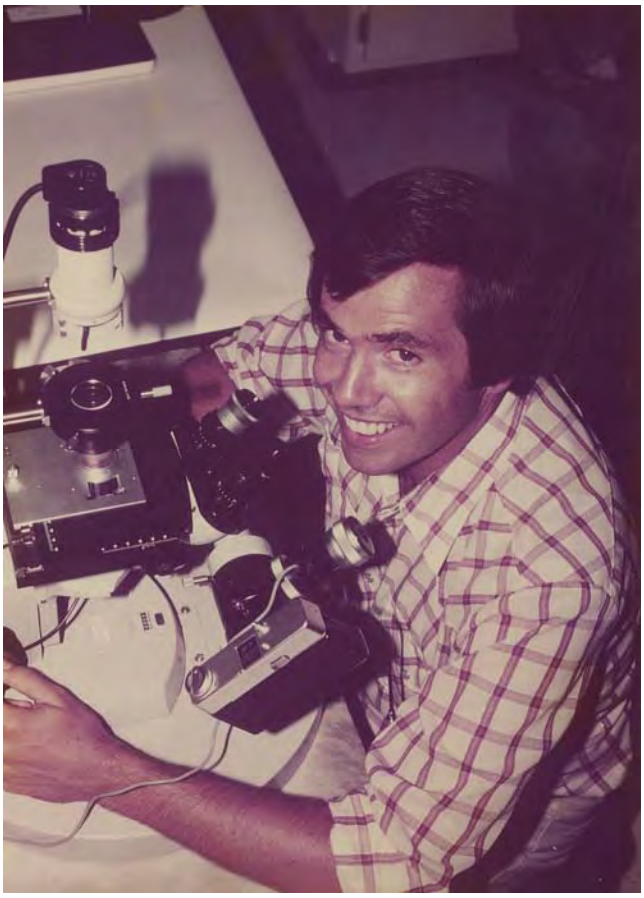
A Tribute to the Life and Work of Ralph Montgomery, Ph.D.

A compendium of his applied research on the Peace River, Charlotte Harbor, and other Florida ecosystems



Charlotte Harbor National Estuary Program
Technical Report 2016-2
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The Charlotte Harbor National Estuary Program is a partnership of citizens, elected officials, resource managers and commercial and recreational resource users working to improve the water quality and ecological integrity of the greater Charlotte Harbor watershed. A cooperative decision-making process is used within the program to address diverse resource management concerns in the 4,700-square-mile study area. Many of these partners also financially support the Program, which, in turn, affords the Program opportunities to fund projects. The entities that have financially supported the program include the following:

U.S. Environmental Protection Agency
Southwest Florida Water Management District
South Florida Water Management District
Florida Department of Environmental Protection
Peace River Manasota Regional Water Supply Authority
Polk, Sarasota, Manatee, Lee, Charlotte, and Hardee Counties
Cities and Towns of Sanibel, Cape Coral, Fort Myers, Punta Gorda, North Port, Venice, Fort Myers Beach, Winter Haven, and Bonita Springs

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List of Acronyms and Abbreviations

AMO	Atlantic Multi-Decadal Oscillation
CAC	Citizens Advisory Committee
CCMP	Comprehensive Conservation and Management Plan
CVA	Canonical Variate Analyses
cfs	cubic feet per second
CHNEP	Charlotte Harbor National Estuary Program
CR	County Road
EMAP	Environmental Monitoring and Assessment Program
ENSO	El Niño / Southern Oscillation
EPA	(United States) Environmental Protection Agency
FGFWFC	Florida Game and Freshwater Fish Commission
FNAI	Florida Natural Areas Inventory
FDEP	Florida Department of Environmental Protection
FSU	Florida State University
GIS	Geographic Information System
GPS	Global Positioning System
HBMP	Hydrobiological Monitoring Program
HEC-RAS	Hydrologic Engineering Center - River Analysis System (model)
mgd	million gallons per day
mg/l	milligrams per liter
PRCIS	Peace River Cumulative Impact Study
PRMRWSA	Peace River Manasota Regional Water Supply Authority
RALPH	Reasonable and Long-term Positional Hydrograph
SEM	Scanning Electron Microscopy
SHCA	Strategic Habitat Conservation Areas
SST	Sea Surface Temperatures
SAS	Statistical Analysis System®
SWFWMD	Southwest Florida Water Management District
TAC	Technical Advisory Committee
TDS	Total Dissolved Solids
UC Davis	University of California at Davis
USF	University of South Florida
USGS	United States Geological Survey
µmhos/cm	micromhos per centimeter

Chapter 1
Report Overview

This report pays tribute to the life and work of Dr. Ralph Montgomery, a noted environmental scientist who was an admired and beloved citizen and family man in Southwest Florida. When Dr. Montgomery passed away in 2015, his friends, family, and colleagues felt it was fitting to prepare a report that paid tribute to his contributions to his family, community, and our understanding of the ecology and natural resources of Florida. Ralph Montgomery has been dearly missed by many who fondly remember his warm and friendly personality and willingness to help others and share helpful information.

A brief description of the life of Ralph Montgomery and his family is presented in Chapter Two, including a collection of photographs from their lives. An overview of Dr. Montgomery's professional work and brief technical summaries of his publications are presented in Chapter Three. Dr. Montgomery was one of the leading authorities on the Peace River and Charlotte Harbor and the summaries presented in this report provide a valuable source of information regarding the hydrology, water quality, and biological characteristics of those water bodies. All references cited in this report are listed in the bibliography.

This report is published by the Charlotte Harbor National Estuary Program, in which Dr. Montgomery was very active. The report and most of the publications by Dr. Montgomery that are cited within it are available online using the digital library link at the Charlotte Harbor National Estuary Program page on the Florida Water Atlas website at http://www.chnep.wateratlas.usf.edu.

This report was a collaborative effort that was based on an inventory of Dr. Montgomery's work, the preparation of text for this report, and personal and technical insight contributed by Sid Flannery, Sam Stone, Lenore Montgomery, Judy Ott, Thomas Fraser, Ph.D., Pamela Latham, Ph.D., Doug Robison, David Tomasko, Ph.D., David Moore, Allan Willis, Robert Woithe, Ph.D., Anthony Janicki, Ph.D., Ernst Peebles, Ph.D., and Michael Coates.

Ralph Montgomery, Ph.D.

Chapter 2
Ralph Montgomery, Ph.D.
Gentleman, Family Man, Fisherman and Scholar

In addition to being recognized as an outstanding environmental scientist, Ralph Montgomery was widely known as a kind and considerate gentleman who was a pleasure to be with. He was known for his humility, kind demeanor, good sense of humor and willingness to help others. A brief overview of Dr. Montgomery's life is presented below, followed by photos of him with his family, friends, and colleagues.

Ralph Montgomery was born in the late 1940s and raised in the San Francisco Bay area. The Montgomery family had lived for several generations in northern California, particularly Trinity and Mendocino counties. A California state park with an impressive grove of old growth redwoods, the Montgomery Woods State Natural Reserve, was named after Ralph's great- great-grandfather who donated the original tract of land to the state.

Ralph was the oldest of four sons. His mother was a teacher and his father a teamster. Ralph attended public schools in San Leandro, California, where he participated on the swimming and rifle teams. Ralph attended the University of California at Davis where he graduated with Bachelor of Science degrees in both Biological Science and Zoology in 1970. While an undergraduate student, Ralph took summer classes at the Stanford University Hopkins Marine Station in Monterey, California, where he participated in research cruises in the Pacific Ocean. After graduation, Ralph worked for one year in the Viticulture Department at UC Davis.

While in Davis, Ralph met this wife to be, Lenore Schlage, who majored in biology at UC Davis. Ralph and Lenore began their loving and long-lasting marriage in 1971. In 1972, Ralph and Lenore moved to Tallahassee Florida, where Ralph attended graduate school at Florida State University. Ralph bypassed the Masters degree program to pursue a Ph.D. in marine ecology under his major advisor, Dr. Albert Collier. Ralph's 1978 dissertation focused on diatoms on coral reefs in the Florida Keys, where he made many field trips to scuba dive and collect samples. Based on his academic work, Ralph was inducted into Sigma Xi, a national scientific fraternity. He was also recognized as a Certified Professional Ecologist by the Ecological Society of America. While in Tallahassee, Ralph and Lenore took many trips to better know Florida, traveling along both the Atlantic and Gulf coasts and to many locations in the interior of the state.

After receiving his Ph.D., Ralph took a job in the Seminole, Florida office of H.W. Lochner, Inc., a consulting engineering firm, where he worked on environmental impact assessments. Ralph and Lenore's son Ryan was born during their stay in Seminole. In 1981 the Montgomerys moved to Port Charlotte, Florida, where Ralph joined the staff of the Environmental Quality Laboratory, Inc., a firm that performed environmental studies and monitoring programs for the General Development Corporation. Ralph and Lenore's daughter, Melissa, was born soon after their arrival in Port Charlotte, where the family settled, eventually purchasing a waterfront home connected to Upper Charlotte Harbor where Lenore lives today.

It was at the Environmental Quality Laboratory that Ralph began his long-term studies of the Peace River and Charlotte Harbor, where he became a leading scientific authority for those water bodies. Ralph served as the director of the Environmental Quality Laboratory from 1990 to 1997, when he then took a position with Coastal Environmental, Inc. in St. Petersburg, FL. Coastal Environmental was later acquired by the firm of Post, Buckley, Shuh & Jernigan , Inc. (PBS&J), where Ralph continued his work on the Peace River, Charlotte Harbor and other Florida ecosystems. In 2010, PBS&J was acquired by Atkins, Inc., where Ralph remained on staff and continued his projects. At all the firms where Ralph worked he was known as a knowledgeable and courteous professional who was easy to work with, often taking time to mentor junior members of the firm on projects on which they were working.

While in Port Charlotte, Ralph also taught courses in biology and ecology for a few semesters at Edison Community College and for one semester at Florida Gulf Coast University. He was also a member of the Lemon Bay Conservancy and the Coastal Conservation Association. Ralph was also active in and supported the Charlotte Harbor National Estuary Program.

Ralph and Lenore enjoyed both the cultural and natural amenities of southwest Florida, frequently boating and fishing on the Peace River and Charlotte Harbor and generally exploring the area. They enjoyed music and traveled to musical events and festivals in the state. They frequently traveled to visit their children, Ryan and Melissa, who lived or continue to live in the Tampa Bay area. Ralph and Lenore celebrated the arrival of their first grandchild in 2014, when Dexter was welcomed into the world by his parents, Melissa and her husband Dustin Mathews.

Ralph and Lenore stayed in close contact with their families in California and would often take summer trips to visit them. On their trips, they enjoyed hiking at places such as Lake Tahoe, the California coast, and visiting the wine country. They also visited Hawaii with Ralph's mother. In recent years, Ralph and Lenore enjoyed taking summer vacations to the mountains of North Carolina where they also enjoyed hiking, relaxing, and listening to live musical performances.

Ralph Montgomery passed away in 2015 and will be dearly missed by his family, friends, and colleagues. This report pays tribute to his life and career in the spirit of continuing his legacy of goodwill and improving our understanding and appreciation of the natural environment and quality of life in Florida. A collection of photographs from Ralph's personal and professional life follows, with a summary of his technical work presented in Chapter Three.

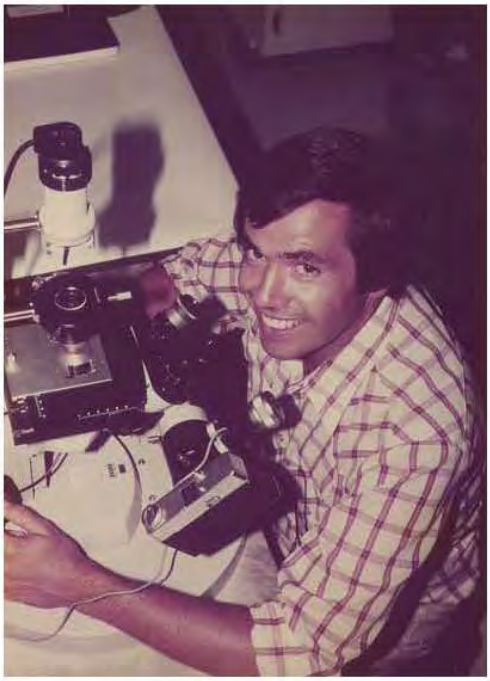
Photographs

Wedding Day, 1971

Ralph and Lenore at FSU, early 1970s

At the Environmental Quality Laboratory with Dr. Thomas Fraser (right)

Ralph, Lenore, Melissa and Ryan



With parents Beverly and Earl Montgomery, Ryan and Melissa

Beach seining with students from Edison Community College

With father Earl, Ryan, and brothers Kreig, Kent and Kirk

At Lake Tahoe

Catching redfish on Charlotte Harbor

With the Frasers at Christmas

Shelling with Ryan and Melissa at Caspersen Beach, Venice FL

Opening Christmas presents, 2009

Ralph and Lenore hiking in California

Golfing with Ryan, Kreig and Kent

With Melissa and her dog Cameron on a cold day in Port Charlotte

The Montgomerys, 2007

Chapter 3
Summary of Technical Publications by Ralph Montgomery, Ph.D.

3.1 Introduction

The major technical publications in which Dr. Ralph Montgomery played a significant role are briefly summarized in this chapter. These publications are grouped into categories of environmental research and management such as graduate studies, phytoplankton and water quality investigations, assessments of the Peace River and its watershed, and other technical areas. Introductory text is presented for each category to provide general information regarding Dr. Montgomery's work in that area. This is followed by the citations for the publications within that category and a brief summary of each publication's emphasis and findings. The technical summaries begin with Dr. Montgomery's graduate work at Florida State University, followed by sections that discuss the other areas of environmental research and management in which Dr. Montgomery was involved.

Because Dr. Montgomery's work was so comprehensive, the technical summaries presented in this chapter cover only a fraction of the findings and conclusions for each publication. **Readers should always consult one of the original publications summarized in this report before describing or otherwise referring to its findings**. Unless identified otherwise, all figures and tables presented in this chapter are taken from the report that is being summarized. References for all publications that are summarized in this chapter are listed in the bibliography of this report, with the publications arranged chronologically within each category. The bibliography also contains references for other minor publications in which Dr. Montgomery was involved that are not summarized in this chapter.

Based on years of extensive work in its watershed, Dr. Montgomery was a leading authority on hydrology, water quality, and ecological characteristics of the Peace River and the estuary to which it flows, Charlotte Harbor. His longstanding involvement with the Hydrobiological Monitoring Program for the Lower Peace River has resulted in an extensive, long-term data base for the lower river and Upper Charlotte Harbor, which is summarized in Section 3.5 of this chapter. Other work on the Peace River for which Dr. Montgomery made particularly important contributions are the Peace River Cumulative Impact Study (Section 3.3), factors affecting future water supply withdrawals from the Peace River (Section 3.4), studies of phytoplankton production in the Lower Peace River and other estuaries (Section 3.6), and studies associated with the Charlotte Harbor National Estuary Program (Section 3.7).

Readers who are involved with research or resource management programs in the watersheds of the Peace River and Upper Charlotte Harbor are strongly encouraged to read those sections for they refer to work by Dr. Montgomery that is among the most complete and valuable information available for understanding the hydrologic and ecological characteristics of those water bodies.

3.2 Graduate Studies

After receiving Bachelors of Science degrees in Biological Science and Zoology from the University of California at Davis in 1970, Dr. Montgomery worked in the Viticulture Department at UC Davis for a year and then pursued graduate studies at Florida State University, where he received his Ph.D. in 1978. Dr. Montgomery's dissertation examined diatom communities on coral reefs in the Florida Keys. His major professor was Dr. Albert Collier of the FSU Department of Biology.

The citations and abstract for Dr. Montgomery's dissertation, which was in two volumes, are presented below. This is followed by two papers that were published in the 1997 Proceedings of the Third International Coral Reef Symposium that were based on this graduate work.

Montgomery, Ralph T. 1978a. Environmental and Ecological Studies of the Diatom Communities Associated with the Coral Reefs of the Florida Keys, Volume 1. Ph.D. Dissertation, Florida State University

The abstract from Volume 1 of the dissertation is reprinted below:

A paradox has long been noted between the dense and complex life of coral reef communities and the relatively low levels of primary productivity in the surrounding surface waters. The purpose of this study was to investigate the magnitude and structure of the benthic diatom floras associated with various substrates of reef communities. The investigation was comprised of two phases: the first dealing with both geographic and seasonal variations along the Florida Keys; and the second attempting to determine the effects of coral species, complexity of substrate, period of colonization, and area of substrate on diatom community structure.

Substrate samples represented the coral sand bottom, various zones of the reef structure, and adjacent grass beds were collected along similar transects at Molasses, Sombrero, and western Sambo Reefs on the open ocean side of the Florida Keys. Counts of 1500 cells were used to determine the relative species composition and community structure of the diatom floras from each sample. High diatom densities were found associated with all substrates. Sand, coral, and *Thalassia* were each characterized by unique floras, with affinity indice measurements indicating a high degree of structural similarity between diatom communities from similar substrates. The diatom populations from coral samples taken at Molasses reef, where only 25% of the surface area was covered by live corals, were structurally dissimilar to the other two reefs. It is suggested that attached diatom populations may represent an important source of primary productivity in reef communities. Due to the continual replenishment of nutrients by bacteria associated with reef substrates, benthic diatom populations may not be nutrient limited as are the true phytoplankton in reef waters.

Analysis of diatom community structure and composition from replicates of five types of coral substrates collected at the same depth over a small area showed no significant differences

other than with respect to density. The relative number of diatoms per unit area was found to be three orders of magnitude greater on dead than on live corals suggesting that colonizing diatom cells are continually removed for the surface of healthy corals.

Studies of five types of substrates placed both in *Thalassia* and coral habitats indicated a positive relationship between species diversity and habitat complexity, rather than the composition of the surrounding species pool, was found to be the dominant factor in establishing community composition and structure on colonized surfaces.

Analysis of replicate pieces of cleaned coral collected over a period of time indicated the occurrence of a marked sequential replacement of diatom taxa on such newly created surfaces, with early r-selected species eventually replaced by K-selected ones. Species composition, rather than density, was suggested as the dominant factor in determining the relative degree of competition within colonizing communities.

The diatom floras colonizing replicate plexiglas plates of different sizes were compared. Unlike other studies, the number of species was not found to increase with area. However, species composition and community structure were both found to be effected by substrate area.

Montgomery, Ralph T. 1978b. Environmental and Ecological Studies of the Diatom Communities Associated with the Coral Reefs of the Florida Keys, Volume 2: A Taxonomic Study of Florida Keys Benthic Diatoms Based on Scanning Electron Microscopy. Ph.D. Dissertation, Florida State University

The abstract from Volume 2 of the dissertation is reprinted below. Scanning electron microscope images of two taxa from Volume 2 of the dissertation are shown on the following page (Figure 1).

The majority of the diatom taxa observed during this study are presented in the following plates. As can be observed, the use of the SEM *(scanning electron microscopy)* not only solves many taxonomic questions, it also presents new ones. Taxa which may appear similar under the light microscope often differ greatly in fine structure when observed under the SEM. This is especially true for those smaller forms less than 10 microns. Thus, being able to see increased detail, in many instances, complicates rather than simplifies taxonomic procedures.

Because of these difficulties and the many "exotic" forms encountered, the taxonomic portion of this work will be the theme of William Miller's dissertation and future joint works. For the present, those taxa with uncertain identities were simply numbered for later reference. Updates on these taxa will be available from the author and suggestions will be gladly accepted.

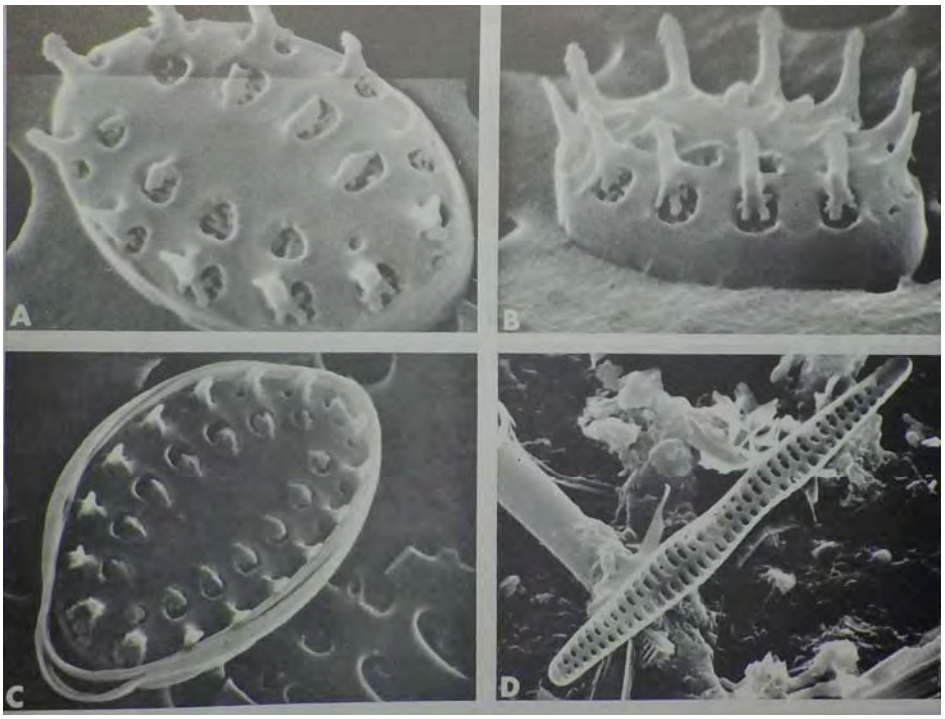


Figure 1. Scanning electron microscope images of *Fragilaria* sp. 3 (A, B and C) and *Dimerogramma opulens* Mann (D).

Montgomery, R.T., W.I. Miller III, and A.W. Collier. 1977. A preliminary investigation of the structure of diatom communities associated with the reef habitats of the Florida Keys. pp. 357-363 In: D.L. Taylor (ed.) Proceedings of Third International Coral Reef Symposium Vol. 1: Biology. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida

The dynamics of energy pathways within coral reef communities have come under increasing investigation. However, few qualitative or quantitative studies of the micro-populations of non-planktonic diatom floras associated with the reef substrates have been done. The structure of such communities associated with coral reefs in the Florida Keys is analyzed and compared.

Substrate samples representing the coral sand bottom, the different zones of the reef structure, and the adjacent grass beds were collected along similar transects at Molasses, Sombrero, and Western Sambo Reefs on the open ocean side of the Florida Keys. The numbers of genera, species, and the species diversity of the diatom floras from these habitats are compared. High densities of diatoms with the degree of structural complexity of the habitat. Comparison of affinity measurements of all samples indicated a high degree of structural similarity between diatom communities from similar substrates. Transect sites of coral substrate from Molasses Reef are demonstrated to be unique and characterized by diatom floras intermediate between the coral substrates of the other reefs and coral sand samples. It is suggested that as a result of continual replenishment of nutrients by bacterial populations associated with reef surfaces, attached diatom populations may not be nutrient limited, as are the planktonic phytoplankton populations in reef waters.

Miller, W.I. III, Montgomery, R. T., and A.W. Collier. 1977. A taxonomic survey of the diatoms associated with Florida Keys coral reefs. pp. 349-356. In: D.L. Taylor (ed.) Proceedings of Third International Coral Reef Symposium Vol. 1: Biology. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida.

Coral, coral sand, and scrapings from surfaces of *Thalassia testudinum* from Western Sambo Reef, Sombrero Reef, and Molasses Reef in the Florida Keys were cleaned of all organic and carbonate material in order to examine the diatoms found in each of these habitats. Observation with scanning electron microscopy and light microscopy showed that each of these habitats has a unique and diverse diatom flora. The coral was characterized by species of *Campylodiscus, Podocystis* and *Triceratium,* the coral sand by *Amphora* and *Diploneis*, and the *Thalassia* by *Mastogloia*.

3.3 Peace River Cumulative Impact Study

During his employment at the firm of PBS&J, Inc., Dr. Montgomery was the project manager and one of the principal authors of a cumulative impact study of the Peace River watershed that was published in 2007. The Peace River cumulative impact study was funded by the Florida Department of Environmental Protection and the Southwest Florida Water Management District.

The Peace River comprises the largest river basin in the Southwest Florida Water Management District (SWFWMD) and provides most of the freshwater inflow to Upper Charlotte Harbor. Natural land covers in many portions of the Peace River watershed have undergone considerable alterations by agriculture, phosphate mining, or urban development. In addition, considerable volumes of ground water, and to a lesser extent surface water, are withdrawn each day to provide for agricultural, industrial, and potable water supplies. It has become evident that these changes in both land and water use have cumulatively impacted the hydrology, water quality, and ecological resources of the Peace River watershed.

In recognition of these impacts, the Florida Legislature enacted Senate Bill 18-E during the 2003 legislative session, which directed the Florida Department of Environmental Protection (FDEP) to conduct a cumulative impact study and then prepare a resource management plan for the Peace River watershed. The Florida Department of Environmental Protection selected PBS&J, Inc. as the prime consultant for preparation of the cumulative impact study. Work on the project began in December of 2004 with the final report published in 2007.

A brief summary of the Peace River Cumulative Impact Study is presented below following the reference for the report. Copies of the report can be obtained from the two agencies that funded the project (FDEP and SWFWMD) and the Florida Water Atlas website referenced on page 1. As with all technical summaries presented in this tribute report to Dr. Montgomery, readers should consult the original report to cite or otherwise describe its findings.

PBS&J, Inc. 2007a. Peace River Cumulative Impact Study. Report prepared for the Florida Department of Environmental Protection Bureau of Mine Reclamation, Tallahassee, FL and the Southwest Florida Water Management District, Brooksville FL.

The purpose of the Peace River Cumulative Impact Study (PRCIS) was to conduct an objective assessment of the individual and cumulative impacts of anthropogenic and natural stressors in the Peace River watershed with respect to historical changes in streamflow, water quality, and various ecological indicators. Based on these findings, the Florida Department of Environmental Protection published a Peace River Basin Resource Management Plan in March, 2007, that indentified regulatory and non-regulatory means to mitigate past impacts and minimize future impacts in the Peace River basin (FDEP, 2007). This technical summary discusses only the cumulative impact study, as that was the focus of Dr. Montgomery's contribution to the overall project.

The Peace River flows in a southerly direction about 105 miles from the confluence of the Peace Creek Drainage Canal and Saddle Creek in central Polk County to Charlotte Harbor (Figure 2). The Peace River watershed is approximately 2,350 square miles in area and includes large portions of Polk, Hardee, DeSoto, and Charlotte counties, and smaller portions of Hillsborough, Manatee, Highlands, Sarasota, and Glades counties.

Figure 2. Location of the Peace River watershed and major drainage sub-basins.

The PRCIS evaluated the potential cumulative impacts on the observed changes in the natural resources of the watershed and the downstream estuarine system with respect to the following hydrologic and ecological indicators:

- Acres of wetlands lost
- Acres of native upland habitats lost
- Miles of streambed lost
- Changes in rainfall
- Changes in streamflow
- Changes in groundwater elevations
- Changes in the concentrations of indicator water quality constituents
- Changes in the abundance, distribution, and diversity of indicator fish communities

The PRCIS was to determine, and quantify where possible, the relative and absolute contribution of each of four stressors to document their effects on historical changes in each of the nine major sub-basins in the Peace River watershed. The stressors that were specifically assessed in this study included:

- Climate variability
- Phosphate mining
- Agriculture
- Urban development

The PRCIS evaluated the effects of these factors on changes in hydrologic and ecological indicators in the nine tributary and river sub-basins that are listed below. The last four sub-basins that are listed occur below the Peace River at Arcadia gage, which is the most downstream streamflow gage on the main channel of the Peace River.

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

Time periods used for comparisons among indicators varied depending on the data available. For example, the benchmark time period for land use data was circa-1940s, based on the availability of quality high-resolution aerial photography. Spatial data were analyzed for three additional incremental time periods including circa 1979, 1990, and 1999. The absence of 1940s aerial photography in some counties precluded land use comparisons between years and accounts for “missing” data at the edge(s) of some sub-basins.

Maps of four categories of developed land uses (improved pasture, intensive agriculture, urban land use, mining) for the 1940s and 1999 time frames are shown in Figures 3 and 4, respectively. Maps of three undeveloped land covers (native uplands, wetlands, lakes) are shown for the 1940s and 1999 in Figures 5 and 6, respectively.

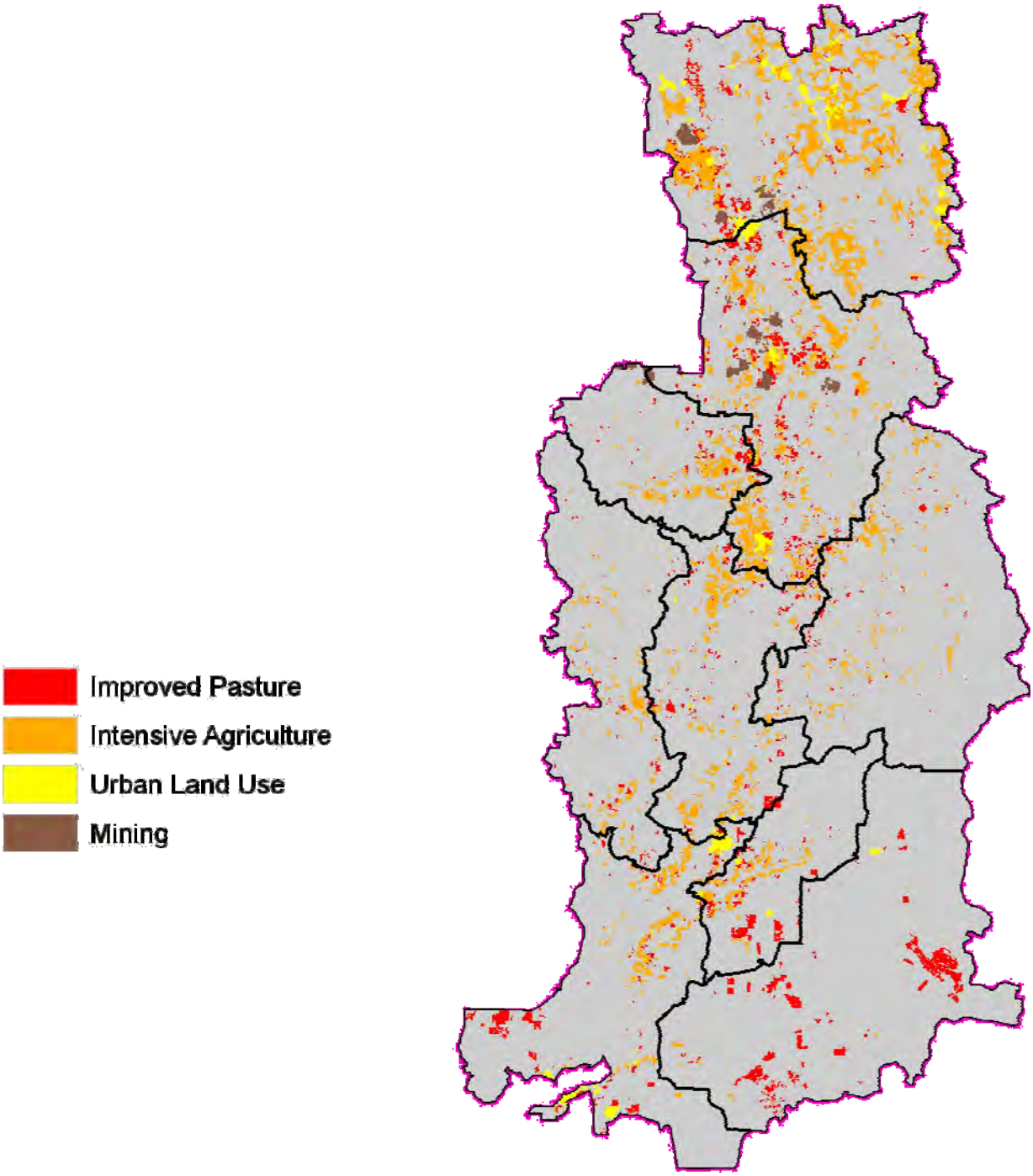


Figure 3. Developed land use in the Peace River watershed in the 1940s.

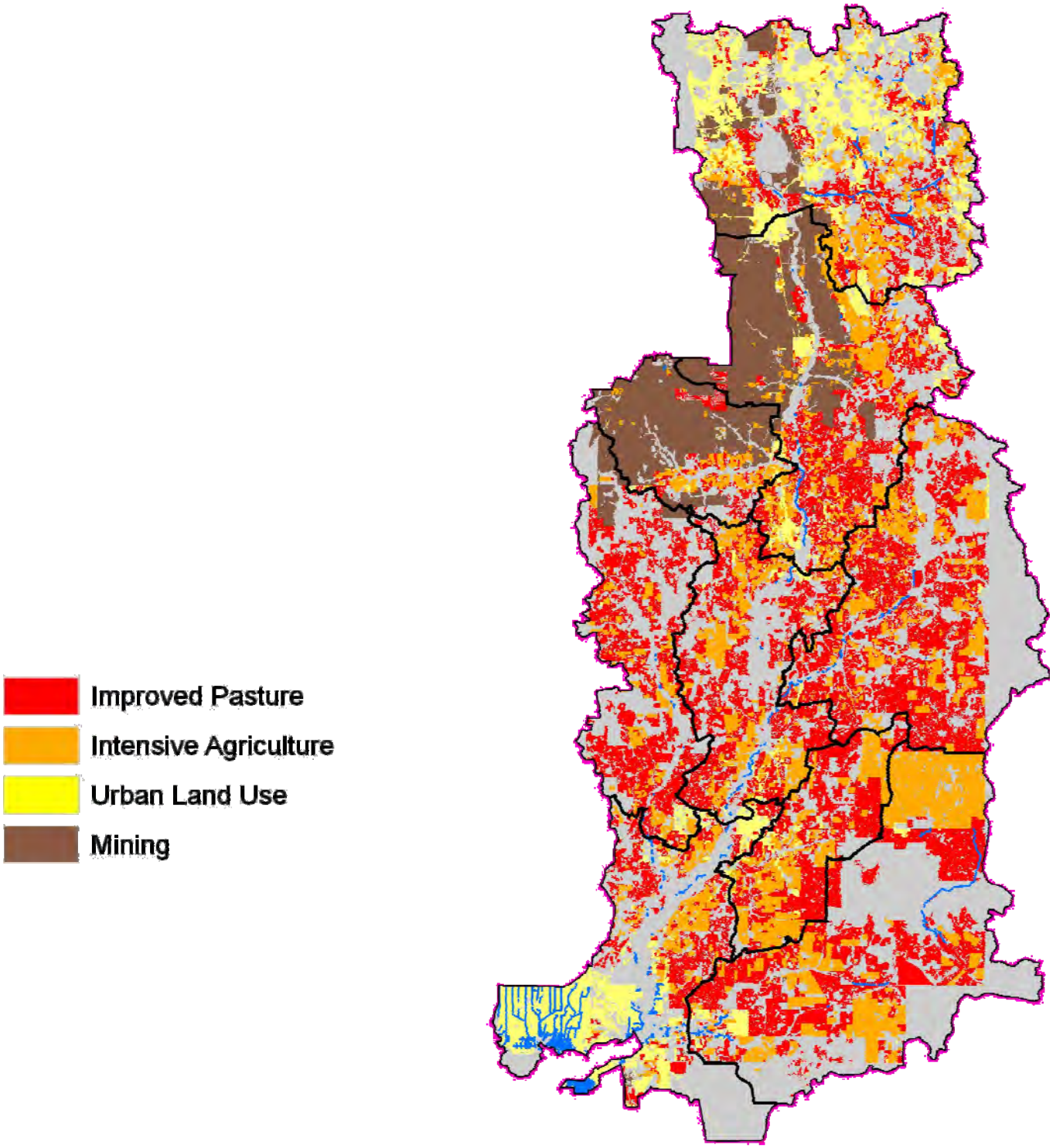


Figure 4. Developed land uses in the Peace River watershed in 1999.

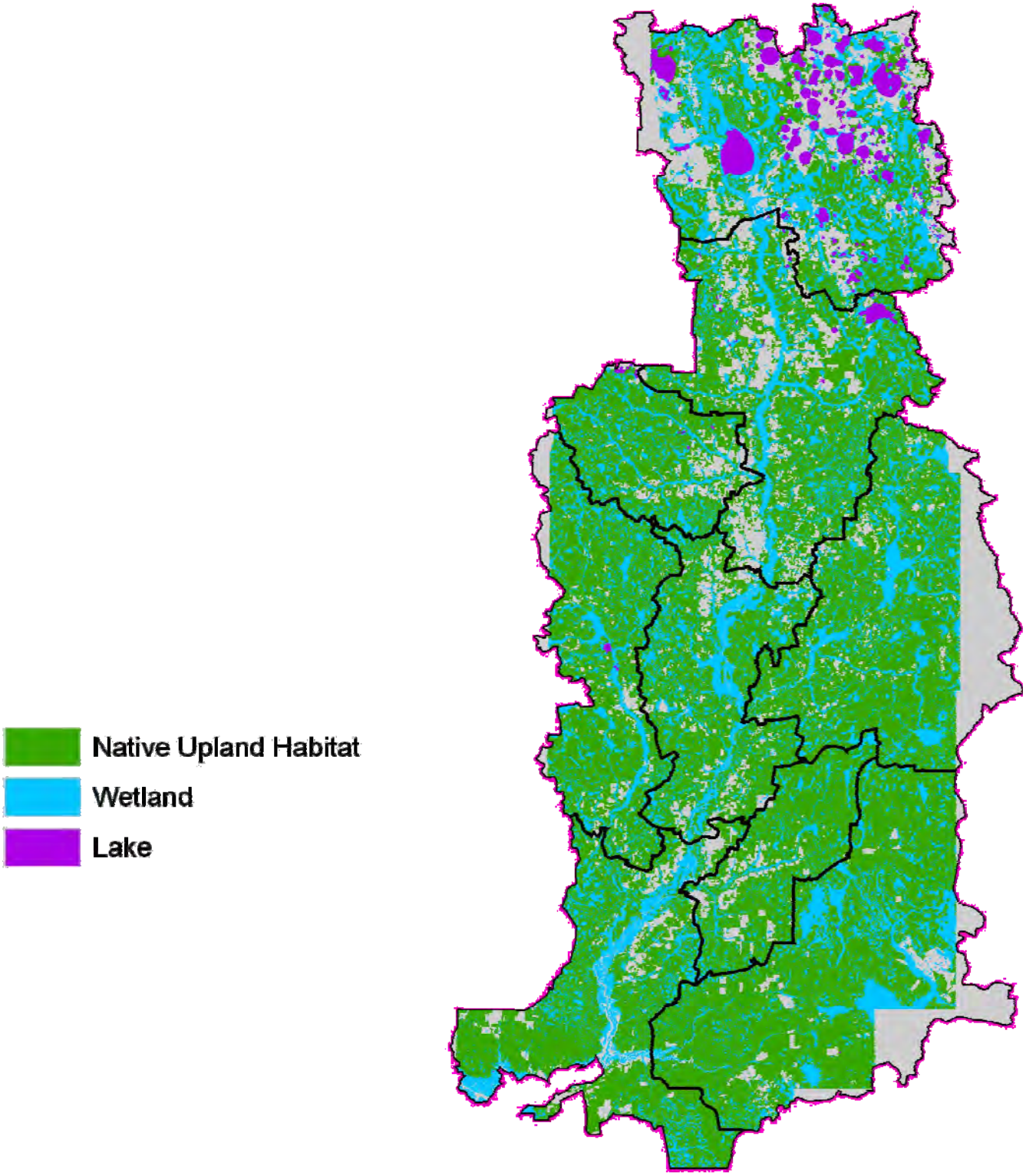


Figure 5. Undeveloped land covers in the Peace River watershed in the 1940s.

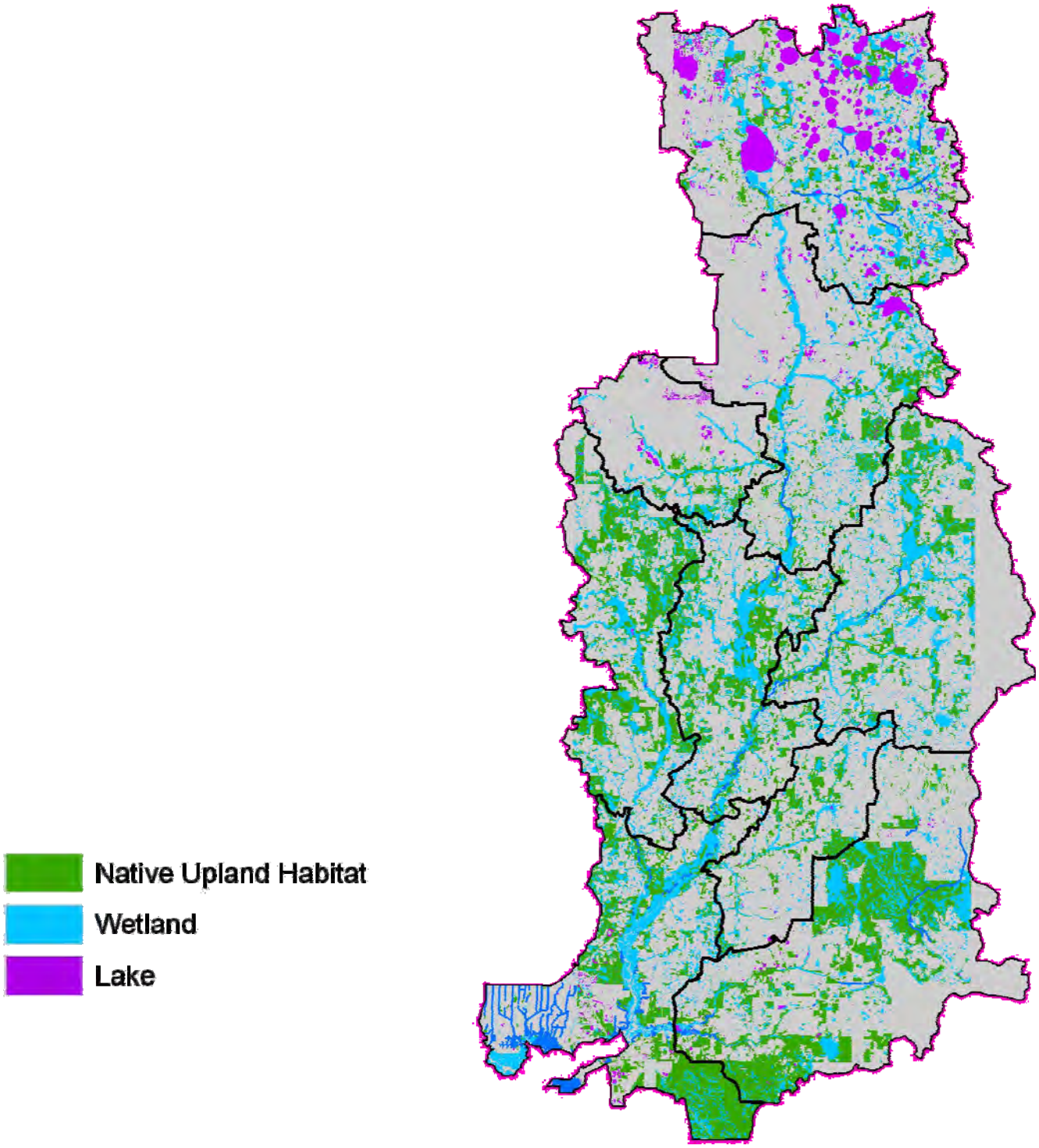


Figure 6. Undeveloped land covers in the Peace River watershed in 1999.

Figures 3 through 6 show there was a large conversion of undeveloped lands to developed land uses in the Peace River watershed between the 1940s and 1999. Table 1 lists changes in the acreage and percent area for these land uses/covers in the Peace River watershed from the 1940s to 1979 and 1999. Table 2 provides a description of the land use/cover changes in the nine sub-basins in the upper, middle, and lower regions of the Peace River watershed over these periods.

Table 1. Land use/cover changes in the Peace River watershed from the 1940s to 1979 and 1999

Land Use	Acres (Percent) in Land Use Class		
	1940s	1979	1999
Developed			
Improved Pasture	39,640 (2.8)	356,925 (25.6)	379,346 (27.2)
Intense Agriculture	107,115 (7.7)	191,496 (13.7)	229,832 (16.5)
Mined lands	7,495 (0.5)	64,437 (4.6)	143,487 (10.3)
Urban Land Use	14,659 (1.0)	73,049 (5.2)	133,571 (9.6)
Undeveloped			
Native Upland Habitat	834,311 (59.7)	419,449 (30.0)	242,849 (17.4)
Wetlands	354,674 (25.4)	249,255 (17.8)	218,232 (15.6)
Water			
Lakes and open water	33,779 (2.4)	35,432 (2.5)	43,027 (3.1)
Other Water	5,011 (0.4)	6,641 (0.5)	6,338 (0.5)
Total	**1,396,683 (100)**	**1,396,683 (100)**	**1,396,683 (100)**

Table 2. Summary of land use/cover changes in the nine sub-basins in the upper, middle, and lower reaches of the Peace River watershed.

Basin Characteristic		Upper Peace River Watershed			Middle Peace River Watershed		Lower Peace River Watershed			
		Peace River at Bartow	Peace River at Zolfo Springs	Payne Creek	Charlie Creek	Peace River at Arcadia	Horse Creek	Joshua Creek	Shell Creek	Coastal Lower Peace
Current Predominant Land Use		Urban	Mining	Mining	Improved Pasture	Improved Pasture	Improved Pasture	Improved Pasture	Intense Agriculture	Urban
Greatest Land Use Conversion	1940s – 1979	Native upland habitat to pasture and urban	Native uplands to pasture and mining	Native uplands to pasture and intense agriculture	Native uplands to pasture	Native uplands to pasture	Native uplands to pasture	Native uplands to pasture	Native uplands to pasture and intense agriculture	Native uplands to urban and pasture
	1979 - 1999	Native uplands and wetlands to urban and pasture; intense agriculture to urban	Native uplands and pasture to mining	Native uplands to mining	Native uplands to pasture	Native uplands to pasture	Native uplands to pasture	Pasture to intense agriculture	Native uplands to pasture and pasture to intense agriculture	Native uplands to urban and pasture
	1940s - 1999	Native uplands to urban and pasture	Native uplands to pasture and mining	Native uplands and wetlands to mining	Native uplands to pasture and intense agriculture	Native uplands to pasture and intense agriculture	Native uplands to pasture	Native uplands to pasture	Native uplands to pasture and intense agriculture	Native uplands to urban and pasture

The largest change in land use was improved pasture, increasing from 2.8% to 27.2% of watershed area from the 1940s to 1999. Intensive agriculture increased from 7.7% to 16.5%. Most of the conversion to these land uses was from native upland forests in the middle and lower regions of the Peace River watershed. Urban land uses increased from 1.0% to 9.6% of total watershed area, mainly in the upper reaches of the watershed near Bartow and in the coastal lower region near the City of Punta Gorda.

The Peace River is notable for the extensive phosphate mining that has occurred in the upper reaches of its watershed. Although phosphate mining began in the early 1900s, there was a large expansion of mining between the 1940s and 1999, increasing from 0.5% to 10.3% of total watershed area. Mining is especially extensive in the upper regions of the Peace River watershed including the Payne Creek, Peace River at Bartow, and Peace River at Zolfo Springs sub-basins (Figure 4). In many of those sub-basins, mining and associated lands (reclaimed land, clay settling ponds) occur very close to the river channel, altering the topography, soils, and the geologic structure of the near-surface zones of groundwater aquifers.

The PRCIS also evaluated changes in the length of natural stream channels in the nine sub-basins between the 1940s and 1999 and totaled these losses for the entire watershed (Table 3). A total of 342.7 miles of natural stream channels were lost in the Peace River watershed over that time. Comparatively large losses of natural stream channels occurred in the upper reaches of the watershed due to mining and agriculture, with stream channels also converted to urban land uses and wetlands in the Peace River at Bartow sub-basin. Losses of natural stream channels to urbanization also occurred in the lower Peace River sub-basin.

Table 3. Change in natural stream and river channel lengths (linear miles) in the Peace River watershed from the 1940s to 1999

Basin	Miles Lost			1999 Land Use in Place of Lost Stream Segment						
	1940s	1999	Change	Urban	Mining	Agriculture	Lakes	Upland habitat	Wetlands	Other
Peace River at Bartow	95.9	38.1	57.8	8.9	10.3	9.8	2.7	7.1	18.7	0.3
Peace River at Zolfo Springs	290.0	240.6	49.4	0.3	31.6	7.8	2.0	1.7	5.9	0.0
Payne Creek	128.7	61.7	66.9	0.4	54.8	6.2	1.1	1.9	2.4	0.1
Charlie Creek	185.8	175.7	10.0	0.0	0.0	6.8	0.1	1.0	2.0	0.0
Peace at Arcadia	133.6	115.7	17.9	0.1	0.0	7.2	0.3	0.1	6.8	4.4
Joshua Creek	57.9	44.2	13.7	0.7	0.0	4.0	0.1	1.4	7.6	0.0
Horse Creek	170.7	140.1	30.6	1.9	4.0	8.6	0.3	6.3	7.2	2.2
Shell Creek	93.0	74.1	18.9	0.3	0.0	7.2	5.4	3.0	2.5	0.5
Coastal Lower Peace	397.7	320.2	77.5	24.8	0.5*	6.8	0.9	13.4	18.7	12.3
Total	**1,553.2**	**1,210.5**	**342.7**	**37.5**	**101.2**	**64.5**	**12.9**	**36.1**	**71.8**	**19.8**

* Sand/shell mining

Similar to the assessment of changes in land use/land cover, trend analyses were performed for water quality, water level, and streamflow data in incremental time steps. Data for these analyses (e.g. daily flows and rainfall, monthly water quality, quarterly groundwater elevations, etc.) spanned the period-of-record through 2004. Additional data were obtained from the mining industry to better differentiate effects among different mining operations, e.g. mandatory and non-mandatory reclaimed lands.

A variety of analytical techniques were used to determine and quantify, where possible, the relative cause and effect relationships between the primary stressors and key hydrologic and ecological indicators. Temporal changes in land uses and cover types associated with the anthropogenic stressors were directly assessed and quantified using various Geographic Information System (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.

Data from available periods-of-record were analyzed and used to quantify relationships between stressors (rainfall, land use changes) and indicators (streamflow, water quality). These results indicated:

- Average rainfall from 1936-1965 was higher than for the more recent 1966–1995 period
- Phosphate mining has altered surface water storage and aquifer recharge
- Agricultural expansion throughout the watershed, and mining and urbanization in the northern watershed, have eliminated large areas of native habitat
- Draining wetlands for agriculture/development decreased surface water storage, increased surface water conveyance, and lowered water table elevations
- Groundwater withdrawals have lowered potentiometric surfaces and altered river base flows

Seasonal Kendall Tau trend tests were run for each of the three USGS streamflow gages on the main channel of the river and various gaged tributaries using standardized five-year intervals. Trend tests for low (Q90), median (Q50), and high (Q10) flows at the three gages on the river channel all showed significant declines since the 1940s, 1950s, and 1960s. However, none of the tested flow metrics exhibited any statistically significant trends in flows since 1970, covering the most recent 35 years at the time of that analysis. An example of these results for trends at the Peace River at Bartow is shown in Table 4.

A different pattern was observed in some of the tributary sub-basins in the southern reaches of the watershed, where increasing trends were observed since the 1950s (see example for the Joshua Creek sub-basin Table 5). These increasing trends in streamflow are due to in part to differences in the geology between the northern and southern part of the Peace River watershed and the effects of different land uses in these areas. The Upper Floridan aquifer is much closer to the land surface in the northern part of the Peace River watershed, where the effects of groundwater withdrawals have resulted in reduced streamflow. The Upper Floridan aquifer is much deeper in the southern part of the watershed, where excess irrigation water from agricultural land use has contributed to increased streamflow.

Natural Long-Term Climatic Variability

Natural, long-term seasonal rainfall patterns and associated hydrologic (ground water and surface water) changes are potential watershed stressors in addition to anthropogenic sources. Climate researchers have suggested that natural climate cycles or phases can persist over

Table 4. Results of seasonal trends tests of monthly flow percentiles for the Peace River at Bartow sub-basin.

USGS Gaging Site	Flow (Percentile)	1935-2004	1940-2004	1945-2004	1950-2004	1955-2004	1960-2004	1965-2004	1970-2004	1975-2004	1980-2004	1985-2004	1990-2004	1995-2004
Peace River at Bartow	Low (Q90)		▼	▼	▼	▼	▼	▼						
	Median (Q50)		▼	▼	▼	▼	▼	▼						
	High (Q10)		▼	▼	▼	▼	▼							

Note: The direction of an arrow denotes a significant increasing or decreasing trend. Arrows are significant at p=0.10 level, and blanks indicate no significant trends in Seasonal Kendall Tau tests corrected for serial correlations. Shaded cells indicate periods prior to USGS gaging data at each location.

Table 5. Results of seasonal trends tests of monthly flow percentiles for the Joshua Creek at Nocatee sub-basin.

USGS Gaging Site	Flow (Percentile)	1935-2004	1940-2004	1945-2004	1950-2004	1955-2004	1960-2004	1965-2004	1970-2004	1975-2004	1980-2004	1985-2004	1990-2004	1995-2004
Joshua Creek at Nocatee	Low (Q90)					▲	▲	▲	▲	▲	▲	▲		
	Median (Q50)					▲	▲	▲	▲	▲	▲	▲		
	High (Q10)					▲	▲	▲	▲	▲	▲			

Note: The direction of an arrow denotes a significant increasing or decreasing trend. Arrows are significant at p=0.10 level, and blanks indicate no significant trends in Seasonal Kendall Tau tests corrected for serial correlations. Shaded cells indicate periods prior to USGS gaging data at each location.

multiple decades. One of these cycles, the Atlantic Multi-decadal 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.

During warm AMOs, there is a higher frequency and duration of major tropical cyclones in the Gulf of Mexico and Atlantic and Caribbean basins. While annual rainfall has not significantly changed over the last century, the decades between the 1930s and 1960s were wetter than more recent periods. Mean and median rainfall in the Peace River watershed indicated average reductions of 4.5 and 5.5 inches per year between two 30-year periods from 1936 to 1965 and 1966 to 1995. Changes in wet season rainfall, primarily linked to the AMO, accounted for approximately 80 percent of the observed differences between these two periods.

A total of 47 documented tropical cyclones (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 cyclone events affected the watershed. During the cooler 1970-1994 AMO period, only 10 tropical systems impacted the watershed.

The Effects of Urban Development, Phosphate Mining and Agriculture on Hydrology, Water Quality and Habitat

The Peace River Cumulative Impact Study discussed the general effects of three major land uses in the Peace River watershed; urban development, phosphate mining and agriculture, on the hydrology, water quality and habitats in the river watershed. It is beyond the scope of this tribute report to Dr. Montgomery to adequately present these findings and readers should consult Chapter Two of the PRCIS for a detailed discussion of this topic.

Water Use

The Upper Floridan aquifer is the primary groundwater supply source in the Peace River watershed. The top of the Upper Floridan aquifer is near land surface in the upper regions of the Peace River watershed, but is deeper and more isolated from the surficial aquifer and streambeds by confining units of lower permeability in the middle and southern regions of the watershed. Near the gulf coast, the Upper Floridan aquifer is highly mineralized and the surficial and intermediate aquifers are used increasingly for water supply.

Groundwater use estimates were developed as part of the PRCIS for each of the nine Peace River sub-basins for four reference periods (Table 6). Historically, ground water has provided the vast majority of the municipal, industrial, and agricultural water supplies used in the watershed. From the 1940s through the 1970s, the predominant groundwater use in the upper watershed was for phosphate mining. However, in the late 1970s, the industry implemented water conservation practices, including 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.

The combined use of ground water in the Peace River watershed has resulted in large drawdowns in the potentiometric surface of the Upper Floridan aquifer (Figure 7). Estimated declines in the potentiometric surface from pre-development conditions to 1975 have exceeded 50 feet in the northern regions of the Peace River watershed. Since the mid-1970s, the area of greatest decline has shifted southward.

Kissengen Spring, which previously discharged an average of approximately 19 mgd (29 cfs) to the upper Peace River, ceased flowing in 1950. The loss of flow was attributed to a progressive decline in the potentiometric surface of the Floridan aquifer, which was associated primarily with historic groundwater withdrawals for phosphate mining (Peek, 1951; Stewart, 1966, Hammett, 1988; Basso, 2003). Phosphate mining withdrawals accounted for an estimated 75 mgd of the 110 mgd of total

Table 6. Estimated average ground water use in million gallons per day (mgd) for nine sub-basins for four 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

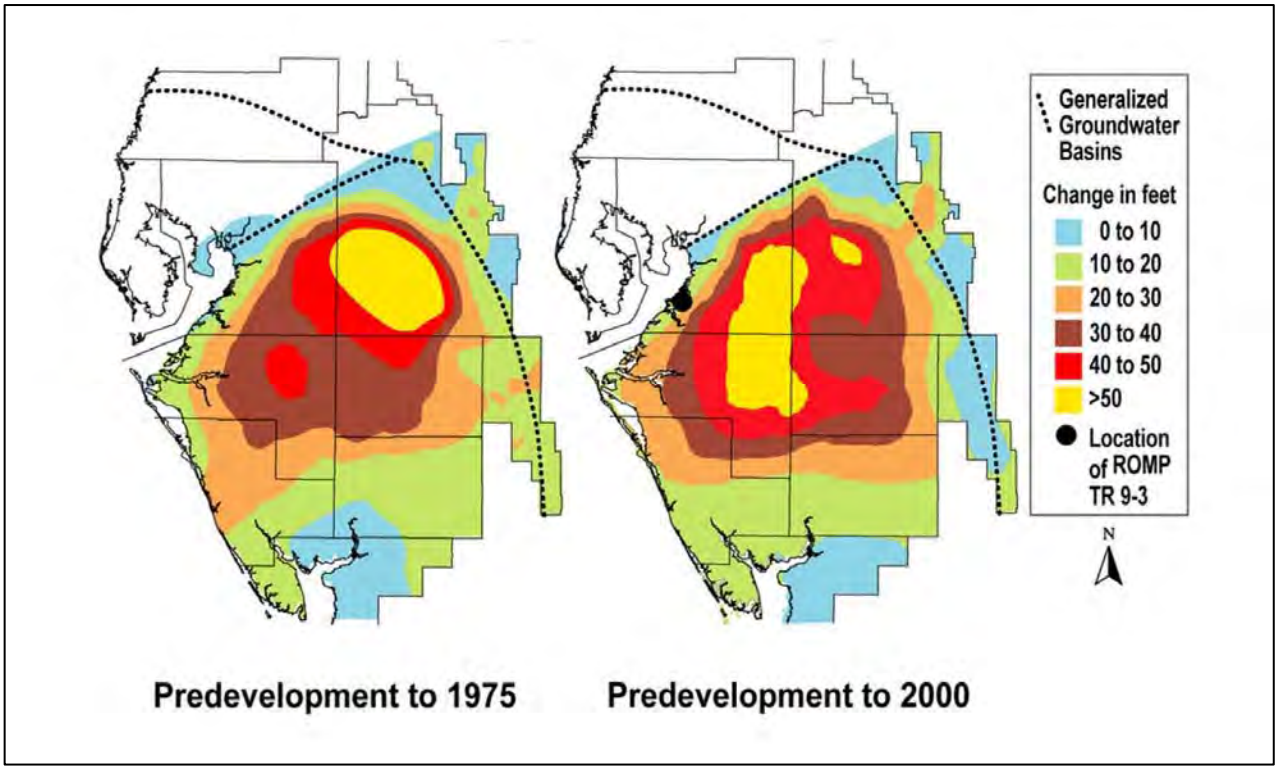


Figure 7. Long-term changes in the potentiometric surface of the Upper Floridan aquifer (from the SWFWMD, based on USGS data).

water withdrawals in southwest Polk County during the years preceding the cessation of flows from Kissengen Spring. In some areas, groundwater withdrawals were accompanied by mining surface water discharges that historically obscured declining dry season baseflow and altered the natural water quality in the upper river.

However, groundwater withdrawals and discharges for mining operations have been dramatically reduced in recent decades due to conservation and capture of surface waters by the mining industry. For example, groundwater withdrawals for mining and industrial uses in Polk County accounted for 81 mgd in 2000, compared with 207 mgd in 1985. Water conservation practices in agriculture and mining have reduced the use of ground water in Polk County by 100 mgd since the 1970s.

In the southern sub-basins in the Peace River watershed, the majority of groundwater withdrawals are associated with agricultural use. Agricultural practices rely primarily on ground water pumped from the Upper Floridan aquifer rather than on surface water. 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 baseflow in the southern tributaries in the watershed. Agricultural pumpage of more mineralized ground water from the well-confined Upper Floridan aquifer has also resulted in increased specific conductance and changes in other water quality parameters (e.g. potassium, chloride) in several tributaries in the southern regions of the Peace River watershed.

The major withdrawal of surface water for urban uses occurs in southern DeSoto County, where the Peace River Manasota Regional Water Supply Authority withdraws water from the Peace River to provide potable supplies for Charlotte, Sarasota and De Soto counties. The City of Punta Gorda operates a smaller water treatment facility that withdraws surface water from behind the Hendrickson Dam on Shell Creek.

Regulatory Assessment

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 policies 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 PRCIS addressed the cumulative impacts to the Peace River watershed as well as efforts underway to help reverse impacts and restore the Peace River to more natural conditions. These findings were used by the Florida Department of Environmental Protection to develop a scientific foundation for the subsequent preparation and adoption of a Resource Management Plan for the Peace River watershed (FDEP, 2007).

3.4 Source Water Protection: Factors Affecting Future Potable Water Supplies from the Peace River

Dr. Montgomery made important contributions to the preparation of the Integrated Regional Water Supply Plan for the Peace River Manasota Regional Water Supply Authority (PRMRWSA). The PRMRWSA operates water production, storage, treatment, delivery and ancillary facilities to serve a four county area of Charlotte, De Soto, Manatee and Sarasota Counties in southwest Florida. The mission statement of the PRMRSA is to provide the region with a sufficient, high quality, safe drinking water supply that is reliable, sustainable, and protective of the region's natural resources now and into the future.

Because of his expertise on the Peace River, Dr. Montgomery wrote the section of the water supply plan that dealt with physical, hydrologic, and water quality factors that could affect the continued use of the Peace River for potable water supply. A discussion of those factors, reprinted from the source protection section of the executive summary of the Integrated Regional Water Supply Plan, is reprinted below.

Atkins, Inc. 2015. Integrated Regional Water Supply Plan - 2015. Report prepared for the Peace River Manasota Regional Water Supply Authority, Lakewood Ranch, FL. in cooperation with the Southwest Florida Water Management District, Brooksville, FL.

> The analysis identified a number of factors with the potential to negatively impact future surface water supplies. All of those factors are of increasing concern primarily under seasonally lower flow conditions. Regionally, within the existing and potential surface water supply watershed of the Authority's member governments there are clear evidence of long-term increasing conductivity levels during lower flows due primarily to the influences of agricultural groundwater discharges. Additionally, within the Peace River watershed, upstream of the Peace River facility, future surface water supplies during lower flows may be further reduced by projected surface/groundwater usage during the proposed expansion of phosphate mining primarily in the Horse Creek basin. The coincident isolation of portions of upstream watersheds for an extended number of years during mining reclamation operations has the potential to seasonally reduce flows at the Peace River facility. Whether regulations alone will completely protect the Peace River facility from these potential anthropogenic influences is still uncertain.
>
> At least two major natural influences have the potential to seasonally influence future Peace River facility operations. Analysis of flows upstream of the Peace River facility show a distinct long-term (60 year) increase in the frequency of lower flow conditions. This pattern is supported by other analyses showing general patterns of longer spring and fall dry-season conditions, and shorter wet-seasons in the Peace River watershed. Further, projected future sea level rises are expected to influence the future availability of lower Peace River water during seasonally lower flow conditions. Analyses suggest that if the magnitude and timing of future sea-level changes remain at current projected ranges, impacts on Peace River facility

operations will be relatively small for several decades. However, should future increases in sea-levels actually turn out to be toward the high end of current projections, then by the middle of this century increasing conductance in the lower Peace River near the current intake structure may begin to limit the availability of water supplies primary to higher flow periods.

Individually and combined, these factors suggest that two options may need to be considered in the future: 1) increase the ability to withdraw river water, and 2) build additional off-stream storage to meet projected increases in demand and maintain overall reliability. The report also presented the following recommendations for source water protection

- Work with member governments, SWFWMD, and the Florida Department of Environmental Protection to resolve regulatory uncertainties associated with high conductivity agricultural discharges and phosphate mining dry-season flow reductions to Peace River facility operations

- Continue collection of monthly water quality information and temporally intensive conductivity data upstream of the Peace River facility intake. These data should be used to improve current estimates of the influences of upstream agricultural ground water on facility operations during lower flow periods, as well as interactions between freshwater inflow and tide stage on conductivity should sea-levels continue to rise

- Calibrate/refine the existing SWFWMD (or other) hydrodynamic model to specifically address potential future impacts of increasing upstream conductivity and future projected seas level increases on Peace River facility operations and reliability. Predicting the threat of sea-level rise through modeling efforts should be an integral component of the Authority's future Integrated Regional Water Supply Management Plan updates

- Utilize the Authority's reliability model to assess the benefits on further increasing the Peace River facility's withdrawal capacity from the river as the facility becomes more reliant on withdrawing more water under higher flow conditions

- Evaluate the viability of constructing additional off-stream storage. Future demand projections, combined with ongoing refinements to the Authority's reliability model could be used to assess both the timing and sizing of such a potential future expansion

- Assess the viability of constructing an additional intake structure located upstream of the existing (and future) lower Peace River estuarine zone

- Consider addition (or alterations) of Peace River treatment processes that would allow the use of waters having higher conductance levels. The major cation associated with brackish estuarine waters is sodium, rather than the calcium and magnesium ions currently associated with the upstream agricultural discharges of ground water

3.5 Studies Conducted As Part of the Hydrobiological Monitoring Program In Support of Potable Water Supply Withdrawals from the Peace River

Upon his relocation to southwest Florida in 1981, Dr. Montgomery became involved in one of the most extensive and longstanding monitoring programs of a tidal river ecosystem in Florida, that being the Hydrobiological Monitoring Program (HBMP) associated with potable water supply withdrawals from the Peace River. Since 1990, Dr. Montgomery was the principal scientist in charge with implementing and interpreting data from this monitoring program. The reports he prepared for the HBMP provide thorough assessments of the interaction of freshwater inflow with key water quality and ecological characteristics in the Lower Peace River / Upper Charlotte Harbor estuary. These reports are among the most informative documents regarding the hydrobiology of this estuary and its contributing watershed. They should be read by any ecologists or resource managers who are doing assessments of the Lower Peace River / Upper Charlotte Harbor ecosystem.

The reports that Dr. Montgomery prepared for the HBMP are summarized in the following section. These summaries are divided into two groups, the first being interpretive reports that evaluated the findings of the HBMP at designated multi-year intervals. Because the interpretive reports for later years cover a longer period of record, the most recent reports are summarized first, followed by earlier reports working back in time. The most complete summary is presented for the most recent report that analyzed data up through 2011. This report provides an excellent overview of the monitoring program and its findings up to that point in time.

The second group of reports that are summarized are special HBMP reports that were limited in duration to evaluate various physical or ecological characteristics (e.g., morphology, zooplankton) of the Lower Peace River. The HBMP also involved the preparation of yearly data reports which are not summarized below, but are listed in the bibliography of this report. As will be discussed, technical documents were also prepared by a scientific review panel for the HBMP, which are not summarized but are also listed in the bibliography. All the reports prepared for the HBMP can be obtained from the Peace River Manasota Regional Water Supply Authority (PRMRWSA) or accessed from the Regulation Division of the Southwest Florida Water Management District in the water use permit file (#2010420) for the PRMRWSA's withdrawals from the Peace River. They can also be accessed online at the Florida Water Atlas website referenced on page 1.

3.5.1 General History of the Peace River Hydrobiological Monitoring Program

It is useful to first describe the general history of the Peace River HBMP**.** Potable water supplies have been obtained from the Peace River since 1980 at a water treatment facility located near State Road 761, approximately 30 kilometers upstream from the river mouth (Figure 8). This water supply facility was constructed by General Development Corporation, who owned and operated the system until 1991, when it was acquired by the Peace River Manasota Regional Water Supply Authority.

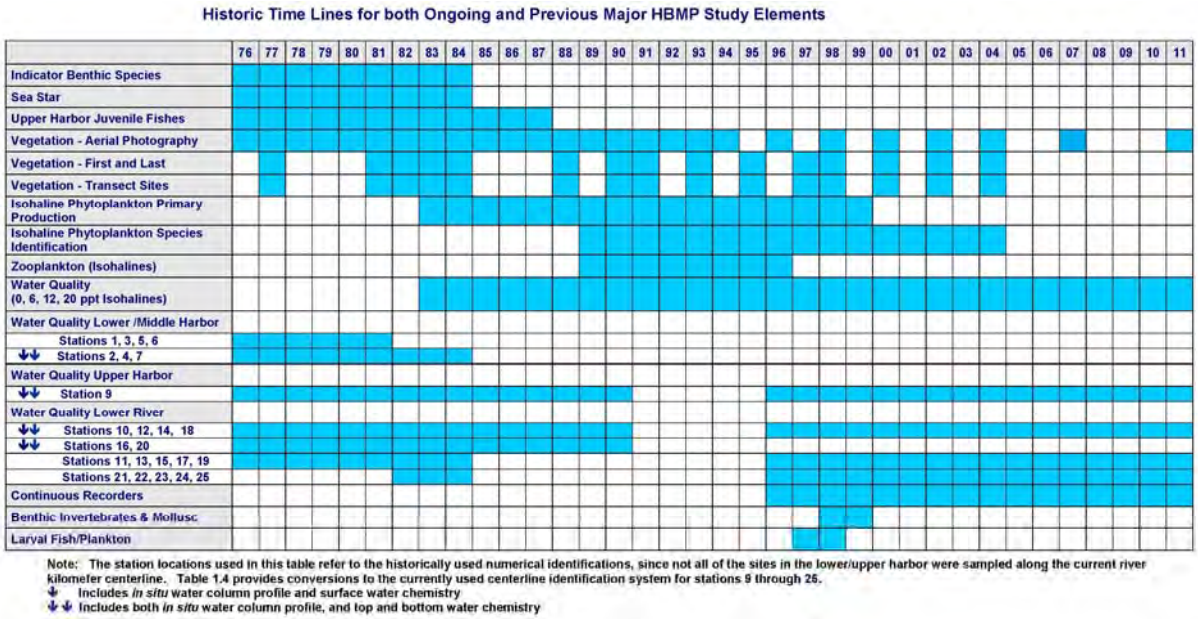
The General Development Corporation contracted the University of Miami Rosenstiel School of Marine and Atmospheric Sciences to conduct a study of the potential effects of the withdrawal

Figure 8. Location of the water treatment facility operated by the Peace River Manasota Regional Water Supply Authority on the Lower Peace River. River kilometers shown in blue. The river mouth (not shown) is at kilometer 0.

of fresh water from the Peace River at the location of the proposed water treatment plant. That study (Michel et al., 1975), collected baseline physical and biological data and developed a one-dimensional (longitudinal) numerical model of salinity/inflow relationships in the Lower Peace River. The report concluded that under low flow conditions, the withdrawals proposed for the water treatment facility would cause only small changes in salinity, which would add little additional stress on the plant and animal communities in the Lower Peace River. A subsequent study of biological communities in the area of the proposed water treatment facility was prepared by Texas Instruments (1978).

Data collection for the HBMP began in the summer of 1975, over four years before completion of construction of the water treatment facility on the Peace River and the first water supply withdrawals. A bar chart of the timeline of the various components of the HMBP from 1976 through 2011 is shown in Table 7. All components of the HBMP that were in effect in 2011 continue at the time of the writing of this tribute report in 2016.

Table 7. Time frame of data collection components of the Peace River HBMP from 1976 though 2011. All data collection components from 2011 are currently in effect.



The initiation of the monitoring program in 1975 involved the sampling of salinity and water quality in the Lower Peace River and Upper Charlotte Harbor and the biological indicators that were considered to be key species and communities to evaluate how they might respond to changes in freshwater inflow. These species and communities included benthic macroinvertebrates, sea stars, and juvenile fishes in the upper harbor and vegetation along the banks of the lower Peace River. Under the direction of Dr. Montgomery, studies of phytoplankton production in the lower river and upper harbor commenced in 1983 to evaluate how variations in freshwater inflow affect these characteristics of the estuary. Monthly sampling was initiated at moving stations based on the mid-day locations of the 0, 6, 12 and 20

psu isohalines in the estuary. The location of the 0 psu isohaline is determined at the boundary between freshwater and the first consistent occurrence of salt in the estuary on each sampling day. Sampling at these moving isohaline stations (and a number of fixed location stations) continues today, comprising an extensive long-term data base to evaluate changes in water quality and phytoplankton production in the estuary in relation to variation in freshwater inflows.

Since 1985, the HBMP has been required as part of the conditions of a water use permit from the Southwest Florida Water Management District (SWFWMD), the governmental agency that regulates water use in the region. From the beginning of the program, it was understood the HBMP could be periodically modified as additional data were collected and new analyses were conducted over time. In 1996, the HBMP was revised to make some modifications in the design of the program and require time limited studies of benthic macroinvertebrate and larval and juvenile fish communities in the Lower Peace River. The 1996 revision also specified that interpretive reports would be submitted in five-year intervals.

Associated with these modifications of the HBMP, a revised quality control and assurance plan was prepared that described the methods and procedures used to assure accurate data collection for the HBMP. The reference for the quality assurance plan (PBS&J, 2001) is listed along with the interpretive HBMP reports in the bibliography of this report.

Role of the Scientific Review Panel in the HBMP

When the renewal of the water user permit for withdrawals from the Peace River was evaluated in the mid-1990s, there was concern among some citizens that the proposed withdrawals would cause harm or reduce the biological productivity of the estuary. In response to these concerns, Dr. Montgomery recommended that the methods and the findings of the HBMP be subject to periodic scientific review.

Based on this recommendation, the 1996 revision of the HBMP required that the design and findings of the HBMP be periodically assessed by a scientific review panel comprised of five individuals with expertise in the relationships of freshwater inflow to estuaries. The panel periodically meets in association with submittal of the drafts the interpretive HBMP reports. The panel can supply comments to the Peace River Manasota Regional Water Supply Authority and the SWFWMD. The interpretive reports are finalized after taking into account the comments of the panel.

The comments provided by the scientific review panel have generally been supportive of the HBMP, but some modifications, special studies, and additional analyses have been conducted for the HBMP in response panel comments. An excellent example of comments submitted by the review panel can be found in the most recent comprehensive summary report submitted for the HBMP (Atkins, 2013), which is summarized in the following section. The comments submitted by the scientific panel for each round of review were concatenated by Dr. Montgomery into corresponding documents. These review panel documents are listed in the bibliography, but summaries of the review panel comments are not presented in this tribute report.

3.5.2 Comprehensive Summary Reports for the Hydrobiological Monitoring Program, 2004 to 2013

The comprehensive summary reports have been submitted at multi-year intervals during the course of the HBMP. The most recent comprehensive report is summarized first below, followed sequentially back in time by summaries of other interpretive reports published since 2004. The next scheduled comprehensive report will analyze data through 2016. Enquiries about future reports should be directed to the Peace River Manasota Regional Water Supply Authority (PRMRWSA) or the SWFWMD.

The reports are referred to in the following sections by the year in which the final report was published, rather than the year in the report title that refers to the last year of data evaluated in that report.

Atkins, Inc. 2013. Peace River Hydrobiological Monitoring Program, 2011 Comprehensive Summary Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District.

The 2013 report is a multi-faceted, comprehensive document that assesses not only HBMP data from the Lower Peace River and Upper Charlotte Harbor, but also long-term trends in land use, water quality, and streamflow at key upstream sites in the Peace River watershed.

The 2013 report analyzed data collected from the beginning of the HBMP through 2011 and was finalized after input from the scientific review panel. Like other interpretive comprehensive reports for the HBMP, the Atkins 2013 report had five basic objectives:

- Evaluate key relationships between ecological variables and parameters and freshwater inflow 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 water supply facility withdrawals

- Assess the presence or absence of any long-term trends for freshwater inflow and water quality and ecological variables in the estuary. The 2013 report also examined long-term trends in rainfall, streamflow and water quality at a number of upstream freshwater sites

- Assess the presence or absence of adverse ecological impacts due to low freshwater inflow and determine the influence that water supply withdrawals my have contributed to such impacts

- Assess and evaluate the effectiveness of the withdrawal schedule for preventing adverse environmental impacts. The objective being to provide the SWFWMD with sufficient analyses to assure that the withdrawal schedule for the water use permit continues to provide adequate and continuing resource protection. Evaluate the potential environmental impacts that may be associated with additional future increased withdrawals from the river and the feasibility of increased water supplies

- Evaluate the overall HBMP design and make recommendations regarding implementing any modifications to the HBMP

Technical Literature Reviews

The comprehensive reports have also provided informative reviews of other studies that were conducted on the Lower Peace River, the Peace River watershed, and Upper Charlotte Harbor. The 2013 report includes excellent technical summaries of fifty-one reports or articles that have evaluated these resources. These publications range from hydrologic studies of the Peace River watershed to assessments of fish populations in the Peace and Myakka rivers and Upper Charlotte Harbor. Appendices to the 2013 report contained reviews of other publications that were discussed in the 2004 and 2009 comprehensive reports. In total, the technical summaries provided in the 2013 report, which were written by Dr. Montgomery, provide one of the most complete literature reviews of technical information pertaining to the hydrologic and ecological characteristics of the Lower Peace River and Upper Charlotte Harbor.

The 2013 Comprehensive Summary Report

Selected findings and conclusions from the 2013 comprehensive report are presented in the following sections. As stated in the Introduction to this chapter, readers should consult this report before referring to or otherwise describing it findings or conclusions.

Status and Trends in Regional Rainfall, Streamflow, and Water Supply Withdrawals

One of the primary objectives of the comprehensive summary reports is to update information on seasonal and long-term patterns of rainfall, streamflow at key locations in the watershed, freshwater inflow to the Lower Peace River, and water supply withdrawals.

The 2013 report relied on rainfall data from three long-term stations distributed from north to south in the Peace River watershed (Bartow, Arcadia, and Punta Gorda). For comparison, the report also analyzed data from a long-term station in the adjacent Myakka River basin to the west to evaluate how rainfall may have varied toward the Gulf Coast.

Extensive results were presented for long-term trends in yearly and dry-season and wet-season rainfall. A variety of graphical techniques and statistical tests were run to examine temporal changes in rainfall. As has been documented in other studies, the report found that yearly rainfall totals were generally higher in the 1940s and 1950s, but since then, have more frequently been below the long-term watershed average of about 52 inches per year.

One finding was that during the six years from 2006 through 2011, there was an unusually consistent pattern of medium to low rainfall years with a lack of wet years. In contrast, this was preceded by a relatively wet four-year period from 2002 to 2005 (Figure 9). It is noted the five-year moving average value shown in Figure 9 was centered on each year, and is not a five-year value for a year and the previous four years, thus the oddly high moving average value for the final few years (e.g., 2009 - 2011).

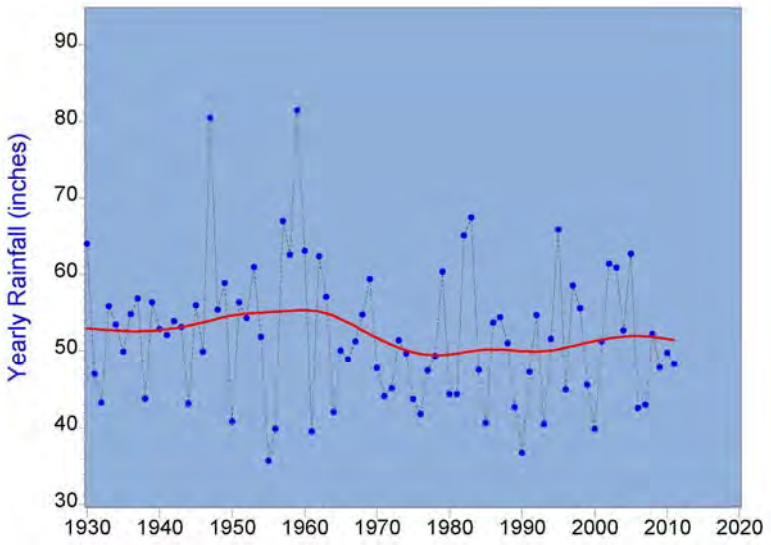


Figure 9. Yearly total and 5-year moving average rainfall for the average of three long-term gages (Arcadia, Bartow, Punta Gorda) in the Peace River watershed , 1930-2011.

Another graphical technique showed that the difference of the cumulative annual rainfall total averaged for these three gages peaked in the early 1960s relative to the long-term watershed average of 52.0 inches, then generally declined during the 1970s and 1980s (Figure 10). The difference of the cumulative rainfall total relative to the watershed average fell to zero in the early 1990s, in the years 2000-2001, and again in 2011, after an upturn near 2005**.**

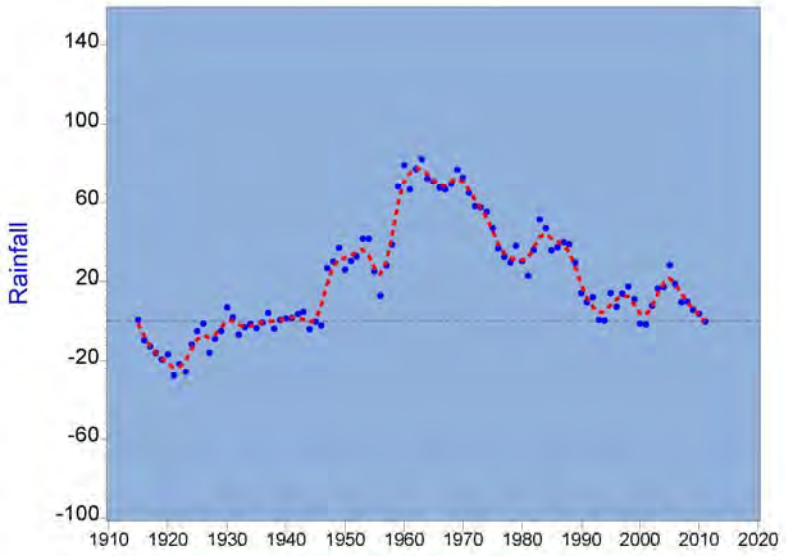


Figure 10. Yearly differences of annual rainfall totals averaged for the Bartow, Arcadia, and Punta Gorda gages accumulated over time relative to an accumulated long-term average of 52.0 inches for the Peace River watershed, 1915 - 2011.

The 2013 report discussed cyclical shifts in climatic factors that could be related to long-term patterns in seasonal and yearly rainfall in the Peace River watershed. The report provides an excellent summary of recent publications that discuss climatic factors that vary on multi-year and decadal time scales, such as the El Niño / Southern Oscillation (ENSO) and the Atlantic Multidecadal Oscillation. The reports points out that El Niño patterns influenced unusually seasonally high flows that occurred during winter and spring months of 1982-1983 and 1997-1998. It is worth noting that another wet El Niño winter occurred at the time of writing of this tribute report (2015-2016).

The 2013 report provides a particularly good review of publications dealing with the Atlantic Mulitidecadal Oscillation (AMO) and its relevance to weather patterns in Florida. Without going into detail in this tribute report, the AMO refers to long-term cyclical changes in cool and warm phase temperature differences of only about 0.6 degrees Celsius in ocean surface temperatures in the North Atlantic. Climatological data indicate that differences between relatively warm and cool AMO periods affect both air temperatures and rainfall patterns over North America and Europe. The effects of warm and cool AMO periods differ between much of the continental United States and peninsular Florida. While warm AMO periods may cause dry periods of much of the continental U.S., small increases in average sea surface temperatures in the Atlantic and Caribbean during warmer AMO periods can result in increased wet-season rainfall across South Florida, including an increased frequency of tropical storms and hurricanes. Conversely, cooler AMO phases typically correspond to decreased summer rainfall in South Florida.

A graph of monthly deviations in North Atlantic sea surface temperatures for the years 1915 to 2011 is shown in Figure 11. The 2013 report summarized several studies that have discussed cyclical patterns in rainfall in southwest Florida, including the generally wet period from the 1940s to the 1960s and a generally dry period from the 1970s to the 1990s, which corresponded to warm and cool AMO periods, respectively. The 2013 report states that yearly mean and median rainfall values calculated from six stations in the Peace River watershed had average declines of 4.5 and 5.5 inches per year between the two thirty-year periods from 1936 -1965 and 1966 - 1995. Changes in wet season rainfall, presumably linked to the AMO, were responsible for approximately 80 percent of these changes in yearly mean and median values.

The 2013 report discussed that during the twentieth century and into the twenty-first century, anthropogenic influences on climate (e.g., global warming) may act to either mask or exaggerate the cyclical influences of the AMO and make it more difficult to determine the relative role of AMO on climate. Also, the 2013 report emphasizes that during warm or cool AMO phases, short-term intervals (1 to 3 years) of either very dry or very wet weather can occur, such as the very dry years of 1955 and 1956 in what was principally a warm and wet AMO period in the Peace River watershed (compare Figures 9 and 11).

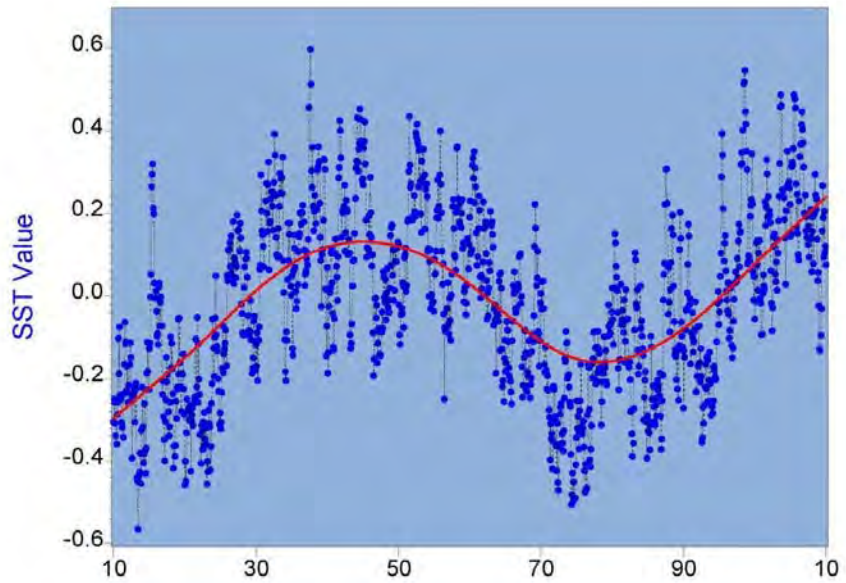


Figure 11. Monthly deviations in North Atlantic Sea Surface Temperature (SST) values for assessing warm and cool AMO patterns, 1910 - 2011.

These inter-annual and multi-year patterns in rainfall are closely related to long-term patterns in streamflow and flow-related variables in the estuary (e.g., salinity, color). Time series graphics for some of those variables are reprinted from the 2013 report on the following pages. For readers concerned with the status of freshwater inflow and water quality in the Lower Peace River estuary, it is emphasized those results end in 2011, which was at the end of a predominantly dry six-year period. Though not shown in this report, there have been a series of wet years since 2012. Updated results including those years will be presented in the next comprehensive summary report for the HBMP, which will be published in 2017 and include data collected through 2016.

Streamflow Trend Analysis

As described in the reviews of previous studies presented in the 2013 report, streamflow trends in the Peace River watershed have been the source of considerable study, not just by the HBMP, but many other investigators in the region. Much of this interest has been driven by the documented reductions in flows in the Upper Peace River in Polk County, where there has been extensive phosphate mining. Although the mining industry has greatly reduced their groundwater use, there has been increasing overall groundwater use in the upper Peace River basin, resulting in large drawdowns of water levels in the Upper Floridan aquifer which have contributed to significant reductions in streamflow in the upper Peace River. The cessation of flow of Kissengen Spring in Polk County is well documented, and portions of the Upper Peace River, which used to be a perennial stream, now go dry during prolonged droughts.

Dr. Montgomery's work, not only for the HBMP but also for the Peace River Cumulative Impact Study (see Section 3.3), has examined and compared differences in long-term trends in streamflow throughout the Peace River watershed. As described above, the 2013 report presented data and discussed findings that indicate that long-term patterns of changes in flow in the river have been influenced by changes in rainfall associated with the Atlantic Multi-decadal Oscillation.

However, analyses presented in the 2013 report found distinct differences in the low-flow characteristics of streams in different regions of the Peace River watershed. As previously described, there have been significant declines in low flows in the upper Peace River. Conversely, at a number of tributaries in the southern part of the Peace River watershed, low flows have increased due to supplementation of streamflow from agricultural irrigation water that originates from groundwater withdrawals. This is due in part to differences in geologic setting. Whereas the top of the Upper Floridan Aquifer is near land surface in the Upper Peace River, the aquifer is much deeper in the southern part of the Peace River watershed and more isolated from the surface water features by less permeable geologic strata. The pumping of deep ground water to the land surface supplements the surficial aquifer with the excess water contributing to increased streamflow.

The report noted that the increase in baseflow in the southern tributaries has seemed to diminish in recent years (as of 2011), but it was not clear if this reflected the typically low rainfall that has occurred between 2006 and 2011 or that possibly there have been improvements in the efficiency of agricultural water use in the region. Trends in flow since 2011 were not evaluated for this tribute report, but will be examined in the next HBMP report that is scheduled for 2017.

The 2013 report presented many tables and graphs that examine flow trends in the Peace River watershed over different time intervals. Readers are encouraged to read that section of the report for a thorough discussion of spatial differences in flow trends throughout the Peace River watershed. A few of those results are presented below. Again, readers are reminded that these results end with a six-year dry period ending in 2011, and there have been a series of normal or wet rainfall years since that time.

The 2013 report performed trend analyses on a number of flow parameters at gages in the Peace River basin, including mean flows and different yearly percentile flows. Hydrographs of yearly median flows for the Peace River at Arcadia and Joshua Creek are shown in Figures 12 and 13. Smoothed lines were also fitted to the data using SAS software. In viewing these graphics, note that period of records differ, with the first year with complete records beginning in 1933 for the Peace River at Arcadia and 1950 for Joshua Creek.

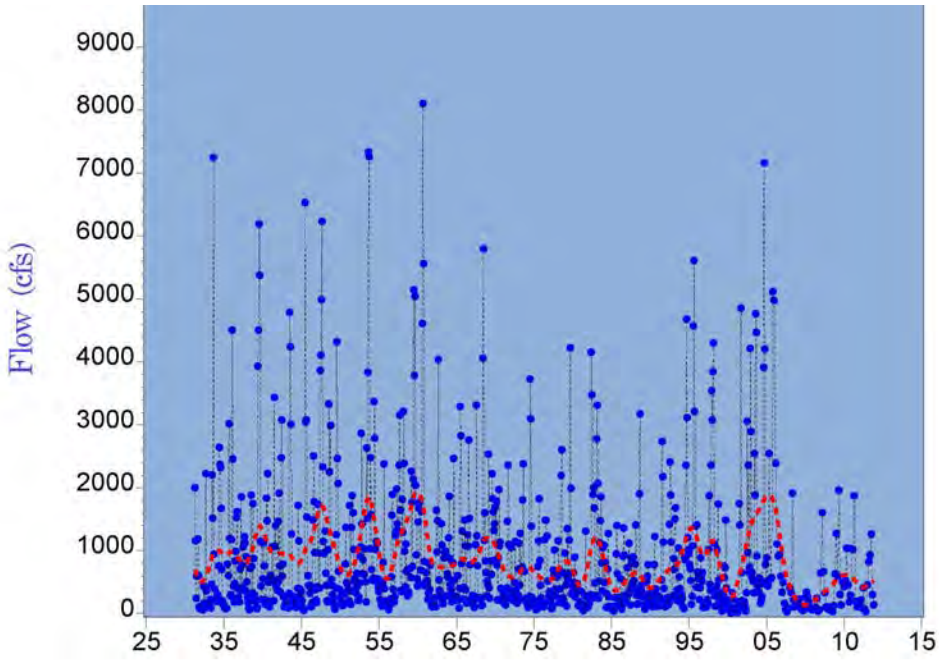


Figure 12. Time series of monthly median flows at the Peace River at Arcadia gage with smoothed trend line, 1933 to 2011.

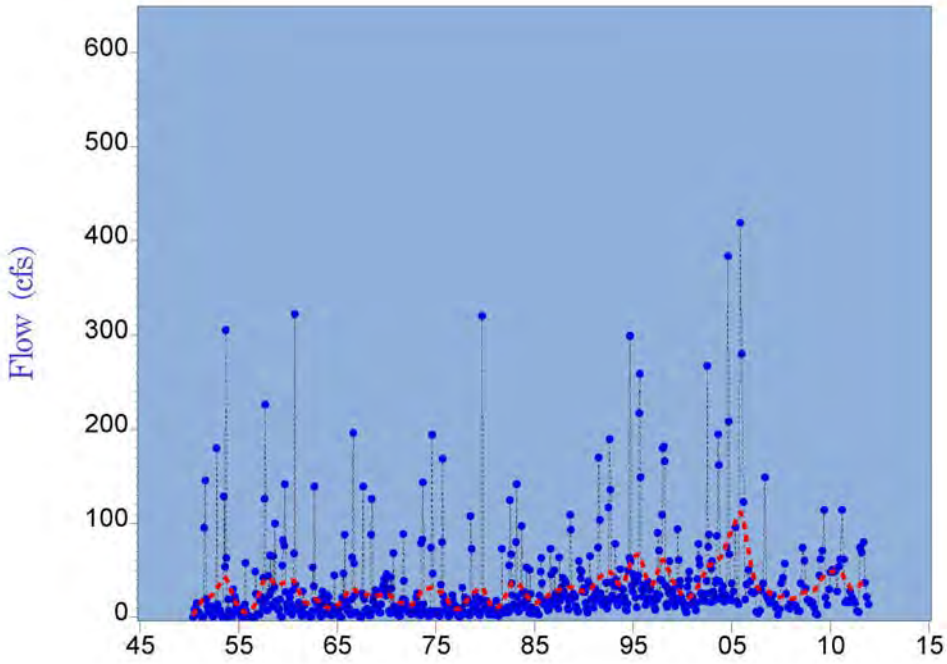


Figure 13. Time series of monthly median flows at the Joshua Creek near Nocatee gage with smoothed trend line, 1950 - 2011.

These two gages show vey different patterns over time. The smoothed trend line shows that median monthly flows in the Peace River at Arcadia, which is the most downstream gage on the main channel of the river, have generally declined, with the exception of some wet periods in the mid-1990s and around 2003 to 2005. The very dry period beginning in 2006 is also very pronounced. Conversely, median flows in Joshua Creek are generally higher now than in the 1950s, when the records begin. As previously discussed, this is due to increasing agricultural water use in the Joshua Creek basin. Studies from the Myakka and Little Manatee River watersheds have shown that not only does excess irrigation water increase baseflow, but by creating more saturated soil conditions, can also increase storm runoff after rainfall events (SWFWMD, 2011a, 2011b).

Geographic differences in changes in flow over time in the Peace River watershed are apparent in Figure 14, where average monthly flows for three time intervals are plotted at three gages in the upper, middle, and lower portions of the watershed. The time intervals roughly correspond to three AMO periods; prior to 1969, from 1969 to 1994, and after 1994 (ending in 2011). The flow reductions for the latter two periods relative to before 1969 are most pronounced at the Bartow gage in the upper reaches of the river, where significant flow declines due to human causes are well documented. Flow reductions are only apparent in the wet season at the downstream Arcadia gage. At Joshua Creek the flows after 1994 are the highest, even though they include the vey dry 2006-2011 period. Because the long-term patterns in rainfall have been generally similar between these sub-basins, these differences in streamflow reflect the different effects of human factors on flow in the upper, middle, and lower regions of the Peace River watershed.

- Text continued on page 42 -

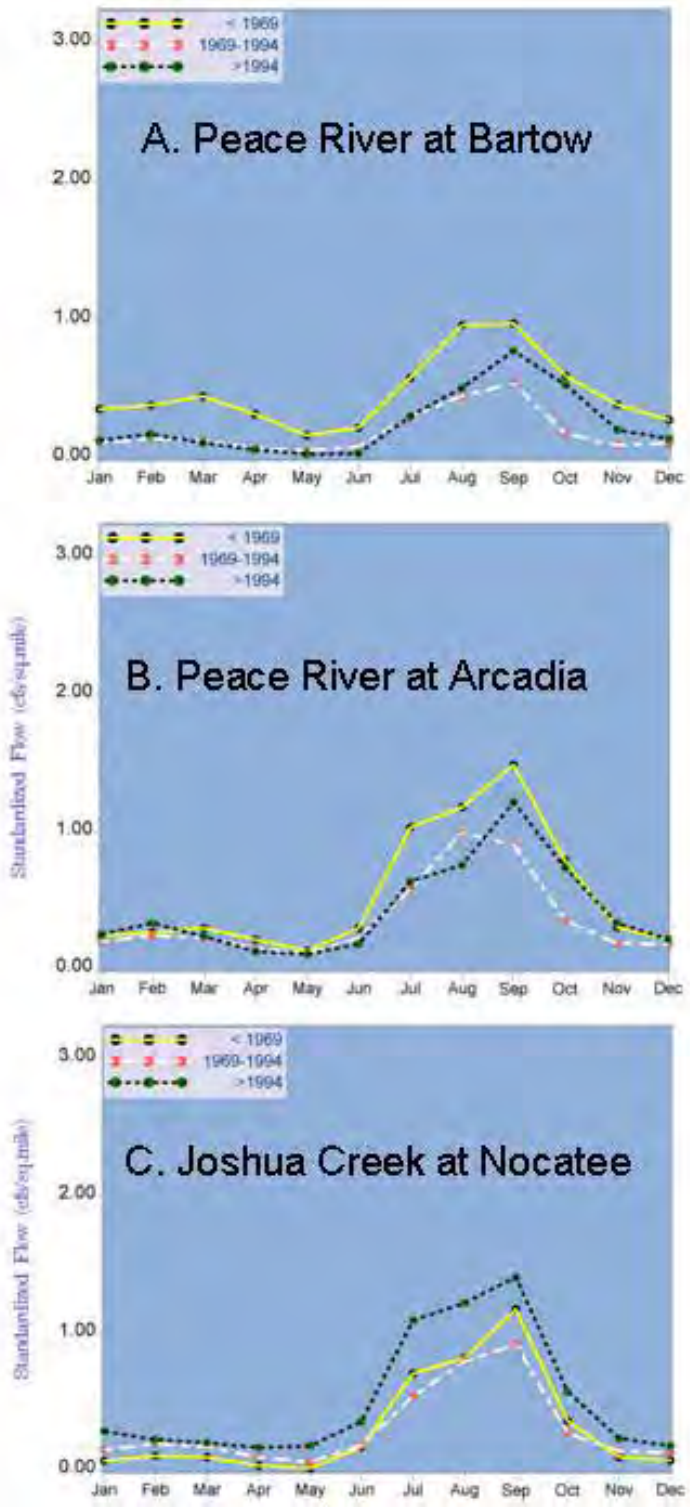


Figure 14. Average monthly flows at the three gages in the upper (A), middle (B) and lower (C) regions of the Peace River watershed during three periods corresponding to shifts in the AMO cycle (see Figure 11).

The 2013 report presented a series of tables listing the results of statistical trend tests of various flow parameters over time at several gaging stations in the Peace River watershed. These tests were performed over different time intervals to determine if the trends were persisting at roughly the same rate or becoming less or more pronounced over time. Table 8 shows the results of trend tests for three flow yearly flow percentiles at six streamflow gages that represent changes in low (P10 = 10th percentile), median (P50), and high flows (P90). The columns in the table represent different starting years for the beginning of each trend test. Significant ($p < 0.05$) declining trends were observed at the three main gages on the main stem of the river (Peace River at Bartow, Zolfo Springs, and Arcadia) over their periods of record which go back to the 1930s. However, when the beginning years of the trend tests start in 1975 or later, there were no significant declining trends at these gages. Also, there has not been a declining trend in Charlie Creek flows going back to 1955 and the flows from Joshua Creek have significantly increased since that time.

These changes in trends over varying lengths of time are due in large part pattern to trends in rainfall over these periods. Also, the effects of different anthropogenic factors, such as phosphate mining, increasing agriculture, and temporal changes in groundwater use have been manifested over different time periods. It is likely that many of the factors associated with flow reductions in the upper Peace River basin were in effect prior to the 1970s or 1980s, and in some cases, may have stabilized since that time.

Table 8. Summary of results of Kendall Tau trend analyses of monthly flow percentiles over different time periods through 2011

USGS Gaging Site	Flow Percentile	1935 - 2011	1940 - 2011	1945 - 2011	1950 - 2011	1955 - 2011	1960 - 2011	1965 - 2011	1970 - 2011	1975 - 2011	1980 - 2011	1985 - 2011	1990 - 2011	1995- 2011	2000- 2011
Peace River Watershed															
Peace River at Bartow	Low (P10)		▼	▼	▼	▼	▼	▼	▼						
	Median (P50)		▼	▼	▼	▼	▼	▼							
	High (P90)		▼	▼	▼	▼	▼	▼							
Payne Creek near Bowling Green	Low (P10)														
	Median (P50)														
	High (P90)														
Peace River at Zolfo Springs	Low (P10)	▼	▼	▼	▼	▼	▼	▼	▼						
	Median (P50)	▼	▼	▼	▼	▼	▼	▼	▼						
	High (P90)	▼	▼	▼	▼	▼	▼	▼							
Charlie Creek near Gardner	Low (P10)														
	Median (P50)														
	High (P90)														
Peace River at Arcadia	Low (P10)	▼	▼	▼	▼	▼	▼	▼							
	Median (P50)	▼	▼	▼	▼	▼	▼	▼							
	High (P90)	▼	▼	▼	▼	▼	▼								
Joshua Creek at Nocatee	Low (P10)					▲	▲	▲	▲	▲	▲				
	Median (P50)					▲	▲	▲	▲	▲	▲				
	High (P90)					▲	▲	▲	▲	▲					

* Note: Direction of arrow denotes significant increasing or decreasing trend. Red arrows are significant at p=0.05 level, blue show trends significant at p=0.10, and blanks indicate no significant trends in Seasonal Kendall Tau tests corrected for serial correlations. Dashed lines indicate periods prior to USGS gaging at each location.

The period from 1975 forward is particularly relevant to understanding freshwater inflow relationships in the Lower Peace River estuary, for this is when data collection for water quality and biological variables in the lower river as part of the HBMP began. In addition to the Peace River at Arcadia, three major tributaries contribute flow to the Lower Peace River. Horse and Joshua Creeks flow into the lower river below the Peace at Arcadia gage, but above the intake for the Peace River water treatment plant. Shell Creek, which is the largest tributary, flows to the estuarine reach of the lower river below the Peace River water treatment plant, about 15 kilometers upstream of the river mouth (see Figure 8 on page 30).

A graph of summed yearly flows for the three gages above the water treatment plant are shown for HBMP period at the time of the 2013 report (1975 - 2011). Although the average flow after 1994 was greater than the average flow from 1975 to 1994, very dry years occurred in 2000 and the six consecutive years from 2006-2011. The six-year average flow for the sum of these three gages in 2011 was 635 cfs , which was the lowest six-year average in a flow record that goes back to 1951.

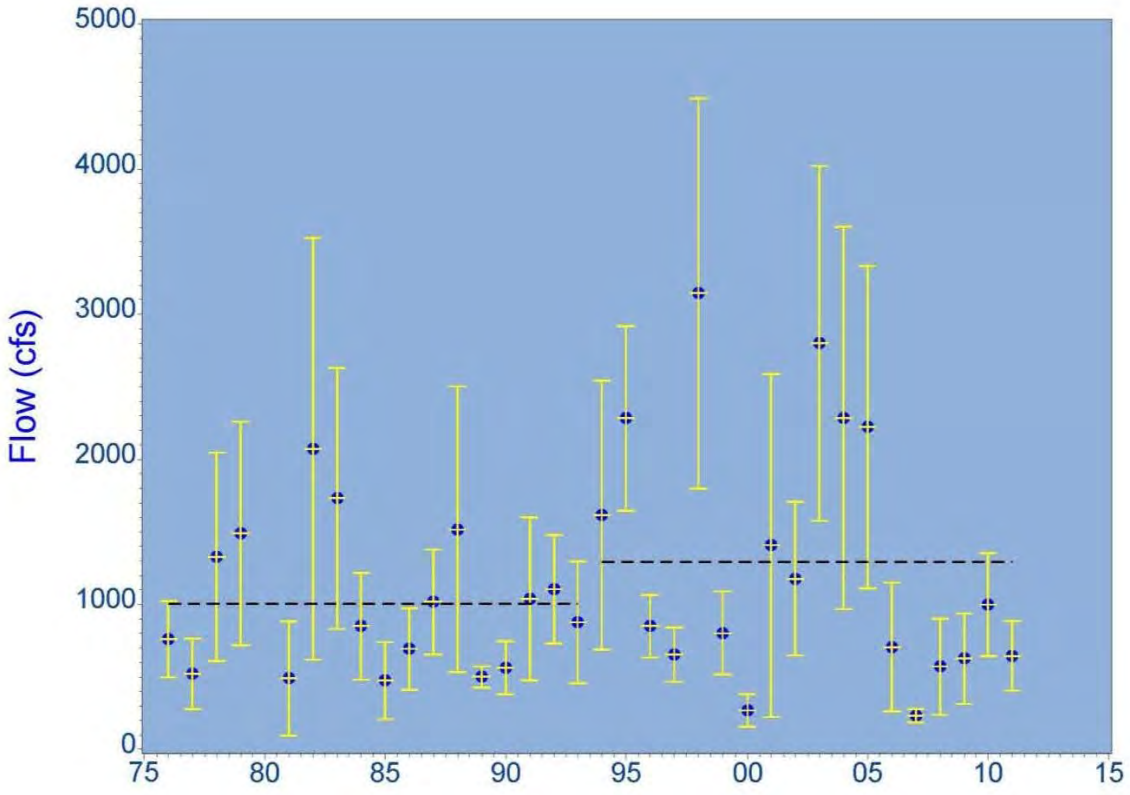


Figure 15. Average yearly values for flows above the Peace River water treatment facility (sum of the Peace at Arcadia, Horse Creek and Joshua Creek gages) for 1975-2011. Dotted reference lines are shown for averages flows calculated for the 1975-1993 and 1994-2011 periods.

This inter-annual pattern of variations in flow is related to time series plots of salinity and other flow related variables in the lower river that are shown in selected graphics in a subsequent section of this tribute report. Though not shown in this report, it is again reiterated that rainfall and flows for the years since 2012 have been comparatively normal to wet. The average flow for these three gages for the years 2012 to 2015 was 1171 cfs, which is close to the average flow for these gages for the entire 1975-2015 period (1147 cfs). These flows will be reported in the next comprehensive report, which will be published in 2017.

Assessment of Water Supply Withdrawals on Freshwater Inflow to the Estuary

One of the goals of the HBMP is to assess the effects of permitted withdrawals on the freshwater inflows, water quality, and ecology of the Lower Peace River estuary. Accordingly, the 2013 HBMP report presented analyses that examined the increase in withdrawals over time and their relative effect on flows and ecological variables in the lower river.

Withdrawals from the Peace River have increased over time due to increases in potable water demand provided to customers first by General Development Utilities and since 1991 by the Peace River Manasota Regional Water Supply Authority (Figure 16). It is apparent that during some years (2000-2001, 2006-2008), more water supply demand is supplied to the customers than is withdrawn from the river. This is possible because the water supply authority can store river water in two offstream reservoirs (Figure 17). It also has aquifer-storage-recovery facilities, by which river water treated for potable supply is stored in the underground aquifer and later pumped to the land surface for a second treatment for water supply use.

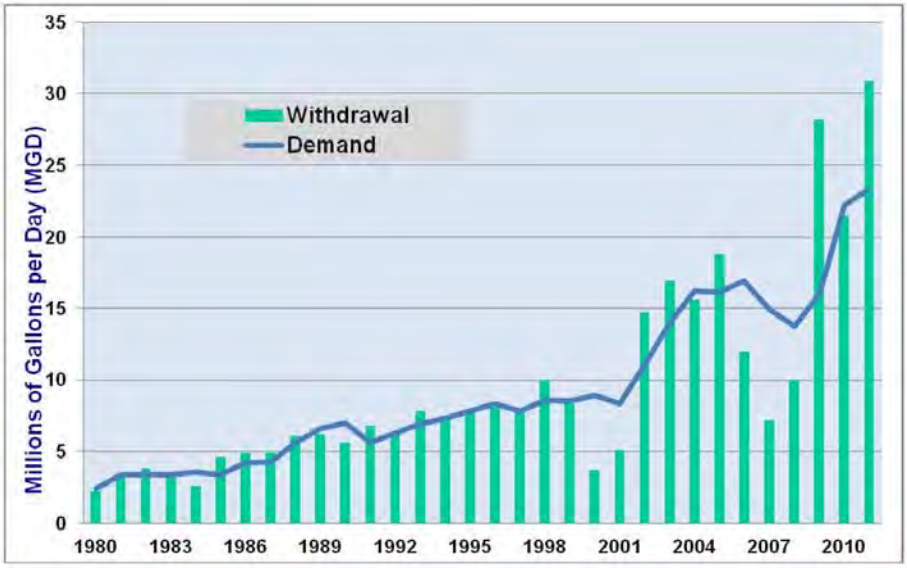


Figure 16. Annual average potable water supply demands and diversions from the Peace River by the Peace River Manasota Regional Water Supply Authority, 1980 - 201

Figure 17. The Peace River water treatment facility, showing the previous (smaller with island) and newer offstream reservoirs and the river intake.

The withdrawal schedule for the water treatment facility has been modified over the years to better mimic the natural variations of flow in the Peace River and to also allow greater withdrawals. Prior to 1988, the maximum daily limit for withdrawals from the Peace River was 22 million gallons per day, equal to 34 cfs. Quantities above this amount could be withdrawn as long as flows at the Arcadia gage were above monthly low-flow cutoffs, which varied from 100 cfs in April and May to 664 cfs in September. Under this schedule, withdrawals could reduce inflow by as much as 24% on some days during the spring.

In 1988, upon the recommendation of the lead consulting scientist (Dr. Thomas Fraser) for General Development Utilities, the District modified the water use permit so that withdrawals from the Peace River could not exceed 10% of the previous day's flow at the Peace River at Arcadia gage. This important step was the first application of a percent-of- flow method for regulating withdrawals from rivers in southwest Florida. Since then, based on studies of many other rivers, the percent-of-flow method has become the SWFWMD's standard method for regulating withdrawals from unimpounded rivers. As part of this approach, the low flow cutoff for withdrawals from the Peace River was set to 130 cfs year-round. This provided more water supply in wet season, but provided much greater protection for the river in the spring dry season, when nursery utilization of the lower river by the early live stages of estuarine dependent fishes is greatest. However, during the severity of the drought of 2006-2011, the SWFWMD issued a series of executive orders to allow for temporary modifications of the permit to allow for short-term demands.

In 2009, the PRMRWSA completed construction of a new 6 billion gallon offstream reservoir to complement their existing, much smaller offstream reservoir (Figure 17). They also expanded their maximum withdrawal capacity to 120 mgd (186 cfs), but withdrawals still had to comply with regulatory limits. In 2010, the District adopted a minimum flow rule for the Lower Peace River that based percentage withdrawals on the sum of the Peace at Arcadia, Horse Creek and Joshua Creek gages. That minimum flow rule kept the 130 cfs low-flow cutoff based on the combined flow of these three gages. The rule also allowed different withdrawal percentages to be taken during three seasonal blocks, which were 16% in Block 1 from April 20 to June 25, 38% in Block 3 from June 26 to October 26, and 29% in Block 2 from October 27 to April 19. However, flows had to remain at the Block 1 percentage (16%) in Blocks 2 and 3 if the combined flows from the three gages are below 625 cfs.

In 2011, a revised withdrawal schedule that was close to the District minimum flow rule was granted to the PRMRWSA which allowed the withdrawal of 16% of the combined flow from the three gages in Block 1 and 28% withdrawals in Blocks 2 and 3, if flows are above 625 cfs. The changes in the withdrawal schedule have affected how much water can be taken from the Peace River at various rates of flow. Figure 18 shows the percentage of flow withdrawn based on the total gaged flows above the water treatment plant (Peace-Arcadia, plus Horse and Joshua Creeks). The data are divided into three different time periods based on the timing of changes in infrastructure at the water treatment facility.

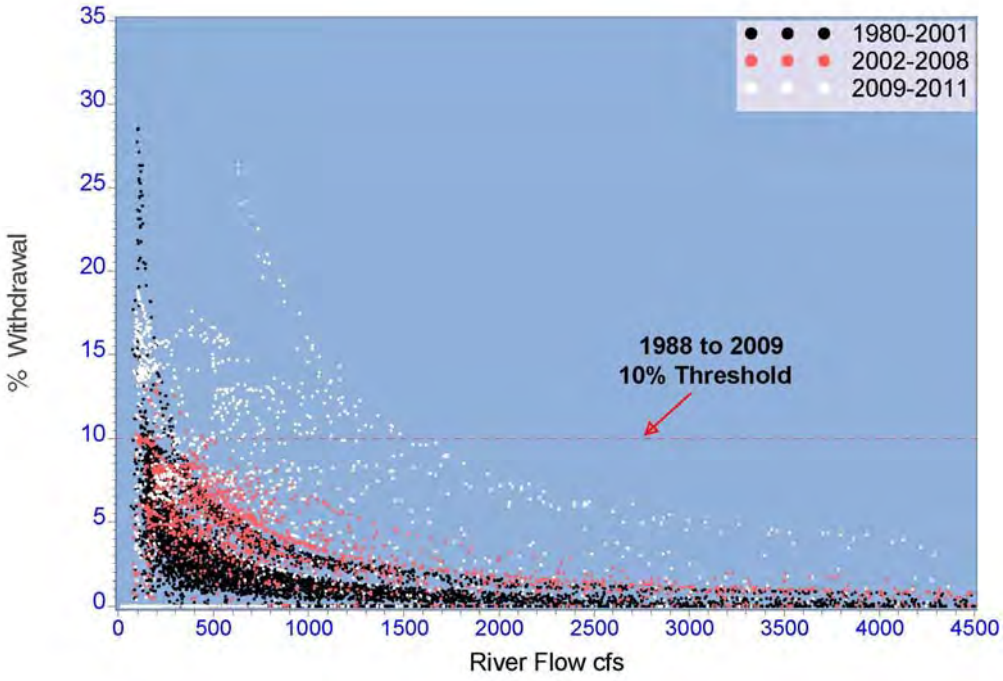


Figure 18. Daily values for percentage of gaged flow above the water treatment plant (sum of Peace at Arcadia, Horse and Joshua Creek gages) comprised by withdrawals by the PRMRWSA versus same-day summed flow at those gages.

The highest withdrawal percentages during low flows in the river (< 200 cfs) occurred in the early 1980-2001 period, which included the time when withdrawals were not regulated using the percent-of-flow method. Withdrawals percentages during this earlier during this early period were typically low at higher flows, simply because the water demands were relatively low (< 10 mgd) up until 2001 (Figure 16 on page 44). The implementation of the 10% withdrawal limit largely kept percentage withdrawals below that threshold from 2002-2008. Higher withdrawal percentages are shown for the 2009-2011 period, which includes when the seasonally based percent withdrawal limits were implemented, which range from 16 to 28% based on the season and rate of flow.

Withdrawal percentages above the regulatory threshold in effect at the time may appear for some infrequent days because the data in Figure 18 were based on final published flow values by the USGS. For the management of withdrawals on a daily basis, operators of the water treatment facility check the provisional flow values available on the USGS water resources web site. For some days, the final values published for one or more of the gages may differ slightly from the real time provisional values due to a shift that has been applied by the USGS to the streamflow rating curve before the flow data are finalized. It is believed that these minor revisions in flows are well below the limits that would result in flow related impacts to the Lower Peace River estuary. The modeling of the impacts of withdrawals on the salinity regime of the estuary is discussed in a following sub-section of this report.

Status and Trends of Water Quality and Chlorophyll *a* in the Estuary

One of the most informative and valuable elements of the HBMP is the long-term monitoring of a series of water quality variables in the Lower Peace River and Upper Charlotte Harbor. This includes both vertical profiles of *in situ* parameters such as salinity, temperature and dissolved oxygen concentrations and laboratory analyses of water chemistry parameters such as nutrients, color, and chlorophyll *a*. This data collection program allows for not only the assessment of long-term trends, but also provides important information on seasonal cycles and interactions of freshwater inflow with the physical and water quality characteristics of the estuary.

Water quality has been monitored in the lower river and upper harbor on a monthly basis under two data collection designs, with data going back decades for each. Water quality sampling began at a series of ten fixed location stations in the lower river in 1976 (see Table 8 on page 42). Data collection at these stations continued until 1989, when they were eliminated from the data collection program. However, when the HBMP was revised in 1996, monthly data collection was resumed at six of these stations in the lower river and a single station in the Upper Charlotte Harbor. It was concluded that data collection at three of the stations in the middle and lower harbor could be discontinued due to their relative lack of sensitivity to changes in freshwater inflow compared to the other stations that were retained.

The other water quality data collection involves a series of four moving, salinity based stations. This program was started by Dr. Montgomery in 1983 as part of studies of primary production rates in the estuary. Each month, water quality is collected from a boat at the location of the 0, 6, 12 and 20 psu salinity values, which in the river channel can each be considered an isohaline (line of equal salinity). The locations of these isohalines can shift many miles based on the rate of freshwater inflow, with the lower salinity isohalines extending to near or above the water treatment facility during very dry periods. The higher salinity isohalines (12 and 20 psu) can extend well into Charlotte Harbor during very wet periods. Stations located within the river are collected at mid-channel locations, while stations located in the harbor are collected along a designated transect extending down the middle of the harbor.

The salinity based isohaline water quality sampling provides informative data because roughly the same ratio of fresh water and seawater is collected at each station each month. The 0 psu station is oriented to collect tidal fresh water, where there is the first occurrence of salt compared to freshwater reaches upstream. The 6 and 12 psu isohaline locations provide important information on the mesohaline zone of the river, which studies have shown to have high rates of both primary and benthic secondary production and high nursery use by juvenile fishes (Mote Marine Laboratory, 2002; Peebles, 2002; Greenwood et al., 2004; Atkins, 2015) The 20 psu sampling station provides valuable information on the polyahaline zone of the estuary (18 to 30 psu), where there is greater influence from the waters of Charlotte Harbor.

Data collection still continues on a monthly basis at both the fixed station and the moving isohaline stations, with sampling for the two programs staggered about two weeks apart. These combined programs have provided an informative data base on which to examine the status and trends of water quality in the Lower Peace River. Some key findings from these data collection programs are summarized below.

One of the most striking trends in the Lower Peace River has been a reduction in the very high concentrations of ortho-phosphorus and total phosphorus in the Peace River. A time series plots of ortho-phosphorus at the fixed station located at river kilometer 30.7 near the water treatment facility is shown in Figure 19. For many years, phosphorus concentrations were extremely high in the Peace River due to extensive phosphate mining in the upper reaches of the watershed. Changes in mining practices and the increased storage of mining process water in the early 1980s greatly reduced ortho-phosphorus concentrations in river, but they still are high (0.5 to 1.0 mg/l) compared to typical unimpacted Florida streams.

There was an upturn in phosphorus concentrations between 2004 and 2011. Other investigations of water quality in the Peace River watershed indicated these increases in concentrations were due to the discharge of waters resulting from the closing of a phosphogypsum stack system associated with the Ft. Meade phosphate mine in Whidden Creek basin, approximately 65 miles upstream of the PRMRWSA water treatment facility.

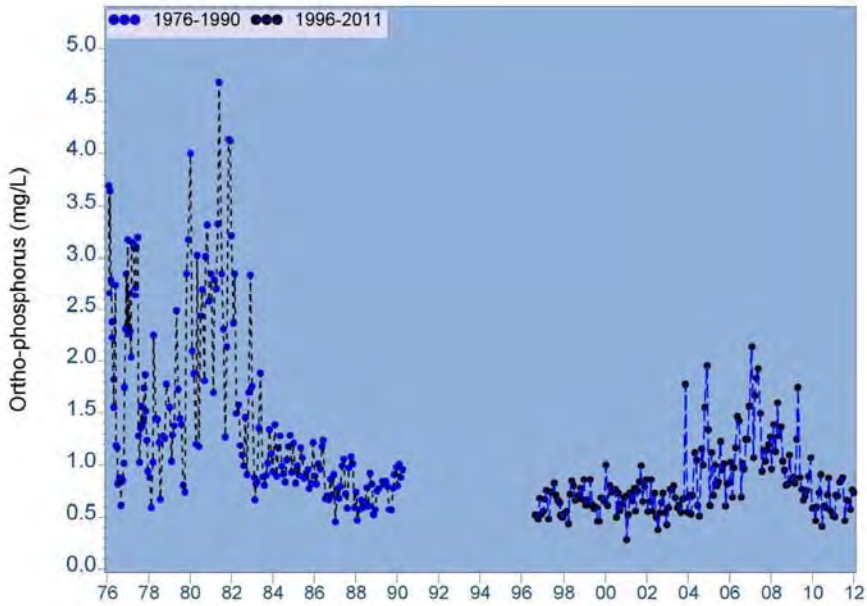


Figure 19. Monthly surface ortho-phosphorus concentrations at the fixed location station at river kilometer 30.7, 1976 - 2011

The data from the moving isohaline stations began in 1983 right after the very high phosphorus concentrations in the river declined to values near 1.0 mg/l. The data from the 0 psu moving isohaline station also show the increase in ortho-phosphorus concentratons during 2004-2010 (Figure 20), associated with operations at the Ft. Meade mine.

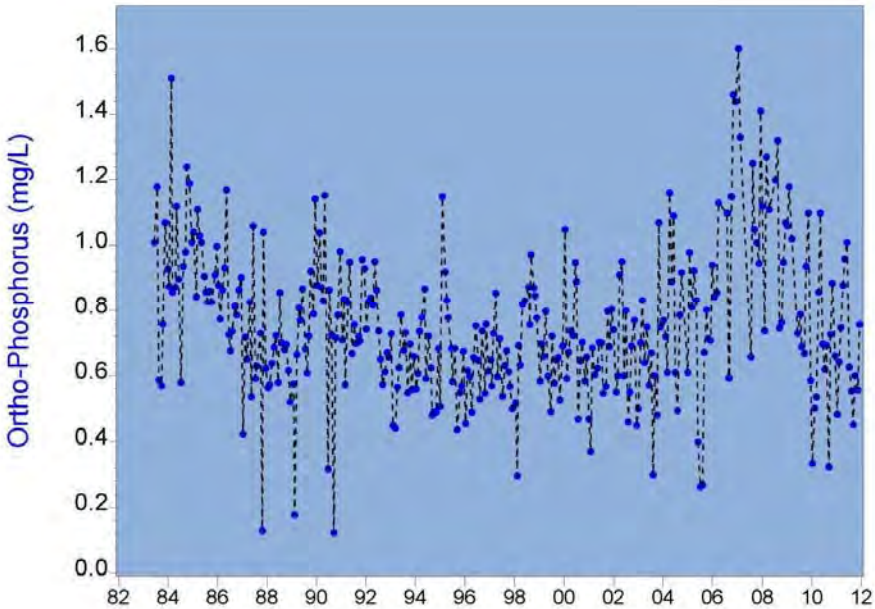


Figure 20. Monthly surface orhto-phosphorus concentrations at the location of the 0 psu isohaline, 1983 - 2011.

Dissolved silica concentrations have also shown distinct changes over time. Data from the fixed location station at river kilometer 30.7 show much higher concentrations of silica in the sampling period starting in 1996 compared to the earlier period that ended in 1990 (Figure 21). Data from the 0 psu isohaline show an increase, but beginning in 2002 (Figure 22). It was suggested in the 2013 HBMP report that increases in silica concentrations further upstream began in the 1990s, but increases at the 0 psu station were delayed due to the very dry years and low flows from 1999 though the summer of 2001.

Similar to the findings for ortho- and total phosphorus, the report suggested that human activities upstream have resulted in the increases in silica, particularly the closing of the phosphogypsum stacks associated with the Ft. Meade Mine. However, unlike with phosphorus, which began to decline in 2009, silica concentrations have remained high.

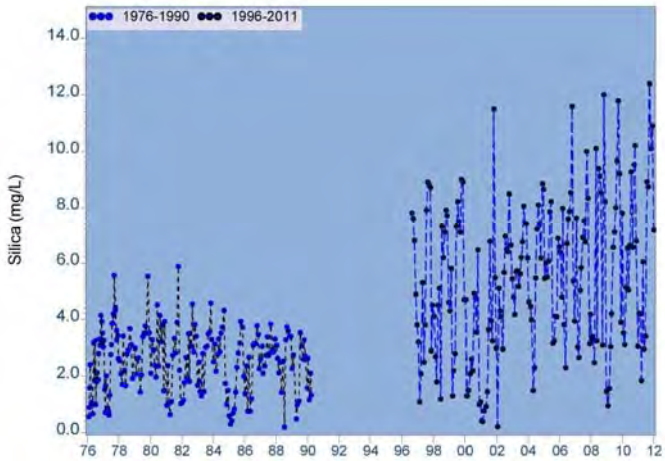


Figure 21. Monthly silica concentrations (mg/l Si) at the fixed location station at river kilometer 30.7, 1976 - 2011.

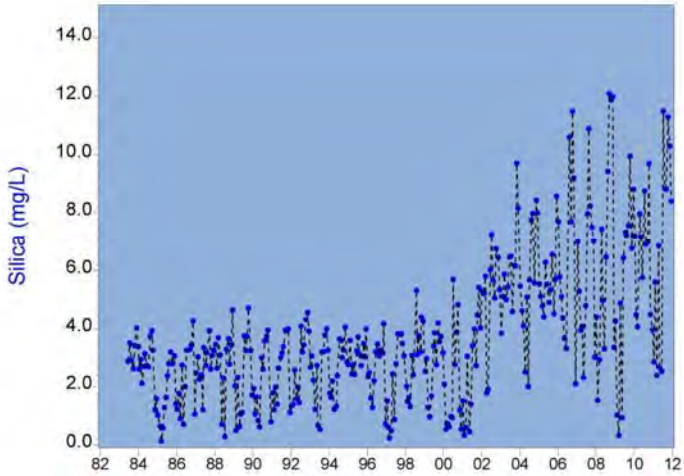


Figure 22. Monthly silica concentrations (mg/l Si) at the location of the 0 psu isohaline, 1983 - 2011.

The 2013 report presented the results of trend analyses for water quality constituents at both the fixed location and the isohaline based stations. Because the fixed location stations involved a discontinuous time periods, a statistical test was used that compared changes in concentrations between the first (1976-1989) and later (1996-2011) periods with complete sampling years. Table 9 summarizes the results of these tests where significant changes were found at the fixed location stations.

Table 9. Results of trend tests of water quality parameters at fixed location stations in the Lower Peace River and Upper Charlotte Harbor (kilometer -2.3 is in the harbor)

Trend Tests Peace River HBMP Estuary Sites Water Quality (1976-1989 and 1996-2011)

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	▼	▼	▼	▼	▼
Silica	▲	▲	▲	▲	▲
Chlorophyll *a*					

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

As shown graphically, there has been a significant decline in phosphorus and a significant increase in silica concentrations at all five of the fixed location stations. Significant increases in surface or bottom salinity were observed at all five of the stations, largely due to predominantly low freshwater inflow during dry years from 2006 to 2011. Color increased at the two most downstream stations. Significant decreases were found for nitrite + nitrate nitrogen and total Kjeldahl nitrogen, which indicates that nutrient over-enrichment has not been a growing issue, for as will be described in Section 3.6 of this report, nitrogen is usually the limiting nutrient in the estuary. There were no trends for chlorophyll *a*, which supports the finding that this region of the estuary has not experienced significant increases in phytoplankton abundance due to increased nutrient enrichment. Bottom dissolved oxygen concentrations decreased at the station at kilometer 15.5.

The report also investigated trends at the moving, salinity based isohaline stations. Because these stations move in the estuary, their recorded locations provide useful information on changes in the salinity regime of the estuary and the distribution of different salinity zones (e.g., tidal freshwater, oligohaline and mesohaline). Figure 23 shows both large seasonal and inter-annual variations in the location of the 6 psu isohaline station, occasionally extending into the harbor (< 0.0 kilometers) during very wet periods and to within one or two kilometers of the water treatment facility near kilometer 30 during very dry periods

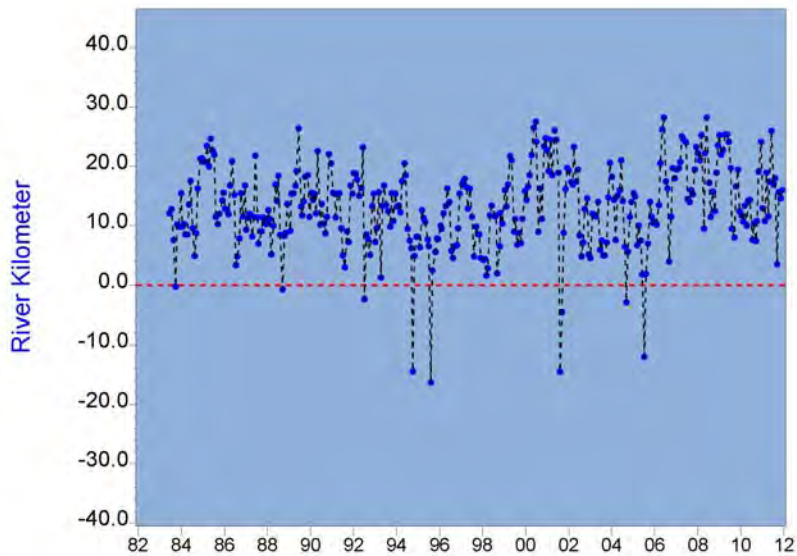


Figure 23. Monthly location of the 6 psu isohaline in the Lower Peace River and Upper Charlotte Harbor, 1983 - 2011.

Trend analyses were also performed on water quality constituents at the isohaline stations. A summary of the significant trend tests at the isohaline stations is presented in Table 10. In some cases (e.g, silica), these trend agreed with the trends observed for the fixed location stations, but in many cases they did not. This disagreement in results was probably due in large part to the different periods of record for the two data sets. Also, different statistical tests were used. Because there was a data gap in the fixed location data, two time periods (1976-1989 and 1996-2011) were compared, rather than a continuous time series as with the isohaline stations. Finally, because the isohalines move with changes in freshwater flow and tides, the geographic areas covered by any moving stations are not directly comparable to a fixed location in the estuary, although some general patterns emerge.

Table 10. Summary of significant trend tests of surface water quality parameters at four isohaline based stations (monthly monitoring, 1984-2011)

Summary of Trend Tests of Surface Water Quality Parameters
HBMP Moving Isohaline-Based Monthly Monitoring (1984-2011)

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

* Red ▲ denotes significance at the 005 level
* Blue ▲ denotes significance at the 0.10 level

An example of inter-annual variation in water quality at one of the isohaline stations is shown in Figure 24, where yearly means and ranges of monthly values for nitrate + nitrite nitrogen concentrations are shown for the 6 psu isohaline station. Similar to the results for the fixed locations stations (Table 9), these results indicate there have been reductions in nitrate-nitrite concentrations in the upper reaches of the estuary. Because these inorganic nitrogen forms are readily taken up by phytoplankton, these reductions may in part be due to changes in freshwater inflow and corresponding lower nutrient loading in dry years.

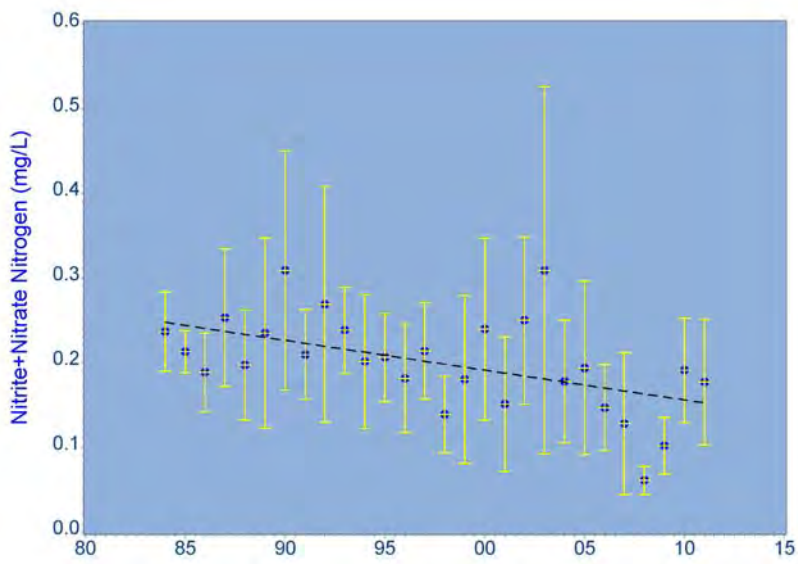


Figure 24. Annual monthly surface nitrate/nitrite nitrogen concentrations at the 6 psu isohaline station, 1984 - 2011.

Relationships of Water Quality with Freshwater Inflow

Because a principal goal of the HBMP is to monitor the potential effects of the withdrawals of fresh water flowing to the Lower Peace River estuary, one emphasis of the HBMP is to examine relationships of freshwater flow with water quality variables in the estuary. Using this approach, relationships between freshwater inflow rates and various water quality constituents were examined for both the fixed location and isohaline based water quality stations. Relationships with freshwater inflow were examined graphically and with correlation analysis to examine possible interactions among factors (e.g., water temperature and dissolved oxygen concentrations). The response of water quality to flow was examined over the entire flow range of the river and separately within different flow ranges.

Examples of the response of two variables to freshwater inflow are shown for the fixed location station at river kilometer 6.6. Dissolved organic color concentrations increase with flow (Figure 25), as increased runoff flushes humic materials and other organic compounds (e.g., tannic acid) from soils and decaying vegetation in the watershed.

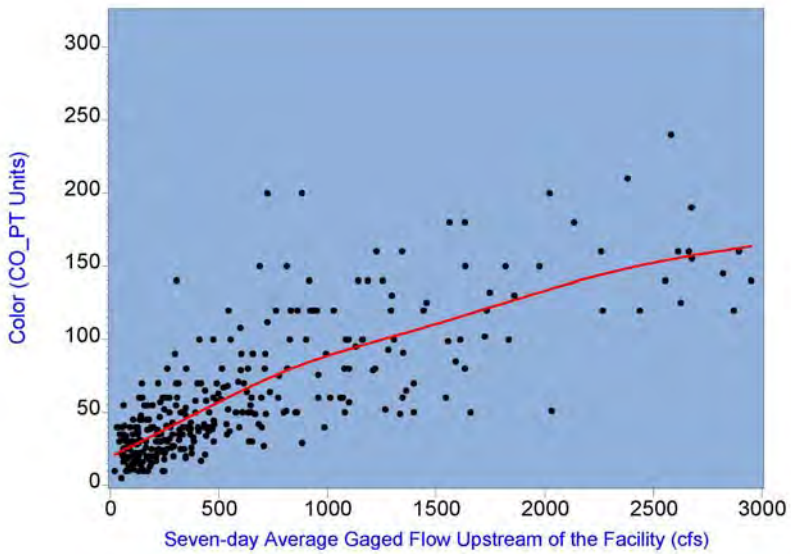


Figure 25. Color concentrations for surface waters at river kilometer 6.6 versus the seven-day average gaged flow upstream of the water treatment facility.

Conversely, bottom dissolved oxygen concentrations at this location tend to decrease with rising freshwater inflow, with hypoxic (low oxygen concentrations) becoming common at flow rates above 800 cfs (Figure 26). This relationship is due to density stratification of the water column that occurs at high flows when lower salinity water tends to layer over higher salinity water, reducing vertical circulation and inhibiting the exchange of oxygen between the atmosphere and bottom waters. High flows often occur in the late summer when water temperatures are high, which also contributes to low dissolved oxygen concentrations. These graphics are shown only as examples and the 2013 HBMP report should be consulted for a thorough assessment of relationships of freshwater inflow and water quality in the Lower Peace River / Upper Charlotte Harbor estuary.

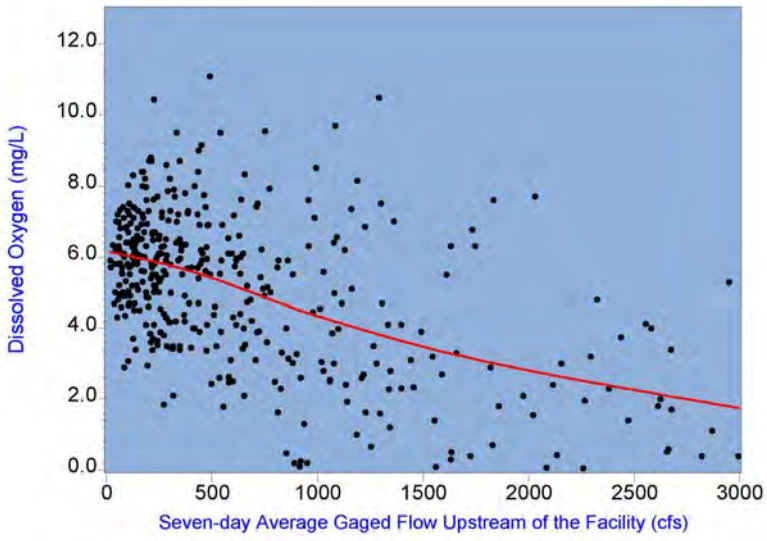


Figure 26. Bottom dissolved oxygen concentrations at river kilometer 6.6 versus the seven-day average flow upstream of the water treatment facility.

Water Quality at Upstream Sites in the Peace River Watershed

In addition to data collected in the Lower Peace River by the HBMP, the 2013 report also provided analyses and an overview of historical changes in water quality at a number of upstream freshwater sites on the channel of the Peace River and several major tributaries. Data for these analyses were obtained from various sources (e.g, USGS, SWFWMD and Florida Department of Environmental Protection). The results presented in the 2013 report built upon the work that Dr. Montgomery did for the 2007 Peace River Cumulative Impact Study, which is summarized in Section 3. 3 of this report.

Factors that have contributed to changes in water quality at upstream freshwater sites are described in the 2013 report. Time series graphs for two variables that have shown trends over time are shown as examples below. Based on data going back to 1960, fluoride concentrations at the Peace River at Arcadia gage in the last twenty years (since 1995) are generally lower and less variable than in earlier decades, particularly in the 1960s (Figure 27). These reductions in fluoride are due to changes in operations techniques by the phosphate industry in the upper reaches of the Peace River watershed, which have resulted in a reduction in the discharge of high fluoride water from mined lands.

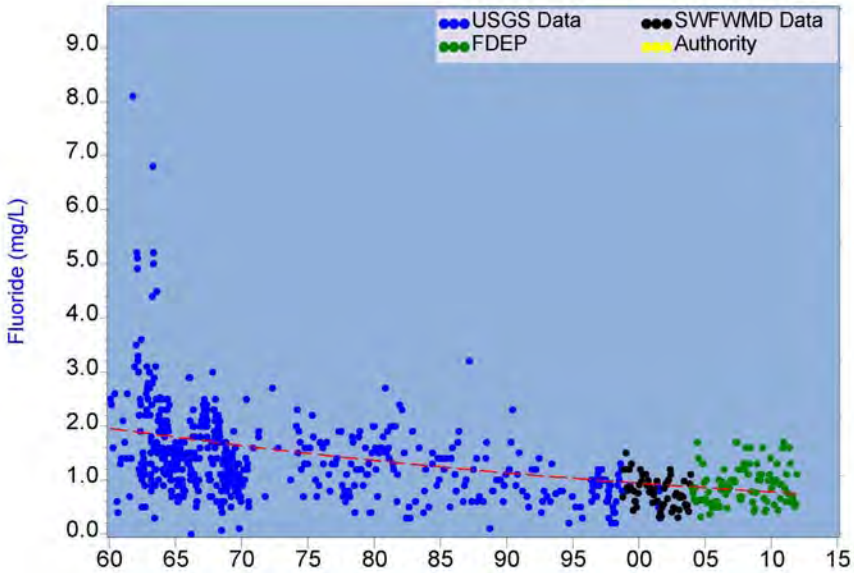


Figure 27. Fluoride concentrations at the Peace River at Arcadia gage, 1960 - 2011.

A time series graph of specific conductance at Joshua Creek in the southern portion of the Peace River watershed is shown in Figure 28. As has been observed in some other tributaries in the southern part of the Peace River watershed, specific conductance values have increased, due in part to agricultural irrigation water entering the stream, which as previously discussed, has also resulted in increased baseflow in Joshua Creek.

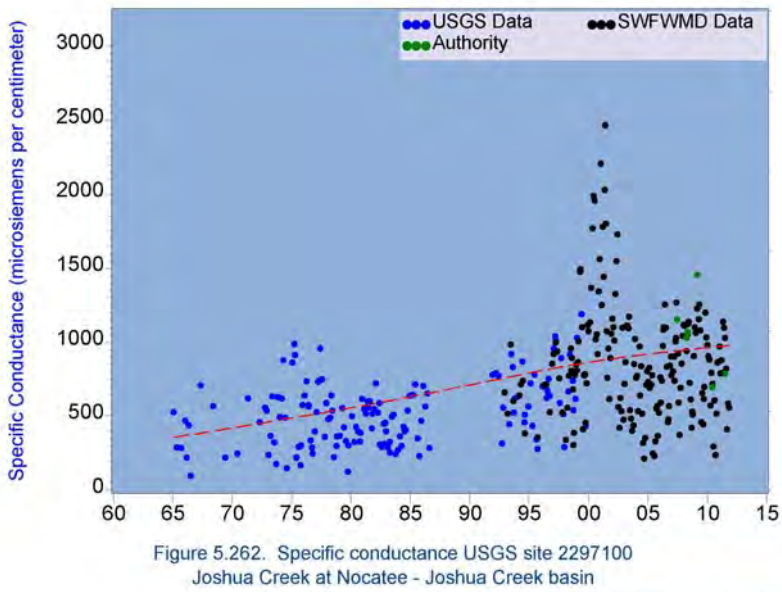


Figure 28. Time series of specific conductance values at the Joshua Creek at Nocatee gage, 1965 - 2011.

Readers should consult the 2013 HBMP report and the 2007 Peace River Cumulative Impact Study for a thorough assessment of historic changes in water quality in the Peace River watershed. Combined with the analyses of data from the lower river and the reviews of the technical literature that are provided in the report, the 2013 HBMP report provides a comprehensive analysis of the effects of human alterations on flows and water quality in the Peace River watershed and its relationships with the hydrobiology of the Lower Peace River / Upper Charlotte Harbor estuary.

Salinity / Flow Relationships and Assessment of the Effects of Withdrawals

A key factor that is assessed as part of the HBMP is the effects of freshwater withdrawals on the salinity regime of the Lower Peace River estuary. The Southwest Florida Water Management District had developed a linked two dimensional / three dimensional hydrodynamic model of the Charlotte Harbor, including the Lower Peace River. However, there is a technical rationale for using the extensive long-term data collected for the HBMP to develop empirical salinity models to independently evaluate the effects of freshwater withdrawals on the salinity regime of the estuary.

Dr. Montgomery was involved in developing two types of empirical salinity models for the HBMP: 1) regression models to predict salinity at a series of continuous recorders located throughout the Lower Peace River and 2) regression models to predict the movement of the four monitored isohalines. These models were then applied to the record of freshwater inflow and withdrawals to predict the relative change in salinity due to withdrawals.

A total of eleven continuous salinity recorders have now been distributed along the length of the Lower Peace River. Three of these recorders are operated by the USGS as part of the HBMP. Eight other recorders have been funded by the Peace River Manasota Regional Water Supply Authority. These recorders were installed and operated by Atkins, Inc. under Dr. Montgomery's supervision to increase the spatial coverage of the recorder network. Tide stage (water levels), water temperature and specific conductance are measured at 15 minute intervals at the USGS recorders with tide stage not recorded at the other sites. At all recorders, salinity values are mathematically calculated from specific conductance data.

Average hourly values for salinity at the recorder at river kilometer 15.5 are plotted vs. freshwater inflow in Figure 29. There is a clear relationship with higher flows resulting in lower salinity, typically reaching freshwater conditions at very high flows (> 2000 cfs). At lower rates of flow, there is a wide variation in salinity due to the effects of tides, winds, and differences in antecedent freshwater inflow.

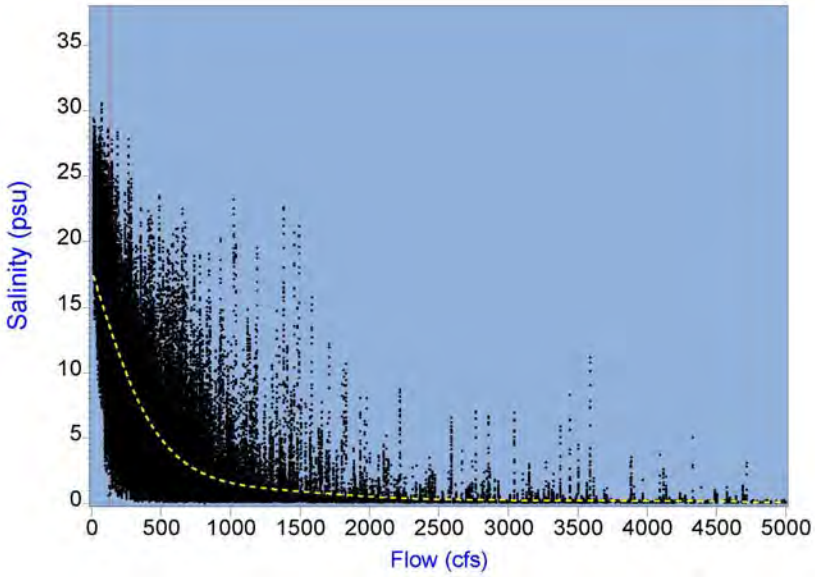


Figure 29. Average hourly surface salinity values at the recorder at river kilometer 15.5 versus same-day freshwater flow upstream of the treatment facility.

Dr. Montgomery developed regression models to predict average hourly salinity values at the continuous recorders as a function of freshwater inflow rate and water levels at the nearest USGS recorder, with variations water levels primarily due to tides. These models were then used to predict salinity in one-hour intervals, which for some analyses were used to generate average daily salinity values. A time series plot of predicted and observed average daily salinity values at the recorder at river kilometer 15.5 during 2011 is shown in Figure 30.

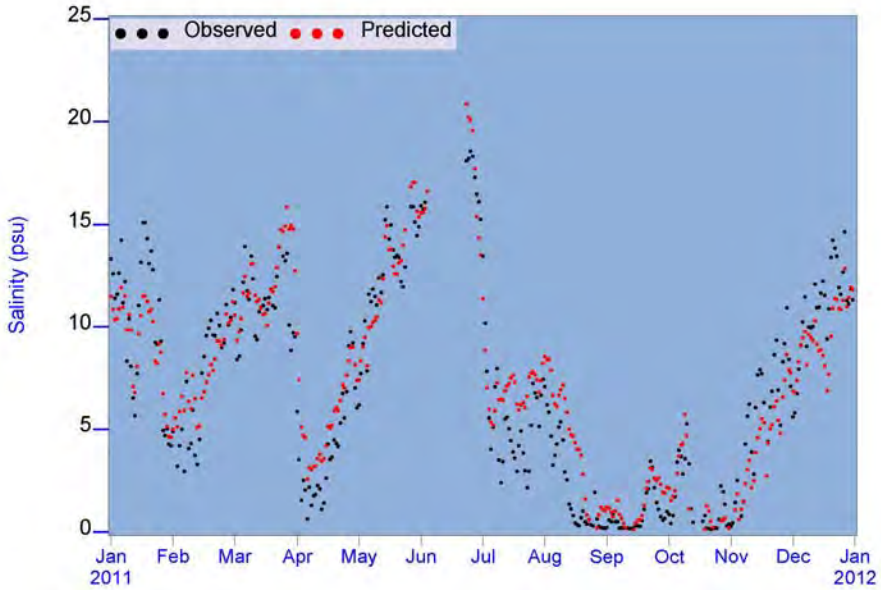


Figure 30. Predicted and observed average daily values for surface salinity at the recorder at river kilometer 15.5 for 2011.

These regression models were then used to evaluate the relative effect of withdrawals at the water treatment facility on salinity at the locations of the recorders. As an example, daily values of salinity and the change in salinity due to freshwater withdrawals are shown in Figure 31. There was no effect of withdrawals on very high salinity values, because withdrawals are prohibited when flows are below the 130 cfs low flow cutoff. The greatest changes in salinity, generally in the range of 1 psu, occurred when salinity at the recorder was in the range of 3 to 10 psu, which at this location corresponds to higher flows when greater amounts of water are being withdrawn.

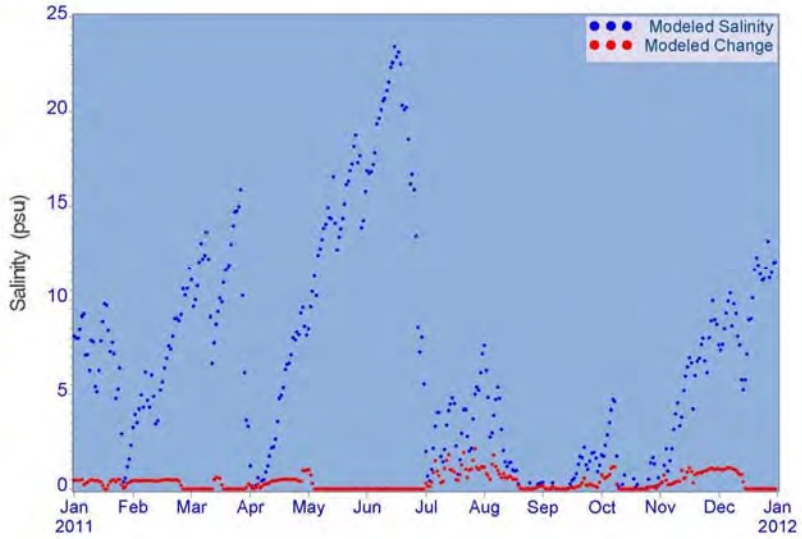


Figure 31. Predicted values for average daily changes in salinity due to withdrawals vs. average daily salinity at river kilometer 15.5 for the year 2011.

The 2013 report also presented regression models to predict the locations of the each of the four isohaline based water quality stations in the Lower Peace River. With nearly thirty years of monthly data collection, the isohaline data provide a robust data base to examine the movement of biologically important salinity zones in the estuary. The relationship of isohaline movement to freshwater inflow is typically nonlinear, as a given amount of flow reduction (e.g., 100 cfs) causes a greater upstream movement of an isohaline than at high flows (Figure 32). This is due to changes in the cross-sectional area of the estuary. Because the upper reaches of the tidal river are generally narrower, cross sectional area and volume decrease upstream, resulting in a greater sensitivity to isohaline movement in the river channel at low flow. The dotted line in Figure 32 was fitted by the graphical software and is not the line of predicted values in the regression developed for the flow assessment.

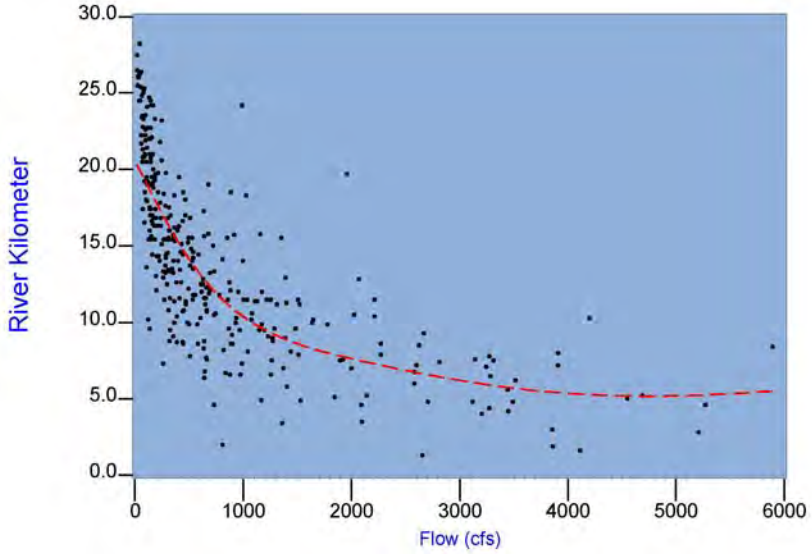


Figure 32. The location of the 6 psu isohaline versus the rate of freshwater inflow above the water treatment facility. The dotted line was fitted by graphical software and does not represent the regression that was fitted to these data.

Using these regressions, Dr. Montgomery simulated the effect of withdrawals from the river on the locations of the four monitored isohalines. Using 2011 as an example, the greatest seasonal movement of the isohalines typically occur in the summer (Figure 33), when flows are the highest and more water is withdrawn using the percent-of-flow based withdrawal schedule. The ecological significance of these changes has to be compared to the natural seasonal movement of these isohalines, which typically shift 10 to 20 kilometers within a year due to seasonal changes in freshwater inflow (see Figure 23 on page 52).

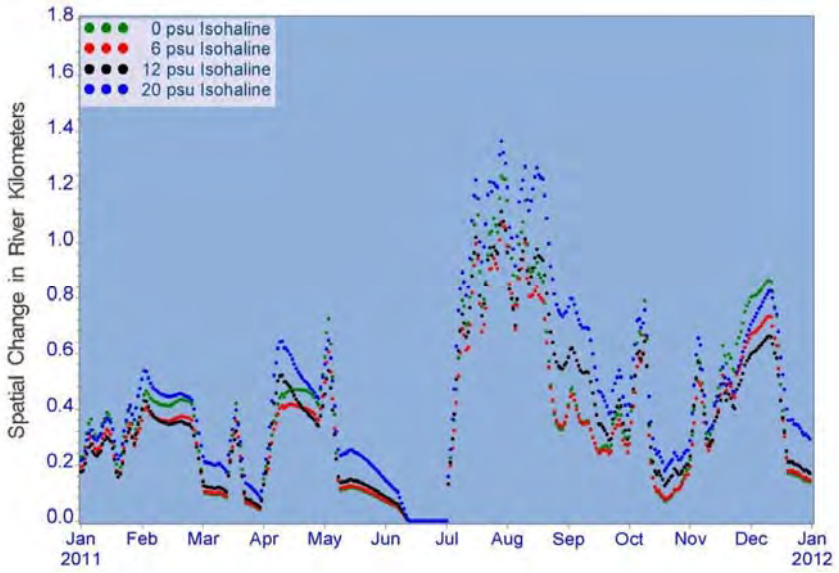


Figure 33. Daily modeled changes in the location of the four monitored isohalines due to withdrawals at the water treatment facility.

Protocol for Assessing Significant Adverse Change

The 2013 report presents a discussion of how detected changes in the Lower Peace River estuary can be assessed in relation to the effects of freshwater withdrawals. The goal of such assessments would be to take regulatory action to alleviate adverse impacts if they are found, or are expected, to occur.

As a general template for these analyses, the report quotes the SFWFMD Basis of Review for Water Use Permit that contains three performance standards that state:

- 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 deviate 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 of aesthetic qualities of the water resource are adversely impacted

With regard to the water use permit for Peace River withdrawals, the SWFWMD has established the primary resources and processes that are to be protected, which are:

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 of sport and commercial importance in the lower Peace River

5. Protect the seasonal patterns of nutrient delivery to the estuary so that trophic interactions are maintained in Lower Peace River and Goals 1 though 4 are met

6. Protect the seasonal patterns of organic matter delivery to the estuary so that trophic interactions are maintained in Lower Peace River and Goals 1 though 4 are met

7. Protect the temporal and spatial characteristics of salinity distributions in the estuary so that Goals 1 though 4 are met

8. Protect dissolved oxygen concentrations in the estuary so that Goals 1 though 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

The 2013 report suggests that it is inherent in the SWFWMD's approach that the effects of surface water withdrawals are linked to changes in salinity, with associated changes in water quality and ultimately biological communities. The effects of freshwater withdrawals on salinity are direct and fairly quick to respond, while the effect of withdrawals on water quality constituents, and especially biological communities, are more indirect and complex. Such indirect impacts are mediated by physical and chemical processes and are typically manifested on slower time scales compared to salinity.

Upon the recommendation of the scientific review panel, a conceptual model was developed to characterize the relationships of freshwater inflow with the estuary, and therefore, potential pathways by which withdrawals of fresh water could affect the estuary. A diagram generally depicting that conceptual model is presented in Figure 34.

Given the resource management goals of the HBMP and the complexity of the role of freshwater inflow to the estuary, the 2013 report proposed a protocol for identifying significant environmental changes in the evaluation of the effects of freshwater withdrawals on the resources of the Lower Peace / Upper Charlotte Harbor estuary. The proposed protocol introduced the definition of significant environmental change that is listed on the next page.

"A detected change, supported by statistical inference or 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 of freshwater inflows caused by permitted surface water withdrawals".

This definition was revised slightly from a previously proposed definition to include not only differences from the pre-withdrawal condition (before 1980), but to also incorporate comparisons between one or more recent periods and conditions under differing permitted withdrawal schedules.

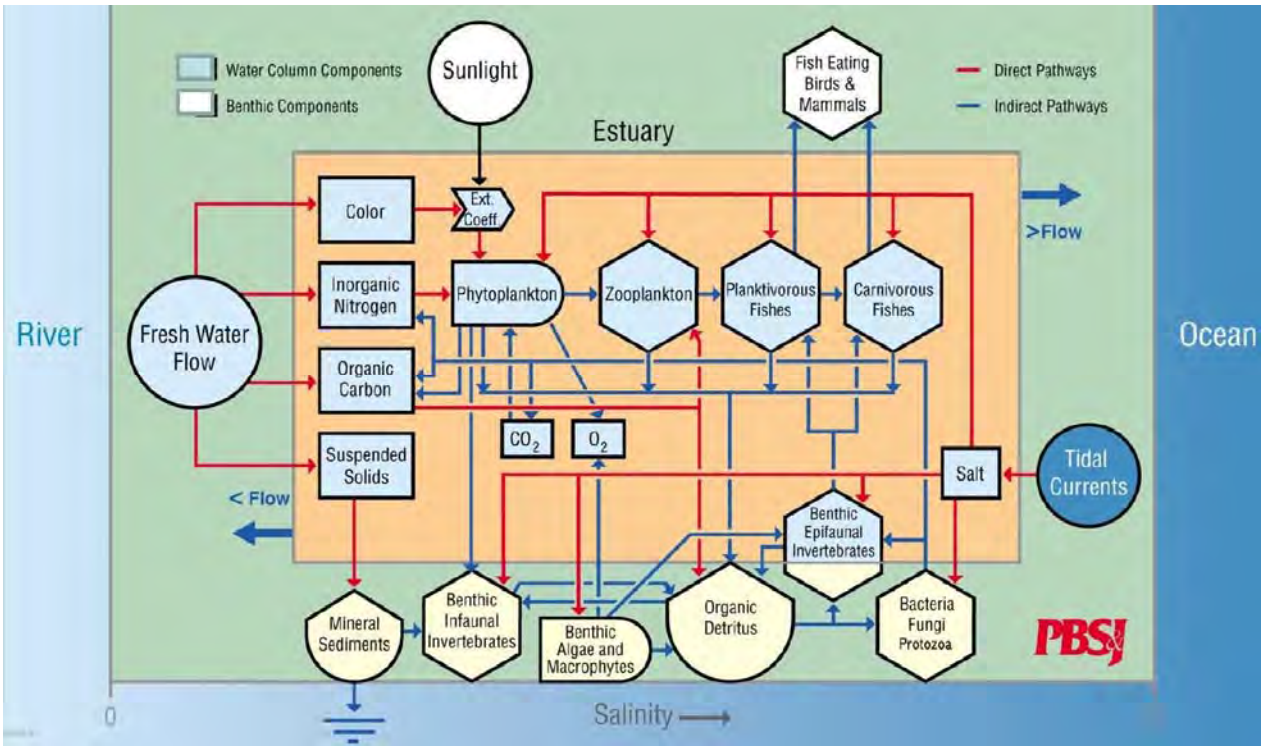


Figure 34. Conceptual model of the effects and interactions of freshwater inflow with the Lower Peace River estuarine system.

The 2013 report also described a management response plan to potential observed significant environmental change. The report suggested this is a proactive approach that could be applied to protect the resources of concern in the Lower Peace River estuary if evidence indicates that adverse impacts are expected to occur. The plan recommended that salinity deviations be used as the primary indicator of significant environmental change. Salinity deviations would be evaluated in terms of magnitude, spatial extent, and/or temporal duration to develop a decision tree that is linked to various management actions. Using this approach, the intensity and urgency of the management response would be appropriately linked to the degree of the observed salinity deviation.

The initial management actions should focus on determining if the observed deviation is real and not a measurement error or an artifact of the sampling design. If the change is real, the next series of management actions focus on better understanding and describing the change and

determining potential cause and effect relationships. Finally, the most intense management actions may involve regulatory enforcement actions, as well as remediation and mitigation. As part of this process, the report suggested the following hierarchy of management actions.

1. Data QA/AC audit
2. Data comparison (correlates)
3. Scientific review panel meeting
4. Redirected sampling effort
5. Determination of significant environmental change
6. Regulatory summit meeting
7. District governing board meeting
8. Remediation

It is emphasized that each of these steps would be done with technical review to ensure that any changes are real and are related to reductions of freshwater inflow, with the relative effect of permitted withdrawals determined and quantified. Since decisions involving changes or trends in data include levels of statistical confidence, the 2013 report presented a table that was proposed as a conceptual decision matrix for determining appropriate management response to a detected hydrobiological change (Table 11).

Table 11. Conceptual decision matrix for determining an appropriate management response to detected hydrobiological change

Probability of Type 1 Error Alpha	**Magnitude of Detected Hydrobiological Change**		
	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
1.05	Redirected sampling	Determination of significant change	Regulatory Summit Meeting

Although this protocol has not yet been formally accepted as part of the HBMP, the 2013 report concluded that analyses conducted to date have indicated the permitted withdrawals up to the year 2011 have not caused any significant environmental change, which was a position that the scientific review panel and the SWFWMD agreed.

Monitoring Design and Modifications to the Long-Term HBMP Components

The final chapter of the 2013 comprehensive interpretive report presented a discussion of the overall effectiveness that past and current HBMP components have had for assessing the relative magnitude of any impacts that freshwater withdrawals have had, or potentially may have, to the estuarine resources of the Lower Peace River/ Upper Charlotte Harbor estuary. In that regard, potential modifications to the HBMP were assessed.

The topics covered in the chapter included the following:

- An overview of the HBMP monitoring objectives
- A review of HBMP design criteria
- Criteria for determining indicators of environmental change
- An overview of previous HBMP elements
- A summary of current HBMP study elements
- Recommended reduction/elimination or enhancement of HBMP study elements to address specific suggestions of the scientific review panel

It is beyond the scope of this tribute report to Dr. Montgomery to summarize all these topics. However, a brief discussion of some the major points from this chapter is presented below. As with other topics regarding the Peace River HBMP, readers should consult the 2013 comprehensive HBMP report.

HBMP Monitoring Objectives

The report identified both a primary and a secondary objective of the HBMP. The primary, overall goal of the HBMP is to provide both the SWFWMD and the PRMRWSA with sufficient information to determine whether the water quality characteristics (including salinity) and biological communities of the Lower Peace River / Upper Charlotte Harbor estuary have been, are being, or may be significantly adversely impacted by permitted freshwater withdrawals by the PRMRWSA. The 2013 report listed six specific components of this primary objective, which are summarized below.

- Monitor withdrawals by the water treatment facility, gaged freshwater flow to the estuary, and direct rainfall input to the Lower Peace River
- Evaluate relationships between the ecology of the Lower Peace Rive / Upper Charlotte Harbor estuary and freshwater inflow

- Monitor selected water quality and biological variables in order to determine whether the ecological characteristics of the estuary that are related to freshwater inflow 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 estuary

- Evaluate whether freshwater withdrawals significantly contribute to any adverse ecological impacts to the estuary resulting from prolonged periods of low freshwater inflow

- Evaluate whether freshwater 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

A secondary objective of the HBMP has been to develop an ongoing base of ecological information sufficient to provide the District and other interested parties 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. This objective has particular relevance to the Peace River HBMP, where water quality data at a series of fixed and moving stations go back decades, providing one of the most extensive long-term water quality data bases for an estuary in Florida.

HBMP Design Criteria

In order to meet these goals and objectives, the 2013 report recommended the design of the HBMP should incorporate the following criteria, which are summarized below.

- Identify those appropriate physical, chemical and biological indicators, and specific mechanisms that are potentially subject to significant change due to freshwater withdrawals

- The HBMP should determine and focus it efforts in those geographical regions of the estuary where naturally occurring and facility induced changes in freshwater inflow would be expected to result in the greatest potential observed changes in indentified key estuarine characteristics

- The HBMP should include sufficient spatial and temporal intensity to assure detection of measurable changes in selected physical/chemical/biological parameters resulting from changes in freshwater inflow

Indicators of Environmental Change

The 2013 report identified three levels of monitoring parameters relative to their degree of overall importance; 1) those critical to the overall success of the monitoring program, 2) those that would provide desirable additional information, and 3) indicators that may have some potential future application.

The report states that a cost-effective HBMP needs to incorporate key critical indicators that exhibit specific and robust direct or indirect quantifiable relationships with changes in freshwater inflow. These would serve as the critical indicators for the HBMP. The report suggested that desirable indicators could include lower trophic level biological indicators that provide insight into the overall health of the estuary or provide insight to longer-term patterns. The potential indicators should be limited to parameters that can be measured quickly with minimum additional effort or cost, but may provide some further insight. The report identified the twelve factors below that could be evaluated to determine in which category a potential indicator would apply.

- New Information - provides specific 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

Previous HBMP Study Components

The 2013 report listed all the ongoing and previous study components that have been part of the HBMP since 1976. Some of these components involved continuing multi-year data collection, whereas others were time limited. Readers should consult the 2013 report for a complete description of these monitoring and study components.

HBMP Design Modifications

The 2013 report described previous modification to the HBMP, including suggestions made by the scientific review panel at various times in the HBMP since 2002. The panel has suggested continuing the key salinity and water quality components of the HBMP and suggested the installation of additional continuous salinity recorders in the estuary, which was implemented.

The panel also suggested reducing the frequency that vegetation along the river bank is monitored and the HBMP should primarily rely on aerial interpretation, with ground-truthing where necessary. The panel also suggested that phytoplankton species composition be eliminated unless large blooms were observed. The panel also endorsed the plan for spatially enhanced measurements of the distribution of chlorophyll *a* concentrations.

In summary, the findings of the 2013 report provided some recommendations for modifications to the HBMP, but it was the consensus of the panel that the HBMP to this point has generally been sufficient and has indicated that withdrawals by the Peace River Manasota Regional Water Supply Authority have not caused significant adverse impacts to the Lower Peace River / Upper Charlotte Harbor estuary.

PBS&J. 2009a. Hydrobiological Monitoring Program, 2006 Comprehensive Summary Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District.

The 2009 HBMP Comprehensive Summary Report was prepared by the firm of PBS&J, Inc., which was the contractor for the HBMP since 1997. In 2010, PBS&J was acquired by the firm of Atkins, Inc., with largely the same staff transferring to the new firm. As an employee of PBS&J and subsequently Atkins, Inc. Dr. Montgomery continually served as the project manager for the HBMP. As described in Chapter 2 and Section 3.5.5, his involvement with the HBMP predated those firms, beginning with his joining the Environmental Quality Laboratory, Inc. in 1981.

As with the 2013 report, the 2009 comprehensive summary report was first published as a draft that was presented to the scientific panel for review. After receiving the comments of the panel, the report was revised with the final report being published in 2009. However, as indicated by the report title, the most recent data analyzed in the report ended in 2006.

The 2009 comprehensive summary report largely had the same format and organization as the 2013 report previously discussed. Because the 2013 report presented more recent data and updated findings, the summary of the 2009 Comprehensive Report presented below is much shorter and more general. The summary emphasizes findings and topics (e.g., revision of withdrawal schedule) that were particularly relevant at the time of that report.

The principal objectives identified for the 2009 report are listed below:

- 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 that 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

As with the later 2013 report, the 2009 report provided technical summaries of other articles and reports that evaluated flows and ecological studies in the Peace River watershed. Nineteen publications were summarized, including reports that presented differing opinions on the effects of phosphate mining on streamflow in the Peace River watershed, which was a subject of controversy at that time.

The 2009 report also described the climatic variations associated with the Atlantic Multidecadal Oscillation (AMO) and an update of streamflow trends in the watershed. Although the year 2006 was very dry, it was preceded by a few wet years including 2004, when four hurricanes passed over the Florida peninsula, including Hurricane Charley which passed through Charlotte Harbor and up the channel of the Peace River. An increase in hurricane activity during that period is shown in Figure 35. The wet years that occurred in 2003 to 2005 affected many of the physical-chemical relationships presented in the 2009 report.

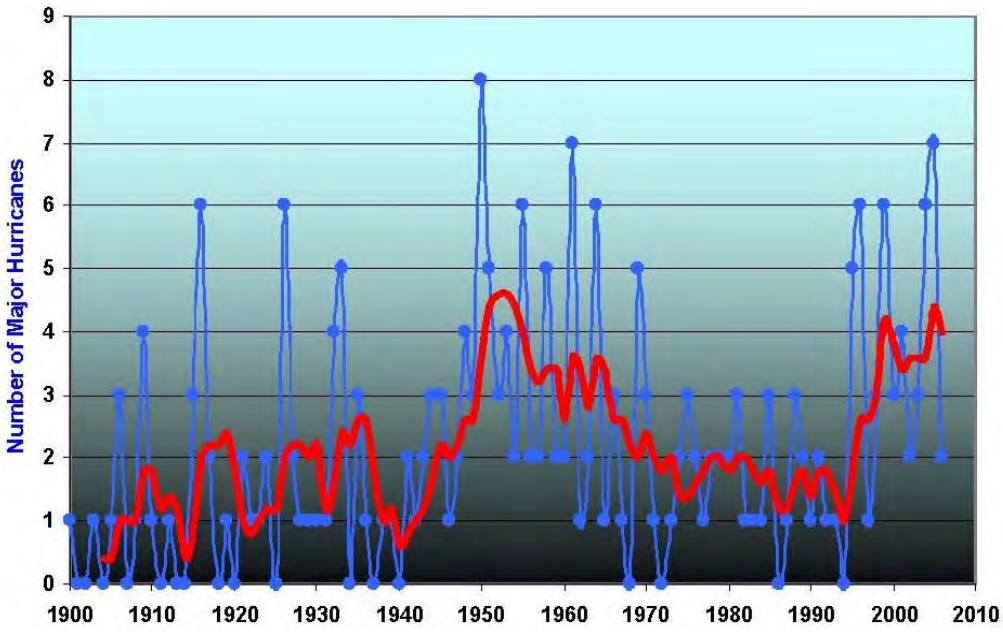


Figure 35. Number of major Atlantic hurricanes (category 2 or above) for 1900-2006 with the moving average shown in red

The 2009 report discusses that during the warmer AMO phase (1930-1969), 33 tropical storm events affected the Peace River basin, while during the following cooler 1970-1994 period, only 10 tropical systems affected the watershed. The report states that after 1995, when the AMO changed to a warmer phase, the frequency of tropical events including major hurricanes increased.

The report states that models capable of predicting future AMO shifts from one phase to another are unavailable. The occurrences of the 1999-2001 drought and the drought that started in 2006 emphasize that the AMO warm/wet phases only describe long-term average conditions, and that very dry intervals have occurred during what might be wetter than average longer time periods. Similarly, very wet years have occurred during cooler/dry AMO periods.

Even with the wet years that occurred near the end of the 2009 report, which evaluated data through 2006, long-term declining trends for a number of streamflow parameters were found at gages on the main channel of the Peace River (Bartow, Zolfo Springs, Arcadia). However, flows increased in some southern tributaries, due in part to the effects of increasing agriculture in that part of the watershed. Even with this increased flow, declining trends for total gaged flow above the Peace River water treatment facility showed declines for yearly flow percentiles below the median. However, there were no declining trends found when flows after 1976 were assessed.

Trend analyses for water quality constituents at the fixed location sites found that color had increased at the two most downstream sites, due in part to the high flow years toward the last part of the monitoring period. As documented in other reports, large declines were observed in ortho-phosphorus concentrations in the early 1980s. However a small rise in ortho-phosphorus was observed in 2004 to 2006, possibly associated with the high flows that occurred during those years.

The increase in silica concentrations that was later reported in the 2013 comprehensive report was documented, and it was stated that investigations were being conducted to determine why this was occurring. There were no significant trends reported for chlorophyll *a* concentrations.

Trend analyses of water quality constituents at the moving, isohaline based stations over the period from 1983 to 2006 found significant ($p<0.05$) increasing trends for color and silica for all stations, surface dissolved oxygen concentrations, and chlorophyll *a* concentrations at 20 psu station. These trends were somewhat different than trends reported five years later in the 2013 report, which was influenced by a succession of dry years from 2006 to 2011.

The 2009 report presented the most thorough discussion to that point in time of the increases in specific conductance and some mineral constituents (e.g., potassium, chloride, fluoride) at a number of gages in the Peace River watershed. These increasing trends were attributed to increases in agriculture and some releases from phosphate mined lands in the watershed. The report discusses that excessive mineralization of the river could periodically jeopardize use of the river for potable water supply, for when specific conductance values rise above 775 microsiemens/cm the water treatment plant has some difficulty processing the water. Since the increased specific conductance (and associated total dissolved solids concentrations) are highest at low flows, application of the 130 low-flow cutoff somewhat alleviates this problem because withdrawals are prohibited from the river for regulatory reasons. However, the increasing mineralization of the river is a growing concern with regard to obtaining dry season water supplies because a greater reliance on stored water supplies would be required.

When the assessment of withdrawals for this report was conducted, the maximum daily permitted withdrawals were limited to 10% of the preceding day flow at the Peace River at Arcadia gage. The report found that application of the ten percent limit prohibited the withdrawal of greater percentages of flow during the dry season, which periodically occurred before the percent limit was implemented. Using empirical regression models, the effects of permitted river withdrawals on average annual salinity values at a series of recently installed continuous recorders in the river were found to be small (0.1 to 0.4 psu).

The report proposed that higher withdrawal percentages could be applied at higher flow rates in the river. These withdrawal percentages should be based on the sum of the flows for the three streamflow gages upstream of the water treatment plant, not just on flow at the Arcadia gage as was the practice in 2006. The utilization of all three gages and higher percentages at higher flows agreed with the approach that was being taken by the SWFWMD in the development of minimum flows for the Lower Peace River. The 2009 report did, however, suggest that consideration should be given to applying a different (more restrictive) flow reduction to the initial late spring/early summer flows relative to similar rates of flow in the late summer/fall period of declining flows.

The 2009 report also described the project conducted as part of the HBMP to improve the data base for the bathymetric/morphometric characteristics of the lower Peace River, which was also presented in a special report for the HBMP (see Section 3.5.6). The 2009 report pointed out that this effort was superseded by later studies of the bathymetry of the Lower Peace River and Charlotte Harbor conducted by the University of South Florida for the SWFWMD (Wang, 2004; 2013).

The 2009 report proposed a set of considerations for determining environmental change and appropriate management actions, which was again discussed in 2013 report. Based on input from the scientific review panel, the installation of additional continuous recorders in the river was pursued and the concept of implementing chlorophyll *a* transects at close spatial intervals in the lower river was introduced. The report also suggested that the yearly data reports submitted for the HBMP be enhanced to include more graphics and some data interpretation, but the mid-term reports could be deemphasized.

PBS&J. 2004. Hydrobiological Monitoring Program, 2002 Comprehensive Summary Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District.

This report was the first comprehensive summary report published after the renewal of the water use permit in 1996, which revised the HBMP and established the scientific review panel. The report, which was published in 2004, presented the results for HBMP data collected through 2002. Like other subsequent comprehensive reports, a draft of the report was presented to the scientific review panel and edits and suggestions by the panel were included in the final report.

The 2004 report presented findings and conclusions for a number of topics that were also discussed in later HBMP reports, such as the development of a conceptual ecological model for the estuary, a decision making protocol for determining significant changes in the estuary and associated management actions, and empirical salinity modeling to evaluate the effects of freshwater withdrawals on the salinity regime of the river.

Those topics have been previously discussed in previous sections of this tribute report, so they are mentioned only briefly in the summary of the 2004 report presented below. One topic that was discussed at length in the 2004 report was changes in the monitoring of shoreline vegetation, which is summarized in more detail below.

The literature review that was presented in the 2004 report was notable for it summarized reports that were short-term (1 to 2 years) studies of benthic macroinvertebrates, mollusks, zooplankton and fish populations that were required as part of the revision of the HBMP in 1996. It also summarized the results of a morphometric study of the Lower Peace River and the establishment of a revised reference centerline for the lower river.

Using graphical analyses and empirical salinity modeling, the 2004 report evaluated the effects of the ten percent withdrawal schedule that was implemented in 1989. The report concluded that the 130 cfs low-flow cutoff for surface water withdrawals based on flow at the Arcadia gage was an effective and conservative mechanism for prohibiting withdrawals during times when there was river water with high specific conductance at the water treatment facility intake. The low-flow cutoff also prevents impacts to the salinity regime of the estuary during times of very low flow.

Using empirical models to predict salinity at two continuous recorders operated by the USGS, the report concluded that the impacts of withdrawals on the salinity regime of the estuary were very small. The report recommended that additional continuous salinity recorders be deployed in the river, which was implemented with the data and modeling results presented in later HBMP reports.

The 2004 report also included a discussion of "pump tests", by which salinity at the continuous recorders was measured during periods when withdrawals were intentionally increased and reduced to measure the effects of varying withdrawal rates. These tests showed very little variation in salinity, even less than predicted by the empirical models, due in part to the short duration of the experiments and the large volume of the lower river which modulates the effects of short-term withdrawals. The report suggested that other recorders be installed and tests be conducted over longer durations.

Like subsequent HBMP reports, the 2004 report presented the results of trend analyses for rainfall, streamflow in the watershed, and water quality constituents in the estuary. Because more recent trend analyses were discussed in previous sections of this tribute report, they are not discussed below other than to say the 2004 report reported data collected during the severe drought that extended from 1999 through 2001 and into the spring of 2002. With regard to streamflow, that was the most pronounced drought that had been recorded in the Peace River basin since data collection began in the 1930s. This allowed for assessment of the salinity and ecological conditions in the estuary under the lowest flows observed to that point in time, as reflected by the upstream location of the 0 psu isohaline water quality monitoring station (Figure 36).

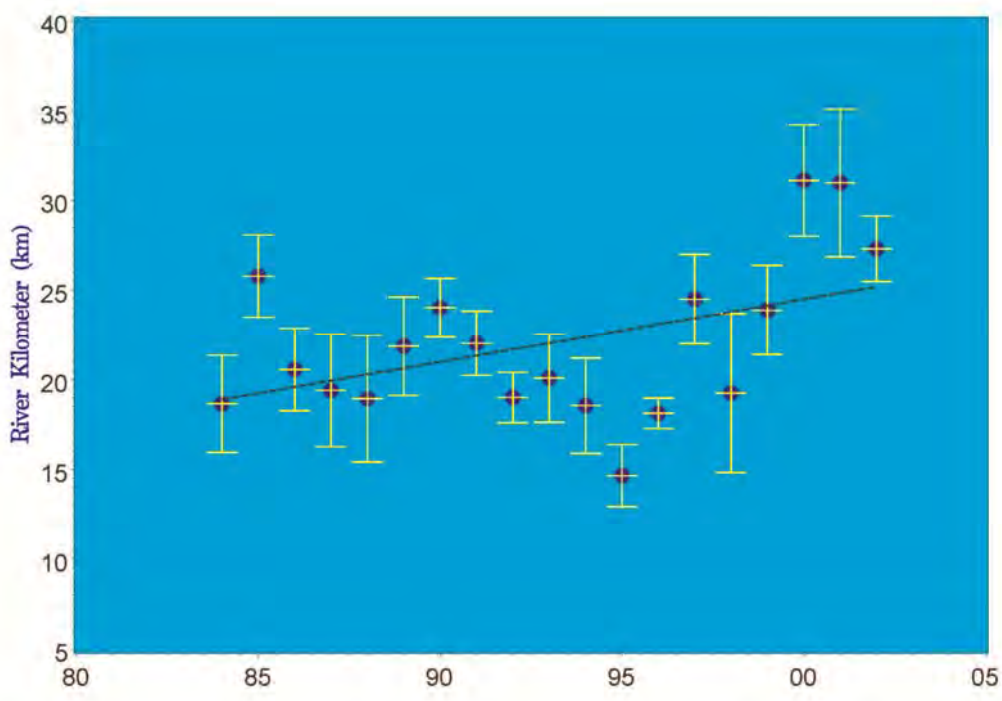


Figure 36. Annual mean values (± 1 std) of the river kilometer location of the 0 psu isohaline water quality sampling station, 1984 - 2002.

The 1999-2001 drought also allowed for the assessment of the ability of PRMRWSA to provide potable water supplies when water withdrawals from the river were prohibited by the 130 cfs low flow cutoff. Water supplies were met during this drought by relying on stored water in the aquifer-storage-recovery system, but a new, larger offstream reservoir was added to the facility eight years later (2009) to meet growing water supply demands during future droughts.

The 2004 report also presented the most complete description of the monitoring of shoreline vegetation to that point in time. Since that monitoring component has been reduced in scope, the 2004 report provides the most thorough description of vegetation along the bank of the Lower Peace River compared to all subsequent reports. The 2004 report presented findings for the first and last occurrence of indicator vegetation, results for quantitative belt transects at three transitional sites, and comparison of vegetation shifts from aerial image interpretation.

The first and last (upstream and downstream) occurrence of seven plant species that are known to exhibit gradients in tidal rivers were measured in mostly two-year intervals from inception of the monitoring program in 1975. Examples of these graphs are shown in Figure 37. Although informative, the first and last analysis showed little relation to inter-annual variation in freshwater inflow and this vegetation measurement method was discontinued from the HBMP in 2004.

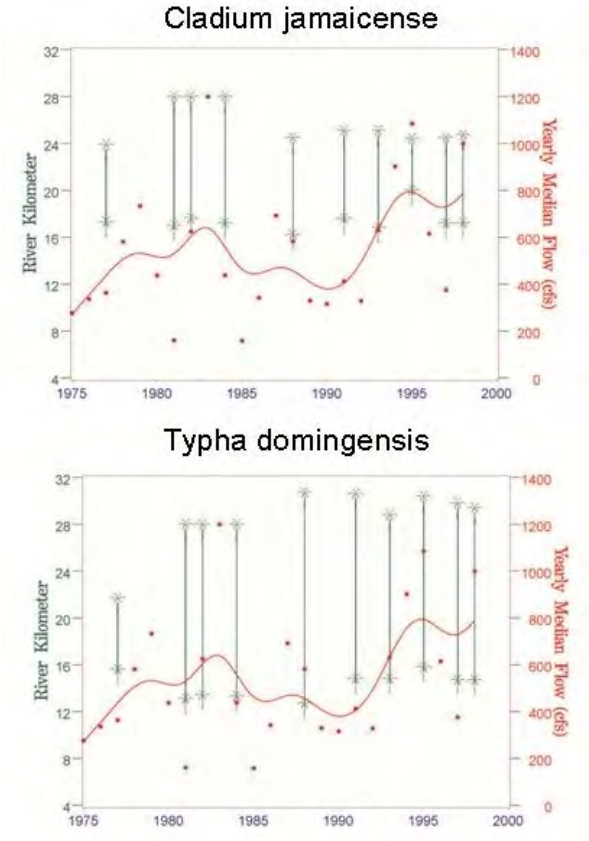


Figure 37. First and last occurrence of sawgrass (*Cladium jamaicense*) and cattail (*Typha domingensis*) in river kilometers on the lower Peace River and yearly median flows at the Peace River at Arcadia gage for 1976 to 1998.

The coverage of plant species was also measured at three transect sites located between kilometers 15.6 and 22.3 kilometers. Vegetation was measured one meter to each side of the transect from the water edge to top of bank. Results were presented for plants growing on the land and in the water. A factor that appeared to affect the results was the growth of large woody trees such was brazilian pepper, and to a lesser extent, live oak. Shoaling and shoreline erosion during extreme storm events also affected the results.

The results from the transect sites found that dominant vegetation species appear to be relatively well established, stable, and not easily affected by the naturally occurring droughts, which resulted in the upstream movement of isohalines orders of magnitude greater than that caused by water withdrawals. The vegetation transect method was also discontinued in 2004.

The 2004 report presented the most complete analysis of the photointerpretation of aerial imagery of vegetation communities along the lower Peace River. Since the 1996 permit renewal, low level aerial photography has been conducted at two-year intervals in a Geographic Information System (GIS) compatible format, allowing for qualitative and quantitative comparison of the coverage of major plant communities over time and comparison to variations in freshwater inflow.

The analysis presented in the 2004 report built upon vegetation results presented by the Florida Marine Research Institute for the SWFWMD based on the photointerpretation of imagery taken in 1994 (FMRI, 1998). Aerial photography similar to that work was repeated in 2002, with photointerpretation performed with similar resolution (Figure 38). The aerial photographs were field verified using notes from previous field ground-truthing efforts to assist in the consistent identification of plant species and communities between the two studies.

This analysis allowed for quantification of the area and distribution of major plant communities along the lower river. An example of the distribution of area values for three major plant communities; saltmarsh, freshwater marsh, and mixed hardwood floodplain forest by river segment is shown in Figure 39 for data recorded in 1998. Also shown is a smoothed curve for the maximum recorded surface salinity value in the river for the twenty-four months prior to the 1998 aerial photography. This graph illustrates the typical zonation of plant communities observed in tidal rivers, transitioning from more salt tolerant communities downstream to freshwater floodplain forests upstream closer to the head of the estuary. The downstream boundary of the data shown in Figure 39 is kilometer 10, as mangroves are consistently dominant further downstream.

- Text resumes on page 77 -

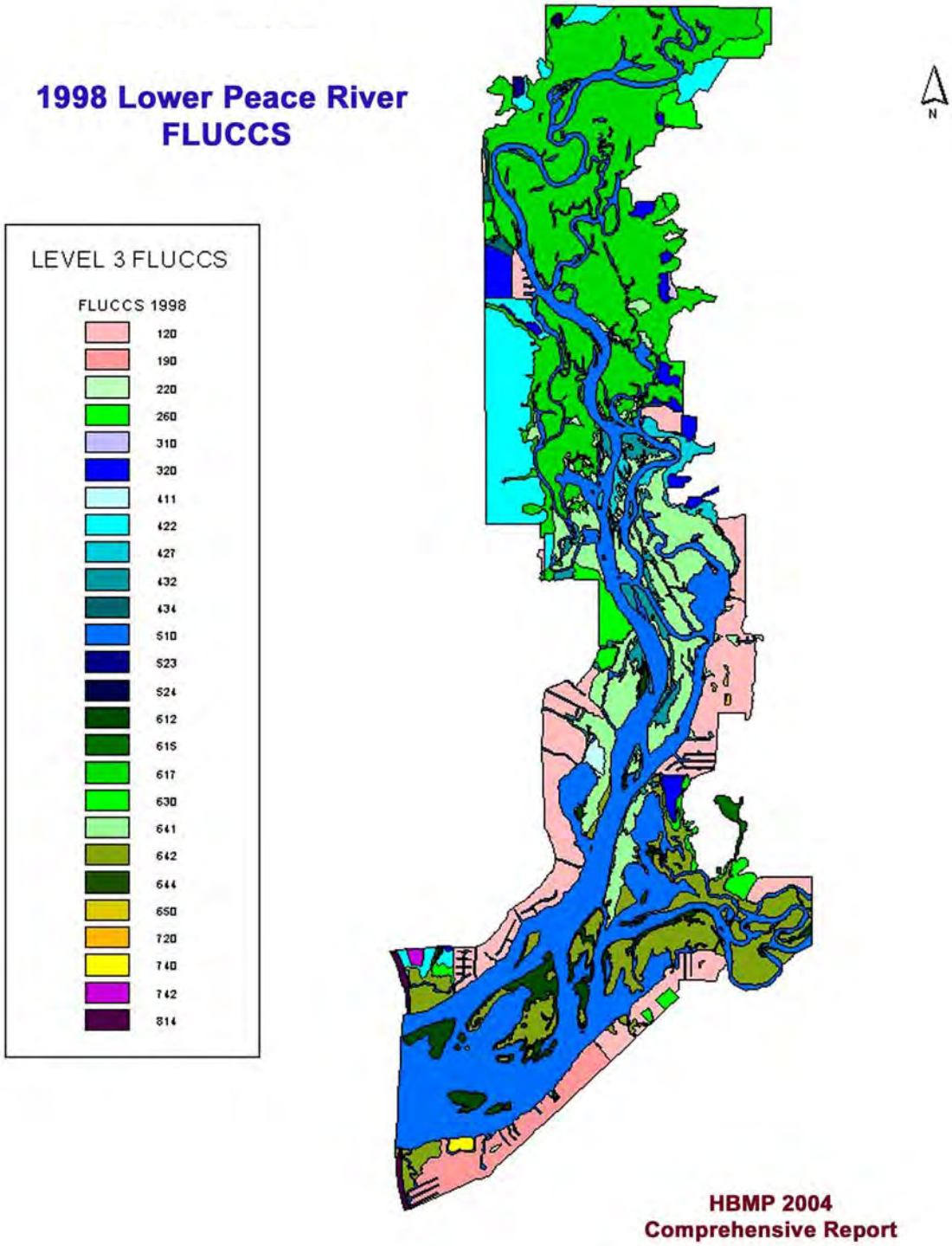


Figure 38. Distribution of major vegetation communities and other land covers along the channel of the Lower Peace River for 1998. A key to the Level 3 FLUCCS codes can be found in PBS&J (2004).

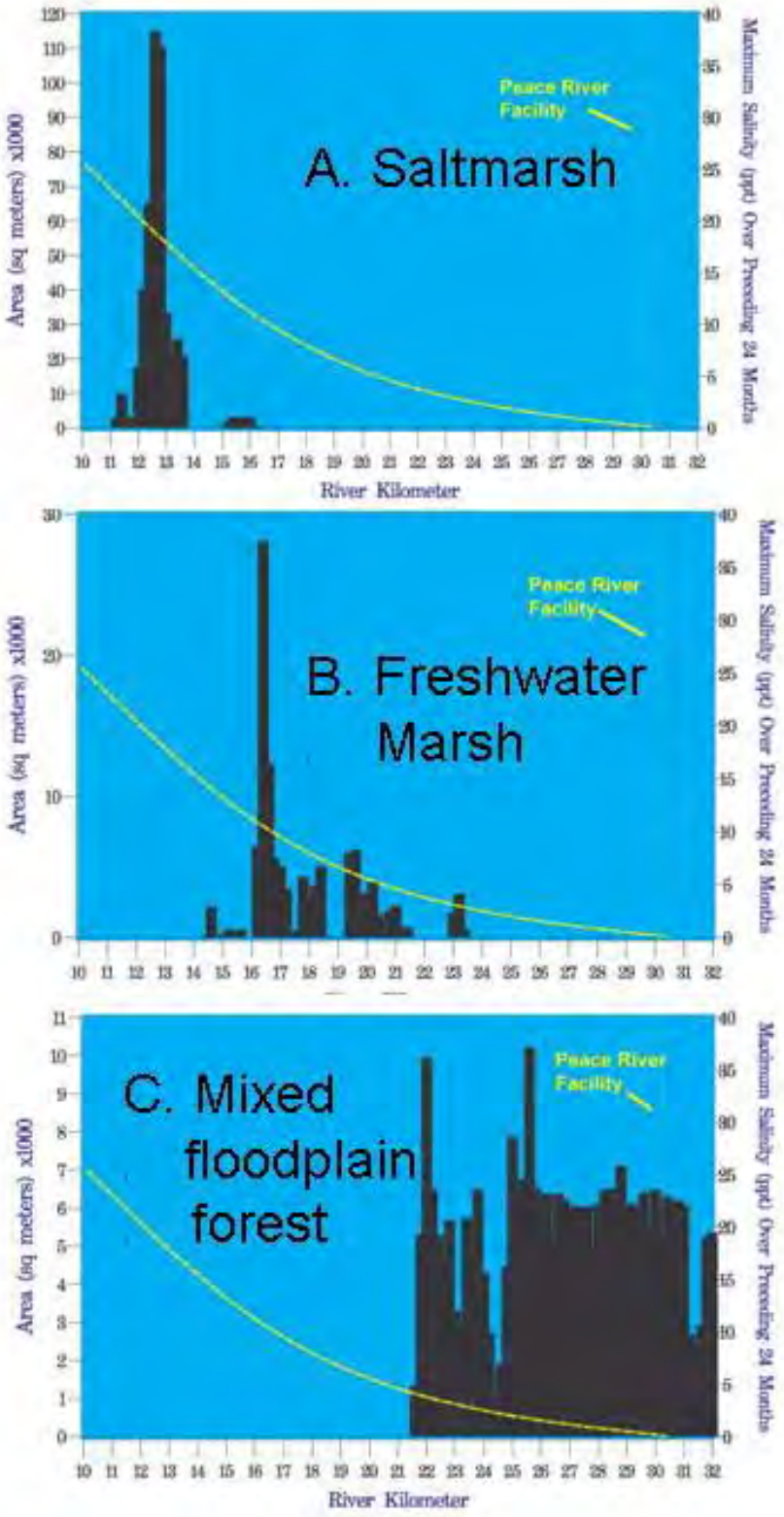


Figure 39. Area of three major vegetation communities along the channel of the Lower Peace River between river kilometer 10 and 32 during 1998 and a smoothed cure of the maximum salinity recorded in the river over the previous 24 months.

A change analysis was performed comparing the 1998 and 2002 coverages using a forward-dating process in GIS, which overlaid the more recent coverage over the previous and examined changes in the distribution and area of vegetation communities. Based on the distribution of the area values per river segment, center of abundance values were calculated for each community. Comparing the 1998 and 2002 coverage estimates, there was small upstream movements of the center of abundance for some communities, due likely in response to the low flows and high salinity conditions in the 1999-2001 drought which preceded the 2002 photography.

The 2004 report concluded with a discussion of proposed modifications to the HBMP program and an assessment of the diversion schedule that was in effect at that time for preventing impacts to natural systems in the lower river. The report concluded that additional continuous recorders be placed in the lower river in addition to the two recorders operated by the U.S. Geological Survey at that time. It was also recommended that *in situ* fluorometer methodology be used from a boat cruising the lower river to better assess the relationship of freshwater inflow with the distribution of chlorophyll *a* concentrations as an indicator of phytoplankton abundance in the lower river. It was also suggested that a limited probability-based sampling element be added to the existing HBMP monitoring elements.

Two additional biological sampling elements were also proposed, depending on the availability of funds from the SWFWMD, to assess the health of the estuary and provide information relevant to the establishment of minimum flows for the Lower Peace River. The first would be a mollusk survey of the lower river, which was subsequently funded by the SWFWMD. It was also mentioned that the ichthyoplankton and zooplankton sampling of the lower river previously performed by the University of South Florida College of Marine Science should be reinstituted for a defined period of time. The SWFMD did later fund an additional five months of dry season sampling of ichthyoplankton and zooplankton in the Lower Peace River in 2008.

The report also recommended elimination of the first and last occurrence of shoreline vegetation along the lower river and the vegetation transect sampling. The assessment of vegetation community changes by photointerpretation was also changed to an average frequency of every five years.

3.5.3 Overview of Other Reports for the HBMP

In preparing this tribute report, it was concluded that the most attention would be given to the comprehensive summary reports that were prepared after the renewal of the Peace River water use permit in 1996 and the concurrent revision of the HBMP. These reports provide the most updated and comprehensive analyses of long-term data collected for the HBMP, and were all prepared primarily by Dr. Montgomery.

However, a number of other reports were prepared for the HBMP in which Dr. Montgomery played a significant role. These include the types of reports listed on the next page, for which references are listed in the bibliography where they are organized by the type of HBMP report.

- Mid-term interpretive reports published in 2002 and 2009 between the five-year comprehensive summary reports
- Interpretive reports submitted periodically between 1979 and 1997
- Special reports that presented the results of time limited studies or supplemental analyses requested by the water management district
- Yearly data reports submitted as part of the HBMP

Text is provided below that describes the purpose and general approach of the mid-term reports that were published in 2002 and 2009. This is followed by brief technical summaries of the interpretive reports that were submitted between 1992 and 1997 and three special studies that were conducted over the course of the HBMP. Text is then provided that generally describes the final category, the yearly data reports. As has been previously discussed, readers should always consult the original HBMP reports for describing or otherwise citing their findings.

3.5.4 Mid-Term Reports Published in 2002 and 2009.

The renewal of the water use permit for withdrawals from the Peace River by the PRMRWSA and revision of the HBMP in 1996 specified that comprehensive summary reports be submitted every five years, with mid-term interpretive reports submitted after year three in each reporting cycle. The mid-term reports provided recent data and analyses for certain variables, but the scope of the mid-term reports was more limited than that of the five-year reports. Because the analyses presented in these mid-term reports were superseded by the five-year reports, technical summaries for the mid-term reports are not presented in this report. However, citations for the mid-term reports are listed below and in the bibliography.

Janicki Environmental, Inc. and PBS&J, Inc. 2002. Peace River HBMP - 1998 Three Year Interpretive Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc. 2009b. Peace River HBMP - 2004 Mid-term Interpretive Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL. (originally submitted as draft in 2006)

3.5.5 Interpretive Reports Submitted Between 1992 and 1997

In 1992, 1995 and 1997, the Environmental Quality Laboratory, Inc. prepared summary reports that described analyses of certain HBMP data collection components up to those points in time. In particular, these reports presented the results of data collection and analyses conducted by Dr. Montgomery on relationships of freshwater inflow with phytoplankton, primary production, and zooplankton in the Lower Peace River / Upper Charlotte Harbor estuary. The 1995 report also contained information on the shoreline vegetation monitoring, but is not summarized below as a more updated summary was previously presented for the 2004 comprehensive report. The 1992, 1995 and 1997 summary reports are described briefly below, with the oldest reports presented first. These reports are also listed in the bibliography along with their corresponding appendices and addenda.

Environmental Quality Laboratory, Inc. 1992a. Peace River Hydrobiological Monitoring Program. Summary Report for the Lower Peace River and Charlotte Harbor. Phytoplankton Production and Structure 1983-1991, Taxonomy 1989-1991, Zooplankton Structure and Taxonomy 1989-1991. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

The 1992 report concluded that to that point in time, no observed short-term, seasonal or long-term trends for any of the physical/chemical or biological parameters monitored in the HBMP had shown any effects from water supply withdrawals by the Peace River regional water supply facility. To that point in time, daily freshwater withdrawals at the facility had ranged from 0 to 18.7 mgd (28.9 cfs) with a mean of 4.5 mgd (6.9 cfs). During this same period, the seven-day Peace River flow prior to monthly monitoring events ranged from 29 to 5,830 mgd (44 to 8997 cfs), with a mean of 455 mgd (704 cfs).

Given this high variation in flow and the very small proportion comprised by freshwater withdrawals, it was not surprising that neither parametric or non-parametric statistical tests were able to detect any significant effects of freshwater withdrawals.

Analyses of long-term seasonal patterns in primary production did indicate, however, that the potential for impacts associated with freshwater withdrawals may be greatest in the late-spring and early summer, with the first pulse of increasing river flow after the typical long-period of low river flow and low nutrient inputs characteristic of the winter/spring dry season. Conversely, the results indicated that primary production in the estuary is fairly insensitive to freshwater withdrawals during periods of higher river flow that are characteristic of the mid-summer to early fall seasons. This suggested the potential to revise the withdrawal schedule to provide for a sliding scale at high rates of freshwater inflow.

The report concluded that measurements of primary production utilizing carbon-14 uptake and other measurements of phytoplankton community biomass and structure, which form part of the base of the food chain, have proven to be the most effective method yet for estimating the potential effects of changes in nutrient loads due to freshwater withdrawals. Measurements of associated zooplankton community structure were found to be less directly sensitive to changes in flow.

The 1992 report therefore suggested that any future monitoring programs continue to emphasize primary production estimates as related to changes in Peace River flow, and avoid the increasing modeling problems associated with corresponding natural noise and loss of statistical information with each higher level in the food chain.

Environmental Quality Laboratory. 1995a. Peace River Hydrobiological Monitoring Program, Summary Report for the Lower Peace River and Charlotte Harbor, Phytoplankton Production and Structure 1983-1993, Taxonomy 1989-1993, Zooplankton Structure and Taxonomy 1989-1993, Vegetation 1976-1993. Main Text Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District.

The 1995 report basically updated and expanded the analyses of the data presented in the 1992 report and also reported on the vegetation monitoring that had been conducted since 1976. The 1995 report provided a thorough discussion of the primary production and water quality work that had been done on the moving salinity-based stations that had been monitored since 1983, with data presented through 1993. The bibliography also lists a similar summary report dated in 1994, but the 1995 report superseded that report, so the 1994 report is not summarized below.

The 1995 report describes four general effects of freshwater inflow to the Lower Peace River / Upper Charlotte Harbor estuary. Moderate changes in flow can: 1) rapidly and significantly affect the relative positions of salinity zones in the estuary; 2) variations in freshwater inflow result in alterations of both the ambient concentrations and loadings of major macro-nutrients (nitrogen and phosphorus) as well as silica, iron, and trace micronutrients which can further affect community structure; 3) decreases in water clarity (due to turbidity and color) associated with increased flows can alter the penetration of light affecting both phytoplankton and seagrass communities; and 4) seasonally high freshwater inflow can result in strong salinity stratification that creates zones in the estuary characterized by hypoxic or anoxic (low to zero dissolved oxygen concentrations) bottom waters which may limit the distribution of many species.

Phytoplankton and Primary Production

Primary production and phytoplankton biomass were examined by comparative graphical and statistical analyses. Water temperature was selected to serve as a stable proxy for seasonal variation, representing both increasing/decreasing ambient light and metabolic activity. Ambient water color was chosen to represent the combined competing influences associated with higher freshwater inflow, the stimulation of increasing nutrient loadings, and the negative effects of decreasing light penetration of the water column. The following patterns were apparent:

1) Both phytoplankton production and biomass were found to be low, regardless of water temperature, during periods of low water color.

2) When color increased to intermediate levels, both phytoplankton production and biomass showed significant positive responses. The magnitude of these responses were observed to be highly temperature dependent.

3) Past a point, however, further increases in color overwhelmed the initial stimulation of increasing nutrients associated with flow, and both production and biomass declined rapidly.

Principal Component Analysis was used to evaluate the potential combined and relative influence on phytoplankton responses from the twenty-five physical and chemical parameters measured during the study. This analysis indicated that:

1) The highest measured primary production rates and chlorophyll *a* levels occurred at the 6 and 12 psu salinity stations during periods of relatively low freshwater inflow, coincident with high seasonal temperature and light.

2) Increasing nutrients, independent of freshwater inflow, resulted in stimulation of phytoplankton production and biomass. Such phytoplankton responses also increased under similar flow conditions with increasing nutrient levels.

3) Strong interactions between light, temperature, and nutrient levels were apparent. At relatively low temperature/light levels, increasing nutrients did little to increase productivity, while increasing temperature/light at relatively constant nutrient levels resulted in dramatic increases in phytoplankton production.

Regression models were developed to predict estimates of phytoplankton production rates and biomass from the measured physical and nutrient parameters. The resultant predictive models accounted for 44% of the observed variability in carbon update and 37% in ambient chlorophyll *a* concentrations.

Phytoplankton species composition and community structure can be used to help assess the effects of long-term changes in water quality in estuarine systems. In order to assess differences and changes in phytoplankton community structure, taxonomic identification and numeration of the phytoplankton taxa at the moving salinity based stations began in 1989. Distinct differences among major taxonomic groups were observed with regard to the four salinity zones, both with consideration to species composition and seasonal patterns.

0 psu salinity zone - Blue-green algae (cyanobacteria) were a very important part of the phytoplankton community during February through April. Green algae were typically dominant or showed major increases in May during periods of low Peace River flow. Flagellates, by comparison, showed a strong increase in importance related to increasing river flow in the summer. Diatoms were less frequent in the phytoplankton during such periods of high river flow, and were important or showed major peaks during the late fall and winter months, as flow and water temperature, declined. Dinoflagellates were not an important component of the phytoplankton community at this salinity zone, which was essentially tidal fresh water.

6 psu salinity zone - This zone was characterized by seasonal blooms of flagellates, diatoms, and dinoflagellates. Flagellates typically dominated through the cooler months and well into the beginning of the summer wet season. As river flow and temperature increased, diatoms began to become more important. Green algae comprised only a smart part of the phytoplankton community.

12 psu salinity zone - This zone was characterized by seasonal blooms of flagellates, diatoms, and dinoflagellates. Flagellates typically dominated through the cooler months and well into the beginning of the summer wet season. As river flow and temperature increased, diatoms began to become more important. Green algae comprised only a small part of the phytoplankton community.

20 psu salinity zone - The seasonal patterns of the major taxonomic groups at this zone followed patterns generally similar to those observed at the 12 psu zone. Diatoms, however, showed a marked increase in their relative importance in the phytoplankton community.

Primary production rates and chlorophyll *a* concentrations were measured on three different size fractions of phytoplankton at each of the four salinity based stations. Those size fractions were < 5 microns, 5 to 20 microns, and > 20 microns. Overall, the smallest size fraction (<5 microns) comprised a much greater percent of the phytoplankton community at the 0 psu zone compared to the 20 psu zone. The reverse was true of the largest measured size fraction (> 20 microns). The intermediate salinities indicated a gradation between these patterns. Strong seasonal differences in the relative importance of the size fractions were apparent at each of the four salinity zones.

Zooplankton

Zooplankton represent an important link between the phytoplankton community and higher levels in the estuarine food chain. Zooplankton were monitored on a monthly basis at the four salinity based stations between 1989 and 1993 for three purposes:

1) Document and catalogue the existing zooplankton communities in the Lower Peace River / Upper Charlotte Harbor estuary

2) Examine relationships between the phytoplankton and zooplankton communities to better understand how zooplankton may affect phytoplankton abundance and production

3) Examine how the zooplankton community and individual zooplankton taxa respond to changes in the physical and chemical characteristics of the estuary, including freshwater inflow, water temperature and nutrient availability. In turn, examine how the effects of these factors on the zooplankton community affect interactions with the phytoplankton.

Eighty-nine species or taxonomic groups of zooplankton were identified, ranging form the eggs of some invertebrates and vertebrates to larval forms and adults. The dominant taxa were rotifers, copepods and their nauplii, barnacle nauplii, mollusc larvae, Platyhelminthes, annelids and various hydrozoa. Total zooplankton density was typically about one million individuals per cubic meter, ranging as high as 5.8 million/m^3 to as low as 10,000/m^3.

The zooplankton community at the 0 psu zone was dominated by rotifers and copepod nauplii, with low densities of adult copepods. Seasonally high densities of ctenophores, sipunclids, larvaceans, gastropods and their larvae, and hydrozoa medusae were also observed. The zooplankton at 6 psu was comprised primarily of copepod nauplii, rotifers, and the calanoid copepod *Arcatia tonsa.* Higher densities of copepods were observed at 6 psu than 0 psu, primarily cyclopoid *Oithona* species. Seasonally high densities of hemicordates, sipunculids, cirrippedian nauplii, gastropod larvae, and pelecypod larvae were also observed during peaks of zooplankton density and diversity at the 6 psu zone.

The zooplankton community at the 12 psu zone was also comprised predominantly by copepod nauplii and *Acartia tonsa*, with increased numbers of polychaete larvae, and increased numbers

and types of calanoid and cyclopoid copepods including *Oithona* sp., *Saphirella* sp. and *Paracalanus crassirostris*. Seasonally high densities of harpacticoid copepods, principally *Euterpiona acutifrons*, sipunculids, cirripedian nauplii, gatropod larvae, and turbellaria were also observed. The zooplankton community at 20 psu was dominated by copepod nauplii, *Acartia tonsa*, and increased numbers of *Oithona nana*. Seasonally high densities of fish eggs and larvae, Cirripedia nauplii, Hemicordates, Ascideanceans, Tubellaria, and Sipunculids were also observed.

Multivariate analyses of taxonomic distributions between zones using Canonical Variate Analyses (CVA) indicated distinct taxonomic patterns within stations that discriminated between the stations in terms of both taxonomic composition and abundances of the dominant zooplankton taxa. Differences between stations were attributable primarily to varying densities of *Oithona* sp., *Acartia tonsa*, and ctenophores.

Possible interactions between physical/chemical and phytoplankton parameters were analyzed for the four salinity zones, resulting in three composite variables for each analysis that accounted for about 60% of the variance at each station. These composite factors were then regressed against zooplankton taxa densities and zooplankton community metrics at each zone. This resulted in the identification of individual zooplankton taxa at each station that responded to changes in a wide variety of variables and conditions.

Continued Hydrobiological Monitoring

Based on data collection and analyses conducted to that point in time, the 1995 report offered perspectives on future directions for monitoring as part of the HBMP. These suggestions were incorporated into revision of the HBMP that accompanied renewal of the water use permit in 1996. The 1995 report recommended that phytoplankton related water quality parameters continue to be a primary component monitored and evaluated as part of the HBMP.

The report concluded that in addition to comprising a major component of the estuary's food chain, there are four principal reasons that information on rates of primary production is important within the Lower Peace River / Upper Charlotte Harbor estuarine system:

1) It may be possible that primary production rates can be modeled and incorporated into models that predict the effects of flow related changes in circulation and water quality with the estuary. The application of such information and models may be of wide interest and application to various governmental and regulatory agencies.

2) Excessive phytoplankton production may reduce light penetration in the water column by increasing turbidity and absorbance. High levels of phytoplankton production may further affect factors which in turn can influence the dominance of estuarine groups. An example would be potential extreme diurnal oscillations in dissolved oxygen concentrations in the water column caused by high phytoplankton densities.

3) Trend analyses of inorganic nutrient inputs and their respective ratios, from freshwater sources such as the Peace, Myakka, and Caloosahatchee Rivers, may also be interpreted more

accurately once the factors influencing phytoplankton production in specific areas of the Charlotte Harbor system are better understood.

4) Significant long-term reductions in flow and related nutrient loading into the estuary could potentially effect overall rates of primary production and phytoplankton species distributions within the estuary. Such changes could have corresponding influences with the associated zooplankton communities resulting in further magnified changes up the food chain, potentially affecting both recreational and commercial fisheries within the estuary.

The 1995 report concluded the unique long-term and comprehensive nature of the studies of phytoplankton production and structure provide a basis for statistical investigations of the interrelations of both short-term and long-term changes in river flow to a subsequent expression of changes at the base of the food-chain in the estuary. Increasing demands for freshwater withdrawals mandate the need to develop corollary potential flow related indicators to ensure that both the amount and timing of withdrawals continue to have minimal impacts on the biological communities of the Lower Peace River / Upper Charlotte Harbor estuarine system.

Environmental Quality Laboratory, Inc. and Coastal Environmental, Inc. 1997. Hydrobiological Monitoring Program. Summary Report for the Lower Peace River and Charlotte Harbor. Zooplankton Structure and Taxonomy 1989-1996. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District as a condition of water use permit number 2010420.02.

The 1997 summary report primarily focused on updated and expanded analyses for the zooplankton monitoring that extended from 1989 to 1996. The report summarized the findings from the 1995 report, but added the following points.

1) The two sampling methods of estimating zooplankton abundances and community structure; oblique tows through the water column and surface samples, often led to slightly different results. As expected, oblique tows tended to result in the collection of a greater number of taxa, while surface samples often produced greater zooplankton densities per cubic meter.

2) The zooplankton communities at each of the four sampled isohalines were extremely variable in time with regard to the number of taxa, diversity and evenness indices, and density.

3) Individual taxa, especially at the species level, sometime showed greater abundances at individual isohalines. However, as more inclusive groupings were analyzed, such individual variability disappeared. Some taxa were extremely euryhaline, while the densities of several of the major zooplankton groupings indicated gradations toward either more fresh or marine waters.

4) During the more than seven years of zooplankton study, the natural variability of flows in the Peace River ranged from extended periods of both very dry and very wet. This provided an

excellent basis for investigating potential relationships between zooplankton community structure and abundance with flow. However, analyses of zooplankton community structure showed no clear correlations with Peace River flows and only limited correlations with phytoplankton primary production.

5) The results of this investigation indicated that the relationships between zooplankton densities and flow are even more complex than those previously identified for phytoplankton biomass and primary production.

The 1997 report also compared the withdrawal quantities taken by the Peace River water treatment facility during the course of the zooplankton study to the variation in flows in the Peace River at the Arcadia gage. Withdrawals from 1989 to 1996 averaged 6.9 mgd (10.7 cfs), equivalent to 1.1 percent of the average flow for that Peace River gage during that time period. When each daily withdrawal was divided by the flow on that day, the average percent daily withdrawal was 2.7% of flow at the Peace River gage. The report concluded these rates of withdrawal were having no significant effect on the ecology of the Lower Peace River / Upper Charlotte Harbor estuary.

3.5.6 Special Reports for the HBMP

Three reports were prepared by the consultants to the Peace River Manasota Regional Water Supply Authority that discussed special topics related to the HBMP. These were comparatively short-term studies that included a general summary of the findings of the HBMP that was prepared in 1999 and a report that characterized the morphometry of Lower Peace River that was published in 2000. The third report discussed the effects of "pump tests" that evaluated the effects of withdrawing different amounts of water at the PRMRWSA facility on continuous salinity measurements at a series of recorders in the lower river. The finding of these reports are briefly summarized below.

Other more limited special reports included a small set of supplemental analyses related to the HBMP requested by the SFWMD in 2002 and metadata that accompanied the submittal of the phytoplankton data set to the PRMRWSA, also in 2002. Those reports are not summarized below, but are listed in bibliography of this report.

PBS&J, Inc. 1999. Summary of Historical Information Relevant to the Hydrobiological Monitoring of the Lower Peace River and Upper Charlotte Harbor Estuarine System. Report prepared for the Peace River Regional Water Supply Authority.

After renewal of the water use permit and revision of the HBMP in 1996, it was desired by the PRMRWSA to have a more generalized report that summarized the findings of the HBMP and related hydrologic and ecological studies. Authors for the report, who wrote separate chapters, included Dr. Montgomery, other staff from PBS&J, two environmental scientists from SWFWMD, and two scientists from Janicki Environmental, Inc. This report provided a very useful summary of the HBMP that could be viewed by a wider audience and is an excellent source of information for the HBMP up to that point in time.

The chapters of the 1999 summary of historical information report covered:

- Physical setting of the Peace River basin
- Hydrology
- Salinity
- Water Quality
- Plankton
- Benthos
- Fish
- Vegetation

This report summarized findings presented in previous HBMP reports, which were updated in more recent years in subsequent HBMP reports. Therefore, a detailed summary of the findings of this report is not presented below. However, readers are encouraged to consult the 1999 summary of historical information for a concise, systematic treatment of findings of the HBMP up to that point of time.

The 1999 summary report also presented the findings of biological studies that were performed as part of the HBMP. Since the findings of these biological studies have not been yet presented in this tribute report to Dr. Montgomery, some representative findings are presented below. These included the multi-year data collection of juvenile fishes in Upper Charlotte Harbor that was performed by the Environmental Quality Laboratory, which was the consultant for the HBMP at that time. The 1999 report also described the design of an ongoing two-year study of benthic macroinvertebrates that was being performed by Mote Marine Laboratory and an ongoing two-year study of fishes performed by the University of South Florida College of Marine Science and the Florida Marine Research Institute.

Macroinvertebrates

The 1999 report describes early studies of the Peace River basin, including the findings reported in Masters thesis by Ellis Landquist (1953), who provided the first description of the benthos of the Upper Peace River, which had already experienced impacts from phosphate mining in the upper river basin. Also described were data collection programs for benthos by the Punta Gorda office of the Florida Department of Environmental Protection at the Peace River near Arcadia and in Horse Creek. Also described was a biological data assessment by Texas Instruments (1978), that was performed as part of the initial siting studies for the Peace River water treatment facliity. The report also described a review of the previous studies of benthic macroinvertebrate infauna within the Charlotte Harbor estuarine system and surrounding inshore waters that was prepared by Dr. Ernest Estevez of Mote Marine Laboratory (Estevez, 1986).

The report also described studies of benthic invertebrates that were instituted as part of the initial HBMP in 1976, four years prior to the start of potable water supply withdrawals from the Peace River began. The basic premise of these investigations was to determine if benthic organisms could be used as sensitive organisms to determine potential effects of freshwater withdrawals. The major period of focus for these studies, which were conducted by the Environmental Quality Laboratory, was between 1976 and 1982.

One HBMP study element focused on the sea star *Luidia clathrata*, collected by otter trawls at twenty-four locations from the Lower Peace River southward to the southern end of Cape Haze (Figure 40). This program found that in the summer, high freshwater inflow caused stratification of the water column and low dissolved oxygen concentrations near anoxia at the bottom which resulted in stress and death of sea stars.

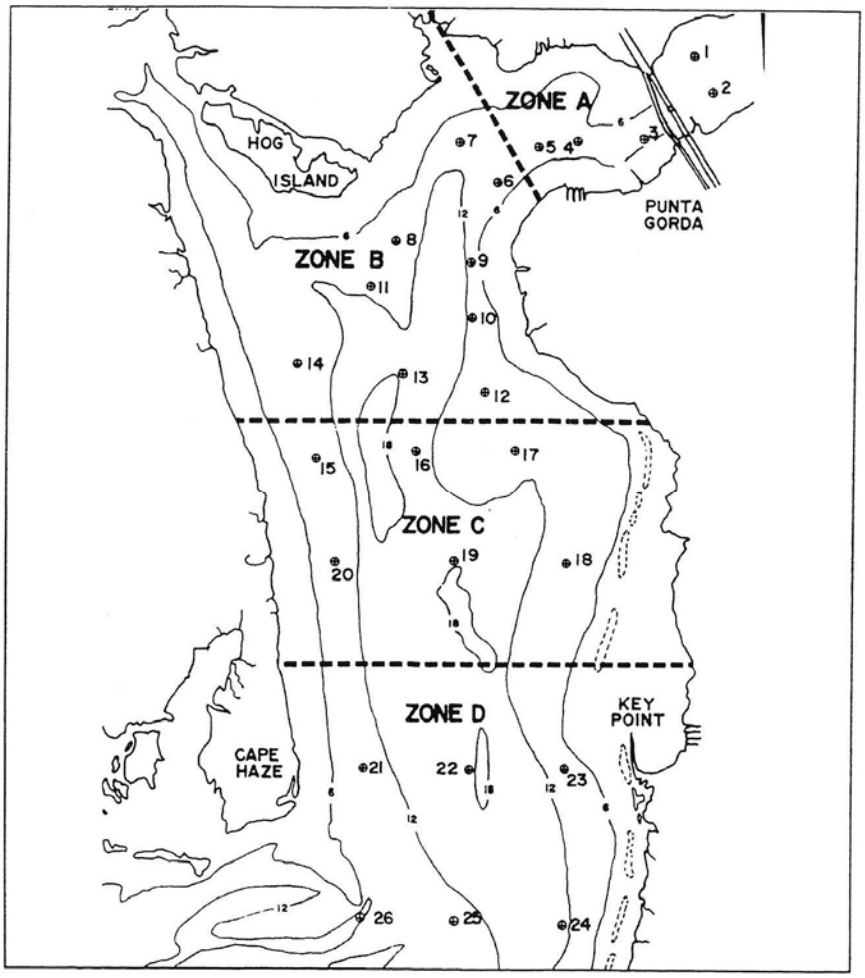


Figure 40. Sampling zones and location collection sites for the sea star, *Luidia clathrata*, 1976 - 1982.

Benthic invertebrate infauna and epifauna were also collected at five sites in the Lower Peace River from near the mouth of Horse Creek to a point 10 kilometers downstream of the water treatment facility. At each site, benthos were collected by ponar grabs. Various species and groups of organisms were collected in predominantly riverine samples, including bivalves, isopods, amphipods, polychaetes and insect larvae. Estuarine samples included a polychaete and brachiopod. An extensive analysis of the over six-year monitoring period was conducted to test for patterns and trends in the frequency and distribution of each of the potential benthic indicator organisms. Modified general linear model procedures were used to test for relationships between freshwater inflow and changes in each group.

The most extensive study of benthic invertebrates in the Lower Peace River was being undertaken by Mote Marine Laboratory at the time of the 1999 historical summary report, therefore, only the design of the study was described. The study divided the lower river into four salinity zones based on salinity data measured as part of the HBMP, which were < 0.5 psu, < 8 psu, 8 to 16 psu, and > 16 psu. Two ranges of depths, the intertidal zone and from the mean low water elevation to a depth of 3.7 meters, were sampled in each salinity zone. A total of 600 core samples and 560 sweep net samples were collected over five wet and five dry time periods. The findings of this study were subsequently published in the report by Mote Marine Laboratory (2002).

The report by Mote Marine Laboratory included the findings of a two-year investigation of the distribution of benthic, hard shell mollusk communities conducted by Dr. Ernest Estevez of their staff. Both live and dead mollusk shells were sampled in 0.5 kilometer intervals in the Lower Peace River and evaluated in relation to salinity, water depth, and substrate.

Fishes

The 1999 historical summary report summarized previous studies of fish communities in upper Charlotte Harbor and the design of a study of fish communities in the Lower Peace River estuary conducted by the University of South Florida College of Marine Science at the time of that report.

With regard to previous studies, Wang and Raney (1971) performed a random, reconnaissance trawl sampling program that collected 107 fish species in the Charlotte Harbor estuarine system. As part of the original HBMP, the Environmental Quality Laboratory conducted monthly trawl sampling between June 1975 and 1988 in a region of Upper Charlotte Harbor south of the mouth of the Peace River. The findings and conclusions of this 13-year fish sampling program were presented in yearly HBMP reports submitted between 1980 and 1989. The findings of this sampling program were subsequently published in an article by Fraser (1997). Table 12 lists total numbers for the thirteen most abundant fish species collected as part of this monitoring program.

Table 12. Total number collected for the thirteen most abundant fish species sampled by the HBMP sampling program in Upper Charlotte Harbor from June 1975 - May 1988.

Species	Total Number Collected
Anchoa mitchilli	14,110
Cynoscion arenarius	9,795
Leiostomus xanthurus	4,982
Arius felis	4,335
Menticirrhus americanus	2,689
Symphurus plagiusa	1,964
Prionotus scitulus	1,908
Trinectes maculatus	1,548
Eucinostomus gula	1,465
Lagodon rhomboides	1,427
Bagre marinus	897
Prionotus tribulus	525
Bairdiella chrysoura	523
Total	46,168

Two distinct groupings of fishes were identified as broadly fitting either a wet or dry season mode, defined by the rate of freshwater inflow. No acceptable quantitative relationships were developed that could that could be used to identify a threshold or critical rate of freshwater inflow for individual species or groups of species.

Spatially intensive, two-year studies of use of the Lower Peace River and the tidal reach of Shell Creek as a nursery zone by estuarine dependent fishes was underway when the 1999 historical summary report was written. Data for ichthyoplankton and invertebrate by-catch sampled by plankton tows were collected by researchers from the University of South Florida College of Marine Science, while juvenile and adult fishes were collected by seines and trawls were by the Florida Marine Research Institute. The sampling zones, which included the tidal reaches of Shell Creek, are shown in Figure 41.

The findings of this study were subsequently presented in reports by the University of South Florida (Peebles 2002) and the Florida Marine Research Institute (Greenwood et al., 2004). These reports included findings for the abundance and distribution of all identifiable taxa over the two years of study. Results were analyzed in relation to physico-chemical variables and the rate of freshwater inflow. Distinct changes in the distribution and composition of fish communities were observed as a function of the of freshwater inflow.

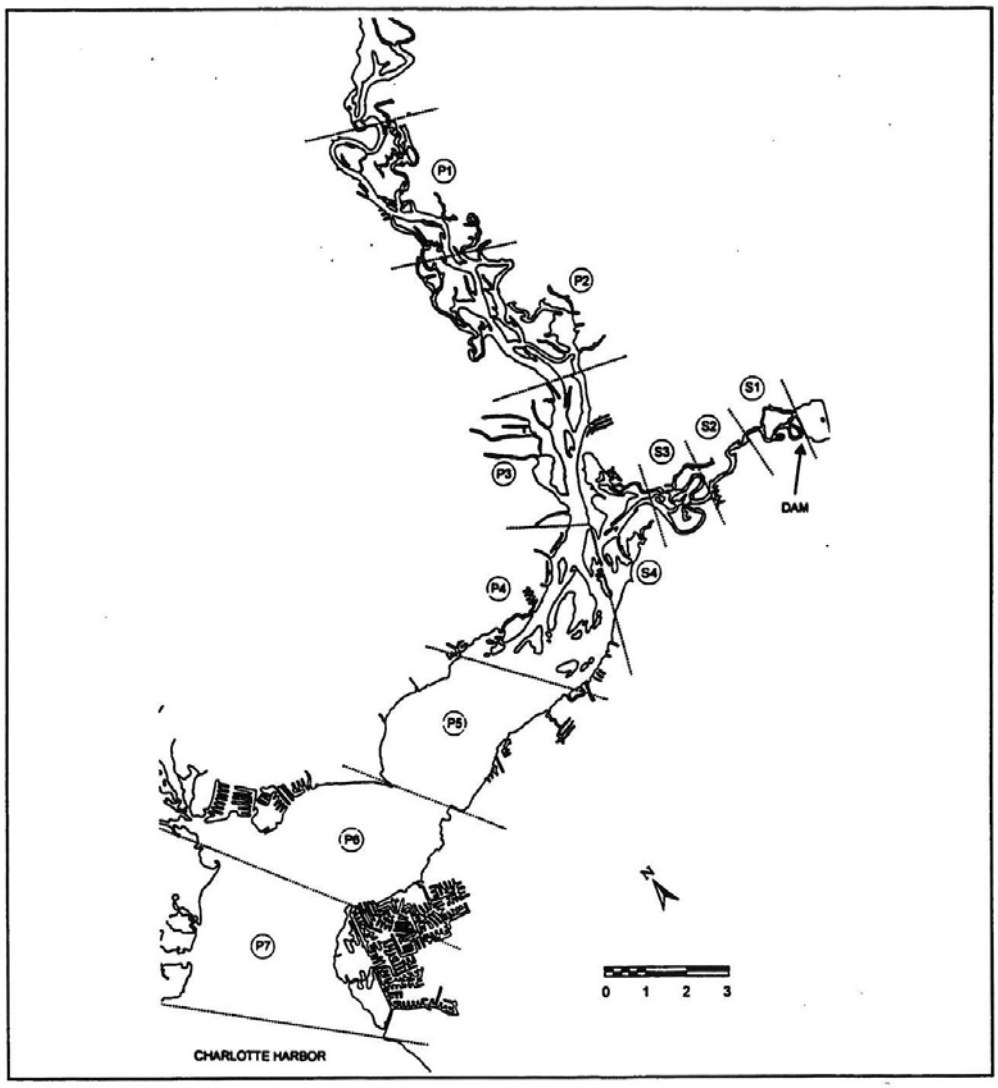


Figure 41. Ichthyoplankton sampling zones in the Lower Peace River and Shell Creek sampled by the University of South Florida, 1998 - 1999.

PBS&J. 2000. Morphometric habitat analysis of the Lower Peace River. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District

The revision of the HBMP in 1996 required that a standardized centerline for the Lower Peace River be developed so that all sampling locations could be related to distance from the river mouth on a consistent scale. The project was to also develop morphometric data for the lower river so that the area, volume, shoreline length, and wetland area of the lower river could be expressed as a function of location on the river centerline.

The river centerline was determined using guidelines for the Charlotte Harbor estuarine system, with the mouth of the Peace River established along an imaginary line running from the point at Punta Gorda to the southern end of Hog Island. Then, using USGS protocols for determining a river centerline, a centerline was extended to a point well above the water treatment facility. The centerline also extended into Charlotte Harbor so that samples collected in the harbor could be referenced to the nearest centerline locations. All files were entered into a Geographic Information System. The centerline of the river with the river mouth at kilometer zero is shown in Figure 42. All research published for the Lower Peace River since the year 2000 has been referenced to this centerline.

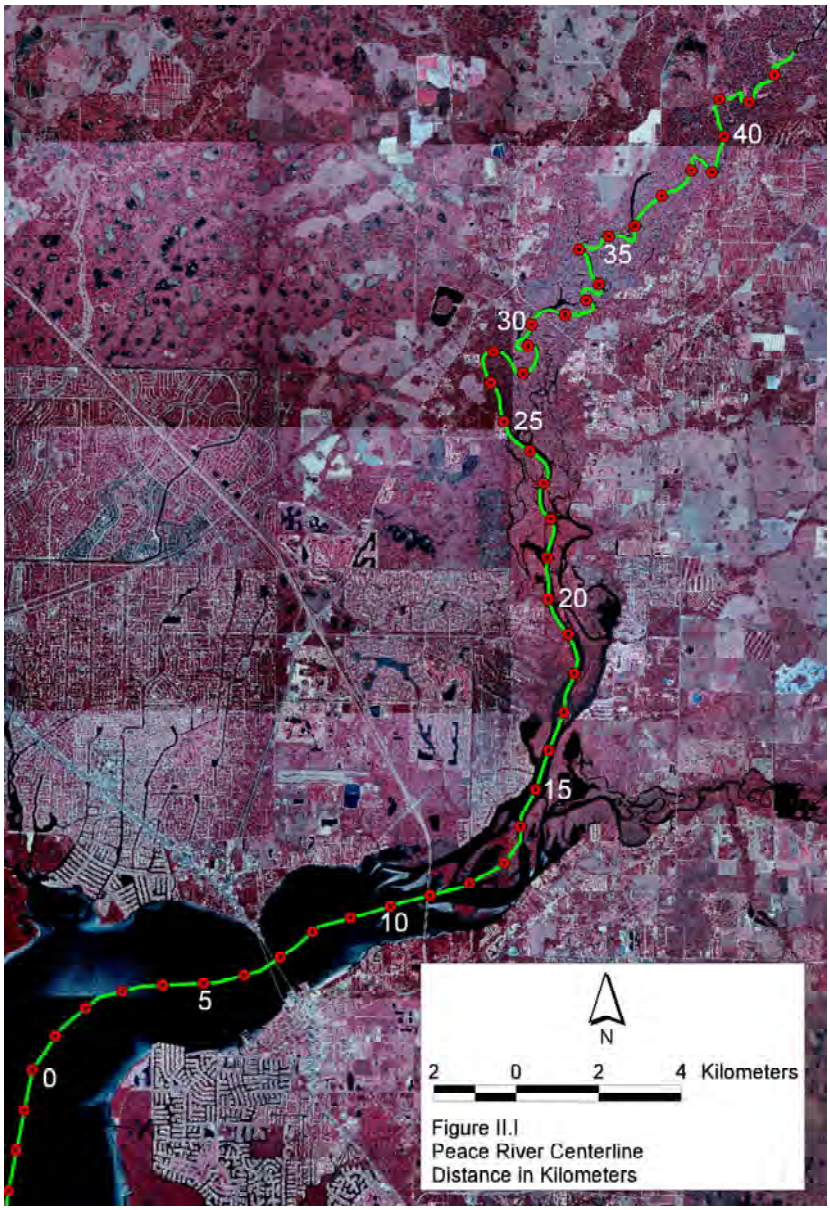


Figure 42. Centerline of the Lower Peace River extending into Upper Charlotte Harbor with distances in kilometers delineated.

In order to improve the data for the bathymetry of the Lower Peace River, cross sectional profiles were run at 0.5 kilometer intervals between the I-75 bridge (near kilometer 10) to a point above where Horse Creek flows into the Peace River. A Global Positioning System (GPS) was used to locate the staring and ending points of all cross sections, and a SiTex recording fathometer was used to record profile depths. These files were then all scanned and digitized and used to develop cross sectional data using Statistical Analysis System (SAS®) software.

The morphometric information generated by this project was very useful, but was later superseded by bathymetric/morphometric characterizations of the Lower Peace River and Charlotte Harbor conducted by the University of South Florida Department of Geology (Wang, 2004; 2013). This more recent information generated by the University has subsequently been used by both the SWFWMD and consultants for HBMP to assess the morphological and shoreline characteristics of the river. However, some graphics generated for the 2000 morphometric study report are presented on the following pages to illustrate some basic physical characteristics of the Lower Peace River.

The Lower Peace River has the typical funnel shape of a tidal river in which the area of the river increases greatly toward the river mouth (Figure 43). Though not shown, river volume shows a similar relationship. These morphometric characteristics have important implications for the ecology of the estuary in relation to salinity, for when isohalines move upstream with reduced flow, the water volume within a given salinity zone (e.g. < 6 psu) generally declines as that salinity zone is located in a narrower reach of the estuary.

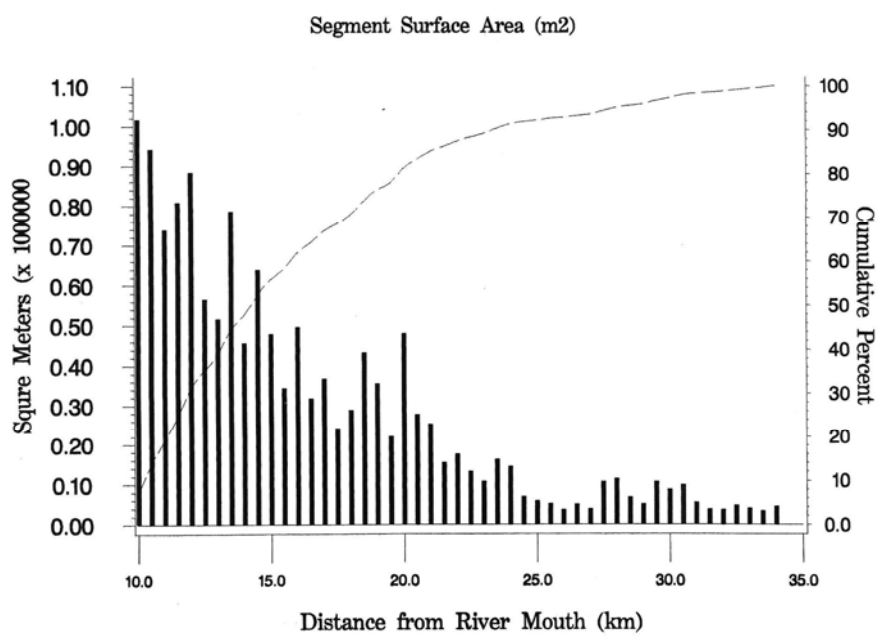


Figure 43. River surface area in 0.5 kilometer increments along the river centerline of the channel of the Lower Peace River between kilometers 10 and 34.

The pattern of shoreline length above kilometer 10 does not show the same relationship as surface area, as there is not a consistent pattern in the increase or decrease in shoreline length between kilometers 10 and 24 (Figure 44). This is a highly braided part of the river in which high shoreline lengths occur in river reaches that have islands and sloughs (see Figure 42 on page 91). In four segments, there is between 6,000 and 13,000 meters (0.6 and 1.3 kilometers) of shoreline within each 0.5 kilometers of river length. This characteristic provides for very high level of shoreline habitat use by the estuarine fishes and invertebrates, contributing to very high secondary biological production that is typically found in estuaries.

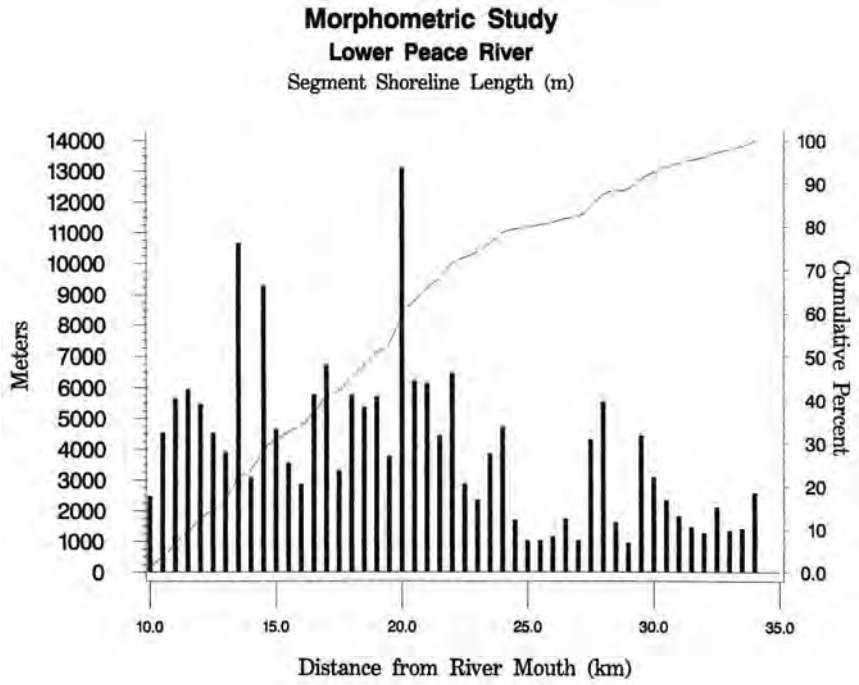


Figure 44. Shoreline length in 0.5 kilometer increments along the river centerline of the channel of the Lower Peace River between kilometers 10 and 34.

Using this morphometric information and GIS coverages of vegetation types along the lower river, the study identified the distribution of major vegetation communities along the lower river. The distribution of three of these communities (saltmarsh, freshwater marsh, and mixed floodplain forest) were shown in Figure 39 on page 76.

PBS&J. 2009c. Evaluation of Low Flow "Pump Test" (December 2006 - May 2007)- Findings Using Observed Data and Modeled Results from the Lower Peace River Continuous Recorders. Report prepared for the Peace River Manasota Regional Water Supply Authority submitted to the Southwest Florida Water Management District.

This report discussed a series of pump tests that were initially suggested by the scientific review panel for the HBMP. The term pump tests refers to short-term periods (days) when

different quantities of water are withdrawn from the river at the PRMRWSA facility and the effect of these withdrawals are examined at a series of continuous salinity recorders in the river. Dr. Montgomery designed and supervised these tests and prepared this report, which also summarizes the statistical salinity models that had been developed for the river up to that time.

The USGS has operated two continuous salinity recorders in the river since the 1997 at river kilometers 15.5 and 26.7. A third recorder was added by the USGS near the water treatment facility in 2009 after the pump test report. In 2006 the HBMP added three additional recorders between kilometers 22 and 25. It was concluded that these recorders in this reach of the river would provide useful data for tracking the movement of the fresh/saltwater interface in the river channel when flows were in the range of 130 cfs, which is the flow rate at which the PRMRWSA is required to cease withdrawals from the river. Figure 45 shows the locations of the five salinity recorders that were in operation during the pump tests.

Figure 45. Location of continuous salinity recorders in the lower Peace River operated by the USGS or the HBMP during the pump tests in 2007.

Sixteen pump test events were conducted between December 2006 and May 2007, with each pump test near three days in duration. Due to the severity of the unusually dry conditions that characterized much of 2006 and the unusual periods of low flow during much of the normal summer wet-season, the PRMRWSA was unable to fully recharge its off-stream reservoir and groundwater storage system during the usually high flow summer months. In response to the very low flows during the late fall of 2006 and in anticipation of predicted unusually dry conditions expected during early 2007, the PRMRWSA received authorization from the SWFWMD in December 2006 to temporarily reduce the low-flow withdrawal threshold from 130 to 90 cfs until after the beginning of the 2007 summer wet-season.

This reduction in the low flow threshold allowed the PRMRWSA the opportunity to withdraw water from the river at lower flows and reduce the demand on stored supplies. This temporary change in the low flow threshold also provided the Authority with the opportunity to run a series of "pump tests" both above and below the permit's 130 cfs limit. Although not originally envisioned under these conditions, both the scientific review panel and the SWFWMD had previously suggested that it would be beneficial to collect such "pump test" data both at flows above and below 130 cfs. The timing of the sixteen pump tests and flows at the Peace River at Arcadia gage are shown in Figure 46, with reference lines for flows of 130 and 90 cfs at that site. The period for the pump tests provided a range of flows at which the effects of withdrawals could be examined at flow rates near either of these two low-flow cutoff thresholds.

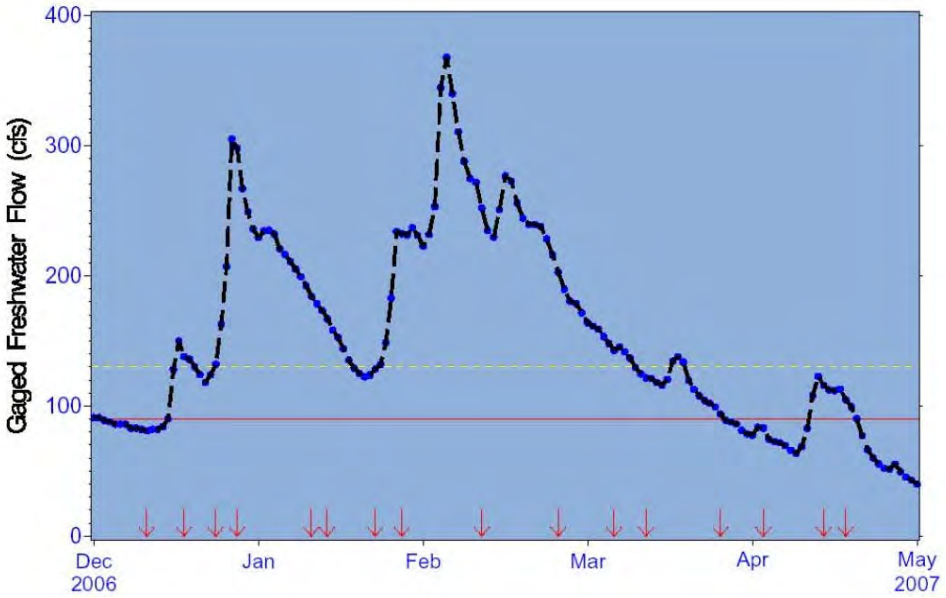


Figure 46. Freshwater flow at the Peace River near Arcadia gage during the pump test period. The upper yellow line denotes the 130 cfs withdrawal cutoff threshold, while the lower red line denotes the temporary 90 cfs cutoff threshold. Red arrows show the timing of the sixteen pump tests.

Each pump test extended over near three diurnal tidal cycles with the withdrawals turned on and off during each three-day time period. A series of graphical analyses of time series plots of salinity over each pump test were then conducted to examine changes in salinity with and without withdrawals. A table of these results are listed in Table 13, with the results ranked from top to bottom based on the flow at the Arcadia gage.

Table 13. Summary of graphical analyses for maximum salinity changes attributable to facility withdrawals during the pump tests

"Pump Test" Event	Daily Conditions		Estimated Changes in Salinity				
	"Revised" Arcadia Gaged Flows (cfs)	Facility Withdrawals (cfs)	USGS RK 15.5	MZ4 RK 21.9	MZ3 RK 23.4	MZ2 RK 24.5	USGS RK 26.7
Flows Above 130 cfs Threshold							
December 28th through 30th	271	26.8	NA	NA	NA	NA	NA
January 28th through 30th	239	21.0	< 0.1	< 0.1	< 0.1	-----	-----
February 11th through 13th	238	21.9	< 0.1	< 0.1	< 0.1	-----	-----
February 24th through 26th	181	20.9	< 0.1	< 0.3	< 0.1	< 0.2	-----
January 11th through 13th	178	17.4	< 0.1	< 0.4	< 0.2	< 0.2	-----
January 14th through 16th	159	15.5	NA	NA	NA	NA	NA
December 24th through 26th	158	13.2	NA	NA	NA	NA	NA
March 6th through 8th	143	15.6	< 0.2	< 0.4	< 0.2	< 0.1	< 0.1
January 23rd through 25th	136	11.7	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
December 18th through 20th	134	15.0	< 0.1	< 0.2	< 0.4	< 0.1	< 0.4
Flows Between 130 cfs Threshold and Temporary 90 cfs Cutoff							
March 12th through 14th	120	13.3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
April 14th through 16th	113	13.6	NA	NA	NA	NA	NA
April 18th through 20th	98	12.6	< 0.5	< 0.5	< 0.8	< 0.5	< 0.5
Flows Below 90 cfs Cutoff							
March 26th through 28th	90	10.7	< 0.4	< 0.2	< 0.4	< 0.4	< 0.4
December 11th through 13th	82	9.6	< 0.3	< 0.2	< 0.2	< 0.3	< 0.3
April 3rd and 4th	79	7.0	< 0.2	< 0.2	< 0.2	< 0.1	< 0.1

* NA – analyses indicate either flow or tidal variability too great to accurately estimate salinity changes due to Facility withdrawals

The effects on salinity from these pump tests were very small, with the maximum salinity changes reported at less than 0.8 psu, with most changes less than 0.2 psu at the five recorders. The duration of these maximum changes in salinity were usually brief near maximum high tides. The report also presented the findings of statistical analyses of differences in salinity, and again the differences between withdrawal and no withdrawal conditions were very small. However, it should be noted that these were changes due to

experimental manipulation of withdrawals over just a few tidal cycles. It is possible that the effects of changes in salinity between withdrawal and no withdrawal conditions might be greater if the experiments were conducted for longer durations.

Statistical models were developed using averaged hourly salinity data gathered during the first four months of 2007 at the five recorders. 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 and measured water levels (which are largely due to tides) as independent variables.

The statistical models for each continuous recorder location were then used to estimate sub-surface salinities, both with and without withdrawals, on an hourly basis during the ten-day interval between April 12 and April 21, 2007. Finalized USGS gaged flow estimates for the Peace River at Arcadia ranged from 77 to 122 cfs over this ten day interval. The PRMRWSA facility was not withdrawing water except for two "pump test" days over this period. Table 14 provides estimates of differences in selected metrics of modeled surface salinities at each of the continuous recorders during this ten-day period with and without withdrawals. Similar to the results for the graphical and statistical analyses for the sixteen pump tests, the changes in salinity as a result of withdrawals were very small.

Table 14. Comparisons of predicted salinities from the statistical models with and without withdrawals for the ten-day period between April 12 and April 21, 2007

Continuous Recorder Location	Mean Salinity		Median Salinity		Minimum Salinity		Maximum Salinity	
	With Withdrawals	Without Withdrawals	With Withdrawals	Without Withdrawals	With Withdrawals	Without Withdrawals	With Withdrawals	Without Withdrawals
Harbour Heights (RK 15.5)	15.8	15.6	15.7	15.5	10.9	10.4	21.2	21.0
MZ4 (RK 21.9)	6.9	6.5	6.9	6.5	1.9	1.3	11.8	11.5
MZ3 (RK 23.4)	4.8	4.5	4.7	4.5	0.5	0.0	9.0	8.7
MZ2 (RK 24.5)	3.7	3.5	3.7	3.5	0.0	0.0	7.2	7.0
Peace River Heights (RK 26.7)	1.9	1.4	1.8	1.4	0.0	0.0	3.9	3.8

The pump test report also addressed questions the scientific review panel raised regarding the pump tests and the corresponding use of statistical models. The report presented a summary of all statistical salinity models that had been prepared for the Lower Peace River to that point in time. It was not the purpose of that report to discuss the mechanistic hydrodynamic models that had been developed for the Lower Peace River and Charlotte Harbor.

3.5.7 Yearly Data Reports for the HBMP

Yearly data reports have been submitted to the SWFWMD annually since 1979, with the first report covering data between the beginning of the HBMP in January 1976 until October 1978. The data reports submitted between 1981 and 1996 were submitted by the Environmental Quality Laboratory, Inc., which was the consultant to the PRMRWSA until that year. Dr. Montgomery was employed by the Environmental Quality Lab from 1981 until 1997 and participated in the preparation of these reports over that time

Dr. Montgomery served as the director of the Environmental Quality Lab between 1990 and 1997. Dr. Montgomery then joined the firm of Coastal Environmental, Inc., which was later acquired by the firm of PBS&J, Inc. which then became the firm running the HBMP for the PRMRWSA. As previously discussed, PBS&J was acquired by Atkins, Inc. in 2010 with Dr. Montgomery remaining on staff and continuing his involvement with the HBMP. All of the annual data reports submitted for the HBMP by these firms are listed in the bibliography and are available from the PRMRWSA and the Florida Water Atlas website described on page 1.

Until 1992, the yearly data reports were the primary reports by which the status of the HBMP were reported to the SWFWMD. It is notable that the period covered by these reports include four years of baseline data (1976 - 1979) before there were any withdrawals from the Peace River.

3.6 Studies of Factors Affecting Phytoplankton Populations, Chlorophyll *a* Concentrations and Primary Production Rates in the Lower Peace River, Upper Charlotte Harbor, and Other Estuaries

Dr. Montgomery performed extensive studies of factors affecting phytoplankton populations, chlorophyll *a* concentrations, and primary production rates in the Lower Peace River / Upper Charlotte Harbor estuary. The combined data for these studies now cover a period of over thirty years, extending from 1983 to 2014. Many components of this data collection program continue today, comprising one of the most extensive and informative data bases of its kind in Florida.

Much of this data collection was conducted for the Hydrobiological Monitory Program (HBMP) associated with permitted water supply withdrawals from the Peace River that was previously discussed. Dr. Montgomery also produced other publications on this subject that were not required as part of the HBMP, including studies in which phytoplankton populations and related parameters were compared among estuaries. The primary production related studies that were not conducted specifically for the HBMP are summarized on the following pages.

McPherson, B. F., R. T. Montgomery, and E.E. Emmons. 1990. Phytoplankton productivity and biomass in the Charlotte Harbor estuarine system, Florida. <u>Water Resources Bulletin</u> 26(5):787-800.

This work was conducted by Dr. Montogery and Edward Emmons of the Enviromental Quality Laborotory, Inc. in conjunction with studies of Charlotte Harbor conducted by the Water Resources Divsion of the U.S. Geological Survey (Dr. Ben McPherson). The abstract from this article is reprinted below.

> Phytoplankton carbon-14 productivity at a depth of 50 percent of surface light and chlorophyll-α concentrations were measured every other month from November 1985 through September 1986 at 12 stations in the Charlotte Harbor estuarine system. Maximum productivity and chlorophyll-α concentrations occurred during summer or early autumn near the mouths of tidal rivers. Most of the variability in light-normalized productivity and chlorophyll-α could be attributed to two factors derived from Principal Component Analysis of ambient water-quality characteristics. One factor related to seasonal variability and the other to spatial variability. The seasonal factor incorporated the interaction of temperature and nutrients. The spatial factor incorporated the interaction of salinity, nutrients, and water color that resulted from the mixing of freshwater inflow and seawater. Although freshwater inflow increased the availability of nutrients in low salinity (less than 10‰) waters, the highly colored freshwater restricted light penetration and phytoplankton productivity. Maximum productivity and biomass occurred where color associated with the freshwater inflow had been diluted by seawater so that light and nutrients were both available. Concentrations of inorganic nitrogen were often at or below detection limit throughout most of the high salinity (greater than 20‰) waters of the estuary and was probably the most critical nutrient in limiting phytoplankton productivity.

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.

This report by the U.S. Geological Survey corresonds to the project summarized above for the article by McPherson et al. (1990). However, the findings presented in this report emphasized the results of *in situ* experiments that examined the effects of inorganic nutrient additions that were conducted as part of the overall study effort. The abstract from this USGS report is reprinted below.

> The response of natural phytoplankton assemblages in a subtrropical coastal plain estuary, Charlotte Harbor, Florida, to inorganic nitrogen and phosphorus addtions was determined from measurements of relative changes in both the update of carbon-14 and concentrations of chlorophyll a. The effect of nitrate plus nitrite nitrogen, ammonia nitrogen, and orthophosphorus additions over a series of concentrations were evaluated through *in situ*

experiments conducted during periods of seasonally low and high river inflows. The response to nutrient addtions were evaluated for three differenet size fractions of phytoplankton. Relative changes of phytoplankton carbon update and chlorophyll *a* concentrations were highly variable with regard to season, location, nutirent, and size fractions.

Within areas of the estuary characterized by lower salinities, phytoplankton exhibied a distinct seasonal pattern to additions of inorganic nitrogen. Under seasonally high freshwater inflow, phytoplnkton showed little response to inorganic nitrogen additions, whereas under seasonallhy low inflow, phytoplnakton responded to the inorganic nitogen addtions. The seasonally high freshwater inflow increased ambient inorganic nitrogen concentrations and water color. The high water color greatly reduced light penentration in the water column and limited photoplankton productivity. The effect of nutrient additions in the higher salinty reaches of the estuary indicates that, under normal condtions, these aeras are continually nitrogen limited.

During periods of high freshwater inflow during the summer months, the estuary can be divided conceptually into a low-salinity zone where phytoplankton production is mediated by light availablility, as determined by high water color, and a high-salinity zone where phytoplankton production is nitrogen limited. Seasonal nutirent concentration data and comparisons among inroganic nitrogen inputs and observed phytoplankton productivity support the bioassy results. Each of these lines of evidence indcates that, exclusive of seasonal riverine influences that affect light penetration of the water column, nitrogen availability normally limits phytoplankton production in the Charlotte Harbor estuarine system.

Vargo, G. A., R. T. Montgomery and M.B. Neely. 2004. An investigation of relationships between phytoplankton populations, water quality parameters and freshwater inflow in three tidal rivers in West-Central Florida. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District

Dr. Montgomery collaborated with the principal investigator (Dr. Gabriel Vargo) from the University of South Florida College of Marine Science for this project which examined relationships of phytoplankton populations with water quality and freshwater inflow in the Peace, Alafia, and Little Manatee Rivers. This study provided an excellent opportunity for a comparative study of phytoplankton communities in tidal rivers as the three rivers were studied under a similar sampling design that employed moving, salinity based stations. Sampling was conducted at monthly intervals at the locations of 0.5 psu, 6 psu, 12 psu and 18 psu isohalines in each river, with the exception of the 20 psu isohaline sampled instead of the 18 psu isohaline in the Peace River. A summary of this report's findings that was prepared for this tribute report is presented below.

The Alafia River typically supported much greater phytoplankton populations and chlorophyll *a* concentrations than the other two rivers. As shown by the separate Y axis scale for the Alafia in Figure 47, annual average total phytoplankton abundance (cells/ml) were much greater in the Alafia. Despite the high levels of phytoplankton and chlorophyll *a*, which would be expected to absorb available inorganic nutrients, the Alafia had the highest average concentrations of inorganic nitrogen and phosphorus, presumably due to higher loadings of nutrients from the watershed.

The Little Manatee River was characterized by much higher N:P ratios for both total nitrogen to total phosphorus and inorganic nitrogen to inorganic phosphorus, due to lower phosphorus concentrations in the inflow from the Little Manatee watershed compared to the Alafia and the Peace, both which have extensive phosphate mining in their watersheds.

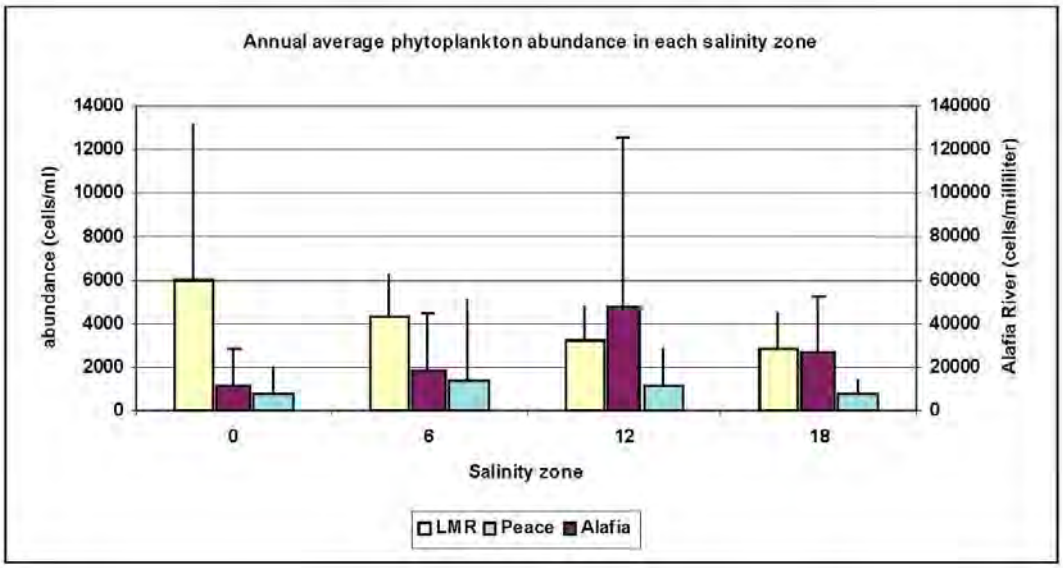


Figure 47. Annual average total phytoplankton abundance in the Little Manatee (LMR), Peace, and Alafia Rivers by salinity zone. The values for the Alafia River correspond to the Y axis on the right, because the counts for the Alafia were often more than an order of magnitude greater than for the other rivers.

Sampling across the salinity gradient found that average phytoplankton abundance was greatest at the 6 and 12 psu stations in the Peace River and at the 12 and 18 psu stations in the Alafia (Figure 47), indicating the highest phytoplankton counts often occur in mesohaline zones (5 to 18 psu salinity) in these rivers. The Little Manatee River showed a different pattern with the highest average phytoplankton abundance at the 0 psu station, followed by the 6 psu station. It is suggested that this is due the highly braided morphology of the tidal freshwater and oligohaline zones of Little Manatee, water slows down relative to the upstream freshwater reach, allowing phytoplankton populations to develop.

Appendices for this report included lists of all phytoplankton taxa collected for each river, taken to the lowest practical taxonomic level. Exact comparisons of phytoplankton species composition between rivers were not possible because the taxonomic counts were conducted by different investigators under separate projects. However, valuable analyses were presented in which the seasonal progression of major phytoplankton groups was compared both within and between rivers.

The report compared phytoplankton communities within pairs of rivers during years in which phytoplankton counts were made in both rivers. Phytoplankton data were available for both the Peace and the Little Manatee rivers for January 1988 to January 1990 and for the Peace and Alafia rivers for March 2000 to November 2001. PRIMER statistical software was used to examine non-parametric multivariate analyses of similarities and differences in community composition within and between rivers and relationships to nutrient and water quality parameters.

Over comparable time frames, the Peace River was dominated by greater cyanobacteria (blue-green algae) and diatom populations compared to the Alafia, which was characterized by flagellate and dinoflagellate blooms. The Alafia River also had periodic large blooms of chrysophytes (yellow-green or golden brown algae). There was greater similarity between the phytoplankton community composition between the Peace and Little Manatee Rivers, particularly at higher salinity zones where flagellates and diatoms were important. However, at the tidal freshwater zone (0.5 psu), chlorophytes (green algae) contributed a greater proportion of the phytoplankton in the Peace compared to the Little Manatee. Large inter-annual differences were observed in the phytoplankton communities of the Peace River. Cyanobacteria populations were more abundant in the 2000-2001 drought than in 1989-1990, when diatoms and chlorophytes were more abundant.

Dixon, L.K., G.A. Vargo, J.O.R. Johannson, R.T. Montgomery, and M.B. Neely. 2009. Trends and explanatory variables for major phytoplankton groups of two southwestern Florida estuaries, U.S.A. Journal of Sea Research 61: 95-102

The abstract for this article that was published in the *Journal of Sea Research* is reprinted below.

Multi-year phytoplankton abundance data from two estuaries in southwest Florida were combined into taxonomic groups, assessed for trend, and compared with water quality data using multivariate techniques. Inter-annual flow variations were linked to climatic indices and were relatively large. Trends in water quality included declining biomass, N and P signals in Tampa Bay, and declining P and a complex but slightly increasing N in Charlotte Harbor. Trends were superimposed on flow-dominated seasonal and annual variations in nutrient loads. Trends in phytoplankton abundance were both gradual and abrupt, were not always monotonic, and were most noted for cyanobacteria. One species of cyanobacteria, *Schizothrix calcicola* sensu Drouet could be considered an indicator species. At specific stations, nutrient concentrations and seasonal parameters were significant explanatory variables for variations in community structure. Clustering of community structure by taxonomic groups did not align well with known trends in nutrient loadings or biomass.

Atkins, Inc. 2014. An analysis of relationships of freshwater inflow and nutrient loading with chlorophyll values and primary production rates in the Lower Peace River. Report prepared for the Southwest Florida Water Management District, Brooksville, FL.

Using long-term data collected between 1983 and 2013, this project examined relationships of freshwater inflow related variables with chlorophyll *a* concentrations and primary production rates in the Lower Peace River. This work was funded by the Southwest Florida Water Management District in support of the re-evaluation of the minimum flows for the Lower Peace River, which are scheduled for adoption in 2018. The overall goal of the project was to assess how reductions of freshwater

inflow would affect the spatial and temporal variation of phytoplankton populations in the Lower Peace River, with chlorophyll *a* concentrations and primary production rates (as carbon-14 uptake) used as indicators of phytoplankton biomass and productivity. A summary of this report's findings prepared for this tribute report is presented below.

The effects of freshwater inflow rates on factors that can affect phytoplankton populations such as nutrient loading, residence time, water color (which affects light penetration) were examined. The interactions of seasonal physical factors that can affect phytoplankton such as water temperature and solar insolation were included in the analysis. The report presented a wide array of graphical results and statistical analysis of univariate and multivariate relationships related to factors affecting chlorophyll *a* and primary production.

The introduction of the report provides an informative general discussion of the role of phytoplankton in maintaining the nursery function of estuaries in which the early life stages of many important fish species migrate to and utilize the low and moderate salinity zones within estuaries as part of their life history. This estuarine utilization is represented in Figure 48, which is based on work conducted on larval and juvenile fish populations in the Lower Peace River and other southwest Florida estuaries by the University of South Florida College of Marine Science (Peebles, 2002; 2005) combined with other estuarine research.

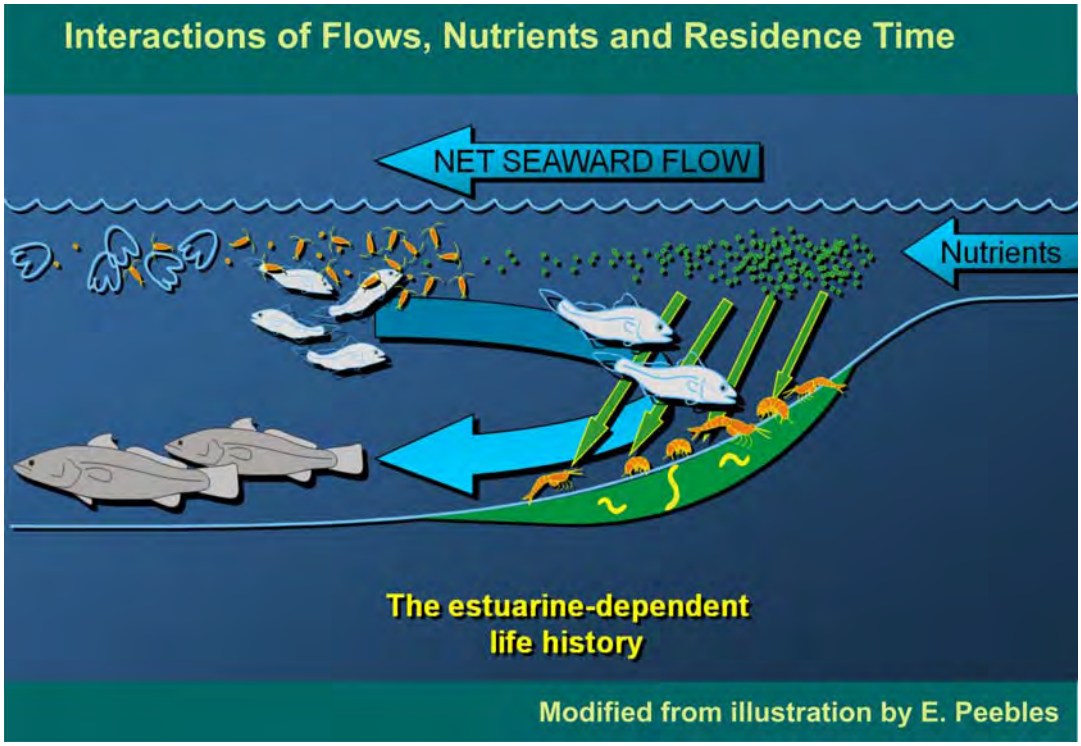


Figure 48. Conceptual general diagram of the interaction of freshwater inflow, nutrient loading, residence time, phytoplankton production and benthic macroinvertebrates in the life history strategy of an estuarine dependent fish species. Modified from illustration provided by Ernst Peebles, University of South Florida, College of Marine Science.

As illustrated in Figure 48, large phytoplankton populations often develop in the low and moderate salinity zones of estuaries as a result of nutrient delivery from the watershed and longer residence times. There is also greater exposure to solar radiation in the estuary compared to the inflowing, more narrow freshwater river. Direct grazing and sedimentation of phytoplankton to benthic zones provides a rich food source for secondary production of invertebrates that are food for juvenile fishes. The report points out that of the various inputs to the Lower Peace River estuary, phytoplankton represents the largest single primary production component that is a food resource to many filter-feeding and detrital feeding organisms. Due to relatively short generation times, phytoplankton production can have a quick response to freshwater inflow and factors affected by inflow (e.g, salinity, nutrient loading, light penetration). As such, the effects of changes in freshwater inflow on phytoplankton production have important implications for overall estuarine productivity, including many fish species of sport and commercial importance

The study found there were relatively strong positive correlations between chlorophyll *a* concentrations and phytoplankton productivity measured as C_{14} uptake. The lowest correlations ($r \approx 0.4$) occurred in the most downstream harbor segment, with the correlations progressively increasing upstream to an r value of 0.9 in the most upstream river segment above kilometer 27.1. This observation means that most of the spatial and temporal patterns described for chlorophyll biomass can also be generally applied with some exceptions to phytoplankton production.

As has been documented in other tidal rivers, this report documented a relationship between the rate of freshwater inflow and the location of the chlorophyll *a* maximum in the Lower Peace River. The power function listed below was fitted to the relationship between the preceding five-day average flow of the Peace River and the location of the chlorophyll a maximum (Figure 49).

$$\textit{Location of chlorophyll a maximum (kilometers)} = 56.3 * \textit{five-day average flow}^{-0.2626}$$

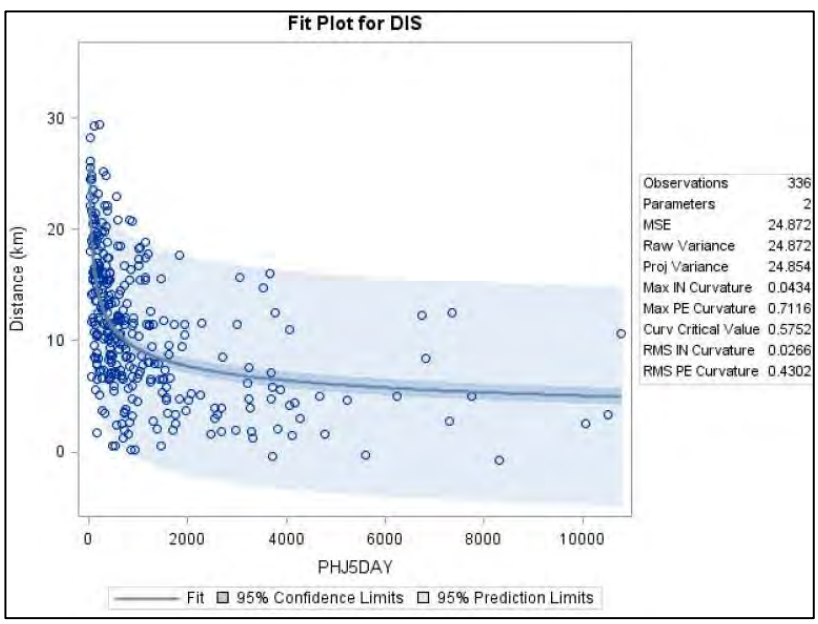


Figure 49. Model fit plot for the power function of the river kilometer location of the chlorophyll *a* maximum with 5-day average flow.

Long-term chlorophyll *a* data from the lower river also show the general relationship between the rate of freshwater inflow and the distribution of chlorophyll *a* values in the tidal river. Box plots of chlorophyll *a* values from five river kilometer intervals in the Lower Peace River are shown in Figure 50 for low flows (0 to 25th percentile flows), medium to moderately high flows (50th to 75th percentile), and high flows (75th to 100th percentile). At low flows, chlorophyll *a* concentrations tend to be highest between river kilometers 10.8 to 27.1, with high concentrations also upstream at kilometer 27.1 As flows increase, there is a clear tendency for higher chlorophyll *a* concentrations to shift downstream. At high flows (75th to 100th percentile), the highest values tend to occur in the two most downstream river segments.

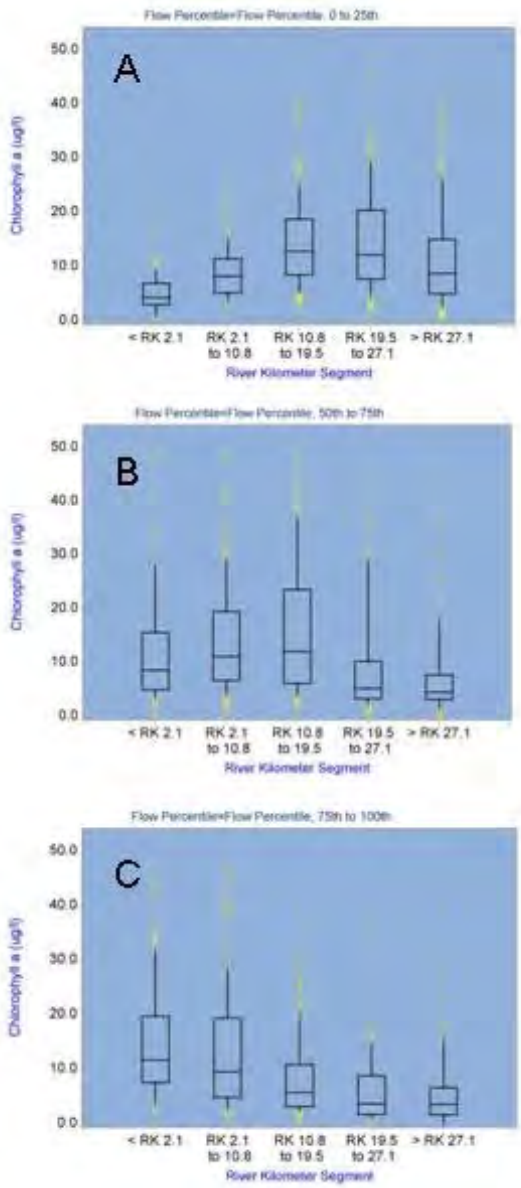


Figure 50. Box plots of chlorophyll *a* concentrations at five river intervals in the Lower Peace River for low flows (A: 0 to 25th percentile), medium to moderately high flows (B: 50th to 75th percentile), and high flows (C: 75th to 100th percentile).

Since phytoplankton form much of the food base in the estuaries, this pattern for chlorophyll *a* concentrations to shift spatially in the river in response to changes in freshwater inflow has important implications for overall estuarine productivity and freshwater inflow management. As inflows decline, the zones of maximum phytoplankton abundance and productivity move upstream into what are typically smaller, more constricted areas of the estuary.

The study therefore focused on the effects of factors related to freshwater inflow that affected the spatial and temporal distributions of chlorophyll *a* and primary production in the river. Freshwater inflow related factors included nutrient loading, residence time, and color, the last of which exerts a strong effect on light penetration. Seasonal factors of solar insolation and water temperature were included in the analysis.

This project calculated a 30-year data base of summed daily nutrient loading rates to the Lower Peace River from the various gaged tributaries (Peace River at Arcadia plus Horse, Joshua, and Shell Creeks). It also incorporated residence time values simulated from a linked two dimensional / three dimensional hydrodynamic model of the Lower Peace River and Charlotte Harbor developed by Dr. Xinjian Chen of the SWFWMD. The residence time term chosen for analysis was water age, or how long a typical particle of fresh water had been in the estuary after entering at the head of the estuary. Output from the SWFWMD hydrodynamic model was used to predict functions that could predict daily values of water ages in two kilometer segments of the lower river. The project also generated values of estimated solar radiation on the Lower Peace River for this same period.

In agreement with the graphical analyses, the report concluded the interactions of these factors vary between the upstream and downstream river reaches. Therefore, a segmented approach is needed to understand the interaction of processes affecting phytoplankton populations in the lower river. When analyzed over the full range of observed flows, chlorophyll/productivity levels were only positively correlated with flow in the two most downstream river segments, reflecting increased nutrient inputs at higher flows. Conversely, chlorophyll/productivity values were negatively correlated with inflow in the more upstream reaches of the lower river, reflecting decreased residence time and the negative effects of water color, which increases with higher flows and reduces light penetration.

Seasonality

Given the typical seasonal pattern of flow in west-central Florida, the highest values for chlorophyll *a* in the most downstream segments of the estuary tend to occur in the fall after summer wet-season flows have delivered large loads of nitrogen to the estuary. The seasonal phytoplankton maxima there typically take place after inflows decline and as tidal flushing reduces water color, allowing for greater light penetration.

In the middle zones of the river (kilometers 10.8 to 19.5), high phytoplankton biomass occurs throughout the year depending on the timing and magnitude of preceding inflows and the combined influence of both water color and residence time. In the most upstream segment (> kilometer 27.1), the occurrence of high phytoplankton biomass occurs in the spring dry season, when increasing solar radiation and water temperature interact with low freshwater inflow that allows sufficiently long residence times but provides enough nutrient load to support increasing primary production in the upper reaches of the estuary.

Principal Components Analysis

Principal Components Analysis (PCA) was performed on the data to examine how multivariate factors interact to influence chlorophyll *a* and primary production rates. PCA provides new generated variables (Factors) that result from optimally-weighted linear combinations derived from an initial much larger number of observed variables. Conceptually, the objective of PCA analysis is to reduce the number of independent variables with the first component capturing most of the observed variance, the second component the next greatest variance, and so on until all the modeled variance has been accounted.

PCA was first run for the entire data set, and then for each of the previously used river segments. A number of differing alternative groupings of potential parameters were tested and evaluated in an iterative process for the entire monitoring transect, as well as for each of the five river segments. Although there were some differences among the river segments relative to parameter loadings, the first three Factors generally contained the following:

Factor 1 - this initial Factor (which accounts for the largest portion of the observed variance) loaded with variables related to freshwater inflow (flow rate, color, nutrient loading and residence time).

Factor 2 - the second Factor accounted for the observed variability due to solar insolation and water temperature.

Factor 3 - this Factor primarily accounted for the day of the year, although within some river segments another parameter was added.

Plotting Factor 1 (flow related) scores vs. Factor 2 (light and temperature) scores showed few differences among the sampling events within the five river segments. However, when Factor 3 scores are plotted against Factor 1 scores (day of year), the observations among the river segments show a pattern of sequential separation (Figure 51A). Thus, flow mediated physical conditions (water age, color, etc.) seem to characterize different segments of the lower river estuary during different temporal intervals (Factor 3). Similarly, chlorophyll vs. Factor 3 scores shows a separation among river segments, indicating different zones of the river respond differently during various seasons (Figure 51B). Thus, the PCA analysis confirmed there are clear temporal differences in how flow related components spatially influence phytoplankton biomass in different segments of the Lower Peace River estuary.

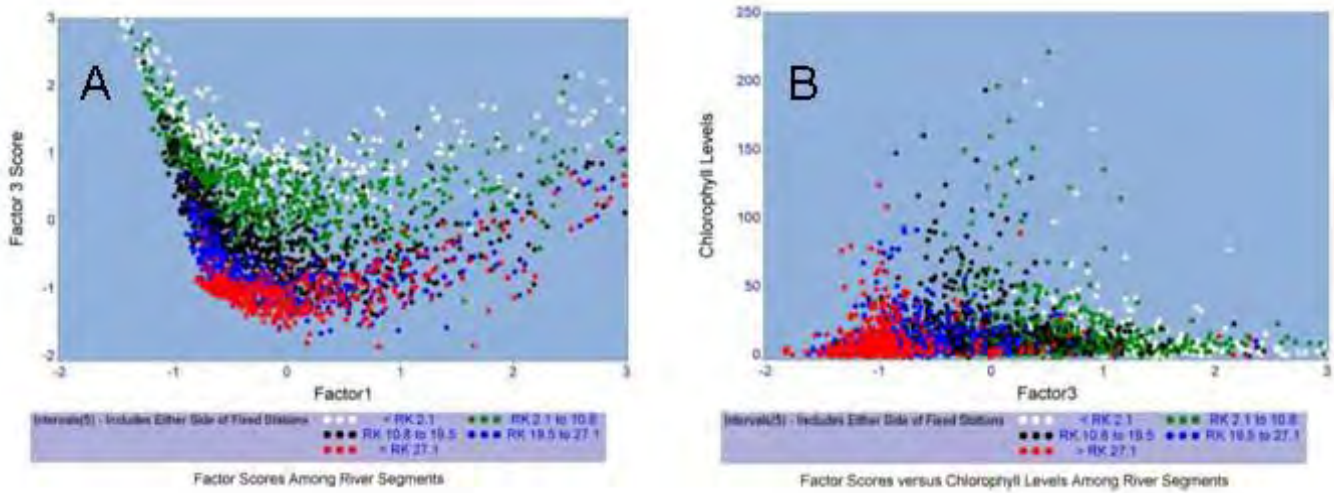


Figure 51. Division of river segments relative to Factor 3 versus Factor 1 scores (A) and chlorophyll *a* concentrations versus Factor 3 scores (B) in the lower Peace River.

RSREG and STEPWISE Analyses Using the Statistical Analysis System (SAS) Software

Using Statistical Analysis System (SAS®) software, the report utilized combined application of the RSREG and STEPWISE procedures to relationships of phytoplankton abundance and primary productivity in the Lower Peace River. Using the RSREG procedure, the interactions of chlorophyll *a* concentrations along the entire monitoring transect and within each river segment were tested against a variety of potential variables. The results of the RSREG procedure were evaluated and potential significant terms, power functions, and interactions were then incorporated into the STEPWISE procedure in order to further test the potential development of additional multivariate modeling.

The results of these combined multivariate procedures indicated a very high degree of variation in temporal/spatial responses of phytoplankton biomass and productivity. This observed high degree of natural variation made additional development of predictive statistical models beyond the results of the applied stepwise regressions of questionable value, since the r^2 values of the initial derived models were low (0.06 to 0.14 for chlorophyll *a* and 0.12 to 0.29 for primary production. Further iterative attempts using liner and nonlinear terms failed to produce useful statistical models that could be predictably applied to estimate chlorophyll biomass within segments of the river.

The results of the combined graphical and multivariate PCA and regression analyses did indicate distinct seasonal flow related temporal/spatial patterns in phytoplankton biomass along the lower river that could conceptually be used for development of resource management strategies. However, the high degree of annual variation made the development and practical application of effective, specific statistically based predictive models that can be used to assess the effect of specific reductions in freshwater inflow, problematic.

3.7 Studies Associated with the Charlotte Harbor National Estuary Program

Because he had been doing research in the Charlotte Harbor watershed since the early 1980s, Dr. Montgomery's expertise was of great value to the Charlotte Harbor National Estuary Program (CHNEP) when it was established in 1996. In the early days of the CHNEP, he participated with others on projects that assessed the existing monitoring programs in the harbor and its watershed and identified management objectives, metrics, and strategies for maintaining or improving the ecological qualities of the Charlotte Harbor ecosystem. Dr. Montgomery often provided data and technical advice to the staff of the CHNEP to assist them in accomplishing their mission. He also gave presentations at several workshops conducted by the CHNEP to address timely scientific and resource management issues concerning Charlotte Harbor ecosystem. Brief technical summaries of the reports that were prepared for the CHNEP and printed abstracts of presentations that Dr. Montgomery gave at CHNEP workshops are provided below.

W. Dexter Bender and Associates, Inc. and Coastal Environmental, Inc. 1997. Compendium of existing monitoring programs in the greater Charlotte Harbor watershed. Technical report 97-03 prepared for the Charlotte Harbor National Estuary Program, Punta Gorda, FL

While employed at Coastal Environmental, Inc., Dr. Montgomery worked on this report which described existing monitoring programs for the Charlotte Harbor NEP study area. Agencies and organizations that had or have such programs were invited to participate in a workshop held in conjunction with a CHNEP Technical Advisory Committee meeting in June 1997. This report built upon the findings of that workshop.

The objectives of this report were:

- To identify and describe all existing land, air, terrestrial and aquatic wildlife and vegetation, and water monitoring programs that pertain to the study area
- To provide a summary of those programs temporally and geographically
- To help identify areas were monitoring is lacking or where protocols are inconsistent
- To assist existing programs in coordinating their efforts and increase understanding of programs across organizations

Although many individual organizations had collected information about Charlotte Harbor's watershed and coastal waters, not all data were known to the technical community. Information had been collected by a wide variety of private and public sector organizations for a variety of purposes. When using data for specific scientific purposes, however, information must be collected through a similar protocol. The report stated for data to be analyzed statistically, sampling sites should be selected by a technique that prevents spatial or temporal bias from being introduced. Also, data sets collected continuously and over long periods of time are more useful than short term or one-time collection efforts .

The report concluded that it would be advantageous for the CHNEP to:

- Have access to large amounts of information about the watershed;
- Encourage organizations to use similar sampling protocols for like data;
- Support long-term, continuous monitoring efforts; and,
- Encourage existing organizations to coordinate data collection efforts and to share data.

The report further stated as a step towards targeting specific issues and selecting strategies for its management plan, the CHNEP should base its analyses on the best available information. Technical programs in the Charlotte Harbor NEP study area were invited to participate and be included in the compendium. This project was intended to ensure that the CHNEP was well-informed with available information and encouraged the coordination of further data collection efforts, especially with regard to protocols, whenever possible.

This report provided an extensive compendium of data collection programs ongoing at that time, either within the harbor or one of its sub-units or in different tributary sub-basins to the harbor. Data collection programs were categorized into living resources, water quality and physical information, habitats, and other. These four types of data collection programs were all grouped by the sub-units or basin(s) in which they occurred (Myakka, Caloosahatchee, Estero Bay, etc.). An extensive index was provided to help readers find in the report information concerning data collection for various biological, physical, and water quality variables.

For each data collection program, one or more summary pages were included that listed the following information:

- Agency
- Contact person
- Status
- Objective
- Approach
- Sample selection
- Sampling effort

As appropriate, maps were reprinted that showed station locations or sampling areas for many of the data collection programs. It is likely that many of the programs that were identified in this report have been modified, dropped, or expanded since the time of that assessment. Regardless, this report provides a useful document of the availability of historical information for the Charlotte Harbor ecosystem and basin which are still valuable today.

Post, Buckley, Schuh and Jernigan, Inc. 1998. Framework for action: Quantifiable objectives and proposed action plan for the greater Charlotte Harbor watershed. Technical Report 98-04 of the Charlotte Harbor National Estuary Program, Punta Gorda, FL

Dr. Montgomery was one of the principal authors of this report which summarized the joint work of the Technical Advisory Committee (TAC) and the Citizens' Advisory Committee (CAC) of the Charlotte Harbor National Estuary Program (CHNEP) that was conducted during an extensive series of workshops in 1997 and 1998 to develop both Quantifiable Objectives as well as an initial list of Priority Action Plans for preservation, restoration, and enhancement of the natural resources within the CHNEP study area. The importance of this effort in the development of the Charlotte Harbor Comprehensive Conservation and Management Plan (CCMP) cannot be overstated, as these Priority Action Plans and the preceding background information gathered during development of the Charlotte Harbor NEP's Quantifiable Objectives formed the technical foundation of the CCMP as well as establish the direction of future management actions for its participants.

In developing the CCMP the staff of the Charlotte Harbor NEP and the members of the Management Conference identified key problems, summarized findings, and determined environmental goals and objectives within each of the Priority Action Plans. It is through these mechanisms that the CCMP serves as a guide for the development of sound alternatives for the management and restoration of natural resources to ensure that both existing and future compatible uses of the watershed are protected.

This Framework for Action report focused on quantifiable objectives for the resources of concern within the Charlotte Harbor NEP study area which include living resources (e.g., fish and marine mammal populations) as well as critical habitats such as seagrass beds, coastal wetlands (e.g. sloughs, salt marshes, mangrove forests), barrier beaches, and functionally related uplands. In consideration of the valuable resources at risk, the Charlotte Harbor NEP has formally established seven goals on which to base the various aspects of the overall program. These are:

1. Improve the environmental integrity of the Charlotte Harbor study area

2. Preserve, restore, and enhance seagrass beds, coastal wetlands, barrier beaches, and functionally related uplands

3. Reduce point and non-point sources of pollution to attain desired uses of the estuary

4. Provide the proper freshwater inflow to the estuary to ensure a balanced and productive ecosystem

5. Develop and implement a strategy for public participation and education

6. Develop and implement a formal Charlotte Harbor management plan with a specified structure and process for achieving goals for the estuary

7. Develop an accessible information management system that integrates data on the Charlotte Harbor study area pertinent to Harbor and watershed management

In order to address these management objectives, the CHNEP identified three priority problem areas which are:

1. Hydrologic Alterations - Adverse changes to amounts, locations, timing of freshwater flows, the hydrologic function of floodplain systems, and natural river flows

2. Water Quality Degradation - Including but not limited to pollution from agricultural and urban runoff, point source discharges, septic tank system loadings, atmospheric deposition, and ground water

3. Fish and Wildlife Habitat Loss - Degradation and elimination of headwater streams and other habitats caused by development, conversion of natural shorelines, cumulative impacts of docks and boats, invasion of exotic species, and cumulative and future impacts

Prior to the preparation of the quantifiable objectives and priority actions plans that were presented in this report, the CHNEP staff, advisory committees, and the CHNEP's consultants completed a series of studies and compilations which in total formed the foundation of information upon which the quantifiable objectives and preliminary priority actions were based. These documents included the Compendium of Existing Monitoring Programs and the Synthesis of Existing Information reports that are summarized in this tribute report to Dr. Montgomery.

A Priority Action is an important environmental management activity which is intended to meet one or more Quantifiable Objectives developed by the Management Conference. Prior to the development of the preliminary Priority Actions, a series of practical and defensible Quantifiable Objectives were developed to address each of the three previously identified Charlotte Harbor NEP Priority Problems. The Quantifiable Objectives presented in this document evolved through an extended series of workshops during which issues and priority problems were discussed. Ballots and rankings by committee members led to the formation and refinement of each of the proposed Quantifiable Objectives. Each quantifiable objective was determined to be technically sound, defensible, objective, and able to be assessed utilizing either existing or planned future monitoring programs. In addition, the quantifiable

objectives address the specific major resource issue(s) which have been identified within the Charlotte Harbor NEP study area.

The report presented a series of tables of issues and quantifiable objectives that were identified during the CHNEP workshops that were conducted to support this effort. For each issue, a group of quantifiable objectives were identified. These in turn were used to develop draft Priority Actions presented in the report which represented a key step to the CCMP development process, since they provide a strategy for how the Quantifiable Objectives will be met. To this end, each of the final Priority Actions should contain a series of key, essential elements including:

- A statement of the Priority Action and its goal
- Brief background of the Priority Action and its rationale
- Where the Priority Action will be implemented
- Strategy for implementing the Priority Action
- Responsible agencies
- Resources required
- Expected benefits derived from the Priority Action, and any drawbacks
- Monitoring the success of the Priority Action
- Regulatory needs
- Related Priority Actions

Based on these criteria, the report presented related information and recommendations for a series of quantifiable objectives and priority action plans for the three priority areas identified by the CHNEP: hydrologic alterations; water quality degradation; and fish and wildlife habitat loss. This information focused on a statement of the quantifiable objective, the CHENP goals, and priority problems addressed by the quantifiable objective, background information and relationship of the quantifiable objective to other related management programs. It is beyond the scope of this tribute report to Dr. Montgomery to identify or describe these many specific objectives and plans. Readers are encouraged to consult this 1998 report to assess the objectives and priority action plans that were identified at that time.

Morrison, G.R., R. Montgomery, A. Squires, R. Starks, E. DeHaven and J.Ott. 1998. Chlorophyll and dissolved oxygen concentrations in Charlotte Harbor: Existing conditions and long-term trends. pp. 201-217 In: Proceedings of the Charlotte Harbor public conference and technical symposium, March 1997. Technical Report 98-02 published by the Charlotte Harbor National Estuary Program. Punta Gorda, Florida

The abstract for this article that was published in the Proceedings of the Charlotte Harbor Public Conference and Technical Symposium, March 15-16, 1998, is reprinted below.

Color levels and concentrations of nitrogen, phosphorus and chlorophyll *a* in Charlotte Harbor exhibit pronounced salinity-related gradients which extend from the head of the estuary to its mouth. In addition to this underlying longitudinal pattern, inputs of nutrient and highly colored fresh water, which enter the Harbor primarily from the north via the Peace and Myakka River basins, provide considerable temporal variability and contribute to the seasonal formation of lateral and vertical concentration gradients. During a recent (1993-1996) monitoring period, seasonal phytoplankton blooms produced maximum chlorophyll *a* concentrations in the range of 60-120 µg/l, primarily in the tidal reaches of the Peace and Myakka rivers and the northern Harbor. Seasonally predictable chlorophyll concentrations of this magnitude are considered evidence of hypereutrophy in some estuarine classification systems. Hypoxia (dissolved oxygen concentrations less than 2 mg/l) also occurred seasonally in 1993-1996. Average concentrations of dissolved inorganic phosphorus (DIP) exceeded the requirements of typical estuarine phytoplankton at all monitoring stations during the years 1993-1996. Average concentrations of dissolved inorganic nitrogen (DIN) also exceeded typical phytoplankton requirements at most stations during the high-flow (July-October) seasons in those years. During the low-flow (November-June) season in the higher salinity portions of the estuary, however, average DIN concentrations fell to levels (<2µM) at which nitrogen limitation is likely to occur for some taxa. In addition to external loadings of "new" nitrogen form the watershed and airshed, monitoring data suggest that DIN concentrations during the high flow season may have been augmented by internal fluxes of "recycled" ammonia-N, presumably generated through bacterial remineralization of organic N and benthic ammonia releases. Available long-term data indicate that concentrations of DIP and TP, although remaining quite elevated, have declined significantly in the Harbor over the period 1976-1996, a pattern reported in previous studies. Dissolved oxygen and salinity levels also showed evidence of statistically significant declining trends over the 1976-1996 period, although these latter trends may represent artifacts arising from methodological differences between the 1976-1990 and 1993-1996 monitoring projects used to construct the long-term data set.

Post, Buckley, Schuh and Jernigan, Inc. and W. Dexter Bender and Associates, Inc. 1999. Synthesis of Technical Information. Volume 1: A characterization of water quality, hydrologic alterations, and fish and wildlife habitat in the greater Charlotte Harbor watershed. Volume 2: Appendices. Report prepared for the Charlotte Harbor National Estuary Program. Punta Gorda, FL

This extensive document synthesizes a great deal of information for the major sub-basins in the Charlotte Harbor watershed and the aquatic and wetland habitats in the sub-units of the Charlotte Harbor ecosystem. Upon its formation, the Charlotte Harbor National Estuary Program (CHNEP) called for the following four major tasks as part of its mission:

1. Establishment of management conference

2. Characterization of the estuary and its watershed (Synthesis of existing information)

3. Establishment of the Comprehensive Conservation Management Plan (CCMP), and

4. Implementation of the CCMP

Following formation of the Management Conference, which was comprised of a series of committees, this report represents completion of task 2 - the characterization of the estuary and its watershed with the corresponding report called the Synthesis of Existing Information. As a scientist with the firm of Post, Buckley, Schuh and Jernigan, Inc. (PBS&J), Dr. Montgomery played a major role in the analyses and writing that comprised this report. He again collaborated with Dr. Thomas Fraser, his former colleague from the Environmental Quality Laboratory, Inc., who was with W. Dexter Bender and Associates when this report was written.

In compiling and analyzing the information contained within this synthesis of existing information document, the focus was to establish the existing background information necessary to address the three priority problems that have been identified as having the greatest potential for degrading the Charlotte Harbor system. These problems are:

1) Hydrologic Alterations · adverse changes to amounts, locations, and timing of freshwater flows, hydrologic function of floodplain systems, and natural river flows

2) Water Quality Degradation · including but not limited to pollution from agricultural and urban runoff, point source discharges, septic tank system loadings, atmospheric deposition, and ground water

3) Fish and Wildlife Habitat Loss · degradation and elimination of headwater streams and other habitats caused by development, conversion of natural shorelines, cumulative impacts of docks and boats, exotic species, and cumulative and future impacts

The CHNEP study area encompasses over 4,500 square miles along the southwest coast of Florida and covers eight distinct sub-areas, or major basins, based on hydrologic, ecologic, and management characteristics. These previously identified basins include those listed below, which are shown in Figure 52.

- Peace River
- Myakka River
- Coastal Venice
- Charlotte Harbor Proper
- Lemon Bay/Gasparilla Sound/Cape Haze Complex
- Pine Island Sound/ Matlacha Pass
- Tidal Caloosahatchee River
- Estero Bay

Within each of these basins, the synthesis report sought to

- Identify and compile relevant sources of information;
- Assess trends in the estuary's water quality, natural resources, and uses
- Assess pollution loadings to the estuary and relate them to obser1ed changes in water quality, natural resources, and land use
- Identify potential environmental problems

For each basin, the report compiled and provided a synthesis of information relevant to the topics listed below. It is beyond the scope of this tribute report to summarize this information for each basin, so as with all references cited in this report, readers should consult the original document for a presentation of these results.

- A characterization of the physical setting, including topographic, geologic, soils, and land use descriptions of the basin
- A review of the rainfall and hydrologic characteristics of the basin
- A review of the water management practices and water uses within the basin
- A summary of current and historical water quality conditions
- An estimation of pollution potential from nonpoint and point sources within the basin

- Text continued on page 118 -

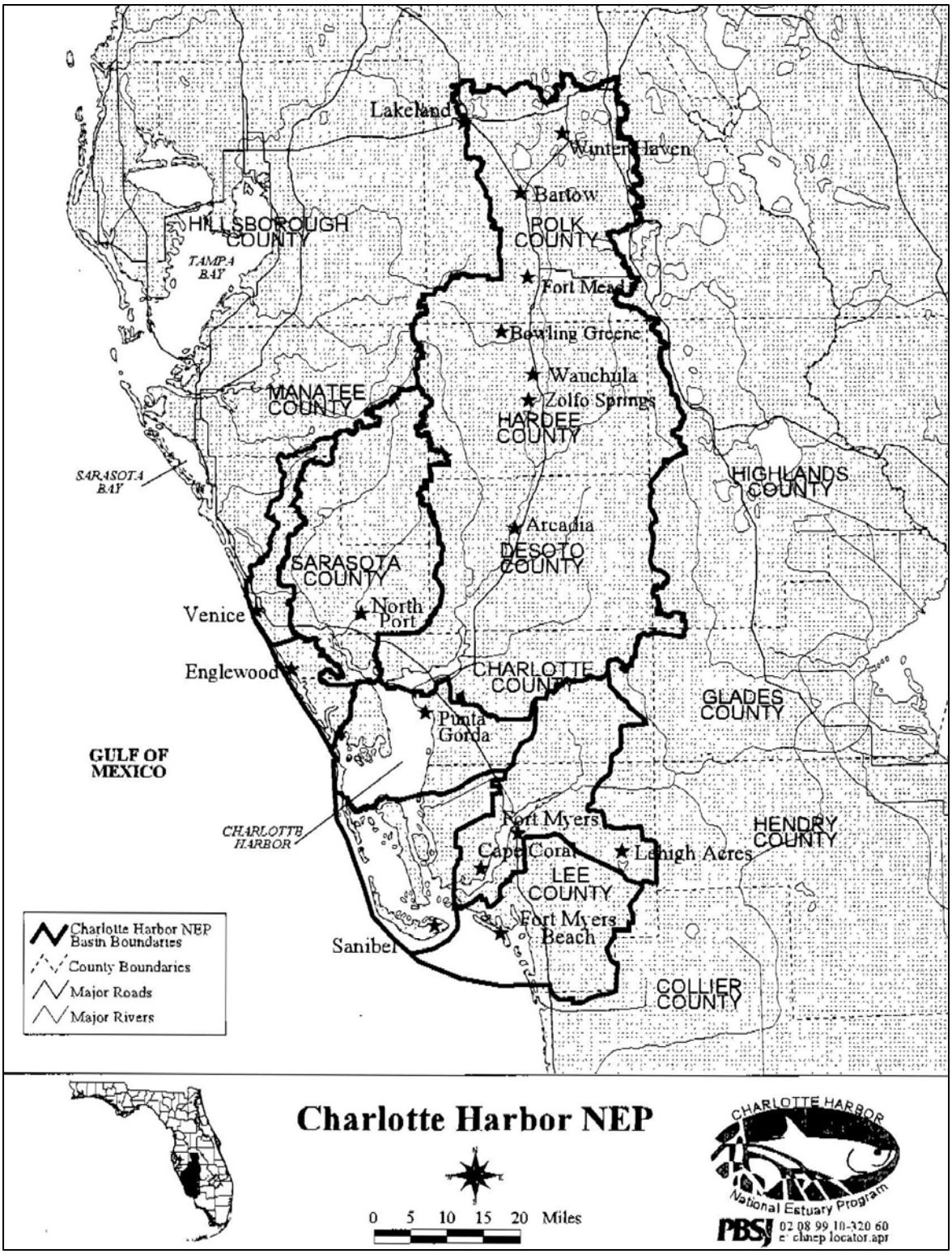


Figure 52. The eight major hydrologic basins that comprise the Charlotte Harbor National Estuary Program.

Assessment of Critical Resources and Habitats in the Charlotte Harbor Ecosystem

The synthesis report also discussed the ecological resources and habitats associated with the Charlotte Harbor estuarine ecosystem. The biological resources that were discussed included fish, marine mammals, benthos, and bird populations. The habitats that were discussed included emergent wetlands (e.g., mangroves and saltmarshes), seagrasses, tidal mud flats, artificial reefs, and shorelines. The report also discussed that these are habitats are most at risk for degradation or loss.

Literature reviews were presented for each of the harbor resources of concern, including life history information for major fish species of sport or commercial importance (e.g., snook, red drum, striped mullet). Information was also presented commercial fisheries data for the region. The report also presented extensive information on the distribution and life history of two marine mammals in Charlotte Harbor, the manatee and bottlenose dolphin. Information was presented on the documented mortality of manatees due to factors such as boat collisions, red tide, and natural causes in the Charlotte Harbor region. Information was also presented for the American crocodile, which is largely restricted to the coastal mangrove swamps and river in extreme southern Florida, including some sights in Pine Island Sound and Estero Bay.

The synthesis report also provided information on commercially and ecologically important invertebrates that inhabit the Charlotte Harbor ecosystem, including blue crab, pink shrimp, American oyster, hard clams, and southern bay scallops. Data for the number of trips and landings of blue crab and pink shrimp were presented.

This report also summarized the life history and ecological significance of a number of important bird species. There are many birds that have special local significance in the Charlotte Harbor NEP area, with the species discussed in the report representing a number of different types of environments and survival strategies. Birds representing wading and diving species, raptor species, and migratory species were included. Detailed information on the distribution and habitat for a number of species was presented, including the eastern brown pelican, white ibis, osprey, and bald eagle.

The distribution of and health of several critical habitats in Charlotte Harbor ecosystem were also discussed. For this analysis, a critical harbor habitat was defined as "the sum of the physical, structural, and vegetative environmental components necessary for the maintenance and reproduction of marine mammals, birds, fish, invertebrates, and other living resources in the harbor." Critical harbor habitats provide the environmental underpinnings the living resources of the estuary need to survive and reproduce, and knowledge of these critical habitats will be the most important source of information for establishing Quantifiable Objectives for the CCMP. The Charlotte Harbor NEP is developing living resource-based Quantifiable Objectives to ensure that the complete sets of environmental requirements of the estuarine life stages of the living resources are met.

In order to focus the CCMP on management-scale planning, the Critical Harbor Habitats were grouped into several comprehensive submerged and emergent habitat types. These groups were based on the dominant physical and vegetation components, and they were centered on habitats at risk. The submerged habitats were defined as seagrasses, oyster reef/hard bottom, tidal/mud flats, and artificial reefs. The emergent habitats were defined as mangroves, saltmarshes, and shorelines. The emergent habitats were as a group termed "Emergent Saltwater Wetlands" in order to distinguish them from the freshwater and tidal oligohaline wetlands discussed under the Inland Habitat section of the report.

Information was presented on the distribution in the different sub-units of Charlotte Harbor where possible, with a series of maps presented for the major habitat types, primarily relying on data available from the Southwest Florida Water Management District and the Florida Marine Research Institute.

Critical Inland Habitats

The report also described important and critical habitats of the inland portions of the major basins of the Charlotte Harbor NEP. Maps of Strategic Habitat Conservation Areas (SHCA maps) and biodiversity "hot spots" were identified for several species. Conservation areas were identified for rare communities (e.g. scrub, pine rocklands), rare plants, wading birds, and bat caves and were included in the strategic habitat conservation areas.

The synthesis report included maps of regional maps of hot spots of biodiversity in the Charlotte Harbor watershed that were prepared by Florida Game and Freshwater Fish Commission (FGFWFC, 1994). Strategic habitat conservation areas maps showed lands needed to meet minimum conservation goals. Individual habitat maps for 44 focal species and rare natural communities highlight potential habitat records from Florida Natural Areas Inventory, the FGFWFC, and other sources were added for other natural resources. Boundaries of public lands were added to show relationships between natural resources and distribution of public ownerships. The 44 focal species serve as indicator species of biological diversity in Florida.

The report also discussed inland resources and habitats that were most at risk, largely from three human activities; population growth and associated residential and commercial development, agriculture, and expanding mining operations for rock/ gravel and phosphate ore. Two species that were determined to be at greatest risk were the Florida scrub jay and the Florida panther. Two inland habitats that were determined to be at the greatest risk were lake and river ecosystems, with Lake Hancock and the Upper Peace River being the specific resources at greatest risk.

Assessment of Management Options

The synthesis report for the CHNEP also presented a large series of potential management options to address priority problems identified for each of the nine major basins in the

Charlotte Harbor watershed. These potential management options were intended to be addressed more specifically for action plans and quantifiable objectives to be developed for other projects to address issues such as flow management, pollutant load reduction, and wildlife habitat loss.

The report included tables that listed topics related to a series of management options for each of the priority basin. For each management option, the objective of the option, the principle behind the option, the basin-specific application of the option, constraints to implementation, potential benefits, and the geographic extent of each potential option were listed in the corresponding tables. It is beyond the scope of this tribute report to summarize these options for any of the priority basins and readers should consult the synthesis report to review the management options that were considered at that time.

W. Dexter Bender and Associates, Inc. 1999. Data Management, Analysis, and Exchange Strategy. Technical report 99-03 prepared for the Charlotte Harbor National Estuary Program, Punta Gorda, FL

Dr. Montgomery assisted Dr. Thomas Fraser of W. Dexter Bender and Associates, Inc. in the preparation of this report. The executive summary from this report is reprinted below.

> The Charlotte Harbor National Estuary Program undertook the development of a Data Management Strategy to provide improved access to data and to effectively communicate research being conducted in southwest Florida. As our region continues to grow, resource management issues increase in complexity. This, in turn, intensifies the need for citizens and scientists to efficiently access information, evaluate resource change, and monitor the quality of the environment.
>
> The Data Management Strategy, a requirement as part of developing a Comprehensive Conservation and Management Plan (CCMP), documents priorities and alternatives for data gaps, data analysis, and data exchange for the greater Charlotte Harbor watershed. During its first year, the program's Management Conference identified and prioritized where data gaps exist, what data exchange needs are, and what data analyses need to be performed. As a result, recommendations were made to establish a regional system to support the exchange of new and existing technical information as well as methods to measure cumulative impacts. This report describes the progress of our data management strategy and presents specific recommendations.
>
> To evaluate the public and scientific communities' data management interests and needs, the Charlotte Harbor National Estuary Program distributed public and technical surveys to citizens and scientists, respectively. The surveys contained questions concerning what types of resource information people use and how they obtain it, their degree of interest in resource topics such as water quality and wetlands, and even their use of the World Wide

Web. The survey results and conclusions of this process are presented in this report. The strategy's purpose is to efficiently provide information to public and technical audiences, to link existing university resources and pertinent web sites, and ensure information is easier to find and in a usable format. The implementation of this Data Management Strategy began in 1999 and will continue through the next several years. As new information is produced, the means of conveying that information must improve and adapt to the needs of citizens and scientists alike.

W. Dexter Bender and Associates, Inc. 2000. Long-term monitoring strategy and gap analysis. Report prepared for the Charlotte Harbor National Estuary Program. Punta Gorda, FL

Dr. Montgomery assisted Dr. Tom Fraser of W. Dexter Bender and Associates, Inc. in the preparation of this report. The Comprehensive Conservation Management Plan (CCMP) is the major product of the planning phase of a National Estuary Program. This report summarized findings of the management conference and including the identification and prioritization of priority problems, environmental goals and quantifiable objectives and action plans with schedules for resource management. These efforts are to protect valued uses of the greater watershed. As priority actions are accepted by agencies as complementary tasks related to their missions and responsibilities, specific monitoring strategies, gaps and points assessments for examining existing management practices are needed.

One of the first steps in CHNEP planning phase was to canvas the existing monitoring programs. A summary of the existing monitoring programs was published by the same authors in 1997. The 1999 report was the initial basis for determining where monitoring gaps exist and identifying which programs might contribute to the implementation phase of the CCMP.

In establishing an overall monitoring strategy, the CHNEP formally established seven goals on which to base the various aspects of the overall program: 1) improve the environmental integrity of the Charlotte Harbor study area; 2) preserve, restore, and enhance seagrass beds, coastal wetlands, barrier beaches, and functionally related uplands; 3) reduce point and non-point sources of pollution to attain desired uses of the estuary; 4) provide the proper freshwater inflow to the estuary to ensure a balanced and productive ecosystem; 5) develop and implement a strategy for public participation and education; 6) develop and implement a formal Charlotte Harbor management plan with a specified structure and process for achieving goals for the estuary; and 7) develop an accessible information management system that integrates data on the Charlotte Harbor study area pertinent to Harbor and watershed management.

The priority problems were hydrology, water quality, fish, wildlife, and flora. The report outlined suggested sampling strategies, experimental design, methodologies, and data

analyses to address these topics, noting that the strategy was similar to EPA EMAP efforts. Data gaps were also noted and an appendix of data analytical techniques was included.

Montgomery, R. and S. Stone. 2003. Differences in long-term Peace River water quality data for the periods 1976-1990 and 1996-2002. p. 23 In: Charlotte Harbor Conference - Focus in 2002-2003 Program Summary. Publication of Mote Marine Laboratory. Sarasota, Florida.

The abstract of this presentation that was given at the 2002 Charlotte Harbor - Focus in 2002-2003 Conference is reprinted below.

On December 10, 1975, the Southwest Florida Water Management (SWFWMD) issued the consumptive permit #7500016 for the Peace River Regional Water Supply Facility. In conjunction with this agreement, a comprehensive hydrobiological monitoring program (HBMP) was set forth to assess the responses of various physical, chemical and biological characteristics of the Charlotte Harbor estuary to changes in Peace River flow. The program was designed to evaluate the impacts and significance of natural salinity changes on the aquatic fauna and flora in Upper Charlotte Harbor, and to determine if freshwater withdrawals by the Peace River Water Regional Water Supply Authority could be shown to alter these patterns. Comparisons are made between spatially collected long-term data collected during the period of 1976-1990 with analogous values measured over the period 1996-2002 in the Lower Peace River/Upper Charlotte Harbor estuarine system.

- Both inorganic nitrite + nitrate and total Kjeldahl nitrogen concentrations indicate very similar seasonal patterns and levels of annual variation over the entire twenty-seven years of monitoring. As expected, spatially inorganic nitrogen concentrations markedly increase moving upstream.

- Most of the apparent marked declines in phosphorus concentrations that have occurred in the Lower Peace River/Upper Charlotte Harbor estuary took place prior to 1985. Since that time, inorganic phosphorus concentrations have shown fairly consistent seasonal patterns over a comparably narrow range of variation.

- Plots clearly show that reactive silica concentrations have both increased and exhibit a much wider range of variation during the recent monitoring period when compared to data collected during the 1976-1990 period. Silica levels are much higher at the upstream sampling sites, and show a strong seasonal pattern in response.

- There has been a marked decline in the very high chlorophyll *a* concentrations "blooms" that commonly occurred during the late 70s and early 80s throughout the Lower Peace River / Upper Charlotte Harbor estuarine system.

Montgomery, R. T. 2004. Analyses of long-term relationships between riparian vegetation patterns and freshwater inflows in the Lower Peace River estuary, 1976-2002. pp. 40-41 In: Charlotte Harbor Conference - Sound Science in 2003-2004 , October 5 - 6, 2004, Mote Marine Laboratory, Sarasota Florida.

The abstract of this presentation that was given at the Charlotte Harbor - Sound Science in 2003-2004 Conference is reprinted below.

The primary object of the analyses were to determine the efficacy and effectiveness of long-term investigations designed to identify potential adverse affects to emergent lower Peace River vegetation and riverine wetlands that might potentially be associated with freshwater withdrawals by the Peace River/ Manasota Regional Water Supply Authority's water treatment facility. Over twenty-seven years of monitoring, the vegetation studies have sought to determine the magnitude of vegetative community's spatial and temporal responses to natural variations resulting from extended periods of both drought and flood along the Lower Peace River. The primary goal of these investigations has been to provide a basis for assessing potential methodologies by which to differentiae between long-term natural changes in riverine vegetative patterns and those that might potentially be induced by Facility withdrawals. The overall objective of the vegetative monitoring HBMP study elements has been to provide a basis for determining the relationships between vegetation patterns and freshwater flows by observing the relative spatial positions and community structure of the freshwater and salt-tolerant plants in the salinity transitional zone of the lower river. The basic assumption has been that a permanent shift of more salt-tolerant plants upriver could be an indication that withdrawals were impacting lower river corridor wetlands, assuming that the effects of natural variability (drought) or other anthropogenic causes could be isolated in the analysis.

Since 1976, at approximately two-year intervals, the spatial first and last occurrences of indicator plant taxa have been recorded along the banks of the Peace River downstream of the facility. Analyses of these long-term data indicate that this information has not been highly effective in determining the potential influences that might be associated with withdrawals. Some species had shown very little variation even following extended periods of high and low flows, while the spatial locations of other taxa have varied considerably as the result of the creation or destruction of shallow shoals along the edges of the river during periods of high flow. The causes of other observed changes were found to be less obvious and clearly indicated the difficulty in determining meaningful relationships between freshwater inflows and the long-tem distribution of many of the riparian taxa that characterize the lower river.

GIS based photointerpretation was further used to conduct change by comparing and assessing differences in the spatial extent of dominant vegetation groups along the lower Peace River following both extended periods of high freshwater inflow (1998) and the recent

extended period of drought (2002). Although fairly substantial differences in the salinity structure characterized the two preceding periods, analyses sowed little differences in the weighted centers of abundance of either the saltwater march or hardwood forest communities along the lower river. These results probably reflect the extensive period of time needed to substantially change the distribution of these communities. While visual observations noted some signs of stress in the hardwood forest community immediately near the river during the driest periods of the extended drought, seasonal periods of higher inflows maintained the relative long-term spatial distributions.

Small upstream movements in the weighted centers of abundances were, however, observed between the two periods in the distribution of mangrove and freshwater marsh along the lower river. To some extent, the upstream movement of mangroves may simply reflect the lack of the occurrence of any sustained hard freezes between the time periods rather than the occurrence of higher salinities during the drought. Historically, the mangroves in this region of the river have been subject to extensive natural die-offs resulting from periodic freezes.

The observed net upstream movement of the weighted center of abundance of freshwater marsh communities following extended wet and dry periods may more directly reflect the influences of increased salinities along the lower river during the extended drought that preceded the 2002 vegetation mapping.

In summary, a comparison of 1998 and 2002 aerial photography using GIS based forward-dating procedures indicates some small changes in the weighted centers of abundance of only two of the major riparian vegetation communities along the Lower Peace River. The measured changes, however, were small in comparison to the differences in the spatial salinity patterns during the extended wet and dry periods that preceded the two selected vegetation surveys. Given these results, it is extremely doubtful whether any quantifiable changes in long-term vegetation patterns along the Lower Peace River will ever be attributable to facility withdrawals, since the magnitude of the predicted influences of facility withdrawals are small relative to the normal ranges of daily and seasonal variations that influences the spatial distributions of these riparian communities.

Montgomery, R. T. and J. Ryan. 2005. Long-term data and nutrient issues within the Peace River Watershed. Slides from presentation given at the Charlotte Harbor Watershed Summit - Lessons Learned from Transferring Science to Watershed Management. CHNEP Watershed Summit - February 14-17, 2005. Charlotte Harbor National Estuary Program. Punta Gorda, FL

This presentation was given at the 2005 Watershed Summit conference sponsored by the Charlotte Harbor National Estuary Program. An abstract for the presentation was not printed in the summary document for the meeting, but a synopsis that was prepared from a review of the slides for the presentation is below. A copy of those slides can be obtained from the CHNEP.

Streamflow trends and water quality characteristics were compared among freshwater stations in the Myakka River watershed and among estuarine stations in the tidal reach of the Myakka River. There are two long-term streamflow stations monitored by the USGS located in the Myakka River watershed. There has been an increasing trend for flows at the long-term gage near Sarasota, due to the influence of agricultural runoff in the upper reaches of the watershed. High conductivity water was observed in Howard Creek and Mud Lake Slough. The highest nitrate/nitrite concentrations were observed in Owens Creek. Comparatively high ortho-phosphorus and low dissolved oxygen concentrations were observed in Howard Creek. Chlorophyll *a* concentrations were highest in Upper Myakka Lake.

Water quality data in the estuarine portion of the Myakka River near the El Jobean bridge were compared for two time periods: data collected during for 1976 - 1990 by the Environmental Quality Laboratory and data collected during 1993-2000 collected by the SWIM program of the Southwest Florida Water Management District. There was a decline in salinity and increase in water color, indicating greater river flow into the estuary between these two periods. Total Kjeldahl nitrogen also increased, while ortho-phosphorus decreased. Similar to but not as pronounced as in the Peace River, there had been an increase in silica at this station. In general, there were significant differences in the water quality of some of the freshwater tributaries and indications of small changes in the water quality of the estuarine reach of the river near El Jobean.

Montgomery, R. T. and S. Stone. 2007. Changes in land use in the Peace River watershed an CDOM in the Lower Peace Watershed and Upper Charlotte Harbor. pp. 35-37 In: Colored Dissolved Organic Matter (CDOM) Workshop Summary. Charlotte Harbor National Estuary Program CDOM workshop May 29-30, 2007. Technical document 07-03 of the Charlotte Harbor National Estuary Program, Punta Gorda, FL.

The text of this abstract for this presentation that was presented at the 2005 CHNEP Colored Dissolved Organic Matter (CDOM) Workshop is reprinted below. However, three figures, one map, and one table that were included in the original abstract are not reprinted.

By the 1940s, only 15% of the Peace River watershed had been developed or cleared: 60% was native uplands; 25% wetlands. By 1979, half of the native uplands had been cleared at a rate of 14 square miles (land sections) per year, and wetlands went from covering 25% of the watershed to 18%. By 1999, native uplands were reduced to 17% from 30%, and additional wetlands were also lost. Agriculture was the main developed land use in the 1940s; mining and urban were still quite small. By 1979, however, cleared agricultural land was 40% of the watershed and mining and urban represented 5% of the land use each. Cleared agricultural land comprised 44% of the watershed in 1999 with urban and mining representing about

10% of the watershed each. Thus, there have been major land use changes in the Peace River Watershed, and the largest of these changes pre-date most available water quality data (e.g., color).

Color appears to be increasing in the upper Peace River basin since the mid 1960s. Color also appears to be increasing at the lower Peace River monitoring station since the 1960s. These changes in color concentrations are associated with changes in flow conditions and are not a result of land use change. Apparent increases in color in the upper and middle watershed are associated with declines in groundwater discharges by mining and local springs. Apparent recent increases in color in the lower river and upper Charlotte Harbor estuary correspond with increases in wet-season. However, long-term changes in water quality characteristics such as orthophosphate and silica levels may be related to recent changes in land use.

Montgomery, R., D. Tomasko, and S. Stone. 2009. Off-stream reservoirs combined with percent flow withdrawal schedules to reduce downstream estuarine impacts. p. 54 In: Workshop on watershed reservoirs: locations, effects and solutions. Workshop summary report. Charlotte Harbor National Estuary Program workshop on watershed reservoirs, April 13-15, 2009. Charlotte Harbor National Estuary Program, FL. Punta Gorda, FL.

The abstract of this presentation that was given at the 2009 Workshop on Watershed Reservoirs: Locations, Effects and solutions Conference is reprinted below:

Historically, larger public drinking water supplies in southwest Florida relied on groundwater well fields or the construction of typical in-stream reservoirs (Hillsborough River, Lake Manatee, Shell Creek). However, by the late 1970s the lack of suitable locations and an increasing concern relative to the environmental impacts posed by in-stream structures began to lead both utilities and regulators to seek potential alternatives. In 1976, the Southwest Florida Water Management District granted a permit to construct a surface water treatment facility on the lower Peace River with the condition that adequate off-stream wet-season raw water storage be constructed to limit withdraws during seasonally drier periods. In 1988, the Peace River Facility's water use permit was modified to include a year round low flow cutoff, combined with a ten percent diversion schedule and a maximum cap on withdrawals. These changes to the Facility's permitted freshwater withdrawal schedule were designed to allow withdrawals to track actual natural variations in flows above the permitted threshold. An integral, critical component of such a variable schedule that matches withdrawals with actual changes in river flows has been the Facility's off-stream reservoir storage. An additional 6 billion gallon off-stream reservoir is scheduled for completion in mid-2009 to meet increasing regional demands.

While the annual average hydrographs of stream flows in southwest Florida generally follow distinct patterns based on characteristically dry and wet seasonal rainfall patterns, the actual seasonal patterns and variability of flows within any given year can be extremely variable. This is clearly evident in comparisons of Peace River flows over the past 5-year (2004-2008) time interval. Within estuarine systems such as the lower Peace River/upper Charlotte Harbor, the overall relationships between such variability in freshwater inflows and the spatial and temporal dynamics of both physical habitat characteristics and the resulting structure of biological communities are complex and mediated through a number of intermediary processes.

Research by the Nature Conservancy has recently addressed the necessity of balancing the needs for surface water withdrawals for public supply with maintaining the magnitude and timing of ecological flows to protect estuarine biological communities. Key components of their recommendations center on maintaining periods of both maximum as well as minimum base flows, as well as protecting flows during periods identified as critical to specific estuarine biological resources.

Since 1976 the permit for the Peace River Water Treatment Facility has required the implementation of a hydrobiological monitoring program (HBMP) to both assess the overall "health of the harbor" by tracking the long-term changes in physical and biological characteristics, and evaluate the magnitude of potential changes due to Facility withdrawals relative to natural seasonal and longer term variations in freshwater inflows. The results of over 30-years of HBMP monitoring have clearly identified critical periods relative to estuarine production when the estuary has greater sensitivity to withdrawals, and conversely extended intervals when the potential impacts of withdrawals are greatly reduced. The use of off-stream reservoirs provides the Facility with the opportunity to harvest water from the river at the appropriate time and the appropriate quantities to reduce potential estuarine impacts.

- Text Continued on Page 128 -

3.8 RALPH Plots and Inundation Simulations - Analyses Conducted to Support the Minimum Flows and Levels Program of the Southwest Florida Water Management District

While employed at the firms of PBS&J and then Atkins, Inc., Dr. Montgomery performed analyses in support of minimum flow studies conducted by the Southwest Florida Water Management District. Minimum flows are defined in Florida Statutes as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." In keeping with this legislative directive, the minimum flow studies conducted by the SWFWMD determine how much water can be removed from a stream or river without causing significant harm to the ecological resources of that ecosystem.

The work conducted by PBS&J for these studies concentrated on the hydrologic relationships of instream habitats and floodplain wetlands associated with the various rivers that included the Alafia, Peace, Anclote, Withlacoochee and Hillsborough Rivers. Dr. Montgomery specifically worked on an analytical hydrologic technique that was named after him - RALPH plots, which is the abbreviation for Recent and Long-Term Positional Hydrographs.

RALPH plots and related statistical analyses utilize the output of HEC-RAS modeling and long-term streamflow records to evaluate the inundation characteristics of instream and floodplain habitats located various distances from a streamflow gage. HEC-RAS is a one-dimensional hydraulic model that is used to evaluate water levels at different locations in a stream channel for various rates of flow. HEC-RAS output generated by other firms was provided to Dr. Montgomery for a series of locations where there were surveyed lateral transects across the channel and floodplain on each river. At each transect, the HEC-RAS output was used to generate a stage discharge relationship at that location in the river.

An example of this approach for a site on the Upper Peace River is shown in Figures 53A and 53B. The output from HEC-RAS model runs for twenty-eight rates of flow at the Peace River at Bartow gage were used to create a stage-discharge relationship for site #150 on the river channel where a surveyed transect across the river floodplain had been conducted (Figure 53A). Using a curve fitted to these model results, the rate of flow necessary to inundate a specified elevation along a surveyed transect at that location was determined. The SWFWMD chose elevations for analysis based on the distribution of physical and ecological features along each transect, such as the median elevation of cypress swamp at that location in the river floodplain.

Once the rate of flow necessary to inundate a reference elevation was determined, regression analysis was used to develop a predictive equation so that the flow at the long-term gage that corresponded to the specified flow at the transect site could be determined (Figure 53B). Then, using long-term streamflow records, statistics were generated identifying the duration that the reference elevation was inundated over various time periods, with yearly values having the greatest utility for applied analysis.

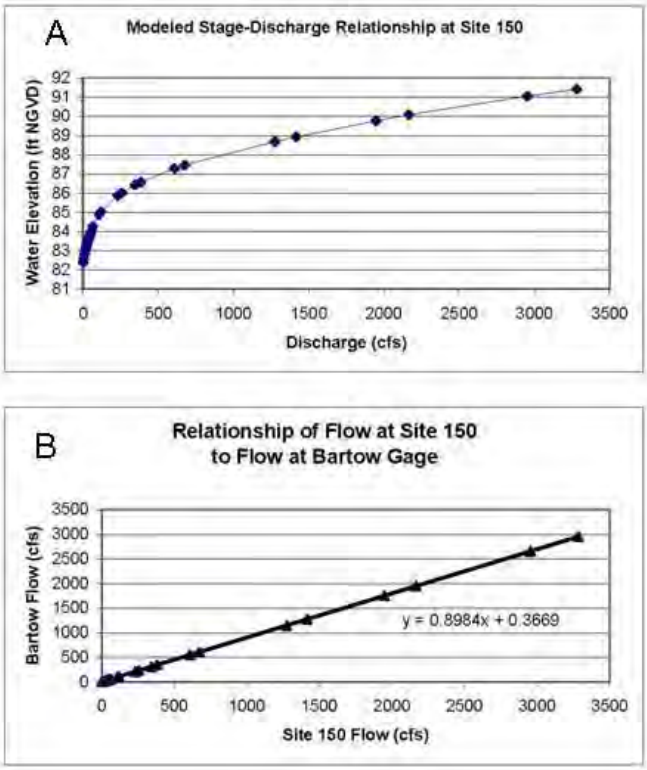


Figure 53. Examples from the Upper Peace River of HEC-RAS model output used to (A) generate a stage discharge relationship at a transect location and (B) convert the modeled flow at the study site to measured flow at the nearest streamflow gage. Reprinted from SWFWMD (2002).

Two examples of long-term yearly inundation durations for an two instream and floodplain habitats in the Upper Peace River that were estimated using this method are shown in Figures 54 and 55. Although changes in channel morphology can affect these relationships over time, this type of analysis presents valuable information for how the inundation durations of riverine habitats may have been affected by changes in flows, with the experimental assumption that channel morphology did not change.

As described elsewhere in this report, there have been significant declines in flows in the Upper Peace River, which is reflected in dramatic estimated reductions over time in the inundation of instream exposed root habitats (Figure 54) and cypress swamps (Figure 55) at two sites in the Upper Peace River near Bartow. Since the longest period of inundation was calculated for the year in which the period ended, the longest period of inundation in some years could exceed the total days of inundation (e.g., late 1950s Figure 55).

Dr. Montgomery's application of RALPH analyses to estimate inundation statistics of floodplain habitats in the Upper Peace River was included in a presentation given at the Annual Conference of the Society of Wetlands Scientists in 2002. This presentation (Latham et al., 2002), which was prepared with colleagues from PBS&J and SWFWMD, won an award for technical excellence. The award poster, which includes the abstract for the paper, is shown in Figure 56 on page 131.

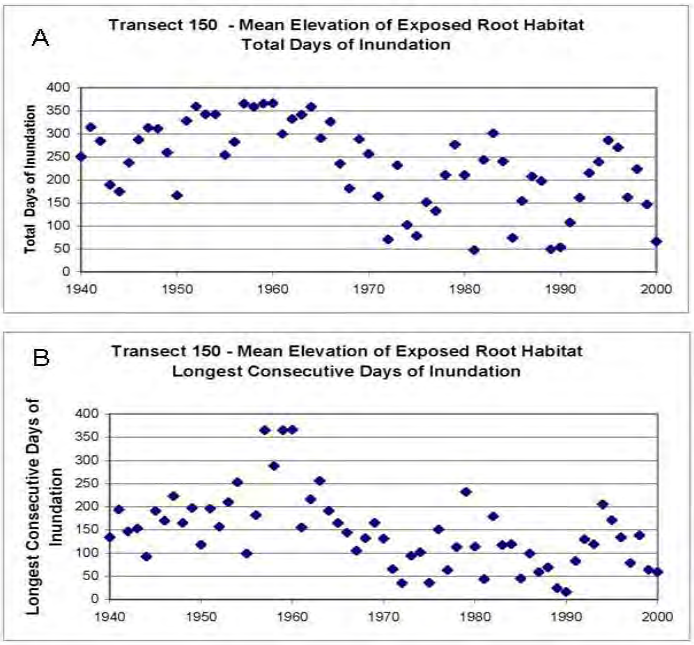


Figure 54. Estimated values for the (A) total days of inundation and (B) longest consecutive days of inundation per year for the mean elevation of exposed root habitat at transect 150 in the Upper Peace River (reprinted from SWFWMD 2002).

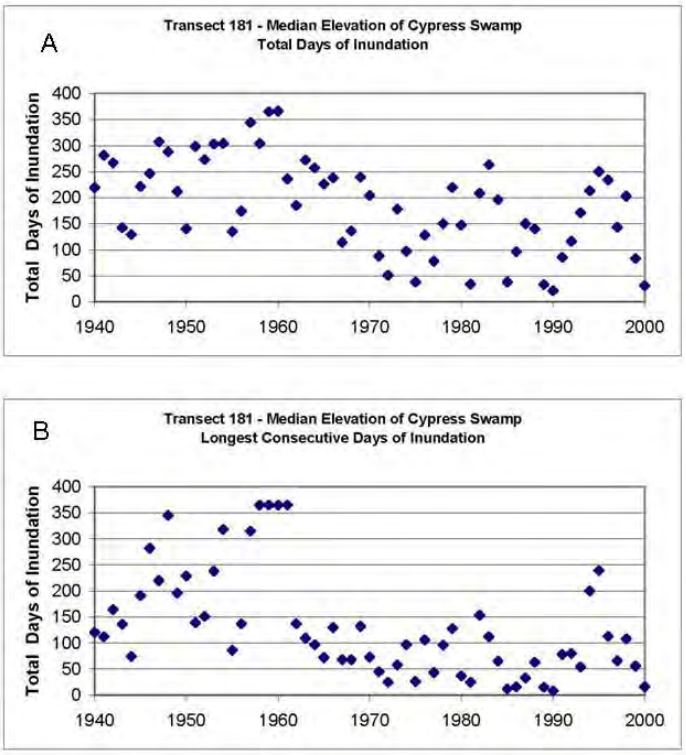


Figure 55. Estimated values for the (A) total days of inundation and (B) longest consecutive days of inundation per year for the median elevation of cypress swamp at transect 181 in the Upper Peace River (reprinted from SWFWMD 2002).

TECHNICAL PAPER AWARD

Establishing Minimum Flows for the Upper Peace River, Florida

Authors
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ABSTRACT

Presented at the Society of Wetland Scientists 23rd Annual Conference: Wetland Linkages – A Watershed Approach, Lake Placid, NY, June 4, 2002.

Florida water management districts are required to establish minimum flows and levels at which further withdrawals would be "significantly harmful" for state waters. Historic modifications (e.g., dams) must also be considered, and are important to the Peace River, which has undergone substantial declines in flows since the 1960s.

The purpose of this study was to evaluate vegetation, soils, elevation, and hydrologic conditions in wetlands along the upper Peace River and use this information in identifying criteria for establishing minimum flows for the river. Species composition, soil characteristics, and elevations were measured and evaluated at 15 transects along the upper Peace River. Hydrologic analyses were used to evaluate periods of inundation.

Results. Three distinct plant communities were identified: swamps (semi-permanently flooded), lower floodplains (seasonally flooded), and upper floodplains (intermittently flooded). Vegetation transitioned downstream from semi-permanently flooded to temporarily flooded, and swamp communities were limited to upstream portions of the study corridor. Wetland vegetation was generally consistent with the occurrence of hydric soils and lower elevations.

Swamp and lower floodplains were characterized by hydric soils. Upper floodplains, especially those below Ft. Meade, indicated flooding, but were generally not hydric.

Historic median flows (1940-1956), total days of inundation, and consecutive days of inundation, were greater than more recent flows (1987-1999) for all vegetation communities. Hydrology was site specific: flows were greater upriver, and were affected by smaller events. Flows required to inundate floodplain communities were greater than existing flows. Predicted inundations requirements, based on vegetation distribution, were similar to those described for other river floodplains.

Conclusion. Floodplain vegetation along the upper Peace River reflects a variety of environmental conditions, including historic flooding, micro-topography, soils, rainfall, and runoff, in addition to flooding. Floodplain forests also respond very slowly to changes in hydrologic regime. Based on the results of this study, the extent of floodplain vegetation alone cannot be used as the criterion on which to base minimum flows in the Peace River.

1. Southwest Florida Water Management District

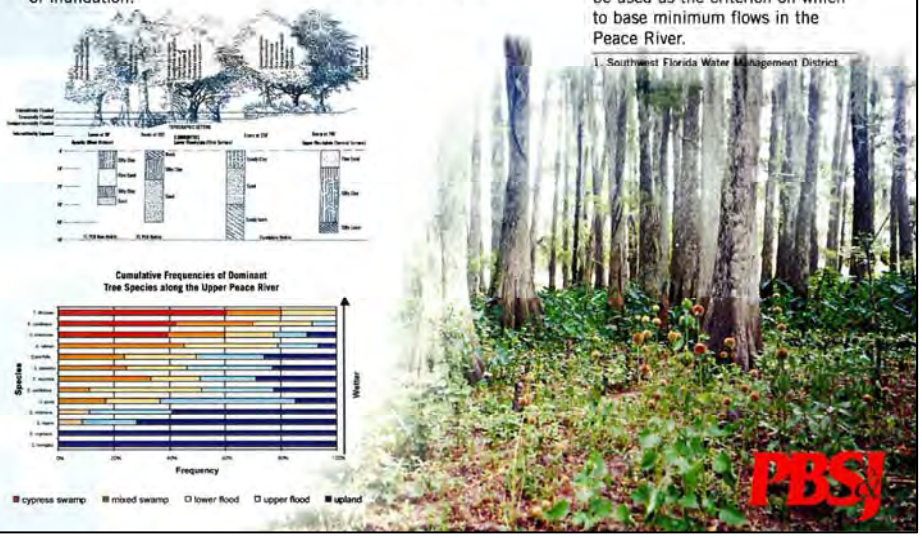

Figure 56. Technical paper award for excellence for a presentation about the inundation of floodplain habitats as part of the determination of minimum flows for the Upper Peace River, presented at the 2002 Annual Conference of the Society Wetland Scientists - Wetland Linkages - A Watershed Approach (Latham et al., 2002).

RALPH analyses have also been used to estimate the potential impacts of future water supply withdrawals on the inundation of instream and floodplain habitats. Again, by applying HEC-RAS model output to a series of measured river cross-sectional transects, the effects of reducing present-day flows at a streamflow gage on the inundation of instream and floodplain habitats at various locations in the river can be determined.

Along with other analytical tools, the SWFWMD has used this method to determine allowable percent flow reductions for freshwater streams within their jurisdiction. An example of the flows required to inundate the mean elevation of exposed root habitat at ten transect locations in the Little Manatee River is shown in Table 15, along with the maximum allowable flow reduction that would not reduce the days of inundation of these habitats at each transect by more than fifteen percent (SWFWMD, 2011a).

Table 15. Mean elevation of instream exposed root habitat at various surveyed cross-sections in the Little Manatee River, with corresponding flows at the Little Manatee River near Wimauma gage required for inundation of the mean elevations and the maximum percent-of-flow reductions associated with less than a 15% reduction in the number of days sufficient to inundate the mean habitat elevation (Adapted from SWFWMD 2011a).

Habitat	Site	Mean Elev (ft NAVD)	Flow (cfs) Required at Wimauma Gage for Inundation	Allowable Percent of Flow Reduction
Exposed Roots	Veg 3	4.38	148	11
Exposed Roots	Lman 7	3.86	88	14
Exposed Roots	Masonic	4.68	83	20
Exposed Roots	Lman 6	3.53	31	Below LFT
Exposed Roots	Veg 2	4.66	77	19
Exposed Roots	Toscana	6.79	55	15
Exposed Roots	Veg 10	17.19	74	21
Exposed Roots	Lman 3	20.69	49	15
Exposed Roots	Veg 14	38.73	207	11
Exposed Roots	Veg 15	39.28	110	18
			MEAN	**16**

The use of RALPH plots and analyses have been reviewed by the scientific review panels that have reviewed minimum flows reports prepared by the SWFWMD. Their use has been endorsed by these panels, for a stated by the panel reviewing the minimum flows report for the middle segment of the Alafia River - "As a means of analysis and graphical visualization, the panel feels that the RALPH plots are an important enhancement to the presentation of MFL for riverine systems and we recommend that the District continue to utilize and refine this tool for future MFL development" (Cichra et al., 2005).

3.9 Studies of the Hydrology and Water Quality of Shell Creek Conducted for the City of Punta Gorda

The City of Punta Gorda has used Shell Creek as a source of potable water supply since the 1940s. Shell Creek is the largest tributary to the Lower Peace River, flowing into the Peace about 14 kilometers upstream of the river mouth, upstream of the Interstate 75 bridge (Figure 57). Withdrawals by the City are made from a small reservoir that is formed by the Hendrickson Dam, which is a low head structure with a spillway elevation of near 5.1 feet NGVD.

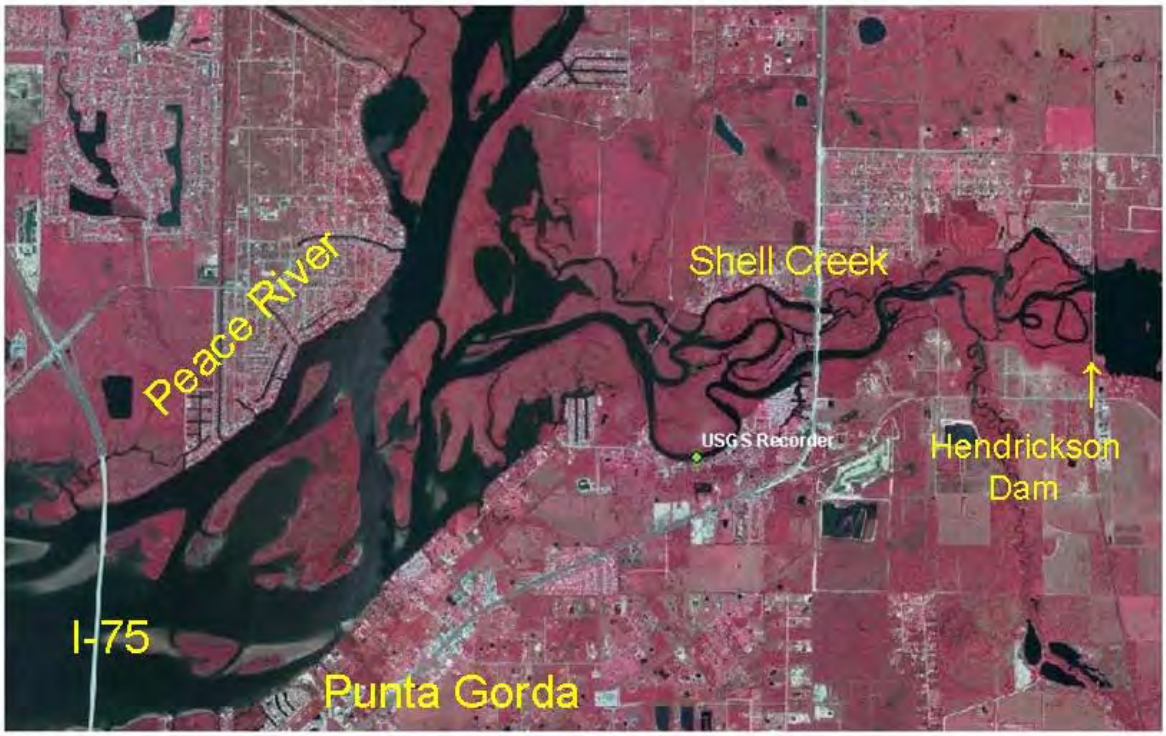

Figure 57. Location of Shell Creek and the Hendrickson Dam in relation to the Lower Peace River and the northern areas of the City of Punta Gorda.

The City of Punta Gorda (the City) has been issued water use permits by the SWFWMD since 1976 to use Shell Creek for water supply. The current water use rates permitted to the City are an average annual withdrawal not to exceed 8.09 mgd (12.5 cfs) and a peak monthly rate not to exceed 11.7 mgd (18.1 cfs). Actual yearly water use averaged between 4.6 and 5.6 and mgd (7.1 to 8.7 cfs) for the years from 2005 to 2010.

As part of their water use permit to withdraw water from Shell Creek, the City of Punta Gorda was required in 1991 to begin a Hydrobiological Monitoring Program (HBMP) for Shell Creek. This program primarily involves the collection of vertical profile and water quality data in the tidal reach of Shell Creek and water quality data within the Shell Creek reservoir behind the

Hendrickson Dam and two upstream tributary sites. Data were also made available from other sources for freshwater tributaries to Shell Creek reservoir to assess how the quantity and quality of water flowing into the reservoir has changed over time.

Three reports concerning the HBMP were prepared for the City of Punta Gorda Utilities Department by the firm of PBS&J, Inc. between the years 2001 and 2010. Serving as the project manager for PBS&J, Dr. Montgomery was the principal author of all three reports. Two of the reports (PBSJ, 2003; PBS&J, 2015) were required by the SWFWMD as requirements of the HBMP. These reports assessed: (1) the status and trends of flow, salinity and water quality in the Shell Creek system; (2) relationships of freshwater flow from the Shell Creek Reservoir with salinity and water quality in the tidal reach of Shell Creek; and (3), the effects of the City's withdrawals on freshwater flow on and salinity water quality in the tidal reach of the creek.

The third report was prepared jointly for the City of Punta Gorda and the Peace River Manasota Regional Water Supply Authority to examine the effects of increasing the quantities of water that could be withdrawn from Shell Creek. This effort was to investigate ways of meeting the expected gap between the water needs of the region and the combined quantities that were permitted from the Peace River and Shell Creek at that time. This report is commonly known and the GAP report (PBS&J, 2007).

The technical approach and of content of these three reports are similar, so the technical summary presented below principally concerns the latter of the two HBMP monitoring reports, with some findings from the GAP report and the earlier HBMP report presented as well. Citations for these three reports are listed below, on the next page, and in the bibliography. All three reports can be accessed from the City of Punta Gorda Water Utilities Department or the Regulatory Division of the Southwest Florida Water Management District.

All three reports are very detailed in their presentation of results and are excellent sources of information concerning the hydrology and water quality of the City of Punta Gorda Reservoir, the two principal tributaries to the reservoir, and the tidal reach of Shell Creek. Any researcher or resource manager who is working on Shell Creek should consult these reports. As with all publications summarized in this tribute report, readers should consult the original documents before describing or otherwise citing their findings.

PBS&J, inc. 2003. Shell Creek HBMP Summary Report - 2001. Report prepared for the City of Punta Gorda Utilities Department, submitted to the Southwest Florida Water Management District. Originally submitted in 2001 and revised in 2003.

PBS&J, 2007b. Inc. Assessment of Potential Shell Creek Impacts Resulting from Changes in City of Punta Gorda Facility Withdrawals. Report prepared for the Peace River Manasota Regional Water Supply Authority and the City of Punta Gorda Utilities Department, submitted to the Southwest Florida Water Management District.

PBS&J, Inc. 2010. City of Punta Gorda Shell Creek HBMP Five Year Comprehensive Summary Report. Report prepared for the City of Punta Gorda Utilities Department, submitted to the Southwest Florida Water Management District.

As previously discussed, the summary below principally describes the most recent HBMP report for the City's HBMP (PBSJ, 2010), for it presents the most updated information for the Shell Creek system. However, some findings from the 2007 GAP report (PBSJ, 2007) and the earlier HMBP report (PBSJ, 2003) are described as they supplement or otherwise pertain to the most recent published HBMP report. The objectives of the Shell Creek HBMP reports are to address:

- The status and trends of hydrologic conditions in the Shell Creek watershed, which includes Prairie Creek, the largest tributary to Shell Creek.

- Temporal and spatial patterns of water quality characteristics upstream of the Hendrickson Dam, summarizing differences in water quality between the Prairie Creek and Shell Creek systems and relationships with flow.

- The salinity and water quality characteristics of the tidal reach of Shell Creek downstream of the dam and relationships with the rate of freshwater flow.

- Changes in freshwater inflow to the tidal reach of Shell Creek that result from withdrawals by the City of Punta Gorda and evaluate the effects of these withdrawals on salinity in tidal reach of the creek.

- Potential changes in the HBMP

A fixed station design was used to measure *in situ* water quality profiles (e.g., salinity, pH, dissolved oxygen) at 16 stations in the tidal reach of Shell Creek and two nearby stations in the Lower Peace River. Surface water samples for nutrients and other parameters (e.g., color, chlorophyll *a*, total suspended solids) were collected at six of these stations in the estuary and taken to the laboratory for analysis. Three full water quality stations were also located in fresh water; Station 1 in Prairie Creek, Station 2 which is Shell Creek above the confluence with Prairie Creek, and Station 3 in the Shell Creek reservoir. Light penetration was measured at all stations as extinction coefficient or Secchi Disk. A table of the constituents measured at each of the sites is shown in Table 16, with a map of the stations shown in Figure 58.

Table 16. Water quality parameters measured at stations as part of the Shell Creek HBMP

	Sampling Location																		
Parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Physical *In Situ* Profiles	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Water Chemistry (surface)	■	■	■	■	■	■	■	■	■										
Secchi Disk Depth	■	■																	
Extinction Coefficient *			■	■	■	■	■	■	■										

* Since November 2005 Test America has done just Secchi Disk depth at all sampling sites

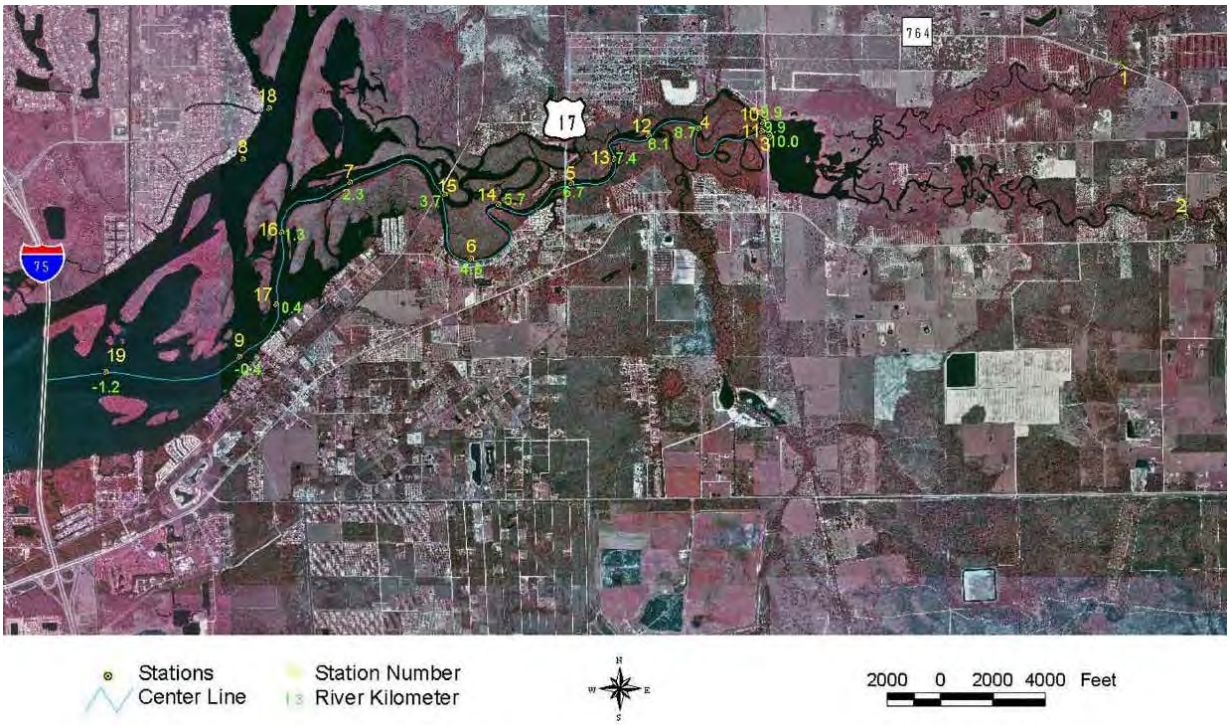

Figure 58. Water quality sampling stations (yellow) for the Shell Creek HBMP and kilometers from the mouth of Shell Creek (green). Water quality stations 1,2 and 3 are at freshwater sites.

Streamflow Trend Analyses

The 2010 HBMP Summary report presented hydrographs and the results of trend analyses for a variety of streamflow parameters at the USGS streamflow gage Shell Creek near Punta Gorda, which measures flow over the Hendrickson Dam. Flow records for complete years at this site began in 1966, providing 45 years of record through 2009 at the time of the analysis. Trends were examined for actual flows at the dam and flows in which the City's withdrawals were added back into the flow record.

There were no significant trends observed for any of the flow parameters over the period of record. Hydrograph of yearly 10th percentile flows (flow that is exceeded 90% of the time within each year) and yearly median flows at this gage are shown in Figures 59 and 60. Peak values were observed between 1993 and 1995 for the 10th percentile flows and in the late 1960s and the early to mid 1990s for the yearly median flows. Declines in both parameters were observed between 2006 and 2009, which all had well below average rainfall. These results differed from that presented in the 2003 report, which listed significant increasing trends for some flow parameters. The dry years from 2006 to 2009 likely strongly influenced these updated results. It is also pointed out that wet years have occurred from 2012 to 2015, which are not captured in the 2010 HBMP report. Updated trend analyses will be prepared for the next HBMP report.

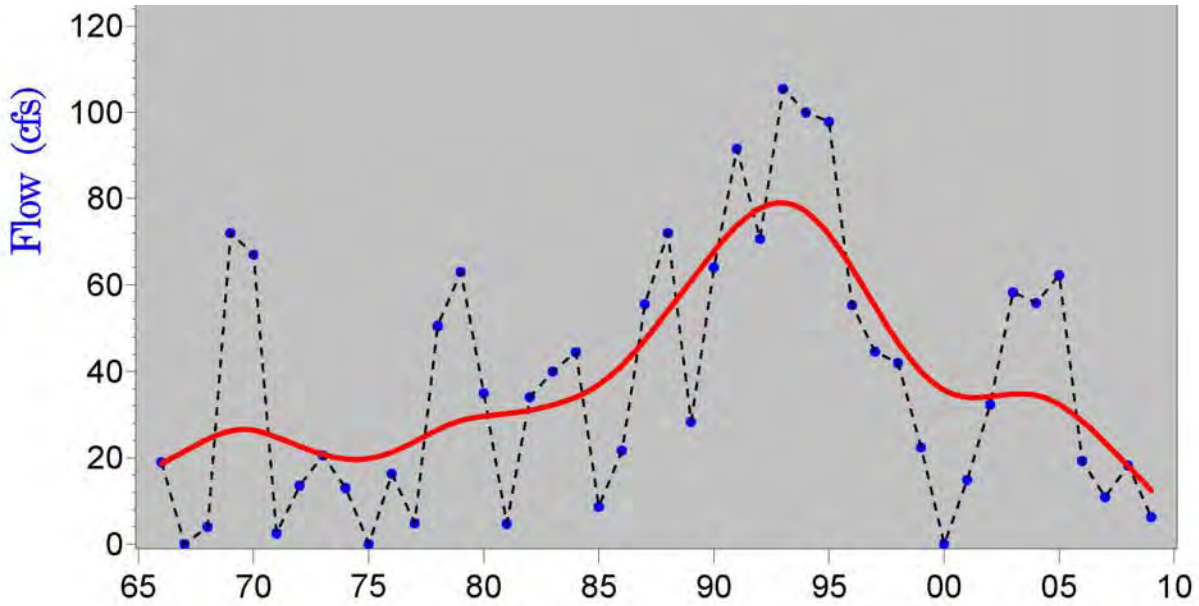

Figure 59. Yearly 10th percentile flows at the USGS Shell Creek near Punta Gorda gage for 1966 to 2009 with a smoothed trend line (withdrawals not added in).

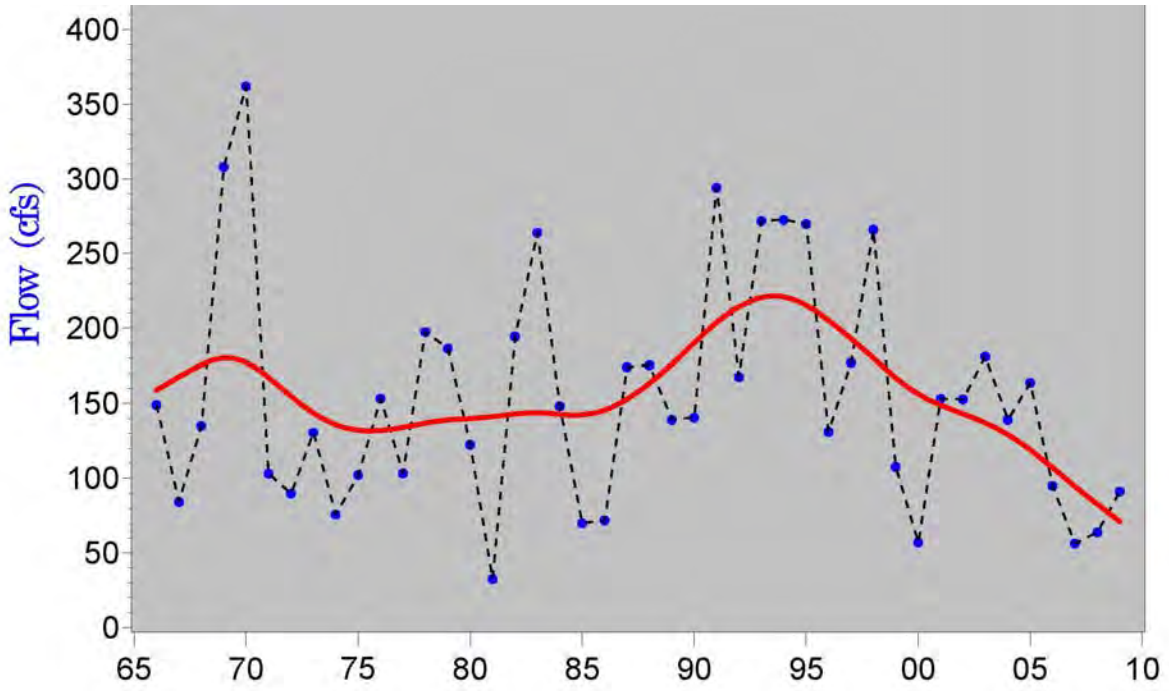

Figure 60. Yearly 50th percentile (median) flows at the USGS Shell Creek near Punta Gorda gage for 1966 to 2009 with a smoothed trend line (withdrawals not added in).

The 2010 report also discussed observed increases in specific conductance in the freshwater reaches of Shell and Prairie Creeks due increasing mineralization of these streams from runoff from agricultural operations, which irrigate crops with ground water pumped from the Upper Floridan aquifer. The report discusses the Shell Creek and Prairie Creek Watersheds Management Plan report that was prepared in 2004 by the SWFWMD and the Florida Department of Environmental Protection (SWFWMD, 2004). The purpose of that report was to develop strategies to provide reasonable assurance that the water quality in Shell and Prairie Creeks would be restored and maintained to meet water quality set forth in the Florida Administrative Code that states "Specific conductance (micromhos/cm) shall not be increased more that fifty percent above background or to 1,275, whichever is greater. "

While specific conductance does not have a corresponding drinking water standard, specific conductance does correlate with total dissolve solids (TDS), which have a secondary drinking water standard of 500 mg/l. Management experience has shown that the specific conductance at the City of Punta Gorda's water treatment plant on Shell Creek needs to be below about 673 µmhos/cm to meet the 500 mg/l TDS standard. The 673 and 1275 µmhos/cm values are shown as dotted reference lines in Figure 61, in which times series of daily specific conductance values are plotted for four gage sites measured by the USGS in the Shell/Prairie Creek watershed from 2004 to 2009. Specific conductance values were

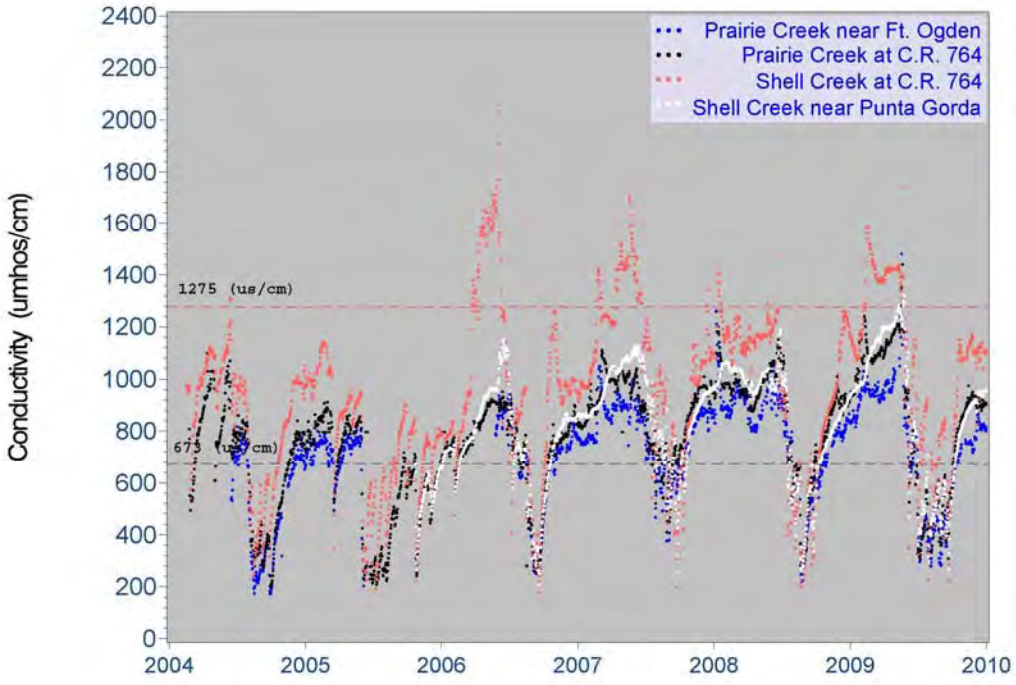

Figure 61. Daily specific conductance (conductivity) measurements at four freshwater sites in the Shell/Prairie Creek watershed from 2004 to 2009.

measured at the Shell Creek near CR 764 site, which is at the same location as water quality station 2 shown in Figure 58. Except for brief period at the Shell Creek near Punta Gorda site (near the Hendrickson Dam), this is the only site where the 1,275 µmhos/cm standard was periodically exceeded. However, at all sites, specific conductance was frequently above the 673 µmhos/cm value that corresponds to a secondary drinking water limit for TDS in the Shell Creek Reservoir.

There were distinct, similar seasonal and inter-annual patterns in specific conductance at all sties in response to changes in low and high flows. The lowest values at the four sites for prolonged periods occurred in the summer of wet years of 2004 and 2005 (Figure 61). Higher values occurred in the dry years from 2006 to the spring of 2009.

As shown in Figure 62, specific conductance is negatively correlated with flow rate at all sites, as the highest values are recorded at low flows when groundwater baseflow and excess irrigation water comprise most of the flow. As flows increase, surface runoff resulting from rainfall in the watershed comprises increasingly greater proportions of streamflow. Since surface runoff typically has much lower mineral concentrations than groundwater baseflow or irrigation water, specific conductance declines as flows increase.

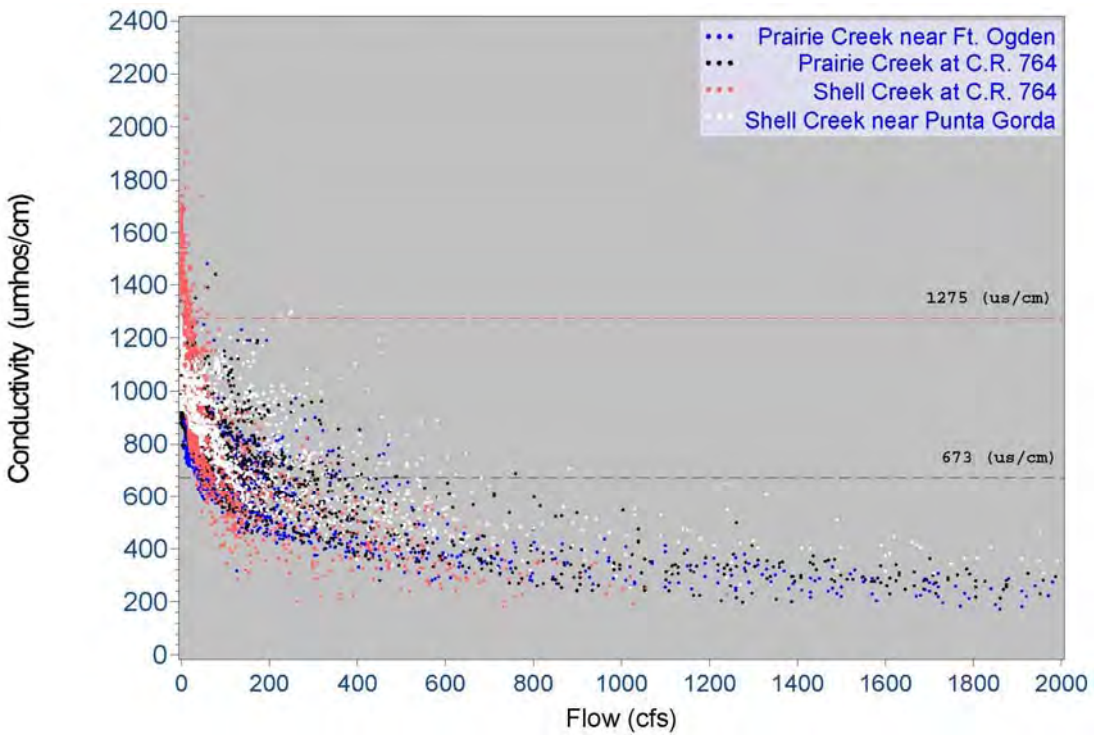

Figure 62. Daily specific conductance values at four freshwater sites in the Shell/Prairie Creek watershed vs. the same-day rate of flow at each gage, 2004 - 2009.

The 2010 Shell Creek HBMP report also examined trends and flow relationships for nutrients and other water quality constituents at the freshwater HBMP sites for an 18-year monitoring from 1991 to 2009. Significant increasing trends were observed for total suspended solids and silica at the Prairie Creek site, while increasing trends for ammonia nitrogen and silica and decreasing trends for nitrate/nitrite and Kjeldahl nitrogen were observed at the upstream Shell Creek site. Increasing trends for total suspended solids and silica and decreasing trends for total Kjeldahl nitrogen were observed at the site in the Shell Creek reservoir.

The report also reported major ion values (e.g, chloride, calcium, sulphate) for several sites upstream of the Shell Creek reservoir that are monitored by the SWFWMD. Comparisons between sites within the Prairie Creek and Shell Creek watersheds generally found higher concentrations in the Shell Creek basin. Some of these differences may due to the natural characteristics of the soils and ground water in these two drainage basins. Approximately 24 percent of the total watershed to the Shell Creek reservoir is from the Shell Creek drainage basin, while 76 percent of the reservoir watershed comes from the Prairie Creek basin.

Influence of Withdrawals on Flow to the Tidal Reach of Shell Creek

The 2010 HBMP summary report investigated the amounts that flows over the Hendrickson Dam to the tidal reach of the Shell Creek have been, and could potentially be, affected by potable water supply withdrawals by the City of Punta Gorda. Flows were examined for three cases:

- Baseline flows - calculated flows that would have occurred in the absence of withdrawals by the City of Punta Gorda

- Gaged flows - flows at the dam reported at the USGS Shell Creek near Punta Gorda gage, which are the actual flows that occurred as they reflect the withdrawals made by the City from the reservoir over time

- Flows that would have occurred if the City had taken the maximum daily amounts specified by the renewal of the City's water use permit in 2007.

Time series of different yearly flow percentiles were calculated and plotted for these three flow scenarios for period 1965 to 2009. As expected, the largest differences were between the baseline and the maximum daily withdrawal scenario. However, the differences were less apparent as flows increase and were small at flows above the yearly medians. Differences were greater at low flow percentiles, as the City's withdrawals comprise a greater proportion of the flow in the creek.

An example of differences in yearly values for the 25th percentile flows for the three scenarios is shown in Figure 63. Note that the differences between baseline flows and actual flows were smallest in the early part of the simulated period, with the differences greater in more recent years as withdrawals by the City increased over time.

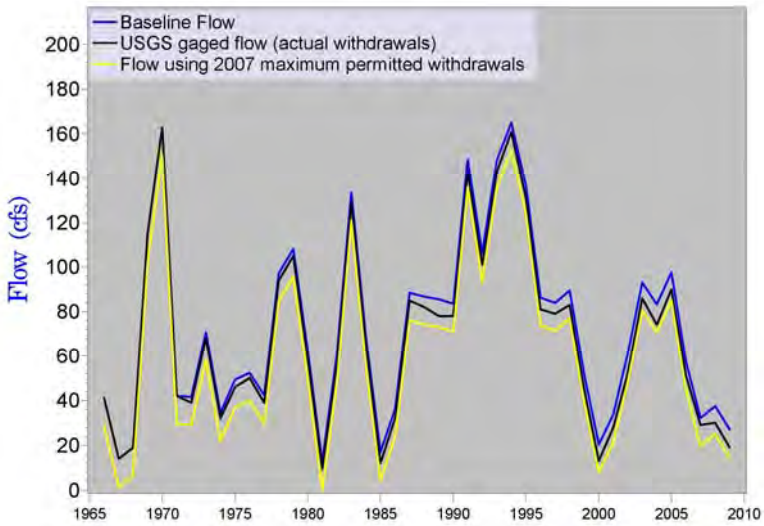

Figure 63. Yearly 25th percentile values for flows at the Shell Creek near Punta Gorda gage for three conditions - baseline flows, actual gaged flows, and flows reduced by maximum permitted daily withdrawals by the City of Punta Gorda.

The differences in flows for these three conditions were also presented as box and whisker plots of monthly and yearly flows and as flow duration curves. Flow duration curves for baseline flows and flows reduced by maximum daily withdrawals are shown in Figure 64. Although the semi-log scale on the Y axis makes visual comparisons of flow differences difficult, it is apparent that the largest relative differences occur at low flows. Though not shown in this tribute report, the differences in flows between baseline flows and flows with actual withdrawals were much smaller than for the maximum permitted withdrawals.

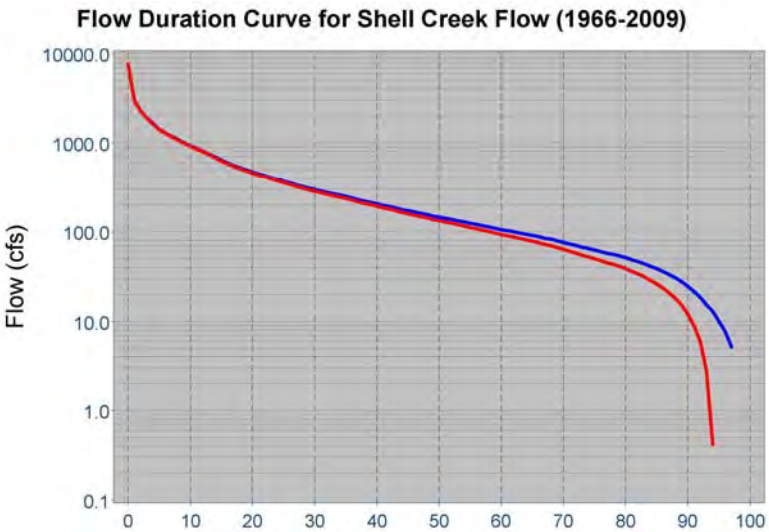

Figure 64. Flow duration curves for daily flows at the Shell Creek near Punta Gorda gage for baseline flows and flows reduced by the maximum permitted daily withdrawals by the City of Punta Gorda

The effects of actual and maximum permitted withdrawals relative to baseline flows were also expressed as differences in the frequency and duration of low flows. Table 17 lists the frequency and duration of flows for selected consecutive day periods ranging from 1 to 120 days for the three flow conditions for five recurrence intervals. For example, the third row for each scenario lists the lowest 10-day flow that would be expected to occur on average every 2, 3, 5, 15 and 25 years, knowing these recurrence intervals will not occur regularly over time.

The largest differences are between baseline flows and the maximum permitted withdrawal scenario. For example, the lowest 60-day flow that would occur on an average 2-year interval is 24.1 cfs for baseline flows, 17.9 cfs for actual withdrawals, and 6.7 cfs for maximum permitted withdrawals. This type of frequency and duration analysis is informative for examining flows that would occur over different periods under different withdrawal scenarios

Table 17. Lowest average consecutive day flows (cfs) for indicated recurrence intervals (years) for the Shell Creek near Punta Gorda gage for baseline flows, actual gaged flows, and flows reduced by maximum permitted daily withdrawals by the City of Punta Gorda

Consecutive Days	Years				
	2	3	5	15	25
"Synthetic" Estimated Baseline Without Withdrawals					
1	0.9	0.2	0.0	0.0	0.0
3	1.0	0.2	0.0	0.0	0.0
10	1.9	0.4	0.1	0.0	0.0
30	7.7	2.4	0.7	0.2	0.0
60	24.1	13.4	7.3	3.7	1.8
90	39.3	25.9	17.1	10.7	6.7
120	56.3	38.9	27.0	18.2	12.2
USGS Gaged Flows (Includes Actual Withdrawals)					
1	0.3	0.1	0.0	0.0	0.0
3	0.4	0.1	0.0	0.0	0.0
10	0.9	0.2	0.0	0.0	0.0
30	4.6	1.2	0.3	0.1	0.0
60	17.9	8.6	4.0	1.7	0.7
90	34.0	21.2	13.2	7.8	4.5
120	51.1	34.3	23.0	15.0	9.7
Estimated Flow After Subtracting Current Maximum Averaged Daily Permitted Withdrawals					
1	0.1	0.0	0.0	0.0	0.0
3	0.1	0.0	0.0	0.0	0.0
10	0.2	0.0	0.0	0.0	0.0
30	1.1	0.2	0.0	0.0	0.0
60	6.7	2.0	0.6	0.1	0.0
90	20.4	9.7	4.4	1.8	0.7
120	37.4	22.2	13.1	7.3	4.0

Salinity Characteristics

A key component of the Shell Creek HBMP is the monitoring and characterization of salinity in the tidal reach of the Creek. Vertical salinity profiles are measured at all the stations downstream of the dam. A box and whisker plot of surface salinity from 1991 to 2000 (taken from the 2003 Summary Report) is shown in Figure 65. Salinity in the tidal reach of the creek generally ranges from a zone of tidal freshwater to mesohaline conditions (5 to 18 psu). Median salinity values less than 1 psu were recorded above kilometer 3 during this period. However, salinity in the creek can vary greatly between wet and dry periods, with maximum salinities above 20 psu recorded near the mouth of the creek during dry periods. Conversely, freshwater conditions have been observed at the mouth of Shell Creek during floods.

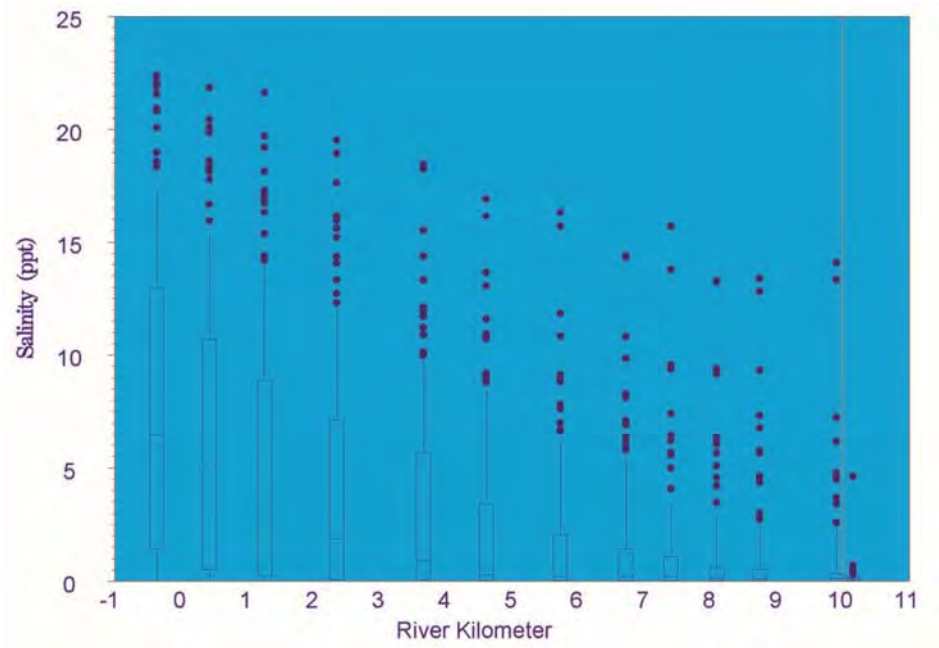

Figure 65. Box of whisker plot of surface water salinity at stations in the tidal reach of Shell Creek and one station above the Hendrickson Dam.

Time series plots of surface salinity at two locations in Shell Creek are shown in Figure 66. The station at kilometer 9.9 is located just below the Hendrickson Dam. Surface salinity at this station is typically fresh, but salinity values above 10 psu were observed on six dates, with a maximum values near 17 psu recorded in 2009. The frequency of high salinity values during the prolonged dry periods during 1999 to 2001 and 2006 and 2009 is apparent.

Surface salinity at kilometer 1.26 near where Shell Creek flows into the Peace River shows high variability. Salinity at or near fresh water is observed for one to a few months most years, but salinity values above 20 psu occur during dry periods, with a maximum salinity value of 29 psu recorded in 2009.

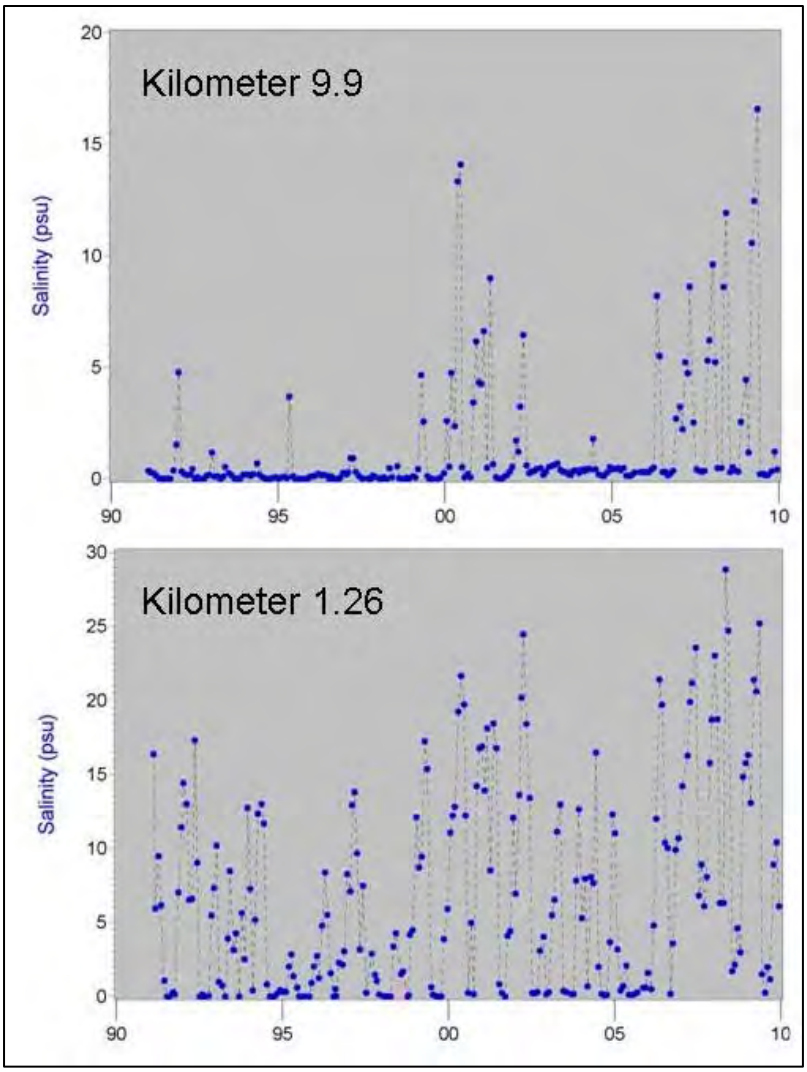

Figure 66. Surface salinity at two stations at kilometers 9.9 and 1.26 in the tidal reach of Shell Creek for 1991 through 2009.

Cumulative distribution function plots of surface salinity values at six stations in Shell Creek are shown in Figure 67. These plots are useful for showing what percent of the time that near freshwater conditions (< 1 psu salinty) were observed at the different stations. This information was then used to delineate Shell Creek into three segments depending on the flow range when freshwater conditions were reached. Statistical regression models were then developed to predict surface and near bottom salinity in each of these segments as a function of freshwater flow at flow rates below the threshold at which freshwater was observed. Statistical models were also developed to predict surface and bottom salinity at a USGS continuous recorder at kilometer 4.6.

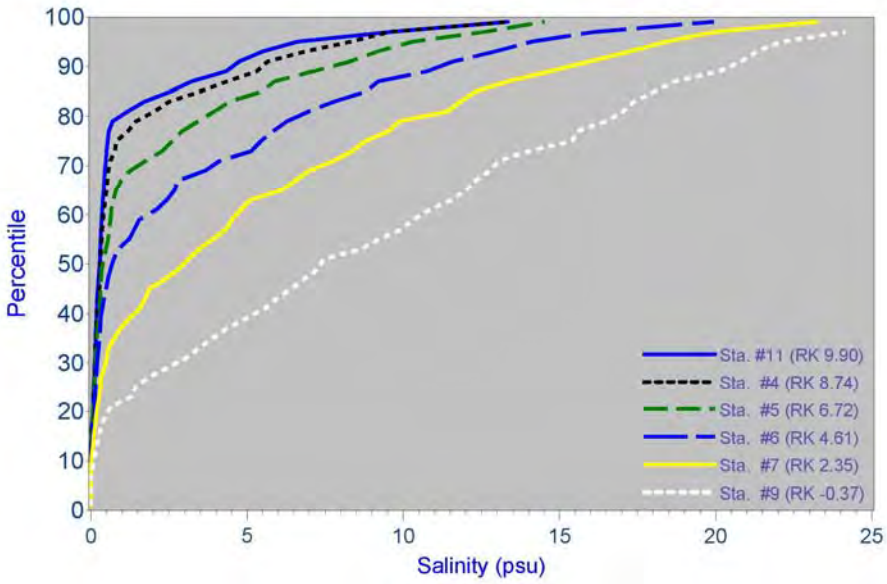

Figure 67. Cumulative distribution functions of surface salinity values at six stations in Shell Creek and one in the Peace River (RK -0.37) for the period 1991 to 2009.

These models were then used to predict changes in surface and near-bottom salinity values in the three segments of Shell Creek for computed baseline flows (no withdrawals) and withdrawals that would correspond to withdrawals of 5.38 mgd (8.3 cfs), which was the City's average daily rate of withdrawal from 1997 and 2007 and an average daily rate of 8.09 mgd (12.52 cfs), which is the rate allowed by the City's permit. A cumulative distribution function of the predicted changes in surface salinity in the middle segment of the tidal reach of Shell Creek is shown in Figure 68.

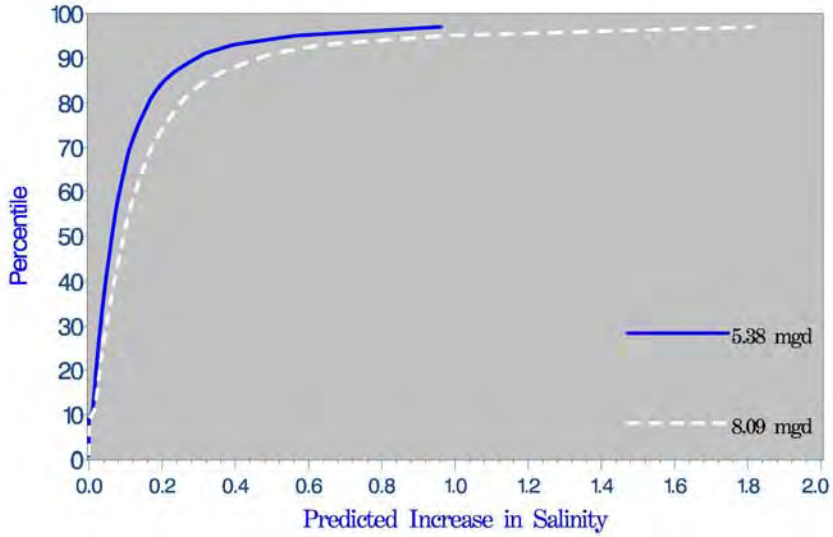

Figure 68. Cumulative distribution functions of predicted increases in salinity in the middle segment of Shell Creek due to withdrawal rates of 5.38 and 8.09 mgd.

The HBMP report also characterized the temporal and spatial distribution of other water quality parameters in Shell Creek and their relationships with flow using various graphical and statistical techniques. For example, cumulative distribution function plots of bottom dissolved oxygen (DO) concentration in six stations in Shell Creek are shown in Figure 69. Generally, low DO concentrations in Shell Creek are fairly infrequent, but most common at the two stations closest to the dam.

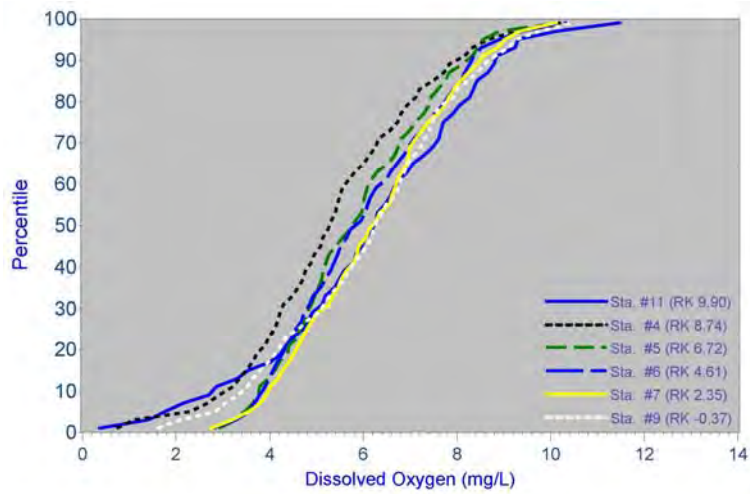

Figure 69. Cumulative distribution functions of bottom dissolved oxygen concentrations at five stations in Shell Creek and one in the Peace River (RK -0.37) for 1991 - 2009.

A graph of bottom DO vs. flow at the station at kilometer 9.9, just below the dam, is shown in Figure 70. The occurrence of low DO concentrations were most frequent at seven-day flows below 50 cfs, when the salt wedge in the creek is in the upper reaches of the tidal creek.

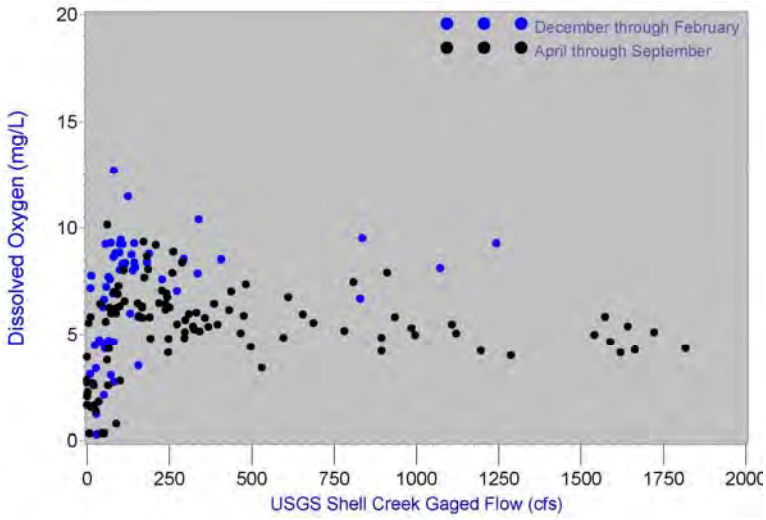

Figure 70. Bottom dissolved oxygen concentrations at river kilometer 9.9 vs. seven-day average flow at the Shell Creek near Punta Gorda gage.

The HBMP report presented similar graphics for chlorophyll *a* and various nutrient parameters. In general, the water quality of the tidal reach of Shell Creek is very good, with nutrient and chlorophyll *a* concentrations indicative of a healthy tidal creek. The highest chlorophyll *a* concentrations typically occur during low flows (Figure 71), as higher flows results in low residence time and rapid flushing in the creek, which prevents large phytoplankton populations from developing.

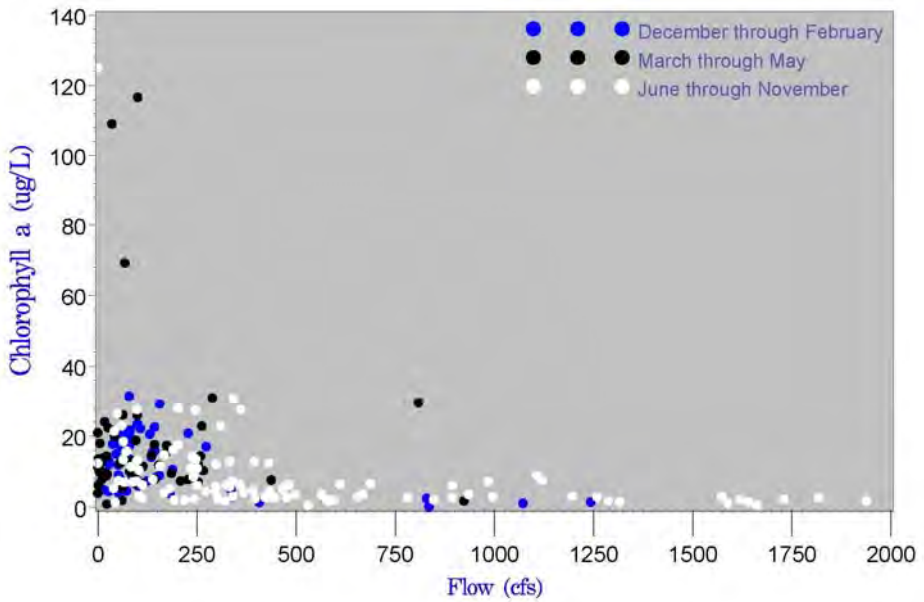

Figure 71. Chlorophyll *a* concentrations at kilometer 6.72 vs. seven-day average flow at the Shell Creek near Punta Gorda gage

2007 GAP Report

Dr. Montgomery was the principal author of a 2007 report prepared by PBS&J, Inc. for the City of Punta Gorda and the Peace River Manasota Regional Water Supply Authority (PRMRWSA) that is commonly known as the GAP report. This report examined the potential effects of increased withdrawals from Shell Creek that might have been needed to address the gap between water supply needs and permitted withdrawal rates in the region that were projected at that time. The reference for this report is listed on page 134 and in the bibliography.

In association with completion of the GAP report, a water use permit was issued jointly to the PRMRWSA and the City of Punta Gorda in 2007 with four other local governments also listed as permit holders. This permit, which is referred to at the Conjunctive Water Use Permit, is to allow greater flexibility in how various water sources can be used to best meet regional water supply needs. It has been modified and renewed since its issuance in 2007. Among other water supply goals pursued in association with this permit, the City of Punta Gorda increased the capacity of their water treatment plant at Shell Creek from 8 to 10 mgd. A pipeline was also constructed between the City's water treatment plant and the water treatment facility on the Peace River

operated by the PRMRWSA. This pipeline has a capacity to convey to 6 MGD in either direction. It is sometimes used to transfer water from the PRMRWSA to the City when water quality in Shell Creek is impaired due to high mineralization in the dry season. Regardless of water quality issues, the pipeline can be used if there are shortfalls in supply by either utility during times of drought.

The 2007 GAP report presented useful analyses and discussion of the potential effects of increased withdrawals on freshwater inflow and salinity, water quality, and biological communities in the tidal reach of Shell Creek. The effects on salinity, dissolved oxygen, and chlorophyll *a* in the creek relied on data collected for the Shell Creek HBMP. The methods of analyses and empirical modeling to predict the effects of increased withdrawals utilized techniques described in either the 2002 or 2010 Shell Creek HBMP interpretive reports, the latter of which has been previously summarized. Therefore, the methods and results to describe the effects on freshwater inflow, salinity and water quality presented in the GAP report are not summarized in this tribute report. The GAP report also discussed water quality issues in the freshwater tributaries to the Shell Creek reservoir similar to the discussions presented in the Shell Creek HBMP reports, so those results from the GAP report are not summarized below.

The GAP report did provide some updated analyses and discussion of the potential effects of freshwater withdrawals on biological communities in Shell Creek. As part of the GAP analysis, the mapping of tidal wetland vegetation communities was updated, producing a detailed map of the gradient of vegetation communities that occur along the tidal reach of Shell Creek (Figure 72). This was compared to mapping that was conducted of Shell Creek performed by the Florida Marine Research Institute in 1994 (FMRI, 1998).

The vegetation communities in the tidal reach of Shell Creek range from a diverse mix of low-salinity and freshwater species located near the dam to estuarine plant communities located further downstream that are comprised of fewer species that are tolerant of a wide range of salinities. The 2007 reported on what appeared to be some shifts in the distribution of some plant species, but cautioned that differences in mapping techniques made such conclusions tentative. In addition to the effects of salinity, the GAP report also discussed the role of bank elevation, distance from channel, and the effect of large storms and hurricanes on vegetation distributions. The mapping for the GAP report, which was done in 2006, accounted for the effects of Hurricane Charley which directly hit the Lower Peace River / Shell Creek area in the summer of 2004.

The GAP report also summarized the findings of two studies of the biological communities in Shell Creek that were conducted as part of minimum flow studies of the Lower Peace River conducted for the Southwest Florida Water Management District. Mote Marine Laboratory (Culter, 2005) conducted a one-time sampling of benthic macroinvertebrate fauna in Shell Creek during 2003. The GAP report reviewed this study, which documented spatial changes in the

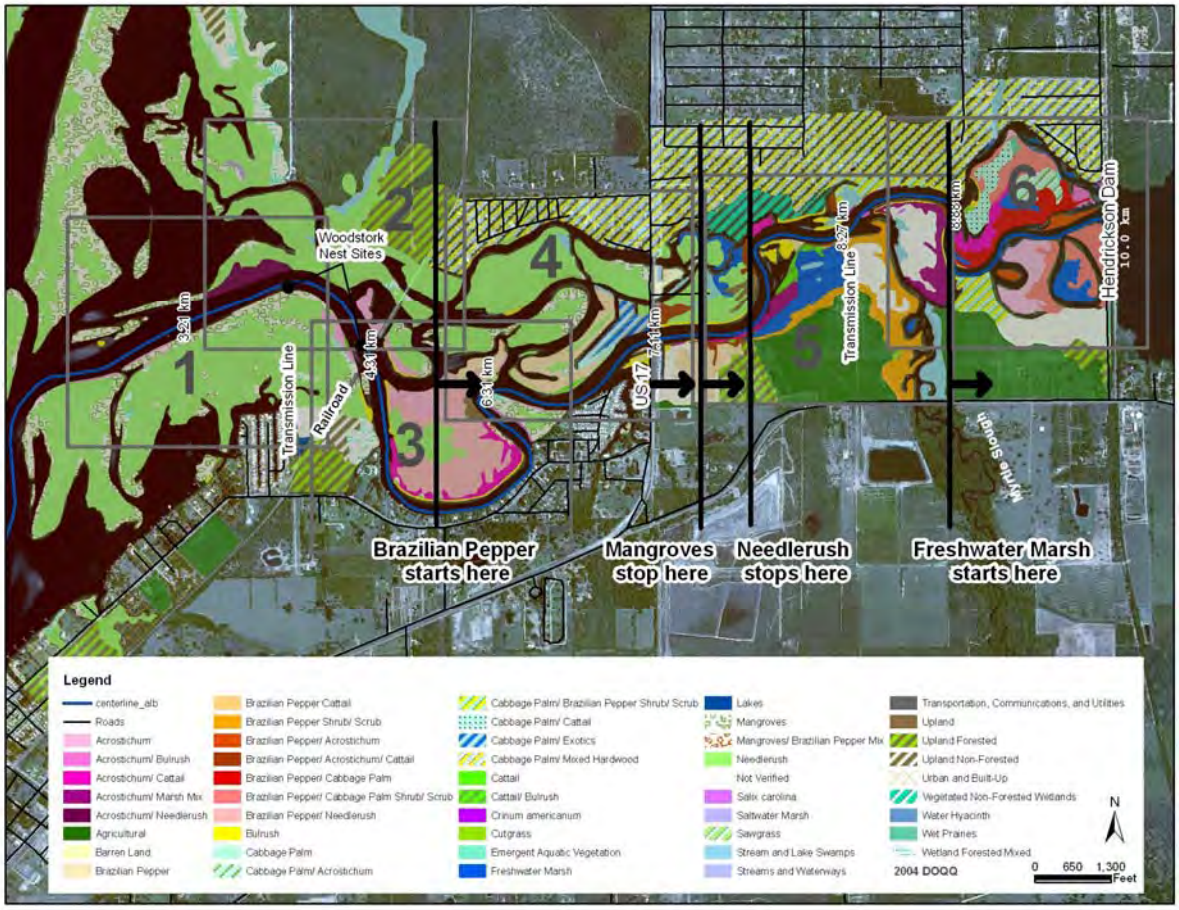

Figure 72. Map of vegetation communities in the tidal reach of Shell Creek

macroinvertebrate communities in the creek corresponding to the salinity gradient. The GAP report concluded, however, that it would be difficult to extrapolate the effects of the projected increased withdrawals on these communities given the timing and hydrologic conditions of this one-time sampling, stating that benthic macroinvertebrate communities respond more slowly to hydrologic and physico-chemical conditions over greater lengths of time.

The GAP report also discussed the findings of a study of planktonic invertebrates and larval and juvenile fishes performed by the University of South Florida College of Marine Science (Peebles, 2002). That study utilized plankton net tows to collect the eggs and larval and juvenile stages of fish, plus planktonic invertebrates (zooplankton) and benthic invertebrate species that had migrated into the water column. The USF report documented gradients and response to freshwater inflow for many taxa, but the applicability of the report to the GAP analysis was hindered by the abnormally high flow conditions that occurred during sampling for the study in the El Niño years of 1997-1998. Because the increased withdrawals examined in the GAP analysis would have the greatest effect on low flows, it was not possible to extrapolate the findings of the USF study to the GAP analysis.

Due to the unusually wet hydrologic conditions during the initial study, the SWFMD contracted USF to do subsequent sampling of the Lower Peace River and Shell Creek during a

predominantly dry five-month period between February and June, 2008. This report (Peebles and Burghart, 2013), presented results that document the response of fish and invertebrates to low flows in Shell Creek, but it was not available for evaluation in the GAP report. However, the SWFWMD will be establishing minimum flow rules for Shell Creek in 2018 as part of the re-evaluation of minimum flows for the Lower Peace River. At that time, all updated information for Shell Creek will be evaluated to determine the maximum water supply withdrawal quantities that are available over the entire flow range of Shell Creek

3.10 Studies of the Hydrology and Water Quality of Myakkahatchee Creek Conducted for the City of North Port

Myakkahatchee Creek is a tributary the Myakka River, which along with the Peace River, is one of the two rivers flowing to Upper Charlotte Harbor. Like Shell Creek on the Peace River, Myakkahatchee Creek is used for municipal water supply by the City of North Port with withdrawals made on the upstream side of a low elevation structure (WC 101) that separates the tidal and freshwater reaches of the creek. The tidal reach of Myakkahatchee Creek is short, extending 4.3 kilometers (2.7 miles) from the water control structure to the confluence with the Myakka River (Figure 73). A channelized drainage system, the Cocoplum Waterway, flows into the tidal reach of Myakkahatchee Creek just below the water control structure.

As part of the requirements of a water use permit issued to the City by the Southwest Florida Water Management District, a Hydrobiological Monitoring Program (HBMP) has been instituted to document water quality conditions below the structure to better evaluate the potential effects of freshwater withdrawals on the water quality and ecology of the tidal reach of Myakkahatchee Creek. The firm of PBS&J, along with Mote Marine Laboratory, was contracted to perform the data collection and analysis for the Myakkahatchee Creek HBMP. PBS&J produced two reports for the City of North for the HBMP which are listed below.

A brief summary of these reports follows, which emphasis of the second report as it contains more recent data collected over a longer time period. Although he was not the project leader for this HBMP, Dr. Montgomery performed analyses as part of this project, which similar to the Peace River and Shell Creek HBMPs, evaluates the effects of freshwater inflow to a tidal tributary to the Upper Charlotte Harbor ecosystem.

PBS&J, Inc. 2006. Myakkahatchee Creek Water Use Permit, Review and Analysis of Supporting Data, 2003 through 2005. Report prepared for the City of North Port Utilities Department, submitted to the Southwest Florida Water Management District.

PBS&J, Inc. 2009d. Myakkahatchee Creek Hydrobiological Monitoring Program, Data Summary Report, HBMP Inception to June 30, 2009. Report prepared for the City of North Port Utilities Department, submitted to the Southwest Florida Water Management District.

Figure 73. Aerial photograph of the lower reaches of Myakkahatchee Creek showing the location of water control structure 101, the water treatment facility, the Cocoplum Waterway, and the confluence of Myakkahatchee Creek with the Myakka River.

Data collection for the Myakkatchee Creek HBMP began in the summer of 2003. The HBMP program was limited to water quality data, with *in situ* vertical profiles measured monthly at ten stations and grab samples for the laboratory analysis of nutrients and other parameters measured at six stations (Figure 74). Both sampling programs included two stations in the Myakka River (#'s 9 and 10) to evaluate the river's influence on the salinity and water quality of Myakkahatchee Creek. Two continuous recorders were also installed to measure salinity on a 15 minute basis, with one located at kilometer 3.6 in the creek and the other near the confluence of the creek with the Myakka River.

The data collected indicate that Myakkahatchee Creek is often a mesohaline (5 to 18 psu) system, although salinity in the creek can vary between freshwater conditions during high flows to salinity values over 25 psu during prolonged dry periods. A graph of median daily surface and bottom salinity values at the continuous recorder at kilometer 3.6 is shown in Figure 75. Fresh water was observed at this site in the summer months of most years, with more prolonged fresh water occurring during the wet years of 2004 and 2005. However, high salinity values in the range of 20 to 27 psu occurred in the dry years of 2006 to 2009.

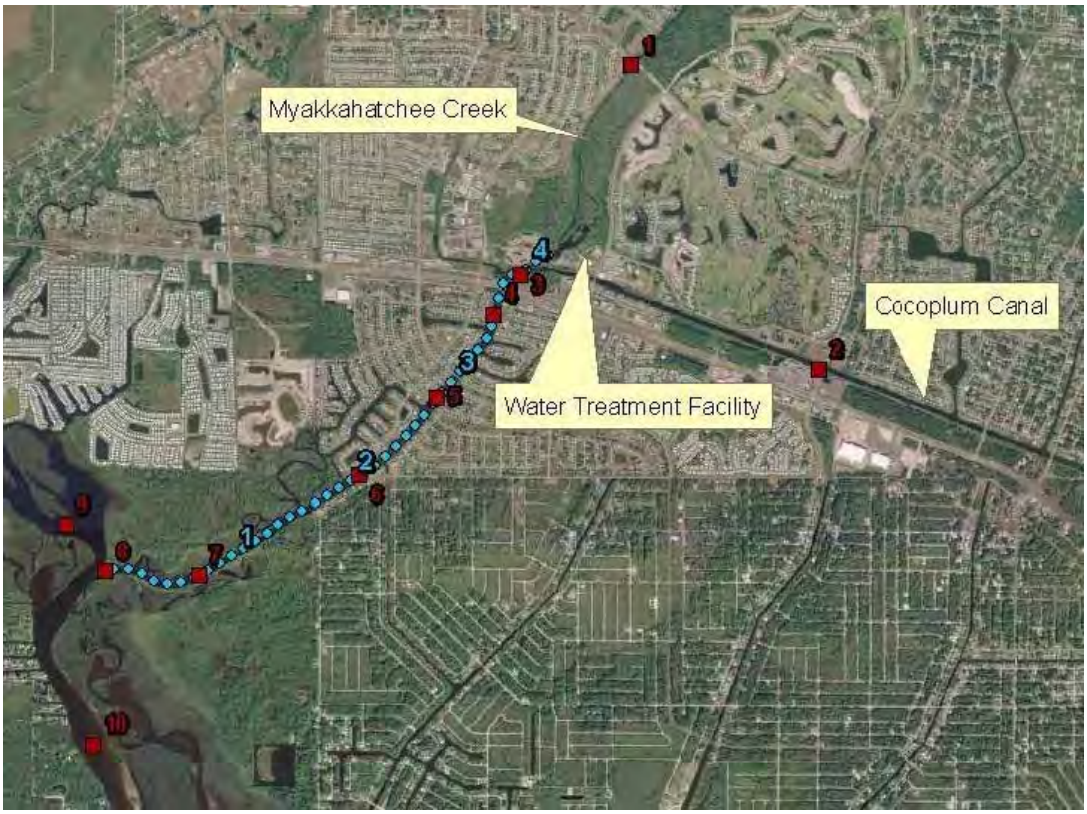

Figure 74. Location of monthly water quality stations (red squares) in the Myakkahatchee Creek, the Cocoplum Waterway and the Myakka River. Kilometers in the Myakkahatchee Creek upstream of the confluence with the Myakka River are in blue.

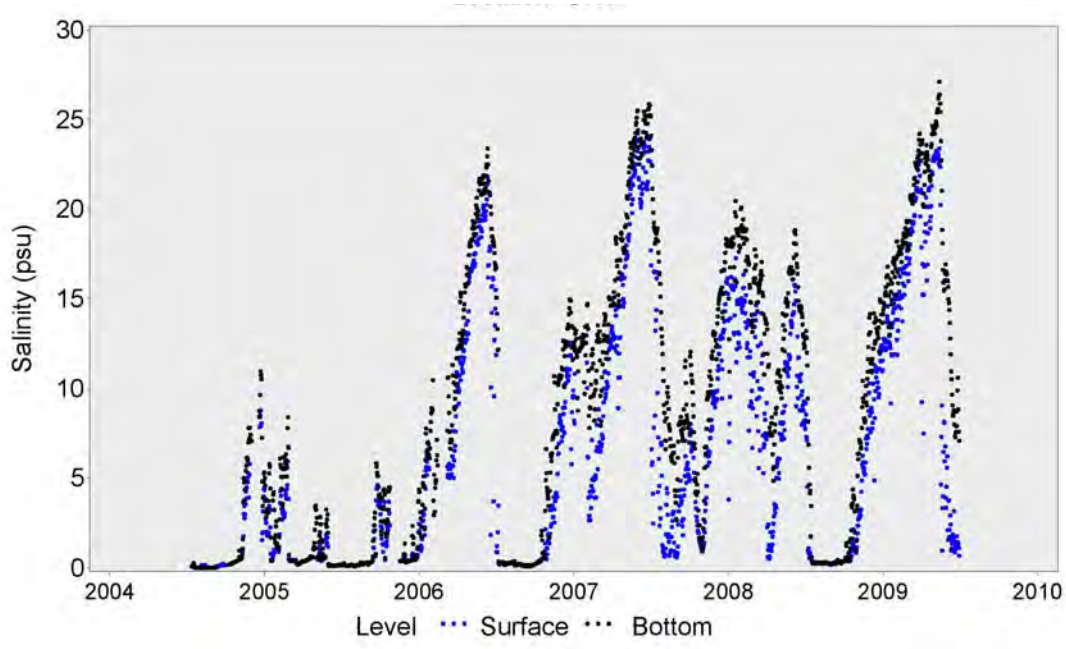

Figure 75. Median daily salinity values at the continuous recorder near kilometer 3.6 in the tidal reach of Myakkhatchee Creek.

PBS&J developed regression models to predict salinity at the continuous recorders and at two of the water quality profile stations. Flows from the USGS streamflow gage Big Slough Canal at Tropicaire Blvd. were used to as the flow variable in these regressions (Myakkahatchee Creek is also known as Big Slough Canal). The flow records at this gage go back to 2001, covering the entire period of HBMP data collection. However, this gage does not measure flow that enters Myakkahatchee Creek from the Stover or the Cocoplum Waterways. In 2007 the USGS installed two additional gages on the Myakkahatchee Creek system. The first was located on Myakkahatchee Creek near West Price Blvd., which is downstream of the Stover Waterway. The second was on the Cocoplum Waterway, which contributes flow to the tidal reach of on the creek downstream of the Water Control Structure 101 on the main stem of the creek.

A hydrograph of flows at the Tropicaire, West Price Blvd. and Cocoplum waterway gages is shown in Figure 76. Flows were slightly higher at the West Price Blvd gage compared to the Tropicaire gage in the dry season, but the differences increased in the wet season when the Stover Waterway contributed more flow following rainfall events. Flows from the Cocoplum Waterway were the greatest of all, on some days contributing more than twice the flow that was measured at either gage in Myakkahatchee Creek. At the time of the preparation of the 2009 report, the years that flows were available for both the Tropicaire gage and two more recent gages (2007 - 2009) were relatively dry. Thus, a comparison of flows from these gages during vey high flows could not be performed. PBS&J therefore recommended that relationships of flows with salinity and other water quality constituents in the tidal reach of Myakkahatchee Creek be revisited in a future HBMP report, when more data over a greater flow range were available for the West Price and Cocoplum Waterway gages.

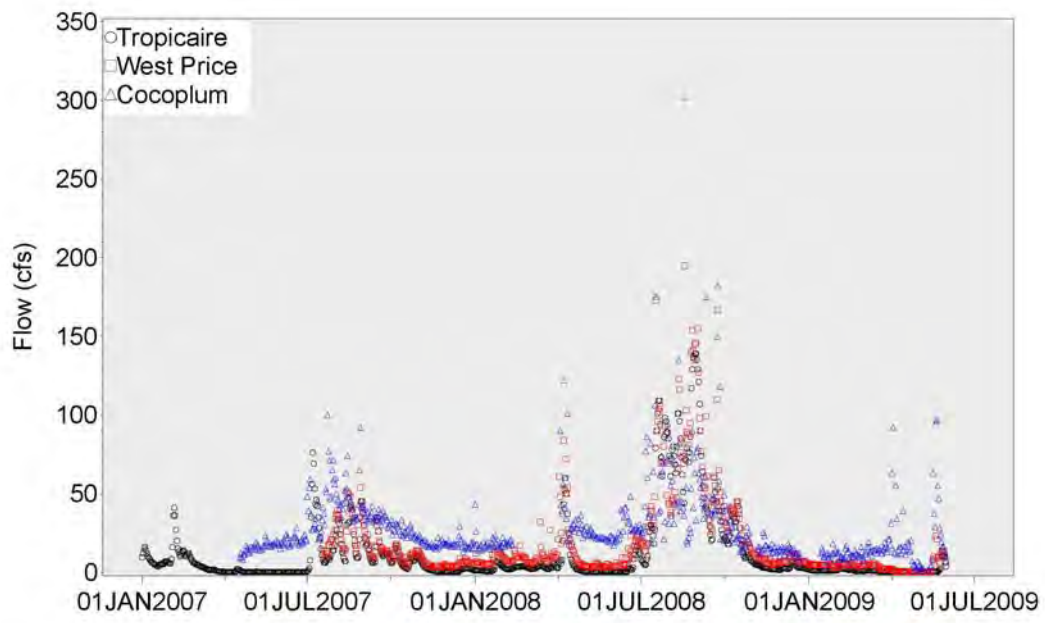

Figure 76. Daily flows at the USGS gages on Myakkahatchee Creek near Tropicaire and West Price Blvds. and the Cocoplum waterway for 2007 though July 2009.

The HBMP report also evaluated gradients in dissolved oxygen concentrations, chlorophyll *a*, color, and nutrients in the tidal reach of the creek and generally found that spatial gradients of these parameters was generally slight. A time series plot of bottom dissolved oxygen concentrations at all stations in the HBMP, including two stations upstream of the water control structure and in the Myakka River, is shown in Figure 77. Bottom dissolved oxygen concentrations in the creek are generally not hypoxic, but were below 2.0 mg/l most frequently in the dry year of 2007.

Based on the findings of the 2009 HBMP report, PBS&J proposed that the two continuous recorders continue to operated, and vertical profile of *in situ* parameters be limited to the stations and frequency for the monthly water quality samples that are collected for laboratory analysis.

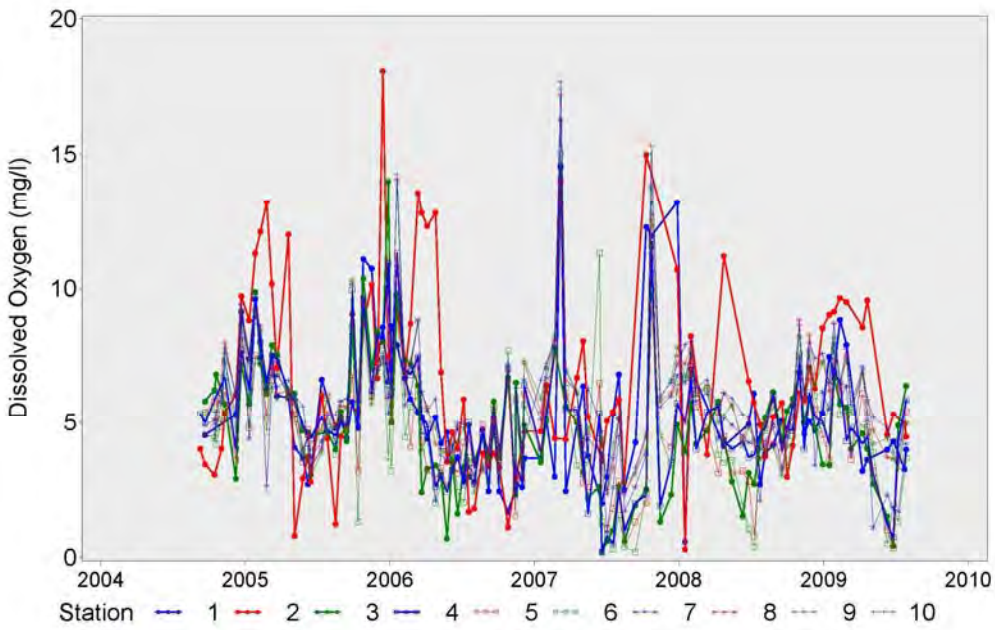

Figure 77. Bottom dissolved oxygen concentrations at stations in Myakkahatchee Creek (3 though 8), upstream of the water control structures in the creek and the Cocoplum waterway (1 and 2) and in the Myakka River (9 and 10).

- Text continued on page 155 -

3.11. Other Hydrologic and Ecological Assessments

This section summarizes various publications in which Dr. Montgomery was involved that were not covered by the technical categories that were previously described.

Weaver, R. J. and R. T. Montgomery. 1974. Effect of Epthephon on coloration and maturation wine grapes. American Journal of Enology and Viticulture. 25: 39-41.

This paper comes from work Dr. Montgomery did with Professor Robert Weaver of the University of California at Davis when he worked in the Viticulture Department after receiving his Bachelors degree. The abstract of the paper is reprinted below.

> 'Zinfandel,' 'Grenache,' and 'Barbera' grapevines were sprayed with Ethephon at 1,000 ppm when the surface of the berries was approximately 15 and 60% colored; 'Ruby Cabernet' was sprayed with the compound at 300 ad 1,000 ppm at 3%, 20%, 60%, and 98% color. Some fruits were enlarged by some treatments. 'Grenache' sprayed at 15% color developed a lower soluble solids content than did the controls, and some fruits of all cultivars except 'Barbera' had lower acid content that the controls. Ethephon aplied to 'Ruby Cabernet' at 1,000 ppm on August 12, 19, or 26 stimulated anthocyanin production. Application to 'Ainfandel' on August 4 or 18 also increased color, whereas with 'Grenache' and Barbera,' only the application on August 11 induced a significant increase in color. Application only to foliage enhanced anthocyanin formation, but application only to clusters was ineffective.

Flannery, M.S, E.B. Peebles, and R. t. Montgomery. 2002. A percent-of-flow approach for managing reductions of freshwater inflows from unimpounded rivers to southwest Florida estuaries. Estuaries: 25 (6B): 1318-1332

This paper in published in 2002 the journal *Estuaries* presented the technical basis at that time for the percent-of-flow approach for managing freshwater withdrawals from river that had been implemented by the Southwest Florida Water Management District. As described elsewhere in this tribute report, studies of the Lower Peace River which Dr. Montgomery directed were instrumental in developing the percent-of-flow approach and the Lower Peace was the river where the percent-of-flow approach was first applied to regulate water withdrawals.

The abstract of this paper is reprinted below, along with a graphic that show the utilization of low salinity habitats by larval and juvenile fishes (Figure 78). A second plot (Figure 79) shows the high chlorophyll *a* concentrations that are typically observed in low and middle salinity zones in tidal rivers, which was first documented in the Lower Peace River by Dr. Montgomery. These results are indicative of the tidal river engine concept illustrated in Figure 48 on page 103 of this report.

> The Southwest Florida Water Management District has implemented a management approach for unimpounded rivers that limits withdrawals to a percentage of streamflow at the time of withdrawal. The natural flow regime of the contributing river is considered to be the baseline for assessing the effects of withdrawals. Development of the percent-of-flow approach has emphasized

the interaction of freshwater inflow with the overlap of stationary and dynamic habitat components in tidal river zones of larger estuarine systems. Since the responses of key estuarine characteristics (e.g., isohaline locations, residence times) to freshwater inflow are frequently nonlinear, the approach is designed to prevent impacts to estuarine resources during sensitive low-inflow periods and to allow water supplies to become gradually more available as inflow increases. A high sensitivity to variation at low inflow extends to many invertebrates and fishes that move upstream and downstream in synchrony with inflow. Total numbers of estuarine-resident and estuarine-dependent organisms have been found to decrease during low-inflow periods, including mysids, grass shrimp, and juveniles of the bay anchovy and sand seatrout. The interaction of freshwater inflow with seasonal processes, such as phytoplankton production and the recruitment of fishes to the tidal-river nursery, indicates that withdrawal percentages during the springtime should be most restrictive. Ongoing efforts are oriented toward refining percentage withdrawal limits among seasons and flow ranges to account for shifts in the responsiveness of estuarine processes to reductions in freshwater inflow.

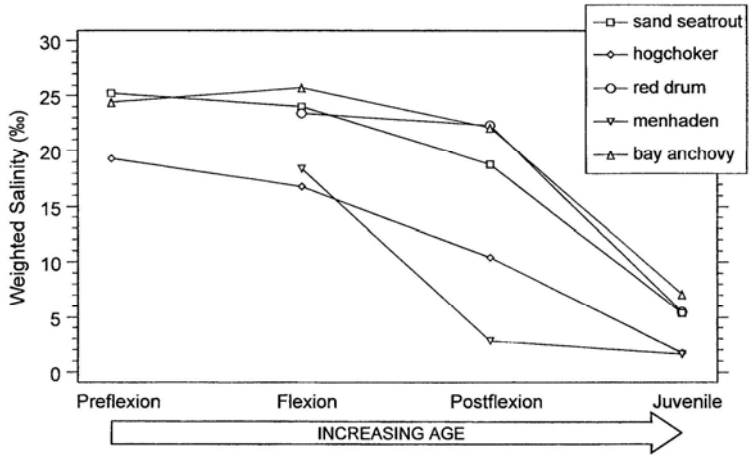

Figure 78. Weighed mean salinity at capture for larval and juvenile stages of five fish species in the Little Manatee River plotted by increasing age

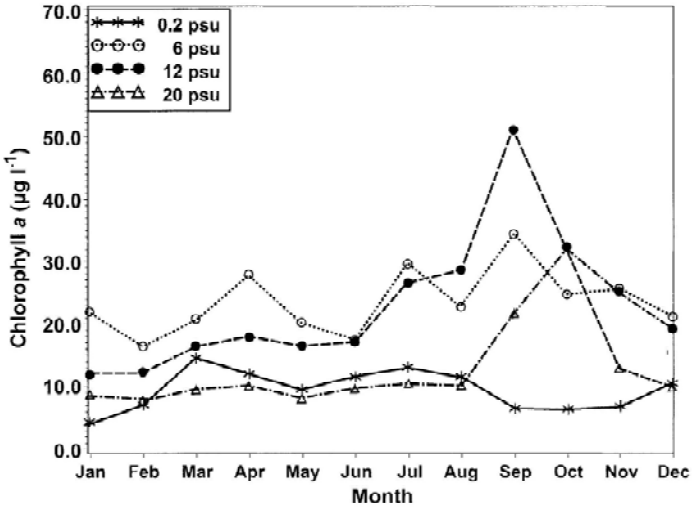

Figure 79. Mean chlorophyll *a* concentrations at four moving salinity based stations in the Lower Peace River.

PBS&J, Inc. 2009e. Investigation of Resources, Threats, and Future Protection of Needs of the Matansas River Study Area. Report prepared for the St. Johns River Water Management District, Palatka, FL

Dr. Montgomery was part of the project team from PBS&J that prepared this study for the St. Johns River Water Management District (SJRWMD), which is centered in Northeast Florida. In response to public concerns regarding the potential for increased stresses on natural resources associated with expected continued future development, the District's Governing Board directed staff to implement the Matanzas River Basin Work Plan. As part of the overall Matanzas River Basin Work Plan, the primary objective of the 2009 report by PBS&J was to investigate and provide the District with information regarding the Matanzas Basin study area's wetland resources, potential threats, and future protection needs (Figure 80).

Figure 80. Location of the Matanzas River study area

The project was designed to:

- Identify, describe, and rank the distinct types of habitat in the Matanzas Basin study area

- Identify observed and expected aquatic and wetland-dependent wildlife within the identified habitats

- Identify the habitat requirements of such identified aquatic and wetland-dependent species

- Work with District staff, identify likely scenarios for future land use development in the Matanzas Basin study area and assess potential impacts to identified aquatic and wetland-dependent species

- Provide an initial assessment of potential additional habitat and resource protection measures to preclude such adverse impacts

The approach to meeting the overall project objectives was divided into the series of tasks that are listed below.

1. Identify the Aquatic and Wetland-dependent Wildlife in the Study Area

2. Catalog the Aquatic and Wetland-dependent Wildlife in the Study Area

3. Identify Upland and Wetland Habitats that are needed to Maintain the Abundance and Diversity of Aquatic and Wetland-dependent Wildlife

4. Identify and Rank the Quality of Upland and Wetland Habitat Available within the Study Area

5. Evaluate whether future development would likely effect wetland-dependent wildlife

6. Determine the need for additional protection of upland and wetland habitat

As part of addressing these tasks, the report presented the results of wildlife surveys in the Matanzas River basin and presented a literature review of the effects of buffers on wildlife utilization of various wetland habitats. Using data from a variety of sources, it also created a predicted future development map for the Matanzas River basin and projected how much wetland habitat would be lost in the basin by the year 2035. While various regulatory programs are in place to guide development away from impacting these wetlands, based on

past patterns it is expected that as much as 2,220 acres of these wetlands may be lost. Thus, by the year 2035, it is probable that the abundance of wetland-dependent animals (especially amphibians) would decrease in response to increasing development of upland habitats adjacent to the remaining wetlands in the Matanzas River basin.

Rather than using a single, default buffer width for protection of wildlife throughout the entire Matanzas River Basin, the report suggested an optional approach would be for buffer width guidance to vary with the "quality" of the wetland system likely to be impacted by development (such as the setback wetland protection rules used in Alachua County). Such a holistic approach to wetland protection might be warranted in the Matanzas River Basin, including assessing the quality of the wetlands in question, their degree of interconnectedness to other valuable habitats (both uplands and wetlands), and developing buffer width requirements based on the results of site specific assessments. This approach might allow the variety of stakeholders in the region to focus their efforts on protecting those wetland features that are more likely to serve as critical wildlife habitat for wetland-dependent species in the Matanzas River watershed.

PBS&J, Inc. 2012. Sunshine Lake/Sunrise Waterway Study. Report prepared for Charlotte County Government, Punta Gorda, FL.

Dr. Montgomery was a member of the team from the firm of PBS&J that evaluated the possible causes of increased algal blooms in the Sunrise Lake/Sunrise Waterway, a man-made water body in Charlotte County, Florida. The Executive Summary of that report is reprinted below.

The primary focus of the Sunshine Lake/Sunrise Waterway Study was to ascertain the potential cause(s) of the existing and persistent algal blooms, to assess the potential factors that may have initiated and exacerbated the ongoing degradation of water quality in the system, and then to recommend appropriate restoration activities, directed toward restoring and enhancing water quality. The following summarizes the existing condition.

- Relatively older, highly urbanized watershed**:** Sunshine Lake's immediate watershed is characterized by a relatively older highly urbanized mixture of single family and multi-family homes. While the immediate watershed of the Sunshine Lake/Sunrise Waterway system has central sewer, most of the surrounding urban area is serviced by on-site sewage disposal system (i.e., septic tanks). Stormwater conveyances draining to the lake are primarily characterized by grassy swales, which correspond well with current suggested Best Management Practices (BMPs) for stormwater treatment.

- Part of larger surface water system: The Sunshine Lake/Sunrise Waterway system appears to have been part of a larger natural feature that was incorporated into the planned overall surface water/master drainage management system for Port Charlotte. The system is one of the oldest in the area, and unlike many of the other major canal

systems in Port Charlotte, it does not include a drop structure on the north side of US 41. A number of stakeholders believe that long-term seasonal dry-season water levels in the system have declined. Without accurate records of stage elevations it is difficult to determine the relative influences of what has been a series of unusually warm/dry periods that have characterized normal dry-season rainfall patterns since 2006, and various stormwater conveyance projects recently (2010) undertaken by the County.

- Past water quality of the lake was better**:** Based on anecdotal evidence and observations by long-term resident stakeholders, the evidence suggests that water quality within the system was good for decades and did not begin to seriously degrade until relatively recently.

- Recent highly noticeable algal problem: Local residents seem to have noticed the algae problem as early as 2007 to 2009, with conditions progressively worsening over time. Currently, the main algal problem is focused in Sunshine Lake where the algal mat is growing from the bottom, up toward the surface. Measurements made in January 2012 found the algal mat in Sunshine Lake varied from 2 to 6 feet in depth, occupying more than 50% of the lake's volume. Observations indicate the same growth of a similar extensive algal mat along the bottom of Sunrise Waterway, with the greatest concentration just downstream of the Gertrude Avenue culvert. Microscopic examination indicated the algal mat to be dominated by a number of blue-green algal (cyanobacteria) species. Under certain conditions some cyanobacteria produce toxins (cyanotoxins) which can produce a wide variety of symptoms depending on exposure. Eye and breathing irrigation can be associated with volatilization of these compounds, while direct skin contact can cause itching and rashes. Both these conditions have been reported by local residents.

This study recommends undertaking the development of a Water Quality Management Plan (WQMP) incorporating a number of elements that have previously been found to be effective in other hypereutrophic (severely nutrient-enriched) Florida lakes. Generally, the types of projects that have had the greatest success, in terms of restoration of water quality, have been those that focused on removing point sources of nutrient pollution, combined with actions to reduce the impacts of past nutrient loading events. Simply treating the symptoms (killing the algae) has generally proven to be both difficult and ineffective without continued high levels of ongoing treatment. The study recommendations include the following series of actions, which should be implemented in sequence.

- Specific focused studies to identify nutrient sources: Calculations of the existing load of nutrients contained and currently recycling within the Sunshine Lake system suggest that it is highly unlikely that the current nutrient load within the lake has been primarily derived from surface stormwater inputs. The surrounding grassy swale conveyances should provide enhanced sediment and nutrient removal. The most likely other source is

groundwater and/or sewage collection systems. A time-limited and focused study on nutrient levels in up-gradient surficial groundwater could help identify and potentially reduce or eliminate potential sources. Depending on the number and depth of surficial groundwater wells selected as well as the study design, such a study might be expected to cost between $40,000 and $80,000.

- Sediment/algal biomass removal or inactivation: This study evaluated the effectiveness and costs of a number of sediment/muck removal projects for lakes in Florida, and developed comparative cost estimates. Potential algal biomass removal efforts should also include removal (not chemical treatment) of the Cattails (Typha sp.) that have begun to establish along the banks of both the lake and waterway. Depending on the method chosen and economic conditions, estimates are that such an effort might cost between $500,000 and $1,000,000.

- Enhanced circulation/aeration: Improved water quality via artificial circulation/aeration may be applicable to maintain improved water quality in Sunshine Lake once the sources of nutrient inputs are addressed, and the existing algae biomass is removed. Typically this is accomplished using aeration pumps to provide enhanced vertical and horizontal circulation. These types of projects typically produce higher levels of dissolved oxygen, reduced quantities of dissolved phosphorus, and reduced concentrations of ammonia and hydrogen sulphide, while simultaneously reducing phytoplankton productivity through net transportation of phytoplankton to deeper, and thus darker, parts of the lake's water column. Depending on the selected number of units and design, the setup costs for such a system for the Sunshine Lake/Sunrise Waterway system is expect to cost between $50,000 and $100,000.

- Modification of lake levels: Experience indicates that seasonally lowered lake levels generally appear to increase the susceptibility of lakes to algal blooms as a result of nutrient enrichment. There is a general impression among the Sunshine Lake/Sunrise Waterway stakeholders that for at least the dry-season (and possibly other times of the year as well) water levels have declined over time. The following two suggestions could be implemented at relatively moderate costs.

  1. A relatively inexpensive structure could be constructed to raise the invert level (elevation of the bottom of the pipe) at the large culvert at the Tamiami Trail frontage road. This could retain additional water (especially in Sunrise Waterway) in the system during the normal dry-season, and could potentially lessen algal growth enhanced due to seasonal lowering of water levels.

  2. In the absence of being able to increase lake water levels in the Sunshine Lake/Sunrise Waterway system, or perhaps in combination with such a project, the addition of a non-potable well to maintain lake levels in the dry-season should be

investigated. A well less than 6” in diameter, with a flow rate of less than 100,000 gallons per day could be relatively inexpensive to permit and install. Such a well could produce a volume of water that would offset lake losses due to evaporation during the dry-season months, thus reducing the lake’s susceptibility to algal blooms during this time of the year.

- The presented cost are provided as planning tools estimating what might be expected to be the relative costs based on other similar efforts. They do not include costs or time estimates for the permitting that will be required for each of the described mitigation efforts. These could be highly variable depending for example on what alternative dredging method might be selected and/or if the County might chose to handle elements of the necessary permitting in-house.

BIBLIOGRAPHY

The publications below are listed chronologically by the sections of Chapter Three in which they are cited. References for publications by other authors that are cited in this report are listed at the end of the bibliography.

Section 3.2 Graduate Studies

Montgomery, R.T., W.I. Miller III, and A.W. Collier. 1977. A preliminary investigation of the structure of diatom communities associated with the reef habitats of the Florida Keys. Pages 357-363 In: Proceedings Third International Coral Reef Symposium, Vol. 1: Biology. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL

Miller, W.I. III, Montgomery, R. T., and A.W. Collier. 1977. A taxonomic survey of the diatoms associated with Florida Keys coral reefs. p. 349-356. In: D.L. Taylor (ed.) Proceedings of Third International Coral Reef Symposium, Vol. 1: Biology. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL

Montgomery. R. T. 1978a. Environmental and Ecological Studies of Diatom Communities Associated with the Coral Reefs of the Florida Keys, Volume 1. Ph.D. Dissertation. Florida State University, Tallahassee, FL.

Montgomery. R. T. 1978b. Environmental and Ecological Studies of Diatom Communities Associated with the Coral Reefs of the Florida Keys, Volume 2. A Taxonomic Study of Florida Keys Benthic Diatoms Based on Scanning Electron Microscopy. Ph.D. Dissertation. Florida State University, Tallahassee, FL.

Section 3.3 Peace River Cumulative Impact Study

PBS&J, Inc. 2007a. Peace River Cumulative Impact Study. Report prepared for the Florida Department of Environmental Protection Bureau of Mine Reclamation, Tallahassee, FL and the Southwest Florida Water Management District, Brooksville FL.

Section 3.4. Source Water Protection: Factors Affecting Future Water Supply Withdrawals from the Peace River

Atkins, Inc. 2015. Integrated Regional Water Supply Plan - 2015. Report prepared for the Peace River Manasota Regional Water Supply Authority, Lakewood Ranch, FL in cooperation with the Southwest Florida Water Management District, Brooksville, FL.

3.5 Studies Conducted as Part of the Hydrobiological Monitoring Program Conducted in Support of Permitted Potable Water Supply withdrawals from the Peace River

Scientific Review Meeting Panel Summaries

PBS&J, Inc. 2002. Peace River HBMP-2002 Scientific Review Panel Meeting Summary Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc. 2004. Peace River HBMP-2004 Scientific Review Panel Meeting Summary Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc. 2007. Peace River HBMP-2007 Scientific Review Panel Meeting Summary Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc. 2010. Peace River HBMP-2010 Scientific Review Panel Meeting Summary Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc., 2013. Peace River HBMP-2013 Scientific Review Panel Meeting Summary Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

3.5.2 Comprehensive Reports for the Hydrobiological Monitoring Program, 2004 to 2013

PBS&J, Inc., 2001. Peace River Hydrobiological Monitoring Program - Project and Quality Control Plan. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J. 2004. Hydrobiological Monitoring Program, 2002 Comprehensive Summary Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District.

PBS&J. 2009a. Hydrobiological Monitoring Program, 2006 Comprehensive Summary Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District.

Atkins, Inc. 2013. Peace River Hydrobiological Monitoring Program, 2011 Comprehensive Summary Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District.

3.5.4 Mid-Term HBMP Reports Published in 2002 and 2009

Janicki Environmental, Inc. and PBS&J, Inc. 2002. Peace River HBMP - 1998 Three Year Interpretive Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc. 2009b. Peace River HBMP - 2004 Mid-term Interpretive Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL. (draft submitted in 2006)

3.5.5 Interpretive HBMP Reports Submitted Between 1992 and 1997

Environmental Quality Laboratory, Inc. 1992a. Peace River Hydrobiological Monitoring Program. Summary Report for the Lower Peace River and Charlotte Harbor. Phytoplankton Production and Structure 1983-1991, Taxonomy 1989-1991, Zooplankton Structure and Taxonomy 1989-1991. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., December 1992b. Peace River HBMP- Phytoplankton and Zooplankton Taxonomy 1988-1991. Appendices Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1994. Peace River HBMP Summary Report. Phytoplankton Production and Structure 1983-1993, Taxonomy 1989-1993, Zooplankton Structure and Taxonomy 1989-1993 Figures Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory. 1995a. Peace River Hydrobiological Monitoring Program, Summary Report for the Lower Peace River and Charlotte Harbor, Phytoplankton Production and Structure 1983-1993, Taxonomy 1989-1993, Zooplankton Structure and Taxonomy 1989-1993, Vegetation 1976-1993. Main Text Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1995b Peace River HBMP Summary Report, Phytoplankton Production and Structure 1983-1993, Taxonomy 1989- 1993, Zooplankton Structure and Taxonomy 1989-1993, Vegetation 1976-1993, Phytoplankton and Zooplankton. Addendum and Tables Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1995c Peace River HBMP Summary Report, Vegetation 1976-1993, Phytoplankton and Zooplankton 1983-1993, Figures and Addendum Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc. and Coastal Environmental, Inc. 1997. Hydrobiological Monitoring Program. Summary Report for the Lower Peace River and Charlotte Harbor. Zooplankton Structure and Taxonomy 1989-1996. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District as a condition of water use permit number 2010420.02.

3.5.6 Special Reports for the HBMP

PBS&J, Inc. 1999. Summary of Historical Information Relevant to the Hydrobiological Monitoring of the Lower Peace River and Upper Charlotte Harbor Estuarine System. Report prepared for the Peace River Regional Water Supply Authority.

PBS&J. 2000. Morphometric Habitat Analysis of the Lower Peace River. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District

PBS&J, Inc. 2002a. Peace River HBMP- Supplemental Analysis Report. Report prepared for the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc. 2002b. Peace River HBMP- 1983-2001 Charlotte Harbor Phytoplankton Data Sets Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District.

PBS&J. 2009c. Evaluation of Low Flow "Pump Test" (December 2006 - May 2007) - Findings Using Observed Data and Modeled Results from the Lower Peace River Continuous Recorders. Report prepared for the Peace River Regional Water Supply Authority, submitted to the Southwest Florida Water Management District.

3.5.7 Yearly Data Reports for the HBMP

Environmental Quality Laboratory, Inc. 1981. Peace River HBMP- February 1980-February 1981Annual Data Report. Report prepared for General Development Utilities, Inc., submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1982. Peace River HBMP- March 1981-February 1982 Annual Data Report. Report prepared for General Development Utilities, Inc., submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1983. Peace River HBMP- March 1982-February 1983 Annual Data Report. Report prepared for General Development Utilities, Inc., submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1985. Peace River HBMP- March 1984-February 1985 Annual Data Report. Report prepared for General Development Utilities, Inc., submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1986. Peace River HBMP- March 1985-February 1986 Annual Data Report. Report prepared for General Development Utilities, Inc., submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1987. Peace River HBMP- March 1986-February 1987 Annual Data Report. Report prepared for General Development Utilities, Inc., submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1989. Peace River HBMP- March 1987-February 1988 Annual Data Report. Report prepared for General Development Utilities, Inc., submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1990. Peace River HBMP- March 1988-December 1989 Annual Data Report. Report prepared for General Development Utilities, Inc., submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1991. Peace River HBMP- January 1990-December 1990 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1992. Peace River HBMP- January 1991-December 1991 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1993. Peace River HBMP- January 1992-December 1992 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1994. Peace River HBMP- January 1993- December 1993 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1995a. Peace River HBMP- January 1994- December 1994 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., July 1995b. Peace River HBMP- January 1994-December 1994 Annual Data Report Appendices. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., 1996a. Peace River HBMP- January 1995-December 1995 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Environmental Quality Laboratory, Inc., July 1996b. Peace River HBMP- January 1995-December 1995 Annual Data Report Appendices. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Coastal Environmental, Inc., and PBS&J Inc., 1997. Peace River HBMP- January 1996- December 1996 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J Inc., 1998. Peace River HBMP- January 1997- December 1997 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J Inc., 1999. Peace River HBMP- January 1998-December 1998 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Janicki Environmental, Inc., PBS&J, Inc., 2000. Peace River HBMP-1999 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc., 2001. Peace River HBMP-2000 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc., 2002. Peace River HBMP-2001 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc., 2003. Peace River HBMP-2002 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc., 2004. Peace River HBMP-2003 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc., 2005. Peace River HBMP-2004 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc., 2006. Peace River HBMP-2005 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc., 2007. Peace River HBMP-2006 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc., 2008. Peace River HBMP-2007 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc., 2009. Peace River HBMP-2008 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

PBS&J, Inc., 2010. Peace River HBMP-2009 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Atkins, Inc., 2011. Peace River HBMP-2010 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Atkins, Inc., 2012. Peace River HBMP-2011 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Atkins, Inc., 2013. Peace River HBMP-2012 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

Atkins, Inc. 2014. Peace River HBMP-2013 Annual Data Report. Report prepared for the Peace River Manasota Regional Water Supply Authority, submitted to the Southwest Florida Water Management District, Brooksville, FL.

3.6 Studies of Factors Affecting Phytoplankton Populations, Chlorophyll *a* Concentrations and Primary Production Rates in the Lower Peace River, Upper Charlotte Harbor and Other Estuaries

McPherson, B. F., R. T. Montgomery, and E.E. Emmons. 1990. Phytoplankton productivity and biomass in the Charlotte Harbor estuarine system, Florida. *Water Resources Bulletin* 26(5):787-800.

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.

Vargo, G. A., R. T. Montgomery and M.B. Neely. 2004. An investigation of relationships between phytoplankton populations, water quality parameters and freshwater inflow in three tidal rivers in West-Central Florida. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District.

Dixon, L.K., G.A. Vargo, J.O.R. Johannson, R.T. Montgomery, and M.B. Neely. 2009. Trends and explanatory variables for major phytoplankton groups of two southwestern Florida estuaries, U.S.A. *Journal of Sea Research* 61: 95-102

Atkins, Inc. 2014. An analysis of relationships of freshwater inflow and nutrient loading with chlorophyll values and primary production rates in the Lower Peace River. Report prepared for the Southwest Florida Water Management District, Brooksville, FL.

3.7 Studies Associated with the Charlotte Harbor National Estuary Program

W. Dexter Bender and Associates, Inc. and Coastal Environmental, Inc. 1997. Compendium of existing monitoring programs in the greater Charlotte Harbor watershed. Technical report 97-03 prepared for the Charlotte Harbor National Estuary Program, Punta Gorda, FL

Post, Buckley, Schuh and Jernigan, Inc. 1998. Framework for action: Quantifiable objectives and proposed action plans for the greater Charlotte Harbor watershed. Technical Report 98-04 of the Charlotte Harbor National Estuary Program, Punta Gorda, FL

Morrison, G.R., R. Montgomery, A. Squires, R. Starks, E. DeHaven and J.Ott. 1998. Chlorophyll and dissolved oxygen concentrations in Charlotte Harbor: Existing conditions and long-term trends. pp. 201-21 *In*: Proceedings of the Charlotte Harbor public conference and technical symposium, March 1997. Technical Report 98-02 published by the Charlotte Harbor National Estuary Program. Punta Gorda, FL

Post, Buckley, Schuh and Jernigan, Inc. and W. Dexter Bender and Associates, Inc. 1999. Synthesis of Existing Information. Volume 1: A characterization of water quality, hydrologic alterations, and fish and wildlife habitat in the greater Charlotte Harbor watershed. Volume 2: Appendices. Report prepared for the Charlotte Harbor National Estuary Program. Punta Gorda, FL

W. Dexter Bender and Associates, Inc. 1999. Data Management, Analysis, and Exchange Strategy. Technical report 99-03 prepared for the Charlotte Harbor National Estuary Program, Punta Gorda, FL.

W. Dexter Bender and Associates, Inc. 2000. Long-term monitoring strategy and gap analysis. Report prepared for the Charlotte Harbor National Estuary Program. Punta Gorda, FL.

Montgomery, R. and S. Stone. 2003. Differences in long-term Peace River water quality data for the periods 1976-1990 and 1996-2002. p. 23 *In*: Charlotte Harbor Conference - Focus in 2002-2003 Program Summary. Publication of Mote Marine Laboratory. Sarasota, FL

Montgomery, R. T. 2004. Analyses of long-term relationships between riparian vegetation patterns and freshwater inflows in the Lower Peace River estuary, 1976-2002. pp. 40-41 *In:* Charlotte Harbor Conference - Sound Science in 2003-2004 , October 5 - 6, 2004, Mote Marine Laboratory, Sarasota FL

Montgomery, R. T. and J. Ryan. 2005. Long-term data and nutrient issues within the Peace River Watershed. Slides from presentation given at the Charlotte Harbor Watershed Summit - Lessons Learned from Transferring Science to Watershed Management. CHNEP Watershed Summit - February 14-17, 2005. Charlotte Harbor National Estuary Program. Punta Gorda, FL.

Montgomery, R. T. and S. Stone. 2007. Changes in land use in the Peace River watershed and CDOM in the Lower Peace Watershed and Upper Charlotte Harbor. pp. 35-37. *In*: Colored Dissolved Organic Matter (CDOM) Workshop Summary. Charlotte Harbor National Estuary Program CDOM workshop May 29-30, 2007. Technical document 07-03 of the Charlotte Harbor National Estuary Program, Punta Gorda, FL.

Montgomery, R., D. Tomasko, and S. Stone. 2009. Off-stream reservoirs combined with percent flow withdrawal schedules to reduce downstream estuarine impacts. p. 54 *In:* Workshop on watershed reservoirs: locations, effects and solutions. Workshop summary report. Charlotte Harbor National Estuary Program workshop on watershed reservoirs, April 13-15, 2009. Charlotte Harbor National Estuary Program, FL. Punta Gorda, FL.

3.8 RALPH Plots and Inundation Simulations - Analyses Conducted to Support the Minimum Flows and Levels Program of the Southwest Florida Water Management District

Latham, P.J., R. T. Montgomery, J. Morales, M. Kelly. 2002. Establishing minimum flows for the upper Peace River. Presentation at the Society of Wetland Scientists 23rd Annual Conference: Wetland Linkages - A Watershed Approach. Lake Placid, NY. June 4, 2002.

3.9 Studies of the Hydrology and Water Quality of Shell Creek Conducted for the City of Punta Gorda

PBS&J. 2003. Shell Creek HBMP Summary Report - 2001. Report prepared for the City of Punta Gorda Utilities Department, submitted to the Southwest Florida Water Management District. Originally submitted in 2001 and revised in 2003.

PBS&J. 2007b. Assessment of Potential Shell Creek Impacts Resulting from Changes in City of Punta Gorda Facility Withdrawals. Report prepared for the Peace River Manasota Regional Water Supply Authority and the City of Punta Gorda Utilities Department, submitted to the Southwest Florida Water Management District.

PBS&J. 2010. City of Punta Gorda Shell Creek HBMP Five Year Comprehensive Summary Report. Report prepared for the City of Punta Gorda Utilities Department, submitted to the Southwest Florida Water Management District.

3.10 Studies of the Hydrology and Water Quality of Myakkahatchee Creek Conducted for the City of North Port

PBS&J, Inc. 2006. Myakkahatchee Creek Water Use Permit, Review and Analysis of Supporting Data, 2003 through 2005. Report submitted to the City of North Port Utilities Department, submitted to the Southwest Florida Water Management District

PBS&J, Inc. 2009d. Myakkahatchee Creek Hydrobiological Monitoring Program, Data Summary Report, HBMP Inception to June 30, 2009. Report submitted to the City of North Port Utilities Department, submitted to the Southwest Florida Water Management District.

3.11. Other Hydrologic and Ecological Assessments

Weaver, R. J. and R. T. Montgomery. 1974. Effect of Epthephon on coloration and maturation wine grapes. *American Journal of Enology and Viticulture*. 25: 39-41.

Flannery, M.S, E.B. Peebles, and R. T. Montgomery. 2002. A percent-of-flow approach for managing reductions of freshwater inflows from unimpounded rivers to southwest Florida estuaries. *Estuaries*: 25 (6B): 1318-1332

PBS&J, Inc. 2009e. Investigation of Resources, Threats, and Future Protection of Needs of the Matansas River Study Area. Report prepared for the St. Johns River Water Management District, Palatka, FL

PBS&J, Inc. 2012. Sunshine Lake/Sunrise Waterway Study. Report prepared for Charlotte County Government, Punta Gorda, FL.

Publications by Other Authors Cited in this Report (arranged alphabetically)

Basso, R. 2003. Predicted Change in Hydrologic Conditions along the Upper Peace River due to a Reduction in Ground Water Withdrawals. Hydrologic Evaluation Section. Southwest Florida Water Management District.

Cichra, C.E., C.N. Dahm, and D.T. Shaw. 2005. A Review of Alafia River Minimum Flows and Levels Freshwater Segment Including Lithia and Buckhorn Springs and Proposed Minimum Flows and Levels for the Upper Segment of the Myakka River, from Myakka City to SR572. Report prepared for the Southwest Florida Water Management District. Brooksville, FL

Culter. 2005. Distribution of Macroinvertebrate in Shell Creek as Related to Salinity and Sediment Structure. Report prepared by Mote Marine Laboratory for the Southwest Florida Water Management District. Brooksville, FL.

Estevez. E.D. 1986. Infaunal Macroinvertebrates of the Charlotte Harbor Estuarine System and Surrounding Inshore Waters. Florida. U.S. Geological Survey Water Resources Investigations Report. 85-4260.

Estevez. E.D. 2004. Molluscan Bio-Indicators of the Tidal Shell Creek, Florida. Report prepared by Mote Marine Laboratory for the Southwest Florida Water Management District. Brooksville, FL.

Florida Department of Environmental Protection. 2007. Peace River Basin Resource Management Plan. Florida Department of Enviromental Protection, Tallahassee, FL.

Florida Marine Research Institute. 1998. Development of GIS-based Maps to Determine the Status and Trends of Oligohaline Vegetation in the Tidal Peace and Myakka Rivers. Final Report to: SWIM Section, SWFWMD, Tampa, FL

Fraser, T. H. 1997. Abundance, seasonality, community indices, trends and relationships with physicochemical factors of trawled fish in Upper Charlotte Harbor, Florida. *Bulletin of Marine Science* 60:(3); 739-763

Greenwood, M.F.D., R.E. Matheson Jr., T.C. MacDonald, and R.H. McMichael. 2004. Assessment of relationships between freshwater inflow and Poplulations of Fish and Selected Invertebrates in the Peace River and Shell Creek, Florida. Report prepared by the Florida Fish and Wildlife Conservation Commission , Fish and Wildlife Research Institute. St. Petersburg, FL

Hammett, K.M. 1988. Land use, water use, streamflow and water-quality characterisitics of the Charlotte Harbor inflow area, Floirda. U.S. Gelological Survey Open-File Report 87-472.

Landquist. E.E. 1953. A Biological Survey of the Peace River, Florida. Masters Thesis University of Florida, Gainesville FL.

Michel, J.F., R.C. Work, F.W. Rose, and R.G. Rehrer. 1975. A study of the effect of fresh water withdrawal on the Lower Peace River, DeSoto County, Florida. University of Miami Rosentiel School of Marine and Atmospheric Science. UM-RSMAS #75002

Mote Marine Laboratory. 2002. Benthic Macroinvertebrate and Mollusk Indicators. Phase II. Final Report for the Peace River Hydrobiological Monitoring Program for WUP 2010420.03. Report submited to the Peace River Manasota Regional Water Supply Authority.

Peebles, E.B. 2002. An Assessment of the Effects of Freshwater Inflows on Fish and Invertebrate Habitat Use in the Peace River and Shell Creek Estuaries. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District. Brooksville, FL.

Peebles, E.B. 2005. An Analysis of Freshwater Inflow Effects on the Early Stages of Fish and Their Invertebrate Prey Habitat Use in Alafia River Estuary. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District. Brooksville, FL

Peebles, E.B. and S. E. Burghart. 2013. Database Amendment and Analysis Update for Plantkon-Net Surveys of the Lower Peace River and Shell Creek Estuaries Including Revised Regressions for Distribution and Abundance Responses. Report by the University of South Florida College of Marine Science for the Southwest Florida Water Management District.

Peek, H.M. 1951. Cessation of flow of Kissengen Spring in Polk County, Florida. Report of Investigations No. 7. Florida Geological Survey. Tallahassee, FL

Stewart, H.G., Jr., 1966, Ground-water resources of Polk County, Florida: Florida Geological Survey Report of Investigations 44, 170 p.

Southwest Florida Water Management District (SWFWMD). 2002. Proposed Minimum Flows for the Upper Peace River. Report of the Southwest Florida Water Management District. Brooksville, FL.

Southwest Florida Water Management District (SWFWMD). 2004. Shell, Prairie, and Joshua Creeks Watershed Management Plan. Report of the Southwest Florida Water Management District. Brooksville, FL.

Southwest Florida Water Management District (SWFWMD). 2011a. Proposed Minimum Flows and Levels for the Little Manatee Rive, Peer Review Draft. Report of the Southwest Florida Water Management District. Brooksville, FL.

Southwest Florida Water Management District (SWFWMD). 2011b. The Determination of Minimum Flows for the Lower Myakka River. Report of the Southwest Florida Water Management District. Brooksville, FL.

Texas Instruments 1978. Preliminary biological report for the proposed DeSoto site development. Report to The Florida Power and Light Company.

Wang, P. 2004. Bathymetric Survey of the Upper Peace River, Shell Creek, and Dona-Roberts Bay. Report prepared by the University of South Florida Department of Geology for the Southwest Florida Water Management District. Brooksville, FL

Wang, P. 2013. Shoreline Mapping and Bathymetric Survey for the Charlotte Harbor, Lower Peace River, and Lower Myakka River System. Report prepared by the University of South Florida Department of Geology for the Southwest Florida Water Management District. Brooksville, FL

Wang. J. C. S. and E.C. Raney. 1971. Distribution and fluctuations in the fish fauna of the Charlotte Harbor estuary, Florida. Charlotte Harbor Estuarine Studies. Mote Marine Laboratory, Sarasota FL.