace River at Arcadia gage.*

  The decision in 1988 to base withdrawals solely on a percent of the preceding days Peace River at Arcadia gaged flows was in large part determined by the limited ability at that time to obtain real-time stage data from the USGS gages. Historically, the Peace River at Arcadia gage has accounted for approximately 82.4 percent of the total gaged flow upstream of the Facility. Correspondingly, the additional two downstream Joshua and

Horse Creek gages have respectively accounted for 7.6 and 10.0 percent of the averaged long-term gaged flow at the Facility. Not initially including these two additional downstream gages also provided some further level of a safety factor to the proposed withdrawal schedule. However, during recent periods of drought (**Table 5.3**), these two downstream watersheds have actually accounted for much higher proportions of low flows, due both to dry-season agricultural augmentation of base flow (see **Chapter 5**) and localized differential wet-season rainfall patterns. Since the salinity structure of the lower Peace River is a direct function of the total combined flow, and continuous real-time data are now available on the USGS web site, it now makes sense to base Facility withdrawals on the combined upstream gaged flows rather than simply the Peace River at Arcadia gage. This would allow some withdrawals when the total gaged upstream flow meets the established cutoff threshold, and provide additional supplies during those instances (such as occurred in 2006) when particularly severe, isolated drought conditions were occurring in the upper Peace River watershed. Under routine normal operations, the Peace River Facility normally does not pump water from the river if the conductivity is above 775 uS/cm (TDS 500). During the recent drought however the Facility has temporarily revised this threshold to a conductance of 1050 uS/cm (TDS 775). However, **Figure 7.1** shows the relationship between hourly averaged conductivities and combined total gaged freshwater inflows at the Peace River Heights continuous recorder, which is located approximately three kilometers downstream of the Facility's intake. While actual conductivities upstream at the intake structure are lower, the figure provides a relative comparison between the Facility's operational conductivity limit and combined upstream gaged flow.

- I*mplement a sliding scale rather than the single fixed percent withdrawal that would allow the Authority to withdraw and store more water under higher flow conditions when resulting salinity increases would be smaller and the lower river/upper harbor estuarine system is less sensitive to potential impacts.*

  The withdrawal schedule could be changed to include a series of increasing fixed percentages based on the preceding day's total upstream gaged flow exceeding certain annual flow criteria. These flow conditions could easily be established using a limited number of annual flow percentiles based on a representative long-term preceding period of record.

- *The current 90 mgd maximum withdrawal could be changed to allow increasingly larger volumes of water to be withdrawn and stored in the Facility's new expanded reservoir using the proposed sliding scale methodology.*

  Under the current District permit, once gaged Peace River at Arcadia flow reaches 1393 cfs, the 90 mgd maximum withdrawal criterion becomes effective and the relative percent of flows potentially available for withdrawal actually begins declining from ten percent as river flows further increase. Theoretically, the lower river/upper harbor estuarine system should become increasing less sensitive and potential salinity changes due to withdrawals should decline as freshwater inflows increase. Applying the 90 mgd cap and effectively reducing the relative percent of flow available for withdrawals under increasing high flow conditions is therefore somewhat counterintuitive. Freshwater flows in the range of 1300-1500 cfs typically characterize conditions where the upper harbor begins to become increasingly stratified, and lower portions of the water column become hypoxic (< 2 mg/l of dissolved oxygen) and even anoxic (< 0.5 mg/l) over extended periods of time during typical periods of high summer wet-season flows. Under increasingly higher flows, the lower river is characteristically fresh, and the benthic estuarine communities in the upper harbor are increasing under stress from depressed dissolved oxygen levels due to flow induced stratification. It would therefore seem that any influences of withdrawals should be particularly muted under such increasingly higher flow conditions.

- *Consideration should be given to applying different percent flow reduction criteria to initial late spring/early summer flows relative to similar rates of flow occurring during the late summer/fall period of declining flows.*

  A number of previous HBMP study elements (including investigations of phytoplankton production and studies of zooplankton and larval/juvenile fishes) have observed the relative high dependence of a number of these important estuarine communities on the nutrient inputs associated with the initial beginning of higher flows following the typical extended spring dry-season. Correspondingly, similar flows at the end of the typical summer wet-season, when flows were declining, were found to be far less critical since primary production in the lower river and upper harbor were primarily controlled by water color rather than nutrient inputs.

7.5 Proposed District Minimum Flows and Levels

In August 2007, the District published an initial draft of its proposed minimum flows and levels (MFLs) for Shell Creek and the lower Peace River. The District has the responsibility to permit the consumptive use of water, while at the same time protecting these water resources from "significant harm." The District is further under legislative mandate to establish MFLs for the streams and rivers within its boundaries (Section 373.042, Florida Statutes). By statute, "the minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area."

The District has proposed using seasonal blocks corresponding to periods of low, medium, and high flows, similar to those previously defined during development of MFLs for the middle Peace River. The underlying concept of utilizing seasonally flow related time "blocks" in establishing MFLs is to get the "right flow at the right time." The proposed MFLs for each system were based on limiting changes in selected criteria to a 15 percent change.

The proposed MFL for Shell Creek was defined extending downstream from the City of Punta Gorda dam to the confluence of Shell Creek with the lower Peace River. In developing the MFL the District's selected criterion was a salinity of 2 psu, which was selected as biologically-relevant in maintaining the integrity of fish and benthic community structures. Applying this criterion, the minimum Shell Creek flows were defined for each block and flow condition as the percentage of the Shell Creek dam flow that could be withdrawn. The proposed allowable percent reductions in flow were:

- **Block 1** (April 20 to June 25)
  - 10% of the flow below the median for Block 1 (84 cfs)
  - 23% of the flow above the median for Block 1 (84 cfs)

- **Block 2** (October 27 to April 19)
  - 18% of the flow below the median for Block 2 (98 cfs)
  - 42% of the flow above the median for Block 2 (98 cfs)

- **Block 3** (June 26 to October 26)
  - 35% of the flow below the median for Block 3 (424 cfs)
  - 83% of the flow above the median for Block 3 (424 cfs)

The proposed MFL for the lower Peace River was defined as the segment of the river downstream from the USGS Peace River at Arcadia gage, including the total combined inflows from the Peace River at Arcadia, Joshua Creek at Nocatee, and Horse Creek near Arcadia gages. The selected salinity criteria for the lower Peace River were 2, 5, and 15 psu, which were determined as biologically-relevant in maintaining the biological integrity of fish, benthic, and vegetation community structures in the lower river. In addition, a more spatially-specific assessment of salinity within a portion of the lower river was also determined to be critical. Studies have shown that a specific area in the river has a significantly abundant and diverse fish community and salinities in this area are typically in the range of 8 to 16 psu. Therefore, the volume of water meeting this salinity range was also analyzed. Based on these criteria, the minimum flows proposed for the lower Peace River were defined for each block and flow condition as the percentage of the total combined flow above 90 cfs that could be withdrawn. The proposed allowable percent reductions in flow were:

- **Block 1** (April 20 to June 25)
  - 10% of the flow below the median for Block 1 (221 cfs)
  - 26% of the flow above the median for Block 1 (221 cfs)

- **Block 2** (October 27 to April 19)
  - 14% of the flow below the median for Block 2 (330 cfs)
  - 21% of the flow above the median for Block 2 (330 cfs)

- **Block 3** (June 26 to October 26)
  - 12% of the flow below the median for Block 3 (1,370 cfs)
  - 15% of the flow above the median for Block 3 (1,370 cfs)

The Peace River Scientific Review Panel met in December 2007. The District made a presentation outlining the proposed MFLs for the lower Peace River and Shell Creek systems, and members of the Panel have provided the District with written comments and questions. The District has forwarded these comments to its own Peer Review Panel, which is expected to provide written comments to the District in the early spring of 2008.

7.6 Recommended Actions

The District's draft proposed approach to establishing MFLs for the lower Peace River represents a systematic shift away from the previous underlying approach that has been historically used to evaluate and limit the potential salinity impacts of Facility withdrawals. Historically, the HBMP has evaluated actual and potential maximum salinity changes due to withdrawals using statistical models developed from measured fixed and moving station data. These statistical models have typically been used to determine the relative daily magnitude of salinity increases due to withdrawals at these fixed locations. The underlying assumption has been that as long as predicted and observed salinity increases due to withdrawals remain small relative to the natural daily (or seasonal) variability at theses locations that any associated biological changes will also be limited.

The District's draft MFL approach, by comparison, is based on application of a hydrodynamic model to predict the reduction in flow needed to change the volume, area or shoreline falling under a cumulative distribution function (CDF) curve by more than 15 percent using adjusted flows over the 1996-1999 time period, which was used to approximate a historic baseline condition. Following any revision made after the District receives comments from its Peer Review Panel, it is recommended that finalized MFL criteria be applied to a select number of the statistical models developed in conjunction with the HBMP to determine relative temporal and spatial differences in predicted salinity changes under the current permitted withdrawal schedule and the final MFL scenarios. These comparisons will then be available to the HBMP Scientific Review Panel to aid in suggesting possible future changes and modifications of the Authority's HBMP program.

The Authority's current ongoing Facility expansion and construction of the new six billion gallon reservoir are projected to be completed during 2009. It is recommended that the Peace River Scientific Review Panel meet again in the later part of 2008 to discuss and make suggestions regarding potential revisions to the Facility's withdrawal schedule and HBMP monitoring programs (see **Chapter 10**) in light of the District's revised and finalized MFLs for the lower Peace River and Shell Creek systems.

7.7 Summary

The long-term goal of the HBMP has been to provide the District with sufficient information to determine whether the water quality characteristics and biological communities of the lower Peace River/upper Charlotte Harbor estuarine system have been, are being, or may be significantly adversely impacted by permitted Facility withdrawals. The overall findings presented in this and previous HBMP reports have indicated that to date the District's permitted withdrawal schedule for the Facility has prevented pronounced, sustained or systematic changes in the salinity structure of the lower Peace River/upper Charlotte Harbor estuarine system.

The results of this and previous HBMP report suggests that a small number of relatively simple alternative approaches that would provide very similar levels of environmental protection while increasing potential supplies from the river. The following outlines recommended guidelines for future modifications.

- Base the percent withdrawal on the combined total of the upstream gaged tributaries rather than simply the USGS Peace River at Arcadia gage.

- Implement a sliding scale rather than the single fixed percent withdrawal that would allow the Authority to withdraw and store more water under higher flow conditions when resulting salinity increases would be smaller and the lower river/upper harbor estuarine system is less sensitive to potential impacts.

- The current 90 mgd maximum withdrawal could be changed to allow increasingly larger volumes of water to be withdrawn and stored in the Facility's new expanded reservoir using the proposed sliding scale methodology.

- Consideration should be given to applying different percent flow reduction criteria to initial late spring/early summer flows relative to similar rates of flow occurring during the late summer/fall period of declining flows.

The District has published an initial draft of its proposed MFLs for Shell Creek and the lower Peace River, and has presented its recommendations to the Peace River Scientific Review Panel. Panel members have provided the District with written comments and questions, and the District has forwarded these comments to its own Peer Review Panel.

The District's draft approach to establishing MFLs for the lower Peace River proposes a systematic shift away from the previous underlying methodology that has been historically used to evaluate and limit the potential salinity impacts of Facility withdrawals. Historically, the underlying assumption of the HBMP has been that as long as predicted and observed salinity increases due to withdrawals remain small relative to the natural daily (or seasonal) variability at specific locations within the lower river and upper harbor that any associated biological changes will also be limited. The District's draft approach is based on application of a hydrodynamic model to predict the reduction in flow needed to change the volume, area or shoreline falling under a cumulative distribution function (CDF) curve by more than 15 percent. It is recommended that finalized MFL criteria be applied to a select number of the statistical models developed in conjunction with the HBMP to determine relative temporal and spatial differences in predicted salinity changes under the current permitted and proposed MFL scenarios. It is recommended that the Peace River Scientific Review Panel meet again in the later part of 2008 to discuss and make suggestions regarding potential revisions to the Facility's withdrawal schedule and HBMP monitoring programs in light of the District's revised and finalized MFLs for the lower Peace River and Shell Creek systems.

8.0 Chapter 8 – Peace River Morphometric Analysis

8.1 Objectives

The objective of this section is to reproduce an earlier Peace River morphometric study using improved data and methods. The first report was produced in 1998 using transect surveys and geometric calculations. The number of Graphical Information System (GIS) tools available at that time were relatively limited. The current report was developed using detailed bathymetric data and current advanced GIS tools. The degree of confidence that relies on both enhanced new data and methods is therefore significantly greater.

8.2 Data Sources

Bathymetry data from a Southwest Florida Water Management District (District) study were used to perform the morphometric analysis (see Figure 8.1). These new data were collected in latitude/longitude (NAD83) and the vertical reference was NGVD29 in 2003. Depth values were recorded in centimeter (negative values).

Raw data were collected using a 22-ft vessel that was equipped with a modern high precision Geographical Positioning System (GPS). Measurements were made approximately every 1.5 meters (m), while the vessel traveled in a pattern such that the width of the river was crossed approximately every 200 meters. Complete details are contained in the final report *Bathymetric Survey in Charlotte Harbor Area* submitted to SWFWMD by Ping Wang from the Department of Geology at the University of South Florida (dated: January 5, 2004).

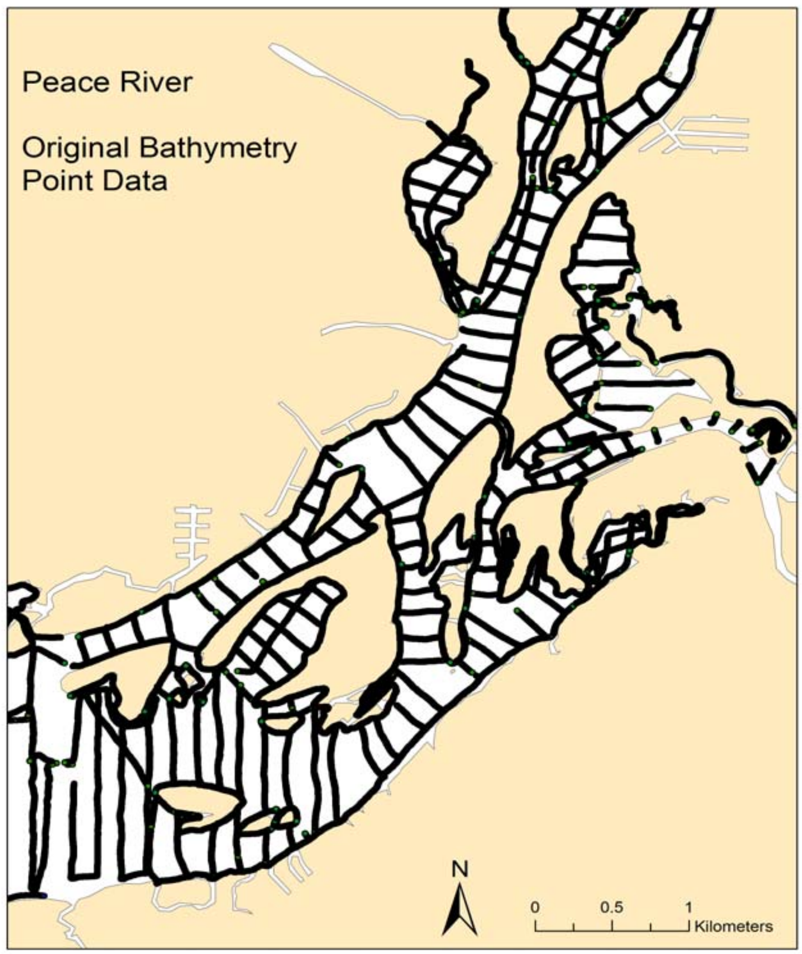

Figure 8.1. Original bathymetry data from SWFWMD study. Data points are approximate 1.5 meters apart and appear like lines due to the resolution of the image.

8.3 Methods

8.3.1 Seamless Grid Creation

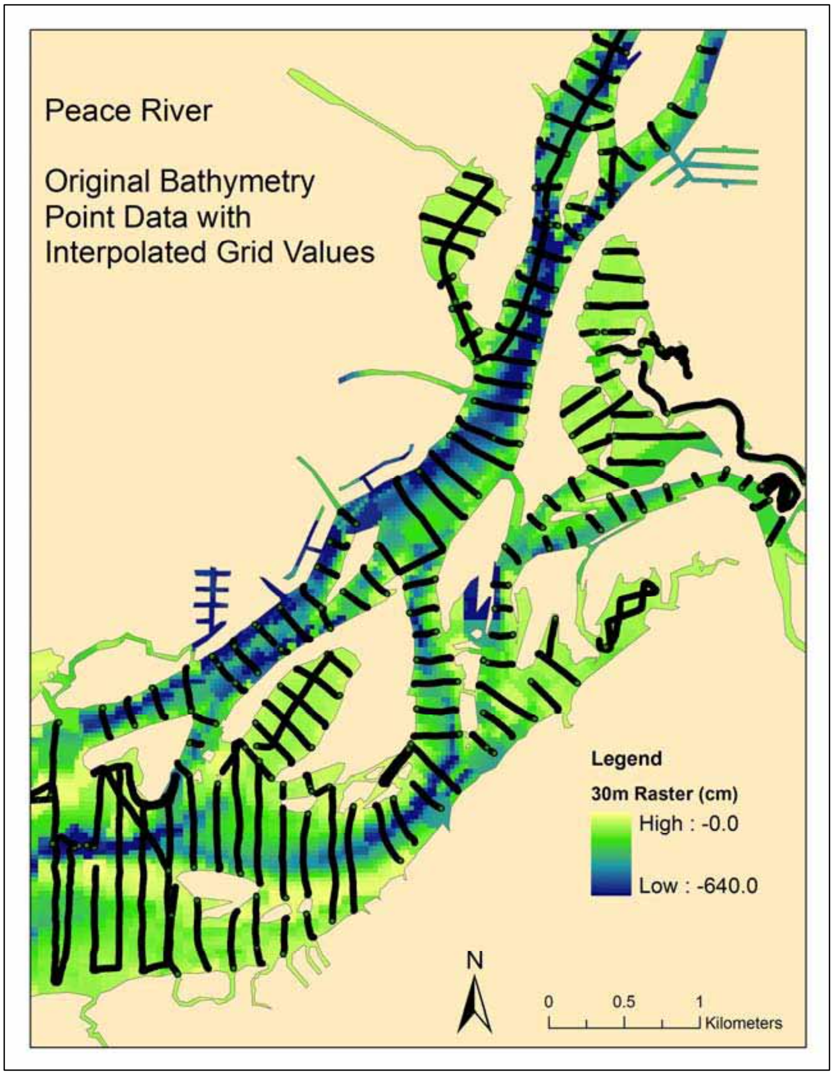

Figure 8.2. Interpolated depth values with original bathymetry points. Dark blue are deepest areas. Shoreline bathymetry points are not shown.

GIS (ArcView 9.0) was used to perform a spatial interpolation routine on the original depth data. Data were projected to UTM NAD83, Zone 17 (meters). Inverse distance weighting was used with the nearest 12 neighbors and a second power relationship to make a seamless 33.33 m grid. This grid size was deemed sufficient given the distance between data paths (150 m). The near shore points were retained or removed depending on the location of the shoreline data points in the original District file and shoreline shapefile from the Florida Department of Environmental Protection (FDEP. The final seamless bathymetry grid is shown in Figure 8.2. Shoreline points were left out to remove clutter from the image. The resulting enhanced bathymetry is shown in **Maps 8.1** through **8.4**.

8.3.2 Transect Creation

A new point shapefile was created from the grid file. Each point represents the middle of a grid cell. Next, a new set of transects was created in the same locations as the transects from the earlier study. These transects were drawn so that they were perpendicular to the river centerline. The start and end points were matched with the original shoreline bathymetry locations. The transects were then sectioned into 30 meter sections and the centerpoint of each section was assigned the depth value of the nearest grid point. Using this method, two transect length values were obtained: the *measured* and *calculated* lengths. The former is the true distance between shoreline points from the shoreline shapefile, while the latter is the sum of the 30m and 15m sections. Figures 8.3a and 8.3b below show the steps that have been described above.

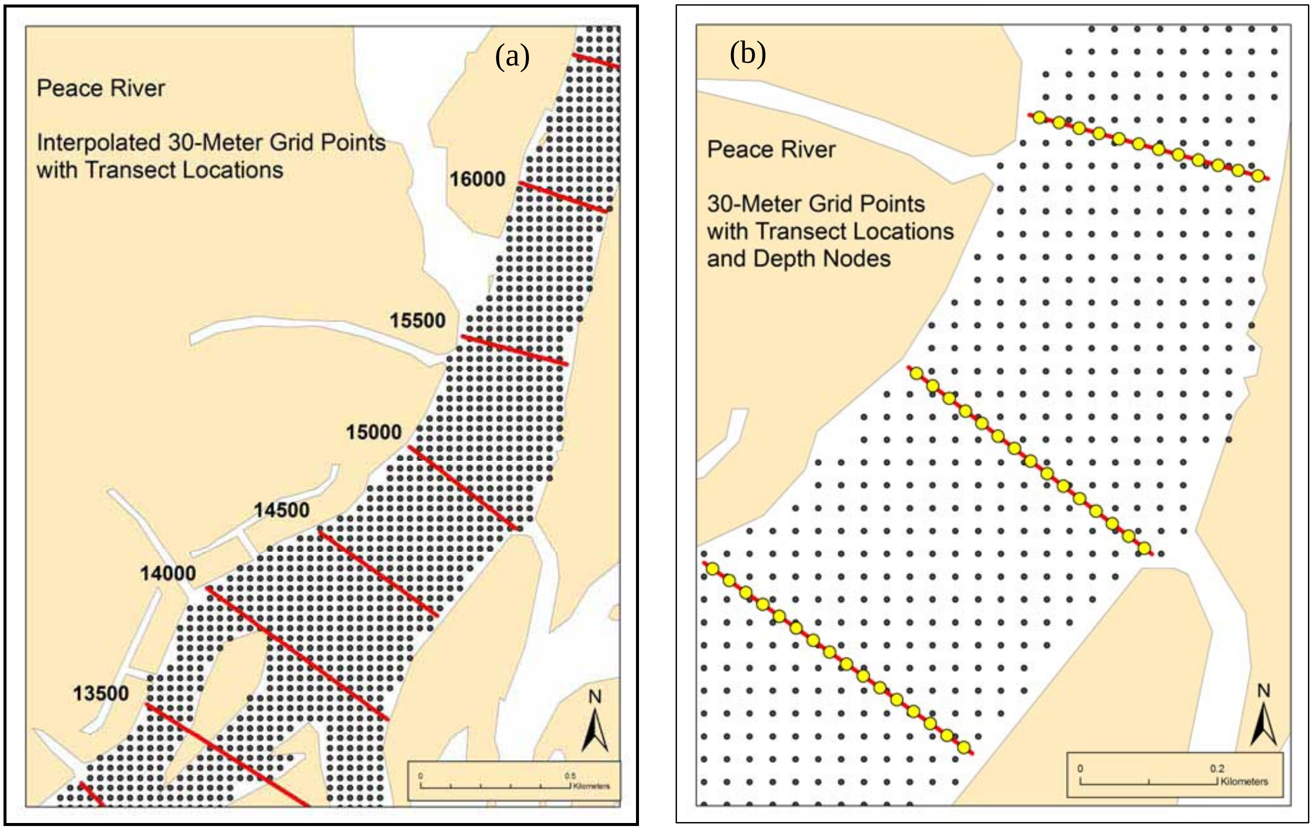

Figure 8.3. (a) Grid values represented as points with new transect locations and (b) transect sections showing points where nearest depth value was assigned.

8.4 Results

A segment is the area between consecutive transects. The following morphometric parameters were calculated for each transect and segment (see Table 1 for results).

- Transect bottom length
- Transect top length (calculated)
- Transect top length (measured)
- Transect cross section area
- Transect mean depth
- Transect maximum depth
- Segment shoreline length
- Segment surface area
- Segment volume

Table 8.1
Peace River Morphometric Statistics by 0.5 Kilometer Intervals

Transect	Transect Bottom Length (m)	Transect Cross Section Area (m2)	Calculated Cross Section Length (m)	Transect Mean Depth (m)	Transect Maximum Depth (m)	Measured Cross Section Length (m)	Segment Shoreline Length (m)	Segment Surface Area (m2)	Segment Volume (m3)
10000	2100	2288	2100	-1.06	-3.94	2106	1279	1349730	1377819
10500	2310	2404	2310	-1.02	-2.84	2300	3458	1469706	1369693
11000	1770	1565	1770	-0.86	-3.74	1778	4288	920927	886989
11500	2010	1599	2010	-0.78	-3.74	2000	4140	778733	913418
12000	1950	2070	1950	-1.05	-3.35	1952	4811	835388	980735
12500	1831	1594	1830	-0.86	-3.53	1831	4800	517674	798116
13000	1681	1495	1680	-0.89	-3.68	1693	3392	352152	562476
13500	1051	981	1050	-0.91	-3.24	1039	3603	289942	481879
14000	750	1456	750	-1.82	-3.13	744	741	233287	464565
14500	480	858	480	-1.64	-3.3	481	1100	209958	422305
15000	450	933	450	-1.89	-3.12	448	1082	232176	507367
15500	360	889	360	-2.18	-3.81	366	691	153303	375031
16000	300	753	300	-2.16	-5.13	303	1052	141083	349846
16500	300	813	300	-2.31	-4.08	290	2022	158857	380892
17000	601	625	600	-1.04	-4.89	608	1813	244396	382994
17500	330	727	330	-1.94	-3.12	325	1231	146637	293633
18000	151	402	150	-2.13	-5.06	148	912	101091	232658
18500	271	465	270	-1.53	-3.77	271	1252	127752	238952
19000	270	532	270	-1.67	-2.48	262	911	81095	202392
19500	151	402	150	-2.11	-4.55	149	1312	102202	257813
20000	180	332	180	-1.46	-3.01	182	1352	104424	137331
20500	120	181	120	-1.16	-3.36	111	1232	69986	103234
21000	90	79	90	-0.64	-1.29	100	1913	64432	92479
21500	91	253	90	-2.02	-3.43	83	1041	73319	108903
22000	180	385	180	-1.75	-3.4	166	1171	69986	186474
22500	151	365	150	-1.95	-4.88	163	1042	98869	221319
23000	121	331	120	-2.06	-3.91	118	1032	65542	155126
23500	151	329	150	-1.72	-3.54	135	1691	78873	130014
24000	180	221	180	-1	-1.67	168	1250	106645	176004
24500	120	74	120	-0.48	-1.39	107	961	44436	84475
25000	90	157	90	-1.25	-2.77	101	1022	53323	82146
25500	90	102	90	-0.82	-1.38	96	1082	58877	81374
26000	120	113	120	-0.72	-1.11	123	891	46657	65470
26500	61	119	60	-1.32	-3.21	58	1231	38881	88260
27000	60	89	60	-0.99	-2	62	1749	62210	99906
27500	30	37	30	-0.83	-2.49	29	700	19996	42662

Table 8.1
Peace River Morphometric Statistics by 0.5 Kilometer Intervals

Transect	Transect Bottom Length (m)	Transect Cross Section Area (m2)	Calculated Cross Section Length (m)	Transect Mean Depth (m)	Transect Maximum Depth (m)	Measured Cross Section Length (m)	Segment Shoreline Length (m)	Segment Surface Area (m2)	Segment Volume (m3)
28000	60	74	60	-0.83	-1.7	54	1281	54434	94312
28500	60	106	60	-1.18	-2.36	50	760	21107	53399
29000	31	45	30	-1.01	-3.02	44	980	36659	93386
29500	30	30	30	-0.66	-1.98	32	880	34438	49080
30000	60	68	60	-0.75	-1.5	67	1001	47768	82193
30500	90	98	90	-0.79	-1.52	98	1099	48879	72804
31000	60	82	60	-0.91	-2.03	57	988	42214	69437
31500	60	88	60	-0.98	-2.14	52	900	31105	85216
32000	30	22	30	-0.49	-1.48	36	1320	28883	40617
32500	30	19	30	-0.43	-1.28	36	580	16663	21510
33000	60	40	60	-0.44	-1.24	59	1161	39992	24048
33500	60	15	60	-0.17	-0.48	57	1171	32216	25916
34000	30	10	30	-0.21	-0.64	27	620	14442	19037

Transects have depth values assigned every 30 meters (starting at 15 meters which is the mid point of the first 30 meter section). The end points are at 0 meters elevation. The total transect length of each transect using this method was rounded to the nearest 30 m, and is shown in Table 1 as the Calculated Cross Section Length. The length of each transect before it was truncated is indicated as the Measured Cross Section Length. The Transect Cross Section Area was also calculated using the rounded 30 m sections.

The transect bottom length was based on the 30 meter sections by calculating the hypotenuse of each 30 m section and corresponding depth. This value is likely underestimated for two reasons. First, it is based on a transect length which was rounded down, and second, the near shore slope was slightly exaggerated (mostly a drop of less than 1 meter for the first 15 meters), which reduces the bottom length. However, given the resolution of the available data, it is a reasonable approximation of the transect bottom length. Moreover, given the width to depth ratio of the Peace River, the difference between bottom length and surface length of each transect should be minimal, as should the difference between surface and bottom area of each segment. The segment bottom areas were therefore not calculated, since the segment surface areas are a reasonable approximation of the bottom area.

The segment surface area and volume was based on the number of grid cells in each segment and their depth values. A grid cell was assumed to fall inside a segment if the center of that grid cell was also inside the segment. The area of a segment was calculated by adding the surface areas of all grid cells in that segment. Similarly, a segment volume was calculated by summing the volumes associated with grid cells in that segment.

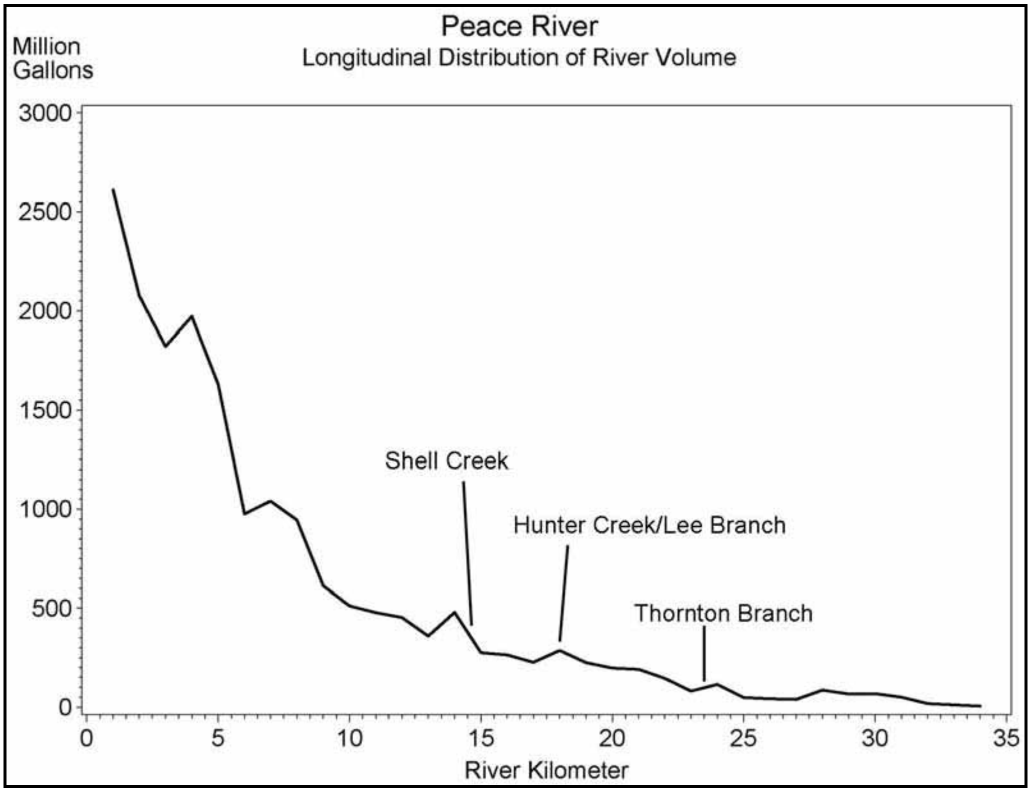

Figure 8.4a. Longitudinal Distribution of River Volume in the Peace River.

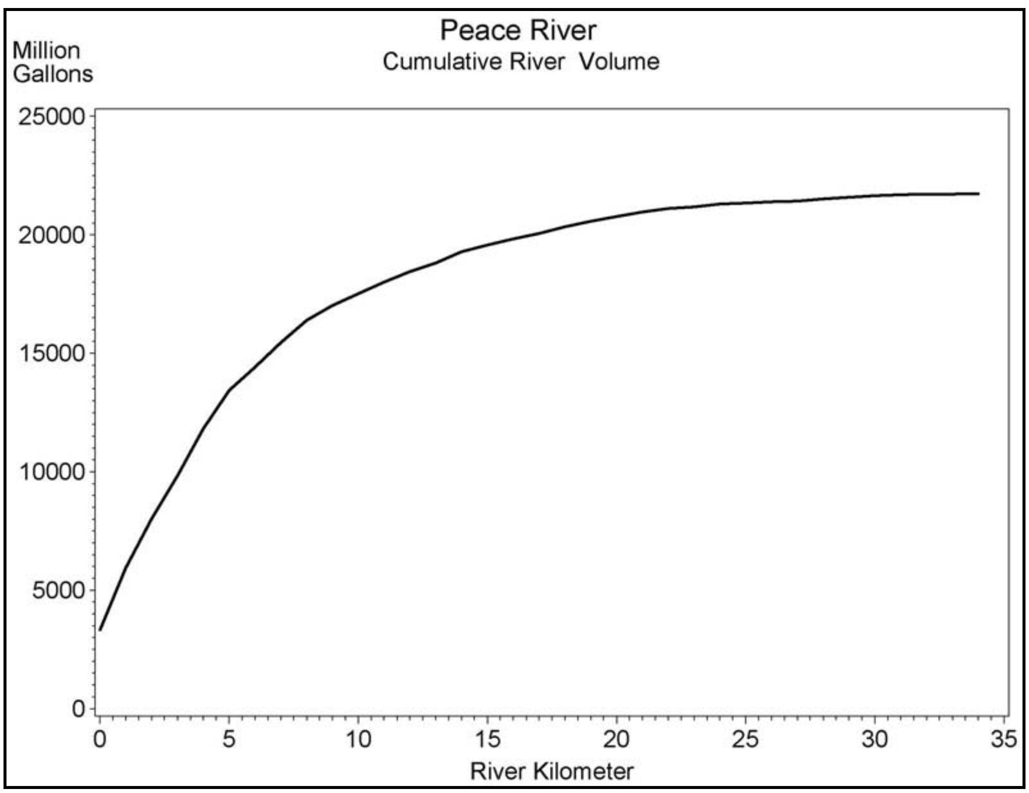

Figure 8.4b. Longitudinal Distribution of Cumulative River Volume in the Peace River.

The longitudinal distribution of river volume was calculated and is represented in Figures 8.4a and 8.4b. The Peace River is quite shallow as can be seen from the mean depth in Table 1. This means that the river volume trend can be primarily explained by the river width. Note that these figures start near the mouth of the Peace River (River Kilometer 0). Transect calculations by comparison started at River Kilometer 10, as this was also the starting point for the 1998 study. Several minor creeks and branches join the Peace River at the following locations.

- Shell Creek (RK 14.7)
- Hunter Creek/Lee Branch (RK 17.0)
- Thornton Branch (RK 23.5)

Final transect profiles were calculated and plotted and examples are presented in Figures 8.5a (RK 10) and 5b (Rk 12.5). A total of 49 transect profiles were determined and the resulting plots between River Kilometers 10.0 (1000 meters) and 34.0 (34000 meters) at 0.5 (500 meter) intervals are presented in Appendix A – River Cross Sections. The first transect is the most downstream and shows how much of the river is less than 1 meter deep except for the channel of approximately 4 meters near the East bank. The transect at RKm 12.5 shows four islands in the river and indicates that two deeper sections exist near the right and left bank of the river. These are approximately 3 meters deep.

While the 1998 study contained a summary of riparian vegetation in each section, this exercise was not repeated in the current study because no new data are available for such an analysis. The results from the 1998 study therefore use the most recently collected data and this report should be consulted for such data inquiries.

The calculated transect depth values were used instead of measured *in situ* data since the latter were generally not collected near the original transect and the primary objective of this study was to reproduce morphometric data similar to that presented in the 1998 study. Typically, the new transects did match the old transects except in a few locations. One of these instances was at River Kilometer 15.5, and the calculated and measured bathymetry data at this transect location are compared in Figure 8.6. The calculations near the banks as was noted earlier were assigned to a location 15 meters from the bank and this forced the depth value at the steepest slope to an artificial point, resulting in a slightly modified profile. The calculated and measured profiles otherwise are shown to have a relatively good fit between the older measured and currently calculated results

The degree of fit between the current enhanced morphometric data collected in 2003 and the older less intense data collected in September 1997 provides assurance that the primary conclusions drawn in the older document should be transferable. It is however recommended that at some point in the future both river bathymetry and vegetation data may need to be evaluated again in a follow-up study, since portions of the lower Peace River morphometry could have been significantly disturbed by Hurricane Charley (a Category 4 storm) in August of 2004 and Hurricanes Frances and Jeanne that also impacted the Peace River watershed to a much lesser extent in the same year.

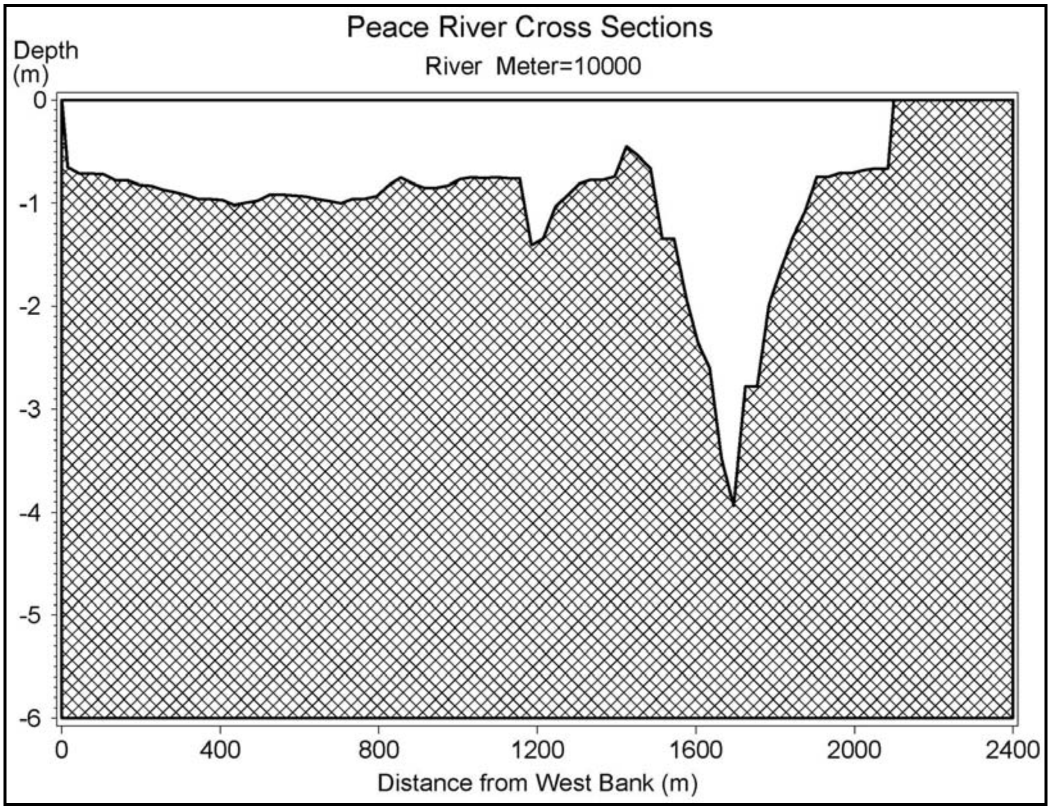

Figure 8.5a. Peace River transect profile at river kilometer 10.

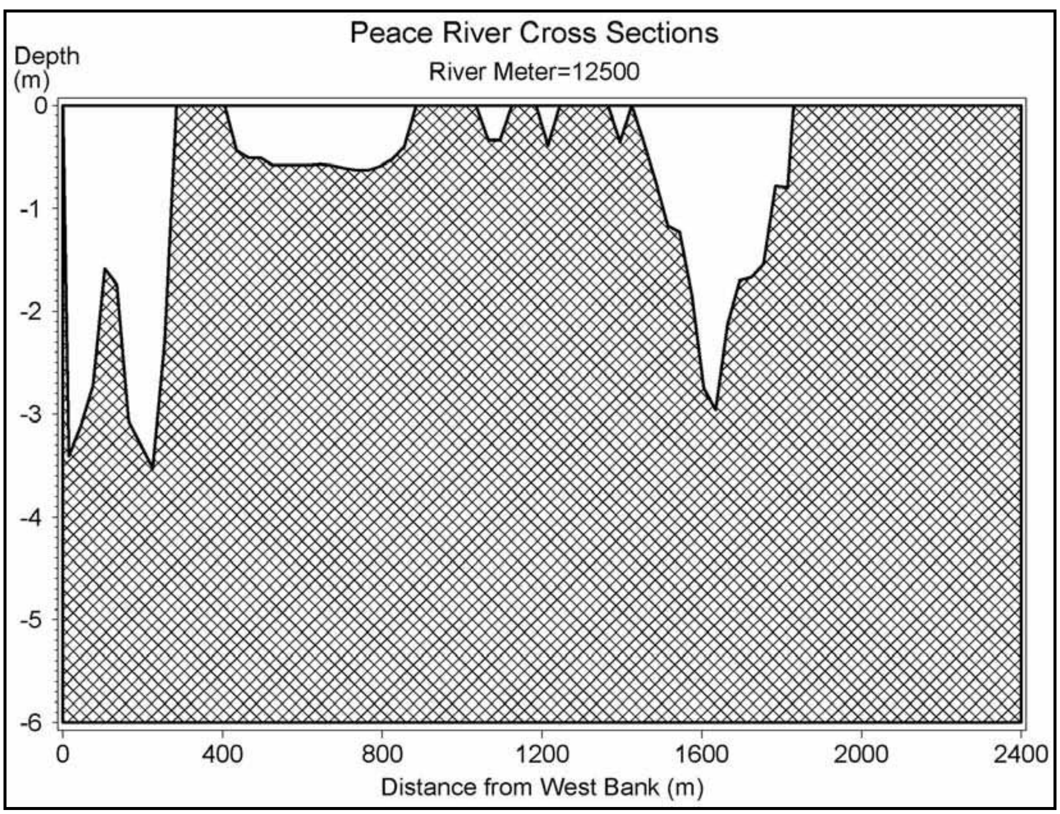

Figure 8.5b. Peace River transect profile at river kilometer 12.5.

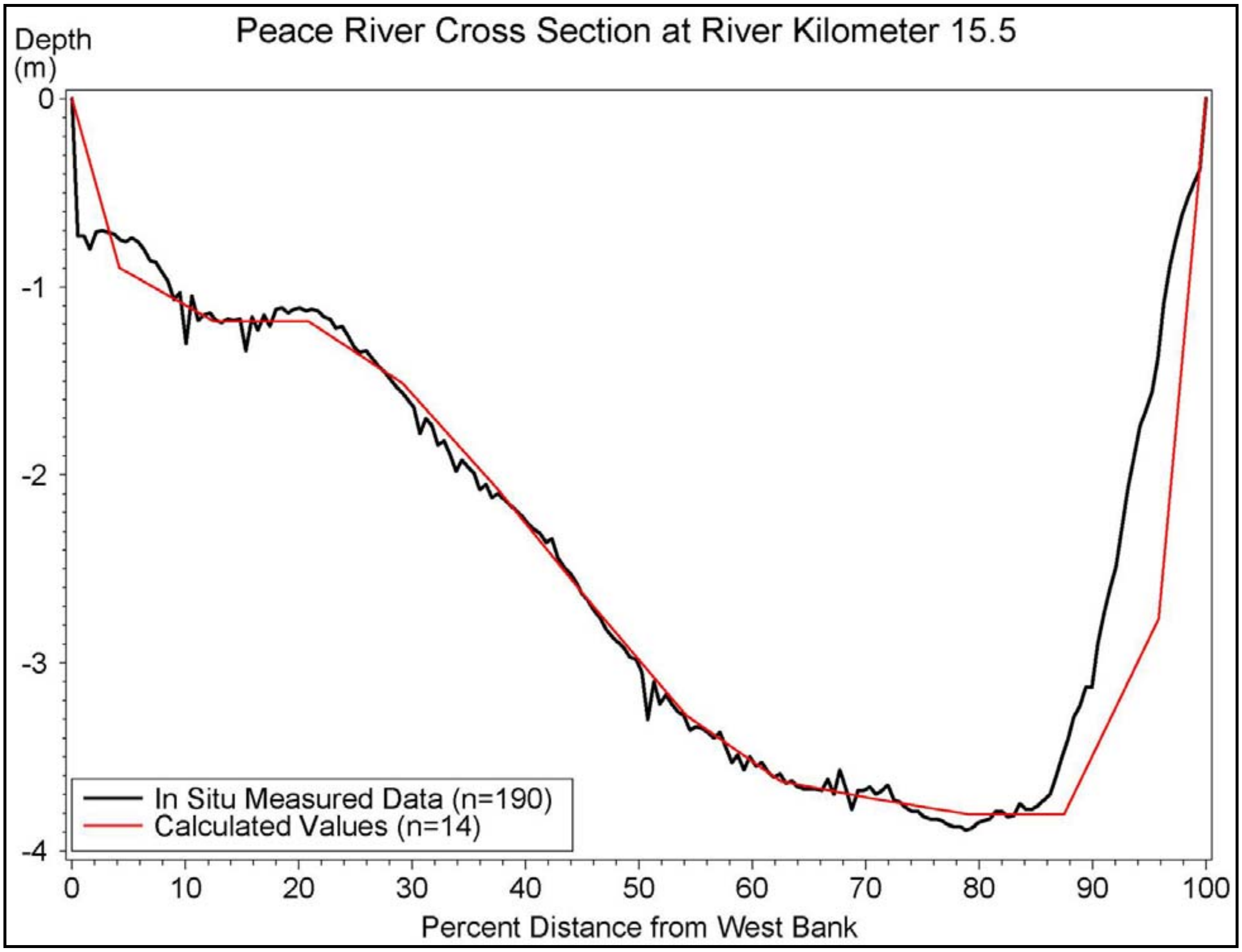

Figure 8.6. Comparison of measured and calculated bathymetry values at River Kilometer 15.5.

8.5 Summary

The objective of this section was to reproduce the earlier Peace River Morphometric Study using improved data and methods. The first report was produced in 1998 using transect surveys and geometric calculations. The number of Graphical Information System (GIS) tools available at that time was relatively limited. The presented updated results were developed using detailed bathymetric data and current advanced GIS tools. Recent enhanced bathymetry data gathered for development of the District's mechanistic hydrodynamic model for the lower Peace River/Shell Creek MFLs were used to perform this morphometric analysis (Figure 8.2 and 8.3). Raw data were collected. Complete details of the procedures used in developing the updated bathymetric data are contained in the *Bathymetric Survey in Charlotte Harbor Area* report submitted to the District by Ping Wang from the Department of Geology at the University of South Florida.

These data were used to calculate and depict both typical cross-sections at 0.5 kilometer intervals along the HBMP monitoring transect, as well as the following morphometric parameters for each transect and segment.

- Transect bottom length
- Transect top length (calculated)
- Transect top length (measured)
- Transect cross section area
- Transect mean depth
- Transect maximum depth
- Segment shoreline length
- Segment surface area
- Segment volume

The calculated and measured profiles otherwise are shown to have a relatively good fit between the older measured and currently calculated results providing assurance that the primary conclusions drawn in the older document should be transferable. It is however recommended that at some point in the future both river bathymetry and vegetation data may need to be evaluated again in a follow-up study, since portions of the lower Peace River morphometry could have been significantly disturbed by Hurricane Charley in August of 2004 and Hurricanes Frances and Jeanne that also impacted the Peace River Watershed to a much lesser extent in the same year.

9.0 Significant Environmental Change

Since its inception, the Hydrobiological Monitoring Program (HBMP) has incorporated numerous study elements directed toward assessing both the overall "health of the estuary" as well as impacts potentially associated with Facility withdrawals. None of the extensive HBMP analyses done to date have indicated any significant long-term physical, chemical or biological changes in the lower Peace River/upper Charlotte Harbor estuarine system, resulting from either current or historic water withdrawals by the Facility.

An approach for determining whether permitted surface withdrawals have or are causing adverse environmental changes in the estuary utilizing HBMP data was proposed in the *2002 HBMP Comprehensive Summary Report* and is summarized in this section. Additionally, this section recounts the hierarchy of management actions proposed to be implemented in response to detected changes that could forewarn of potential future changes that would constitute an adverse change.

9.1 Regulatory Basis of Review

The Southwest Florida Water Management District's (District) *Basis of Review* has established a specific series of performance standards for water use permits associated with withdrawals from natural surface waterbodies, such as the Peace River.

- *Flow rates shall not deviate from the normal rate and range of fluctuation to the extent that water quality, vegetation, and animal populations are adversely impacted in streams and estuaries.*

- *Flow rates shall not be reduced from the existing level of flow to the extent that salinity distributions in tidal streams and estuaries are significantly altered as a result of withdrawals.*

- *Flow rates shall not deviate from the normal rate and range of fluctuation to the extent that recreational use or aesthetic qualities of the water resource are adversely impacted.*

From a technical standpoint, adverse environmental impact can be defined using a wide range of metrics that quantify deviations from the pre-withdrawal salinity patterns, water quality conditions, and the distribution and abundance of biological communities. The Peace River HBMP Scientific Review Panel (Panel) has been established primarily to assist District and Peace River/Manasota Regional Water Supply Authority (Authority) staff in assessing the continued technical efficacy and ability of the HBMP to detect potential adverse impacts caused by the Facility, and secondarily to assist in the interpretation of analysis of HBMP data.

9.2 Resource Management Goals and Relevant Hydrobiological Indicators

In issuing the Peace River Facility's water use permit, the District has identified the primary resources of interest, as well as resource management and protection goals for the lower Peace River and upper Charlotte Harbor estuarine system.

1. Protect the extent, distribution, and diversity of physical and biological habitats in the lower Peace River and upper Charlotte Harbor.

2. Protect the abundance of fish and invertebrate species of sport and commercial importance in the lower Peace River and upper Charlotte Harbor.

3. Protect the estuarine fish nursery function in the lower Peace River and upper Charlotte Harbor.

4. Protect the spatial and temporal distributions of organisms that are important food sources for fish in the lower Peace River.

5. Protect seasonal patterns of nutrient delivery to the estuary so that trophic interactions are maintained in the lower Peace River and Goals 1 through 4 are met.

6. Protect seasonal patterns of organic matter delivery to the estuary so that trophic interactions are maintained in the lower Peace River and Goals 1 through 4 are met.

7. Protect the temporal and spatial characteristics of salinity distributions in the estuary so that Goals 1 through 4 are met.

8. Protect dissolved oxygen concentrations in the estuary so that Goals 1 through 4 are met.

9. Protect the abundance of any rare, threatened or endangered species that use the lower Peace River or upper Charlotte Harbor.

10. Protect suitable habitats and water quality for fish and wildlife that are not of sport or commercial importance.

9.3 Rationale for Defining Significant Environmental Change

Inherent in the District rules is the recognition that surface water withdrawals are linked to potential changes in salinity, associated water quality constituents and biological communities. Freshwater withdrawals have a direct and instantaneous physical affect on salinity, while the effects of freshwater withdrawals on other water quality constituents, and biological communities in particular, are typically indirect and more complex (**Figure 9.1**). Such indirect impacts are mediated by physical and chemical processes, and are typically manifested on slower time scales (i.e. weeks, months, or seasons).

District staff, with assistance from the HBMP Scientific Review Panel, is responsible for the interpretation of data collected from the HBMP and other sources to determine if the permitted Facility surface water withdrawals have caused harm to the lower Peace River/upper Charlotte Harbor estuarine systems. The term *adverse impact*, which is included in the Authority's water use permit, has a distinct legal meaning in the context of water use permitting. The HBMP Scientific Review Panel expressed a concern that delaying action until this regulatory threshold had been cross limited the ability to avoid perceived potential impacts. Therefore, based on consultation with the HBMP Scientific Review Panel and District staff, the *2002 Peace River Comprehensive Summary Report* proposed that the less restrictive term *significant environmental* *change* be used by the Authority as a lower threshold criterion for assessing the findings of the HBMP

The following definition of *significant environmental change* has been revised slightly from that originally proposed to include not only differences from the pre-withdrawal condition (before 1980), but also to incorporate comparisons between more recent periods and conditions under differing permitted withdrawals.

Significant Environmental Change

> ***A detected change, supported by statistical inference or a preponderance of evidence, in the normal or previous abundance, distribution, species composition, or species richness of biological communities of interest in the lower Peace River and upper Charlotte Harbor that is directly attributable to reductions in freshwater inflows caused by permitted surface water withdrawals.***

Conditions meeting the working definition of *significant environmental change* stated above could be measured and described in many different ways. Some simple examples are described below.

- **Significant environmental changes in lower river/upper harbor habitats** - this would include measurable spatial and temporal changes in the natural variability of the salinity structure of characteristic fixed and/or dynamic estuarine components of sufficient magnitude to alter effected biological communities.

- **Change in species richness or community balance** - numerous measures and indices exist to describe species richness, community balance, and biodiversity (e.g. Shannon-Weaver index) for various biotic indicators.

- **Dislocation of an indicator species' distribution -** the "center of abundance" statistic and observed first and last occurrences have been used in the HBMP with respect to the distribution of larval and juvenile fish, benthos, and vegetation.

- **Elimination or reduced abundance of a "desirable" indicator species -** the elimination, or a significant reduction in the abundance, of a desirable (e.g. economically or ecologically important) indicator species would likely be considered a significant environmental change.

- **Introduction or increased abundance of an "undesirable" indicator species** - the converse of the above described scenario, the introduction, or a significant increase in the abundance, of an "undesirable" (e.g. non-native or nuisance) indicator species within a reporting unit would also likely be considered a significant environmental change.

Using this framework for identifying whether a significant environmental change has occurred, a series of hierarchy of management responses can be developed and structured according to various potential criteria and outcome objectives.

9.4 Authority's Management Response Plan (MRP) to a Potential Observed Significant Environmental Change

Waiting until an adverse environmental impact has occurred to initiate appropriate management actions or remedial measures reduces the opportunity to adequately protect resources that may be at risk. Therefore, the Authority has adopted a MRP that is a proactive approach to protecting the resources of concern in the lower Peace River estuarine system.

The plan recommends that salinity deviations be used as the primary indicator of significant environmental change that could lead to potential adverse environmental impact. In addition, salinity deviations will be used as the triggering mechanism for a range of management responses aimed at reversing or minimizing the change to prevent potential adverse environmental impact. Salinity deviations from the target distribution (**Figure 9.2**) will be evaluated in terms of magnitude, spatial extent, and/or temporal duration to develop a decision tree that is linked to various management actions (**Figure 9.3**). Using this approach, the intensity and urgency of the management response would be appropriately linked to the degree of the observed salinity deviations.

Initial management actions will focus on determining if the observed deviation is in fact real and not a measurement error or an artifact of the sampling design. If the change is determined to be real, the next series of management actions will focus on better understanding and describing the change, and determining potential cause and affect relationships. Finally, the most intense management actions may involve regulatory enforcement actions as well as remediation and mitigation. A hierarchy of management actions, contained in the Authority's MRP is listed sequentially in order of increasing intensity and urgency below.

1. **Data QA/QC Audit** - This action would involve the performance of an intense QA/QC audit to determine if the detected change was the result of laboratory problems, data entry errors, violation of sampling protocols, etc.

2. **Data Comparison (Correlates)** - This action would involve a review of data correlates (e.g., specific conductance is a correlate to salinity) to determine if there is more than one line of evidence reflecting the detected change.

3. **Scientific Review Panel Meeting** - If Steps 1 and 2 indicate that the detected change is not due to quality control problems, and is reflected in multiple lines of evidence, the next step would be to convene a special meeting of the Panel. The purpose of the meeting would be to review the findings of Steps 1 and 2, and to determine a possible modified course of action to refine the understanding of the magnitude and extent of the detected change. If deemed appropriate, the Panel could recommend additional data analyses, or a redirected and focused sampling effort to better elucidate the detected change. Recommendations of the Panel would be subject to further review and approval by District staff.

4. **Redirected Sampling Effort** - This action would involve conducting more focused supplemental sampling in the affected river segments with the objective of gaining a better understanding of the detected change. The additional data collected from this effort could then be subjected to Steps 1 and 2 above if deemed appropriate. This action would determine if detection of the change is repeatable under a more focused sampling program. Although this step could be valuable, it may not be necessary for a redirected sampling effort to be conducted for all hydrobiological changes detected by the HBMP. For some hydrobiological changes, District staff could recommend proceeding directly to Step 5 without conducting any redirected or additional sampling.

5. **Determination of Significant Environmental Change** - Based on the findings of Steps 1 through 4, the next step would be to reconvene the Panel with the objective of evaluating whether the detected change is substantial enough to potentially constitute an adverse environmental change. This step would involve a detailed assessment of the data analyses conducted in Steps 1 through 4 to ascertain whether conditions consistent with the working definition of significant environmental change presented above have been met. A formal determination of significant environmental change would be made via a consensus of professional opinion by District staff and the Panel members in consideration of technical and scientific factors only. Following this determination, the Peace River/Manasota Regional Water Supply Authority Board would be briefed on the findings and recommendations of District staff and the Panel.

6. **Regulatory Summit Meeting –** If, after the completion of Step 5, District staff and the Panel conclude that a significant environmental change has occurred, the next step would be to convene a meeting with all applicable regulatory agencies and affected parties to determine the appropriate regulatory course of action. At a minimum, the regulatory agencies represented would include the District and FDEP, however, depending on the environmental changes involved other state and federal agencies may be involved (e.g., Florida Fish and Wildlife Conservation Commission; U.S. Fish and Wildlife Service). Actions by the group in attendance would include revisiting Steps 1, 2 and 4 above. If after reviewing the presented evidence the group (via a consensus of professional opinion) formally determines that significant environmental change has occurred, then the group must decide on the urgency or type of regulatory actions required. Further actions could include deferral to the Water Management District Governing Board, or immediate enforcement of regulatory actions such as temporary modification of the withdrawal schedule. If more substantial regulatory actions such as permanent modifications to the withdrawal schedule and/or mitigation were determined to be appropriate, preparations would be made for presenting recommendations to the District Governing Board for formal action.

7. **District Governing Board Hearing** - This step would involve the presentation of data and other evidence indicating the occurrence of significant environmental change to the District Governing Board. The formal determination of adverse impact from a regulatory and legal standpoint would be made by the District Governing Board. If it is determined that the detected change constitutes an adverse environmental impact, then the Governing Board could require appropriate remediation and or mitigation.

8. **Remediation** - The requirement of appropriate remedial measures by the District Governing Board could include such actions as permanent modifications to the permitted withdrawal schedule. Modifications to the withdrawal schedule could include provisional or temporary reductions in withdrawal rates, or modifications to the schedules such that greater withdrawals would occur during high flows, but lesser withdrawals would occur during low flows. In the event that the permitted withdrawals resulted in irreversible significant harm to resources of concern, mitigation could be required.

In the implementation of the sequence of management responses described above, the primary objective is the prevention of any adverse impacts. However, the intensity of the management response should not be the only criteria considered. The detection of any hydrobiological change must always be framed within the degree of certainty that the detected change is real, and not solely due to chance. Therefore, the intensity of the management response should be tied not only to the magnitude or severity of the hydrobiological change, but also to the degree of certainty that the detected change is real, and whether it is caused by Authority withdrawals. Table 9.1 below presents a conceptual matrix approach that integrates the magnitude of the detected change and the probability that the change is due to chance alone (e.g. alpha).

Table 9.1
Conceptual Decision Matrix For Determining An Appropriate Management Response To Detected Hydrobiological Change

Probability of Making a Type I Error	Magnitude of Detected Hydrobiological Change		
Alpha	Small	Moderate	Large
0.20	Data Comparison	Scientific Review Panel Meeting	Redirected Sampling
0.10	Scientific Review Panel Meeting	Redirected Sampling	Determination of Significant Change
0.05	Redirected Sampling	Determination of Significant Change	Regulatory Summit Meeting

As shown in Table 9.1, the intensity of the selected management response is a function of both factors. If the detected change is relatively large, but the degree of certainty is low (e.g. high alpha) then a less intense management response would be appropriate. If, on the other hand, the detected change is considered to be moderate, but the degree of certainty is high (e.g. low alpha), then a more intense management response would be indicated. The application of this approach would obviously vary with the specific hydrobiological changes and statistical measures of certainty involved. The approach of the selected management response would also depend on whether the observed change was found to be attributable directly to Facility withdrawals or potentially to anthropogenic upstream activities.

9.5 Assessment of Permitted Withdrawals

Since its inception in 1976, the HBMP has incorporated numerous physical, chemical, and biological study elements directed toward assessing both the overall "health of the estuary" as well as direct and indirect adverse impacts potentially associated with Facility withdrawals. To date none of the extensive analyses that have been conducted in conjunction with these long-term monitoring program elements, and reported in numerous previous HBMP documents submitted to the District, have found or suggest any significant long-term physical, chemical or biological changes in the lower Peace River/upper Charlotte Harbor estuarine system resulting from either current or historic water withdrawals by the Facility. The data and analyses presented in this 2006 HBMP Comprehensive Report continue to support this overall conclusion.

9.6 Summary

An approach for determining whether permitted surface withdrawals have or are causing adverse environmental changes in the estuary utilizing HBMP data was proposed in the *2002 HBMP Comprehensive Report*. This chapter summarizes the hierarchy of management actions proposed to be implemented in response to detected changes that could forewarn of potential future changes that would constitute an adverse change.

9.6.1 Regulatory Basis of Review

The District's *Basis of Review* has established a specific series of performance standards for water use permits associated with withdrawals from natural surface waterbodies.

- *Flow rates shall not deviate from the normal rate and range of fluctuation to the extent that water quality, vegetation, and animal populations are adversely impacted in streams and estuaries.*

- *Flow rates shall not be reduced from the existing level of flow to the extent that salinity distributions in tidal streams and estuaries are significantly altered as a result of withdrawals.*

- *Flow rates shall not deviate from the normal rate and range of fluctuation to the extent that recreational use or aesthetic qualities of the water resource are adversely impacted.*

An adverse environmental impact can be defined from a technical standpoint using a wide range of metrics that quantify deviations from the pre-withdrawal salinity patterns, water quality conditions, and the distribution and abundance of biological communities. The Peace River HBMP Scientific Review Panel (Panel) has been established primarily to assist District and Authority staff in assessing the continued technical efficacy and ability of the HBMP to detect potential adverse impacts caused by the Facility, and secondarily to assist in the interpretation of analysis of HBMP data.

Inherent in the District rules is the recognition that surface water withdrawals are linked to potential changes in salinity, associated water quality constituents and biological communities. Freshwater withdrawals have a direct and instantaneous physical affect on salinity, while the effects of freshwater withdrawals on other water quality constituents, and biological communities in particular, are typically indirect and more complex. Such indirect impacts are mediated by physical and chemical processes, and are typically manifested on slower time scales (weeks, months, or seasons).

Since the term *adverse impact* has distinct legal meaning in the context of water use permitting, it was proposed that this term be supplanted by *significant environmental change* with respect to the role of the District staff and the HBMP Scientific Review Panel, and be used as the established criteria for assessing the findings of the HBMP.

Significant Environmental Change

> *A detected change, supported by statistical inference or a preponderance of evidence, in the normal or previous abundance, distribution, species composition, or species richness of biological communities of interest in the lower Peace River and upper Charlotte Harbor that is directly attributable to reductions in freshwater inflows caused by permitted surface water withdrawals.*

9.6.2 Authority's Management Response Plan (MRP) to a Potential Observed Significant Environmental Change

Waiting until an adverse environmental impact has occurred to initiate appropriate management actions or remedial measures reduces the opportunity to adequately protect resources that may be at risk. The Authority has therefore adopted a MRP that is a proactive approach to protecting the resources of concern in the lower Peace River estuarine system.

The plan recommends that salinity deviations be used as the primary indicator of significant environmental change that could lead to potential adverse environmental impact. In addition, salinity deviations would be used as the triggering mechanism for a range of management responses aimed at reversing or minimizing the change to prevent potential adverse environmental impact. Salinity deviations from the target distribution will be evaluated in terms of magnitude, spatial extent, and/or temporal duration to develop a decision tree that is linked to alternative management actions.

The objective of implementing a management response is the prevention of an "adverse impact". Any hydrobiological change must always be framed within the degree of certainty that the detected change is real, and not solely due to chance. Therefore, the intensity of the management response should be tied not only to the magnitude or severity of the hydrobiological change, but also to the degree of certainty that the detected change is real, and whether it is caused by Authority withdrawals.

If the detected change is relatively large, but the degree of certainty is low then a less intense management response would be appropriate. If, on the other hand, the detected change is considered to be moderate, but the degree of certainty is high, then a more intense management response would be indicated. The approach of the selected management response would also depend on whether the observed change was found to be attributable directly to Facility withdrawals or potentially to anthropogenic upstream activities.

10.0 Proposed Monitoring Design Modifications to the Existing Long-term HBMP Elements

10.1 Introduction and Overview

The primary objectives of this section are to review the effectiveness and address potential modifications of the current Hydrobiological Monitoring Program (HBMP) study elements based on the results of the analyses and conclusions presented in this *2006 HBMP Comprehensive Summary Report.* Also addressed are those found within the previous *HBMP 2004 Midterm Interpretive Report* (PBS&J 2006), *2002 Comprehensive Summary Report* (PBS&J 2004), and *2000 Midterm Interpretive Report* (PBS&J 2002) documents submitted in compliance with the Facility's 1996 water use permit renewal. The following topics are included in this chapter.

- An overview of the HBMP monitoring objectives.
- A review of established HBMP design criteria.
- Criteria for determining indicators of environmental change.
- An overview of previous HBMP elements.
- Summary of current HBMP study elements.
- Recommended reduction/elimination/enhancement of HBMP elements to address specific Scientific Review Panel (Panel) suggestions.

10.2 HBMP Monitoring Objectives

The HBMP design needs to cost-effectively address the articulated goals and objectives delineated in the Southwest Florida Water Management District's (District) specific water use permit conditions. The combined elements of the program's design need to meet the specific expectations and objectives set forth in the permit as well as provide sufficient long-term information on which to base the development of answers to potential future questions that might be expected to arise.

The following summarizes the primary monitoring objectives of the HBMP study elements, as contained within the water use permit's specific conditions.

- Monitor withdrawals from the Peace River Facility (Facility) and evaluate data as provided by the District for the gaged tributary flows from Joshua, Horse and Shell creeks, as well as the primary Peace River flows measured at Arcadia, and direct rainfall to the lower Peace River.
- Evaluate relationships between the ecology of the lower Peace River/upper Charlotte Harbor Estuary and freshwater inflows.

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

- Determine the relative degree and magnitude of effects of Peace River withdrawals by the Facility on ecological changes that may be observed in the lower Peace River/upper Charlotte Harbor estuarine system.

- Evaluate whether consumptive freshwater withdrawals significantly contribute to any adverse ecological impacts to the estuary resulting from extended periods of low freshwater inflows.

- Evaluate whether the withdrawals have had any significant effects on the ecology of the estuary, based on related information such as nutrient loadings, fish abundance, or seagrass distributions data collected by other studies conducted by the District or other parties.

The overall goal of the HBMP continues to be to provide the District with sufficient information to determine whether the water quality characteristics and biological communities of the lower Peace River/upper Charlotte Harbor estuarine system have been, are being, or may be significantly adversely impacted by permitted facility withdrawals. A secondary objective has historically been to develop an ongoing base of ecological information sufficient to provide the District with critical information regarding the overall status and relative "health" of the lower Peace River/upper Charlotte Harbor estuarine system, by evaluating the status and trends of selected water quality and biological parameters.

10.3 HBMP Design Criteria

In order to effectively meet these goals and objectives, the integrated design of HBMP elements should incorporate the following criteria.

- The program needs to identify those appropriate physical and biological indicators, and specific mechanisms of action, potentially subject to significant changes resulting from permitted freshwater withdrawals from the lower Peace River/upper Charlotte Harbor estuarine system.

- The program should determine and predominantly focus it efforts in those geographical regions of the lower river where naturally occurring and Facility induced changes in flows would be expected to result in the greatest potential observed changes in identified key estuarine characteristics.

- The design of the HBMP monitoring element should include sufficient spatial and temporal intensity to assure detection of measurable changes in selected physical/chemical/biological parameters resulting from changes in freshwater inflows.

It is therefore important that the following be clearly delineated for each of the HBMP study elements in order to meet these design criteria, and provide technically supportable data.

- The goals, objectives and specific sampling parameters need to be defined. This should include the specific purpose and application of each monitoring parameter.

- The sampling and analytical data gathering procedures need to be thoroughly described, specifically detailing the required temporal and spatial density of data collection.

- Data acquisition quality control and assurance methodologies need to be described, as well as potential methodologies and procedures for data analysis.

It is important that each HBMP study element, as well as the overall program, have specific clearly stated goals and objectives to cost-effectively meet the design criteria needed to accomplish the monitoring program's multiple expectations. These goals and objectives need to clearly establish the scientific basis needed to provide sufficient information to meet the District's criteria for required reasonable assurance, as well as provide meaningful information to both the public and the members of the HBMP Scientific Review Panel. It is also essential that the HBMP study elements delineate the types and amounts of monitoring data necessary to construct, calibrate, and verify the quantitative predictive models needed to evaluate both current as well as possible future alternative withdrawal strategies (**Chapter 7.0**).

Often a well-designed monitoring program results in unanswered questions concerning key environmental processes or potential impacts. It is therefore important that the HBMP design criteria provide for opportunities, where feasible, to include the incorporation of short-term, intensive monitoring elements needed to provide answers to specific questions or issues that may arise periodically during the review process. A clear example of such flexibility was the recently completed series of low flow "pump tests" (PBS&J 2007) and draft report submitted to the District and the Panel. The Panel had previously suggested that such a series of intensive short-term tests be undertaken to provide the directly measured collaborative physical data needed to verify the overall conclusions obtained from previous statistical models regarding the potential temporal and spatial magnitudes of predicted salinity increases resulting from permitted Facility river withdrawals. The HBMP design elements further need to be sufficiently flexible to allow incorporation of modifications when and where changes in conditions, or new gathered information, suggest the need for specific monitoring program changes.

10.4 Indicators of Environmental Change

The following provides a brief overview of a number of the considerations and criteria associated with the selection of potential indicators (or parameters) that should be considered during the development and application of each HBMP study element. Possible monitoring parameters can generally be divided into three primary categories relative to their degree of overall importance in assessing the potential impacts of Facility withdrawals on the lower Peace River/upper Charlotte Harbor estuarine system.

- Those ***critical*** to the overall success of the monitoring program
- Parameters that would provide ***desirable*** additional information
- Indicators that may have some ***potential*** future application

Cost-effective HBMP elements need to incorporate key selected indicators that exhibit specific and robust direct (or indirect) quantifiable relationships with changes in freshwater inflows. The previous "Conceptual HBMP Estuarine Model" developed as part of the *2002 HBMP Comprehensive Summary Report* found that the primary indicators that show direct relationships to temporal variations in freshwater inflows are typically physical or chemical in nature. Often, such parameters are characterized by rapid measurable responses to even relatively small changes in flows. In comparison, commonly utilized indicators characterized by indirect relationships with variations in flow are typically biological in nature. The relationships between changes in freshwater inflows and the distribution, structure and abundance of biological populations/communities within estuarine systems are mediated by preceding alterations of physical and chemical conditions. Thus, these indirect relationships generally exhibit much slower responses over time scales measured in days, months, seasons or even years. However, not only does the time scale potentially lengthen between variations in flow and observed responses with each trophic step up the food web (**Figure 10.1**), often the strength of the responses lessen relative to other seasonal factors associated with particular life-cycles and/or feeding-prey relationships.

A cost-effective HBMP monitoring design needs to focus on identifying and incorporating those *critical indicators* known to exhibit marked direct responses to variations in freshwater inflow, since it is these parameter measurements that present the greatest probability of both detecting and assessing the principle underlying causative factor(s) to observed environmental changes. The further incorporation of accompanying *desirable indicators* within the HBMP study elements should include those lower trophic level biological indicators that provide insight into the overall "health of the estuary," or those that afford insight into the integration of longer-term patterns. The utilization of *potential indicators* should be strictly limited to those few associated parameter measurements that can be quickly made with minimal additional effort or additional cost, and that may provide some further useful insight, without specifically being directly related to the study element's primary goals or objectives. The following basic criteria should be evaluated in assessing the relative efficacy of various potential indicators.

- **New Information** - provides specific fresh information and does not duplicate data already collected by other agencies or investigators.
- **Spatially Responsive –** the indicator should reflect changes in ecosystem conditions in response to an environmental stressor across a broad spatial range.
- **Anticipatory** - provides an accurate early warning of potential ecosystem changes.
- **Cost-Effective** - has low incremental cost relative to its information value.
- **Available Methodology** - should be generally accepted and standardized.
- **Unambiguously Interpretable** - must be indicative of either a direct or indirect pathway describing the structure and function within the context of an overall conceptual estuarine model.

- **Simple Quantification** – indicator measurements can be quantified relatively quickly with limited known variability among investigators.

- **Low Measurement Error –** parameter values should have known estimated levels of error than can be defined spatially and temporally.

- **Low Among Year Variability** – in order to detect ecologically significant changes within reasonable time frames, parameter values need to have low natural inter-annual variation relative to variables outside the environmental stressor of interest.

- **Sampling Stability** - measurements of the indicator should be spatially stable over the course of each sampling period.

- **Historical Record** – the availability of collaborative historical data from acceptable sources.

- **Retrospective** - can potentially be related to past conditions via retrospective analyses.

10.5 Previous HBMP Study Elements

Since the initiation of HBMP monitoring in 1976, the program has incorporated a number of differing physical, chemical, and biological study elements (see **Table 1.3**) that have been directed toward assessing both the overall "health of the harbor" as well as direct and indirect potential impacts that might be associated with Facility withdrawals. These HBMP studies have included the following program elements.

- A nine-year monthly study of the seasonal distribution of the sea star *Luidia clathrata* at twenty-six monitoring locations distributed between River Kilometers (RK) –28.0 and 8.0 throughout Charlotte Harbor and the lower Peace River was conducted.

- A benthic invertebrate ponar sampling program was conducted monthly between 1976–1984 at nineteen monitoring sites distributed between the river's mouth (RK 0.0) and the point upstream of the Facility where Horse Creek enters the river (RK 34.0). This nine-year HBMP monitoring element was conducted to assess temporal and spatial responses of key benthic indicator invertebrates to both seasonal and long-term variations in freshwater inflows, salinity and dissolved oxygen.

- Monthly night-time otter trawls were performed around a fixed monitoring location in upper Charlotte Harbor (RK –2.4) over twelve years in order to determine the influences of freshwater inflows on the abundance and structure of juvenile fishes in the upper harbor.

- The HBMP program incorporated three long-term vegetation studies along the lower Peace River downstream of the Facility over the twenty-nine year period between 1976 and 2004. These vegetation HBMP elements include infra-red aerial photography, the first and last occurrences of indicator species, and the monitoring of emergent riparian community structure at selected transitional sites.

- The seasonal effects of freshwater inflows on phytoplankton primary production were assessed based on monthly measurements of radioactive carbon uptake rates at four isohalines between 1983 and 1998. Corresponding chlorophyll *a* measurements of phytoplankton biomass have continued since 1983 at the isohaline-based sampling sites. The associated composition of the phytoplankton communities at these locations was also determined between 1989 and 2004.

- A corollary study of zooplankton community structure was conducted monthly between 1989 and 1996 at each of the four monitored phytoplankton isohalines. The objectives of this eight-year HBMP study were to assess correlations among variations in freshwater inflow, phytoplankton production and biomass, and zooplankton populations.

- Since its inception, the HBMP has included extensive long-term monthly monitoring elements associated with both the physical and chemical water quality characteristics of the lower river and upper harbor at "fixed" monitoring locations. In 1983 corresponding monthly physical and water quality determinations were instituted at the four "moving" isohaline-based locations. These data have historically been utilized to assess both physical and chemical seasonal responses to changes in freshwater inflows, as well as long-term trends in water quality characteristics in the lower river and upper harbor estuary.

- The U.S. Geological Survey (USGS) began a cooperative water quality data collection program with the Peace River/Manasota Regional Water Supply Authority (Authority) in August 1996. An initial USGS continuous recorder (15-minute intervals) was installed later that month in the lower river at the end of an exiting private dock at Harbour Heights (River Kilometer (RK) 15.5). This USGS gaging site (02297460) monitors water level, surface and bottom specific conductance, and temperature. The USGS added a second continuous recorder at the request of the Authority in November 1997 further upstream (RK 26.7) on a private dock near Peace River Heights (**Figure 6.1**). This USGS site (02297350) also measures water level, surface and bottom specific conductance, and corresponding temperatures at 15-minute intervals (see **Chapter 6.0**).

- A morphometric investigation was undertaken in the late 1990s to establish a river kilometer-based centerline transect against which to standardize all historic and future HBMP monitoring data. Additional analyses were conducted to determine typical cross-sections, open-water areas, water volumes, shoreline lengths, and the areas/types of adjacent wetland habitat along 0.5 kilometer segments of the lower Peace River study area.

- Intensive short-term investigations were conducted of the relative influences of variations in freshwater flows on the relative temporal/spatial distributions of both benthic macroinvertebrates and mollusks (1998-2000), and juvenile fishes and selected invertebrates (1997-2000). One of the objectives of both investigations was to determine potential monitoring strategies relating to future inclusions of additional HBMP study elements.

- The *2002 HBMP Comprehensive Report* (finalized in September 2004) recommended that an additional series of continuous conductivity gages be established by the Authority downstream of the USGS Peace River Heights recorder location. The primary objective of installing an additional series of HBMP continuous conductivity recorders, when combined with the two existing long-term USGS sites, was to obtain greater resolution of the direct relationships among freshwater flow, stage height, and conductivity downstream of the Facility during periods of withdrawals. In December 2005, the Authority installed three new continuous recorders located on Manatee Speed Zone Markers at RK 21.9 near the Liverpool side channel, at RK 23.4, and just downstream of the Navigator Marina at RK 24.5.

- Between December 2006 and May 2007, the Authority conducted a series of sixteen "pump test" events conducted under relatively low flow conditions. Graphical analyses of the relationships between average hourly gage heights and conductivities at the five continuous recorder locations downstream of the Facility showed that under ideal conditions of similar flows and tides, differences attributable to withdrawals were, as expected, relatively small given the normal daily range of variation. These analyses showed that salinity changes due to withdrawals were primarily confined to the peaks of incoming tides. The average salinity differences observed from these graphical analyses were well within those limits predicted by previous statistical models. In fact, when averaged over the entire range of the daily tidal cycles, these directly observed daily salinity changes were far less than those estimated from the previously developed statistical models.

The specific objectives, methods and results of these historic and ongoing HBMP study elements have been presented in the extensive series of HBMP Annual Data Reports and periodic Summary and Interpretive Reports submitted to the District since 1979. Comprehensive summaries of the objectives and conclusions of the major recent HBMP-related documents are presented in **Section 2.0**. To date none of the extensive analyses conducted in conjunction with these HBMP study elements have indicated or suggested that there have been any significant physical, chemical or biological changes within the lower Peace River/upper Charlotte Harbor estuarine system resulting from water withdrawals by the Peace River Regional Water Supply Facility. All modeling efforts of changes in either salinities or isohaline locations (see **Section 7.0**) have concluded that the maximum expected changes potentially resulting from Facility withdrawals would be difficult to actually measure using only monthly monitoring given the range of the normal daily tidal and seasonal ranges of salinity variations.

10.6 HBMP Design Modifications

Modifications have been made to the elements of the HBMP throughout its history. While the overall cost (inflation adjusted) of the monitoring program has remained relatively constant, study elements have been added and deleted in order to enhance the overall knowledge base of the lower Peace River/upper Charlotte Harbor estuarine system. Historically, those major monitoring elements aimed at assessing direct relationships with variations in freshwater inflow have had the longest histories (vegetation and water quality – see **Table 1.3**). Other program elements, primarily those focused on assessing indirect biological indicators, have extended over a number of years and then ended once a sufficient baseline basis of information had been accumulated.

10.6.1 2002 Scientific Review Panel Recommended Modifications of the HBMP Design

The HBMP Scientific Review Panel met in November 2002 and reviewed the monitoring program modifications recommended in the *2000 Midterm Interpretive Report*, which focused on reducing the number of water quality parameters included in both the "fixed station" and "moving" isohaline-based HBMP study elements. The panel agreed that both the "fixed" and "moving" water quality monitoring programs were important, and that if a water chemistry parameter wasn't providing useful information relative to seasonal variations in freshwater inflows and potential Facility impacts, it should be deleted from the HBMP. The Panel recommended that the District accept the suggested chemical parameters revisions with the caveat that chlorides and silica continue as HBMP parameters. Based on these recommendations, the District agreed to the revised HBMP water chemistry parameters.

The following outlines other suggestions and recommendations made by the Panel regarding the monitoring program at that time.

- Continue collecting non-size fractioned phytoplankton biomass estimates at both the "fixed" and "moving" physical/chemical water quality monitoring locations.
- Continue enumeration of phytoplankton taxonomic composition at the "moving" isohalines for at least major taxonomic groupings (blue greens, diatoms, flagellates, dinoflagellates, etc.).
- Determine whether either the benthic invertebrate/mollusk investigations conducted by Mote Marine Laboratory, or the juvenile fish/zooplankton study undertaken by the University of South Florida should be incorporated in part into HBMP study elements.
- Evaluate the need to continue monitoring at the existing spatial and temporal intensity.

Overall the Panel recommended that the HBMP should focus monitoring primarily on assessing long-term trends in key physical, chemical and biological characteristic directly related to the Facility's potential influences and less on "health of the estuary" issues that should be the task of other (District) monitoring efforts.

10.6.2 2004 Scientific Review Panel Recommended Modifications of the HBMP Design

The HBMP Scientific Review Panel met in September 2004 to review the findings of the *2002 Comprehensive Summary Report*. Again, the Panel considered a number of recommendations and suggestions regarding the additions and potential deletions of specific elements to the HBMP. The following summarizes those recommendations.

- The Panel suggested that the Authority consider expanding the number of continuous recorders beyond the two USGS recorders in order to better be able to describe the spatial extent, timing and magnitudes of salinity changes in the lower river due to facility withdrawals. The Authority installed three new HBMP continuous recorders at RK 21.9, 23.4 and 24.5 in December 2005 after evaluating a series of potential alternative locations.

- The draft report suggested potentially using monthly transects of chlorophyll *a* levels to link seasonal changes in distribution patterns with natural variations in freshwater inflows. Peaks in chlorophyll *a* concentrations could then be used to estimate potential changes in other communities such as were observed in the previous University of South Florida (Ernst Peebles) studies of fish distributions. The Panel agreed that such a program might be a useful addition to the overall HBMP design and the Authority committed to evaluating potential alternative methodologies. Since then, the University of South Florida has compared a number of different instruments and procedures to correct for the naturally high levels of humic compounds found in southwest Florida "black water" estuaries using currently available *in situ* fluorometric instrumentation.

- The draft report included a discussion of the current fixed sampling site design versus potentially adding a new stratified random design. The Panel members generally felt that using a random stratified design would be inappropriate given the strong salinity gradients and the specific questions that the HBMP was designed to answer.

- The Panel members also expressed the opinion that use of additional salinity measurements and potentially enhanced spatial estimates of chlorophyll *a* distributions would be preferable to including additional studies of benthic invertebrates and larva fishes in the lower river.

- The Panel agreed that a mistake was made by locating the Boca Grande tide gage near the pass due to problems with hydraulic drawdown, and there was a strong consensus among the members to remove this gage from the HBMP program.

- The Panel felt that the historic aerial vegetation photographs along the lower river had provided useful information showing a lack of any long-term change in the weighted centers of abundance of major vegetation assemblages. It was suggested that the HBMP could effectively continue using this program element using digital satellite imaging combined with the existing GIS baselines. There was Panel consensus to change aerial photography to five-year increments and that there would only be a need to assess changes on the ground if the aerial analysis indicated any major changes.

- There was a strong consensus among the Panel that both monitoring of the first and last occurrence of riverine vegetation, and at the fixed transitional sites, should be deleted following analyses of the data collected in the spring of 2004.

- Finally, the Panel expressed a consensus that phytoplankton taxonomy be deleted unless major blooms were noted.

10.6.3 2007 Scientific Review Panel Recommended Modifications of the HBMP Design

The most recent meeting of the HBMP Scientific Review Panel was in December 2007 to review the draft results of the 2006/2007 Facility "pump tests" and the District's draft proposed Minimum Flows and Levels (MFL) for the lower Peace River and Shell Creek (see **Chapter 6**). The following summarizes the Panel's recommendations regarding specific HBMP elements.

- The Panel felt that the analyses conducted in conjunction with the pump test, following suggested revisions, were sufficient to indicate the relative timing and magnitude of expected salinity increases resulting from currently permitted withdrawals. They suggested that there was, therefore, no reason to continue such testing until such time as there was a substantial increase in Facility capacity or permitted withdrawals.

- A number of Panel members strongly recommended that the Authority consider expanding the current array of continuous recorders, with instruments placed near and upstream of the Facility.

10.7 Proposed HBMP Sampling Design Modifications

The following series of proposed modifications are presented based on the results presented in this *2006 HBMP Comprehensive Summary Report*, and recent recommendations and suggestions made by the HBMP Scientific Review Panel.

10.7.1 Additional Continuous Recorders

The HBMP study design currently includes continuous (fifteen-minute interval) measurements of subsurface and near bottom water column conductivities at two fixed USGS monitoring gages located at River Kilometers 15.5 and 26.7 (**Figure 6.1**). The particular locations of these two gages on existing docks were established in part due to the USGS need to be able to have land based access for the ease of routine maintenance and the downloading of data. The HBMP Scientific Review Panel recommended that an additional series of continuous conductivity gages be established by the Authority downstream of the USGS Peace River Heights location. The primary objective of installing additional conductivity recorders, when combined with the two existing long-term USGS sites, was to obtain greater resolution of the direct relationships among freshwater flow, stage height, and conductivity downstream of the Facility during periods of withdrawals. The Authority installed three new HBMP continuous recorders measuring 15-minute surface conductivities at River Kilometers 21.9, 23.4 and 24.5 in December 2005 after evaluating a series of potential alternative locations. The locations of these additional gages were specifically designed to determine salinity increases directly due to Facility withdrawals within the reach of the river characterized by the movement of the freshwater/saltwater interface at flows immediately above (or below) the 130 cfs threshold.

Based on the ongoing analyses of the data collected from these five continuous recorder locations, the Panel recently recommended that the Authority consider expanding the current array of continuous recorders to include instruments placed near and upstream of the Facility. In response, the Authority has purchased additional continuous recorders and selected several potential new sites for their deployment (**Figure 10.2**). The Authority proposes to move the existing HBMP surface conductivity continuous recorder from the Manatee Marker at RK 23.4 and relocate it to one of the abandoned railroad bridge pilings upstream at RK 39.0. A second new surface recorder would simultaneously be located immediately upstream of the Facility's point of intake using an existing Manatee Speed Zone Marker (see **Figure 6.6**) located at RK 30.1. A final additional continuous recorder would be located downstream of the existing Harbour Heights USGS recorder (RK 15.5). This recorder would be attached in relatively shallow water to an existing Manatee Marker near RK 12.6. This recorder would be positioned near the bottom of the stilling well and also gather 15-minute interval data on dissolved oxygen levels using an optical sensor. The objective of this downstream HBMP recorder would be to gather additional direct measurements on the influences of Shell Creek flows on lower Peace River salinities, as well as to begin gathering detailed information regarding the influences of seasonal flows and temperature on observed diurnal dissolved oxygen patterns in the lower river estuarine system.

10.7.2 Chlorophyll *a* Phytoplankton Biomass Measurement

Both the "fixed" and "moving" HBMP water quality study elements currently include monthly monitoring of chlorophyll *a* levels along the lower river/upper harbor monitoring transect. As a common photosynthetic pigment among all major primary producers, chlorophyll *a* is widely used as an estimate of phytoplankton biomass in both freshwater and estuarine systems. The spatial and temporal variability of phytoplankton chlorophyll *a* concentrations is widely applied in estuarine ecology as a relative indicator of overall integrated levels of primary production. As a measure of phytoplankton biomass, chlorophyll *a* has a number of distinct advantages.

- Measured values can be quantitatively coupled to important physical and chemical water quality characteristics.

- Measurements integrate phytoplankton cell types, sizes, and growth stages, and to some degree the relative overall cell health/viability.

- Applied methods of measurement are relatively simple and direct.

The development of a comprehensive understanding of phytoplankton production (biomass) is a fundamental component in developing an integrated understanding of the interrelated physical/chemical systems and biological processes within the lower Peace River estuarine system (**Figure 10.1**). Phytoplankton production represents a large, immediately available food resource directly accessible to many lower rivers' grazing, filter and detrital feeding estuarine organisms. Phytoplankton production represents a basic, integrated estuarine food-web component directly influenced by variations in freshwater inflows (**Chapter 4**). Due to the very short generation times involved (hours/days), phytoplankton production, when compared with many other potential biological indicators, can potentially be more directly quantitatively linked to changes in freshwater inflows. The observed numbers and spatial distributions of other potential biological estuarine indicators are subject to the confounding additional influences associated with longer generation times, intricate life-cycles, and the increasing complexity of predatory/prey interactions with each additional trophic level.

It should be noted that even though widely used as a standard relative measure, chlorophyll *a* concentration can still inherently be an imperfect absolute measure of phytoplankton biomass, since cellular pigment contents are influenced both by relative phytoplankton community structure and a wide array of commonly variable ambient physical (water color, shading, temperature) and chemical (nutrients) environmental conditions.

Advances in fluorescence technology have resulted in the recent capability of semi-quantitatively measuring of *in situ* phytoplankton chlorophyll *a* estimates, without having to employ extensive filtering and expensive laboratory chemical extraction and analyses. *In situ* fluorometer chlorophyll *a* measurement procedures also present the potential utility of particularly near-real-time data acquisition in synoptically identifying spatial phytoplankton biomass patterns along the lower river salinity gradient. The accuracy of such *in situ* measurements can be greatly enhanced through employing pre- and post-sampling fluorometer calibrations and comparisons to field measurements with "reference" values obtained utilizing standard laboratory (extraction) procedures. Ongoing work by University of South Florida researches have recently provided insight into correcting *in situ* fluorometer chlorophyll levels in highly colored waters such as the Peace River estuarine system.

Previously reported results, from both the "fixed" and "moving" HBMP study elements, have indicated the existence of a distinct, seasonally-variable chlorophyll *a* maxima along the lower Peace River/upper Charlotte Harbor monitoring transect. Including a new HBMP study element employing *in situ* fluorometer chlorophyll *a* methodology could provide the fine-grained spatial information needed to accurately define on a monthly basis both the magnitude and spatial extent of variations in chlorophyll *a* patterns within the lower Peace River/upper Charlotte Harbor Estuary. Accurate spatial determinations of the relative intensity and location of monthly chlorophyll *a* maxima patterns would provide additional information regarding the known seasonal interactions between changes in freshwater flow (relative to additions of both nutrients and color) and the seasonal movement of important estuarine zones of primary (and secondary) production. The resulting high resolution data could then be graphically analyzed using standardized GIS krieging procedures and relative weighted centers of abundance determined using Spatial Analyst routines. Calculated metrics of observed spatial patterns could then be statistically seasonally analyzed relative to natural variations in flow and measured water quality parameters obtained from other HBMP study elements. The following criteria should be included in the design components of such a monitoring effort.

- Synoptically monthly measuring *in situ* chlorophyll *a* levels at a relatively large number of locations along the HBMP monitoring transect using a slow moving boat, GPS unit and submersible fluorometer.

- Standardizing sampling to the greatest extent possible within a defined temporal period relative to noon (EST) in order to avoid known daily variations in apparent chlorophyll *a* levels.

- Measuring subsurface (0.2 meter) concentrations at regular defined intervals along the HBMP centerline monitoring transect in order to facilitate both krieging and estimating the weighted center of chlorophyll *a* abundance.

- Thorough analyses of the utility of this HBMP study element, and recommendations for its continuance, should be made at specific intervals as part of future major summary monitoring program reports.

10.7.3 Scope and Frequency of Major HBMP Reports

The 1996 permit renewal required that the HBMP program submit “Midterm Interpretive Reports” at the end of each third year and “Comprehensive Summary Reports” approximately at the end of the fifth year within each of the five-year intervals of the overall 20-year life of the permit. The permit also required the Authority to provide “Data Reports” to the District during the 1st, 2nd and 4th years of each five-year cycle. The following summarizes the relative differences, and levels of information and analyses originally envisioned regarding each of these three types of reports in the 1996 permit conditions.

- **Annual Data Reports –** These reports were simply to contain all raw data collected during the previous year (typically delivered to the District as SAS data sets covering the entire cumulative period-of-record), with summary data submitted in tabular form and accompanying text limited to an explanation of variable names and descriptions of any problems encountered or important observations made during the preceding interval.

- **Year Three Midterm Reports –** These expanded reports were to contain basic figures, tables and statistical summaries of the data for the entire period-of-record for selected variables, as well as providing the District with all data. The interpretative text contained within the midterm reports was to be restricted to descriptions of the monitoring progress, and observed changes in stream flow, salinity and other selected variables.

- **Year Five Reports –** The overall object of these comprehensive, interpretive reports was to provide complete analyses of all the continuing data collected to date. These year five reports were to determine whether long-term patterns or trends could be identified in key selected variables, and identify relationships between ecological characteristics and freshwater flows. The reports were to further analyze the data to determine the status of the lower river/upper harbor estuarine system with regard to changes in freshwater inflows, and determine if the biological health and productivity of the estuary were under stress due to natural periods of low inflows and potentially associated influences of Facility withdrawals. The proportions of the freshwater estuarine flow budget reduced by withdrawals were to be determined relative to the magnitude of the overall effects on the ecology of estuary.

  The HBMP design was to be reviewed and re-evaluated within these year five reports, and modifications proposed as necessary. These comprehensive summary reports were envisioned as the District’s primary tools for evaluating the presence or absence of adverse ecological impacts, determining the relative significance of withdrawals to any such observed impacts, and assessing environmental considerations regarding further increased river withdrawals. The effectiveness of the existing withdrawal schedule was to be evaluated in preventing adverse environmental impacts, and potential environmental factors related to the feasibility of expanded diversions and additional storage to increase potential water supplies were to be determined.

In response to the high degree of public interest and concerns regarding the overall status and health of the lower Peace River/Charlotte Harbor estuarine system, the Authority has voluntarily provided expanded reports beyond those basics stated in the 1996 permit requirements. The Authority has continued to submit Annual Data Reports to the District yearly. These annual reports go far beyond simply providing tabular summaries of the previous year's data and "limited" text. The most recently submitted Annual Data Report contained over 60 pages of text, numerous tables and over 200 figures, summarizing the collected HBMP data over both the previous year and over the long-term period-of-record. In addition, the Authority has submitted Midterm Interpretive Reports covering monitoring through 2000 and 2004, and a previous Comprehensive Summary Report preceded this current document summarizing information through 2002.

It is recommended that the Authority continue to submit Annual Data Reports to the District following the currently expanded format that has been provided to the District. These reports actually meet or exceed the basic requirements set forth in the permit for the Year Three Midterm Reports. It is recommended that the Authority also continue to submit Comprehensive Summary Reports to the District and HBMP Scientific Review Panel following the current approximate five-year intervals. It is, however proposed that the Authority drop the separate Year Three Midterm Reports, since the information is highly repetitive to that currently contained in the Annual Data Reports and the Comprehensive Summary Reports. It is recommended that the Authority continue to provide specific, focused reports such as the recently submitted "Facility Pump Test Report" on an as-need basis in response to specific requests made by the HBMP Scientific Review Panel following consultation with District staff.

10.8 Summary

The combined elements of the program's design need to meet the specific expectations and objectives set forth in the permit as well as provide sufficient long-term information on which to base the development of answers to potential future questions that might be expected to arise.

In order to effectively meet these goals and objectives, the integrated design of HBMP elements should incorporate the following criteria.

- The program needs to identify those appropriate physical and biological indicators, and specific mechanisms of action, potentially subject to significant changes resulting from permitted freshwater withdrawals from the lower Peace River/upper Charlotte Harbor estuarine system.

- The program should determine and predominantly focus it efforts in those geographical regions of the lower river where naturally occurring and Facility induced changes in flows would be expected to result in the greatest potential observed changes in identified key estuarine characteristics.

- The design of the HBMP monitoring element should include sufficient spatial and temporal intensity to assure detection of measurable changes in selected physical/chemical/biological parameters resulting from changes in freshwater inflows.

It is important that each HBMP study element, as well as the overall program, have specific clearly stated goals and objectives to effectively meet the design criteria needed to accomplish the monitoring program's multiple expectations. These goals and objectives need to clearly establish the scientific basis needed to provide sufficient information to meet the District's criteria for required reasonable assurance, as well as provide meaningful information to both the public and the members of the HBMP Scientific Review Panel. The HBMP design elements further need to be sufficiently flexible to allow incorporation of modifications when and where changes in conditions, or new gathered information, suggest the need for specific monitoring program changes.

The HBMP monitoring design needs to focus on identifying and incorporating those *critical indicators* known to exhibit marked direct responses to variations in freshwater inflow, since it is these parameter measurements that present the greatest probability of both detecting and assessing the principle underlying causative factor(s) to observed environmental changes.

Since the initiation of HBMP monitoring in 1976, the program has incorporated a number of differing physical, chemical, and biological study elements. Modifications have been made to the elements of the HBMP throughout its history. Historically, those major monitoring elements aimed at assessing direct relationships with variations in freshwater inflow have had the longest histories. Other program elements, primarily those focused on assessing indirect biological indicators, have extended over a number of years and then ended once a sufficient baseline basis of information had been accumulated. The following series of proposed modifications are presented based on the results presented in this *2006 HBMP Comprehensive Summary Report*, and recent recommendations and suggestions made by the HBMP Scientific Review Panel.

10.8.1 Additional Continuous Recorders

The HBMP study design currently includes continuous conductivity measurements at River Kilometers 15.5, 21.9, 23.4, 24.5 and 26.7. Based on analyses of the data collected from these five continuous recorder locations, the Peace River HBMP Scientific Review Panel recently recommended that the Authority consider expanding the current array of continuous recorders to include instruments placed near and upstream of the Facility. In response, the Authority has purchased additional continuous recorders and selected several potential new sites for their deployment.

10.8.2 Chlorophyll *a* Phytoplankton Biomass Measurement

Both the "fixed" and "moving" HBMP water quality study elements currently include monthly monitoring of chlorophyll *a* levels along the lower river/upper harbor monitoring transect. However, advances in fluorescence technology have resulted in the recent capability of semi-quantitatively measuring of *in situ* phytoplankton chlorophyll *a* estimates. *In situ* fluorometer chlorophyll *a* measurement procedures present the potential of synoptically identifying spatial phytoplankton biomass patterns along the lower river salinity gradient.

Previously reported results, from both the "fixed" and "moving" HBMP study elements, have indicated the existence of a distinct, seasonally-variable chlorophyll *a* maxima along the lower Peace River/upper Charlotte Harbor monitoring transect. Including a new HBMP study element employing *in situ* fluorometer chlorophyll *a* methodology could provide the fine-grained spatial information needed to accurately define on a monthly basis both the magnitude and spatial extent of variations in chlorophyll *a* patterns within the lower Peace River/upper Charlotte Harbor Estuary. Accurate spatial determinations of the relative intensity and location of monthly chlorophyll *a* maxima patterns would provide additional information regarding the known seasonal interactions between changes in freshwater flow (relative to additions of both nutrients and color) and the seasonal movement of important estuarine zones of primary (and secondary) production.

10.8.3 Scope and Frequency of Major HBMP Reports

The 1996 permit renewal required that the HBMP program submit "Midterm Interpretive Reports" at the end of each third year and "Comprehensive Summary Reports" approximately at the end of the fifth year within each of the five-year intervals of the overall 20-year life of the permit. The permit also required the Authority to provide "Data Reports" to the District during the 1st, 2nd and 4th years of each five-year cycle. The Authority has voluntarily provided expanded reports beyond those basics stated in the 1996 permit requirements. The Authority has continued to submit Annual Data Reports to the District yearly that go far beyond simply providing tabular summaries of the previous year's data and "limited" text. It is recommended that the Authority continue to submit Annual Data Reports to the District following the currently expanded format. These reports actually meet or exceed the basic requirements set forth in the permit for the Year Three Midterm Reports. It is recommended that the Authority also continue to submit Comprehensive Summary Reports to the District and HBMP Scientific Review Panel following the current approximate five-year intervals. It is however proposed that the Authority drop the separate Year Three Midterm Reports, since the information is highly repetitive to that currently contained in the Annual Data Reports and the Comprehensive Summary Reports. It is recommended that the Authority continue to provide specific, focused reports such as the recently submitted "Facility Pump Test Report" on an as-need basis in response to specific requests made by the HBMP Scientific Review Panel following consultation with District staff.

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