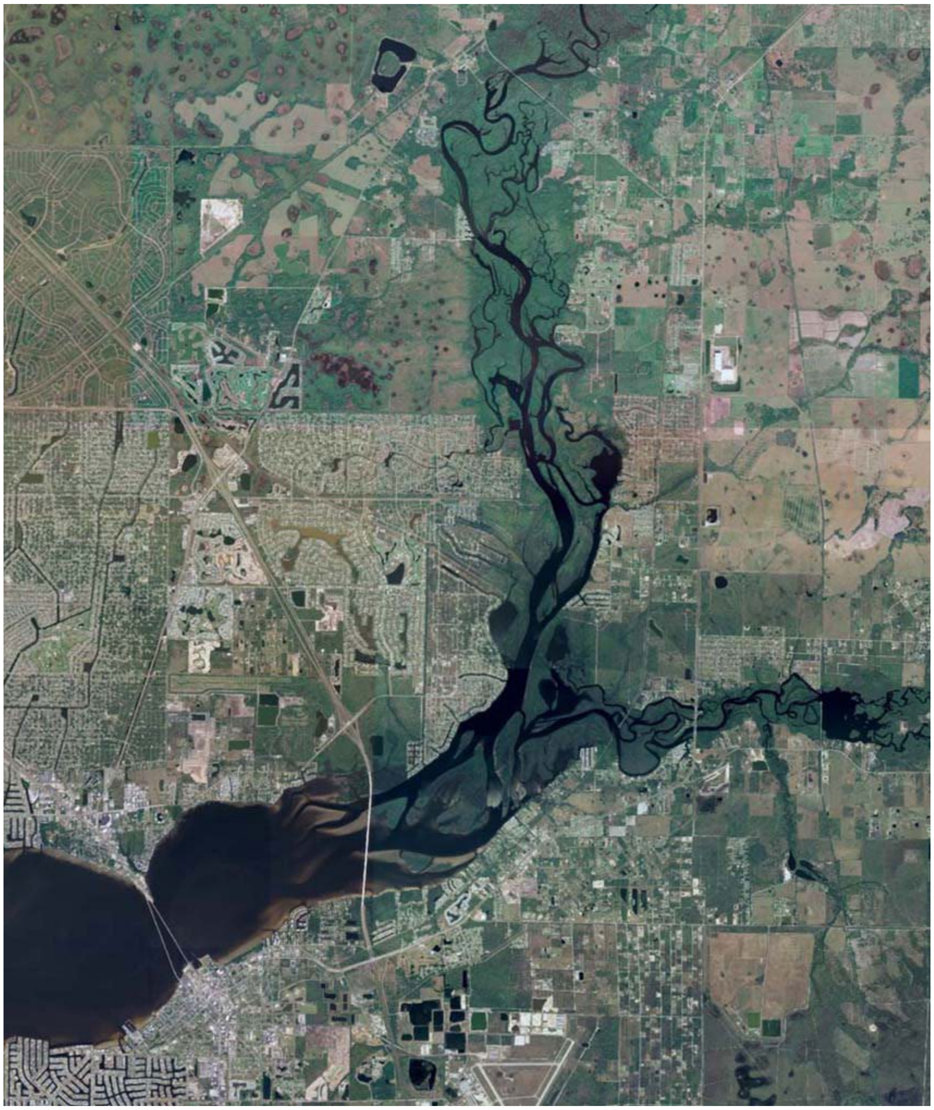
Recommended Minimum Flows for the Lower Peace River and Lower Shell Creek, Final Draft



November 30, 2021

Southwest Florida Water Management District

Recommended Minimum Flows for the Lower Peace River and Lower Shell Creek, Final Draft

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Appendix E. Rubec, J.P., Santi, C., Ghile, Y.B., and Xinjian Chen, X. 2018. Modeling to Assess Spatial Distributions and Population Numbers of Estuarine Species in the Lower Peace River and Charlotte Harbor, Florida. Prepared for the Southwest Florida Water Management District.

Appendix F. Janicki Environmental, Inc. 2019. Lower Peace River Water Quality Study. Final Report. Prepared for Southwest Florida Water Management District.

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Acronym/Abbreviation List

Acronym	Definition
ADCP	acoustic Doppler current Profiler
AIC	Akaike Information Criterion
AMO	Atlantic Multidecadal Oscillation
ArcGIS	Geographic information software developed by Esri
AVEVD	Ambient vertical eddy viscosity/diffusivity
BL	Baseline scenario descriptor for HSMs
cfs	cubic feet per second (ft^3/s)
CDF	Cumulative Distribution Function
CLC	[Florida] Cooperative Land Cover [Map] of the Florida Fish and Wildlife Conservation Commission and Florida Natural Areas Inventory
CPUE	Catch-per-unit-effort
CPUE-GC	Catch-per-unit-effort corrected for sampling gear type
GAM	General Additive Model
DEM	Digital Elevation Model
District	Southwest Florida Water Management District
F.A.C	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
FWC	Florida Fish and Wildlife Conservation Commission
FIM	Fisheries-Independent Monitoring of the FWRI
F.S.	Florida Statutes
ft	Feet or foot
FWRI	Fish and Wildlife Research Institute of the FWC
GIS	Geographic Information System
HA	Habitat Availability
HEC-GeoRAS	A set of procedures, tools and utilities for processing geospatial data in ArcGIS using a graphical user interface
HEVD	Horizontal eddy viscosity/diffusivity
HSM(s)	Habitat Suitability Model(s)
HSPF	Hydrological Simulation Program-FORTRAN
km	kilometer
LAMFE	Laterally averaged two-dimensional model
LESS	Lakes and Estuary Simulation System (model)
m	Meter
MAE	Mean absolute error (for statistical analyses)
ME	Mean error (for statistical analyses)
MF	Minimum Flows scenario descriptor for HSMs

MFL	Minimum Flow and/or Minimum Water Level (as defined in Section 373.042, F.S.)
mg	million gallons
mgd	million gallons per day
mi^2	square miles
mm	millimeter
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
No.	Number
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council of the United States Academies of Sciences, Engineering and Medicine
PLRG	Pollutant Load Reduction Goal
PRIM	Peace River Integrated Model
PRMRWSA	Peace River Manasota Regional Water Supply Authority
psu	Practical salinity unit
R^2	Coefficient of determination (for statistical analyses)
RKm (or rKM)	River kilometer (linear distance system used for river segments)
SERC	Statement of Estimated Regulatory Cost
SID	WMIS Site Identification Number
SL	Standard Length
SWFWMD	Southwest Florida Water Management District
TINs	Triangulated irregular networks (used in GIS analyses)
TMDL	Total Maximum Daily Load
UGF	Ungaged flow
UnLESS	Unstructured LESS (model)
UnLESS3D	3-Dimensional unstructured Cartesian grid model
U.S.	United States
USACOE	United States Army Corps of Engineers
USGS	United States Geological Survey / Department of Interior.
WBID	Water Basin Identification number
WMIS	Water Management Information System
z_0	Bottom roughness

Conversion Units

Metric to U.S. Customary		
Multiply	By	To Obtain
cubic meters per second (m^3/s)	35.31	cubic feet per second (cfs)
cubic meters per second (m^3/s)	23	million gallons per day (mgd)
millimeters (mm)	0.03937	inches (in)
centimeter (cm)	0.3937	inches (in)
meters (m)	3.281	feet (feet)
kilometers (km)	0.6214	statute miles (mi)
square meters (m^2)	10.76	square feet ($feet^2$)
square kilometers (km^2)	0.3861	square miles (square miles)
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.315	cubic feet ($feet^3$)
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
Celsius degrees (^oC)	1.8*(^oC) + 32	Fahrenheit (^oF)
U.S. Customary to Metric		
Multiply	By	To Obtain
inches (in)	25.40	millimeters (mm)
inches (in)	2.54	centimeters (cm)
feet (feet)	0.3048	meters (m)
statute miles (mi)	1.609	kilometers (km)
square feet ($feet^2$)	0.0929	square meters (m^2)
square miles (square miles)	2.590	square kilometers (km^2)
acres	0.4047	hectares (ha)
gallons (gal)	3.785	liters (l)
cubic feet ($feet^3$)	0.02831	cubic meters (m^3)
acre-feet	1233.0	cubic meters (m^3)
Fahrenheit (^oF)	0.5556*(^oF-32)	Celsius degrees (^oC)
U.S. Customary to U.S. Customary		
Multiply	By	To Obtain
acre	43560	square feet ($feet^2$)
square miles (square miles)	640	acres
cubic feet per second (cfs)	0.646	million gallons per day (mgd)

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We are also indebted to the independent, scientific peer review panelists, Dave Tomasko, formerly with Environmental Science Associates, Y. Peter Sheng, and Laura Bedinger with Water & Air Research, Inc., for their constructive criticism and improvement of the District's presentation of the minimum flow recommendations included in this report.

EXECUTIVE SUMMARY

The Southwest Florida Water Management District (District) has been directed by the State Legislature to establish minimum flows for flowing watercourses within its boundary. As currently defined by statute, "the minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." Each water management district of the state or the Florida Department of Environmental Protection identify specific metrics or criteria that can be associated with significant harm and used for minimum flows development. Once adopted into the District's Water Levels and Rates of Flow Rules within the Florida Administrative Code, minimum flows are used for water supply planning, water use permitting and environmental resource regulation.

This report summarizes minimum flows for the Lower Peace River and Lower Shell Creek developed by the District as part of a comprehensive reevaluation of minimum flows previously established for the Lower Peace River. For minimum flow purposes, the Lower Peace River is defined as the river segment from the U.S. Geological Survey (USGS) Peace River at Arcadia, Florida gage downstream to Charlotte Harbor. Lower Shell Creek is defined as the segment of the creek that extends from the Hendrickson Dam at Shell Creek Reservoir to the confluence of Shell Creek with the Lower Peace River.

The District previously developed minimum flows for the Lower Peace River and drafted proposed minimum flows for Lower Shell Creek in 2010. Following an independent, scientific peer review process, minimum flows were adopted into District rules in July 2010 for the Lower Peace River and became effective in August 2010. Minimum flows were not established for Lower Shell Creek at that time based on an identified need for development and implementation of a recovery strategy to achieve the minimum flows proposed for the creek, which were not being met.

The established Lower Peace River minimum flows rule required reevaluation of the minimum flows within five years of their adoption to incorporate additional ecological data. In response to this requirement, the District completed an initial reevaluation of the minimum flows for the Lower Peace River in 2015 and scheduled completion of a more comprehensive reevaluation for 2020.

In support of the comprehensive reevaluation described in this report, new, recommended minimum flows for the Lower Peace River and Lower Shell Creek were developed using the best information available, as required by the Florida Statutes, The recommended minimum flows were also based on all relevant environmental values identified in the Florida Water Resource Implementation Rule for consideration when setting minimum flows.

For the comprehensive reevaluation, the District: updated hydrologic data sets used in the analyses; re-mapped the bathymetry of the Lower Peace River; Lower Myakka and Charlotte Harbor; produced a LiDAR-based high resolution digital elevation model for the area; refined a hydrodynamic model used to predict salinity, water level and temperature in the system; and expanded application of the hydrodynamic model to the entire Charlotte Harbor. In addition, habitat modeling for seven estuarine dependent fish species and Blue Crab, water quality analysis and floodplain inundation analysis for the upper portion of the Lower Peace River were conducted.

Baseline flow records used for the minimum flows analyses were developed for the Lower Peace River and Lower Shell Creek to account for decreases and increases (from excess agricultural runoff) in gaged flows associated with surface and groundwater withdrawals. The Lower Peace River baseline flow record extended from 1950 through 2014 and the Lower Shell Creek baseline flows extended from 1966 through 2014. Flow-based blocks corresponding to periods of low (Block 1), medium (Block 2), and high (Block 3) flows based on the annual 75% and 50% exceedance of the baseline flow records were identified to develop proposed minimum flows for the river and creek.

The Lower Peace River and Lower Shell Creek were modeled with the refined hydrodynamic model as one system, “the Lower Peace/Shell System”, to appropriately characterize the strong hydrologic interactions between the river, creek, and Charlotte Harbor. Block-specific percent-of-flow reductions associated with significant harm thresholds based on a 15% reduction in the most sensitive assessed habitat were used to develop recommended minimum flows for the system. Use of percent-change-based metrics permitted assessment of environmental factors that typically exhibit continuous or incremental responses to changes in flows. Environmental resources or goals assessed for development of the minimum flows for the Lower Peace/Shell System included: maintenance of biologically relevant salinities with water volumes, shoreline lengths and bottom areas associated with salinities ranging from 2 to 20 psu; inundation of floodplain wetlands; habitats for selected fish species and Blue Crab; and water quality.

Results from models runs used to evaluate relationships between flows and environmental criteria in the Lower Peace/Shell System did not exhibit breakpoints or inflections. Rather, the analyses indicated that the < 2 practical salinity unit (psu) salinity zone was the most sensitive criterion to flow reductions. Based on this criterion, recommended minimum flows in the Lower Peace River and Lower Shell Creek were determined for each flow-based block as percentages of baseline flows. The approach also permitted identification of allowable percent-of-flow reductions that can be used to describe the minimum flows. To ensure protection of a recommended low flow threshold for the Lower Peace River and smooth transitions in flows between defined flow blocks, each flow-based block for the river was sub-divided into defined flow ranges for minimum flow purposes. The minimum flows for the Lower Peace River and Lower Shell Creek were developed with consideration of and are protective of all relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing minimum flows and levels.

Recommended minimum flows and corresponding, allowable percent-of-flow reductions in the Lower Peace River were defined for each sub-divided flow-based block as defined flow rates or percentages of the total combined baseline flow at the USGS Peace River at Arcadia FL (No. 02296750), Joshua Creek at Nocatee FL (No. 02297100), and Horse Creek near Arcadia FL (No. 02297310) gage sites. Results from models runs conducted to evaluate relationships between flows and environmental criteria in the Lower Peace/Shell System did not exhibit breakpoints or inflections. However, a low flow threshold of 130 cfs was recommended as an operational, minimum flow criterion for the Lower Peace River to assist in maintaining freshwater conditions at the withdrawal point of the Peace River Manasota Regional Water Supply Authority (PRMRWSA). This low flow threshold of 130 cfs has been included in currently established minimum flows for the Lower Peace River and successfully implemented for permitted withdrawals by the PRMRWSA since 2010. Inclusion of a maximum daily withdrawal limit of 400 cfs was also recommended for the Lower Peace River to ensure protection of extremely high flows while meeting the water needs of the region.

The recommended minimum flows for the Lower Peace River based on combined, adjusted flows for the previous day at the USGS Horse Creek near Arcadia, Joshua Creek near Nocatee and the Peace River at Arcadia gages are summarized in the following table. Adjusted flow is defined as flow that would exist in the absence of withdrawal impacts. Allowable percent-of-flow reductions associated with the minimum flows, and formulas that may be used to implement surface water withdrawals in accordance with the minimum flows are also provided.

Lower Peace River Recommended Minimum Flows				
Flow-Based Block	**If Combined Flow, in Cubic Feet per Second (cfs) on the Previous Day, Adjusted for Upstream Withdrawals is:**	**Minimum Flow is:**	**Potentially Allowable Flow Reduction is:**	**Formula for Calculation of Potentially Allowable Flow Reduction (Q_{Red}) based on Combined Flow on Previous Day (Q_{Prev})**
1	≤130 cfs	Combined flow on the previous day	0 cfs	Q_{Red} = 0 cfs
	> 130 cfs and ≤149 cfs	130 cfs	Combined flow on the previous day minus 130 cfs	$Q_{Red} = Q_{Prev}$ - 130 cfs
	> 149 cfs and ≤ 297 cfs	87% of combined flow on the previous day	13% of combined flow on the previous day	$Q_{Red} = Q_{Prev}$ * 13%
2	> 297 cfs and ≤ 335 cfs	258 cfs	Combined flow on the previous day minus 258 cfs	$Q_{Red} = Q_{Prev}$ - 258 cfs
	> 335 cfs and ≤ 622 cfs	77% of combined flow on the previous day	23% of combined flow on the previous day	$Q_{Red} = Q_{Prev}$ * 23%
3	> 622 cfs and ≤ 798 cfs	479 cfs	Combined flow on the previous day minus 479 cfs	$Q_{Red} = Q_{Prev}$ – 479 cfs

	> 798 cfs	60% of combined flow on the previous day	40% of combined flow on the previous day[a]	$Q_{Red} = Q_{Prev} * 40\%$

[a] 400 cfs maximum daily withdrawal

Minimum flows status assessments for the Lower Peace River were conducted using flow and water withdrawal records, block-specific and five-year and ten-year moving mean and median flow statistics, and review of water use permit conditions aligned with the recommended minimum flows. Assessment results indicated the recommended minimum flows for the Lower Peace River are being met and are also expected to be met over the next 20 years. Development of a recovery strategy or specific prevention strategy associated with adoption of the minimum flows for the Lower Peace River was, therefore, not necessary.

Similar to the minimum flows recommended for the Lower Peace River, recommended minimum flows for Lower Shell Creek were developed as block-based minimum flows that specify allowable percentage reductions in baseline flows into Shell Creek Reservoir and past Hendrickson Dam to the lower creek.

Specifically, the recommended minimum flows for Lower Shell Creek summarized in the following table are based on daily average flow at the USGS Shell Creek near Punta Gorda, FL Gage (No 02298202), adjusted for withdrawals and agricultural runoff. The necessary adjustments include addition of the previous day's withdrawals from Shell Creek Reservoir to the measured flow or volume of water impounded in the reservoir, and subtraction of estimates of agricultural runoff volumes from the Shell Creek watershed above Hendrickson Dam. Allowable percent-of-flow reductions consistent with the minimum flows are also provided in the table below.

Lower Shell Creek Recommended Minimum Flows			
Flow Based Block	**If Adjusted Flow, in Cubic Feet per Second (cfs) on the Previous Day is:**	**Minimum Flow is:**	**Potentially Allowable Flow Reduction is:**
1	< 56 cfs	87% of adjusted flow on the previous day	13% of adjusted flow on the previous day
2	56 cfs – 137 cfs	77% of adjusted flow on the previous day	23% of adjusted flow on the previous day
3	> 137 cfs	60% of adjusted flow on the previous day	40% of adjusted flow on the previous day

An initial status assessment using historical, gaged flows indicated the recommended minimum flows for Lower Shell Creek would not have been met 20% of days in the 47-year simulation period associated with the baseline flows record. At the time of this initial assessment, the District identified two recovery projects that could individually or in combination prevent the recommended Lower Shell Creek minimum flows from being violated due to consumptive water use, i.e., from withdrawals from Shell Creek Reservoir. The projects include a reverse osmosis project (RO) and a plant-to-plant interconnect project between the PRMRWSA Peace River Water Treatment Facility and the City of Punta Gorda Shell Creek Water Treatment Plant (Phase 1 Interconnect project).

These two alternative water supply projects were completed in August 2020 and the District received information regarding how the City of Punta Gorda would use the projects to enhance water supply reliability and meet the minimum flows recommended for Lower Shell Creek. In addition, the City provided its updated 2040 water demand projection and monthly withdrawal peaking ratios.

Investigations based on this updated information and other factors that affect flows in the creek indicated the recommended minimum flows for Lower Shell Creek are being met and development of a recovery strategy is not required. The analyses also identified the recommended minimum flows would not be met during a 20-year planning horizon. In that instance, the District would typically move forward with the adoption of a prevention strategy. A modification of the City's water use permit that imposes withdrawal limitations consistent with the recommended minimum flows for Lower Shell Creek was identified to obviate the need for a prevention strategy. These withdrawal limitations are based on consideration of the City's use of the RO and Phase I Interconnect projects. The City has now modified its water use permit consistent with the recommended minimum flows for Lower Shell Creek. Compliance with the modified permit conditions ensures the Lower Shell Creek minimum flows are met over the next 20 years and a prevention strategy is not required.

The recommended minimum flows for the Lower Peace River and Lower Shell Creek described in this report were subjected to independent, scientific peer review facilitated by the District from late-March through June 2020. With the goal of assessing the technical defensibility of the minimum flows, the review process included three phases that culminated in the development of an initial peer review report, a District response to the initial peer review report, and development of a final peer review report. Following completion of the peer review the District prepared a summary response to the final peer review report.

Findings and recommendations included in the initial and final peer review reports, and information included in the response documents prepared by District staff and other information discussed during the peer review process were incorporated into this current draft minimum flows report and are included in Appendix G. Based on the District responses to peer review panel comments, additional technical documentation, and updates made to the draft minimum flows report, the panel supported the conclusions presented within the District's minimum flows report.

This current draft minimum flows report also includes updates associated with the substantial stakeholder outreach activities and stakeholder input provided through November 2020, which are summarized or included in Appendix H.

In December 2020, the District Governing Board approved initiation of rulemaking for establishment of the recommended minimum flows for the Lower Peace River described in this report. The recommended minimum flows became effective in April 2021, replacing the previously established minimum flows for the lower river.

Because climate change, structural alterations and other changes in the watershed could potentially affect flow characteristics, and because additional information relevant to minimum flows development may become available, the District is committed to periodic reevaluation and, if necessary, revision of minimum flows established for the Lower Peace River and Lower Shell Creek.

CHAPTER 1 - INTRODUCTION

1.1. Reevaluation of 2010 Lower Peace River Minimum Flows and Development of Recommended Minimum Flows for the Lower Peace River and Lower Shell Creek

This report documents a reevaluation of the minimum flows established for the Lower Peace River, and development of new, recommended minimum flows for the Lower Peace River and Lower Shell Creek. For minimum flow purposes, the Lower Peace River is defined as the river segment from the U. S. Geological Survey (USGS) Peace River at Arcadia, Florida gage downstream to Charlotte Harbor. Lower Shell Creek is defined as the segment of the creek that extends downstream from the Hendrickson Dam at Shell Creek Reservoir to the confluence of Shell Creek with the Lower Peace River.

The Southwest Florida Water Management District (District) initiated work supporting development of minimum flows for the Lower Peace River in 2007. After an extensive review process, which included the District's facilitation of independent scientific peer review (Montagna et al. 2008), minimum flows for the Lower Peace River summarized in SWFWMD (2010) were adopted into the District's Water Levels and Rates of Flow rules (specifically Rule 40D-8.041(8), Florida Administrative Code or F.A.C.) in July 2010, and a minimum flows rule for the river became effective in August 2010.

The minimum flows established for the Lower Peace River in 2010 were based on the sum of the combined flows of the USGS Peace River at Arcadia, FL gage (02296750) plus the flow at the USGS Horse Creek near Arcadia, FL gage (02297310), and the USGS Joshua Creek at Nocatee, FL gage (02297100).
The minimum flows were both seasonal and flow dependent and included a low flow threshold applicable throughout the year as well as seasonally dependent (i.e., block-specific) minimum flows that specified allowable reductions in the sum of flows at the three gages denoted above that would occur in the absence of any permitted upstream withdrawals. The Lower Peace River minimum flows rule also specified that the total permitted maximum withdrawals on any day should not exceed 400 cfs and included summary flow statistics that could be used as a tool to assess whether flows in the Lower Peace River remain above flow rates that are expected to occur with implementation of the minimum flows requirements.

The District developed proposed minimum flows for Lower Shell Creek in 2010 in conjunction with the development of minimum flows for the Lower Peace River. As part of that effort, the District determined that a recovery strategy would be required for Lower Shell Creek, because the existing flow rates in the creek were below the proposed minimum flows. Based on the need for development of recovery strategies, the minimum flows proposed for Lower Shell Creek in 2010 were not adopted into District rules.

The minimum flows rule established for the Lower Peace River in 2010 required the reevaluation of the minimum flows within five years of their adoption to incorporate additional ecological data. Five years from the date of adoption was in July 2015 and in keeping with the specified timeline, the District prepared an initial reevaluation report (Ghile and Leeper 2015) to summarize progress made until 2015 and highlight ongoing activities to support a more comprehensive minimum flow reevaluation scheduled for completion in 2018. Revision of this reevaluation timeline, with completion scheduled for 2020 permitted further improvement of the District's hydrodynamic model of the Lower Peace River, extension of the model domain to Lower Shell Creek and the entire Charlotte Harbor, and analysis of potential flow-related changes in water quality, floodplain wetlands, and fish habitats.

Based on the comprehensive reevaluation, the District developed new, recommended minimum flows for the Lower Peace River and Lower Shell Creek. These minimum flows, which are described in this report, were developed with consideration of and are protective of all relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing minimum flows or levels (see Rule 62-40.473, Florida Administrative Code, or F.A.C.).

The recommended minimum flows for the Lower Peace River and Lower Shell Creek were subjected to independent, scientific peer review facilitated by the District from late-March through June 2020. With the goal of assessing the technical defensibility of the minimum flows, the review process included three phases that culminated in the development of an initial peer review report, a District response to the initial peer review report, and development of a final peer review report. Following completion of the peer review the District prepared a summary response to the final peer review report.

Findings and recommendations included in the initial and final peer review reports, and information included in the response documents prepared by District staff and other information discussed during the peer review process were incorporated into this current draft minimum flows report and are included in Appendix G. Based on the District responses to peer review panel comments, additional technical documentation, and updates made to the draft minimum flows report, the panel supported the conclusions presented within the District's minimum flows report.

This current, updated draft minimum flows report also includes revisions associated with the substantial stakeholder outreach activities and stakeholder input provided through November 2020, which are summarized or included in Appendix H.

On December 15, 2020, the District's Governing Board approved initiation of rulemaking for establishment of the recommended minimum flows for Lower Peace River The recommended minimum flows became effective on April 12, 2021, replacing the minimum flows established in 2010.

Although the Lower Peace River and Lower Shell Creek can be considered separate water bodies, they are hydrologically connected – Lower Shell Creek is a tributary of the Lower Peace River. The two water bodies can be and for much of the minimum flows analyses described in this report, were modeled as a single system, the "Lower Peace/Shell System." Consideration of this combined "system" was critical to understanding potential effects of changes in flows in the Lower Peace River, Lower Shell Creek and Charlotte Harbor, the receiving water body at the terminus of the Lower Peace River.

1.2. Legal Directives for Establishment of Minimum Flows and Levels

1.2.1. Relevant Florida Statues and Rules

Flowing surface waters provide numerous benefits to society and are an integral part of the natural functioning of ecosystems within the state of Florida. Surface water withdrawals can directly affect the water volume or rate of flow in rivers. Similarly, groundwater withdrawals have the potential to alter groundwater levels and thereby reduce the water volume or flow in rivers. These cause-and-effect relationships between water withdrawals and reduced flows in surface watercourses have been recognized by the Florida State Legislature through enactment and updates of the Florida Water Resources Act of 1972 (Chapter 373, Florida Statutes or "F.S."). Based on this legislation, the District has the responsibility for establishing minimum flows for all surface watercourses within its boundary. Six primary legal directives guide the District's establishment and implementation of minimum flows:

1. Section 373.042 of The Florida Water Resources Act of 1972 (Chapter 373, F.S.) directs the Department of Environmental Protection (FDEP) or the District to establish minimum flows for all surface watercourses in the area. This section states that "the minimum flow and minimum water level shall be calculated by the department and the governing board using the best information available." This statute also establishes the priority list and schedule which is annually updated and approved by the District Governing Board. Section 373.042 also allows for the establishment of an independent scientific peer review panel and use of a final report prepared by a peer review panel when establishing minimum flows and minimum water levels.

2. Section 373.0421, F.S., allows for considerations and exclusions concerning minimum flows or minimum water level establishment, including changes and structural alterations to watersheds, surface waters and aquifers and their effects. In cases where dams, or extensive channelization have altered the hydrology of a system for flood control and water supply purposes, the District attempts to balance protecting environmental values with the human needs that are met by these alterations. This section also requires that recovery and prevention strategies must be adopted and implemented if flows in a water body are not currently meeting or are projected to not meet an applicable minimum flow within the next 20 years. In addition, the periodic and as needed, revision of established minimum flows and minimum water levels is required.

3. Rule 62-40.473 of the Florida Water Resource Implementation Rule (Chapter 62-40, F.A.C.), provides goals, objectives, and guidance regarding the establishment of minimum

flows and minimum water levels. This rule identifies the ten environmental values described in section 1.2.2 below that are to be considered when establishing minimum flows and minimum water levels. In recognition of the fact that flows naturally vary, this rule also states that minimum flows should be expressed as multiple flows defining a minimum hydrological regime to the extent practical and necessary.

4. Rule 62-41.304 of the Regulation of the Consumptive Uses of Water Rule (Chapter 62-41, F.A.C.) of the FDEP addresses a uniform process for setting minimum flow and minimum water levels in the Central Florida Water Initiative (CFWI) Area. The CFWI area includes all of Orange, Osceola, Polk and Seminole counties and a southern portion of Lake County, in the region of central Florida where the boundaries of the St. Johns River Water Management District, South Florida Water Management District, and Southwest Florida Water Management District abut. The uniform process for establishing minimum flows and levels in the CFWI area includes directives concerning development of priority lists and schedules for the establishment of minimum flows and levels by the three water management districts, sharing of technical information supporting proposed minimum flows and levels, and status assessments for established minimum flows and levels.

5. Chapter 40D-8, F.A.C., the District's Water Levels and Rates of Flow Rules, describes the minimum flows established for surface watercourses in the District. Rule 40D-041(8), F.A.C., include the currently adopted minimum flows for the Lower Peace River and establishes a schedule for their reevaluation.

6. Chapter 40D-80, F.A.C., the District's Recovery and Prevention Strategies for Minimum Flows and Levels Rules, sets forth the regulatory portions of the recovery or prevention strategies to achieve or protect, as applicable, the minimum flows and minimum water levels established by the District.

The District's Minimum Flows and Levels Program addresses all relevant requirements expressed in the Water Resource Implementation Rule, Water Resources Act of 1972 and the CFWI-specific chapter of the F.A.C. The District has developed specific methods for establishing minimum flows or minimum water levels for lakes, wetlands, rivers, springs and aquifers, subjected the methods to independent, scientific peer-review, and in some cases, adopted the methods into its Water Level and Rates of Flow Rule. In addition, regulatory components of recovery strategies necessary for the restoration of minimum flows and minimum water levels that are not currently being met have been adopted into the District's Recovery and Prevention Strategies for Minimum Flows and Levels Rule (Chapter 40D-80, F.A.C.).

A summary of efforts completed for the District's Minimum Flows and Levels Program is provided by Hancock et al. (2010). Additional information pertaining to the establishment and implementation of minimum flows and other related issues is available from the District's Minimum Flows and Levels (Environmental Flows) Program web page at https://www.swfwmd.state.fl.us/projects/mfls.

1.2.2. Environmental Values

The Florida Water Resource Implementation Rule, specifically Rule 62-40.473, F.A.C., provides additional guidance for the minimum flows and levels establishment, requiring that "…consideration shall be given to natural seasonal fluctuations in water flows or levels, nonconsumptive uses, and environmental values associated with coastal, estuarine, riverine, spring, aquatic and wetlands ecology", including:

a) Recreation in and on the water;
b) Fish and wildlife habitats and the passage of fish;
c) Estuarine resources;
d) Transfer of detrital material;
e) Maintenance of freshwater storage and supply;
f) Aesthetic and scenic attributes;
g) Filtration and absorption of nutrients and other pollutants;
h) Sediment loads;
i) Water quality; and
j) Navigation.

The ways in which these environmental values were considered for development of recommended minimum flows for the Lower Peace/Shell System are discussed in Chapter 6.

1.3. Development of Minimum Flows and Levels

Implementation of the District's Minimum Flows and Levels Program is based on three fundamental assumptions:

1. Alterations to hydrology will have consequences for the environmental values listed in Rule 62.40.473, F.A.C., and Section 1.2.2 of this report.

2. Relationships between some of these altered variables can be quantified and used to develop significant harm thresholds or criteria that are useful for establishing minimum flows and levels.

3. Alternative hydrologic regimes may exist that differ from non-withdrawal impacted conditions but are sufficient to protect water resources and the ecology of these resources from significant harm.

Support for these assumptions is provided by a large body of published scientific work addressing relationships between hydrology, ecology and human-use values associated with water resources (e.g., see reviews and syntheses by Postel and Richer 2003, Wantzen et al. 2008, Poff et al. 1997, Poff and Zimmerman 2010). This information has been used by the District and other water management districts within the state to identify significant harm thresholds or criteria supporting development of minimum flows and minimum water levels for over 400 water bodies (FDEP 2019), as summarized in numerous publications associated with these efforts (e.g., SFWMD 2000, 2006, Flannery et al. 2002, SRWMD 2004, 2005, Neubauer et al. 2008, Mace 2009).

With regard to the assumption associated with alternative hydrologic regimes, consider a historic condition for an unaltered river or lake system with no local groundwater or surface water withdrawal impacts. A new hydrologic regime for the system would be associated with each increase in water use, from small withdrawals that have no measurable effect on the historic regime to large withdrawals that could substantially alter the regime. A threshold hydrologic regime may exist that is lower or less than the historic regime, but still protects the water resources and ecology of the system from significant harm. This threshold regime could conceptually allow for water withdrawals, while protecting the water resources and ecology of the area. Thus, minimum flows and minimum water levels may represent minimum acceptable rather than historic or potentially optimal hydrologic conditions.

1.3.1. Flow Definitions and Concepts

To address all relevant requirements of the legal directives associated with minimum flows and aid in the understanding of information presented in this report, we think it is appropriate to elaborate on several flow-related definitions and concepts, including the following.

- Flow or streamflow refers to discharge, i.e., the rate a specified volume of water flows past a point for some unit of time. For minimum flow purposes, flow is typically expressed in cubic feet per second (cfs) but may be express in million gallons per day (mgd) or other units.

- Long-term is defined in Rule 40D-8.021, F.A.C., as an evaluation period for establishing minimum flows and levels that spans the range of hydrologic conditions which can be expected to occur based upon historical records.

- Reported flows are directly measured or estimated by a relationship developed using measured flows and water depth or velocity. Examples include measured and estimated flows reported by the USGS and those included in the District's Water Management Information System. Most reported flows are actually estimated using velocity and water-depth measurements or regressions or other models developed from empirical measurements. For example, reported flows are typically estimated from measured water levels using rating curves. Reported flows are alternatively referred to as *observed or gaged* flows.

- Modeled flows are flows that are derived using a variety of modeling approaches. Examples include flows predicted using numerical groundwater flow models, flows predicted with statistical models derived from either observed or other modeled hydrologic data, and impacted flows adjusted for withdrawal-related flow increases or decreases.

- Impacted flows are flows that include withdrawal-related impacts. Impacted flows can be *reported flows*, and they can also be *modeled flows* based on simulated groundwater withdrawal scenarios.

- Baseline flows are flows that have occurred or are expected in the absence of withdrawal impacts. Baseline flows may be *reported flows* if data exists prior to any withdrawal impacts. More typically, baseline flows are *modeled flows*. Baseline flows may alternatively be referred to as adjusted, natural, unimpacted, unimpaired *or* historic flows.

- Minimum flow is defined by the Florida Water Resources Act of 1972 as “the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.”

- A flow regime is a hydrologic regime characterized by the quantity, timing, and variation of flows in a river. Rule 62-40.473, F.A.C., dictates that “minimum flows and levels should be expressed as multiple flows or levels defining a minimum hydrologic regime, to the extent practical and necessary to establish the limit beyond which further withdrawals would be significantly harmful to the water resources or the ecology of the area as provided in Section 373.042(1), F.S.”

1.3.2. Baseline Flow Conditions

Use of significant harm criteria for minimum flows development is predicated upon identification of a baseline flow record or records that characterize environmental conditions expected in the absence of withdrawals. For river segments or entire rivers where flows are currently or have not historically been affected by water withdrawals, reported flows for the period without withdrawal effects or, respectively, for the entire period of record can be used as baseline flows. More typically, reported flows are impacted flows that incorporate withdrawal effects, or are available for a limited period, and baseline flows must be modeled.

Once developed, a baseline flow record or records can be used in association with significant harm criteria for identifying potential flow reductions and establishing minimum flows that are not expected to result in significant harm. In some cases, a single baseline flow record is used; in other situations, or for differing analyses, use of two or more baseline flow records is necessary.

1.3.3. Building Block Approach

Building-block approaches for environmental flow efforts frequently involve categorization of the flow regime into discrete blocks defined by flow volume and/or day of the year or water-year (summarized in Postel and Richter 2003). These blocks are then “assembled” to create a prescribed flow regime that includes necessary elements of the natural flow regime or another specified flow regime.

The District's building-block approach has typically involved assessing the potential for significant harm separately within three seasons of the year, including the late spring dry season referred to as Block 1, the summer wet season referred to as Block 3, and an intermediate flow season as Block 2. Our use of these three blocks is based on the typical seasonal variation of flows in streams in west-central Florida that are dominated by surface runoff. This seasonal, building-block approach allows for the assessment of potential changes in habitat availability and other environmental values for periods of relatively higher or lower flows, when they may be most critical for maintaining ecological structure and function or exhibit increased sensitivity to flow reductions (Flannery et al. 2002).

For some baseflow-dominated systems, for example, short, coastal rivers where discharge from spring vents accounts for much of the flow, use of a seasonal, building-block approach may not be necessary.

In addition, association of blocks with specific flow-ranges, which typically, but not always correspond with seasonal periods, may be appropriate for establishing minimum flows for some systems.

1.3.4. Low Flow Threshold

Criteria used to establish low flow threshold in freshwater rivers, such as fish passage depths or potential changes in wetted perimeter (i.e., stream bottom) generally do not apply in estuaries, because tides largely control water levels at low flows and these environmental values may not be strongly associated with flows in lower river segments. Although this is the case in the Lower Peace/Shell System, a Low flow threshold has been adopted for the Lower Peace River. This Low Flow Threshold was developed based upon identifying flows associated with maintaining freshwater conditions at the Peace River Manasota Regional Water Supply Authority (PRMRWSA) Water Treatment Facility where water is withdrawn directly from the river.

1.3.5. Significant Harm and 15% Change Criteria

Significant harm is the criterion on which the establishment of minimum flows must be made to protect the water resources and ecology of the area, but no definition of significant harm is provided in the Water Resources Act of 1972 or the Water Resource Implementation Rule. This makes the District or FDEP responsible for determining the conditions that constitute significant harm in each priority water body within the District.

Criteria for setting minimum flows are selected based on their relevance to environmental values identified in the Water Resource Implementation Rule and confidence in their predicted responses to flow alterations. The District uses a weight-of-evidence approach to determine if the most sensitive assessed criterion is appropriate for establishing a minimum flow, or if multiple criteria will be considered collectively.

For criteria selection and use, the District uses natural breakpoints, inflections, or thresholds when available. For example, in perennially flowing freshwater systems, a water depth of 0.6 ft is used to establish a minimum low flow threshold for promoting fish passage and flow continuity. Another threshold-based criterion used for flowing freshwater systems is the lowest wetted perimeter inflection point, where inflections in curves relating flow and wetted perimeter are used to determine threshold flows for significant harm.

When natural breakpoints, inflections, or thresholds are not available, the District has used a presumptive 15% habitat or resource-reduction standard as a criterion for significant harm. The basis for the management decision to equate a 15% change to significant harm lies, in part, with a recommendation put forth by the peer-review panel that considered the District's proposed minimum flows for the upper Peace River. In their report, the panelists note that "In general, instream flow analysts consider a loss of more than 15% habitat, as compared to undisturbed or current conditions, to be a significant impact on that population or assemblage" (Gore et al. 2002). The panel's assertion was based on consideration of environmental flow studies employing the Physical Habitat Simulation System (PHABSIM) for analyzing flow, water depth and substrate preferences that define aquatic species habitat availability. Nineteen peer review panels have evaluated the District's use of the 15% standard for significant harm. Although many have questioned its use, they have generally been supportive of the use of a 15% change criterion for evaluating effects of potential flow reductions on habitats or resources when determining minimum flows.

Potential loss of habitats and resources in other systems has been managed using methods other than the 15% resource reduction standard. In some cases, resources have been protected less conservatively: habitat loss > 30% compared with historical flows (Jowett 1993) and preventing > 20% reduction to historical commercial fisheries harvests (Powell et al. 2002). Dunbar et al. (1998) note, "… an alternative approach is to select the flow giving the 80% habitat exceedance percentile," which is equivalent to an allowable 20% decrease from baseline conditions. More recently, the Nature Conservancy proposed that in cases where harm to habitat and resources is not quantified, presumptive standards of 10% to 20% reduction in natural flows will provide high to moderate levels of protection, respectively (Richter et al. 2011).

Gleeson and Richter (2017) suggest that "high levels of ecological protection will be provided if groundwater pumping decreases monthly natural baseflow by less than 10% through time." Presumptive flow-based criteria such as these assume that resources are protected when more detailed relationships between flow and resources of interest are not available. Habitat- or resource-based presumptions of harm are based on data and analyses linking incremental reductions in flow to reductions in resources or habitats. As such, the 15% habitat- or resource-based standard makes more use of the best information available than a presumptive, flow-based criterion would. In the absence of natural breakpoints, inflections, or thresholds, the 15% presumptive habitat or resource-based standard for significant harm represents the District's best use of the best available information.

1.3.6. Percent-of-flow Method

Through use of 15% habitat or resource-reduction standards, the District has typically incorporated percent-of-flow methods into its building-block approach for establishing minimum flows. The percent-of-flow method is considered a “top-down” approach (Arthington et al. 1998, Brizga et al. 2002, Arthington 2012), in that modeled scenarios involving incremental reductions in baseline flows and resultant changes in important ecological parameters are evaluated to determine the flow reductions that would potentially result in significant harm to the river. The percent-of-flow method is regarded as a progressive method for water management (Alber 2002, Postel and Richter 2003, National Research Council 2005, Instream Flow Council 2002). A goal for use of the percent-of-flow method is to ensure that temporal patterns of the natural flow regime of the river are largely maintained, with some allowable flow reductions for water supply.

The District has successfully used a percent-of-flow method, often in combination with a low flow threshold, to establish minimum flows for numerous flowing systems including the Upper and Lower Alafia River, Upper and Lower Anclote River, Upper Braden River, Chassahowitzka River/Chassahowitzka Spring Group, Crystal River/Kings Bay Spring Group, Gum Slough Spring Run, Homosassa River/Homosassa Spring Group, Upper Hillsborough River, Upper and Lower Myakka River, Middle and Lower Peace River, Upper and Lower Pithlachascotee River, Rainbow River/Rainbow Spring Group and Weeki Wachee River/Weeki Wachee Spring Group.

Minimum flows developed using the percent-of-flow method allow permitted surface-water users to withdraw a percentage of streamflow at the time of the withdrawal and permitted groundwater users to potentially reduce baseline flows by prescribed percentages on a long-term basis. By proportionally scaling water withdrawals to the rate of flow, the percent-of-flow method minimizes adverse impacts that could result from withdrawal of large volumes of water during low flow periods, especially when river systems may be vulnerable to flow reductions. Similarly, larger volumes may be available for withdrawal during periods of higher flows.

The percent-of-flow approach has been effectively implemented for numerous permitted surface water withdrawals within the District, including those associated with water-supply withdrawals from the Peace River, Alafia River, and Little Manatee River (Flannery et al. 2002). These withdrawals are typically based on a percentage of the previous day's average flow. Applications of the percent-of-flow method for regulation of groundwater withdrawals involve different considerations that must account for the gradual and more diffuse manner that changes in groundwater levels are manifested in changes in streamflow. The percent-of-flow method has, however, been successfully implemented to regulate groundwater withdrawals throughout the District.

1.3.7. Adaptive Management

Adaptive management is a standard approach for reducing the inherent uncertainty associated with natural resource management (Williams and Brown 2014) and is recommended by the U.S.

Department of the Interior for decision making in the face of uncertainty about management impacts (Williams et al. 2009). Adaptive management is a systematic, iterative approach to meeting management objectives in the face of uncertainty through continued monitoring and refinement of management actions based on consideration of alternatives and stakeholder input (Herrick et al. 2019).

Between the adoption of minimum flows for the Lower Peace River in 2010 and this 2020 reevaluation, the District and other agencies (e.g., PRMRWSA, USGS, Florida Fish and Wildlife Conservation Commission) have continued monitoring the Lower Peace/Shell System through collection of data on fish, plants, invertebrates, water quality, water flows and levels; evaluated compliance with permitted withdrawal requirements; and assessed the status of minimum flows in the Lower Peace River.

For example, a rule-required reevaluation of minimum flows established for the Lower Peace River (Ghile and Leeper 2015) documented compliance with all regulatory constraints, included a summary ecosystem assessment, and described then-ongoing and planned projects and data collection efforts that would be used to support a more comprehensive minimum flows reevaluation.

The more comprehensive reevaluation of adopted minimum flows for the Lower Peace River and previously developed draft minimum flows for Lower Shell Creek described in this report reflects the application of an adaptive management strategy for dealing with uncertainty associated with determining withdrawal impacts on physical, biological, and chemical aspects of the river/creek system. Continued adaptive management will require ongoing monitoring, assessment, and periodic reevaluation of all minimum flows that are ultimately adopted for the Lower Peace River and Lower Shell Creek.

1.4. Vertical Datums

The District has recently converted from use of the National Geodetic Vertical Datum of 1929 (NGVD 29) to use of the North American Vertical Datum of 1988 (NAVD 88) for measuring and reporting vertical elevations. In some circumstances within this document, elevation data that were collected or reported relative to mean sea level or relative to NGVD 29 are converted to elevations relative to NAVD 88. All datum conversions were derived using the Corpscon 6.0 software distributed by the United States Army Corps of Engineers.

1.5. Updates Made in Reevaluation of the Minimum Flows

Much of the information associated with the technical assumptions, methods and analyses described in the 2010 minimum flows report (SWFWMD 2010) and the 2015 reevaluation for the Lower Peace River minimum flows (Ghile and Leeper 2015) also support the current minimum flow reevaluation. However, several analytical methods described in the previous efforts were updated and improved where necessary to ensure use of the “best available information” for minimum flows development. For minimum flows development, we note that the best available information includes information that exists at the initiation of the minimum flows development process and information that is acquired specifically to fill data requirements deemed necessary for establishment of the best, defensible minimum flows.

Since 2011, the District initiated several technical projects to support updates for the reevaluation. These major initiatives and updates can be briefly summarized as follows.

1. The District developed the Peace River Integrated Model (PRIM) to gain a better understanding of the factors that control the Peace River flows and investigate effects of climate variability, groundwater pumping and land use changes.

2. The District's original building-block approach for characterizing the flow regime for the Lower Peace River and Lower Shell Creek was based on fixed dates. This fixed-date approach for block definition is not currently considered appropriate for representing seasonal flow regimes for the system in some years when flows remain relatively low or high throughout the year. To overcome this issue, the District used flow-based blocks that correspond with typical, seasonal periods of low, medium, and high flows.

3. A new hydrodynamic model was developed to substantially improve the prediction of water levels, salinities and water temperatures in the Lower Peace/Shell System and Charlotte Harbor.

    a. The hydrodynamic model used in 2010 was a coupled model which dynamically links a laterally averaged two-dimensional (2D) model with a three-dimensional (3D) model. The 3D model was updated to a 3D unstructured Cartesian grid model.
    b. The 2010 hydrodynamic model boundary was limited to the Lower Peace River-Lower Myakka River-Upper Charlotte Harbor area. For the 2020 modeling study, the boundary was extended to the entire Charlotte Harbor, including portions of the Caloosahatchee River.
    c. A 13-month calibration/verification period in the 2010 study was extended to a 20-month period for development of the 2020 hydrodynamic model.
    d. A new bathymetry survey was conducted for the Charlotte Harbor area and the tidal reaches of the Myakka and Peace Rivers for use in the reevaluation. These new survey data addressed discrepancies associated with landscape alterations that occurred in the region in 2004 due to Hurricane Charley.
    e. To improve model predictions in overbank areas, a high-resolution Digital Elevation Model (DEM) was developed using Light Direction and Ranging (LiDAR) photogrammetric mapping, and a new data collection tower was installed to collect hourly boundary conditions (e.g., salinity, temperature) in the upper Charlotte Harbor.

4. The estimation of flows from ungaged streams, creeks and canals that directly or indirectly flow into the Upper Charlotte Harbor Basin was updated.

The District approach for setting minimum flows in 2010 was based on the maintenance of the volume and distribution of various salinity zones. This was also the case for development of the recommended minimum flows for the Lower Peace River and Lower Shell Creek summarized in this report, with the newly created hydrodynamic model providing the primary basis for the effort.

To further investigate and potentially strengthen the protection of estuarine resources, the District developed Habitat Suitability Models (HSMs) for predicting effects of flow changes to abundance of eight estuarine-dependent taxa. The District also examined various floodplain features, including soils and vegetation communities along selected cross-sections in the Lower Peace River and evaluated how their inundation may be affected by changes in river flows. In addition, the District investigated whether the seasonal timing and locations of chlorophyll maximum changes in the estuary are associated with and can be predicted from withdrawals from the Lower Peace River and Lower Shell Creek (Atkins, Inc. 2014b). In 2019, Janicki Environmental, Inc. was contracted to update the 2014 work by Atkins and investigate the interactions between freshwater inflows and water quality constituents in the Lower Peace/Shell System.

The District has used information from these initiatives and updates, along with other best available information described in this document to develop recommended minimum flows for the Lower Peace River and Lower Shell Creek. The hydrology, geology, soils, and land use of the Lower Peace/Shell System are described in Chapter 2. Chapter 3 summarized water quality information for the system and ecological resources (i.e., shoreline vegetation, fish, and benthic macroinvertebrates) are described in Chapter 4. Chapter 5 describes the various methods used to develop the minimum flows. Results of the analyses, including the recommended minimum flows and assessments of the ten environmental values listed in the Water Resource Implementation Rule for consideration developing minimum flows and water levels are presented in Chapter 6. Information related to compliance and minimum flow status assessment are provided in Chapter 7.

CHAPTER 2 - PHYSICAL AND HYDROLOGIC DESCRIPTION OF THE LOWER PEACE RIVER AND LOWER SHELL CREEK

This chapter presents brief descriptions of the Peace River and Shell Creek watersheds including their location, physiography, climate, hydrogeology, land-use and cover, soils, freshwater flows and water use relevant to the development of minimum flows for the Lower Peace River and Lower Shell Creek.

2.1. Peace River and Shell Creek Watersheds

The Peace River watershed (Figure 2-1) is approximately 2,350 square miles and extends from the headwaters in Polk County to the river mouth in Charlotte Harbor (PBS&J 1999; SWFWMD 2010). The watershed includes small portions of eastern Sarasota and Manatee counties, parts of central and southern Polk County, most of Hardee and DeSoto counties, part of northern Charlotte County, and western portions of Highlands County. The Peace Creek Drainage Canal and Saddle Creek join south of Lake Hancock near Bartow to form the Peace River. The river originates at an elevation of approximately 100 feet NGVD 29 (Kelly et al. 2005) and flows south for approximately 75 miles into the northeastern portion of Charlotte Harbor near the City of Punta Gorda. Other major tributaries to the Peace River include Payne Creek, Charlie Creek, Horse Creek, Joshua Creek, and Shell Creek (Figure 2-2).

The Peace River is a free-flowing system over its entire length, although flows in two of its tributaries, Saddle Creek and Shell Creek are regulated (Kelly et al. 2005). The Peace River represents a major source of fresh water to Charlotte Harbor, a bay with a surface area of approximately 142 square miles and an average depth of about 11 feet (Kelly et al. 2005). The Peace River, with approximately three-times the freshwater flow as the Myakka River, is a major influence on the freshwater inflow to the Charlotte Harbor (SWFWMD 2010). The average flow into Charlotte Harbor from the Peace River (including Shell Creek) is 2,010 cfs (Hammett 1990).

For the purpose of minimum flows development, the Lower Peace River is defined as the portion of the river below the USGS Peace River at SR 70 at Arcadia, FL gage (No. 02296750) (Figure 2-2). Upstream from Arcadia, the channel of the Peace River is well defined, while downstream the floodplain widens, and the channel becomes braided (Hammett 1990; SWFWMD 2010). The portion of the watershed downstream of Arcadia represents approximately 42% (990 square miles) of the entire Peace River watershed. Three major tributaries flow into the Lower Peace River: Joshua Creek, Horse Creek, and Shell Creek. Of these three tributaries, Shell Creek is the largest at 434 square miles, Horse Creek is the second largest at 245 square miles, and Joshua Creek is the smallest at 121 square miles.

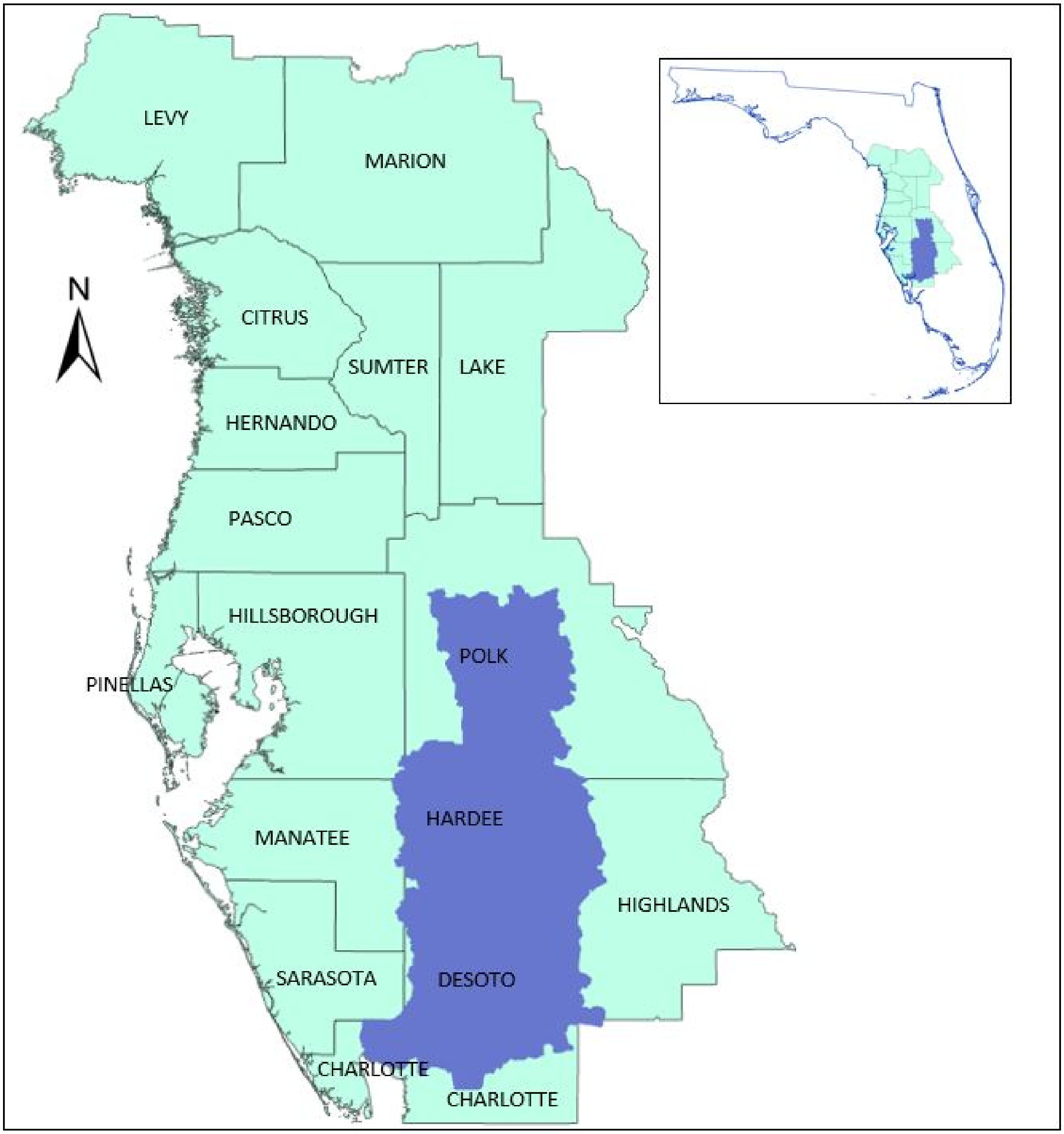

Figure 2-1. Location of the Peace River watershed within the Southwest Florida Water Management District.

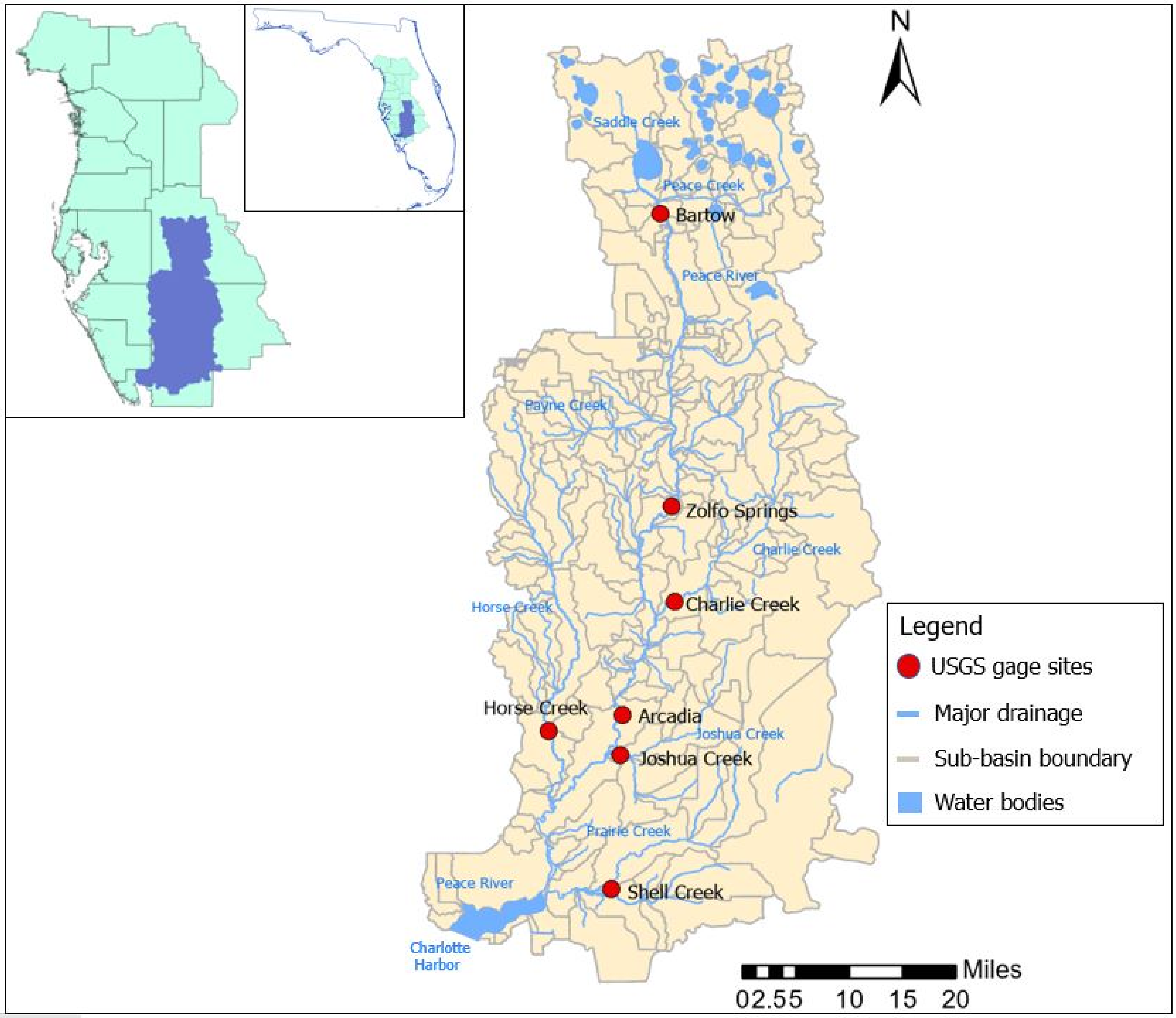

Figure 2-2. Map of the Peace River watershed showing the Peace River main-stem and tributaries, sub-basins and selected long-term USGS gage site locations. The inset map highlights the location of the Peace River watershed both within the SWFWMD and in the state of Florida.

The Shell Creek watershed (Figure 2-3 basin extends from its headwaters in Desoto and Charlotte Counties and flows into the lower tidal reach of the Peace River near the City of Punta Gorda. Shell Creek is impounded by Hendrickson Dam below the confluence of Prairie Creek with Shell Creek, east of U.S. Route 17, approximately eight miles east of the City of Punta Gorda. The impounded section of the creek, Shell Creek Reservoir, is the primary water supply for the City (Stanley Consultants, Inc. 2006; PBS&J 2007). For the purpose of minimum flows development, Lower Shell Creek is defined as the portion of the creek extending from Hendrickson Dam to the confluence of Shell Creek with the Lower Peace River, a distance of approximately 6.2 miles (SWFWMD, 2010).

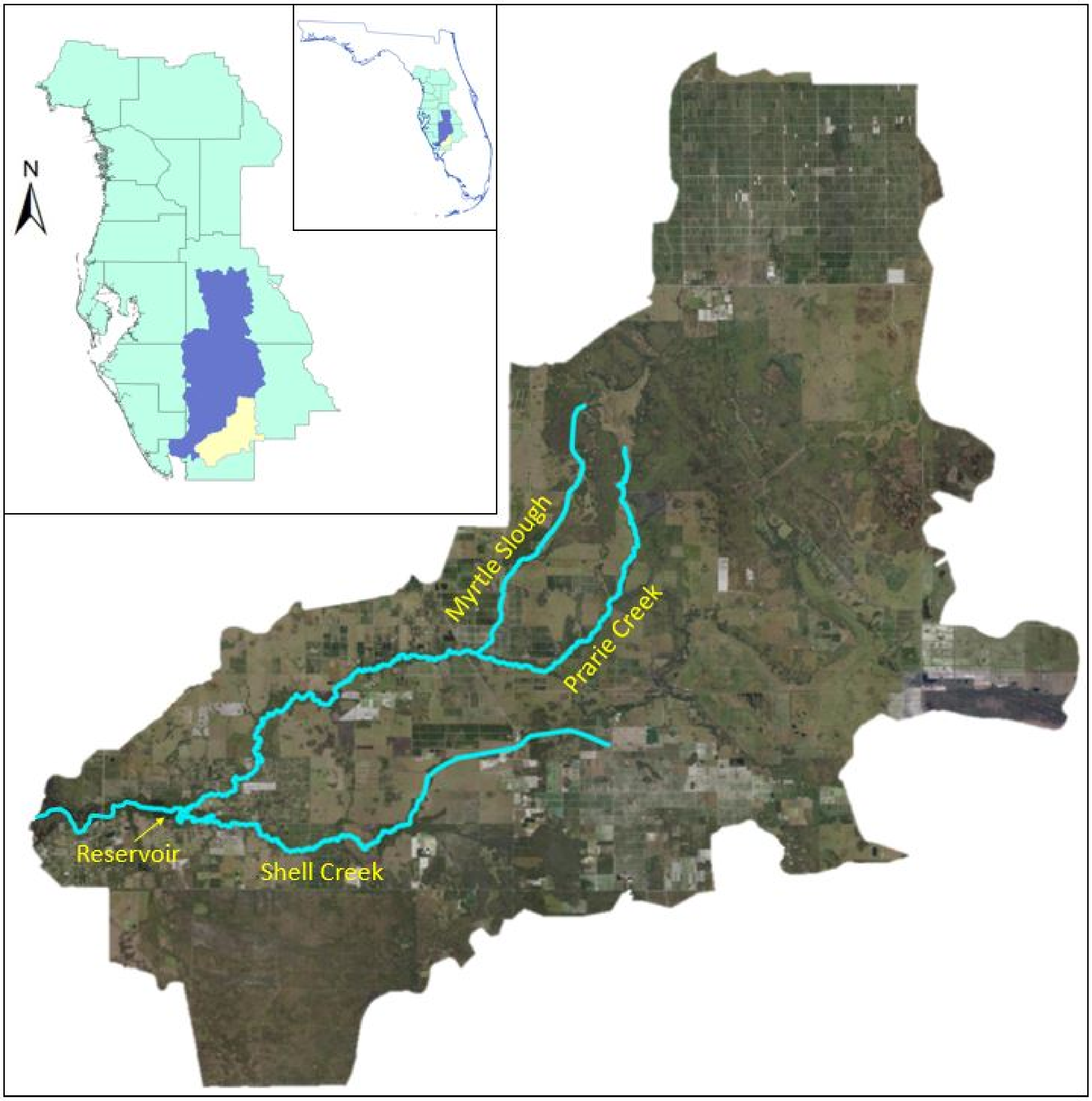

Figure 2-3. Map of the Shell Creek watershed. The inset map indicates the location of the Shell Creek (yellow) watershed within the larger Peace River watershed (blue) in the SWFWMD and the watershed's location in the state of Florida.

2.2. Land Use and Land Cover

The 2017 land use map for Lower Peace/Shell System is depicted in Figure 2-4. The land use and land cover features were categorized according to the Florida Land Use and Cover Classification System (FLUCCS). Wetlands buffer most of the Lower Peace River and Lower Shell Creek channels and the remaining dominant land uses are agricultural, range land, and urban developments near the mouth of the Peace River. Land use and land cover within the Peace River watershed have changed over time primarily in response to agricultural and residential/urban development (FDEP 2007).

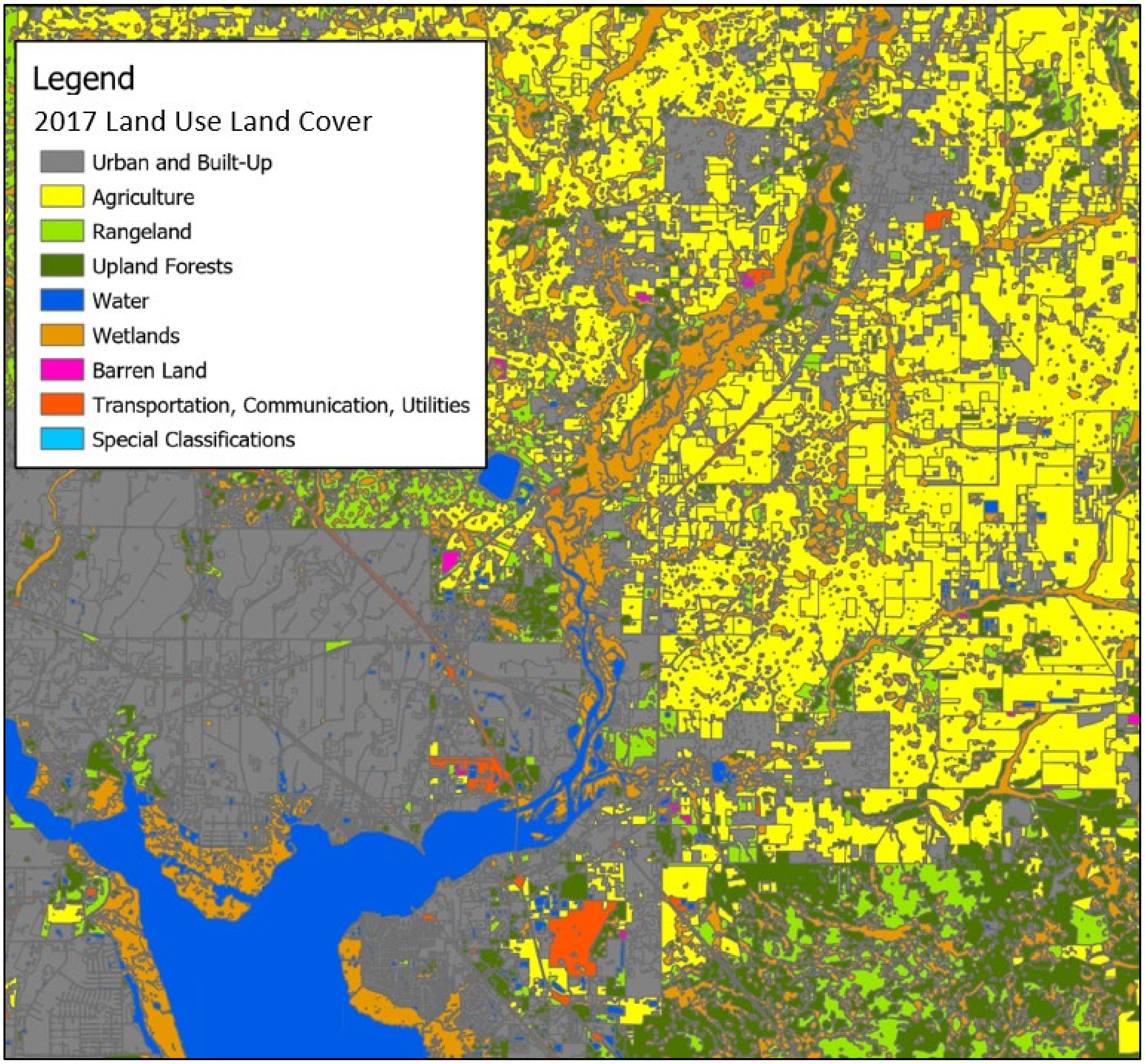

Figure 2-4. Land use map of the Lower Peace River watershed (SWFWMD 2017).

Land use change in the Peace River basin from 1990 to 2017 are summarized in Table 2-1. Based on the 2017 data, citrus and other agriculture combined comprised 38.6% of the land use and land cover in the Peace River watershed. Upland forest and wetlands account for a combined 24.8%, while urban account for approximately 21.6%. Lakes and open water accounts for less than 5% of the land cover of the basin (Table 2-1). The changes to more intensive agricultural land uses have caused an increasing pattern in streamflow in many of the Peace River tributaries, especially the Horse, Joshua, and Shell Creeks. Flow changes associated with land use change are described in Chapter 5.

Table 2-1. Land use change in the Peace River watershed between 1990 and 2017.

Land use and land cover	1990		1999		2009		2017	
	Mi^2	%	Mi^2	%	Mi^2	%	Mi^2	%
Urban	433	18.9	506	21.8	502	21.3	498	21.6
Agriculture	981	42.9	966	41.5	912	39.0	890	38.6
Rangeland	193	8.4	175	7.5	139	6.3	141	6.1
Upland Forests	210	9.2	190	8.2	129	5.6	129	5.6
Water	77	3.4	86	3.7	92	4.1	93	4.0
Wetlands	356	15.6	359	15.4	438	19.3	443	19.2
Barren Land (Mining)	3	0.1	3	0.1	3	0.2	5	0.2
Transportation, Utilities	9	0.4	9	0.4	14	0.6	14	0.6
Other	27	1.2	31	1.3	76	3.6	91	3.9

2.3. Soils

Soils within the Lower Peace and Shell Creek watersheds (Figure 2-5) are primarily classified as A/D (mix of high infiltration rate and moderate infiltration rate) and B/D (mix of moderate infiltration rate and slow infiltration rate) hydrologic soil groups. Class D (very slow infiltration rate and high run off potential) soils buffer the Shell Creek channel upstream of the reservoir, with isolated areas of Class A soils (high infiltration rate and low run off potential) further from the channel but still within the floodplain areas.

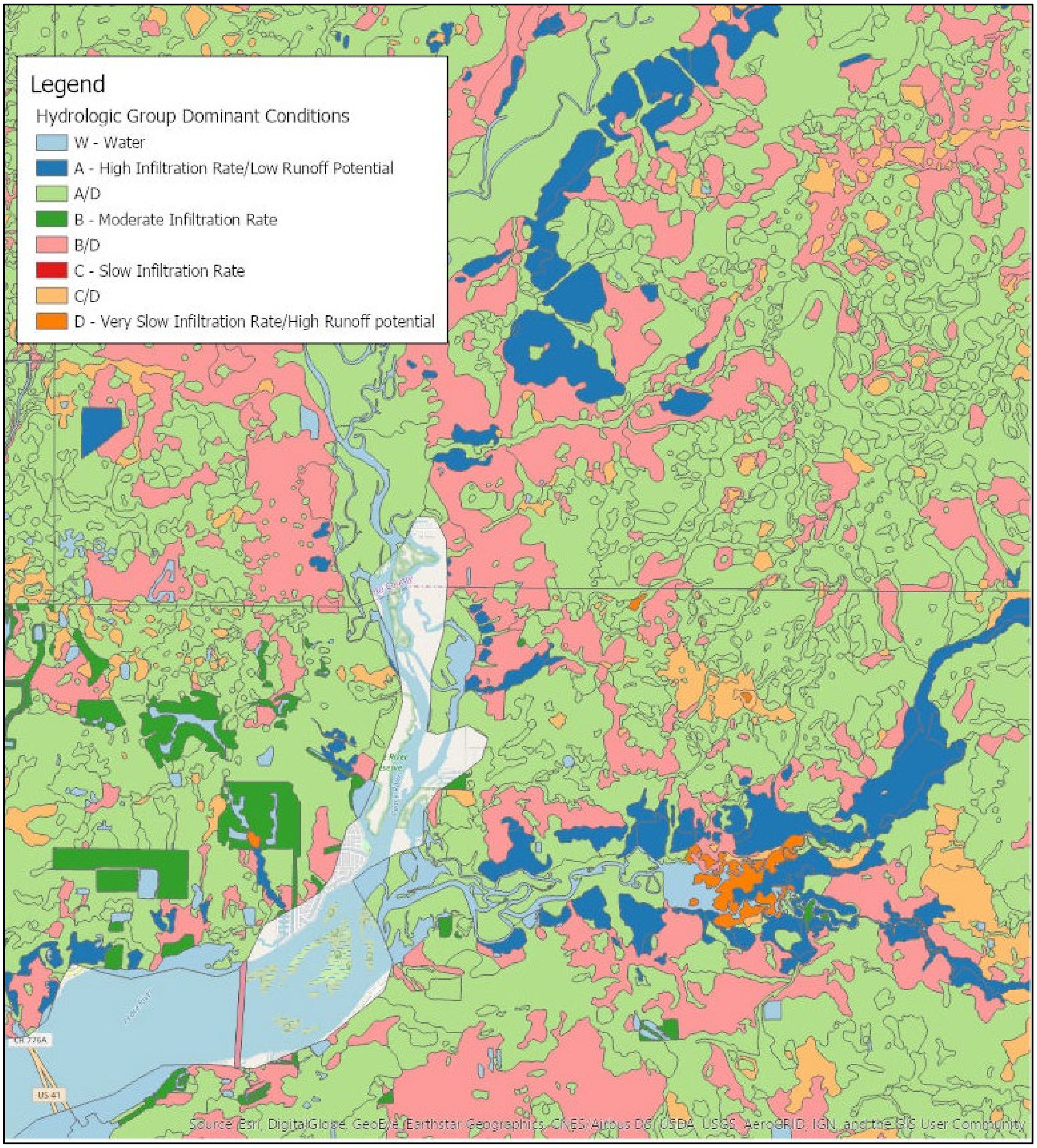

Figure 2-5. Soil types in the Lower Peace River watershed (SWFWMD 2017).

2.4. Bathymetry and Morphometry

The morphology of a riverine system can strongly influence the hydrology and biology of the system. For example, the shape of the river can affect current velocities and sediment composition and distribution. Sediment composition and distribution, in turn can affect benthic organisms and vegetation. The shape of the river also determines the volume of water it can contain, which can affect habitat zonation and availability (SWFWMD 2010).

For the 2010 minimum flows study of the Lower Peace/Shell System, information pertaining to system morphology and bathymetry were obtained from PBS&J (1998), Mote Marine Lab (2002), and Wang (2004). Comparison of these bathymetric data with more recently collected survey data (i.e., LiDAR data) identified some discrepancies for portions of the Lower Peace River and the Lower Myakka River. These discrepancies may be attributable to landscape alterations associated with Hurricane Charley in 2004. To eliminate these discrepancies and improve model performance, new LiDAR, shoreline mapping and bathymetric surveying of the Charlotte Harbor and the tidal reaches of the Myakka, Peace River and the Caloosahatchee Rivers were conducted in 2013.

The LiDAR photogrammetric mapping was conducted by Aerial Cartographic of America, Inc. (2015) and covered an area of approximately 150 square miles, extending from Lake Hancock in Polk County to Sand Hill in Charlotte County (Figure 2-6a). The Lower Peace River portion of the LiDAR data collection effort was conducted primarily to support development of the District's hydrodynamic model for the reevaluation and development of minimum flows for the Lower Peace/Shell System. All LiDAR data were collected using approved Multi-beam Green & Infrared LiDAR photogrammetric mapping sensors. Routing sensor calibration and maintenance were performed as needed to ensure proper function of the LiDAR system. The LiDAR data were verified by Wantman Group Inc. (2015) and delivered to District in March 2015. District staff completed a final data review and produced a digital, high resolution DEM to support development of a new hydrodynamic model for the Lower Peace/Shell System.

Wang (2013) mapped shorelines using a Trimble RTK GPS mounted on board the survey vessels and measured bottom elevations for inundated areas using a synchronized Odem narrow beam precision echo sounder with the RTK GPS. A total of 4,862,650 survey points and over 994 miles survey lines were collected for the assessed area (Figure 2-6b). Measurement errors associated with motion waves and tidal water-level variations were filtered-out using accepted techniques.

Bathymetry surveys obtained from Wang (2004) for the Lower Shell creek portion of the Lower Peace/Shell System were added to the bathymetric data collected by Wang (2013) for development of the hydrodynamic model domain, which included the Lower Peace River, Lower Shell Creek, the Lower Myakka River, a lower portion of the Caloosahatchee River, and Charlotte Harbor.

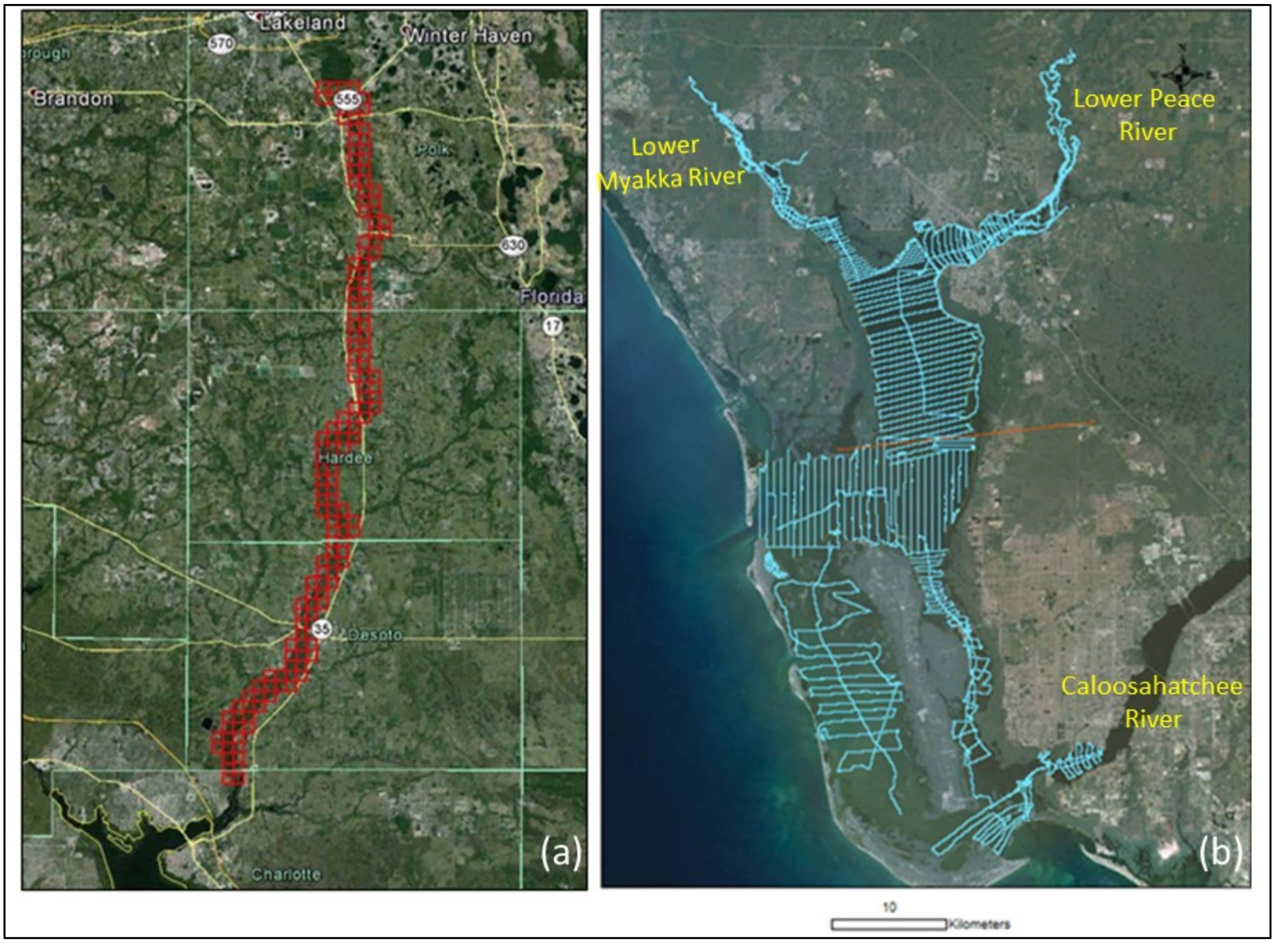

Figure 2-6. (a) LiDAR-surveyed area for the Peace River and (b) shoreline and river cross-section bathymetric survey for the Lower Peace River, Myakka River, Caloosahatchee River, and Charlotte Harbor.

The bathymetric data collected by Wang (2013) were rasterized to a resolution of 15 square meter size by Rubec et al. (2018). Generally, the bathymetric map indicated depths of less than three meters for most areas of the Lower Peace River and Lower Myakka River. Depths in Charlotte Harbor ranges from four to twelve meters (Figure 2-7). Bathymetry surveys obtained from Wang (2004) also indicated depths of less than three meters for most areas of the Lower Shell creek portion.

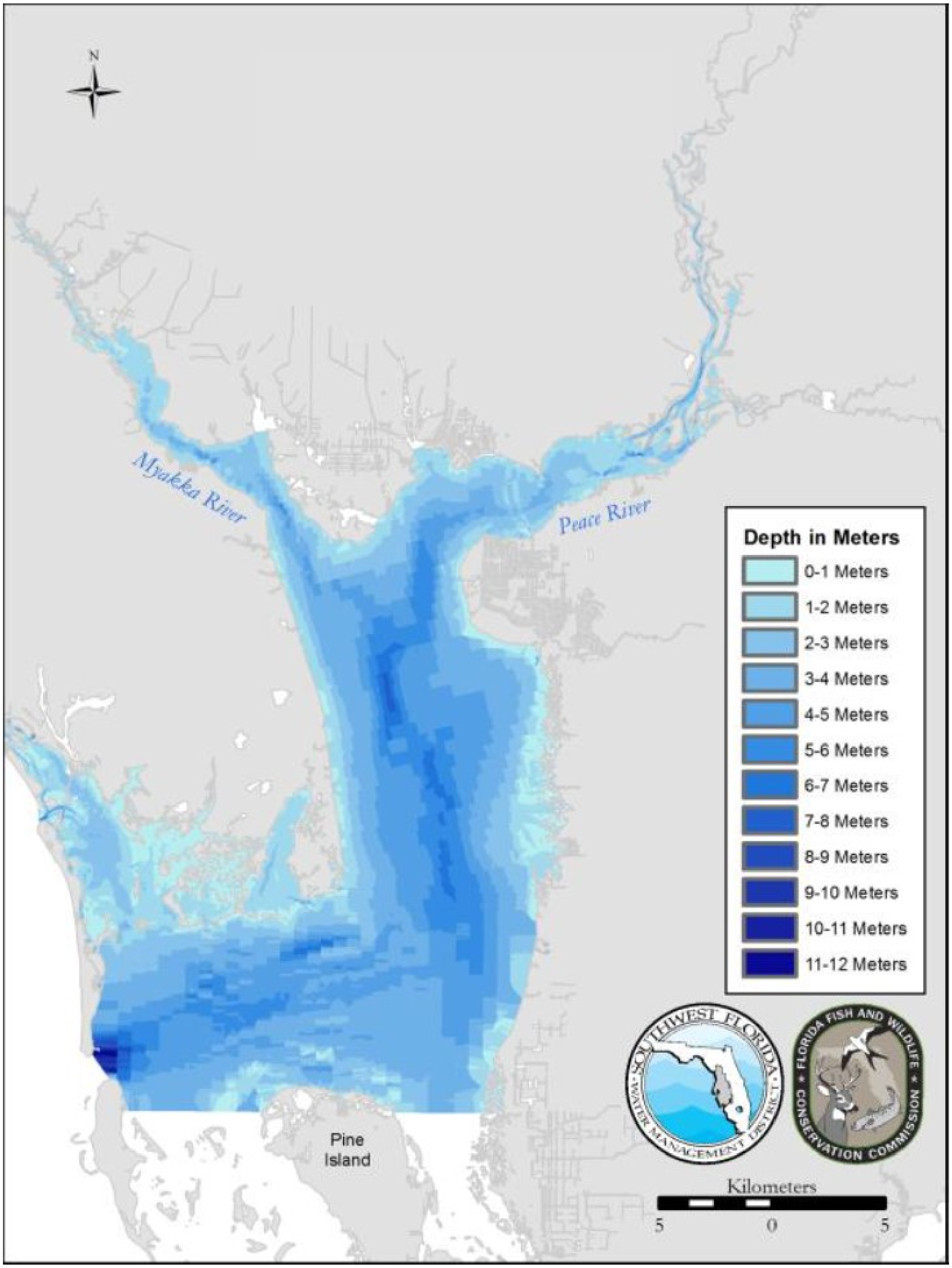

Figure 2-7. Bathymetric map for the Lower Peace River, Lower Myakka River and Charlotte Harbor (reproduced from Rubec et al. 2018).

2.5. Climate

The climate of west-central Florida can be characterized as humid subtropical. The mean annual temperature in the region ranges from 91°F in July and August to a typical low of 49° F in January. The average annual rainfall based on the Arcadia National Weather Service site (District Site Identification [SID] No. 24570) is approximately 49 inches and more than 60% of the annual rainfall occurs during the months of June, July, August, and September. The Arcadia site has a rainfall record that extends back to 1908 (Figure 2-8). Annual rainfall totals of less than long term average (49 inches) were recorded for 49 years during the period of record from 1908 through 2018, while the highest three yearly rainfall totals occurred in 1947, 1982 and 1959 with 80, 78 and 74 inches respectively.

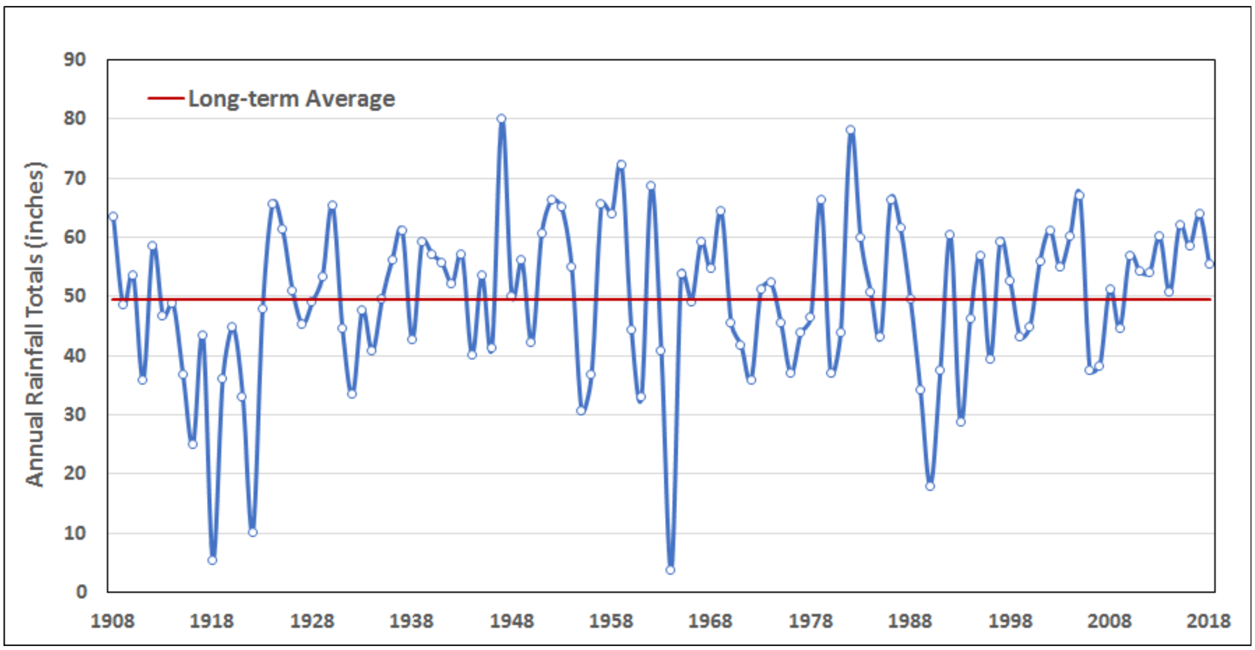

Figure 2-8. Annual rainfall totals (inches) at the Arcadia National Weather Service site from 1908 through 2015.

Average monthly rainfall at the Arcadia site exhibits the typical June-September rainfall peak and lower values during the remainder of the year. Within this general seasonal cycle, rainfall intensities and frequencies are controlled by the effects of larger scale oscillations, notably the Atlantic Multidecadal Oscillation (AMO) and the El Niño-Southern Oscillation (ENSO) (Kelly 2004; Kelly and Gore 2008).

The AMO is an index of Sea Surface Temperature (SST) anomalies averaged over the North Atlantic from 0–70°N and has a strong influence on summer rainfall over the conterminous U.S. (McCabe et al. 2004). The ENSO, a naturally occurring phenomenon associated with an irregular cycle of warming and cooling of SSTs in the tropical Pacific Ocean (5°N to 5°S, 150° to 90°W) is also known as dominant force causing climate variations over the U.S. and much of the globe (Hansen et al. 1997; Schmidt and Luther 2002).

To better understand how these climate indices are related to the temporal variability of streamflow in the Lower Peace/Shell System, the mean annual SST patterns tracked by these two indices and the Lower Peace River streamflow (i.e., the sum of flows at the USGS Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee gages) were normalized. Plots of 5- and 10-year moving averages of the normalized values of AMO and the Lower Peace River streamflow are shown in Figure 2-9. A similar pattern is evident in the two data sets, with higher flows occurring during warmer AMO phases and lower flows occurring during cooler AMO phases. The Pearson's coefficient between 5-year running means of AMO and Lower Peace River streamflow series is 0.68, while the Pearson's coefficient between 10-year running means of AMO and Lower Peace River streamflow series is 0.83. This is consistent with Kelly's (2004) previous findings for the river.

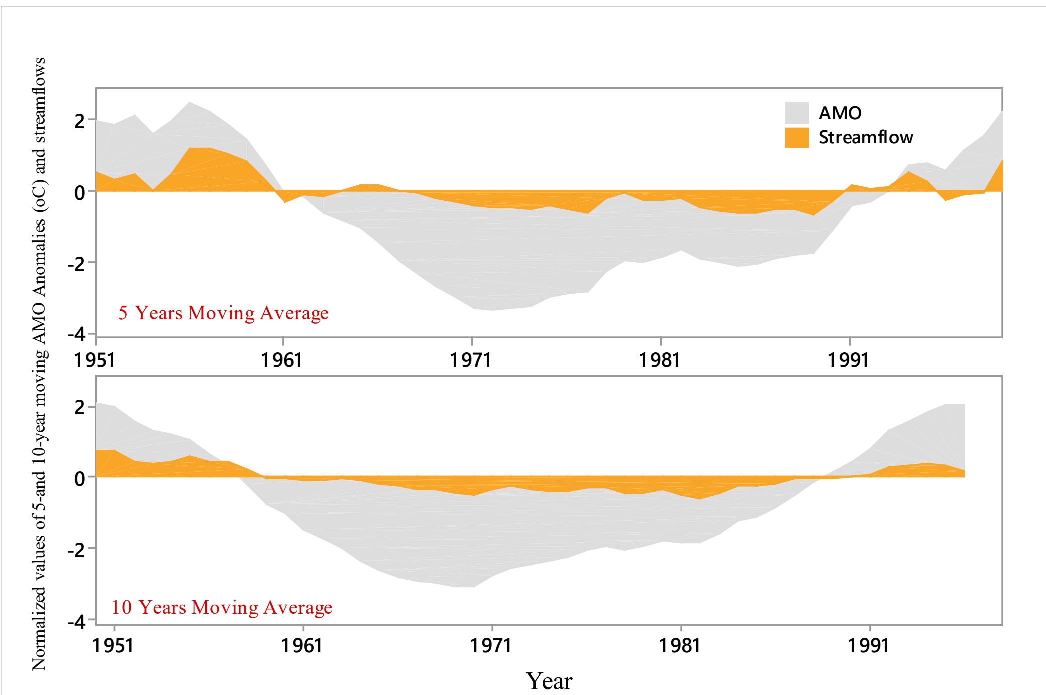

Figure 2-9. Normalized values of 5-and 10-year moving averages of annual AMO anomalies and Lower Peace River flows (i.e., the sum of flows at the USGS Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee gages) for the period 1951 through 1998.

Superimposed within the AMO cycle, the ENSO anomalies were also related to the year-to-year streamflow variability in the Lower Peace River as shown in Figure 2-10. El Niño years are wetter than La Niña years in the region. However, El Niño effects during the summer wet season are somewhat attenuated by the seasonal occurrence of thunderstorms (Kelly and Gore 2008).

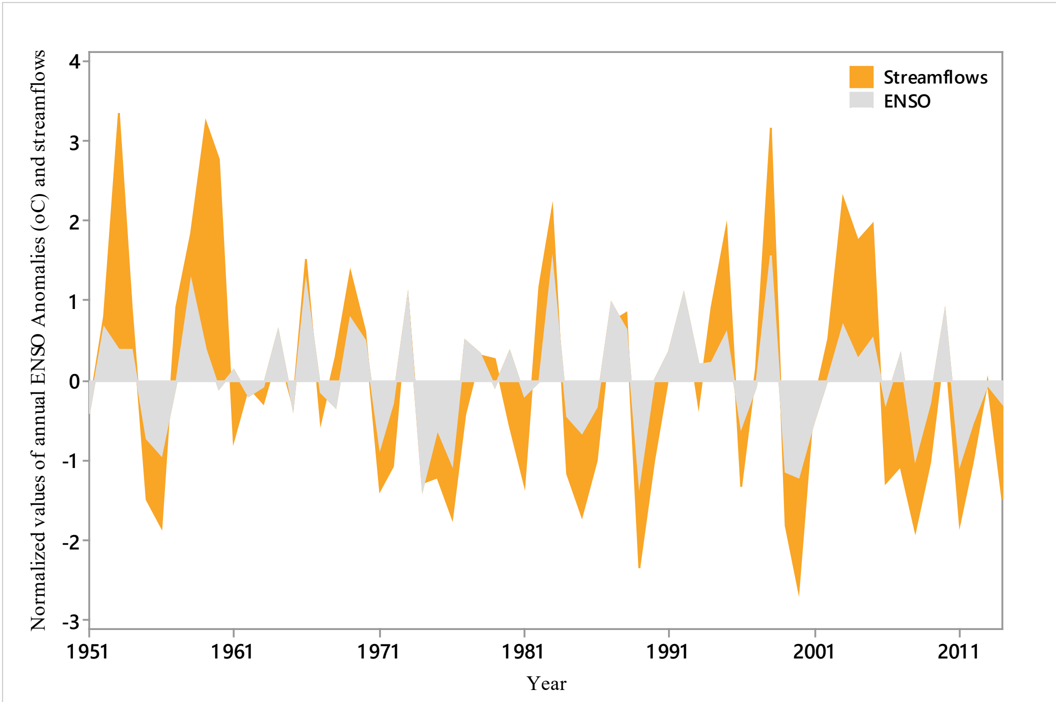

Figure 2-10. Normalized values of annual ENSO anomalies (°C) and Lower Peace River flows (i.e., the sum of flows at the USGS Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee gages) for the period 1951 through 2014.

2.6. Tides

The entire Lower Peace/Shell System is tidally affected. Tidal-flow currents move seawater up into the estuary during high tides and tidally-based currents contribute to the draining of seawater during low tides. The extent to which flow currents move upstream or downstream is also dependent upon the amount freshwater entering the system. Water levels in the Lower Peace/Shell System are typically highest during the summer wet season rather than during the dry season, reflecting the increased freshwater inflows from the Peace River and Shell Creek.

Using data from USGS continuous recorder at the USGS Peace River at Harbour Heights, FL gage site (No. 02297460), water height for the period from 2007 through 2014 tide fluctuated between –3.8 to 3.3 feet (Figure 2-11a) while data collected at the USGS Peace River at Punta Gorda, FL gage (No. 02298300) from 2007 through 2014 indicates that tide fluctuates between –2.7 to 2.3 feet (Figure 2-11b). Median stage levels were -0.2 and -0.32 feet (NAVD88) at the at Harbour Heights and Punta Gorda sites, respectively.

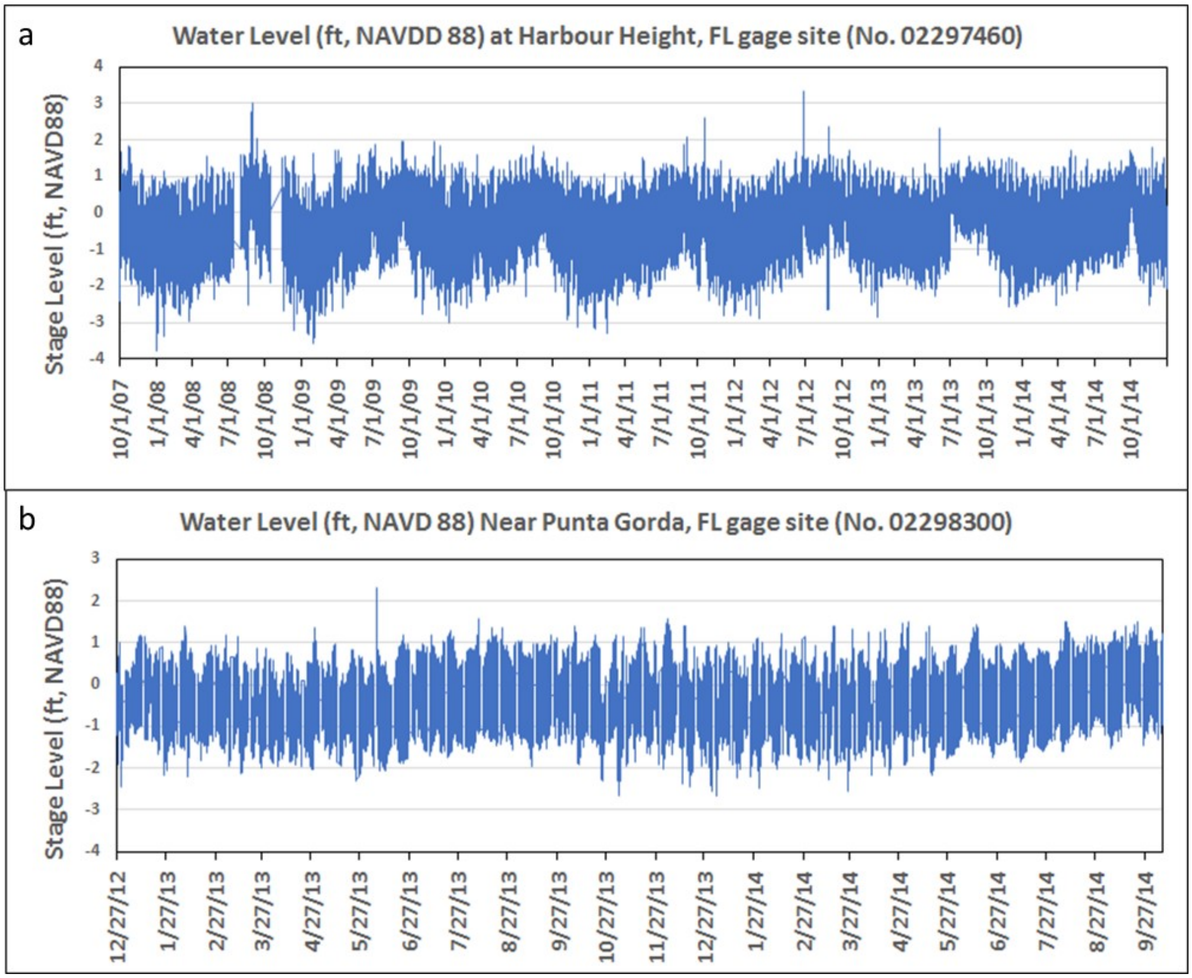

Figure 2-11. Water levels (ft, NAVD88) at a) the USGS Peace River at Harbor Heights gage from 2007 through 2014 and b) the USGS Peace River at Punta Gorda gage from 2012 through 2014.

2.7. Streamflow

Streamflow represents the sum of the contributions of groundwater, runoff, direct rainfall, and anthropogenic discharges (e.g., wastewater) minus the volume of water that is lost due to evapotranspiration, losses to groundwater, and withdrawals. The physical, chemical, and biological properties of aquatic ecosystems can all be affected by the hydrologic regime (Poff and Ward 1989, 1990), so substantial ecological changes can be associated with long-term changes in flows. In tidal rivers like the Lower Peace/Shell System, freshwater inflow can affect water residence time and is a critical determinant of the spatial and temporal variation in salinity. In turn, salinity is a critical determinant of the structure and function of tidal river and estuarine ecosystems.

There are four USGS gages (see Figure 2-2) where flows that enter the Lower Peace/Shell System are recorded: Peace River at SR 70 at Arcadia, FL (No. 02296750), Horse Creek at SR

72 near Arcadia, FL (No. 02297310), Joshua Creek at Nocatee, FL (No 02297100), and Shell Creek near Punta Gorda, FL (No. 02298202).

2.7.1. Mean Annual Flows

Peace River flows have been measured at the Arcadia gage since 1932. Mean annual flows at the gage for the period 1950 through 2018 are shown in Figure 2-12. The mean annual flows for this period ranged from a minimum of 139 cfs in 2000 to a maximum of 2,724 cfs in 1953, with a long-term (1950-2018) average of 1,000 cfs and recent, short-term (2000-2018) average of 961 cfs.

The period of record for Horse Creek near Arcadia flows is from 1950 to the present. Mean annual flows in the creek for the period 1950 through 2018 are shown in Figure 2-13. The minimum and maximum Horse Creek mean annual flows of 23 cfs and 494 cfs occurred respectively in 2007 and 1959. The long-term (1950-2018) and recent, short-term (2000-2018) mean annual flows in Horse Creek near Arcadia are 190 cfs and 193 cfs, respectively.

Measured flows for Joshua Creek at Nocatee are also available for the period 1950 to the present. Figure 2-14 shows the annual mean flows in the creek for the period 1950 through 2018. The minimum annual mean flow of 24 cfs occurred in 1956 and the maximum of 264 cfs in 1953. The long-term mean (1950-2018) annual flow in Joshua Creek at Nocatee is 112 cfs and the recent, short-term (2000-2018) mean annual flow is 126 cfs

Minimum flows for Lower Peace River are established based on the sum of flows from Peace River at Arcadia gage, the Horse Creek near Arcadia gage, and Joshua Creek at Nocatee gage. The mean annual combined flows from these three gage sites for the period 1950 through 2018 are presented in Figure 2-15. The combined mean annual flows ranged from a minimum of 221 cfs in 2000 to a maximum of 3,465 cfs in 1953. The long-term (1950-2018) and recent, short-term (2000-2018) combined mean annual flows in the Peace River at Arcadia, Horse Creek near Arcadia, and Joshua Creek at Nocatee gages are 1,302 cfs and 1,279 cfs, respectively.

Minimum flows for Lower Shell Creek are established based on flows measured at the Shell Creek near Punta Gorda gage. Shell Creek is impounded by the Hendrickson Dam for public water supply approximately 6.2 miles upstream of the confluence of the creek with the Lower Peace River. The dam presents a barrier to the downstream flow conveyance when water levels in the reservoir drop below the spillway crest elevation of 5 ft. Medium and higher flows of Shell Creek are minimally affected by the presence of the low-elevation dam.

The mean annual flows at the Shell Creek near Punta Gorda gage for the period from 1966 through 2018 are shown in Figure 2-16. The minimum mean annual flow of 115 cfs occurred in 2007 and the maximum of 821 cfs occurred in 1995. The long-term mean (1966-2018) annual flow at the site is 363 cfs, while the short-term (2000-2018) mean annual flow is 389 cfs.

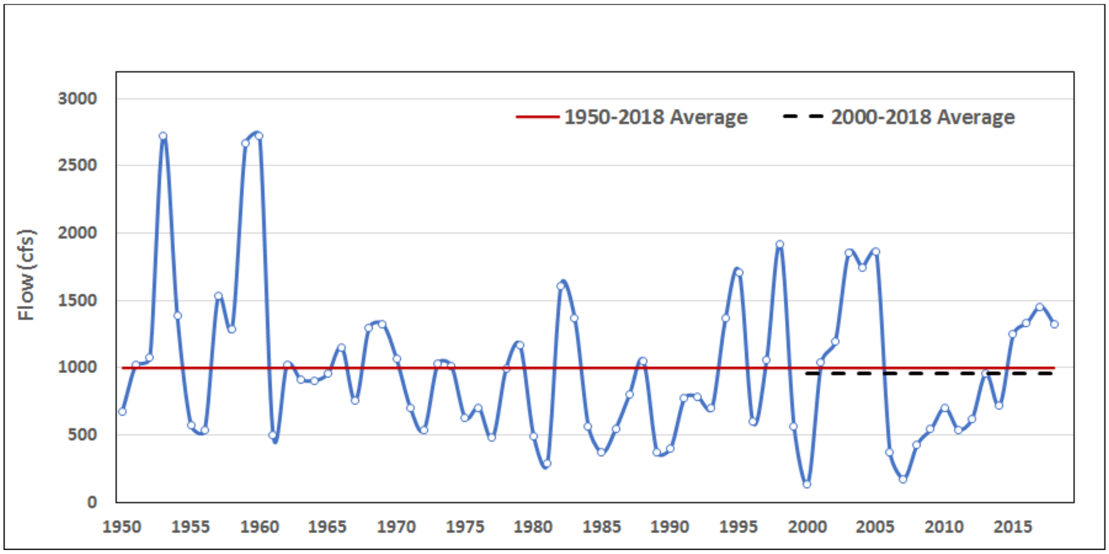

Figure 2-12. Time series of mean annual flows (cfs) at the USGS Peace River at SR 70 at Arcadia gage for the period 1950 through 2018, with long-term average (red line) and short-term (2000-2018) average (black dashed line).

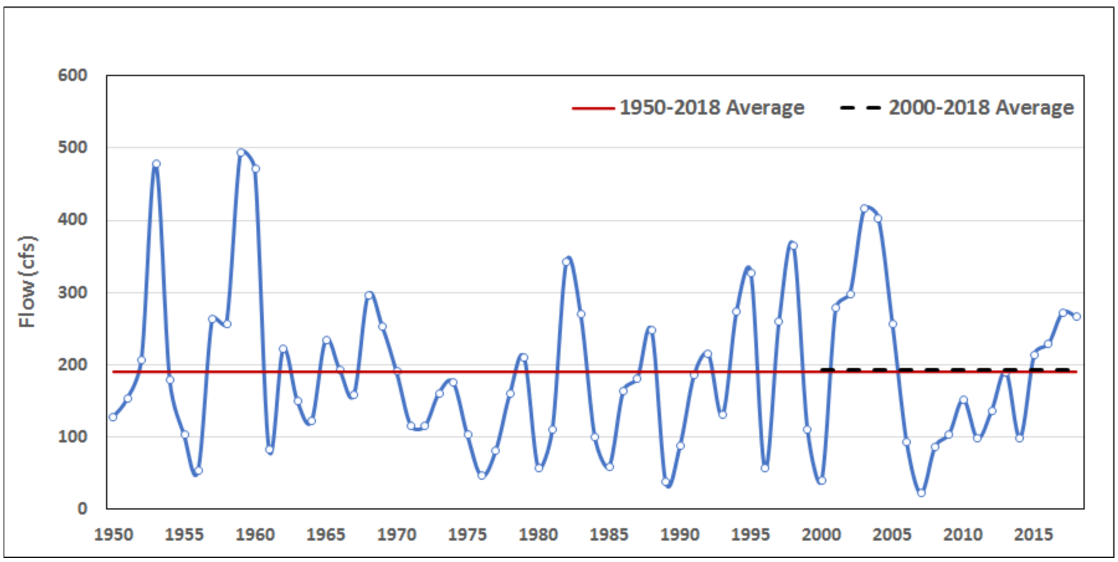

Figure 2-13. Time series of mean annual flows (cfs) at the USGS Horse Creek at SR 72 near Arcadia gage for the period 1950 through 2018, with long-term average (red line) and short-term (2000-2018) average (black dashed line).

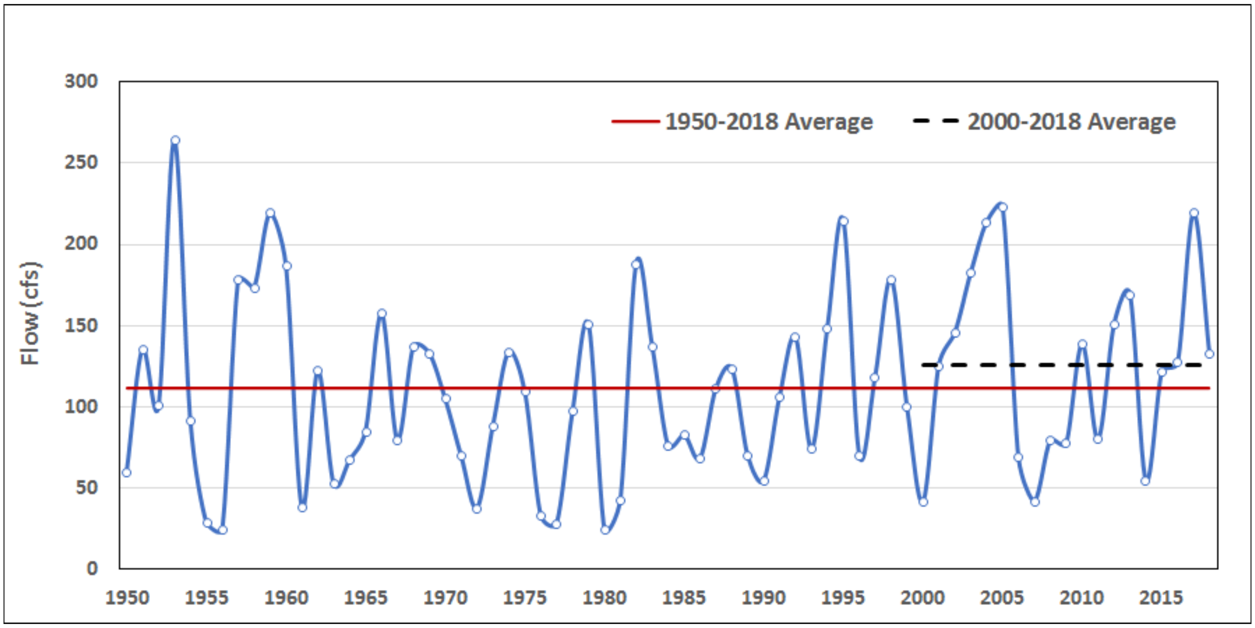

Figure 2-14. Time series of mean annual flows and long-term average flow (cfs) at the USGS Joshua Creek at Nocatee gage for the period 1950 through 2018, with long-term average (red line) and short-term (2000-2018) average (black dashed line).

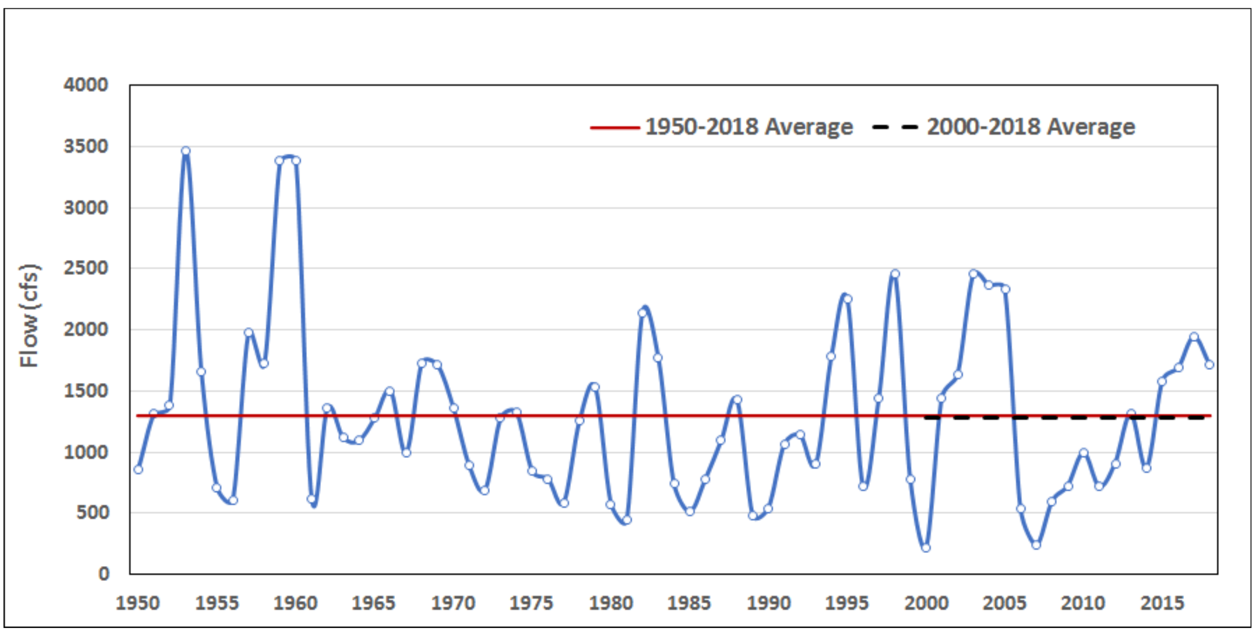

Figure 2-15. Time series of combined mean annual flows (cfs) at the USGS Peace River at Arcadia, Horse Creek near Arcadia, and Joshua Creek at Nocatee gages for the period 1950 through 2018. Long-term average and short-term (2000-2018) average indicated by red line and black dashed line, respectively.

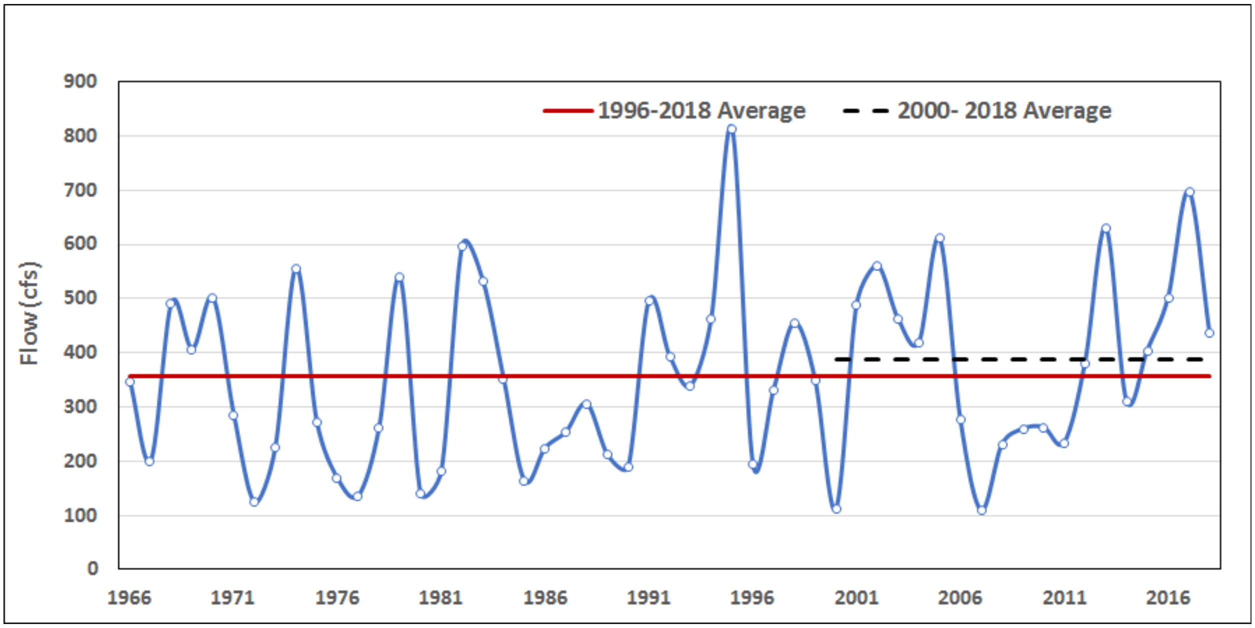

Figure 2-16. Time series of mean annual flows (cfs) at the USGS Shell Creek near Punta Gorda gage for the period 1966 through 2018, with long-term average (red line) and short-term (2000-2018) average (black dashed line).

2.7.2. Seasonal Flows

Box and whisker plots of the daily flows at the Peace River at Arcadia, Horse Creek near Arcadia, Joshua Creek at Nocatee, and Shell Creek near Punta Gorda gages are presented in Figure 2-17. The typical seasonal distribution of flows in the Peace River generally follows the seasonal pattern of rainfall in west-central Florida, with high flows occurring during a four-month summer wet season (June to September) followed by medium and low flow periods associated with the dry season that extends from October to May. Streamflow reaches its lowest values in May and June, when potential evapotranspiration rates are high, groundwater levels are low, and surface water storages available in sinks, depressions, soils, and wetlands are high. In the late summer and fall, surface and ground-water levels are higher, soils are more saturated, and there is much greater streamflow production for each unit of rainfall, with peak flows typically occurring in August and September.

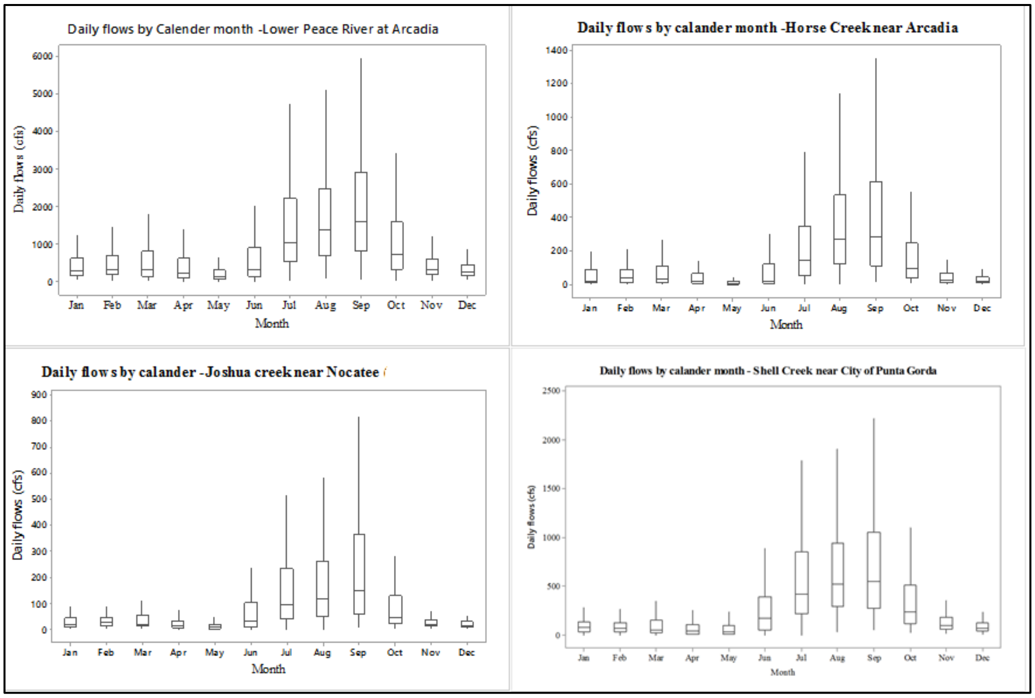

Figure 2-17. Box and whisker plots of daily flows (cfs) by calendar month for the USGS Peace River at Arcadia, Horse Creek near Arcadia, Joshua Creek at Nocatee and Shell Creek near Punta Gorda gages. Boxes represent the inter-quartile range; whiskers represent lowest and highest observations.

Flows in the Peace River have been affected by mining and agricultural activities, drainage alterations and water withdrawals. Phosphate mining and domestic waste discharges to the river have gradually declined since the mid-1980s, while agricultural runoff originating from groundwater withdrawals has contributed to increased baseflow in the Joshua, Horse, Prairie, and Shell Creek tributaries (SWFWMD 2002). Studies conducted by HydroGeoLogic, Inc. (2012) (included as Appendix A) indicate that groundwater withdrawals have a significant impact on the Upper Peace River flows, but much less impact on flows at the lower segment of the Peace River. The lessened impact at the Lower Peace at Arcadia can be attributed to the much tighter confinement of the Upper Floridan Aquifer in the lower area of Peace River basin. Additional information pertaining to anthropogenic impacts on flows in the Lower Peace/Shell System is provided in Section 2.9 below and in Chapter 5.

2.8. Hydrogeology and Aquifer Levels

The hydrogeology of the Peace River basin includes a surficial, intermediate and the Floridan aquifer systems. The uppermost system is the unconfined surficial aquifer composed primarily of unconsolidated quartz sand, silt, and clayey sand (SWFWMD 2004; Gates 2009). The surficial aquifer is mainly recharged by rainfall and other sources of recharge, including wastewater, reclaimed water, septic effluent, and irrigation of agricultural land or landscape areas (Weber 1999; Spechler and Kroening 2007; McBride and Barcelo 2015). The water table is at or near the land surface near the river, wetlands, tributary streams, and natural lakes in the northern portion of the Peace River basin. Areas of higher elevation typically exhibit a water table of about 5 to 10 feet below the land surface depending on the rain season and topography (McBride and Barcelo 2015). The hydraulic conductivities range from 20 to 50 ft/day in the lower area of the Peace River basin (SWFWMD 2001; HydroGeoLogic, Inc. 2009).

Underlying the surficial aquifer is the confined intermediate aquifer consisting of water bearing and confining beds between the overlying surficial aquifer system and the underlying Floridan aquifer system (Gates 2009; HydroGeoLogic, Inc. 2009). The water-bearing units are confined above and below by less permeable materials such as sandy clay, clay and marl (Duerr and Enos 1991; SWFWMD 2001). The confining units hinder vertical movement of groundwater between the overlying surficial aquifer and the underlying Upper Floridan aquifer, but it is a leaky aquifer system (Duerr and Enos 1991; Spechler and Kroening 2007; HydroGeoLogic, Inc. 2009). The Intermediate Aquifer is relatively thin in the upper reaches of the Peace River basin and thickens to the south (SWFWMD 2001). The elevation of the top of the intermediate aquifer system ranges from about 25 feet below sea level in northeastern DeSoto County to about 100 feet above sea level in northwestern Hardee County (Duerr and Enos 1991; Gates 2009).

Underlying the Intermediate Aquifer, the confined Floridan Aquifer exists as a major source of fresh groundwater for most of southwest Florida. The Floridan Aquifer is composed primarily of limestone and dolostone that are hydraulically highly permeable (Duerr and Enos 1991; Weber 1999; Gates 2009). The Floridan Aquifer is subdivided into the Upper Floridan aquifer and Lower Floridan aquifer which are separated by a confining unit. The Upper Floridan aquifer is separated from the Intermediate Aquifer by a lower Hawthorn Group confining unit consisting of clays and dolomitic limestones (Gates 2009; HydroGeoLogic, Inc. 2009; Lewelling and Metz 2009).

About 85% to 90% of all groundwater used in the region is derived from the Upper Floridan aquifer. The Lower Floridan aquifer is generally brine-saturated (SWFWMD 2004), there is an ongoing feasibility study in the upper Peace River region to derive water supply from it. Geology in the Upper Peace River area (upstream of Fort Meade) is dominated by karst features and large sinks (SWFWMD 2002). Historically, substantial amounts of the groundwater were withdrawn from the region and contributed to the decline of groundwater levels and the disappearance of flow from Kissengen Spring near Bartow (SWFWMD 2002; FDEP 2007; Lewelling and Metz 2009). Figure 2-18 presents groundwater elevation history near Arcadia at District Site Identification (SID) No. 24144, which is used to monitor water levels within the Upper Floridan aquifer. Aquifer water levels at the site have generally fluctuated between 34 and 49 feet NAVD88 during the period from 2011 through 2018. Water levels since 2011 have generally increased, although no significant trend is evident.

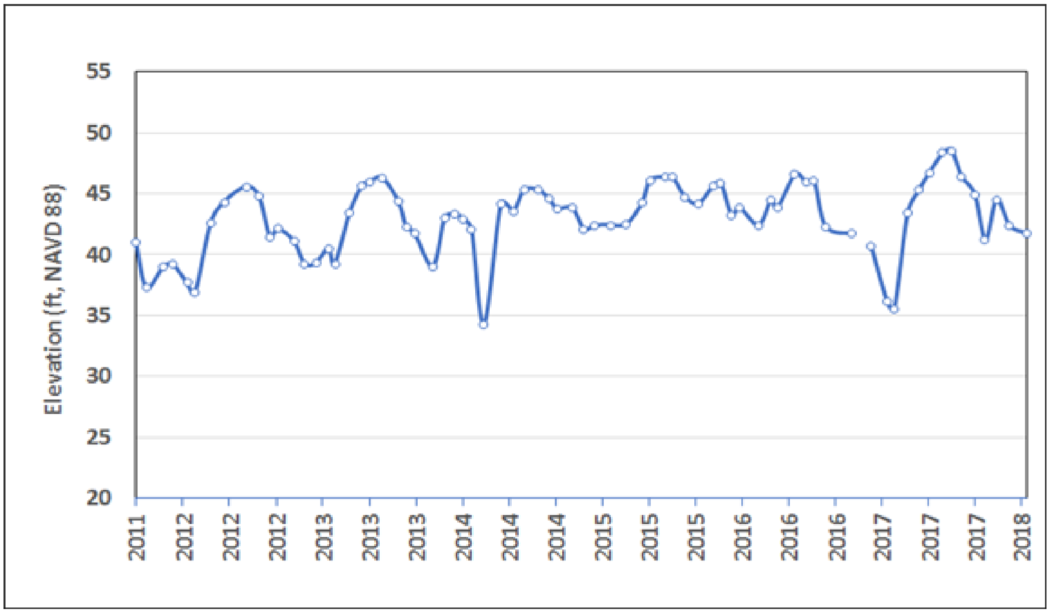

Figure 2-18. Average daily water level elevations (NAVD88) in the Upper Floridan aquifer at District Site Identification (SID) No. 24144 near Arcadia for the period 2011 through 2018.

2.9. Water Use

While groundwater has historically served the majority of consumptive uses of water in the Peace River basin, there are two major surface water supplies in the southern portion of the basin. The PRMRWSA withdraws water from the Lower Peace River and the City of Punta Gorda withdraws water from the Shell Creek Reservoir.

The PRMRWSA is the primary existing legal water user on the Peace River, with the first permit for withdrawals at this site (Water Use Permit 27500016) issued in 1975 (Table 2-2). Withdrawals from Peace River authorized by this original permit began in 1980. The intake for the PRMRWSA Peace River facility is located on a slough connected to the west bank of the river approximately 19 miles upstream of the river mouth at Charlotte Harbor (SWFWMD 2010).

Subsequent to issuance of the original permit in 1975, additional and revised permits (Tables 2-2) were issued by the District to regulate permitted withdrawals from the river by the PRMRWSA.

Table 2-2. Historic PRMRWSA water use permits (source: Atkins, Inc. 2013a).

Year	December 1975	March 1979	May 1982	October 1988	March 1996
Water Use Permit	27500016	27602923	202923	2010420	2010420.02
Average Permitted withdrawal (mgd)	5.0	5.0	8.2	10.7	32.7
Maximum Permitted withdrawal (mgd)	12 &18	12 &18	22	22	90
Low Flow Cutoff (cfs)	91-664*	91-664*	100-664*	100 & 664*	130**
Maximum Percent of Withdrawals (%)	5	5	n/a	10	10

* Withdrawals based on historic monthly averages

** Withdrawals based on the preceding actual daily flow at the USGS Peace River at Arcadia gage

In response to the severity of the 2006-2009 drought in the region, the 1996 version of the water use permit was modified several times through issuance of several executive orders (Table 2-3).

In 2009, the PRMRWSA expanded the Peace River Facility to increase its pumping capacity from 44 million gallons per day (mgd) to a maximum diversion of 120 million mgd and built a 6-billion-gallon reservoir. In 2011, the District issued a revised version of the water use permit for facility withdrawals (Table 2-4) that was consistent with the minimum flows for the Lower Peace River (see Table 1-1) that had been adopted in 2010. However, allowable diversions specified by the permit when the combined flows at the Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee gages exceed 625 cfs during Blocks 2 and 3 are, respectively, 1% and 10% less than the withdrawal limits included in the currently established Lower Peace River minimum flows rule. The 2011 water use permit authorizes a daily maximum withdrawal of 120 mgd, annual average withdrawal of 32.855 mgd and monthly maximum withdrawals 38.3 mgd, with no withdrawals allowed if the combined previous day flow at the three gages is less than 130 cfs.

Table 2-3. Historic modifications of the water use permit issued to the PRMRWSA in 1996 through executive orders issued by the District in response to the severity of the 2006-2009 drought in the region (source: Atkins, Inc. 2014a).

Event	Effective Dates	Low flow Threshold	Gages Used	Withdrawal Issued
Temporary WUP*	12/1/06 to 8/12/08	90 cfs	Arcadia	10%
Executive Order	8/13/07 to 8/29/08	130 cfs	Arcadia + Horse + Joshua	12%
Executive Order	8/30/07 to 10/31/08	90 cfs	Arcadia + Horse + Joshua	12%
Executive Order	11/1/07 to 4/19/09	90 cfs	Arcadia + Horse + Joshua	14% to 330 cfs 21% > 330 cfs
Executive Order	4/20/08 to 6/25/08	90 cfs	Arcadia + Horse + Joshua	10% to 221 cfs 26% > 221 cfs
Executive Order	6/26/08 to 10/26/08	90 cfs	Arcadia + Horse + Joshua	12% to 1370 cfs 15% > 1370 cfs
Executive Order**	10/23/08 - 7/15/09	90 cfs	Arcadia + Horse + Joshua	**4/20-6/25** 10% to 221 cfs 26% > 221 cfs **6/26-10/26** 12% to 1370 cfs 15% > 1370 cfs **10/27-4/19** 14% to 330 cfs 15% above 330 cfs
Executive Order	7/16/09 to March 2010	Same as above but increases maximum withdrawal from 90 to 120 mgd		

* Note 1: The temporary WUP was extended each month by the District Governing Board until the first Executive Order was approved
** Note 2: Variable % withdrawal based on District proposed MFLs criteria

Table 2-4. Permitted withdrawals from the Lower Peace River by the PRMRWSA based on the sum of flows at the USGS Horse Creek near Arcadia, Joshua Creek at Nocatee, and the Peace River at Arcadia gages.

Period	Effective Dates	Where Flow on Previous Day Equals	Allowed Withdrawals
Block 1	April 20 through June 25	≤ 130 cfs > 130 cfs	0 cfs 16% of the previous day's flow*
Block 2	October 28 through April 19	≤ 130 cfs > 130 cfs and < 625 cfs ≥ 625 cfs	0 cfs 16% of the previous day's flow* 28% of the previous day's flow*
Block 3	June 26 through October 27	≤ 130 cfs > 130 cfs and < 625 cfs ≥ 625 cfs	0 cfs 16% of the previous day's flow* 28% of the previous day's flow*

*The total permitted maximum withdrawals on any day shall not exceed 400 cfs.

On February 26, 2019, the permit issued to the PRMRWSA was renewed for a 50-year period, with an increase in the daily maximum withdrawal from 120 mgd to 258 mgd (400 cfs) and an increase in the annual average withdrawal from 32.855 mgd (51 cfs) to 80 mgd (124 cfs). However, before the renewal of the permit the PRMRWSA entered into agreement with the Polk Regional Water Cooperative (PRWC) to reduce the permitted maximum daily withdrawal by up to 48 mgd (74.2 cfs) (i.e., to 210 mgd or 325 cfs) to offset impacts from future permitted withdrawals by the PRWC from Peace Creek in Polk County for natural system restoration and potable supply or from the Upper Peace River in Polk County for storage in reservoirs or other approved consumptive uses – ultimately for potable use. If a water use permit is not issued to the PRWC for withdrawals from Peace Creek or the Upper Peace River within 10 years of the issuance date of the agreement, then the PRMRWSA shall no longer be bound by the agreement.

Following adoption of the recommended minimum flows for the Lower Peace River described in this report, the permit issued to the PRMRWSA was modified on July 19, 2021, to incorporate withdrawal limitations consistent with the updated minimum flows. No changes to the authorized allocation or permit expiration date were included in the revised permit (i.e., Water Use Permit No. 20010420.011).

Monthly average withdrawals at the PRMRWSA Peace River facility for the period 1980 through 2018 are shown in Figure 2-19. The highest average withdrawals occur in July and the lowest in May.

The City of Punta Gorda withdraws water from Shell Creek reservoir upstream of Hendrickson Dam, as authorized by Water User Permit No. 2000871.011 issued by the District in 2018, with an expiration date of 2027. The current permit allows for an average withdrawal of 8.1 mgd (12.5 cfs) and a maximum peak monthly withdrawal of 11.73 mgd (18.1 cfs). Monthly average withdrawals from Shell Creek Reservoir by the City of Punta Gorda from 1972 through 2014 ranged from 4 cfs in July to 5.5 cfs in November and are shown in Figure 2-20.

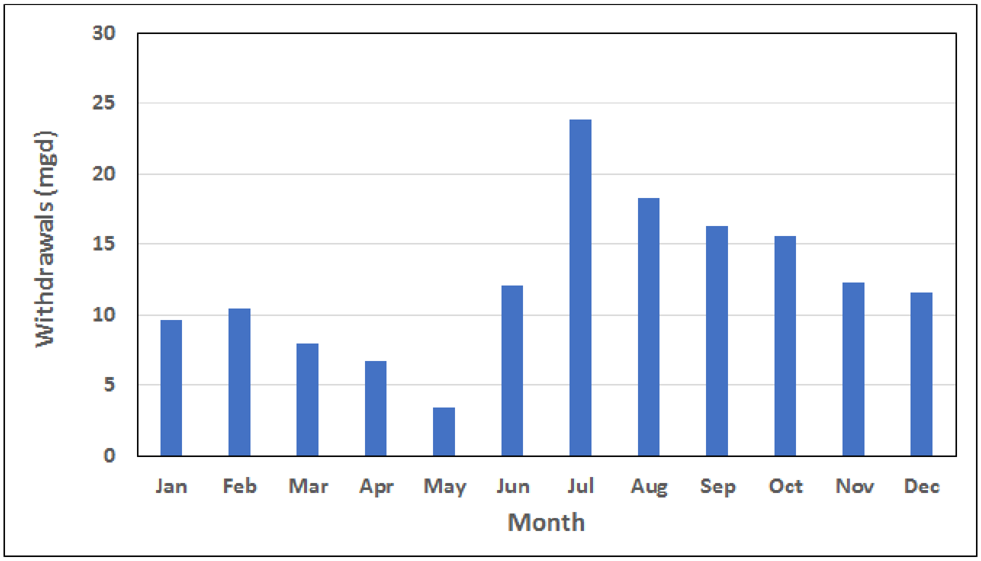

Figure 2-19. Monthly average withdrawals (cfs) from the Peace River by the PRMRWSA for the period 1980 through 2018.

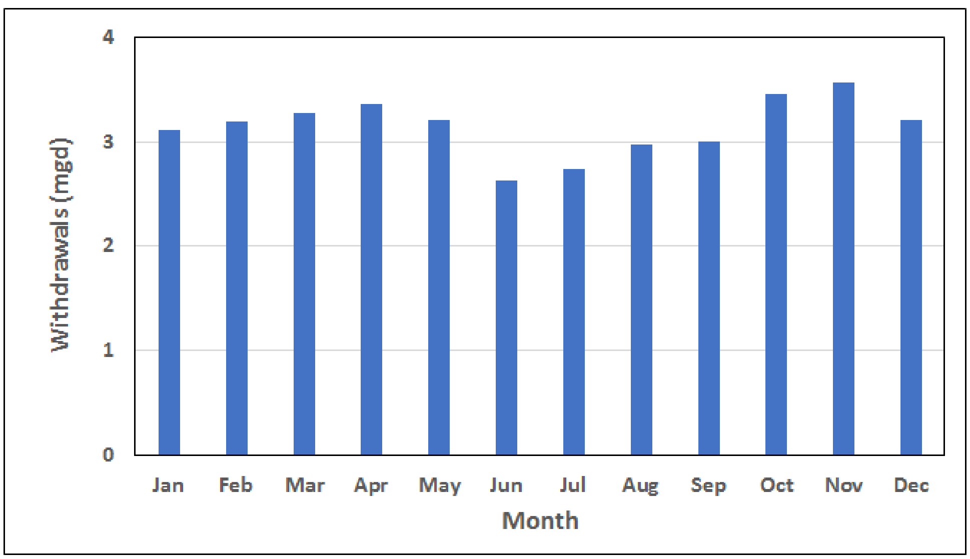

Figure 2-20. Monthly average withdrawals (cfs) from Shell Creek Reservoir by the City of Punta Gorda for the period 1972 through 2018.

CHAPTER 3 - WATER QUALITY CHARACTERISTICS

Water quality is one of ten “Environmental Values” defined in the State Water Resource Implementation Rule for consideration when establishing minimum flows. Water quality of the Lower Peace/Shell System and Charlotte Harbor have been studied by several agencies, including FDEP (2007, 2019), Charlotte Harbor Environmental Center (1999, 2000, 2001, 2002, 2003), PRMRWSA (PB&J 1998, 1999, 2002, 2003, 2004, 2005, 2006b, 2007, 2008, 2009, 2010; Atkins 2011, 2012, 2013a, 2013b, 2014a, 2014b, 2017); Janicki Environmental, Inc. (2017): City of Punta Gorda (PBS&J 2006a, 2010), the USGS (Stoker et al. 1989, Stoker 1992) and the District (Coastal Environmental, Inc. 1996; CDM 1998; Ghile and Leeper 2015; SWFWMD 2001, 2002; Kelly et al. 2005; SWFWMD 2007, 2010; Janicki Environmental, Inc. 2019). Although flow can affect water quality, findings summarized to date for the Lower Peace/Shell System indicate that withdrawals have had little measurable influence on system water quality.

3.1. Water Quality Classification

Under Rule 62-302.200, F.A.C., Florida’s surface water quality standards consist of four components: 1) the designated use or classification of each water body, 2) the surface water quality criteria (numeric and narrative) for each water body, which are established to protect its designated use, 3) the anti-degradation policy, and 4) moderating provisions, such as mixing zones. Each surface water body in Florida is classified according to its present and future most beneficial use, referred to as its designated use, with class-specific water quality criteria for select physical and chemical parameters, which are established to protect the water body’s designated use (Chapter 62-302, F.A.C.).

Charlotte Harbor is classified as a Class II water body with a designated use of shellfish propagation or harvesting (Rule 62-302.400(17)(b), F.A.C.). The Lower Peace River and Lower Shell Creek are classified as Class III waters with designated uses of recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife (Rule 62-302.400(15), F.A.C.) The Gasparilla Sound-Charlotte Harbor Aquatic Preserve and Cape Haze Aquatic Preserve are classified as Outstanding Florida Waters, a designation associated with Florida’s anti-degradation policy (Rule 62-302.700, F.A.C.). In addition, Charlotte Harbor is designated a Southwest Florida Water Management District Surface Water Improvement and Management (SWIM) Priority Waterbody and has a comprehensive SWIM Plan (SWFWMD 2000) that was recently updated (SWFWMD 2020a) and which identifies management strategies intended to prevent water quality degradation.

Specific water quality criteria corresponding to each surface water classification are listed in Rules 62-302.500 through 62-302.540, and 62-302.800, F.A.C. Numeric interpretations of narrative nutrient water quality criteria for all Class I, II and III waters of Florida (Rule 62.302.531, F.A.C.) became effective in 2012. Estuary-specific numeric interpretations of the narrative nutrient criteria (Rule 62.302.532, F.A.C.), also became effective in 2012. The estuarine-specific rules apply to Charlotte Harbor Proper but are not applicable to the Lower Peace River and Lower Shell Creek, which are tidally influenced areas that fluctuate between predominantly marine and predominantly fresh waters during typical climatic and hydrologic conditions.

3.2 Impaired Waters and Pollutant Load Reduction Goal

3.2.1 Impaired Waters

Section 303(d) of the Federal Clean Water Act requires each state to identify and list "impaired" waters where applicable water quality criteria are not being met. In addition, development of Total Maximum Daily Loads (TMDLs) is required for impaired water bodies. A TMDL is the amount of a specific pollutant that a receiving water body can assimilate without causing exceedance of water quality standards. To meet the reporting requirements of the Federal Clean Water Act, the State of Florida publishes the Integrated Water Quality Assessment for Florida. Assessment is made based on specific segments each assigned a specific Waterbody Identification (WBID) number.

Several WBIDs in the Lower Peace River and Lower Shell Creek (Figure 3-1) are included on the most recent statewide comprehensive verified list of impaired waters published on November 15, 2019 (FDEP 2019). Within the Lower Peace River, WBID 2056B (Middle Peace River Estuary [Middle Segment]) and WBID 2056C2 (Peace River Estuary [Upper Segment South]) are listed as impaired due to nutrients based on total nitrogen concentration exceedances. WBID 2056D (Alligator Bay) is listed as impaired for nutrients based on chlorophyll-a exceedance in a single year. In the upper portion of the Lower Peace River, WBID 1623C (Peace River Above Joshua Creek) is listed for fecal coliform exceedances. Downstream, near the mouth of the river, WBIDS 2060A1 (Myakka Cutoff [Western Portion]) and 2060A2 (Myakka Cutoff [Eastern Portion]) are impaired for fecal coliform based on the shellfish harvesting classification being not fully approved by the Environmental Assessment Section (EAS) of the Florida Department of Agriculture and Consumer Services.

Additionally, although iron concentrations in the Lower Peace River WBIDs 2056A, 2056B and 2056C2 are due in part to naturally occurring groundwater inputs, these WBIDs are listed as impaired because the FDEP could not eliminate possible anthropogenic sources of the metal. In Shell Creek, WBID 2041A (Shell Creek below Hendrickson Dam) is listed as impaired for nutrients, based on total nitrogen and total phosphorus concentration exceedances.

To date, no TMDLs have been developed for specific WBIDs in the Lower Peace River or Lower Shell Creek (FDEP 2019). However, Florida’s statewide TMDL for mercury (FDEP 2013) is applicable to the river and creek.

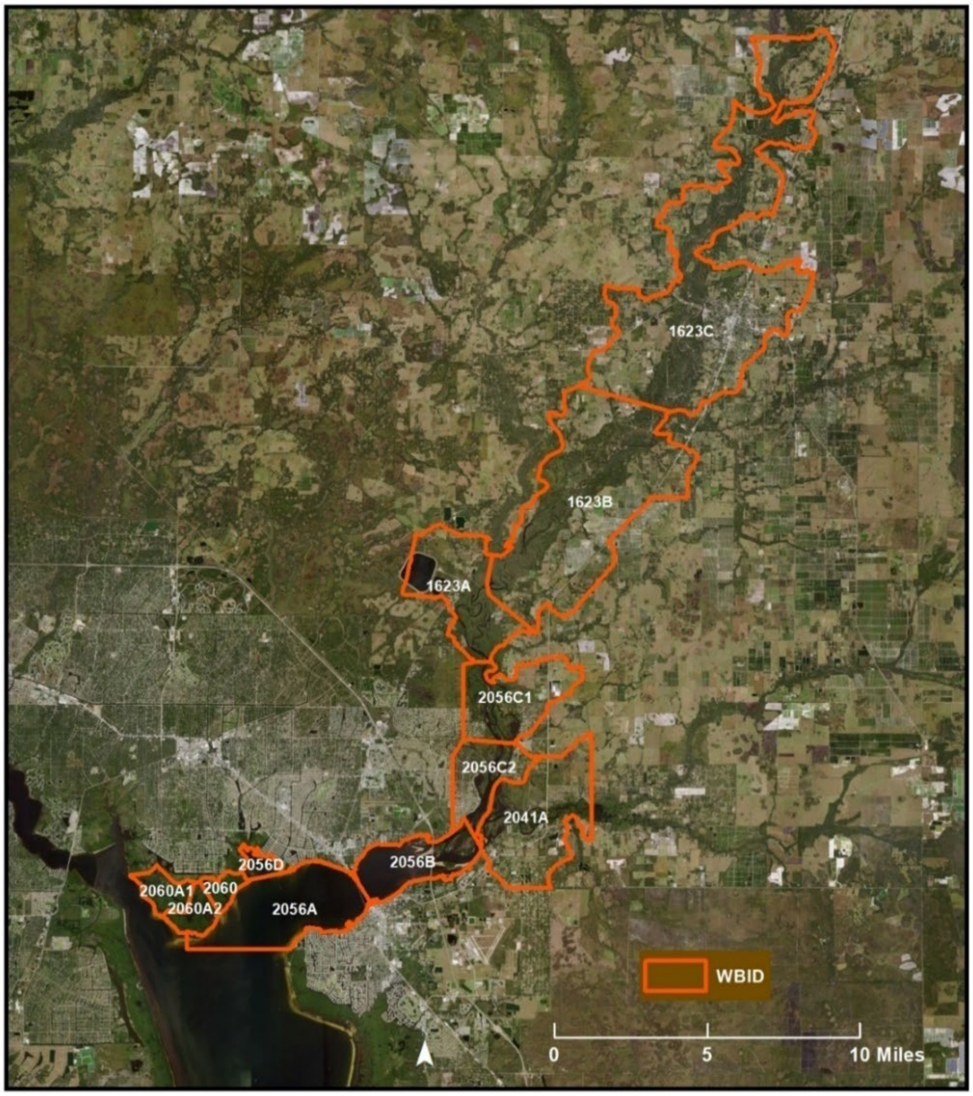

Figure 3-1. Selected Florida Department of Environmental Protection Waterbody Identification (WBID) boundaries in the vicinity of the Lower Peace River and Lower Shell Creek.

3.2.2. Pollutant Load Reduction Goal

The 2000 SWIM Plan for Charlotte Harbor (SWFWMD 2000) included a Pollutant Load Reduction Goal (PLRG) that was developed to "hold the line" on nitrogen loads from the Peace River watershed to Charlotte Harbor. The PLRG was developed based on potential increases in bottom water hypoxia in the harbor that could be associated with increased nitrogen loads.

The hold-the-line approach was also developed with acknowledgement of environmental effects associated with the relatively large, seasonal inflows of fresh water with high concentration of dissolved organic matter to Charlotte Harbor from the Peace and Myakka Rivers. These inflows lead to natural stratification patterns that are associated with low dissolved oxygen concentrations (CDM 1998) and strongly affect seagrass biomass and productivity (Tomasko and Hall 1999).

As noted in the recent Charlotte Harbor SWIM plan update (SWFWMD 2020a), the “hold-the-line” approach is being adequately implemented for the gaged portion of the Peace River watershed. Modeling results of nitrogen loading indicate the average load from the gaged portion of the Peace River for two seven-year periods, 1985 through 1992 and 2009 through 2015 differ by less than 0.5%.

The recently completed Lake Hancock Lake Level Modification and Lake Hancock Outfall Treatment Marsh projects (SWFWMD 2020b), and additional projects to be implemented in the future will continue to support the “hold-the-line” approach for nutrient loading from the Peace River basin.

3.3 Water Quality Review

In support of the current reevaluation and development of recommended minimum flows for the Lower Peace River and Lower Shell Creek, studies completed after publication of the District’s 2010 minimum flows report for the Lower Peace River (SWFWMD 2010) that included in-depth analyses of the spatial and temporal variation in water quality within the system were reviewed. Key studies included in the review include the following.

1. Atkins, Inc. (2014b), which was prepared for the District to assess relationships between freshwater inflow and nutrient loading with chlorophyll concentrations and primary production in the Lower Peace/Shell System and upper Charlotte Harbor.
2. Janicki Environmental, Inc. (2017) prepared for the PRMRWSA to provide the District with information for evaluating environmental effects of withdrawals from the Peace River Facility.
3. Janicki Environmental, Inc. (2019), which is included as Appendix F to this minimum flows report, was prepared for the District to investigate relationships between freshwater inflow and water quality in the tidal portion of the Lower Peace/Shell System and ensure that the recommended minimum flows resulting from the current minimum flows reevaluation/development process do not result in unacceptable water quality impacts.
4. Atkins, Inc. (2017) prepared for the City of Punta Gorda for evaluating environmental effects of withdrawals from Shell Creek Reservoir.

3.3.1 Water Quality Characteristics in the Lower Peace River

Stoker et al. (1989) address hydraulic and salinity characteristics of the tidal reach of the Peace River, concluding that the hydraulic characteristics of the river segment are influenced primarily by fluctuations in tidal stage. They also note that salinity characteristics in the tidal portion of the Peace River are influenced by freshwater inflows, tide, and the salinity in Charlotte Harbor, and that wind effects may occasionally become important by affecting tidal patterns. Stoker (1992) further investigated salinity variation due to freshwater inflow and tides and the potential changes in salinity due to altered freshwater inflow into Charlotte Harbor, noting that seasonal fluctuations in harbor salinity occur primarily in response to fluctuations in freshwater inflow from the Peace, Myakka, and Caloosahatchee rivers. Also, as noted in section 3.2.2 of this chapter, the importance of inflows of fresh water with high concentration of dissolved organic matter to the harbor are associated with natural patterns of low dissolved oxygen concentrations. Collectively, these and numerous other studies highlight the importance of water quality within the Lower Peace/Shell System and the receiving, Charlotte Harbor.

Pursuant to Water Use Permit No. 20010420, the PRMRWSA has been implementing a Peace River hydrobiological monitoring program (HBMP) since 1976 to provide the District with information sufficient for evaluating environmental effects of withdrawals at the Peace River Water Treatment Facility. Over the years, elements of the HBMP have been modified to enhance understanding of the Lower Peace/Shell System and upper Charlotte Harbor. Much of the recent HBMP data collection has focused on physical factors (water temperature, color and extinction coefficients), water quality (salinity, nitrogen, phosphorus, nitrate/nitrite and reactive silica), and phytoplankton biomass (chlorophyll *a*) that may be directly linked to freshwater inflow variation. Appendix A to the Peace River Hydrobiological Monitoring Program 2016 HBMP Comprehensive Report (Janicki Environmental, Inc. 2017) summarizes efforts of a scientific review panel, which was initiated in 1996, that have helped shape the current HBMP.

Since many biotic communities are dependent on estuarine salinity variation for survival, the need to collect salinity data at much greater frequencies was identified during the 1996 renewal of the permit issued to the PRMRWSA. The PRMRWSA subsequently deployed three additional floating continuous recorders in December 2005 for monitoring surface salinity , two additional, similar recorders again in May 2008, and three more recorders by the end of June 2011. In December 2009, the USGS installed near-surface and near-bottom continuous recorders immediately adjacent to the PRMRWSA Peace River Water Treatment Facility intake structure. The HBMP fixed-station sampling locations for the Lower Peace River are shown Figure 3-2.

Janicki Environmental, Inc. (2017) selected a representative group of stations (RKm 2.4, 6.6, 15.5, 23.6, and 30.7; see Figure 3-2) and moving isohaline-based stations (0, 6, 12, and 20 psu) to evaluate spatial and temporal variation and long-term trends of key water quality characteristics for the Lower Peace River. For trend analysis, a method developed by Coastal Environmental, Inc. (1996) for FDEP using seasonally weighted yearly averages and a seasonal Mann-Kendall trend test was used. Summary results of the trend analyses are presented in this chapter. Much of the information provided in this chapter are either taken directly or paraphrased for brevity from the Janicki Environmental, Inc. (2017) HBMP report and the Janicki Environmental, Inc. (2019) water quality study report, which is included as Appendix F to this document.

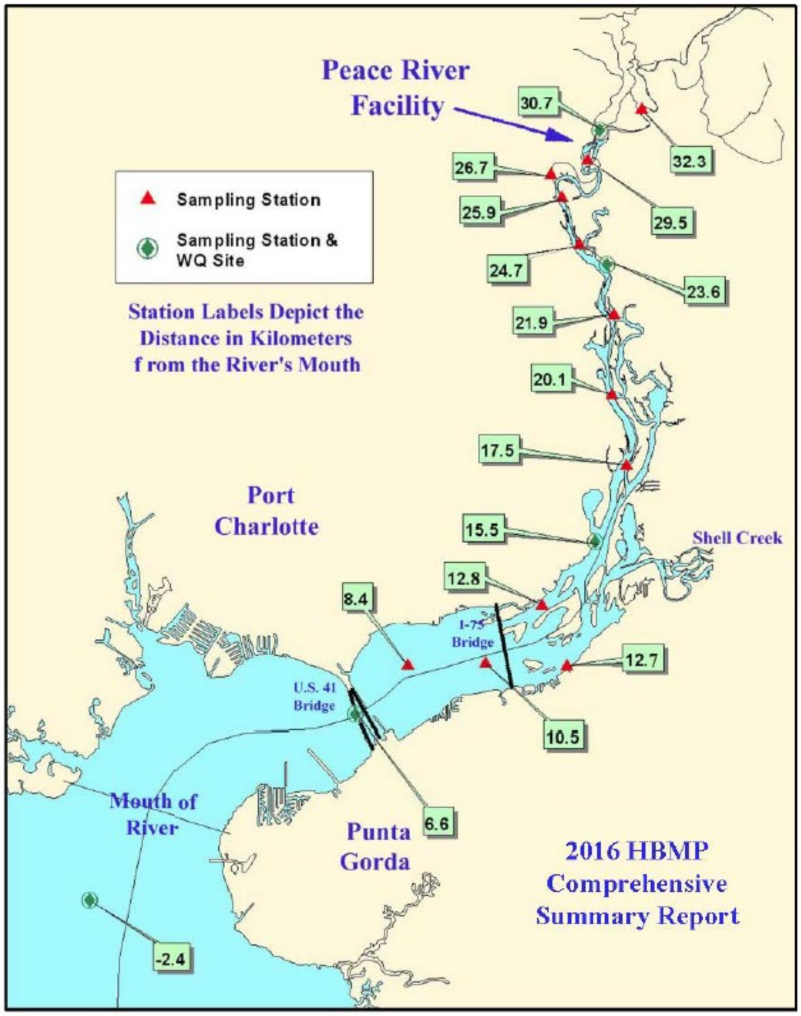

Figure 3-2. Map of the Lower Peace River HBMP fixed-station sampling sites installed during 2005, 2008, and 2011 by the PRMRWSA (reproduced from Janicki Environmental, Inc. 2017). Sampling site labels correspond to river kilometer (RKm) location.

3.3.1.1 Salinity

Monthly salinity (surface and bottom) data collected at fixed stations RKm -2.4, 6.6, 15.5, 23.6, and 30.7 between 1976 and 2016 show that as expected, salinity was lowest during the wet season, from July through September and highest during the dry season, from January to March (Figure 3-3).

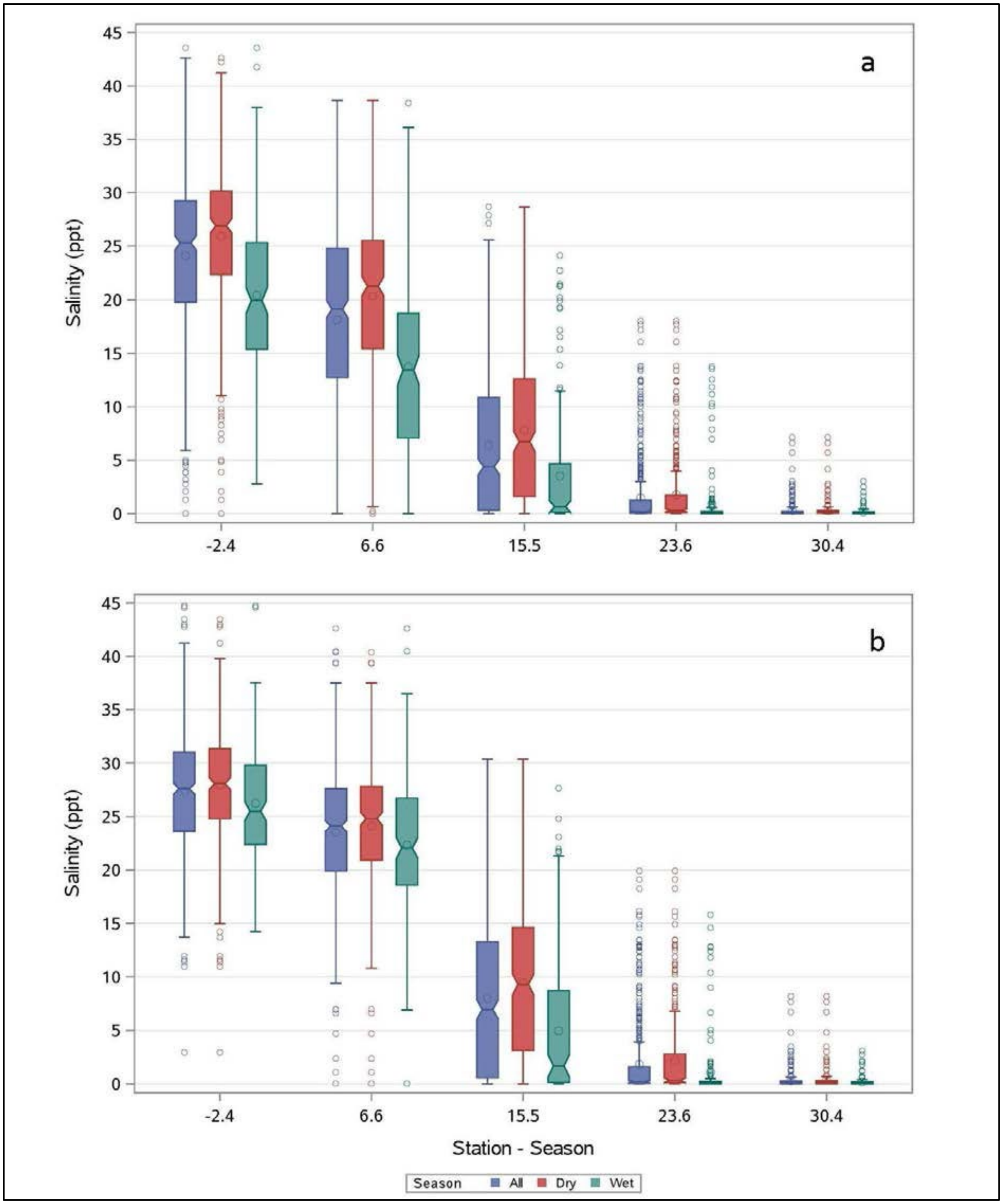

Figure 3-3. Box and whisker plots of a) surface and b) bottom salinity measured at selected HBMP fixed-stations in the Lower Peace River and near the river mouth (sampling station identifiers correspond to river kilometer (RKm) location; see Figure 3-2) between 1976 and 2016, including Dry and Wet seasons, respectively from January through March and July through September (reproduced from Janicki Environmental, Inc. 2017).

In addition, Figure 3-3 shows a distinct longitudinal spatial salinity gradient along these fixed stations. Salinity levels were much higher near the vicinity of the river mouth (RKm -2.4) and are typically low (< 0.5 psu) upstream of the PRMRWSA water-intake location. Similar patterns were observed for both surface and bottom salinity levels, even though salinity values are greater for bottom measurements than those taken at the surface as expected. The inter-annual variability in salinity generally increased from upstream station (RKm 30.4) to the most downstream station where seasonal differences reached up to 40 psu.

Trend analyses indicated significant upstream-movement trends for the 0 psu and 20 psu isohaline locations during the 1984 through 2016 period (Table 3-1). A possible explanation for these trends is the prolonged droughts that occurred in 2000, 2007 and 2014.

Table 3-1. Trend tests (seasonal Mann-Kendall) for movement of 0, 6, 12 and 20 psu isohaline locations for the period 1984 through 2016 (source: Janicki Environmental, Inc. 2017).

	Trend Test for Isohaline Location Movement			
	0 psu	**6 psu**	**12 psu**	**20 psu**
P value	0.037*	0.227	0.171	0.044*

* Upstream movement significant at 0.05 level

3.3.1.2 Dissolved Oxygen

Dissolved oxygen (DO) concentrations in the Lower Peace River and Charlotte Harbor were typically higher in surface waters than near the bottom of the estuary. Seasonal patterns in DO concentrations were typically evident in the Lower Peace/Shell System and Charlotte Harbor, with lower DO levels occurring during the wet season in association with higher water temperatures and increased phytoplankton production. Surface concentrations of DO at monitoring stations were similar throughout the system. However, bottom dissolved oxygen levels tended to be somewhat lower in the downstream portion of the monitored area, especially during summer periods of increased freshwater inflow and increased vertical stratification of the water column (Figure 3-4).

Table 3-2 summarizes the results of trend tests for statistically significant changes in dissolved oxygen at the selected (0 psu, 6 psu, 12 psu and 20 psu) moving isohaline locations. Surface dissolved oxygen levels at the 0 psu isohaline location exhibited a statistically significant increasing trend through time. Again, this may have been related to the extended periods of drought and reduced freshwater inflows in 2000, 2007 and 2014.

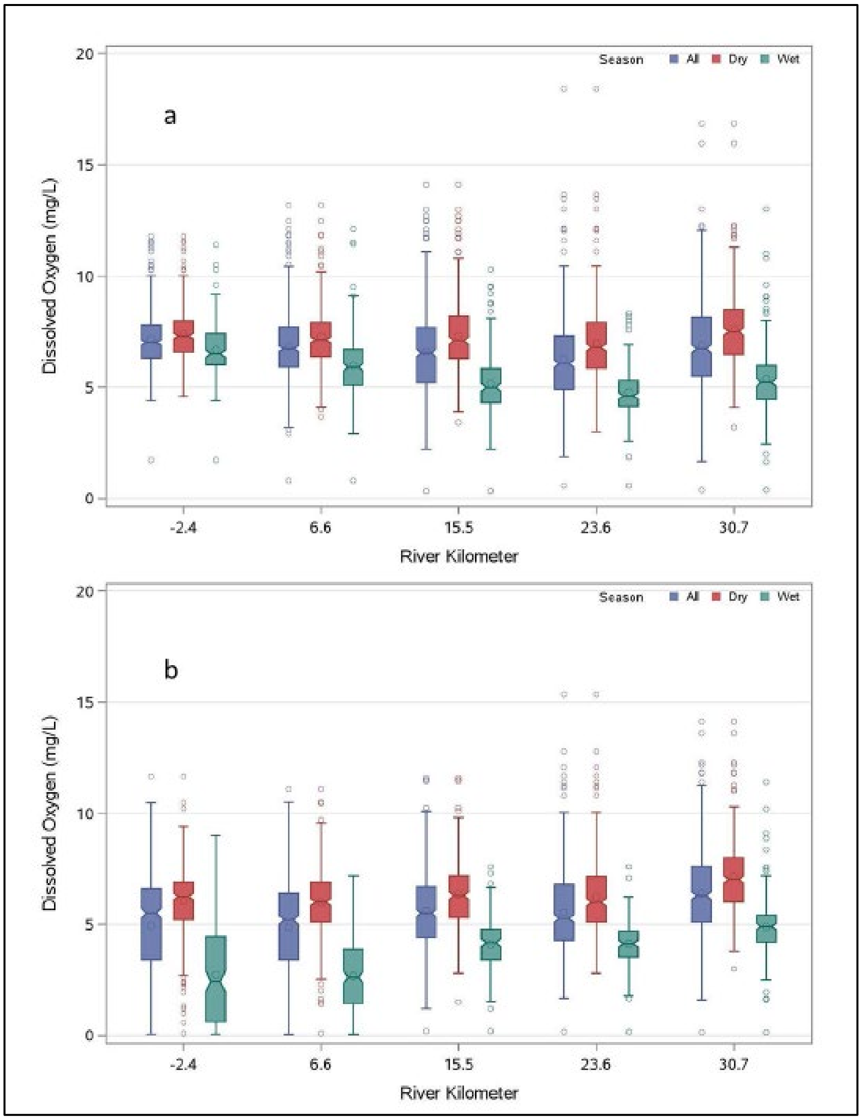

Figure 3-4. Box and whisker plots of a) surface and b) bottom dissolved oxygen levels measured at selected HBMP fixed-stations in the Lower Peace River and near the river mouth (sampling station identifiers correspond to river kilometer (RKm) locations; see Figure 3-2) between 1976 and 2016, including Dry and Wet seasons, respectively from January through March and July through September (reproduced from Janicki Environmental, Inc. 2017).

Table 3-2. Trend tests (seasonal Mann-Kendall) of surface dissolved oxygen concentrations for the period 1984 through 2016 at 0, 6, 12 and 20 psu moving isohaline locations. (source: Janicki Environmental, Inc. 2017).

	Trend Test for Dissolved Oxygen Levels at Isohaline Locations			
	0 psu	**6 psu**	**12 psu**	**20 psu**
P value	0.016*	0.316	0.121	0.192

* Significant increasing trend at 0.05 level

3.3.1.3 Chlorophyll

Chlorophyll concentrations can serve as an indicator of phytoplankton biomass, an important component of the Lower Peace River/Shell Creek food web. Chlorophyll concentrations are highly variable to season, location, and nutrient concentrations in the Charlotte Harbor estuary (Montgomery, et al. 1991). Conceptually, freshwater withdrawals have the potential to influence chlorophyll levels primarily through one of three major mechanisms: decreased colored dissolved organic matter (color), nutrient load reductions, and longer residence times. Color is reduced with decreases in freshwater flow, thereby reducing light-limitation and increasing light penetration into the water column. Nutrient loads positively correlate with flow and chlorophyll, whereas residence time has a negative relationship with flow. The location of peak chlorophyll concentration would be expected to coincide with the zone of maximum residence time in the Lower Peace/Shell System, and in the upper Charlotte Harbor estuary. While flow can be a major influence affecting chlorophyll concentration and distribution in upper Charlotte Harbor, other factors, many of which covary with flow, can also affect chlorophyll. For example, during periods of high flow, physical factors like vertical stratification can regulate phytoplankton bloom dynamics. Temperature can also regulate chlorophyll production, with lower concentrations during the winter dry season when flow tends to be less, but water temperatures are at a minimum.

Although there are many types of chlorophyll, chlorophyll *a* is commonly assessed for aquatic ecosystems studies. For simplicity, in this report, chlorophyll *a*, uncorrected for phaeophytin, is denoted as chlorophyll. Figure 3-5 shows box and whisker plots of longitudinal pattern of chlorophyll at selected fixed stations in the Lower Peace River and upper Charlotte Harbor. Average chlorophyll concentration was highest in the middle portion (RKm 15.5) of the monitored area. In the lower portion of the system, average chlorophyll values tended to increase during the summer wet season, while in the upper monitored area, chlorophyll values were lower in the wet season.

Depending on the magnitude of flows, color and water age, high chlorophyll levels may occur throughout the year. However, there are distinct temporal patterns of chlorophyll within certain regions of the Lower Peace/Shell System and Charlotte Harbor. In the most downstream portion of the monitored area (e.g., < RKm -2.1), a relatively small phytoplankton peak was common in the wet season when high freshwater inflows introduce nutrients into the slow moving, clear harbor waters. The highest chlorophyll concentrations occurred, however, during fall (Figure 3-6) when freshwater inputs declined after conveying nitrogen loadings, allowing tidal inputs to decrease watercolor and allow more light penetration and phytoplankton production. In the upper portion of estuarine system (e.g., > RKm 27.1) highest chlorophyll levels occurred during the spring dry season (Figure 3-6) when the low freshwater inflows provide enough nutrients to support phytoplankton production and residence time is relatively long (Atkins, Inc. 2014b).

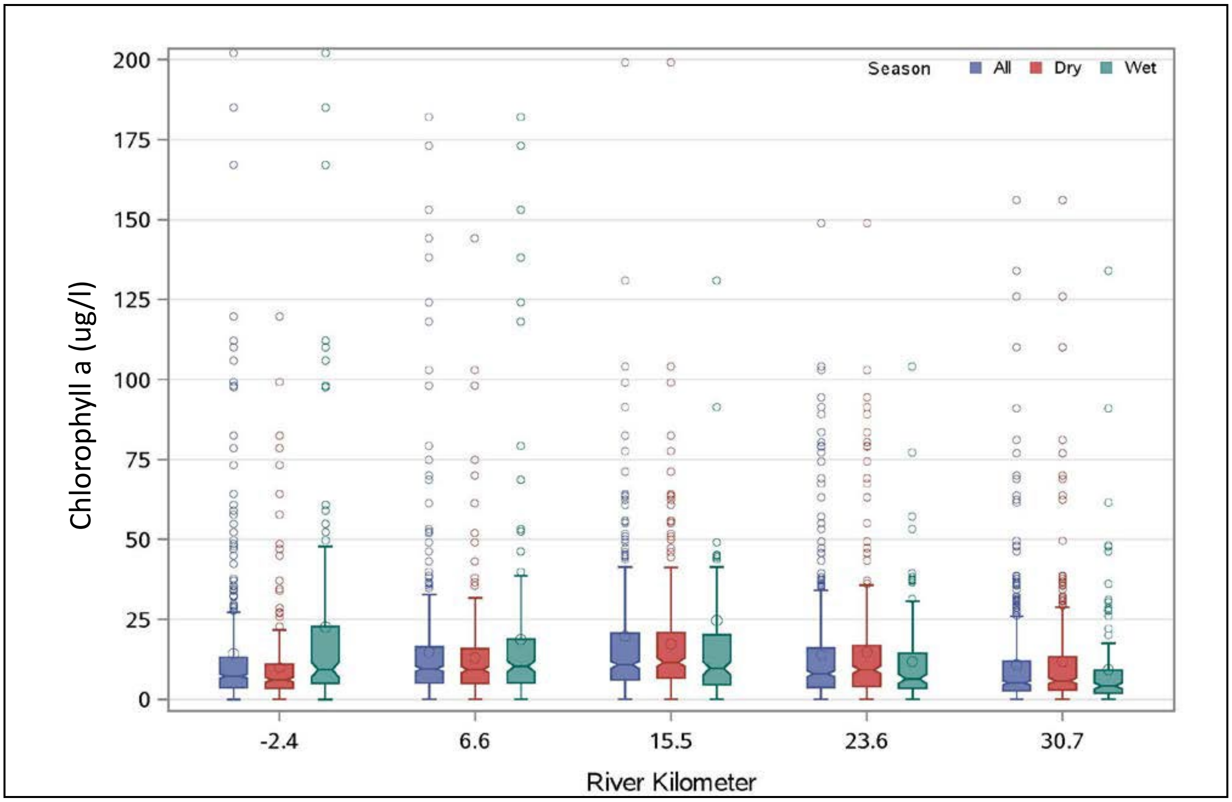

Figure 3-5. Box and whisker plots of chlorophyll measured at selected HBMP fixed-stations (sampling station identifiers correspond to river kilometer (RKm) location; see Figure 3-2) in the Lower Peace River and near the river mouth between 1976 and 2016, including Dry and Wet seasons, respectively from January through March and July through September (reproduced from Janicki Environmental, Inc. 2017, with y-axis label units changed from mg/m3 to ug/l).

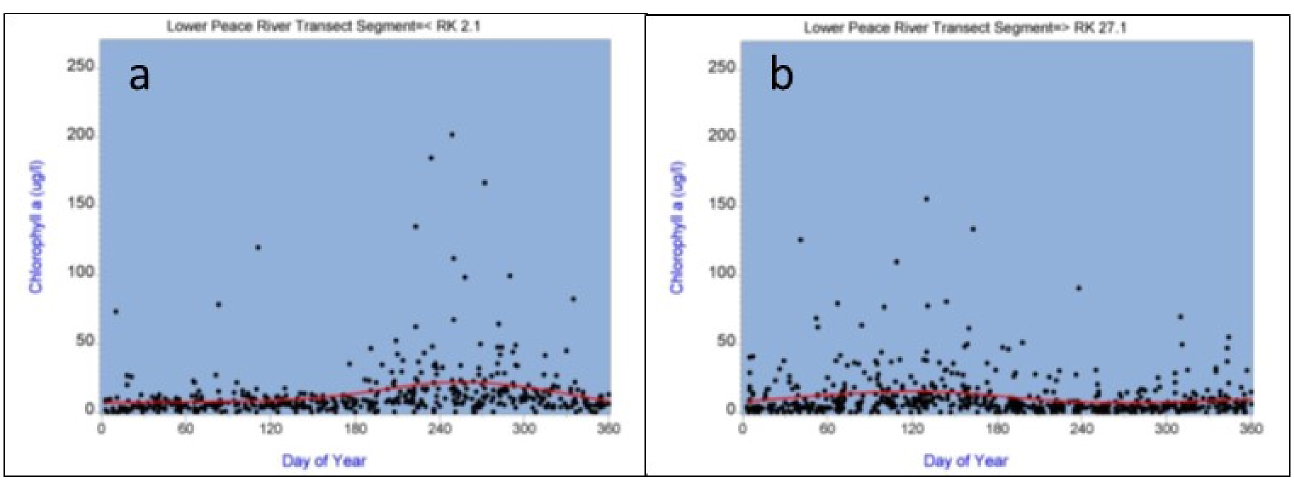

Figure 3-6. Plots of chlorophyll at a) RKm 2.1 and b) RKm 27.1 in the Lower Peace/Shell System and upper Charlotte Harbor (see Figure 3-2) (reproduced from Atkins, Inc., 2014b).

Previous HBMP studies (PBS&J, Inc. 2009) reported declines in chlorophyll concentrations during late 1970s and early 1980s. Since that time, however, higher concentrations have been observed; for example, the peaks that occurred from 2004 through 2006, following the high nutrient loading associated with Hurricanes Charley, Francis and Jeanne in 2004 (PBS&J, Inc. 2009). Over the entire monitoring period (1976 through 2016), increases in chlorophyll concentrations within the upper portion of the estuary (0 to 12 psu isohaline locations) were not statistically significant. Chlorophyll increases associated with location of the 20 psu isohaline were, however, significant (Table 3-3).

Table 3-3. Trend tests (seasonal Mann-Kendall) of chlorophyll concentrations for the period 1984 through 2016 at 0, 6, 12 and 20 psu moving isohaline locations. (source: Janicki Environmental, Inc. 2017).

	Trend Test for Chlorophyll at Isohaline Locations			
	0 psu	**6 psu**	**12 psu**	**20 psu**
P value	0.540	0.402	0.930	0.041*

* Significant increasing trend at 0.05 level

3.3.1.4 Total Nitrogen, Nitrate+Nitrite, and Total Kjeldahl Nitrogen

Concentrations of total nitrogen (TN) has been reported in the HBMP. Inorganic nitrate+nitrite (NOx), and total Kjeldahl nitrogen (TKN) are also reported in the HBMP and are presented here. TN is the sum of NOx and TKN. TKN is the sum of Organic Nitrogen and Ammonia. Box and whisker plots depicting spatial and temporal variability in TN, NOx, and TKN at selected fixed stations in the Lower Peace/Shell System, and Charlotte Harbor are presented in Figure 3-7. NOx concentrations progressively decreased moving downstream along the sampling locations in association with reduced color and nitrogen uptake by phytoplankton. Figure 3-7a shows that dissolved NOx concentrations near the mouth of the Lower Peace River (RKm -2.4) were typically at or near detection limits. NOx concentrations were lower in wet season than in the dry season at upstream stations. Unlike NOx, TKN concentrations were typically highest during the summer wet season rather than during the dry season, reflecting the increased freshwater inflow inputs of organic nitrogen from Peace River and Shell Creek watersheds (Figure 3-7b). Because TN is simply the sum of NOx and TKN, the spatial and temporal trends are a combination of both nitrogen species (Figure 3-7c).

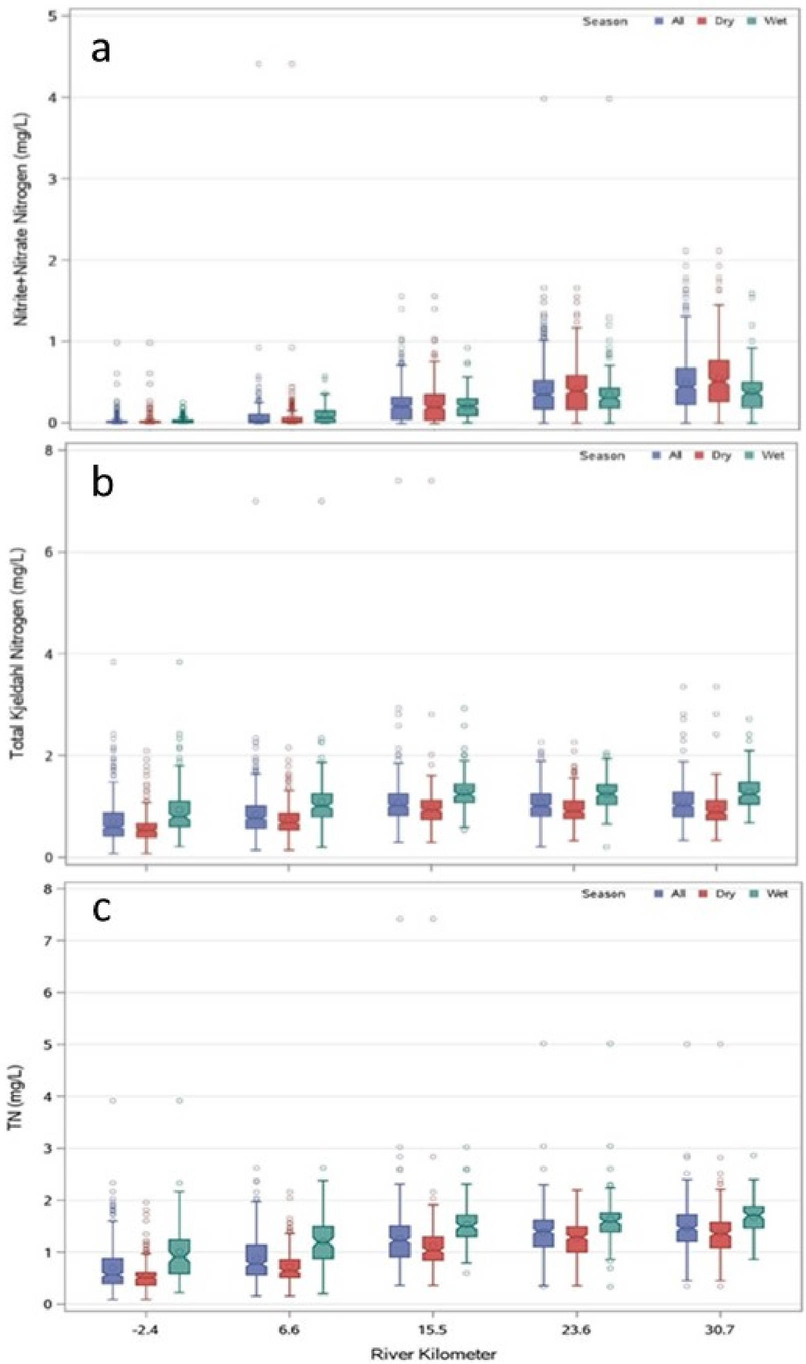

Figure 3-7. Box and whisker plots of a) Nitrate+Nitrite (NOx), b) Total Kjeldahl Nitrogen (TKN), and c) Total Nitrogen (TN) concentrations measured at selected HBMP fixed-stations in the Lower Peace River and near the river mouth (sampling station identifiers correspond to river kilometer (RKm) location; see Figure 3-2) between 1996 and 2016, including Dry and Wet seasons, respectively from January through March and July through September (reproduced from Janicki Environmental, Inc. 2017).

Trend tests for NOx concentrations exhibited a significant decreasing trend for the 0 and 6 psu isohaline locations, while a significant increasing trend was observed for the 20 psu isohaline for the period from 1984 through 2016 (Table 3-4). Trend tests for TKN did not indicate any trend at all isohaline locations. Decreasing trends in TN concentrations over the monitoring period 1984 through 2016 were identified at 0 psu and 6 psu isohaline locations but were not significant at an 0.05 alpha-level (Table 3-4).

Table 3-4. Trend tests (seasonal Mann-Kendall) for NOx, TKN and TN concentrations for the period 1984 through 2016 at 0, 6, 12 and 20 psu moving isohaline locations (source: Janicki Environmental, Inc. 2017).

	P values			
	0 psu	6 psu	12 psu	20 psu
NOx	0.00*	0.00*	0.96	0.01**
TKN	0.67	0.45	0.53	0.76
TN	0.06	0.10	0.41	0.66

* Significant decreasing trend at 0.05 level
** Significant Increasing trend at 0.05 level

3.3.1.5 Orthophosphate

Natural phosphorus concentrations in the Lower Peace/Shell System and upper Charlotte Harbor are high due to the extensive area of phosphate deposits that exist in the Peace River basin. Phosphorus concentrations in the estuary generally reflect both the spatial and temporal variation in Peace River freshwater inputs. The highest phosphorus concentrations are typically associated with seasonal low river flows when the influences of groundwater discharges are more pronounced.

For the Peace River HBMP, total phosphorus measurement was terminated in 2003 and phosphorus concentrations are currently reported as orthophosphate. However, scatterplot analyses of orthophosphate vs. total phosphorus for the period 1996 through 2003 at 5 stations indicated about 81-88% of total phosphorus is attributed to ortho-phosphorus (data not shown here but see Table 5 in the Southwest Florida Water Management District Response to the Initial Peer Review of Proposed Minimum Flows for the Lower Peace River and Lower Shell Creek included in Appendix G).

Orthophosphate concentrations at selected fixed-station locations were indicative a longitudinal gradient with values decreasing from upstream to downstream in the estuary (Figure 3-8). The patterns and responses of orthophosphate to increasing flows in the Lower Peace/Shell System and Charlotte Harbor estuarine were like those exhibited for NOx.

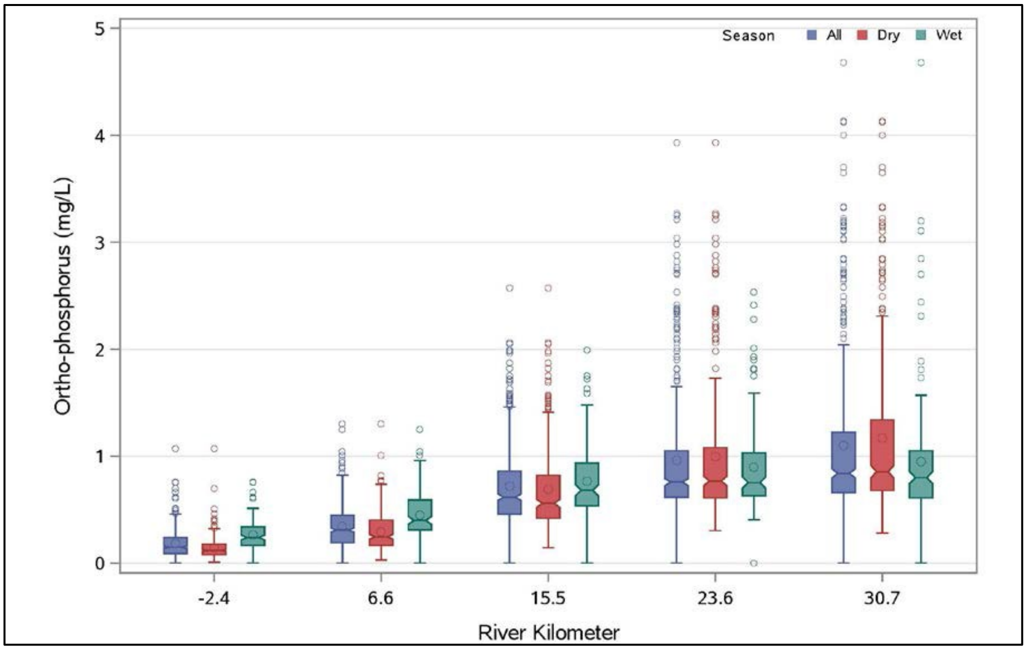

Figure 3-8. Box and whisker plots of orthophosphate measured at selected HBMP fixed-stations in the Lower Peace River and near the river mouth (sampling station identifiers correspond to river kilometer (RKm) location; see Figure 3-2) between 1976 and 2016, including Dry and Wet seasons, respectively from January through March and July through September (reproduced from Janicki Environmental, Inc. 2017).

Lower orthophosphate levels in upstream stations (RKms 23.6 and to 30.7) during wet season were likely associated with reduced influence of groundwater discharges to surface waters in summer, when surface runoff is greater.

Stricter regulations in late 1970s resulted in subsequent decreases in both point and nonpoint discharges to surface waters from phosphate-mining areas. This was associated with substantially decreased magnitude and seasonal variability of phosphorus concentrations in the Lower Peace/Shell System and Charlotte Harbor (Figure 3-9). However, from 2004 through 2008, phosphorus levels throughout the lower Peace River/upper Charlotte Harbor estuary were elevated. In the 2006 HBMP Comprehensive Summary Report, PBS&J, Inc. (2009) suggested that the historically high flows that occurred in the upper Peace River watershed following Hurricanes Charley, Francis and Jeanne in August and September 2004 were associated with increased phosphorus concentrations throughout the system. Subsequent investigations conducted by PBS&J (2009, 2010) and Atkins (2011, 2012) concluded that the direct cause for the observed increase in phosphorus levels was more likely to have been related to surface water discharges during the closure of the Ft. Meade phospho-gypsum stack system within the Whidden Creek Basin of the upper Peace River watershed. Since about 2009, phosphorus concentrations similar to those observed prior to 2004 have been observed (Figure 3-9).

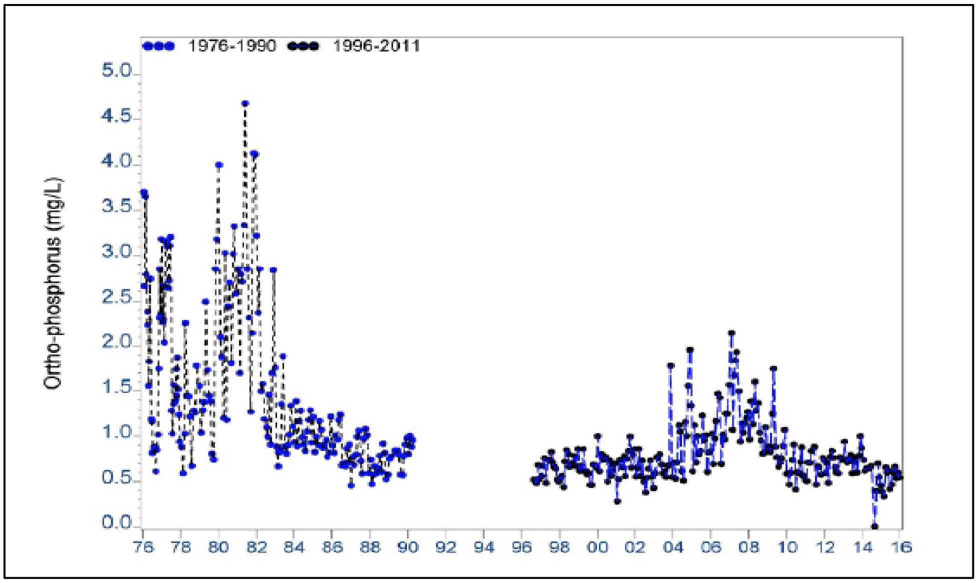

Figure 3-9. Monthly long-term surface orthophosphate at river kilometer 30.7 in the Lower Peace River (sampling station identifiers correspond to river kilometer (RKm) location; see Figure 3-2) for the period from 1976 through 2016 (reproduced from Janicki Environmental, Inc. 2017).

A trend test for the orthophosphate time series identified a significant increasing trend for the most saline water (i.e., in association with the 20 psu isohaline) but not for the other assessed isohalines (Table 3-5).

Table 3-5. Trend tests (seasonal Mann-Kendall) of total orthophosphate concentrations for the period 1984 through 2016 at 0, 6, 12 and 20 psu moving isohaline locations. (source: Janicki Environmental, Inc. 2017).

	Trend test for Ortho-phosphate at Isohaline Locations			
	0 psu	6 psu	12 psu	20 psu
P value	0.103	0.192	0.584	0.001*

* Significant at 0.05 level

3.3.1.6 Color

Color affects light penetration into the water column and can thereby influence the abundance and distribution of phytoplankton. Figure 3-10 shows longitudinal gradients in color, reported as the concentration of dissolved and suspended organic and inorganic particles, at the fixed monitoring stations RKms -2.4, 6.6, 15.5, 23.6 and 30.7. Color levels were typically higher upstream than in the lower portions of the estuary. This typical gradient was more pronounced during the wet season than the dry season (Figure 3-10).

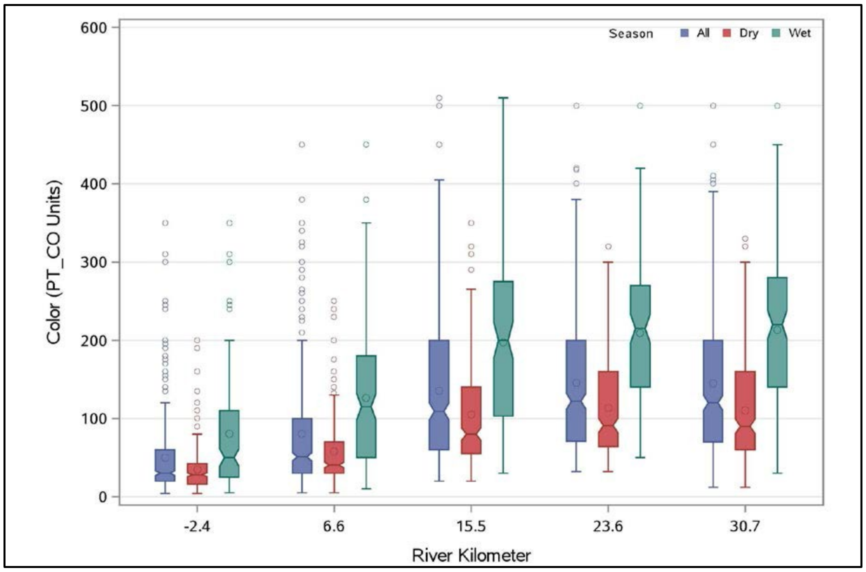

Figure 3-10. Box and whisker plots of color measured at selected HBMP fixed-stations in the Lower Peace River and near the river mouth (sampling station identifiers correspond to river kilometer (RKm) location; see Figure 3-2) between 1976 and 2016, including Dry and Wet seasons, respectively from January through March and July through September (reproduced from Janicki Environmental, Inc. 2017).

The trend testing indicated significant increases in color within salinity zones 6 psu, 12 psu and 20 psu. These trends reflected the high concentration of organic and inorganic compounds delivered to the estuary during periods of high flows (Table 3-6).

Table 3-6. Trend tests (seasonal Mann-Kendall) of color levels for the period 1984 through 2016 at 0, 6, 12 and 20 psu moving isohaline locations. (source: Janicki Environmental, Inc. 2017).

	Trend Test for Color at Isohaline Locations			
	0 psu	**6 psu**	**12 psu**	**20 psu**
P value	0.075	0.001*	0.000*	0.000*

* Significant at 0.05 level

3.3.2 Relationships between Lower Peace River Flow and Water Quality Constituents

As part of the minimum flows reevaluation/development process for the Lower Peace/Shell System, the District consulted with Akins, Inc. (2014b), to assess relationships between chlorophyll and freshwater inflows to the system. In 2019, Janicki Environmental Inc. was contracted by the District to further investigate relationships between flows and water quality in the Lower Peace/Shell System and assess whether recommended minimum flows for the system would result in adverse effects on water quality constituents other than salinity.

For the more recent analyses, Janicki Environmental Inc. (2019) used bivariate plots to examine the relationships between flows and various water quality constituents using data obtained from 5 HBMP fixed-stations. Spearman's rank correlation was also conducted for water quality constituents of interest and lag-average flows with lag-periods between 2 and 60 days (i.e., periods including the sampling day and the preceding day, the sampling day and the preceding two days, etc., through the sampling day and the preceding 59 days) to determine the temporal scale at which the constituents might be correlated to flows.

Correlation coefficients derived from the Spearman's rank correlation analyses range between 1 and -1 with negative correlations indicating that as flows increase the magnitude or concentration of the constituent of interest decreases. Correlation coefficients above an absolute value of 0.5 were considered strong correlation for this analysis while others were considered weak.

3.3.2.1. Relationships between Flow and Salinity

Although there is considerable natural variation in salinity for a given flow condition, salinity declines at any given location in the Lower Peace/Shell System with increasing freshwater inflow. Salinity field observations from a representative group of HBMP fixed-stations were plotted against freshwater inflows in the Lower Peace River and Shell Creek (Figure 3-11). As expected, variation in flow explained a greater amount of the variability in salinity at upstream stations (RKms 23.6 and 30.4) than in the downstream stations (RKms 6.6 and 15.5).

Given the strong interaction between freshwater flows, water circulation and salinity transport processes, the District (SWFWMD 2010) previously developed a coupled 3D and 2D hydrodynamic model (Sheng et al. 2006, Chen 2008) to estimate responses of salinity to reductions in freshwater inflows and support development of currently established minimum flows for the Lower Peace River. In addition, a regression model was developed to average water-column salinity at any location in Lower Shell creek as a function of flow and other factors, including site location, season, tide stage, flow in the Peace River and salinity in the northeastern portion of Charlotte Harbor (SWFWMD 2010).

As part of the current minimum flow reevaluation and development process for the Lower Peace/Shell System, the hydrodynamic model was upgraded and the model domain was substantially expanded to include the Lower Peace River, Lower Shell Creek, Lower Myakka River, all of Charlotte Harbor, Gasparilla Sound, Pine Island Sound, Matlacha Pass and the most downstream portion of Caloosahatchee River. The upgraded hydrodynamic model is discussed briefly in Chapter 5 and in greater detail in Chen (2020), which is included as Appendix C to this report.

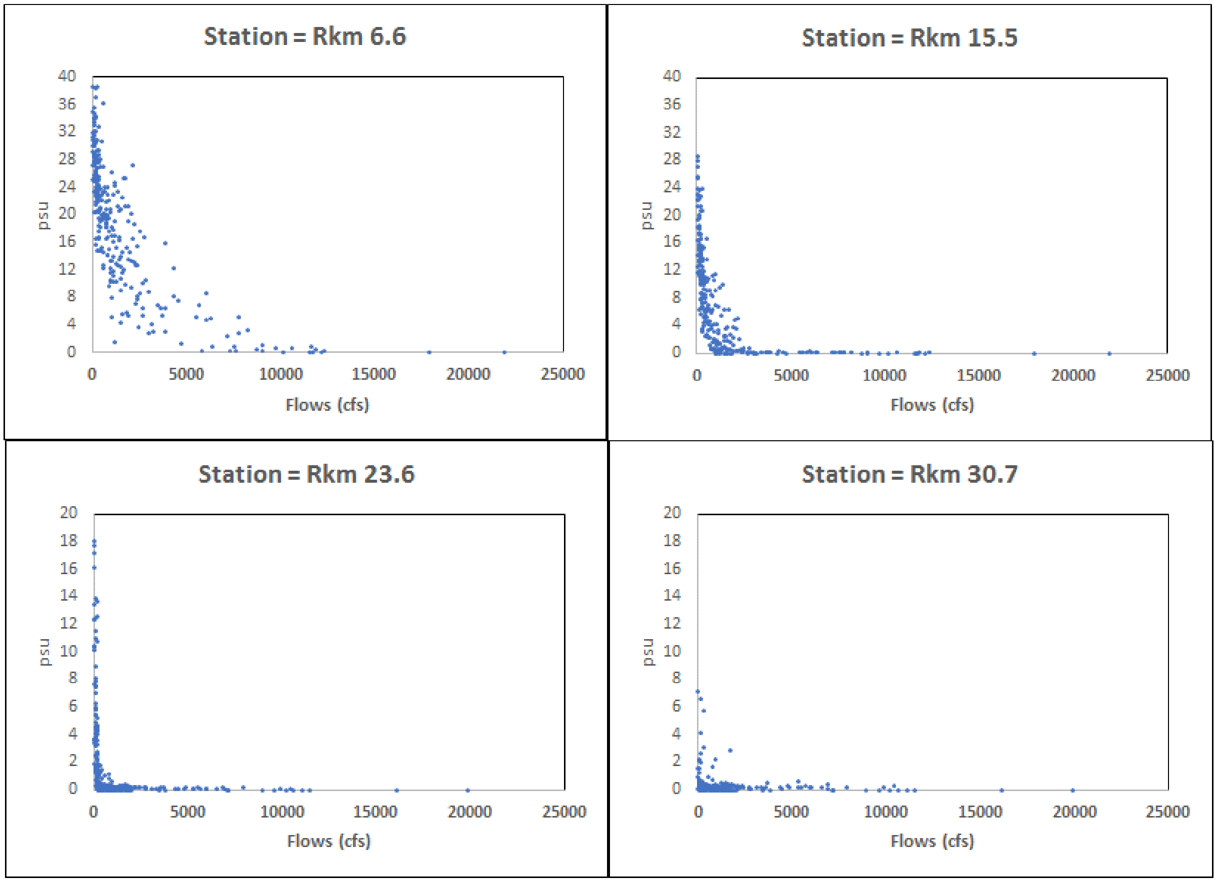

Figure 3-11. Scatter plots of the Lower Peace River and Shell Creek flows versus salinity at Rkm 6.6 and 15.5 stations, and Lower Peace River flows versus salinity at Rkm 23.6 and 30.7 stations (sampling station identifiers correspond to river kilometer (RKm) location; see Figure 3-2).

3.3.2.2 Relationships between Flow and Chlorophyll

The relationship between flows and chlorophyll was found to be site-dependent and variable across the Lower Peace River, likely in response to the combined effects of nutrient supply and residence time. As freshwater inflow initially increases from a low flow condition, chlorophyll is expected to increase in response to the increased nutrient supply. However, when flow rate increases further, the negative effects of shortening residence time become greater than the positive effects of increasing nutrient supply, and the chlorophyll concentrations decline (Atkins, 2014b).

Plots of the relationship between flow and chlorophyll at the selected HBMP fixed-stations are presented in Figure 3-12. A positive correlation at the furthest downstream station (RKm -2.4) indicates higher flows resulted in higher chlorophyll concentrations, had no effect at river kilometer 6.6, and a resulted in lower chlorophyll levels for upstream stations (RKms 15.5, 23.6 30.7). There was little difference in correlations among flow lags at the downstream station while in the uppermost stations shorter lag averages were better correlated with chlorophyll than longer lag averages.

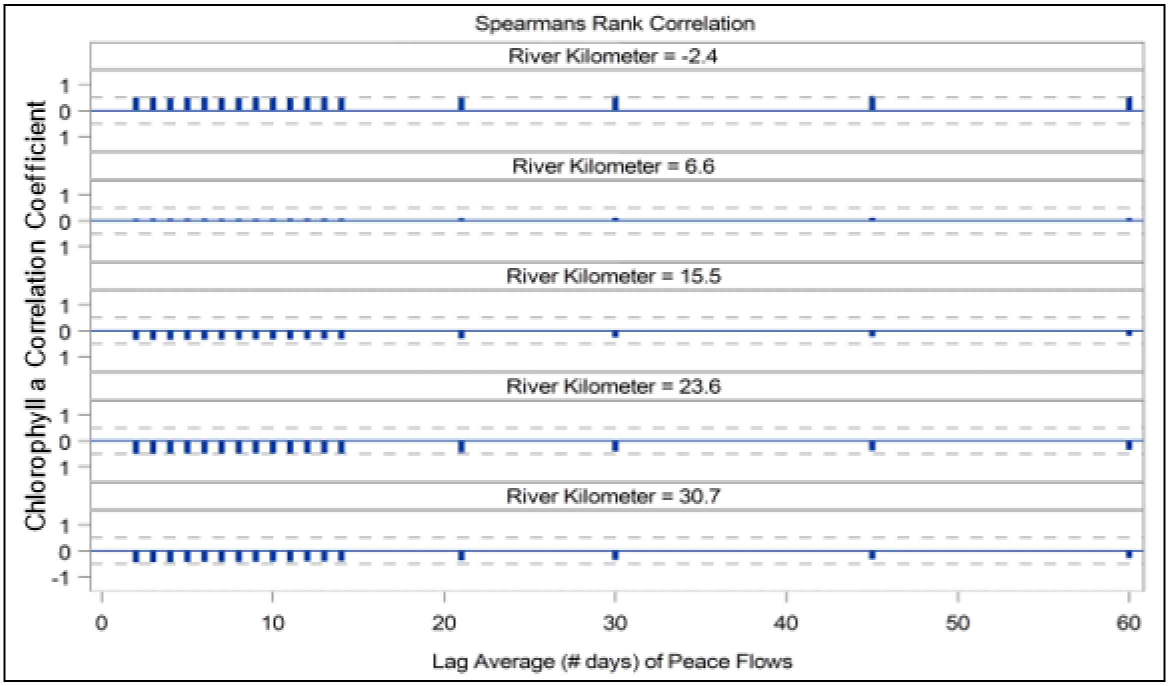

Figure 3-12. Spearman's rank correlation between lag average flows and chlorophyll a concentrations at selected HBMP fixed-stations in the Lower Peace River and near the river mouth (sampling station identifiers correspond with river kilometer (RKm) locations; see Figure 3-2). Correlation coefficients range from 1 to -1, with positive values indicating higher concentrations with higher flows and negative values indicating higher concentration with lower flows. Dashed line identifies 0.5 and -0.5 values used to identify strong correlations (reproduced from Janicki Environmental, Inc. 2019).

3.3.2.3 Relationships between Flow and Dissolved Oxygen

Percent of saturation was used to evaluate dissolved oxygen (DO) correlations with flows. The relationship is seasonally dependent with stronger correlations in the wet season than in dry the season. Plots of Spearman's rank corrections shows a negative correlation with all flow lags at all stations (Figure 3-13). Shorter lags (less than 10 days) were more correlated with flows than longer lags at all stations.

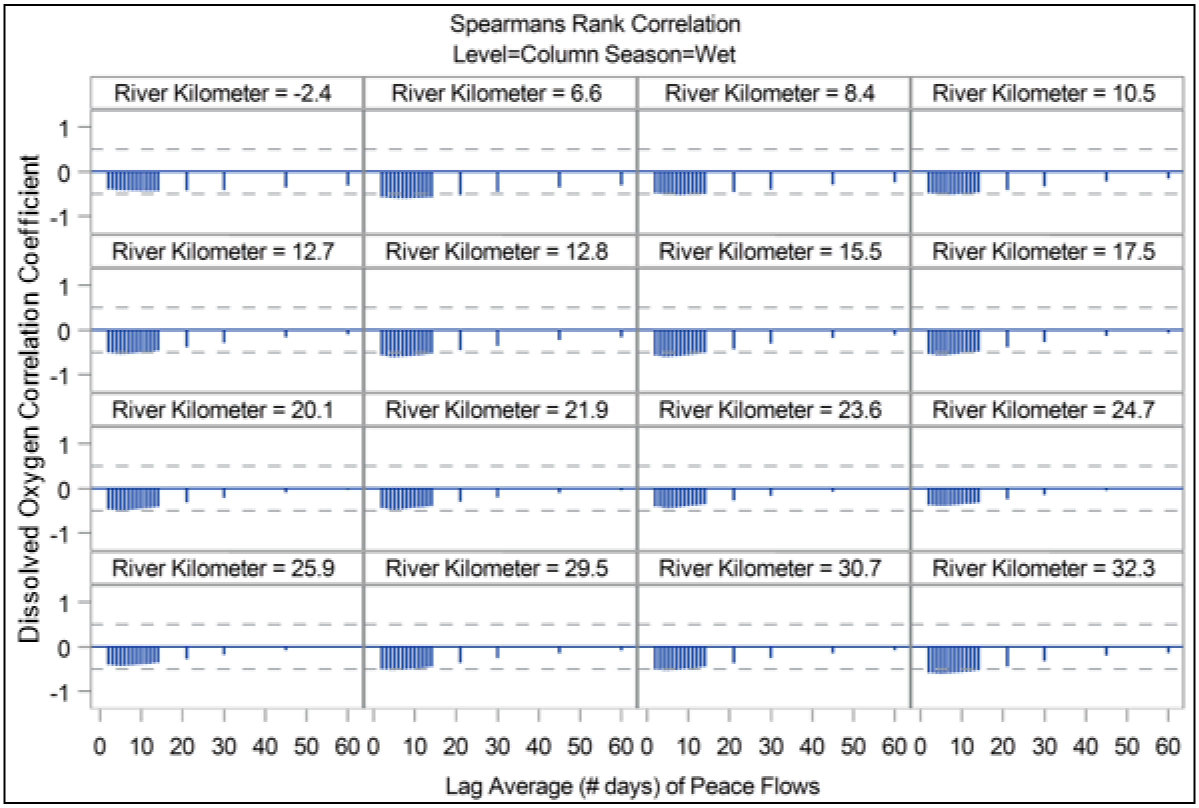

Figure 3-13. Spearman's rank correlation between lag average flows and water column average dissolved oxygen (% saturation) concentrations during the wet season season at selected HBMP fixed-stations in the Lower Peace River and near the river mouth (sampling station identifiers correspond with river kilometer (RKm) locations; see Figure 3-2). Correlation coefficients range from 1 to -1, with positive values indicating higher concentrations with higher flows and negative values indicating higher concentration with lower flows. Dashed line identifies 0.5 and -0.5 values used to identify strong correlations (reproduced from Janicki Environmental, Inc. 2019).

3.3.2.4 Relationships between Flow and Nutrients

Total nitrogen concentrations were positively correlated with lag average flows at all assessed HBMP fixed-stations (Figure 3-14), while orthophosphate concentrations were positively related to flows only at stations in the lower portion of the system (Figure 3-15), with similar correlation coefficients for all lag averages. At upstream stations orthophosphate concentration correlations with flow are weak and negative indicating that higher flows result in lower orthophosphate concentrations in the upper portion of river.

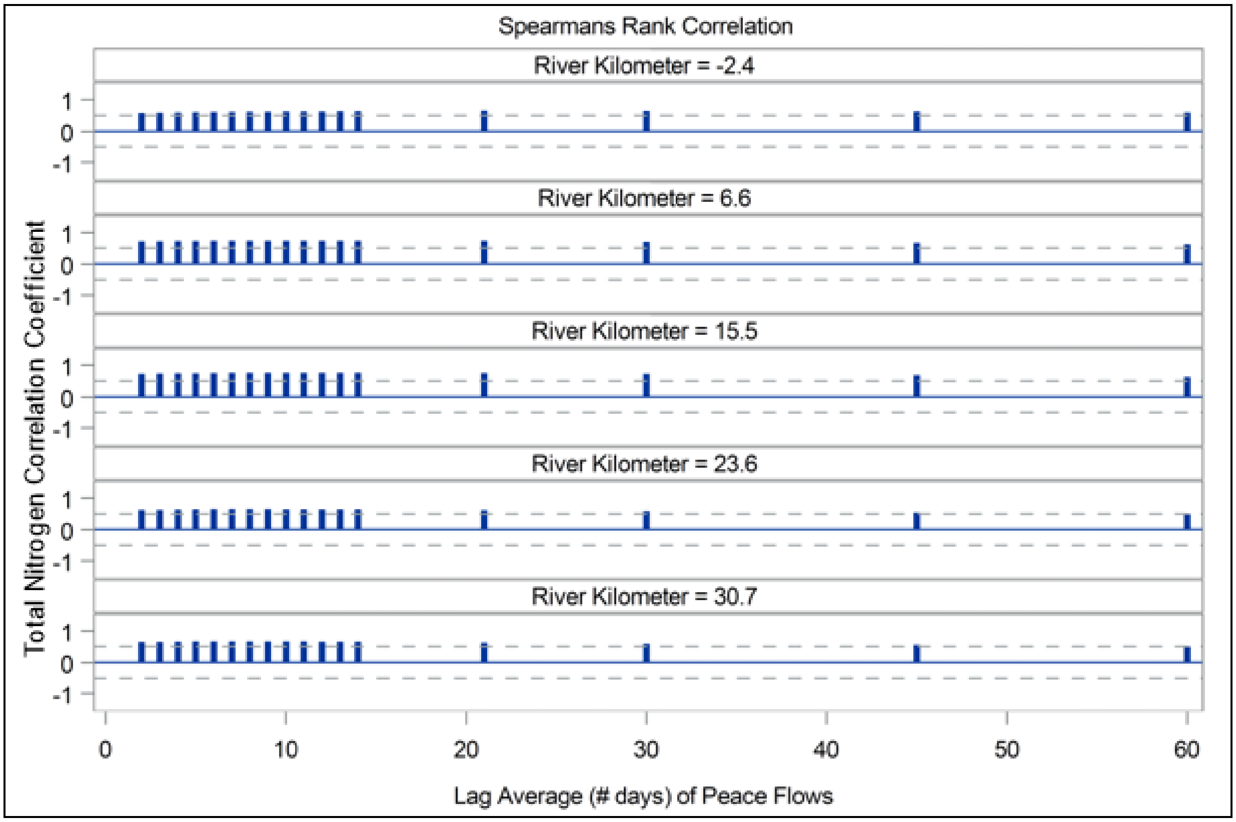

Figure 3-14. Spearman's rank correlation between lag average flows and Total nitrogen concentrations at selected HBMP fixed-stations in the Lower Peace River and near the river mouth (sampling station identifiers correspond with river kilometer (RKm) locations; see Figure 3-2). Correlation coefficients range from 1 to -1, with positive values indicating higher concentrations with higher flows and negative values indicating higher concentration with lower flows. Dashed line identifies 0.5 and -0.5 values used to identify strong correlations (reproduced from Janicki Environemental, Inc. 2019).

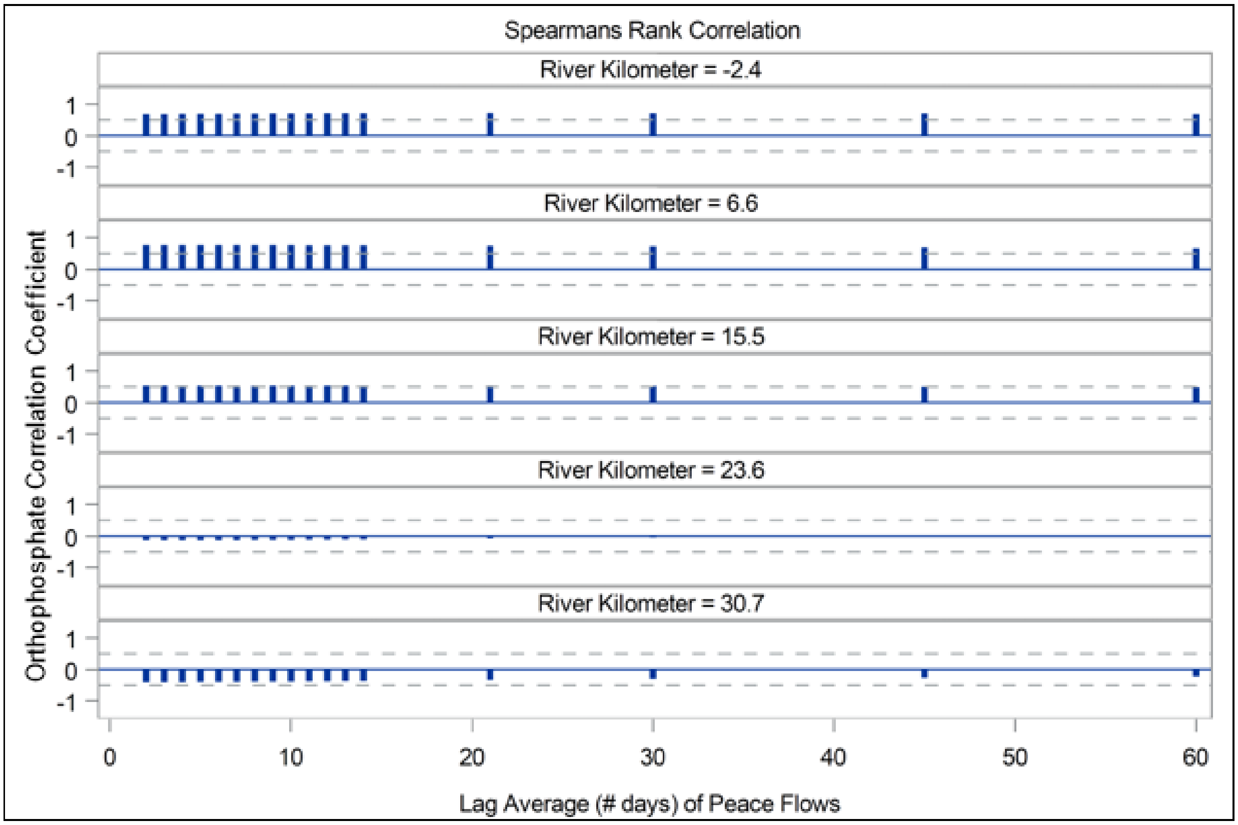

Figure 3-15. Spearman's rank correlation between lag average flows and orthophosphate concentrations at selected HBMP fixed-stations in the Lower Peace River and near the river mouth (sampling station identifiers correspond with river kilometer (RKm) locations; see Figure 3-2). Correlation coefficients range from 1 to -1, with positive values indicating higher concentrations with higher flows and negative values indicating higher concentration with lower flows. Dashed line identifies 0.5 and -0.5 values used to identify strong correlations (reproduced from Janicki Environmental, Inc. 2019).

3.3.2.5 Relationships between Flow and Color

Color was also examined as a potential covariate since flows have a strong seasonal correlation with colored dissolved organic matter in the Lower Peace/Shell System, with correlation coefficients above 0.5 for all stations (Figure 3-15). Correlation coefficients were very similar across lag averages and among stations as shown in Figure 3-16.

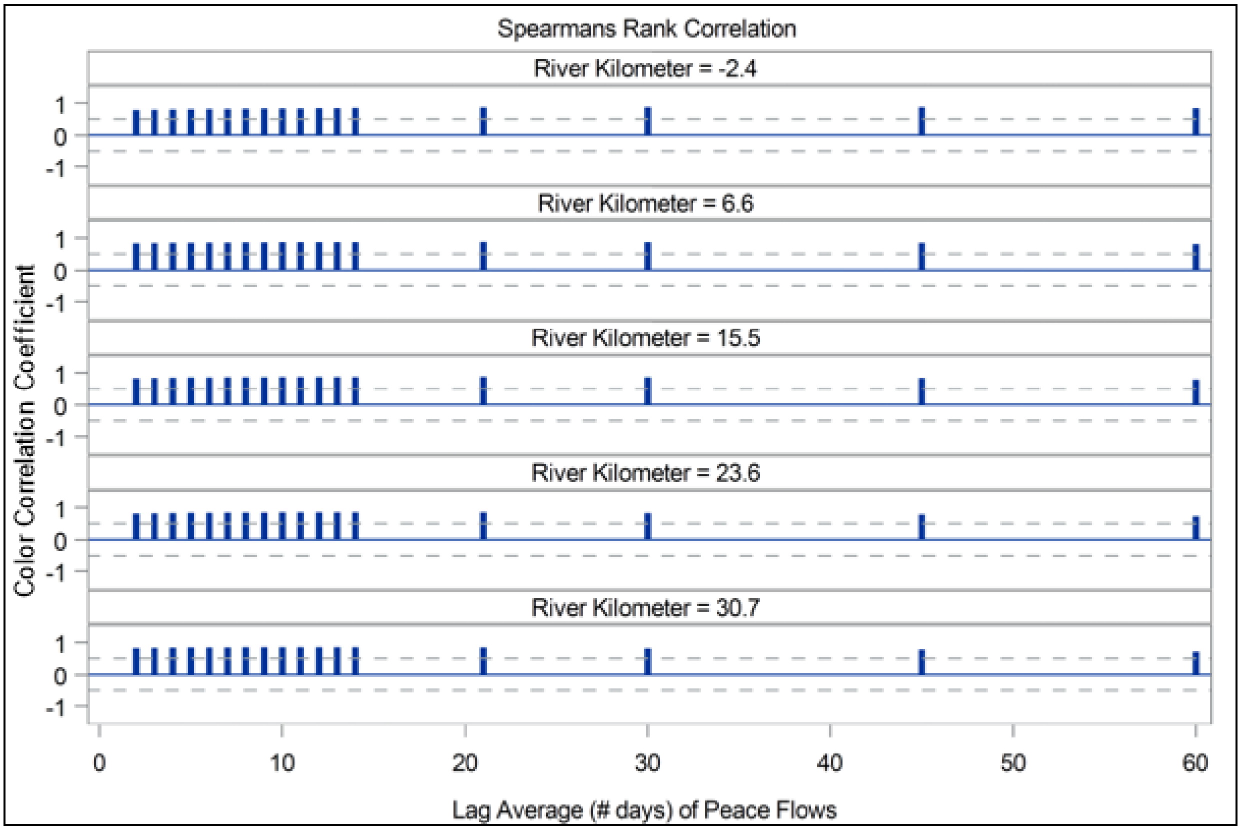

Figure 3-16. Spearman's rank correlation between lag average flows and color at selected HBMP fixed-stations in the Lower Peace River and near the river mouth (sampling station identifiers correspond with river kilometer (RKm) locations; see Figure 3-2). Correlation coefficients range from 1 to -1, with positive values indicating higher concentrations with higher flows and negative values indicating higher concentration with lower flows. Dashed line identifies 0.5 and -0.5 values used to identify strong correlations (reproduced from Janicki Environmental, Inc. 2019).

In conclusion, statistically significant relationships were found between salinity and average lag freshwater flows at all assessed stations. Chlorophyll correlations with flow were site dependent within the Lower Peace/Shell System. A positive chlorophyll versus flow relationship was identified for the downstream stations while an inverse relationship was identified at upstream stations. The relationship between DO and flow was found to be seasonally dependent with correlations much stronger in the wet season than in the dry season. Nutrient loadings (nitrogen and phosphorus) and color were directly, i.e., positively, related to flow. Additional information concerning water quality constituents and freshwater flow assessments is provided in Janicki Environmental Inc. (2019), appended as Appendix F.

3.3.3 Water Quality Characteristics in Lower Shell Creek

The City of Punta Gorda has been implementing an HBMP since 1991 to evaluate potential effects of withdrawals from the Shell Creek Reservoir on environmental conditions in Lower Shell Creek. The Shell Creek HBMP includes monthly sampling of in-situ profiling of water column salinity at

19 fixed sampling stations and monthly sampling of surface water chemistry at 10 stations (Figure 3-17).

Atkins, Inc. (2017) selected water chemistry stations 4, 5, 6, 7 and 9 and salinity stations 11, 16 and 17 for spatial variability analyses of salinity, dissolved oxygen (DO) and chlorophyll in the Lower Shell Creek. Temporal variability (monthly and annual) was analyzed at station 11, just downstream from Hendrickson Dam.

Long-term patterns of change were also summarized at stations at Hendrickson Dam (station 3) and upstream on Upper Shell Creek (station 2) and Prairie Creek (station 1). At these three stations, seasonal Kendall Tau tests were also conducted for water quality trend analyses. Data from the period from 1991 through 2014 was used for the spatial and temporal variations in water quality parameters reported by Atkins (2017).

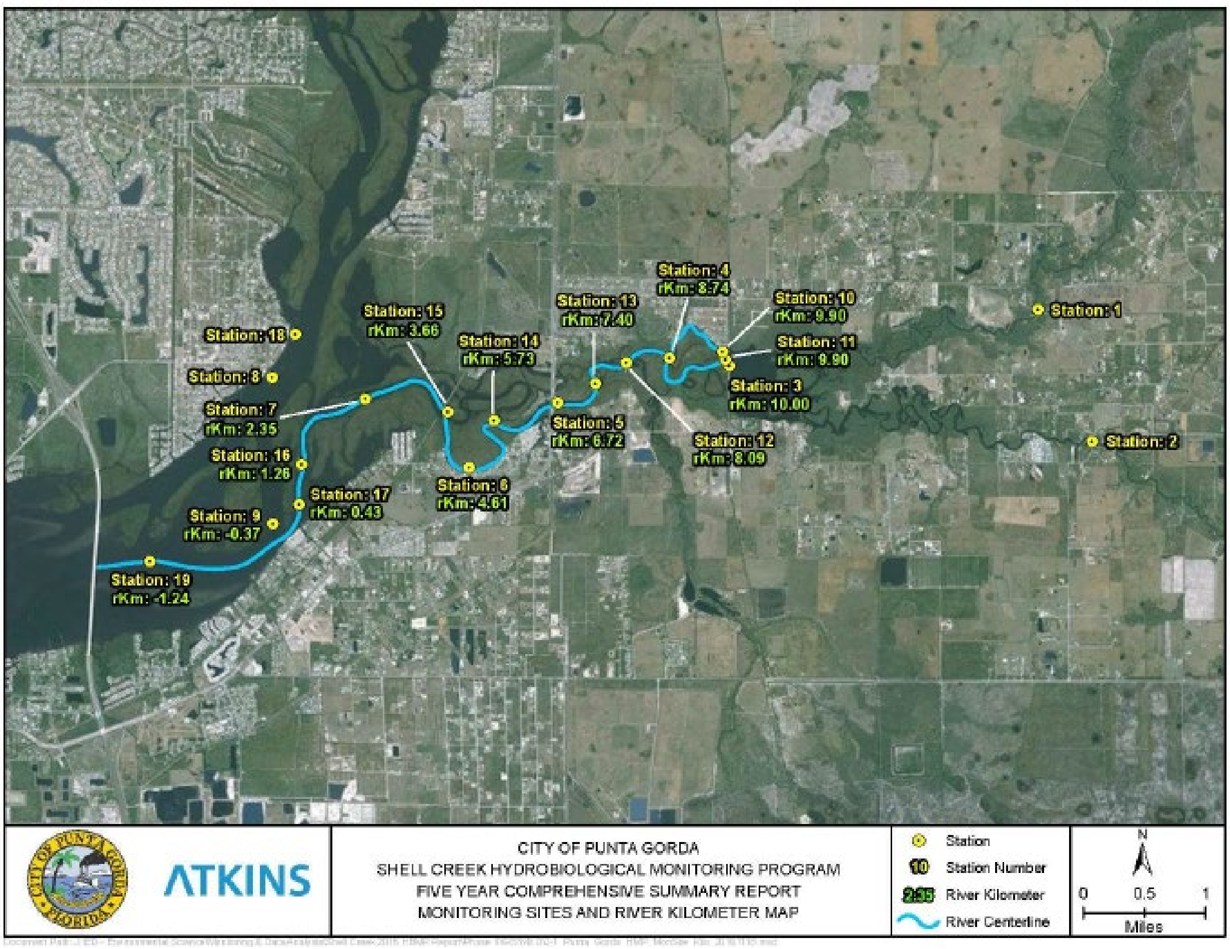

Figure 3-17. City of Punta Gorda Shell Creek HBMP salinity and water chemistry sampling locations (reproduced from Atkins (2017). Note that sampling station identifiers do not correspond with river kilometer (rKM = RKm) locations.

3.3.3.1 Salinity

Monthly average surface, midwater and bottom salinity from 1991 through 2014 at station 11 just below Hendrickson Dam shows that salinity was lowest during the wet season, from July through September and highest during the dry season from January to June (Figure 3-18), reflecting the seasonal changes in rainfall and flow.

Vertical salinity stratification between surface and midwater was not significant, especially in the drier months from April through June. Vertical stratification was, however, apparent throughout the year, with surface water typically fresher than bottom water, as expected.

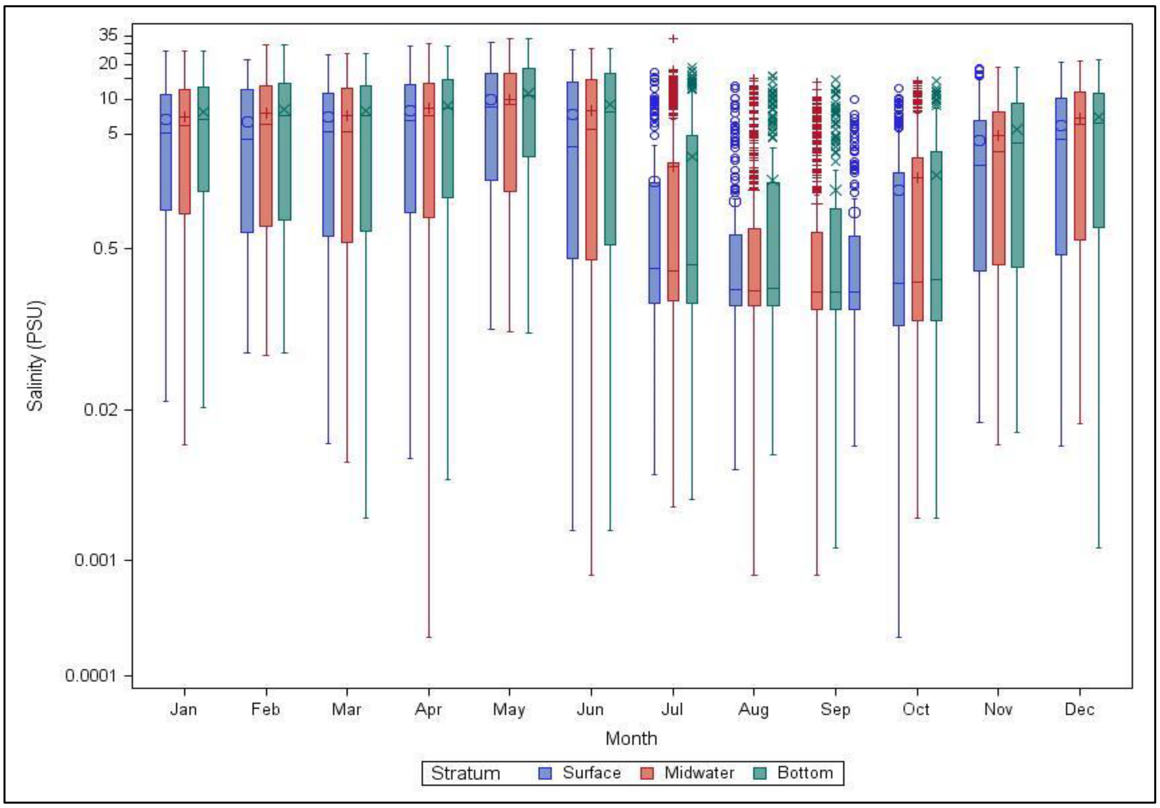

Figure 3-18. Box and whisker plots of monthly average surface, midwater, and bottom salinity at station 11 (just downstream of Hendrickson Dam at river kilometer [RKm] 9.90; see Figure 3-17) between 1991 and 2014 (reproduced from Atkins, Inc. 2017).

Figure 3-19 shows annual average salinity of surface, midwater and bottom waters at stations 4, 5, 6, 7, 9 and in situ stations 11, 16 and 17. A distinct longitudinal spatial salinity gradient along these fixed stations is evident, with highest salinities near the river mouth (e.g., at Station 9) and lower salinities in the upper portion of Lower Shell Creek. At station 11, just downstream from the Hendrickson Dam, salinities were typically < 0.1 psu. The high salinity gradient along the lower portion of the Lower Shell Creek (e.g., at stations 9, 17, 16 and 7) is attributed to high tides in the Lower Peace River that pushes salinity into the creek.

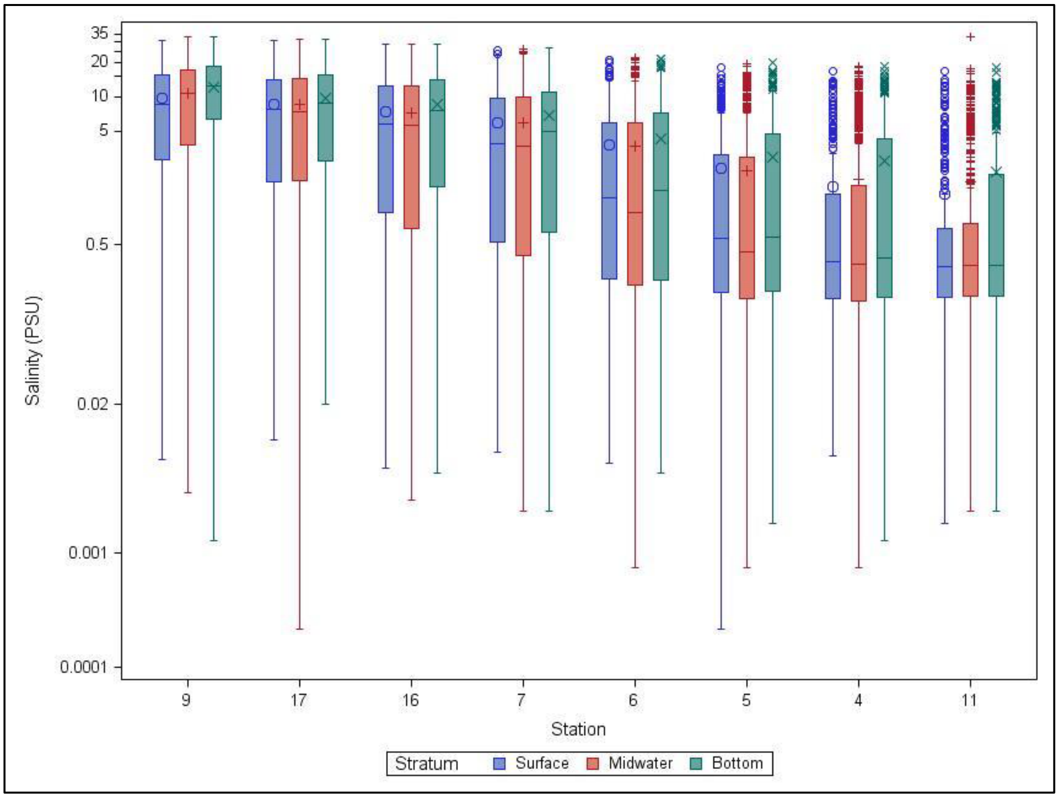

Figure 3-19. Box and whisker plots of surface, midwater, and bottom salinity at selected fixed-stations (sampling station are arrayed from downstream to upstream along the x-axis; see Figure 3-17) between 1991 and 2014 (reproduced from Atkins, Inc. 2017). Stations are arrayed from downstream to upstream along the x-axis.

3.3.3.2 Dissolved Oxygen

Dissolved oxygen concentrations in Lower Shell Creek exhibited vertical stratification, with typically higher values in surface and midwaters than in the bottom waters (Figure 3-20). As is in the Lower Peace River, seasonal patterns in DO concentrations were evident in Lower Shell Creek, with lower DO levels occurring during the wet season in association with higher water temperatures and increased phytoplankton production (Figure 3-20). Surface concentrations of DO at monitoring stations were similar throughout the system (Figure 3-21).

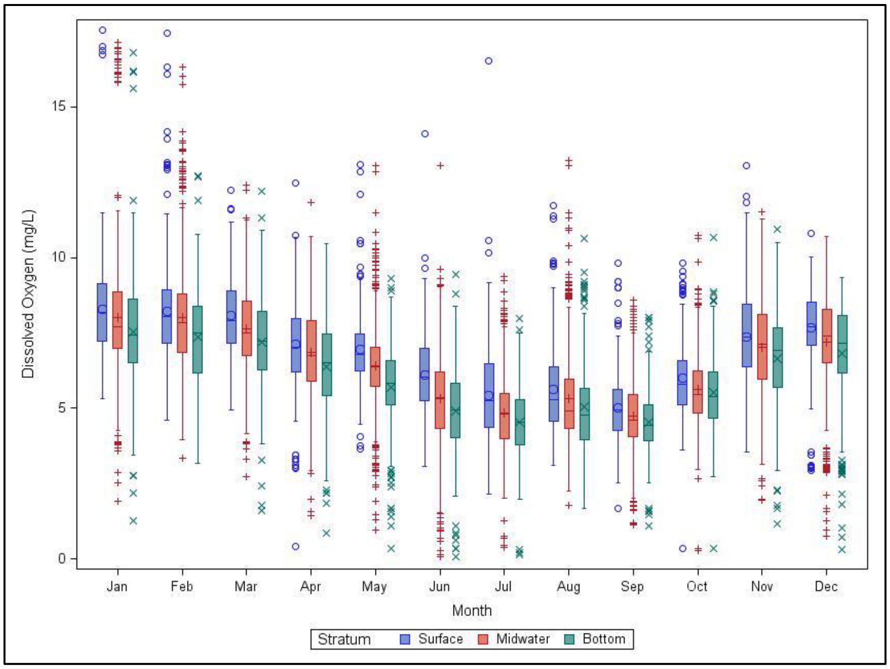

Figure 3-20. Box and whisker plots of monthly surface, midwater, and bottom dissolved oxygen concentrations at station 11 (just downstream of Hendrickson Dam at river kilometer [RKm] 9.90; see Figure 3-17) between 1991 and 2014 (reproduced from Atkins, Inc. 2017).

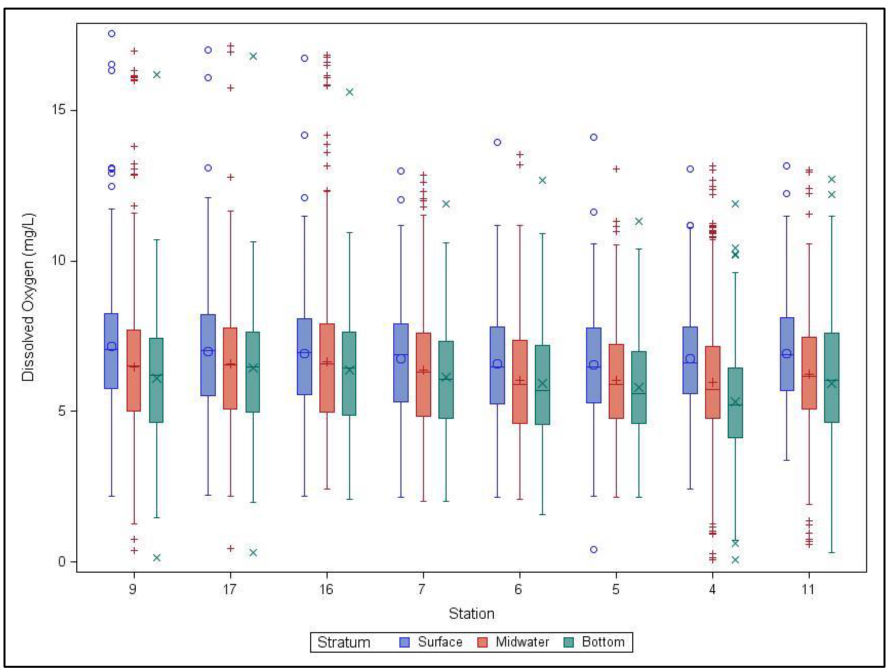

Figure 3-21. Box and whisker plots of surface, midwater, and bottom dissolved oxygen concentrations at selected fixed-stations (sampling station are arrayed from downstream to upstream along the x-axis; see Figure 3-17) between 1991 and 2014 (reproduced from Atkins, Inc. 2017).

3.3.3.3 Chlorophyll

Chlorophyll concentrations in Lower Shell Creek were lowest during summer and were relatively higher during November and December (Figure 3-22) when freshwater flows and nutrient inputs declined. Higher chlorophyll levels also occurred during the spring dry season (April and May) when residence time was relatively long. However, monthly mean mid-water chlorophyll concentrations were mostly under 20 ug/L (Figure 3-22). Variation in chlorophyll concentrations among stations was minimal as expected (Figure 3-23).

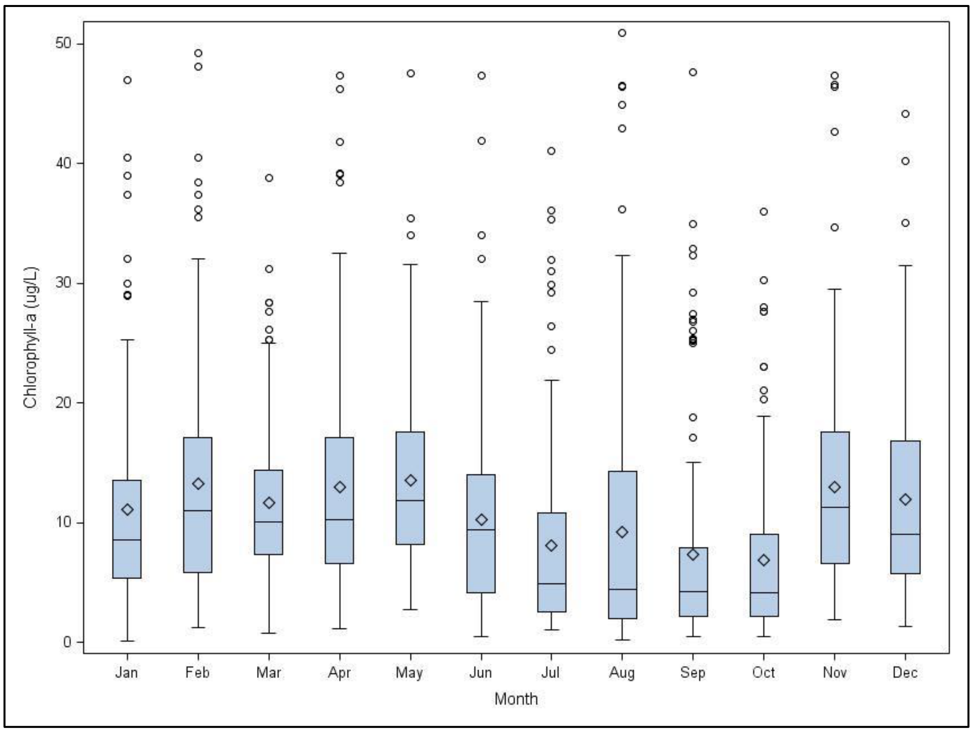

Figure 3-22. Box and whisker plots of monthly mid-water chlorophyll concentrations at selected fixed-stations (sampling stations 4, 5, 6, 7 and 9; see Figure 3-17) between 1991 and 2014 (reproduced from Atkins, Inc. 2017).

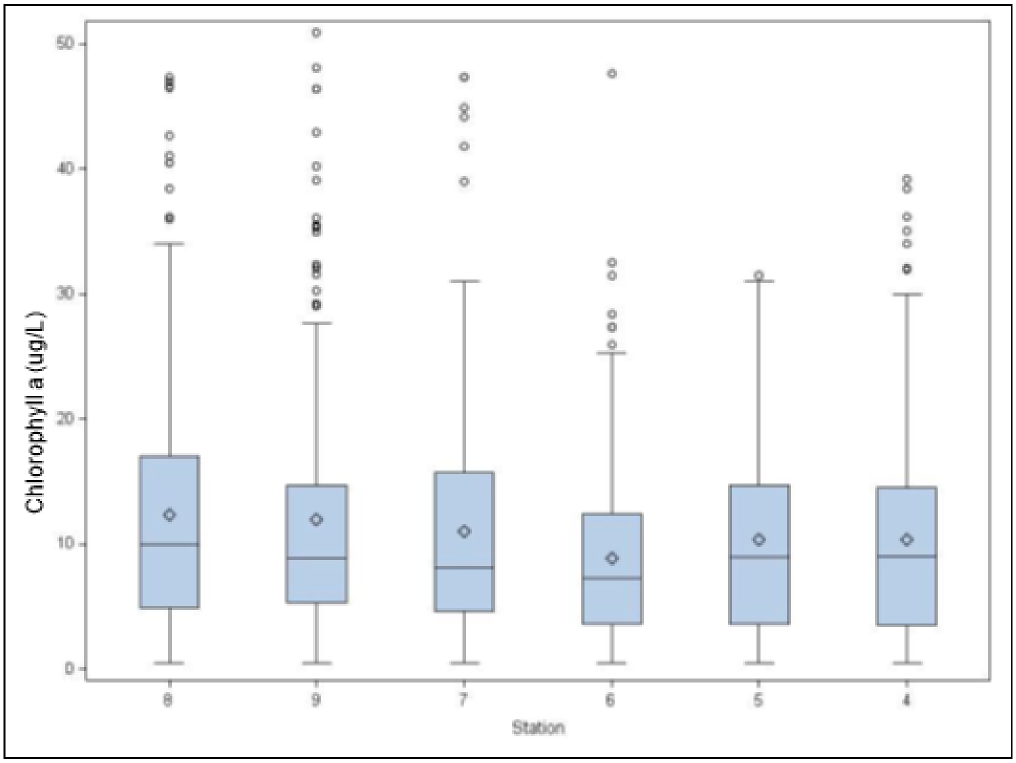

Figure 3-23 Box and whisker plots of chlorophyll concentrations at selected fixed-stations (sampling station are arrayed from downstream to upstream along the x-axis with the exception of station 8, which is located between stations 9 and 7; see Figure 3-17) in Lower Shell Creek (reproduced from Atkins, Inc. 2017).

3.3.3.4 Total Kjeldahl Nitrogen and Orthophosphate

Box and whisker plots depicting temporal variability in total Kjeldahl nitrogen (TKN) and orthophosphate at station 4 in Lower Shell Creek are presented in Figure 3-24. TKN concentrations were typically highest during the summer wet season reflecting the increased freshwater inflow inputs of organic nitrogen from Shell Creek watershed (Figure 3-24). In contrast, highest phosphorus concentrations were typically associated with seasonal low river flows when the influence of groundwater discharges are high (Figure 3-24).

TKN concentrations progressively increased moving downstream along the sampling locations (Figure 3-25), in association with reduced watercolor and nitrogen uptake by phytoplankton. Unlike TKN, orthophosphate concentrations did not exhibit a longitudinal gradient (Figure 3-25).

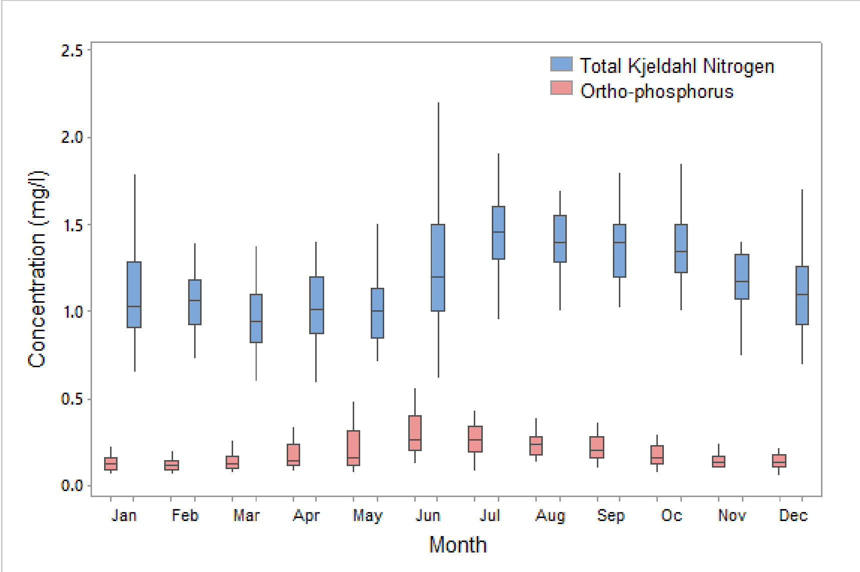

Figure 3-24. Monthly box and whisker plots of TKN and orthophosphate (labeled as Ortho-phosphorus) at station 4 (at river kilometer [RKm] 8.74; see Figure 3-17) in Lower Shell Creek between 1991 and 2018.

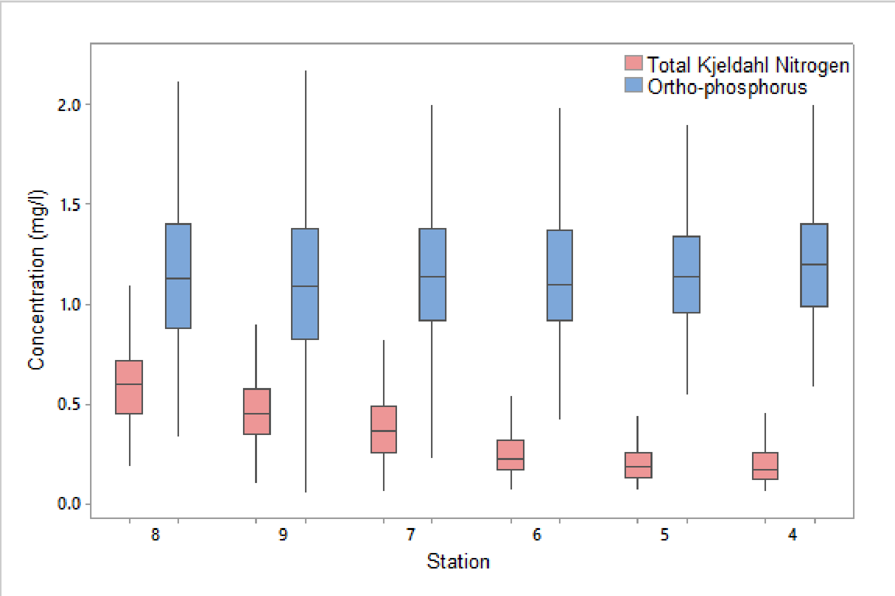

Figure 3-25. Box and whisker plots of TKN and orthophosphate (labeled as Ortho-phosphorus) concentrations at selected fixed-station sampling station are arrayed from downstream to upstream along the x-axis with the exception of station 8, which is located between stations 9 and 7; see Figure 3-17) in Lower Shell Creek between 1991 and 2018.

3.3.3.5. Color

Color was typically highest during the summer wet season reflecting the increased freshwater inflow inputs of dissolved and suspended organic and inorganic particles from Shell Creek watershed (Figure 3-26). Figure 3-27 shows longitudinal gradients in water color at the monitoring stations 4, 5, 6, 7, 9 and 8. Color levels were typically similar along the length of Lower Shell Creek, especially at stations 4,5 and 6. The slight increase in color from stations 7,9 and 8 was likely associated with organic and inorganic particulate inputs from the Peace River.

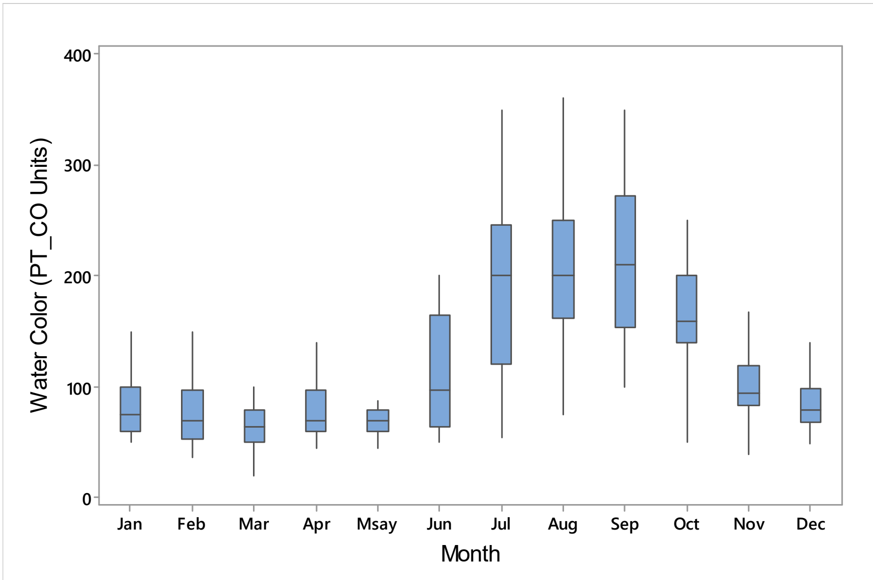

Figure 3-26. Box and whisker plots of monthly color at station 4 (river kilometer [RKm] 8.74; see Figure 3-17) between 1991 and 2018.

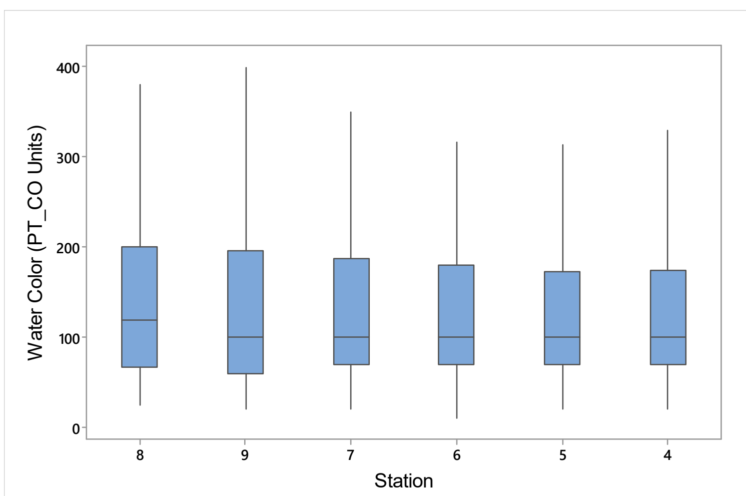

Figure 3-27. Box and whisker plots of color at selected fixed-stations (sampling station are arrayed from downstream to upstream along the x-axis with the exception of station 8, which is located between stations 9 and 7; see Figure 3-17) in the Lower Shell Creek between 1991 and 2018.

3.3.4 Relationships between Shell Creek Flow and Water Quality Constituents

Table 3-7 shows relationships between flow and salinity, DO and chlorophyll at stations 11, 4, 5, 6, 7, 16, 17, 9 and 8 in Lower Shell Creek. Concentrations of these three water quality parameters decreased with increasing creek flows (Table 3-7). Coefficient of determination values (R^2) for the relationships were weak, however, indicating that other factors (e.g., tide, residence time, nutrients) likely affect these water quality parameters in Lower Shell Creek.

Table 3-7. Relationships between flow at the USGS Shell Creek near Punta Gorda gage and salinity dissolved oxygen and chlorophyll at selected stations (and river kilometer [RKm] locations; see Figure 3-17) in the Lower Shell creek between and 1991-2014 (reproduced from Atkins, Inc. 2017).

Station	RKm	Salinity		Dissolved Oxygen		Chlorophyll	
		R^2	Slope	R^2	Slope	R^2	Slope
4	8.74	0.07	Decreasing	0.06	Decreasing	0.17	Decreasing
5	6.72	0.10	Decreasing	0.09	Decreasing	0.17	Decreasing
6	4.61	0.13	Decreasing	0.10	Decreasing	0.14	Decreasing
7	2.35	0.17	Decreasing	0.10	Decreasing	0.13	Decreasing
9	-0.37	0.24	Decreasing	0.10	Decreasing	0.07	Decreasing
8	NA	0.19	Decreasing	0.12	Decreasing	0.08	Decreasing

NA = Station is located in the main stem of the Peace River.

CHAPTER 4 – ECOLOGICAL RESOURCES

Estuaries are dynamic and complex ecosystems that provide connectivity between freshwater and marine environments and are strongly influenced by freshwater inflows and oceanic tides. Changes to the freshwater flow regime can affect factors such as salinity, dissolved oxygen, nutrient loading, chlorophyll, and water clarity, which in turn affect the production and distribution of fish species, macroinvertebrates, vegetation, and other ecological resources.

Numerous investigators have characterized the flora and fauna of the Lower Peace/Shell System. Many of these studies are discussed in the District's 2010 minimum flows report for the system (SWFWMD 2010). In this chapter, we briefly highlight some of this information and additional studies completed after 2010 as part of the District's adaptive management approach for water resources and in support of the current minimum flows development/reevaluation process. The District is likely to continue supporting data collection on seagrass and other vegetative communities, benthic macroinvertebrates, and fish, as needed, to support future reevaluation of minimum flows established for the system.

4.1 Vegetation

4.1.1. Shoreline Vegetation

Shoreline vegetative communities along southwest Florida tidal rivers, such as the Lower Peace/Shell System, typically transition from forested freshwater wetlands in upstream areas to tidal freshwater forest/marsh communities, and to brackish and salt marsh communities in middle to lower reaches. Descriptive information on the vegetation communities along the shores of the Lower Peace/Shell System are available from FMRI (1998) and PBS&J (1999). The recent distribution of major vegetative communities within the system is shown in Figure 4-1.

4.1.2. Bottomland Hardwood and Mixed Wetland Forests

Bottomland hardwoods are a wetland forest type that includes a diverse array of hydric hardwood species. Generally, these wetlands occur on rich alluvial silt- and clay-rich sediments deposited by river overflow. Common species in bottomland hardwood forests along the upper part of the Lower Peace River include bald cypress (*Taxodium distichum*), water hickory (*Carya aquatica*), ash (*Fraxinus caroliniana*) and red maple *(Acer rubrum)*. These forests are subject to periodic inundation from the river during periods of high flows, and more frequently, to tidal water-level fluctuations that occur in the lower part of the system (SWFWMD 2010). Although classified as bottomland hardwoods by FMRI (1998), these forests may more properly be classified as tidal freshwater forested wetlands, using the terminology applied by Conner et al. (2007). Excessive saltwater intrusion into the tidal freshwater forested wetlands of the Lower Peace River could affect their persistence and distribution.

The FMRI (1998) also identified mixed wetland forests on the Lower Peace River floodplain downstream of the PRMWRSA Water Treatment Facility intake. These forests are found at higher relative elevations than the forested systems classified as bottomland hardwoods and include habitats that can be considered uplands (FMRI 1998). Common tree and shrub species within these mixed wetland forests included sabal palm (*Sabal palmetto*), wax myrtle (*Myrica cerifera*), oaks (*Quercus* spp.) and saltbush (*Baccharis halmifolia*).

4.1.3. Tidal Marshes and Saltmarshes

Tidal marshes provide important foraging, refuge, and reproductive habitat for a wide variety of species (Odum et al. 1988; McIvor et al. 1989; Shellenbarger 2007). Tidal fresh-water marshes are generally associated with salinities of < 0.5 psu, although infrequent saltwater incursions may occur. Plant diversity is high in tidal marshes, as they typically include species tolerant of freshwater conditions and those associated with oligohaline (0.5 to 5 psu) conditions.

Tidal fresh-water marshes in the Lower Peace/Shell System include sawgrass (*Cladium jamaicense*), bulrush (*Scirpus californicus*), wild rice (*Zizania aquatica*), cattail (*Typha* spp.), arrowhead (*Sagittaria latifolia),* water parsnip (*Sium suave*), pickerelweed (*Pontederia cordata*), spatterdock (*Nuphar luteum*), and other fresh-water emergent marsh plants (Clewell et al. 1999; Clewell et al. 2002). Some of these species, including cattail and sawgrass, as well as other species such as bulrush and leather fern (*Acrostichum danaefolium*) are considered representative of oligohaline marshes. These marshes provide extended foraging ground, temporary refuge from predation, and essential nursery habitat for many animal species. The fisheries habitat value of tidal freshwater marshes is likely equivalent to those of downstream, higher salinity marshes (Odum et al. 1984). Beck et al. (2000) identified "tidal fresh marshes" as a high priority habitat target for conservation in the northern Gulf of Mexico.

Saltmarshes dominated by black needlerush (*Juncus roemerianus*) occur downstream of fresh and oligohaline marshes in the Lower Peace/Shell System. Saltmarshes are characterized by somewhat higher salinities, frequently in the mesohaline (5 to 18 psu) salinity range (Stout 1984, Clewell et al. 2002). Plant species that intergrade along the boundary between oligohaline marshes and saltmarshes in the Lower Peace River include sawgrass, black needlerush, bulrushes, cordgrasses (*Spartina* spp.), and lance-leaved arrowhead (*Sagittaria lancifolia*) (Clewell et al. 2002; PBS&J 2004).

4.1.4. Mangroves

Mangroves are tropical trees that occur in brackish and saltwater environments, typically near the mouths of tidal rivers. While mangroves can grow in freshwater, mangrove communities only become established in saltwater systems, because of the absence of competition from freshwater species (Odum et al. 1984). Red and white mangroves *(Rhizophora mangle* and *Laguncularia racemosa)* are most common downstream of the confluence of Lower Shell Creek and the Lower Peace River (see Figure 4-1).

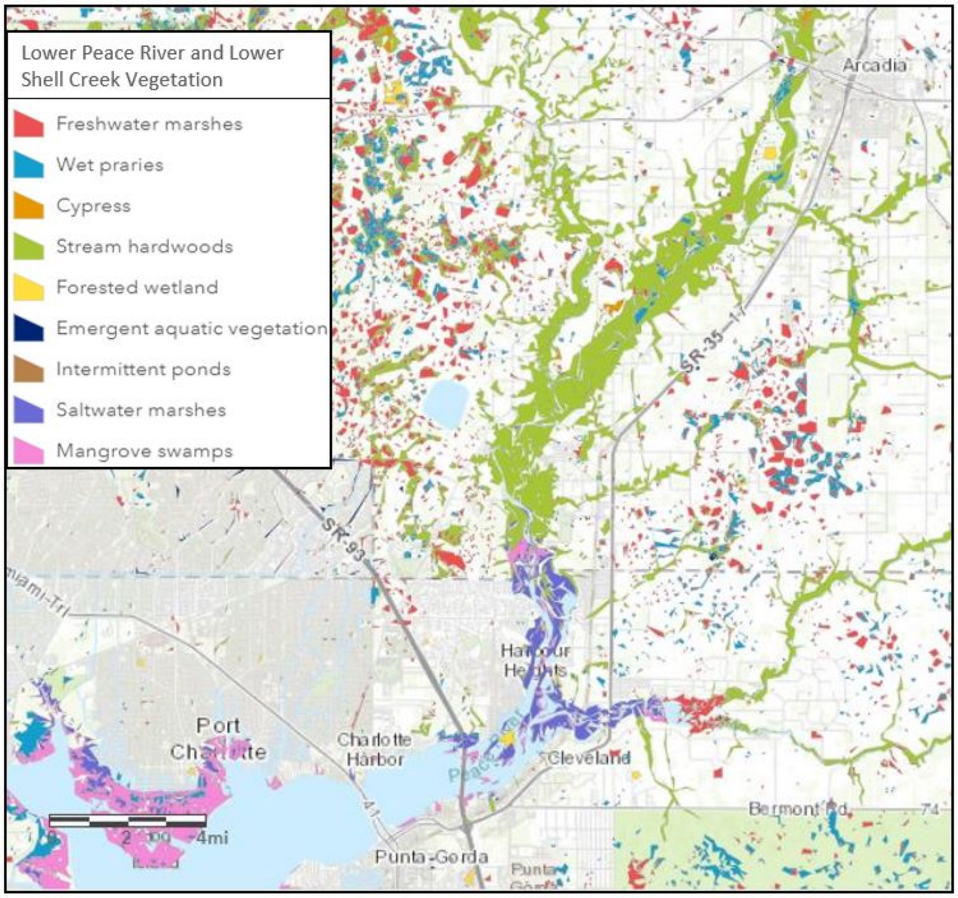

Figure 4-1. Lower Peace/Shell System vegetation (source: Land Use Land Cover 2017 layer maintained by the SWFWMD Mapping and GIS Section).

4.1.5. Seagrasses

Seagrasses are important coastal resources, based on their habitat value, and roles in sediment stabilization, nutrient dynamics, and carbon cycling. Seagrass distribution in the Charlotte Harbor area, including the Lower Peace River and Lower Shell Creek, has been summarized in numerous studies (e.g., McPherson et al. 1996, Corbett 2006, Greenwalt-Boswell et al. 2006, Tomasko and Hall 1999, Brown et al. 2013, Tomasko et al. 2005, 2018). Many of these investigations are based on the District's long-term, biennial seagrass mapping efforts (e.g., SWFMWD 2018, Quantum Spatial, Inc. 2019).

Seagrass species in the Charlotte Harbor area include shoal grass (*Halodule wrightii)*, turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), *star grass* (*Halophila eglemanni*), paddle grass (*Halophila decipiens*), and widgeon grass (*Ruppia maritima*) (Corbett 2006). Shoal grass, turtle grass and manatee grass are the most common species, although shoal grass is not found in the Peace and Myakka rivers (Brown et al. 2013). In general seagrasses are only patchily distributed in the most downstream portion of the Lower Peace River and are not found in Lower Shell Creek, as indicated by mapping completed in 2018 (Figure 4-2).

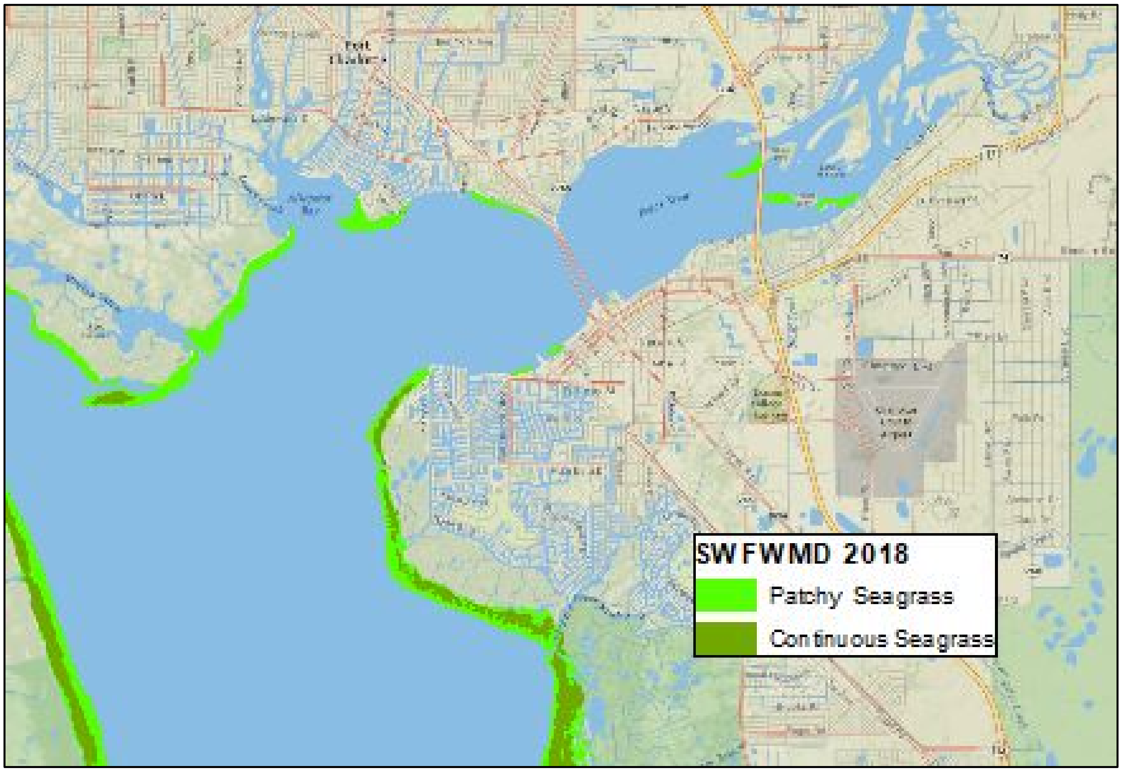

Figure 4-2. Seagrass distribution and density in the Lower Peace River, Lower Shell Creek, and upper portion of Charlotte Harbor (source: 2018 Sea Grasses layer maintained by the SWFWMD Mapping and GIS Section). "Continuous Seagrass" indicates coverage from ~75% to 100% and "Patchy Seagrass" is associated with coverage from ~ 25% to 75%.

Seagrass coverage in the greater Charlotte Harbor area has remained relatively consistent since the late 1980s, although the highest coverage estimates have been reported for the last three biennial surveys, which were conducted in 2014, 2016 and 2018. Figure 4-3 illustrates this pattern of recent, increased coverage for the Tidal Peace River segment of Charlotte Harbor.

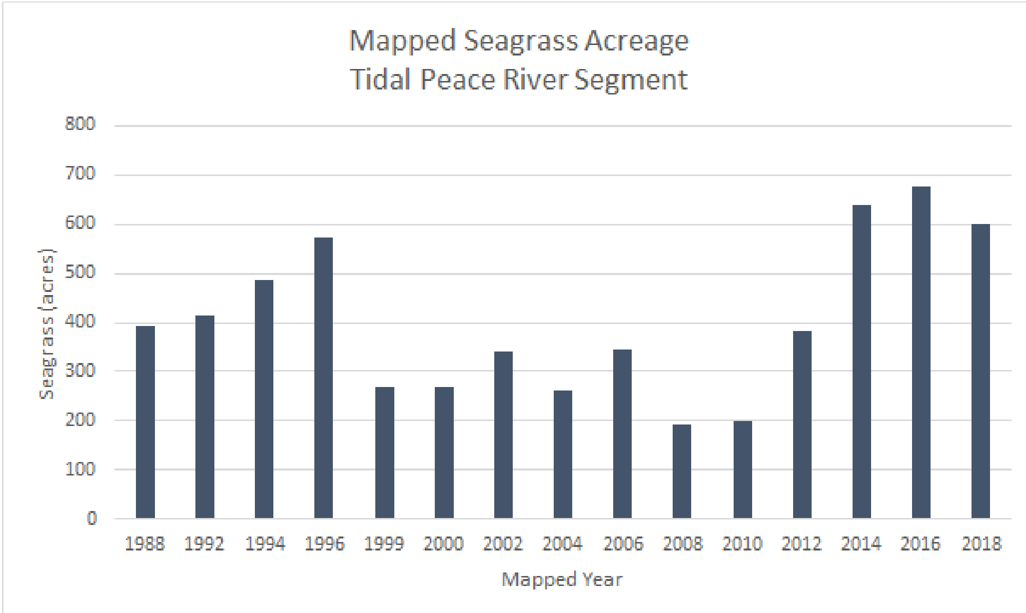

Figure 4-3. Mapped seagrass acreage in the tidal Peace River segment of Charlotte Harbor from 1988 through 2018.

4.2 Fish and Benthic Macroinvertebrates

Salinity is an important physical factor affecting biota of tidal rivers that is influenced by both freshwater inflow and tidal effects. Osmotic limitations impose restrictions on the range of freshwater and marine species and fish communities in the Lower Peace River can be separated based upon their primary salinity habitat (Call et al. 2013, Stevens et al. 2017). Estuaries also support euryhaline communities, which are organisms that can tolerate a wide range of salinities and have adapted to seasonal fluctuations in flow regimes (Banks et al. 1991). Many species, including estuarine-dependent fish, rely on different salinity zones during different life stages (Wang and Raney 1971; Kelley and Burbanck 1976; Peebles 2002; Greenwood et al. 2004; Rubec et al. 2018). Based upon catch data, the oligohaline zone (0.5 to 5 psu) in the Lower Peace River may serve as an extension of juvenile habitat for estuarine residents and transients, species that can tolerate a wide range of salinities (Banks et al. 1991, Stevens et al. 2013).

Flow can shift salinity regimes to either expand either the freshwater habitat during wet periods or the saline conditions in dry periods, with subsequent impacts on the structure of biological communities (Alber 2002). Several researchers have evaluated the effects of flow on fish assemblages and on individual fish species in the Lower Peace River (Stevens et al. 2013, Blewett and Stevens 2013, Call et al 2013). In a study comparing fish populations in the lower and oligohaline portions of the river in years of comparatively high and low flow, communities in the oligohaline zone were distinct from those in the lower river during wet years, but became more similar in dry years, when Sand Seatrout (*Cynoscion arenarius*), Tidewater Mojarra (*Eucinostomus harengulus*), and Red Drum (*Sciaenops ocellatus*) became more abundant in the oligohaline stretch (Stevens et al. 2013). The three dominant predators of the Peace River, Common Snook (*Centropomus undecimalis*), Largemouth Bass (*Micropterus salmoides*), and Florida Gar (*Lepisosteus platyrhincus*) are also affected by salinity constraints, with Common Snook being most abundant within the Lower Peace River (Blewett and Stevens 2013).

Flow has additional effects on the growth and abundance of fish species by altering the amount and duration of floodplain inundation and subsequently the availability of habitat and prey derived therein (Wharton et al. 1982, Ainsle et al. 1999, Hill and Cichra 2002). Tropical floodplains are highly productive habitats for invertebrates and small fish, important prey items for large-bodied predators that become available in the main river channel as water levels fall (Blewett et al. 2017). In the Lower Peace River, Common Snook abundance and body condition was positively correlated with flow over an eight-year record. This was likely due to increased consumption of prey items whose life cycles are associated with inundated floodplains during periods of high flow, particularly Crayfishes (*Procambarus* spp.) and Brown Hoplo (*Hoplosternum littorale*) (Blewett et al. 2017).

Changes in water level with flow exposes different amounts of critical habitat for fish and their prey, such as snags or woody debris. Snags provide cover for ambush predators, refuge from high velocity currents, and habitat for prey items like invertebrates (Blewett and Stevens 2013). The period of inundation of woody habitat is important for prey production, as sustained submersion is necessary for microbial conditioning and periphyton development prior to invertebrate colonization. Highlighting the importance of structure to fish assemblages, the presence of woody debris in the Lower Peace River described changes in fish community structure between sampling events over a three-year period (Call et al. 2013).

Freshwater inflow can affect substrate composition in tidal rivers based on effects associated with current velocity, and input and transport of sediments and organic matter. At lower flows, downstream sediment transport is diminished. This may adversely affect habitat availability for emergent vegetation and may contribute to the retention of contaminants in the estuary (Alber 2002). Additionally, if freshwater flows are diminished, tidal currents may displace coarser sediments upstream (Flemer and Champ 2006), altering the physical habitat of benthic organisms. Generally, biotic abundance and diversity increases with increasing substrate stability and the presence of organic detritus (Allan 1995).

The magnitude and timing of freshwater inflows affect the amount of nutrients and organic matter that enters a waterway. Higher flows are associated with increased nutrient loading and lower nutrient concentrations. Low flows contribute to decreased turbidity, increased water clarity (Alber 2002; Flemer and Champ 2006). Under extreme low flows primary production could even shift from a phytoplankton-based system to one driven by benthic algae (Baird and Heymans 1996). Increased secondary production by benthic organisms is typically observed after a period of increased flow (Kalke and Montagna 1989; Bate et al. 2002).

Flow can affect dissolved oxygen concentrations in different ways. Decreased flows may increase hydraulic residence times in tidal rivers which, can interact with the effects of nutrient loading and lead to lowered levels of dissolved oxygen associated with development of algal blooms and increased respiration (Latimer and Kelly 2003). However, decreased flows may also contribute to increases in day-time dissolved oxygen concentrations as a result of enhanced algal growth. Also, in association with reduced flows, the volume of density-stratified water in the estuary may be reduced as a result of decreased flows and lead to increased mixing of oxygenated surface water with bottom waters (Alber 2002; Flemer and Champ 2006).

Any adverse effects of flow on dissolved oxygen could have an impact on the organisms that live in the river. For example, Fraser (1997) looked at the relationship between physiochemical factors and fish abundance in Upper Charlotte Harbor, and noted a sharp decrease in fish abundance and number of species in areas where dissolved oxygen was less than 2 mg/L.

4.2.1 Fish and Planktonic/Nektonic Invertebrates

The Florida Fish and Wildlife Conservation Commission (FWC) Fisheries-Independent Monitoring (FIM) program has been monitoring the relative abundance of fishery resources in Charlotte Harbor since 1989. During 2018, FIM conducted monthly sampling of fish and selected invertebrates in Charlotte Harbor, including fish and invertebrates of recreational or commercial importance, (FWRI 2018). The region was divided by zones (Figure 4-4) for the general Charlotte Harbor area, Peace, Myakka, and Caloosahatchee Rivers, and Alligator Creek. Monthly stratified-random sampling was conducted in all regions and followed multi-gear approach, which allowed collection of data on various life-history stages of fish and invertebrates from a variety of habitats. All fish captured were counted and identified to the lowest practical taxonomical level. Certain taxa were not identified to species due to the possibility of hybridization (e.g., Menhaden, *Brevoortia* spp.) or juveniles that were morphologically indistinguishable (e.g., Mojarras; *Eucinostomus* spp. < 40 mm standard length).

From 1,476 samples (i.e., seine hauls and otter trawls) collected in 2018 in the full study area, 143 fish taxa and 13 invertebrate taxa were identified. Of the 453,677 animals collected throughout the entire study area, the most numerous species were: Bay Anchovy (*Anchoa mitchili*), Pinfish (*Lagodon rhomboides*), Silversides (*Menidia* spp.), and Mojarras.

The 84 samples collected within the Lower Peace/Shell System portion (i.e., area P, Figure 4-4) of the study area yielded 11,681 animals from 66 taxa. The three most abundant taxa in this area were (Table 4-1): Bay Anchovy (n = 8,015), Silversides (n = 896), and Hogchoker (*Trinectes maculatus*) (n = 647). The three most abundant taxa of commercial and recreational importance (Table 4-2) were: Southern Kingfish (*Menticirrhus americanus*) (n = 210), Sand Seatrout (n = 132), and Pink Shrimp (*Farfantepenaeus duorarum*) (n = 59). The high abundance of Bay Anchovy in the Lower Peace/Shell System has also been reported by others (e.g., Wang and Raney 1971, Fraser 1997, Greenwood et al. 2004, Idelberger and Greenwood 2005, SWFWMD 2010, Peebles and Burghart 2013).

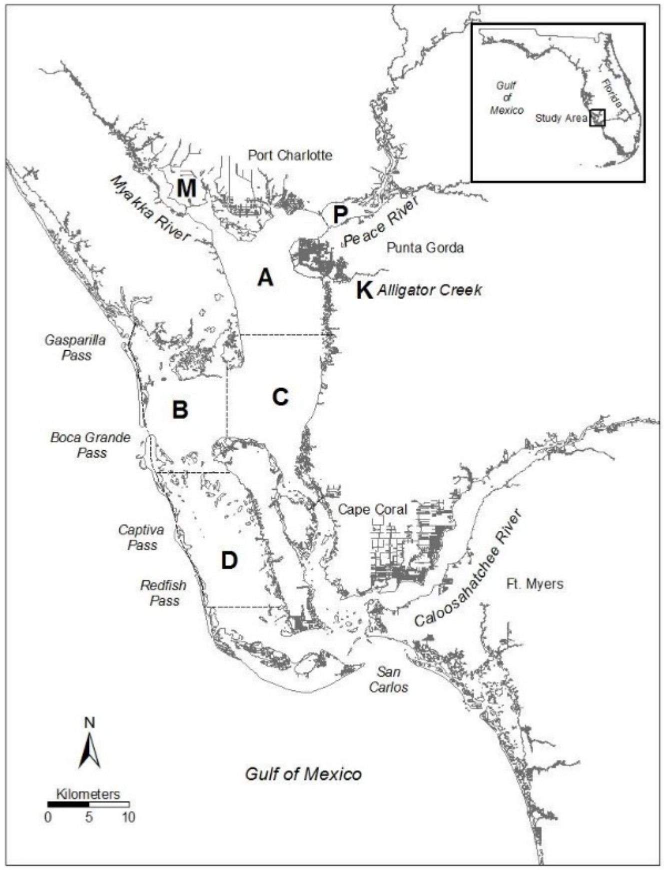

Figure 4-4. Map of Charlotte Harbor sampling area. A-D general area, M: Myakka River, P: Peace River, K: Alligator Creek. Figure extracted from the Fisheries-Independent Monitoring Annual Report (reproduced from FWRI 2018).

The lower reaches of the Peace River provide habitat to popular gamefish such as the Common Snook and Largemouth Bass. Common Snook are tropical, euryhaline fish that are obligate marine spawners, but use oligohaline portions of tidal rivers as adults (Blewett et al. 2009; Blewett et al. 2017). Blewett and Stevens (2013) looked at the effects of environmental disturbances on the abundance of these two species. Hurricanes can cause high river-inflows events, which reduce the salinity in the area and reduce dissolved oxygen. In such events, freshwater obligate fishes such as the Largemouth Bass can be confined to the hypoxic freshwater regions of the river and experience high mortality rates. Euryhaline fishes would have the advantage of leaving the affected areas and find more suitable habitat. Changes in the physicochemical characteristics of a tidal river can change the distribution and abundance of the resident and transient species (Wang and Raney 1971, Call et al. 2013).

Table 4-1. Top ten most abundant taxa found in Peace River from a total of 66 taxa and 11,681 animals collected during 84 sampling events (source: FWRI 2018).

Scientific Name	Common Name	Number of Animals
Anchoa mitchilli	Bay Anchovy	8,015
Menidia spp.	Silversides	896
Trinectes maculatus	Hogchoker	647
Eucinostomus spp.	Mojarra	563
Eucinostomus harengulus	Tidewater Mojarra	318
Menticirrhus americanus	Southern Kingfish	210
Cynoscion arenarius	Sand Seatrout	132
Callinectes sapidus	Blue Crab	131
Membras martinica	Rough Silverside	93
Gambusia holbrooki	Eastern Mosquitofish	63

Table 4-2. Taxa of commercial or recreational importance found in the Peace River from a total of 66 taxa and 11,681 animals collected during 84 sampling events (source: FWRI 2018).

Scientific Name	Common Name	Number of Animals
Menticirrhus americanus	Southern Kingfish	210
Cynoscion arenarius	Sand Seatrout	132
Callinectes sapidus	Blue Crab	131
Farfantepenaeus duorarum	Pink Shrimp	59
Leiostomus xanthurus	Spot	53
Centropomus undecimalis	Common Snook	28
Mugil cephalus	Striped Mullet	19
Sciaenops ocellatus	Red Drum	16
Lutjanus griseus	Gray Snapper	5
Archosargus probatocephalus	Sheepshead	3
Micropterus salmoides	Largemouth Bass	3
Cynoscion nebulosus	Spotted Seatrout	2
Elops saurus	Ladyfish	2
Mugil trichodon	Fantail Mullet	2

Call et al. (2013) also looked at the freshwater fish communities and habitat use in the Upper, Middle and Lower portions of the Peace River. The objectives of their study were to a) determine fish community metrics in the freshwater portion of the Peace River, b) identify differences in fish communities among sections of the river, and c) evaluate fish association with quantified habitat. Fish were sampled by electrofishing during spring and fall of 2007 through 2010. This project concluded that fish communities vary spatially in the river, but not temporally across seasons or years. This variability was correlated to variables such as macrophyte cover, woody debris, depth, and water velocity. Species such as the Eastern Mosquitofish (*Gambusia holbrooki*), Seminole Killifish (*Fundulus seminolis*), Redear Sunfish (*Lepomis microlophus*), and Bluegill (*Lepomis* *macrochirus*) were more likely to be found in the lower portions of the Peace River than the Upper (above the Zolfo Springs area) and Middle (from the Arcadia and Zolfo Springs areas) portions. Other species found in the oligohaline portions of the Peace River are the Rainwater Killifish (*Lucania parva*) and Hogchoker, which are both estuarine residents (Stevens et al. 2013).

Smalltooth Sawfish (*Pristis pectinata*) also inhabit parts of the Lower Peace/Shell System. These were the first elasmobranch (i.e., shark, skates, and rays) to be listed as endangered under the Endangered Species Act in 2003. The Charlotte Harbor estuary contains two distinct nursery hotspots for Smalltooth Sawfish juveniles: 1) the Caloosahatchee River and 2) the Peace River (Simpfendorfer 2001; Poulakis et al. 2011; Scharer et al. 2017). The shoreline of the Caloosahatchee River has been altered by the creation of seawall canal systems, whereas the Peace River is less developed, with more natural shorelines. Recent studies by the FWC used acoustic monitoring to track Smalltooth Sawfish movement within nursery hotspots as a function of freshwater inflows and observed largescale movement after significant freshwater inflow events of >500 cubic meters/second (Poulakis et al. 2013; 2016). This behavioral response to freshwater inflows, i.e., movement into identified hotspots, was more commonly reported for the Sawfish population in the Caloosahatchee River than those in the Peace River (Scharer et al. 2017). Downstream movements primarily occurred when salinities approached 0 psu and upstream movements occurred at salinities approaching 30 psu (Poulakis et al. 2013). Thus, protection of sensitive salinity habitat associated with minimum flows development will not likely affect Sawfish distribution in the Lower Peace/Shell System, though maintenance of the natural freshwater flow regime would potentially benefit the capability of Sawfish to locate nursery grounds (Poulakis et al. 2016). The juvenile (<3 years of age) sawfish population in the Peace River may be more tolerant of lower salinities and showed high site fidelity as it would travel a smaller distance downriver before returning to their nursery grounds, compared to the population in Caloosahatchee (Huston et al. 2017; Scharer et al. 2017).

4.2.2 Macroinvertebrates in the Lower Peace/Shell System

There have been limited number of benthic sampling events to study the benthic fauna of the Lower Peace River and Shell Creek. Mote Marine Laboratory studied the benthic invertebrates within the tidal Peace River and Shell Creek (Mote Marine Laboratory 2002; 2005). The Mote Marine Laboratory study divided the Lower Peace River into four longitudinal zones (Figure 4-5). These zones were based upon an analysis of long-term mean bottom salinity data. Zone 1 had mean bottom salinities of < 0.5 psu. Zone 2 had mean bottom salinities ranging from 0.5 to 8.0 psu. Zone 3 had mean bottom salinities ranging from 8.0 to 16.0 psu and Zone 4 had mean bottom salinities > 16 psu.

The dominant taxa within each of the zones were as follows:

- Zone 1 had predominantly freshwater taxa that can tolerate low salinities. These include the invasive Asiatic Clam (*Corbicula fluminensis)*, hydrobiid gastropods and non-biting midge (Chironomidae) larvae.

- Zone 2 (including Hunter Creek) had predominantly estuarine taxa such as the amphipods *Apocorophium lacustre* and *Grandidierella bonnieroides*; and some freshwater taxa such as non-biting midge larvae.
- Zone 3 (Lower Peace River proper) was also dominated by estuarine taxa. Although, unlike Zone 2, bivalves, including the Dwarf Surf Clam (*Mulinia lateralis)*, Atlantic Paper Mussel (*Amygdalum papyrium*), and Carolina Marshclam (*Polymesoda caroliniana*) were more highly ranked. Amphipods were more abundant in Zone 3 than in Zone 2.
- Zone 4 was dominated by estuarine bivalves and crustaceans.

The dominant species in Shell Creek included the Carolina Marshclam, the amphipod *Grandidierella bonnieroides*, and hydrobiid gastropods (Mote Marine Laboratory 2005).

The District funded a study that looked at the relationship of mollusk distribution to the physiochemical characteristics and freshwater inflows in tidal rivers of Southwest Florida (Montagna 2006). The study reported relatively high abundance of the Asiatic Clam, which represented the dominant taxa in the overall number of mollusks samples in Lower Peace River. This introduced bivalve can survive salinities up to 13 psu, but in sampling events on the Peace River, was found in higher densities in salinities equal or lower than 2 psu. Montagna (2006) also concluded that salinity had the strongest correlation with the structure of the mollusk community, compared to other abiotic variables such as temperature, pH, and sedimentation.

Oyster habitat can also be found in the estuaries within the Lower Peace/Shell System and Charlotte Harbor estuarine system. Although adult oysters can temporarily tolerate a wide range of salinities (0–42.5 psu), their optimal salinity habitat lies between 14 to 28 psu (Barnes et al. 2007). Their upstream extent is limited by low reproductive rates and low spat recruitment in salinities 0–15 psu. At high salinities (e.g., > 25 psu), oysters are limited by increased stress and disease prevalence by the protozoan *Perkinsus marinus*, which has devastated oyster populations in the Atlantic and Gulf of Mexico (Barnes et al. 2007). Oyster bars provide refuge for a variety of other invertebrates such as bivalves, gastropods, small crustaceans (e.g., crabs and amphipods), and polychaete worms (Mote Marine Laboratory 2007).

The oyster restoration plan by Boswell et al. (2012), identified the tidal portion of Lower Peace River downstream of the Interstate-75 bridge as area suitable for restoration. The recommended areas for restoration were Alligator Bay, northwest of Punta Gorda Isles, and in the vicinity of Hog Island. The restoration plan defined oyster habitat as substrate upon which a self-sustaining native oyster community could develop and provide habitat for commensal flora and fauna. The results from the restoration suitability model (Boswell et al. 2012), have further led to pilot studies for oyster restoration near the Trabue Harborwalk park in Punta Gorda (Geselbracht et al. 2017).

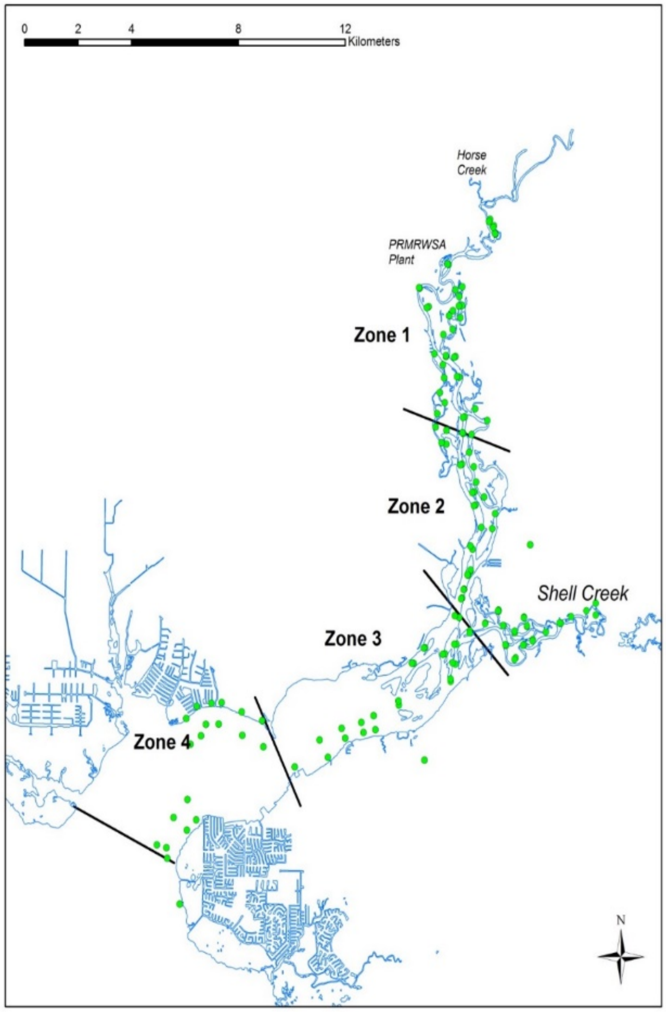

Figure 4-5. Location of benthic sampling station in the Lower Peace River and Shell Creek (Mote Marine Laboratory 2002; 2005).

CHAPTER 5 – FLOW BLOCKS, BASELINE FLOWS, RESOURCES OF CONCERN AND MODELING TOOLS RELEVANT TO MINIMUM FLOWS DEVELOPMENT

5.1. Overview

Resources of concerns and methods used to determine the minimum flow requirements for the Lower Peace River and Lower Shell Creek are described in this chapter. The approach outlined for the river involves identification of a proposed low flow threshold, and development of prescribed flow reductions proposed for periods of low, medium, and high flows (Blocks 1, 2 and 3). The low flow threshold is used to identify a minimum flow condition and is expected to be applicable to river flows throughout the year. The prescribed flow reductions are based on limiting potential changes in key habitat indicators that may be associated with changes in river flows during Blocks 1, 2 and 3.

5.2. Flow Blocks

For most rivers in the District, there is a repetitive annual flow regime that can be described on the basis of three periods. These three periods are characterized by low, medium, and high flows and for the purpose of developing minimum flows and levels, are termed Block 1, Block 2, and Block 3, respectively (Kelly et al. 2005). For the original characterization of the specific blocks, flow records for long-term USGS gage sites including the Alafia River at Lithia, the Hillsborough River at Zephyrhills, the Myakka River near Sarasota, the Peace River at Arcadia, and the Withlacoochee River at Croom were reviewed. Block 1 was defined as beginning when the average median daily flow for a given time period fell below and stayed below the annual 75% exceedance flow (April 20 - June 24, for the originally assessed records). Block 3 was defined as beginning when the average median daily flow exceeded and stayed above the annual 50% exceedance flow (June 25 - October 27, for the originally assessed records). The medium flow period, Block 2, was defined as extending from the end of Block 3 to the beginning of Block 1 (October 28 – April 19, for the originally assessed records).

Estuaries are tidally influenced ecosystems where freshwater flows from a contributing watershed mix with saltwater from a receiving ocean, bay, or gulf. Given the complex and dynamic interaction between fresh and marine waters, we determined it was necessary to develop a 3D hydrodynamic model of the Lower Peace/Shell System to provide detailed information on water circulation, and salinity and temperature distributions for a baseline and a series of flow scenarios with different percent-of-flow reductions. Analyses of seasonal flows for the Peace River (i.e., the sum of flows at the USGS Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee) for the 2007 through 2014 period that were simulated with the hydrodynamic model indicated that flows during the Block 2 period (October 28 – April 19) identified in the original 2005 analyses was dominated by flows less than the annual 75% exceedance flow as opposed to flows between 75% and 50% exceedance flows (Figure 5-1). The fixed-date block definition was therefore not considered appropriate for characterizing the seasonal flow regimes of the 2007 through 2014 period.

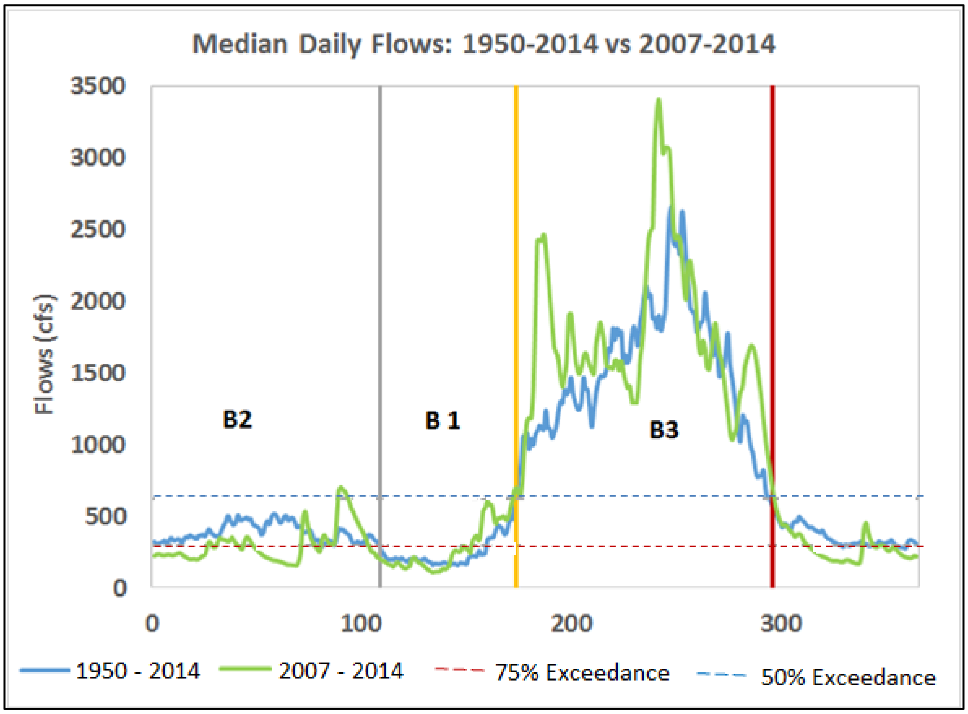

Figure 5-1. Comparison of median flows in the Lower Peace River (combined flows at USGS gages in the Peace River at Arcadia, Horse Creek near Arcadia, and Joshua Creek at Nocatee) for 1950 through 2014 and 2007 through 2014 under the calendar day-based seasonal flow blocks.

To address this issue, the District used the annual 75% and 50% exceedance flow thresholds to define the flow-based blocks, as shown in Figure 5-2. Based on the long-term, historic flow data from 1950 through 2014, the annual 75% and 50% exceedance flow thresholds for the Lower Peace River are 297 and 622 cfs, respectively. For Shell Creek, the annual 75% and 50% exceedance flows using available long-term, historic flow data for the period from 1966 through 2014 are, respectively, 56 and 137 cfs. With this new approach, the determination of transitional flow trigger (e.g., 625 cfs in the previously established Lower Peace River minimum flows; Table 1-1) was not required when high flows remained depressed due to climatological conditions.

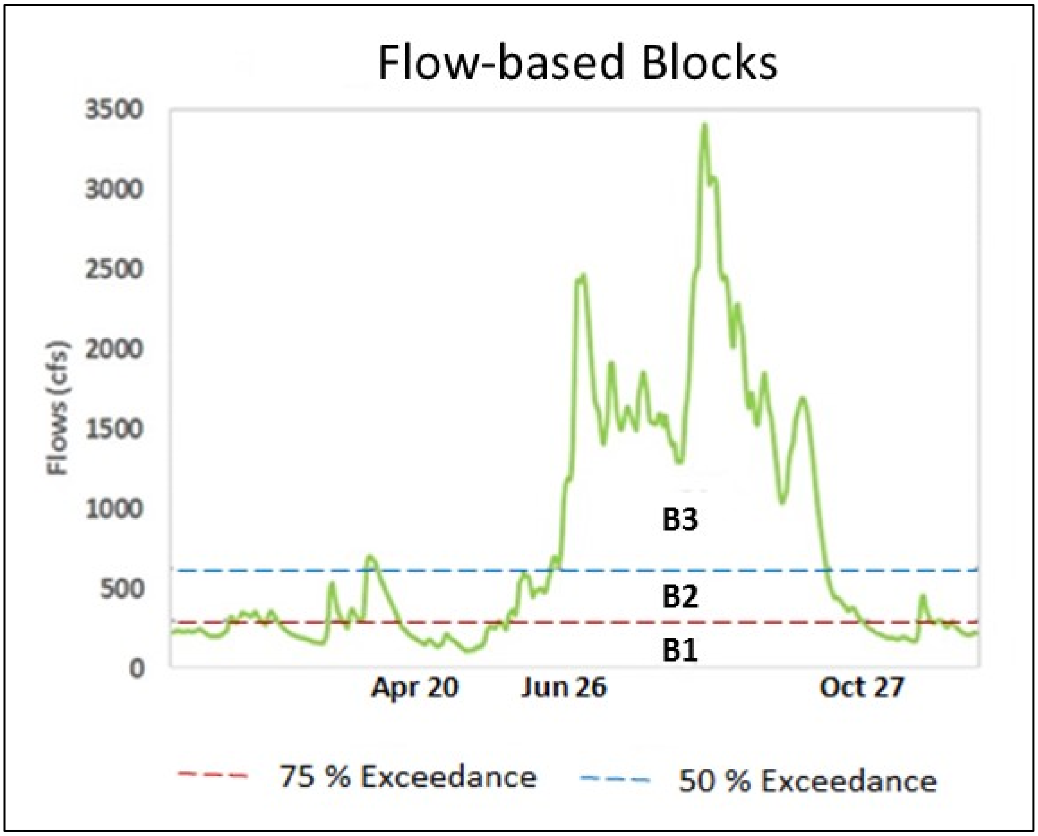

Figure 5-2. Median flows in the Lower Peace River (combined flows at USGS gages in the Peace River at Arcadia, Horse Creek near Arcadia, and Joshua Creek at Nocatee) for 2007 through 2014 (green line) and flow-based blocks defined using 75% and 50% exceedance flows derived from long-term, historic flow data for 1950 through 2014.

5.3. Reconstruction of Baseline Flows

Several investigators (e.g., Hammett, 1990; Flannery and Barcelo 1998; Kelly 2004; Kelly et al. 2005; Kelly and Gore 2008) have examined trends in the Peace River flows and have reached a variety of conclusions regarding anthropogenic effects on the river's flows. Using data collected through 1985, Hammett (1990) concluded that "much of the flow decline seen in the Peace River is attributable to factors other than rainfall." In contrast, others (e.g., Kelly 2004; Kelly et al. 2005; Kelly and Gore 2008) have identified climate as a major factor for most of the flow decline observed for the river from the 1970s through the 1990s.

Assessing the Lower Peace/Shell System flow records for anthropogenic impacts is essential for determination of minimum flows. Flow variation associated with warming and cooling of the Atlantic Multi-decadal Oscillation (AMO) and El Niño Southern Oscillation (ENSO) were investigated. To gain a better understanding of factors that control Peace River flows and simulate the effects of climate, groundwater withdrawals, land use change, District findings from the Peace River Integrated Model (PRIM) project, which was completed in 2012, were also evaluated. Collectively, these data were used to construct a baseline flow record for Lower Peace River as described in subsection 5.3.2 of this chapter. This process included adding withdrawals from the river by the PRMWSA to the gaged flow record.

The baseline flow record for Shell Creek was constructed by subtracting excess groundwater runoff from the gaged flow record and adding the City of Punta Gorda's withdrawals from the Shell Creek Reservoir to the adjusted record. The approach used to construct the Shell Creek baseline flows is described in subsection 5.3.3.

5.3.1. Flow Trends and Possible Causes

For trend analysis, we compiled flow data collected from May 1950 through December 2018 for the USGS Peace River at Bartow, FL (No. 02294650), Peace River at Zolfo Springs, FL (No. 02295637), Peace River at Arcadia, FL (No. 02296750) gage sites, and for gages on the major tributaries to the river, including the Horse Creek near Arcadia, FL (No. 02297310), Charlie Creek near Gardner, FL (No. 02296500), and Joshua Creek at Nocatee, FL (No. 02297100) sites. For the USGS Shell Creek near Punta Gorda, FL (No. 02298202) gage, flow data from January 1966 through 2018 were used. Rainfall data (Site Identification No. 24570) from May 1950 through 2018 for the Peace River watershed were obtained from the District's Water Management Information System (WMIS) (http://www.swfwmd.state.fl.us/data).

Using the nonparametric Mann-Kendall's trend test on monthly time-step, trend analysis for rainfall identified a significant decreasing trend at alpha level of 0.05 for February and October. Peace River flows at Arcadia exhibited a significant decreasing trend for February, March, and May, whereas the Charlie Creek flows exhibited no significant trends. Peace flows at Zolfo Springs exhibited significant decreasing trends for January through June, while flows at Bartow from January through June, as well as November and December exhibited significant decreasing trends. Flows at Joshua Creek exhibited an increasing trend for most months, but these trends were significant only for January, April, May, November, and December (Table 5-1).

The decreasing trends in the Peace River at Arcadia, Bartow and Zolfo Springs are primarily the result of rainfall declines through time, but also partly reflect effects of increased groundwater withdrawals in the upper Peace River watershed. The significant increasing trends in Joshua Creek is attributed to flow increases from agricultural return flows in recent decades. Charlie and Horse Creek flows exhibited no significant trend pattern for all months, suggesting that anthropogenic influences on flows in the two creeks are less than those in the upper portion of the Peace River and in Joshua Creek. Trend analysis conducted by PBS&J (2007) indicated that the Charlie Creek historic flows are consistent with the timing of the wet and dry climate periods in southwest Florida. Based on land use change analysis for the period from 1940 to 1999, They found that, among the nine watersheds in the Peace River Basin, Charlie Creek remains relatively un-impacted, with no phosphate mining and limited urbanization and agriculture. However, as is shown in Figure 5.3, Horse Creek flows for May (May 1 is day 121 for non-leap years) through June (June 30 is day 181 for non-leap years) during the 1996 to 2014 period appear to be greater than in earlier assessed periods. This increased flow in Horse Creek is most likely due to agricultural return flows.

Table 5-1. Trend analysis for rainfall and flows at USGS gages in the Peace River at Arcadia, Bartow and Zolfo Springs, and in Horse, Shell, Charlie, and Joshua Creeks.

Month	Peace River Rainfall		Peace River at Arcadia		Horse Creek near Arcadia		Joshua Creek at Nocatee	
	P	Trend Direction	P	Trend Direction	P	Trend Direction	P	Trend Direction
Jan	0.52	No trend	0.11	No trend	0.74	No trend	0.01*	Increasing
Feb	0.05*	Decreasing	0.02*	Decreasing	0.28	No trend	0.06	No trend
Mar	0.88	No trend	0.02*	Decreasing	0.37	No trend	0.11	No trend
Apr	0.98	No trend	0.12	No trend	0.79	No trend	0.02*	Increasing
May	0.97	No trend	0.04*	Decreasing	0.09	No trend	0.00*	Increasing
Jun	0.27	No trend	0.34	No trend	0.23	No trend	0.09	No trend
Jul	0.97	No trend	0.83	No trend	0.68	No trend	0.18	No trend
Aug	0.08	No trend	1.00	No trend	0.5	No trend	0.06	No trend
Sep	0.72	No trend	0.90	No trend	0.64	No trend	0.29	No trend
Oct	0.02*	Decreasing	0.78	No trend	0.89	No trend	0.82	No trend
Nov	0.11	No trend	0.40	No trend	0.65	No trend	0.03*	Increasing
Dec	0.14	No trend	0.37	No trend	0.46	No trend	0.00*	Increasing
Month	Charlie Creek near Gardner		Shell Creek near Punta Gorda		Peace River at Zolfo Springs		Peace River at Bartow	
	P	Trend Direction	P	Trend Direction	P	Trend Direction	P	Trend Direction
Jan	0.65	No trend	0.18	No trend	0.02*	Decreasing	0.01*	Decreasing
Feb	0.42	No trend	0.05*	Decreasing	0.00*	Decreasing	0.00*	Decreasing
Mar	0.22	No trend	0.03*	Decreasing	0.01*	Decreasing	0.00*	Decreasing
Apr	0.56	No trend	0.20	No trend	0.03*	Decreasing	0.08	No trend
May	0.82	No trend	0.29	No trend	0.00*	Decreasing	0.00*	Decreasing
Jun	0.85	No trend	0.92	No trend	0.04*	Decreasing	0.02*	Decreasing
Jul	0.60	No trend	0.22	No trend	0.57	No trend	0.36	No trend
Aug	0.91	No trend	0.22	No trend	0.86	No trend	0.36	No trend
Sep	0.61	No trend	0.05*	Increasing	0.81	No trend	0.85	No trend
Oct	0.74	No trend	0.63	No trend	0.86	No trend	0.57	No trend
Nov	0.91	No trend	0.98	No trend	0.06	No trend	0.02*	Decreasing
Dec	0.42	No trend	0.45	No trend	0.07	No trend	0.03*	Decreasing

* p values significant at an alpha level of 0.05

Using flows from Charlie Creek as a reference, a comparison of median daily flows per unit area for three periods for the Peace River at Arcadia, Horse Creek and Joshua Creek is presented in Figure 5-3. If climate is the major controlling factor, one should expect similar flow patterns in these neighboring watersheds. Figure 5-3 suggests that flow patterns in the Peace River at Arcadia for the periods 1970-1995 and 1996-2014 remain similar to the pattern observed during the period 1950-1969, indicating that there has not been a significant anthropogenic impact over time as appears to be the case in Horse and Joshua Creeks. The 1950-1969 flow patterns for Horse and Charlie Creeks were similar for most of the year with the exception that Horse Creek flows during May-June were relatively lower than the flows in Charlie Creek. During the periods of 1970-1995 and 1996-2013, however, the May through June flows in Horse Creek increased over time (see the middle and lower panels of Figure 5-3). These increases are consistent with the timing of growing season where return flows from irrigated fields is expected to contribute to streamflow. The flow in Joshua Creek clearly shows an increasing trend throughout the year since the early 1970s and the trend has increased significantly during the 1996-2013 period (Figure 5-3, lower panel). This is attributed largely to return flows from irrigated fields. Historic data for conductivity and nitrite +nitrate nitrogen in Joshua Creek also shows an increasing pattern due to changes to more intensive agricultural land uses and discharges of mineralized groundwater into the creek.

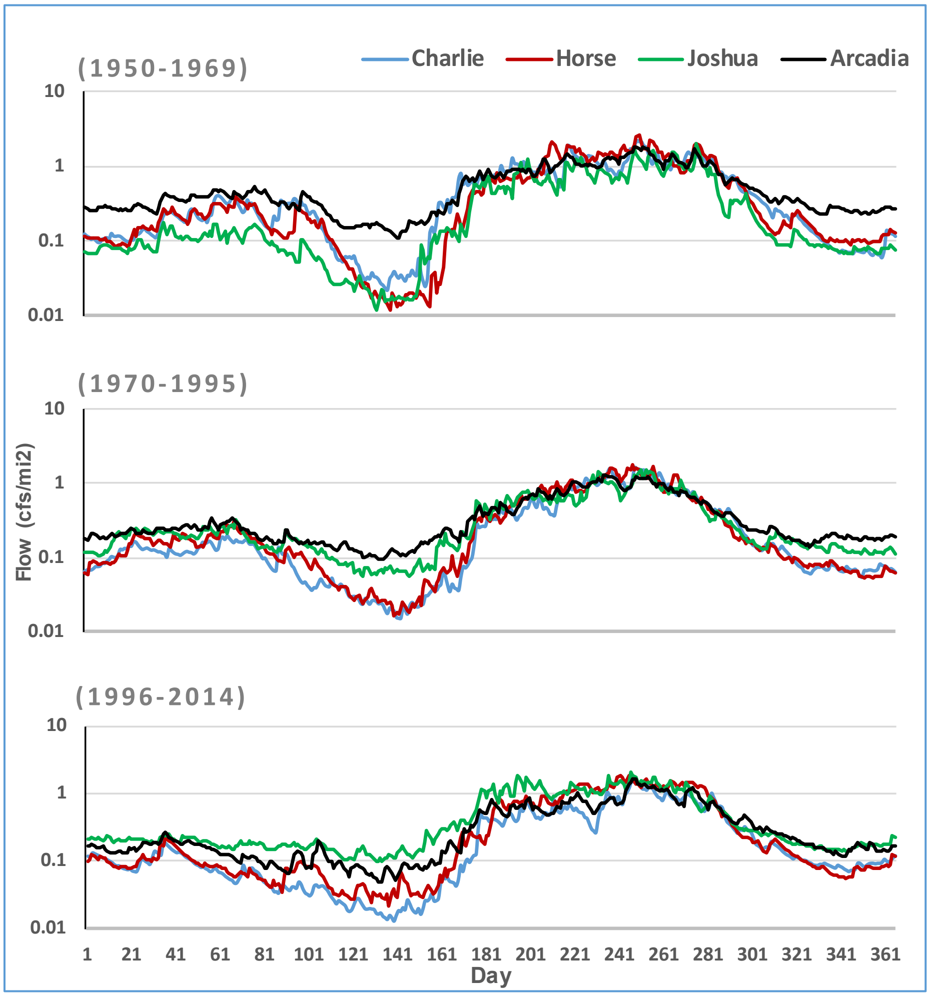

Figure 5-3. Comparison of median daily flows [logarithmic scale] for three time periods for the USGS Peace River at Arcadia, Charlie Creek near Gardner, Horse Creek near Arcadia, and Joshua Creek at Nocatee gages. Data from 1950 begin on May 01.

Although we believe that the variations in Peace River flows are largely controlled by climate, a comprehensive study was necessary to better understand the relative impact of anthropogenic factors that influenced flow decreases in the upper and middle Peace River and flow increases in

Horse, and Joshua Creeks. The District developed the PRIM for investigating effects of climate variability, groundwater pumping, land use changes and other factors on flows in the Peace River. Detailed information on model components, required inputs and the results of calibration and validation as well as scenarios that have been simulated are documented in HydroGeoLogic, Inc. (2009, 2011 and 2012).

The PRIM was used with measured groundwater withdrawals to simulate flows for a 13-year period, from 1994 through 2006. The daily flows produced by PRIM agreed fairly well with the observed streamflow in the Peace River at Arcadia (r^2 = 0.82), Joshua Creek at Nocatee (r^2 = 0.57) and Horse Creek near Arcadia (r^2 = 0.78) that collectively make up the Lower Peace River flows.

After calibration with measured flows that potentially integrate withdrawal effects, PRIM was run for two groundwater withdrawal scenarios (25% and 50% reduction) to assess the effects of reducing pumping on streamflow in the Peace River Basin. Effects of reduced groundwater withdrawals were strong in the Peace River at Bartow and Ft. Meade (6% increase in flow), moderate at Zolfo Springs (2.1% increase in flow) and minimal at Arcadia and in Horse Creek (< 1% increase in flow) for a 50% groundwater withdrawal reduction. The modeled simulations also indicated a 3.8% decrease in Joshua Creek flows when groundwater withdrawals were reduced by 50% (Table 5-2). Effects of reduced groundwater withdrawals at the USGS Payne Creek near Bowling Green FL (No 02295420) gage were minimal, with 0.5% increases in flows associated with both the 25% and 50% withdrawal reductions.

Table 5-2. Impact of groundwater withdrawals on streamflow in the Peace River and selected tributaries (HydroGeoLogic, Inc. 2012).

USGS Gage Site	Streamflow Changes	
	25% Pumping Reduction (%)	50% Pumping Reduction (%)
Peace River at Bartow	3.00%	6.00%
Peace River at Ft. Meade	3.00%	6.00%
Peace River at Zolfo	0.91%	2.09%
Peace River at Arcadia	0.22%	0.65%
Horse Creek near Arcadia	0.00%	0.00%
Joshua Creek at Nocatee	-1.84%	-3.75%
Charlie Creek near Gardner	-1.49%	-2.26%
Payne Creek near Bowling Green	0.50%	0.50%

This result for Joshua Creek is indicative of the degree to which agricultural return flows from groundwater pumping have increased flows in the creek. Generally, the lesser impacts to Peace River flows below Zolfo Springs at Arcadia and in Horse Creek are due partly to the tighter confinement on the upper Floridan Aquifer in the lower Peace River area. In addition, streamflow reduction due to groundwater withdrawals may partly be compensated for by excess baseflow associated with agriculture (HydroGeoLogic, Inc. 2012).

Since groundwater demands vary seasonally, development of a daily flow record corrected for seasonal effects of groundwater withdrawals, rather than yearly average, was required for minimum flows analyses. The development of a daily Lower Peace River baseline flow record based on seasonal groundwater withdrawals is briefly discussed in the sub-section which follows.

5.3.2. Lower Peace River Baseline Flows

Results from the PRIM simulations indicated a strong linear relationship between groundwater withdrawal percentage change and streamflow. Daily flows for zero groundwater withdrawals were therefore extrapolated using linear regressions developed from the PRIM scenarios results. However, given the uncertainties associated with model inputs and simplified assumptions and approximations of complex hydrologic interactions in the model, the daily flows generated using PRIM were not considered appropriate for use. Rather, the simulation results were aggregated into a longer timescale for use in establishing a reasonable cause-and-effect relationship between baseline and impacted flows.

The specific steps undertaken to develop the Lower Peace River daily baseline flows were as follows:

(1) The daily simulated flows for both the actual and zero-pumping scenarios were aggregated into seasonal flow blocks corresponding to the periods of low, medium, and high flows used to establish the previously established Lower Peace River minimum flows.

(2) The aggregated flow block values for the 13-year period from 1994 through 2006 were averaged and used to calculate the block-specific average percentage differences in flows between the pumping and zero-pumping scenarios.

(3) The daily gaged flows measured in the Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee were corrected for the effects of groundwater withdrawals using the average percentage flow change calculated for each seasonal block in step 2.

(4) The daily baseline flows for Lower Peace River for the period from 1950 through 2014 were calculated by combining the corrected daily flows for these three gage sites. However, 2007 through 2014 period was used as input in the hydrodynamic model.

Estimated percentage changes expected in the absence of groundwater withdrawals for flows in the Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee are presented in Table 5-3. Although the percentage differences in flows in the Peace River at Arcadia and Horse Creek do not differ much between the actual and the estimated zero groundwater withdrawal condition, the estimated streamflow is diminished in the dry season (Block 1) for the reduced (zero) pumping condition. This is due predominantly to runoff associated with agricultural withdrawals from surficial and intermediate aquifers discharging into the river and creek. The effects of agricultural runoffs are more pronounced in Joshua Creek, where runoff associated with groundwater withdrawals for agricultural purposes has increased block-specific flows in the creek from 6.1 to 21.4%. These results indicate that agricultural groundwater withdrawals constitute a significant percentage of the Joshua Creek flows throughout the year.

Table 5-3. Estimated block-specific percentage changes in flows in the absence of groundwater withdrawals (and associated runoff).

USGS Gage	Seasonal Streamflow Percentage Changes		
	Block 1	**Block 3**	**Block 2**
Peace River at Arcadia	-1.0%	0.8%	2.1%
Horse Creek near Arcadia	-1.2%	0.6%	0.3%
Joshua Creek at Nocatee	-21.3%	-6.1%	-8.5%

The PRIM was developed to account for all major hydrologic processes, including rainfall, runoff, groundwater exchange, evapotranspiration, net evaporation from lakes, wastewater returns by municipal, industrial, and agricultural uses, as well as groundwater pumping and discharges. However, like any physically based model, PRIM is limited by uncertainties that stem mainly from model assumptions, input errors and parameter estimation. To minimize these uncertainties, seasonal, rather than, daily or monthly adjustments were used to reconstruct the baseline flows for the Lower Peace River. Detailed information on the PRIM is provided in HydroGeoLogic, Inc. (2012) report (included as Appendix A).

Median daily baseline and gaged combined flows for the period 1950 through 2014 for the USGS Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee gage sites are shown in Figure 5-4. During April, May and June, the long-term monthly average combined baseline flows is shown to decrease by 0.2%, 2.6% and 2.3%, respectively, due to removal of agricultural return flows from the gaged flows. For the remaining months, the long-term monthly average combined baseline flows increased ranging from 0.2% in March to 0.9% in October.

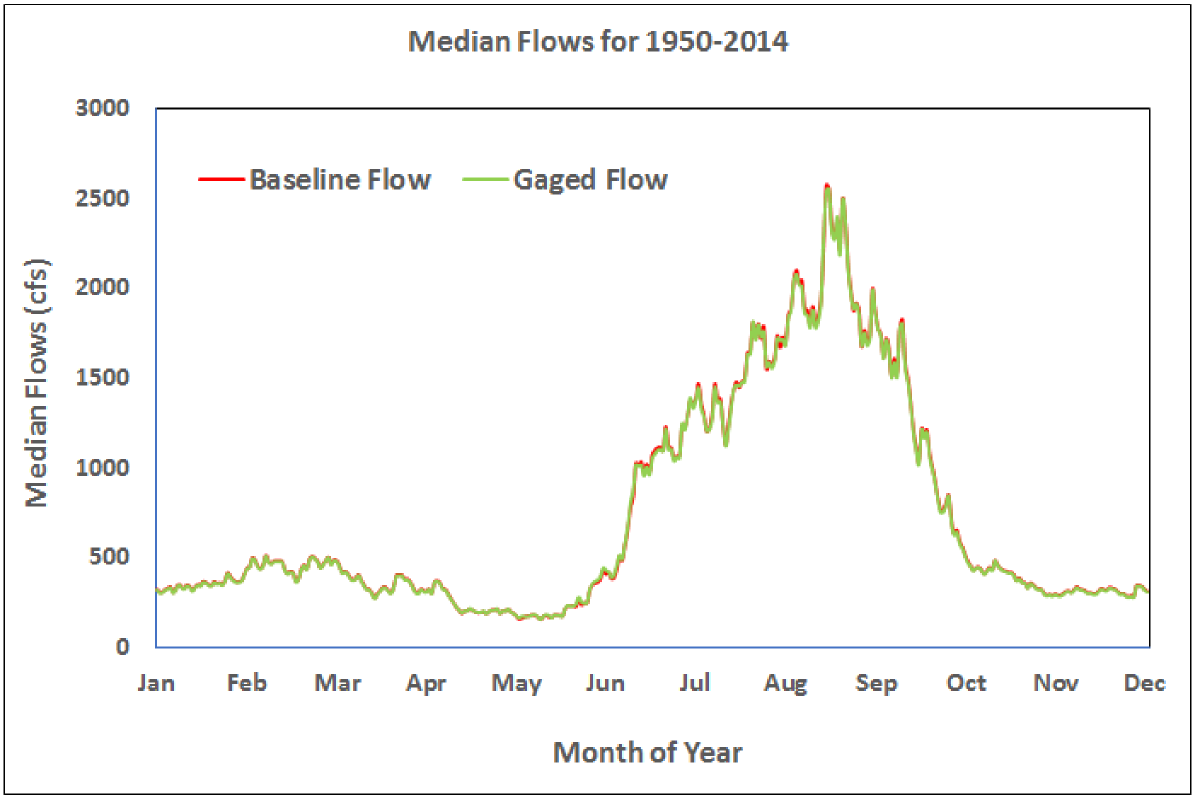

Figure 5-4. Median daily baseline and gaged flows for the Lower Peace River (combined flows at USGS gage sites in the Peace River at Arcadia, Horse Creek near Arcadia, and Joshua Creek at Nocatee) for the period from 1950 through 2014.

5.3.3. Lower Shell Creek Baseline Flows

The observed discharge from Shell Creek Reservoir at Hendrickson Dam has been increased by the addition of runoff associated with groundwater pumped for agricultural purposes and been decreased by City of Punta Gorda withdrawals from the reservoir. The dam and reservoir were constructed in 1965. The reservoir extends over 800 acres, with a maximum depth of 12 feet, and a total storage capacity of approximately 765 million gallons at a water surface elevation of 5.0 feet (PBS&J, 2007). The record of discharges from the dam begins in 1966 and the record of potable withdrawals from the reservoir begins in 1972, when the mean annual withdrawal was 2.0 cfs.

Because of backwater effects from the reservoir, there are no immediately upstream gages on Shell Creek or Prairie Creek that can be used to estimate inflows to the reservoir. Several adjustments were made to the gaged flow at the reservoir outfall, i.e., at the USGS Shell Creek near Punta Gorda, FL (No. 02298202) gage, to account for missing records, withdrawals from the reservoir by the City of Punta Gorda, recorded zero flow days at the gage, and additional flows into the reservoir from agricultural runoff in the watershed.

The period of record for Shell Creek near Punta Gorda gage is from 1966 to the present, with missing records from October 1, 1987, to September 30, 1994. To infill the missing flow records, a regression was developed using the flows measured at the Shell Creek near Punta Gorda gage and the USGS Prairie Creek near Fort Ogden, FL (No. 02298123) gage. Prairie Creek is a major tributary to Shell Creek, accounting for approximately 62% of the Shell Creek watershed above Shell Creek near the Punta Gorda gage.

Various approaches were used to account for withdrawals from Shell Creek Reservoir by the City of Punta Gorda. When measurable flow over the dam occurred at the Shell Creek near Punta Gorda gage, flows were adjusted simply by adding the withdrawal quantities back to the gaged flows. For 479 days in the flow record when flow was reported as zero at the gage at the dam, a regression-based approach was developed using Shell Creek near Punta Gorda flows and flows measured at the Prairie Creek near Fort Ogden and the USGS Charlie Creek near Gardner (No. 02296500) gage. The regression based on Charlie Creek flows was necessary because flows in Prairie Creek were not monitored from October 1, 1968, to September 30, 1977.

A third correction to the observed discharge record at the Shell Creek near Punta Gorda gage involved adjusting for anthropogenic groundwater discharges that result from agricultural practices in the watershed. Two approaches were used to estimate the contribution of excess irrigation water to the volume of water in the reservoir. First, an estimate of the monthly fraction of excess irrigation water in the reservoir was developed from the observed reservoir chloride level and the ratio of groundwater to surface water reaching the reservoir. Second, excess irrigation flows were estimated for Shell Creek and Prairie Creek using recommended irrigation rates and application inefficiencies for crops specific to the watershed. Rates and periods of application were taken from the University of Florida Institute of Food and Agricultural Sciences recommendations for nearby Manatee County.

To estimate excess irrigation contributions to the Shell Creek Reservoir, we assumed that row crops were irrigated using open ditch sub-irrigation techniques (ridge and furrow) and that citrus was irrigated using drip (trickle irrigation). As was done for the District's previous development of proposed minimum flows for the Lower Peace River and Lower Shell Creek (SWFWMD 2010), irrigation efficiency was assumed to be 60% and 85%, respectively, for row crops and citrus irrigation. Irrigation areas, application rates, periods and excess rate of flow delivered from Prairie Creek and Upper Shell Creek to the reservoir are listed in Table 5-4. The average excess irrigation flow estimates were 7.6 cfs for Prairie Creek and 9.5 cfs for Shell Creek. Using a mass balance equation, monthly estimates of excess groundwater flow in the reservoir were computed as shown in Table 5-5. Detailed information on the mass balance equation is provided in the HSW Engineering, Inc. (2016), included as Appendix B.

Table 5-4. Irrigation efficiency, periods, application rates and excess flows for row crops and citrus in Prairie Creek and Shell Creek (SWFWMD 2010).

Crop Type	Irrigation Efficiency	Irrigation Period		Application Rates (in/d)	Prairie Creek			Shell Creek		
		Start	End		Area (acres)	Irrigation Rates (cfs)	Excess Flow (cfs)	Area (acres)	Irrigation Rates (cfs)	Excess Flow (cfs)
Row Crops	60%	15-Jan	15-May	0.375	1,170	18.4	7.4	2,400	37.8	15.1
		15-Aug	14-Nov	0.272		13.4	5.3		27.4	11.0
		15-Nov	15-Dec	0.125		6.1	2.5		12.6	5.0
Citrus	85%	1-Apr	31-May	0.058	35,004	85.3	12.8	12,647	85.3	4.6
		1-Oct	15-Dec	0.032		47.1	7.1		47.1	2.6
				Average			**7.6**			**9.5**

Table 5-5. Excess groundwater flow at the USGS Shell Creek Near Punta Gorda gage (HSW Engineering, Inc. 2016).

Month	Average Rainfall (in)	Average Evaporation (in)	Average Flow (cfs)	Withdrawals (cfs)	Stage (ft)	Volume (mg)	Area (acres)	Chlorides (mg/l)	Total Excess Groundwater Flow (cfs)
1	0.06	0.084	147.16	4.81	5.18	1082	642	137.52	13.1
2	0.08	0.102	157.00	4.94	5.21	1092	643	149.35	17.0
3	0.09	0.138	215.98	5.06	5.25	1102	645	151.51	22.7
4	0.06	0.158	103.36	5.27	5.15	1074	640	161.19	13.5
5	0.10	0.171	79.25	5.15	5.09	1057	638	164.22	10.5
6	0.29	0.160	488.40	4.16	5.36	1137	650	143.41	41.8
7	0.25	0.151	688.19	4.03	5.54	1188	658	107.03	15.6
8	0.27	0.151	722.86	4.36	5.57	1196	659	85.99	0.0
9	0.22	0.138	822.38	4.44	5.63	1214	661	73.76	0.0
10	0.10	0.123	442.37	5.14	5.36	1136	650	89.87	1.1
11	0.06	0.091	171.33	5.47	5.20	1089	643	111.58	8.2
12	0.06	0.077	141.81	4.96	5.17	1080	641	123.95	9.3

The pattern of the monthly excess flow, expressed as the ratio of groundwater flow (Total Excess Groundwater Flow in Table 5-5) to surface water flow (Average Flow (cfs) in table 5-5), is consistent with observed chloride concentration in the reservoir (Figure 5-5).

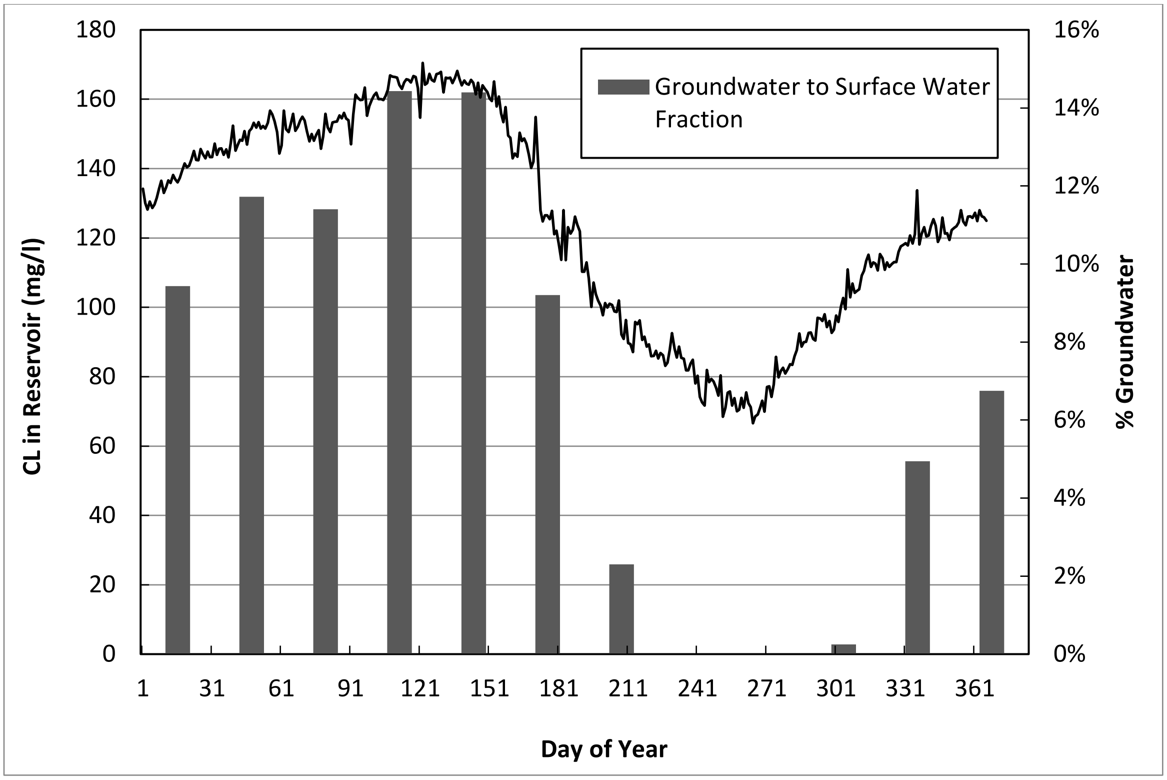

Figure 5-5. Measured chloride (CL) in Shell Creek Reservoir and estimated groundwater to surface water fraction (HSW Engineering, Inc. 2016).

Based on the reported City of Punta Gorda withdrawals from Shell Creek Reservoir, flows into and out of the reservoir, and estimates of inflow from groundwater withdrawals associated with agricultural uses, a baseline flow record for Shell Creek was developed for the period from 1966 through 2014. The baseline record was developed by subtracting excess groundwater runoff from the gaged flow record and adding the City of Punta Gorda's withdrawals from the Shell Creek Reservoir to the adjusted record.

Median daily flows for the period 1966 through 2014 for baseline record and gaged flows at the Shell Creek near Punta Gorda gage are shown in Figure 5-6. Except in July and August, there was a contribution from excess irrigation flow that ranged from 1.1cfs in October to 41.8 cfs in June (see Table 5-5).

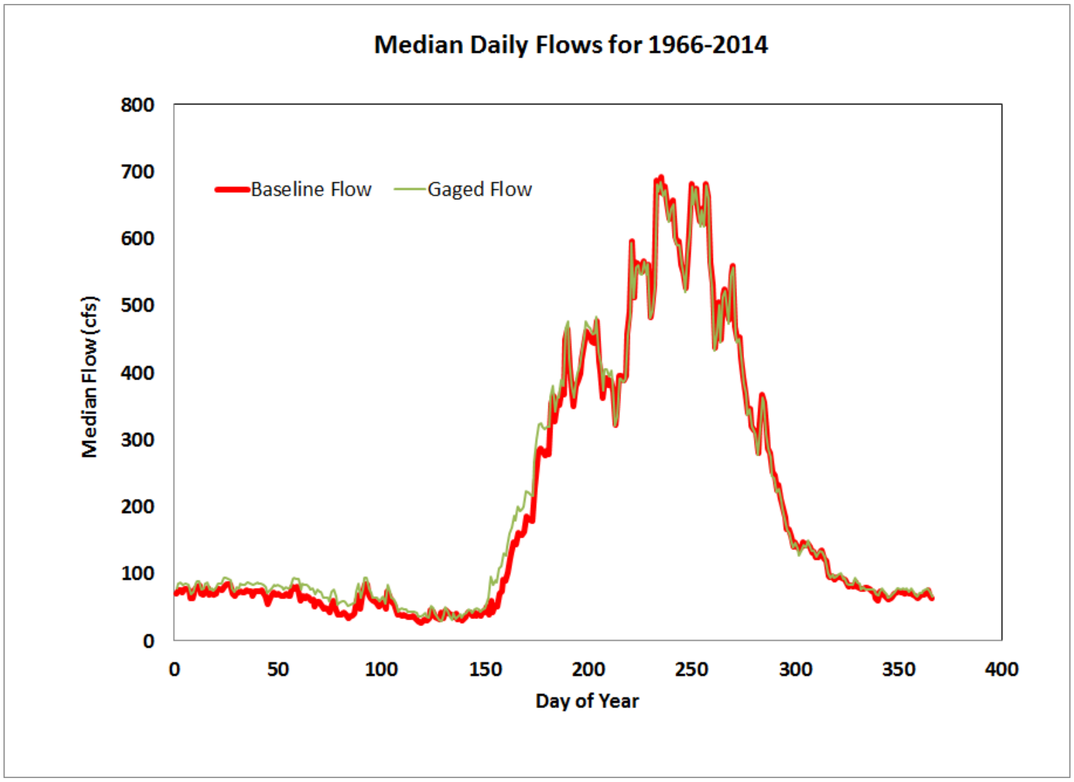

Figure 5-6. Comparison of median daily baseline and gaged flows for the USGS Shell Creek near Punta Gorda gage for the period from 1966 through 2014 (HSW Engineering, Inc. 2016).

5.4. Resources of Concern for Determining Minimum Flows

The District approach for setting minimum flows is habitat-based. Because river systems include a great variety of aquatic and wetland habitats that support diverse biological communities, it is necessary to identify key ecological resources for consideration, and when possible, determine hydrologic requirements for specific habitats associated with the resources. It is assumed that protecting the resources of concern will also provide protection for other ecological aspects or functions of the river system that are more difficult to quantify, such as transfer of detrital material and the maintenance of river channel geomorphology (Kelly et al. 2005). Resource management goals that were subject to technical analysis for the development of minimum flows for the Lower Peace River and Lower Shell Creek and the relevant environmental values associated with each of these goals are listed below.

1. Determination of a low flow threshold to provide protection for ecological resources of the river by prohibiting withdrawal impacts during critical low flow periods and prevent water users from reducing flows to rates that will result in brackish water at the PRMRSWA Water Treatment Facility intake on the Peace River.

Relevant environmental values: fish and wildlife habitats and the passage of fish, estuarine resources, transfer of detrital material, maintenance of freshwater storage and supply, filtration and absorption of nutrients and other pollutants, and water quality.

2. Maintenance of biologically relevant salinities over a range of flow conditions that protect the distribution of fish species, benthic macroinvertebrates, and shoreline vegetation communities.

   Relevant environmental values: recreation in and on the water, fish and wildlife habitats and the passage of fish, estuarine resources, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, sediment loads and water quality.

3. Maintenance of seasonal hydrologic connections between the river channel and floodplain to ensure the persistence of floodplain structure and function.

   Relevant environmental values: recreation in and on the water, fish and wildlife habitats and the passage of fish, estuarine resources, transfer of detrital material, aesthetic and scenic attributes, filtration and absorption of nutrients and other pollutants, sediment loads, water quality and navigation.

Once the low flow threshold was established, the criteria used for seasonal minimum flows development was maintenance of 85% of the most sensitive criterion associated with the resource management goals.

To further investigate and strengthen the protection of the Lower Peace/Shell System, two additional resource management goals were subject to technical analysis for evaluation of recommended minimum flows. The evaluations involved two scenarios, one with no freshwater withdrawals (i.e., the baseline condition) and the other with maximum withdrawals allowed by the minimum flows recommended for the Lower Peace River and Lower Shell Creek. The two management goals and the relevant environmental values associated with these goals are listed below.

1. Assess how the recommended minimum flows will affect the abundance and distribution of selected fishes in the Lower Peace/Shell System and Charlotte Harbor.

   Relevant environmental values: recreation in and on the water, fish and wildlife habitats and the passage of fish, estuarine resources and aesthetic and scenic attributes.

2. Assess how the recommended minimum flows will affect the status and trends in water quality parameters of the Lower Peace/Shell System.

   Relevant environmental values: recreation in and on the water, fish and wildlife habitats and the passage of fish, estuarine resources, transfer of detrital material, aesthetic and *scenic attributes, filtration, and absorption of nutrients and other pollutants, and water quality.*

5.4.1. Low Flow Threshold

Protection of aquatic resources associated with low flows is an important component of minimum flows development. A low flow threshold is defined as a flow rate below which no surface water withdrawals are allowed throughout the year. Although flows less than the low flow threshold may occur at any time of year and, they are most likely to occur during the dry season, i.e., in Block 1.

For the estuarine Lower Peace/Shell System, goals for developing a low flow threshold are to minimize upstream saline incursions that could affect salinity at an existing, permitted withdrawal location on the Lower Peace River, and to minimize adverse effects on the ecology of the river.

In establishing the 2010 minimum flows for the Lower Peace River, models developed to relate flows to ecological criteria in the Lower Peace River and Shell Creek showed no breakpoints or inflections in these relationships at low flows, thus it was concluded that development of a low flow threshold based on ecological criteria was not necessary. However, maintaining fresh water at the PRMRWSA Peace River Water Treatment Facility was identified as an operational criterion for establishing a low flow threshold to prevent intake of brackish water from the river. Based on this criterion and analyses conducted in 2009, a low flow threshold of 130 cfs for the sum of the flows at the Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee gages was identified and subsequently included in the minimum flows established for the Lower Peace River and in the water use permit issued to the PRMRWSA by the District.

The low flow threshold for the Lower Peace River stipulated that when the previous day's combined flows from Peace River at Arcadia, Horse Creek and Joshua Creek gages was less than or equal to 130 cfs, no withdrawals from the river would be allowed. The continued need for a low flow threshold for the Lower Peace River was deemed appropriate as part of the reevaluation process used to develop the recommended minimum flows for the Lower Peace River described in this report which were ultimately adopted into District rules in 2021.

As part of the 2010 development of minimum flows for the Lower Peace River, a low flow threshold was not identified for Lower Shell Creek, primarily because the City of Punta Gorda is permitted to withdraw water from the reservoir upstream of Hendrickson Dam. Development of a low flow threshold for Lower Shell Creek was similarly not advanced as part of the current minimum flows reevaluation/development process for the Lower Peace/Shell Creek System.

5.4.2. Biologically Relevant Salinities Zones

Alterations to timing and amount of freshwater inflow has a direct and instantaneous impact on salinity while impacts on other water quality constituents and biological communities may be indirect and are typically manifested on longer time scales (Atkins, Inc. 2013a). Since many estuarine communities are dependent on salinity variation for persistence and reproduction, the District uses the response of salinity distributions to change in freshwater flow as important, protective criteria for establishing estuarine minimum flows.

Various salinity zone classifications have been used to evaluate ecological characteristics of estuaries. Based on the Venice System for classification of marine waters (Anonymous 1958), five salinity zones have been established: limnetic (freshwater) at < 0.5 psu, oligohaline at 0.5 to 5 psu, mesohaline at 5 to 18 psu, polyhaline at 18 to 30 psu, and euhaline at > 30 psu. Schireiber and Gill (1995) used a three-tiered salinity classification for identifying and assessing important fish habitats: tidal freshwater (0 to 0.5 psu), mixing (0.5 to 25 psu) and seawater (> 25 psu).

Bulger et. al (1993), used a principal component analysis (PCA) of fish catch data from the mid-Atlantic region to establish four overlapping, biologically important salinity ranges of 0 to 4 psu, 2 to 14 psu, 1 to 18 psu and 16 to 27 psu. Using combined data from the nine study rivers in west-central Florida, Janicki Environmental, Inc. (2007) used an PCA of species presence-absence data to identify salinity zones of 0 to 7 psu, 7 to 18 psu, and 18-29 psu that were related to macroinvertebrate community structure. In a survey of seven rivers on the coast of west-central Florida, Clewell et al. (2002) found that freshwater plants that tolerate some combination of salinity levels and durations were primarily located upstream of the median location of 2 psu salinity in the river channels. They also report that freshwater plants tolerant of low salinity, which are often dominant in brackish marshes (e.g., cattails, sawgrass, and bullrush), were most common where median surface salinity values were less than 4 psu. These plants also occurred in somewhat higher salinity waters but were rarely found where median salinity values exceeded 12 psu. Similarly, in a study of the Suwannee River estuary, Clewell et al. (1999) found that the transition from sawgrass to saltmarsh species occurred where maximum salinities in the dry season were near 10 psu. To assess the relationship between fish community structure and salinity in the Lower Peace/Shell System, PCA was used to identify four salinity classes separately for seines and trawls, and scores greater than 0.60 were used as a criterion for identifying the significantly correlated salinity classes (Figure 5-7).

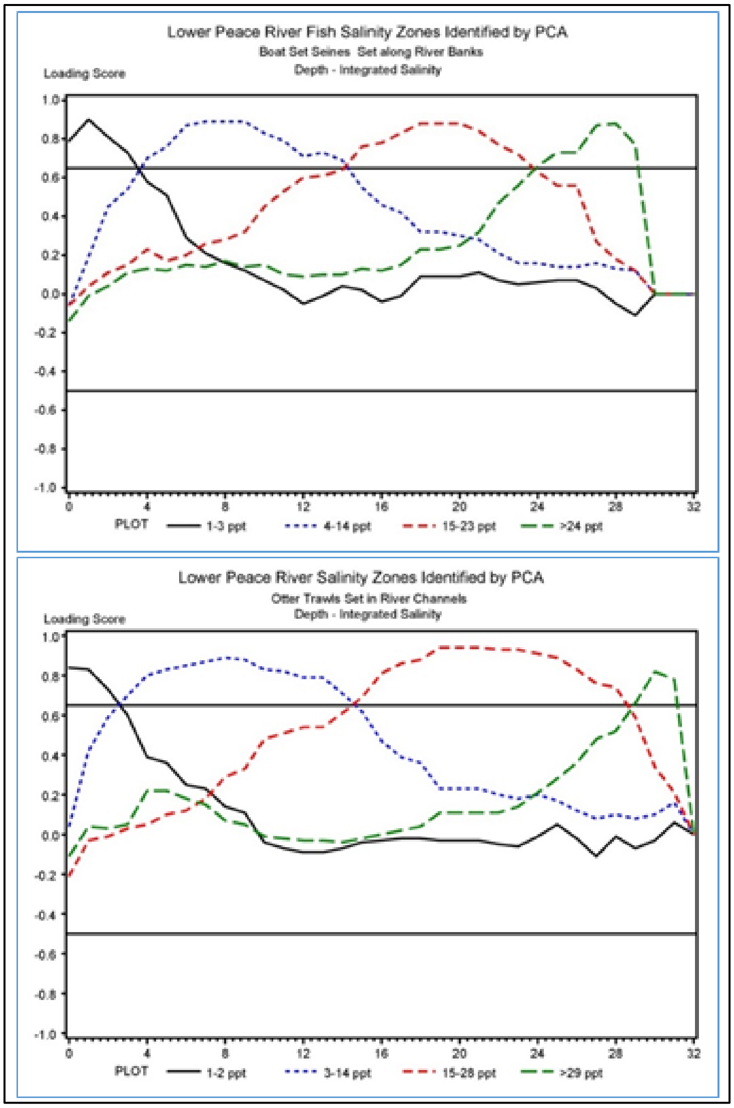

Figure 5-7. Salinity classes identified by Principal Component Analysis for the Lower Peace River, based upon the distribution of fish captured in seine (upper panel) and trawl (lower panel) samples. (Data source: FWRI 1998).

Based on these findings and other literature (e.g., Beck et al. 2000, Hoyer et al. 2004, Jassby et al. 1995, Kimmerer 2002, SFWMD 2002, Water Resource Associates, Inc. et al. 2005, Tampa Bay National Estuary Program 2006, Culter 2010), five isohalines (< 2, < 5, < 10, < 15 and < 20 psu) were selected to represent the boundaries of salinity zones that are important to either shoreline plant communities, benthic macroinvertebrates, or fishes in the Lower Peace/Shell System. The < 2 and < 15 psu zones were chosen because analysis of fish community structure in the Lower Peace River reveals break points at approximately 2 and 15 psu. The < 5 psu zone corresponds to the upper limit of the oligohaline zone in the Venice system. The < 10 psu zone roughly serves as a mid-point to the mesohaline zone and is critical for saltmarsh species according to Clewell et al. (1999).

5.4.3. Floodplain, Soils and Vegetation

Ensuring sufficient flows for biological communities associated with river floodplains is an important component of the development of minimum flows. Periodic inundation of riparian floodplains by high flows is closely linked with the overall biological productivity of river ecosystems (Crance 1988, Junk et al. 1989). Many fish and wildlife species associated with rivers use both instream and floodplain habitats, and inundation of the river floodplains greatly expands the habitat and food resources available to these organisms (Wharton et al. 1982, Ainsle et al. 1999, Blewett et al. 2017, Hill and Cichra 2002). Inundation during high flows also provides a subsidy of water and nutrients that supports high rates of primary production in river floodplains (Conner and Day 1976, Brinson et al. 1981). This primary production yields large amounts of organic detritus, which is critical to food webs on the floodplain and within the river channel (Vannote et al. 1980, Gregory et al. 1991). Floodplain inundation also contributes to other physical-chemical processes that can affect biological production, uptake, and transformation of macro-nutrients (Kuensler 1989, Walbridge and Lockaby 1994).

Soils in river floodplains exhibit physical and chemical properties that are important to the overall function of the river ecosystem (Wharton et al. 1982, Stanturf and Schenholtz 1998). Anaerobic soil conditions can persist in areas where river flooding or soil saturation is of sufficient depth and duration. The decomposition of organic matter is much slower in anaerobic environments, and mucky or peaty organic soils can develop in saturated or inundated floodplain zones (Tate 1980, Brown et al. 1990). Although these soils may dry out on a seasonal basis, typically long hydroperiods contribute to their high organic content. Plant species that grow on flooded, organic soils are tolerant of anoxic conditions and the physical structure of these soils (Hook and Brown 1973, McKevlin et al. 1998). Such adaptations can be an important selective mechanism that determines plant community composition. Because changes in river hydrology can potentially affect the distribution and characteristics of floodplain soils, soil distributions and their relationship to river hydrology are routinely investigated as part of minimum flows and levels determinations for District rivers.

Based on the Cooperative Land Cover (CLC) Map developed by the Florida Fish and Wildlife Conservation Commission and Florida Natural Areas Inventory, the lower portion of the Peace River is predominantly classified as floodplain swamp. However, land-based field examination identified at least two distinguishable floodplain zones (HSW Engineering, Inc. 2016). The inner floodplain wetland zone had an over story dominated by cypress (*Taxodium distichum*) where soils are permanently or semi-permanently flooded. The outer floodplain wetland zone is distinguishable by the predominance of over story species such as Laurel oak (*Quercus laurifolia*), Water oak (*Quercus nigra*) and Red maple (*Acer rubrum*).

5.4.4. Fish Abundance and Distribution

Relationships between freshwater inflow and the abundance and distribution of selected estuarine dependent fishes and invertebrates were examined to evaluate potential impacts of the recommended minimum flows on fish habitats in the Lower Peace/Shell System and Charlotte Harbor (Rubec et al., 2018; included as Appendix E to this report). A primary goal of this investigation was to ensure that the recommended minimum flows do not result in unacceptable environmental impacts to fish populations.

The project included development and use of habitat suitability modeling and related mapping (e.g., creation of Habitat Suitability Models [HSMs] and maps) for eight estuarine-dependent taxa. Based on review of previous studies of Charlotte Harbor and consultation with Dr. Ernst Peebles of the University of South Florida College of Marine Science, the FWC identified seven fish or fish life-history stages and one commercially-important invertebrate species that are known to be responsive to freshwater inflows in the Lower Peace/Shell System and Charlotte Harbor:

1. Juvenile Bay Anchovy (*Anchoa mitchilli*) (15-29 mm Standard Length (SL);
2. Adult Bay Anchovy (*Anchoa mitchilli*) (30-60 mm SL);
3. Early Juvenile Southern Kingfish (*Menticirrhus americanus*) (10-119 mm SL);
4. Early-Juvenile Red Drum (*Sciaenops ocellatus*) (10-299 mm SL);
5. Early-Juvenile Spot (*Leiostomus xanthurus*) (10-149 mm SL);
6. Juvenile Sand Seatrout (*Cynoscion arenarius*) (10-149 mm SL);
7. Hogchoker (*Trinectes maculatus*) (10-100 mm SL); and
8. Blue Crab (*Callinectes sapidus*) (10-150 mm SL).

The HSMs were developed for two scenarios, one with no freshwater withdrawals (baseline) and another associated with the maximum percent-of-flow reductions allowed by the recommended minimum flows for the Lower Peace River and Lower Shell Creek. This latter scenario did not, however, include a maximum flow-reduction cap or limit for water withdrawals that is included in the recommended minimum flows for the Lower Peace River.

5.4.5. Water Quality

As part of the District's efforts to evaluate the recommended minimum flows for the Lower Peace River and Lower Shell Creek, Janicki Environmental, Inc. (2019) was contracted to evaluate relationships between flows and observed water quality. The specific tasks within this study consisted of data compilation, summarizing existing studies, conducting exploratory data analysis, conducting stochastic predictive modeling, and synthesizing information regarding the potential effects of the recommended minimum flows on selected water quality constituents.

For the evaluation, water quality data from the PRMRWSA and City of Punta Gorda's HBMP databases, as well as from multiple sources including FDEP's Impaired Water Rule (IWR) database and USGS continuous recorders were used. Emphasis was given to the effects of flow on total nitrogen, total phosphorus, chlorophyll, and dissolved oxygen concentrations, which may all be directly influenced by freshwater withdrawals.

5.5. Technical Approaches for Addressing Resources of Concern

5.5.1. Salinity-based Habitat Modeling

In establishing the 2010 minimum flows for the Lower Peace River, a coupled 3D-2DV model, named Lakes and Estuary Simulation System (LESS) was developed, which dynamically links a laterally averaged two-dimensional model (LAMFE) and a three-dimensional hydrodynamic model (LESS3D) to simulate circulations, salinity transport processes, and thermal dynamics in a domain that includes the upper portion of Lower Peace River, Lower Myakka River and Upper Charlotte Harbor (Chen 2008).

As part of the current minimum flow reevaluation and development process, the LESS model was upgraded to unstructured LESS model (UnLESS), which dynamically links the LAMFE (Chen 2004) with a 3D unstructured Cartesian grid model, named UnLESS3D (Chen 2011 & 2012). For application of the UnLESS model, the simulation domain is divided into a 3D subdomain and a 2DV subdomain, with the former being simulated with the UnLESS3D model and the latter with the LAMFE model. As both UnLESS3D and LAMFE can fit the bottom bathymetry and the shoreline and automatically track the dynamic position of the shoreline, the UnLESS model retains all these features.

5.5.1.1 Setup of the UnLESS Model

As shown in Figure 2-6, a new bathymetric survey was conducted for Charlotte Harbor and the tidal reaches of the Myakka and Peace rivers. These new bathymetric data, along with available high-resolution LiDAR data, were used for the grid generation of the UnLESS model for Charlotte Harbor.

Figure 5-8 shows the simulation domain and model mesh for the current modeling study of the hydrodynamics, salinity transport processes, and thermodynamics in the Lower Peace/Shell System and greater Charlotte Harbor estuary. In the figure, the 3D grids consist of different sizes of rectangular bricks (tiles) plotted in green and 2DV grids are bounded by cross-sections plotted with yellow lines. The 3D subdomain includes the entire Charlotte Harbor, Gasparilla Sound, Pine Island Sound, Matlacha Pass and the most downstream portion of Caloosahatchee River, the downstream 16.13 kilometers of the lower Peace River, the downstream 12.64 kilometers of the lower Myakka River, and the most downstream 1.74 km of the Shell Creek, and an offshore area which is about 20 – 30 km into the Gulf of Mexico. The 2DV subdomain includes the main stems of the Lower Peace River, Lower Myakka River, and Lower Shell Creek, as well as their branches. The downstream 3.67 km of the Big Slough Canal is also included in the 2DV subdomain. The upstream limits of the 2DV subdomain are at a cross section just downstream of the confluence of Horse Creek with the Lower Peace River, at River-kilometer 37.27 for the Lower Myakka River, and at the base of the Hendrickson Dam for Shell Creek.

The Caloosahatchee River was not included in the simulation domain, as it has relatively insignificant interactions with the Lower Peace River and Lower Shell Creek. Although Caloosahatchee River flows may only slightly affect salinity and temperature in the Lower Peace/Shell System, their effects were indirectly considered in the simulation with the proper specification of the open boundaries near the mouth of the Peace River.

In Figure 5-8, the 3D subdomain was discretized with 4,790 grids in the horizontal plane and 17 layers in the vertical direction. Vertical spacings of the 17 layers varied from 0.4 m to 4 m, while the dimension of the unstructured Cartesian grid varied from 37.5 m × 37.5 m in Peace River and Shell Creek to 3,500 m × 2,400 m for the offshore area, where the first number represents the length in the *x*-direction and the second number the length in the *y*-direction. The 2DV subdomain was discretized with 311 longitudinal grids and the same 17 vertical layers as those in the 3D subdomain. The longitudinal spacing in the 2DV subdomain varied from 39 m to 4,147 m.

In summary, the updated model domain included the entire Charlotte Harbor, entire Lower Peace River, Lower Shell Creek, Lower Myakka River, Gasparilla Sound, Pine Island Sound, Matlacha Pass, and the most downstream portion of Caloosahatchee River (Figure 5-8).

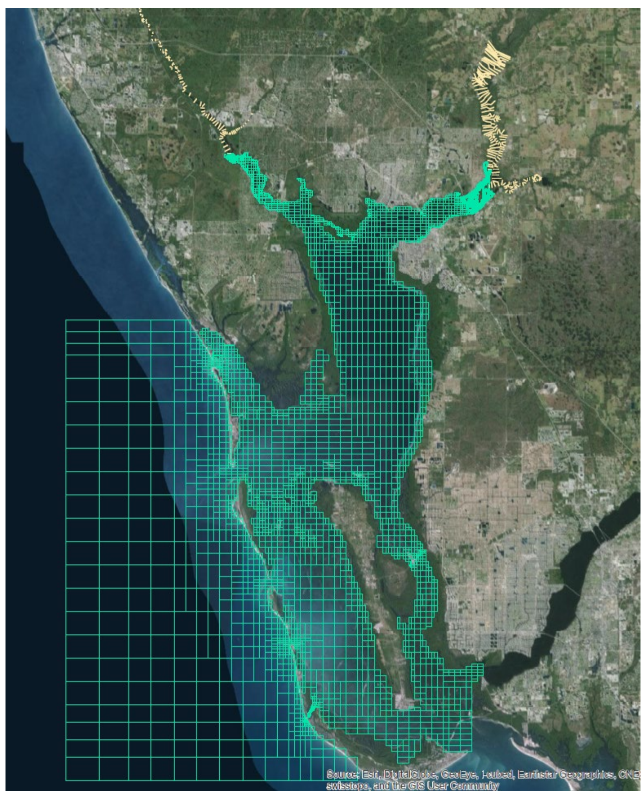

Figure 5-8. Mesh and simulation domain of the UnLESS hydrodynamic model developed to support the current reevaluation and development of minimum flows for the Lower Peace River and Lower Shell Creek. Green gridded area depicts area addressed with a three-dimensional hydrodynamic model (UnLESS3D). Areas identified with yellow cross-sections were addressed with a laterally averaged two-dimensional model (LAMFE).

5.5.1.2 UnLESS Hydrodynamic Model Input Data

Input data used to drive the UnLESS model include flow data at the upstream boundaries, water level, salinity, and temperature data at the downstream open boundaries, as well as meteorological data for wind shear stress and heat flux calculations at the free surface. Some of these input data are directly measured in the system, while others are estimated using models. Based on the availability of all the data, including those to drive the model (input data) and to calibrate/verify the model (as discussed in the next section), a 20-month period between January 2013 and August 2014 was chosen for the modeling study.

At the upstream boundaries of the Lower Peace River, Shell Creek, and Lower Myakka River, including the Blackburn and Big Slough canals, freshwater flows, which included both gaged and estimated flows, were specified. Gaged flow used at the upstream boundary of the Lower Peace River included data measured at the USGS Peace River at Arcadia, Joshua Creek at Nocatee, and Horse Creek near Arcadia gage sites. At the upstream boundary of the Lower Shell Creek, gaged flow was from the USGS Shell Creek near Punta Gorda site. For the Myakka River, gaged flows were those measured at the USGS Myakka River near SR 72 near Sarasota, FL (No. 02298830), Big Slough at Tropicaire Blvd. near North Port, Florida (No. 02299450), and Blackburn Canal near Venice, Florida (No. 02299692) gage sites.

The total area gaged at the Peace River at Arcadia, Joshua Creek at Nocatee, and Horse Creek near Arcadia accounts for about 84% of the Peace River watershed. The remaining 16% of the Peace River watershed is ungaged with unknown freshwater contribution to the Charlotte Harbor. For the Myakka River, about one half of the watershed is ungaged. Although gaged flows contribute most of the total hydrologic loading to the Charlotte Harbor estuary, ungaged flows make up a substantial fraction of freshwater inflow to the estuary and affect salinity distributions in the simulation domain. For these reasons, good estimation of ungaged flows into the simulation domain is important. Details about the methods used to estimate ungaged flows for the Peace and Myakka Rivers can be found in Ghile and Leeper (2015).

Another freshwater inflow loss to Charlotte Harbor is associated with the Blackburn Canal, which drains the Myakka River and connects the river with Donna/Roberts Bay on the Florida Gulf Coast. Withdrawals by the PRMRWSA represents freshwater inflow loss to the Lower Peace/Shell System and the greater Charlotte Harbor area and are accounted for in the input data for the UnLESS hydrodynamic model. Another freshwater inflow loss to Charlotte Harbor is associated with the Blackburn Canal, which drains the Myakka River and connects the river with Donna/Roberts Bay on the Florida Gulf Coast. We used USGS tide-filtered (residual) daily mean flow at the Blackburn Canal near Venice site measured on and before May 4, 2013, and estimated the daily Blackburn Canal flow after May 5, 2013, using a correlation between gaged flow at the USGS Myakka River near SR 72 near Sarasota gage site and that in Blackburn Canal.

Boundary conditions of water level, salinity, and temperature at the downstream open boundaries in the Gulf of Mexico and Caloosahatchee River during the simulation period were provided by Zheng and Weisberg (2014) from their WFCOM model. Water levels and salinities and temperatures in eight equal-spacing σ layers were provided along the south, west, and north open boundaries in the Gulf as well as in the Caloosahatchee River (see Fig. 5-8). Because the UnLESS model is a z-level model, salinity and temperature results from the WFCOM model were interpolated from the eight σ layers to eight fixed elevations before they were read to the UnLESS model, which further interpolates these boundary conditions from the eight fixed elevations to the 17 z-level layers in UnLESS each time step.

Weather data used for the Charlotte Harbor UnLESS model included rainfall, wind speed and direction, solar radiation, air humidity, and air temperature. These data were measured at a station in Charlotte Harbor during 2/7/2013 – 8/31/2014. For time periods prior to February 7, 2013, average rainfall data at the following District sites in the watershed, which are close to the simulation domain, was used: New Charlotte South (SID 24710), Punta Gorda 4 ESE NWS (SID 25105), Punta Gorda NWS (SID 24711), ROMP TR1-2 Tropical Gulf (SID 25220), and ROMP TR3-1 Point Lonesome (SID 25218). Measured solar radiation, air humidity, air temperature, and wind speed and direction at the District site Peace River II ET (SID 24571) were used prior to February 7, 2013.

5.5.1.3 UnLESS Hydrodynamic Model Calibration and Verification

There were five real-time data stations available in the Charlotte Harbor estuarine system that could be used for model calibration and verification. These stations included one in the upper portion of Charlotte Harbor, which was established and maintained by the Mote Marine Laboratory (Mote), and two USGS gage sites in the Lower Peace River−Peace River at Punta Gorda, FL (No. 02298300) (PR_PG) and Peace River at Harbour Heights, FL (No. 02297460) (PR_PRH). The two Shell Creek stations were the Shell Creek near Punta Gorda (SC_PG) station and the Shell Creek below the reservoir (SC_BR) station, which were both maintained by the District. The Mote and PR_PG stations are in the 3D subdomain, while PR_HT, SC_PG, and SC_BR are in the 2DV subdomain.

Measured data at these stations included water levels, salinities, and temperatures. Except for the Mote station, where top, mid-depth, and bottom salinities and temperatures were measured, all stations have top and bottom salinity and temperature measurements. At the Mote station, real-time current data were collected with an acoustic Doppler current Profiler (ADCP), which measured current speed and direction in six bins, covering the depth between -3.25 m, NAVD88 and -0.25 m, NAVD88 with each bin being about 0.5 m in height.

Out of the 20-month modeling study period, model calibration was from August 2013 to August 2014, while model verification was from January 2013 to July 2013. Model calibration involved adjusting model parameters such as bottom roughness, eddy viscosities and diffusivities, etc., in the 3D and 2DV subdomains to obtain best matches between model results and field data at the five measurement stations. After the model was calibrated and verified, the model was run for the entire 20-month period from January 2013 to August 2014.

The time step used in the simulation was 90 seconds for most of the simulation period but was reduced to 75 or 72 seconds during a few short periods when storms occurred. With a grid size as small as 37.5 m × 37.5 m in or near the passes, where the water depth is relatively deep (> 6 m), the gravity wave celerity is no less than 7.6 m sec^{-1} and the Courant number is greater than 14 even when Δt = 72 seconds. In other words, The UnLESS model can be run with a Courant number that is greater than 14 without any stability problems.

Comparisons of time series of simulated water levels, velocities, salinities, and temperatures were made with measured real-time data at the five stations. Modeled velocities at the vertical layers were interpolated to the exact elevations of the ADCP bins for comparison with measured data. Similarly, modeled salinities and temperatures over the water depth were interpolated to the exact elevations of the salinity and temperature sensors for comparison with field data. Discussions of model results of water level, salinity, temperature, and current and visual comparisons of time series of modeled variables with measured data can be found in Appendix C.

Although visual comparisons of model results with field data indicated that the UnLESS model was successfully calibrated and verified for the Charlotte Harbor estuarine system, including its major tributaries, model skills were also assessed to quantify the model performance. A skill assessment parameter of Willmott (1981) was used to judge the agreement between model results and measured data. The Willmott skill assessment parameter varies between 0 and 1, i.e., a perfect agreement between simulated results and measured data yields a skill of one and a complete disagreement yields a skill of zero.

In addition to the Willmott skill parameters for simulated water levels, salinities, and temperatures at the five stations, other statistical parameters such as the coefficient of determination (R^2 value), the mean error (ME), and the mean absolute error (MAE) were also calculated to quantify the error of the model. As such, the skill metrics includes a total of four statistical measurements, which were not only calculated for results at each individual sensor but also for those at all the sensors at all the five stations to get the overall measurements of the model performance for water level, salinity, temperature, and current predictions. A discussion of the model performance at each individual sensor for the five stations is provided in Appendix C.

Table 5-6 lists the overall skill metrics for water level, salinity, temperature predictions by the UnLESS model. Although the model performance varied for predicting different variables, the overall skills for all four variables were satisfactory. We therefore concluded that the UnLESS model was successfully calibrated and verified for the Lower Peace River/Shell System and is appropriate for assessment of effects of the flow reduction on salinity habitats in support of minimum flows establishment.

Table 5-6 Skill metrics for water level, salinity, temperature, and current predictions by the UnLESS hydrodynamic model during the calibration and verification periods.

Variable	Calibration Period				Verification Period			
	ME	MAE	R2	Skill	ME	MAE	R^2	Skill
Water Level (cm)	-0.34	7.90	0.78	0.94	0.52	7.36	0.80	0.94
Salinity (psu)	-0.35	0.83	0.99	0.99	-0.33	0.99	0.98	0.99
Temperature (oC)	-0.15	1.84	0.89	0.94	0.02	1.74	0.87	0.95
Velocity (cm/s)	-0.38	5.64	0.81	0.95	-0.31	5.49	0.81	0.95

5.5.1.4 UnLESS Hydrodynamic Model Uncertainty

Although the UnLESS model is well calibrated and validated against real-time field data of water level, current, salinity, and temperature measured at five locations in the simulation domain, the model is subject to uncertainties with some model parameters and input data. Chen (2012) examined sensitivities of simulated salinity habitats in the Lower Manatee/Braden River system to bottom roughness (z_0), ambient vertical eddy viscosity/diffusivity (AVEVD), horizontal eddy viscosity/diffusivity (HEVD), and ungaged flows (UGF) and found that low salinity habitats are most sensitive to AVEVD, followed by UGF, z_0, and HEVD, with HEVD's influence being almost one order of magnitude smaller than the other three. The sensitivity analysis of Chen (2012) provides insight into effects of uncertainties in AVEVD, Z0, HEVD, and UGF on salinity habitats in the Lower Peace River/Shell Creek system simulated by the UnLESS hydrodynamic model. While AVEVD, Z_0, and HEVD have been extensively discussed and researched in literature and involve relatively small uncertainties, uncertainties associated with flow estimation from several small ungaged streams, creeks and canals that directly or indirectly flow into the Upper portion of Charlotte Harbor are difficult to quantify. Previously, the flows from those ungaged sites were simulated using a surface water model HSPF, Hydrological Simulation Program-FORTRAN (Ross, et al. 2005). The HSPF model has been less accurate than preferred for this area, due to the strong effects of surface/groundwater interactions on streamflow in the area, and a lack of explicit representation of the hydro-geologic processes that control baseflow which is typically needed for modeling purposes. In addition, large portions of the ungaged area have been altered to urban land use, and not knowing how much of the urbanized area is directly flowing into the drainage systems and how much is draining into wastewater treatment systems has affected model accuracy.

As an alternative, a simple drainage ratio-based method was used to estimate streamflow at some of the ungaged sites from neighboring gaged sites. The gaged sites were weighted based on their proximity and similarity in runoff response to a given ungaged site. The drainage area ratio method generally allowed maintenance of the hydrograph patterns observed in the gaged basins and improved the performance of the UnLESS hydrodynamic model. However, there are uncertainty errors in this method, as some altered ungaged basins (e.g., basins dominated by urban land use) do not exhibit runoff responses similar to neighboring gaged basins.

5.5.1.5 UnLESS Hydrodynamic Model Simulations

As discussed in Section 3.5 above, freshwater inflows to Charlotte Harbor are reduced by withdrawals and augmented by excess agricultural runoff. These effects on flows were accounted for in the development of baseline flow records for the Lower Peace River and Lower Shell Creek that were used in model simulations.

After calibration against measured real-time salinity and water elevation data collected by the District and the USGS at five stations, the UNLESS model was run for an 8-year period, from 2007 through 2014 using baseline flows (i.e., flows corrected for withdrawals and return-irrigation flows) and numerous reduced flow scenarios. Results from the reduced flow scenarios were compared with results from the baseline scenario to evaluate effects of various freshwater inflow reductions on the water volume, shoreline, and bottom area salinity habitats in the Lower Peace/Shell System.

For each scenario simulation, model outputs (water level, salinity, and temperature) were summed across space to produce instantaneous total habitats for one-hour intervals. These instantaneous estimates were averaged across the entire 8-year simulation period to produce estimates of shoreline length, total water volume, and bottom area for the entire system at salinity concentrations ranging from ≤ 0.5 psu to ≤ 20 psu. Water volume was calculated across all model layers and shoreline habitat was calculated based on bottom elevations at the four corners of a model grid and the simulated water surface elevation. Bottom-layer salinity zones in model grids were used for estimate bottom-area salinity habitats.

The method used to evaluate changes between baseline and reduced-flow scenarios involved preparing cumulative distribution function (CDF) plots of habitat area, shoreline and volume for baseline flows and the different flow reduction scenarios. The CDF plots are a useful tool, as they incorporate the spatial extent and the temporal persistence that a given salinity zone is achieved. This allows quantification of habitat availability in terms of both space and time.

The method used to compare alternative scenarios to the baseline condition using CDF plots is illustrated in Figure 5-9. The habitat available for a given scenario is estimated by calculating the area under the curve from a CDF plot. The blue-hatched area (area under the curve) in Figure 5-9a is the estimate of the habitat available for baseline flows (HA_B) for the entire modeling period. Figure 5-9b presents the habitat available under an alternative scenario, e.g., Scenario 1 (HA_{S1}), for the same period. The difference in area between the two curves is the habitat loss from the baseline condition for the specific flow reduction scenario (Figure 5-9c).

Using this approach, the relative change from baseline can be calculated for selected flow reduction scenarios. For the reevaluation and development of minimum flows for the Lower Peace River and Lower Shell Creek, relative flow reductions from baseline flows associated with preserving 85% of < 2, < 5, < 10, < 15 and < 20 psu salinity-based habitats were calculated to determine minimum flows for the three blocks previously described in Section 5.2. These habitats were assessed using nine simulations, including the baseline scenario and scenarios associated with 5, 10, 15, 20, 25, 30, 35 and 40% reductions in baseline flows. When necessary linear interpolation was used to identify specific flow reductions intermediate to the reduced flow scenarios that were associated with more than a 15% reduction in salinity habitat.

Once the block-specific minimum flows were determined, evaluation of potential sea level change was evaluated for low, intermediate, and high rates of sea level rise for the period from 2010 through 2035. This evaluation was conducted to estimate potential salinity habitat metrics might be determined in the future under both the baseline and the recommended minimum flow scenarios.

Details about the model theory of the dynamically coupled model UnLESS can be found in Appendix C and in Chen (2020).

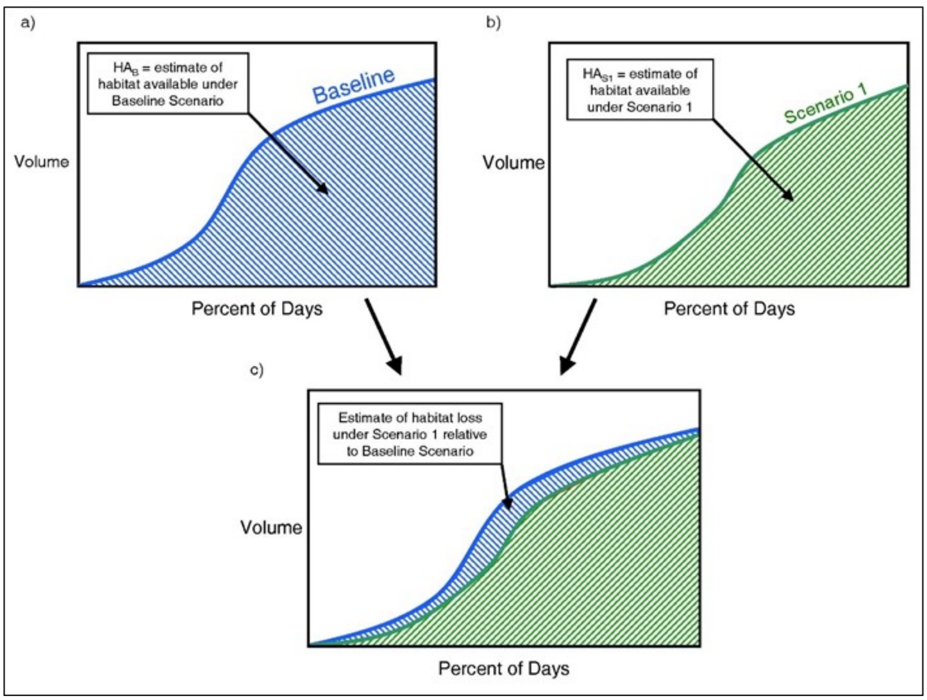

Figure 5-9. Example of area under curve calculated from a CDF plot: (a) represents the area under the curve for the baseline condition; (b) represents the area under the curve for an alternative flow reduction Scenario 1; and (c) represents the loss of habitat for the flow reduction relative to the habit associated with the baseline condition.

5.5.2. Floodplain Inundation Modeling

In support of the development of recommended minimum flows for the Lower Peace River and Lower Shell Creek, the District contracted with HSW Engineering, Inc. (2016; included as Appendix D to this report) to evaluate relationships between flows and floodplain wetland inundation patterns for the Lower Peace River. The evaluation focused on the Lower Peace River based on the occurrence of floodplain swamp in that portion of the Lower Peace/Shell system.

Floodplain swamp is not found in Lower Shell Creek, likely as a function of the location of the Hendrickson Dam in the portion of the Shell Creek watershed that is most strongly affected by incursion of higher-salinity water from the Peace River and Charlotte Harbor.

The framework for simulating floodplain inundation areas for the Lower Peace River involved using the UnLESS model to simulate a water-surface profile at selected, surveyed cross-sections within the Lower Peace River area (Figure 5-10), and HEC-GeoRAS to process those water surface profiles and generate floodplain inundation profiles in ArcGIS 10.6. The framework also required a high-quality DEM representing the ground surface and a land cover map reflecting the location and extent of wetlands along the Lower Peace River (Figure 5-10).

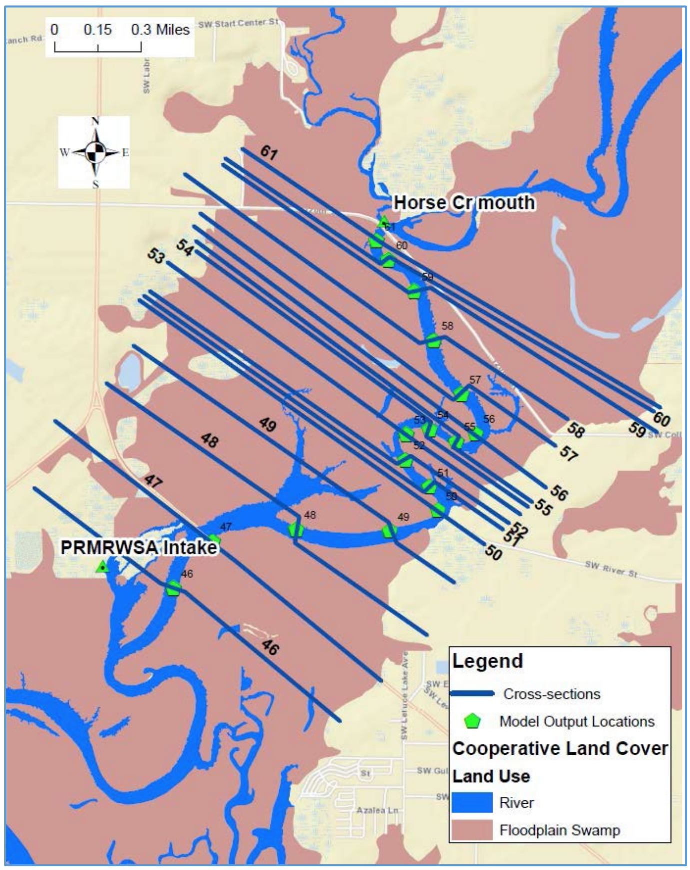

Figure 5-10. Location of cross-sections and wetlands for a floodplain inundation assessment for the Lower Peace River. Note that cross-section numbers do not correspond with river kilometer (RKm) locations.

The steps involved in the floodplain inundation modeling, detailed in HSW Engineering, Inc. (2016; see Appendix D), were as follows:

1. The UnLESS model was run for the period from 2007 through 2014 and provided water surface elevation at the surveyed cross-sections. The water surface elevation in the study area is controlled by flows in the Lower Peace River and tides. To capture the flow-tide

variability, 10 flow scenarios and 8 stage scenarios were evaluated resulting in 80 water surface elevation combinations at each cross-section.

2. The 80 water elevations were converted to triangulated irregular networks (TINs) using HEC-GeoRAS in ArcGIS for the representation of water surfaces.
3. The water-elevation TINs were rasterized in ArcGIS 10.6 at a spatial resolution of the DEM (i.e., 5 ft by 5 ft).
4. The rasterized water surface profiles and DEM data were overlain to determine the extent and depths of inundation. Inundation area was defined as the area encompassed by the intersection of the water surface and land surface.
5. The total inundated floodplain wetland area was determined for each of the 80 flow-stage scenarios by converting the rasterized inundation areas to shapefiles and overlaying with the CLC land cover shapefile.
6. To quantify a daily inundated wetland area, a flow-stage-inundated area rating curve was developed using piecewise regression analysis in IBM® SPSS statistical software.
7. Using the rating curve, a daily time series of inundated floodplain wetland area for the baseline condition was generated for the period from 2007 through 2014.
8. A total available inundated floodplain area was calculated for the baseline condition by summing the daily time-series area values.
9. Steps 7 and 8 were repeated for scenarios associated with 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40 % reductions in the baseline flows.

Habitat decreases for the reduced flow scenarios were calculated by subtracting the total available inundated floodplain area for each simulation from the total available inundated floodplain area for the baseline condition to determine which, if any of the flow reduction scenarios resulted in more than a 15% reduction in inundated floodplain wetland area.

Multiple sources of uncertainty can be associated with our floodplain inundation modeling for the Lower Peace River. These sources can be ascribed to hydrologic data (e.g., gaged tide stage and flows) measurement errors; spatial (horizontal and vertical) ground elevation measurement and data-processing errors associated with DEM development; estimation of flows from ungaged watersheds used in the hydrodynamic modeling analyses (see Section 5.5.1.4); and uncertainty associated with the Florida CLC map layer.

5.5.3. Fish Habitat Modeling

The Habitat Suitability Modeling (HSM) completed for the District by Rubec et al. (2018; included as Appendix E to this report) was based on information in the FWC Fish and Wildlife Research Institute (FWRI) Fisheries-Independent Monitoring (FIM) database that was collected from 2004-2013 and information associated with the District's hydrodynamic modeling of the Lower Peace/Shell System and Charlotte Harbor for the period from 2007 through 2014.

Steps involved in the model framework used to assess impacts of the recommended minimum flows on the abundance of selected fish and Blue Crab in the Lower Peace/Shell System and Charlotte Harbor were as follows:

1. Datasets for the selected fish and invertebrate species or life-stages, including catch numbers and effort, temperature, salinity, dissolved oxygen, and site-depth at capture for the period from 1996 through 2013 were extracted from the FIM database. Bottom types at the FIM sampling locations were assigned based on District seagrass mapping information for 2012 and a National Oceanic and Atmospheric (NOAA) database.
2. The data were converted to habitat grids with 15m x 15m cells using kriging in ArcGIS (Figure 5-11).
3. Datasets for salinity and temperature derived from UnLESS hydrodynamic model were averaged within seasons across years (2007 through 2014) and used to create seasonal salinity and seasonal temperature grids in the study area.
4. Non-linear splines were fit to fish catch rate data (catch-per-unit-effort or CPUE) across gradients for water temperature, salinity, dissolved oxygen, bottom type, and depth. The HSMs were built using statistical functions that choose the best combination of environmental variables based on the lowest Akaike Information Criterion (AIC).
5. Predicted sampling gear corrected CPUEs (or GC-CPUEs) derived from the HSM analyses were imported into the ArcGIS datasets/layers to create baseline seasonal GC-CPUE grids for each species or life-stage.
6. Each continuous GC-CPUE grid was partitioned into four zones (Low, Moderate, High, Optimum) using the Jenks natural breaks classification method to create seasonal HSM maps.
7. Graphs of observed mean GC-CPUEs across the zonal grids were used to spatially validate the reliability of the predicted HSM maps. Increasing mean observed GC-CPUEs across the zones indicated agreement between the FIM data that went into the models and the predicted HSM maps.
8. Steps 5 and 7 were repeated for a minimum flow scenario associated with the recommended minimum flows for the Lower Peace River and Lower Shell Creek.
9. Potential decreases in habitat area and population numbers were calculated by subtracting results from a recommended minimum flows scenario (which was based on the maximum percent-of-flow reductions associated with the recommended minimum flows but did not include the maximum flow-reduction cap or limit for water withdrawals that is included in the recommended minimum flows for the Lower Peace River) from the baseline scenario results to predict potential impacts of the recommended minimum flows on the abundance of selected fishes and a commercially important invertebrate in the Lower Peace/Shell System.

Multiple sources of uncertainty can be associated with our habitat suitability modeling for the Lower Peace/Shell System and Charlotte Harbor. Specific sources of uncertainty that could affect the accuracy of the HSM modeling, particularly the estimation of population numbers, include:

- Hydrologic data (e.g., gaged tide stage and flows) measurement errors.

- Spatial (horizontal and vertical) topographic (ground elevation and bathymetric data) measurement and data-processing errors.
- Use of NOAA bottom-type data surveyed in the 1980s, that may have been changed over the years (e.g., due to hurricanes).
- Uncertainty associated with spatial interpolation of environmental data (salinity, dissolved oxygen, temperature, substrate, and bathymetry) to a 15 x 15 m grid size.
- Assumption that dissolved oxygen remained time-invariant within each season for baseline and recommended minimum flows scenarios.
- Estimation of flows from ungaged watershed used in the hydrodynamic modeling analyses (see Section 5.5.1.4).
- Parameterization uncertainty associated with the delta-type generalized additive models (GAMs) used to associate CPUE-GC data with environmental variables.

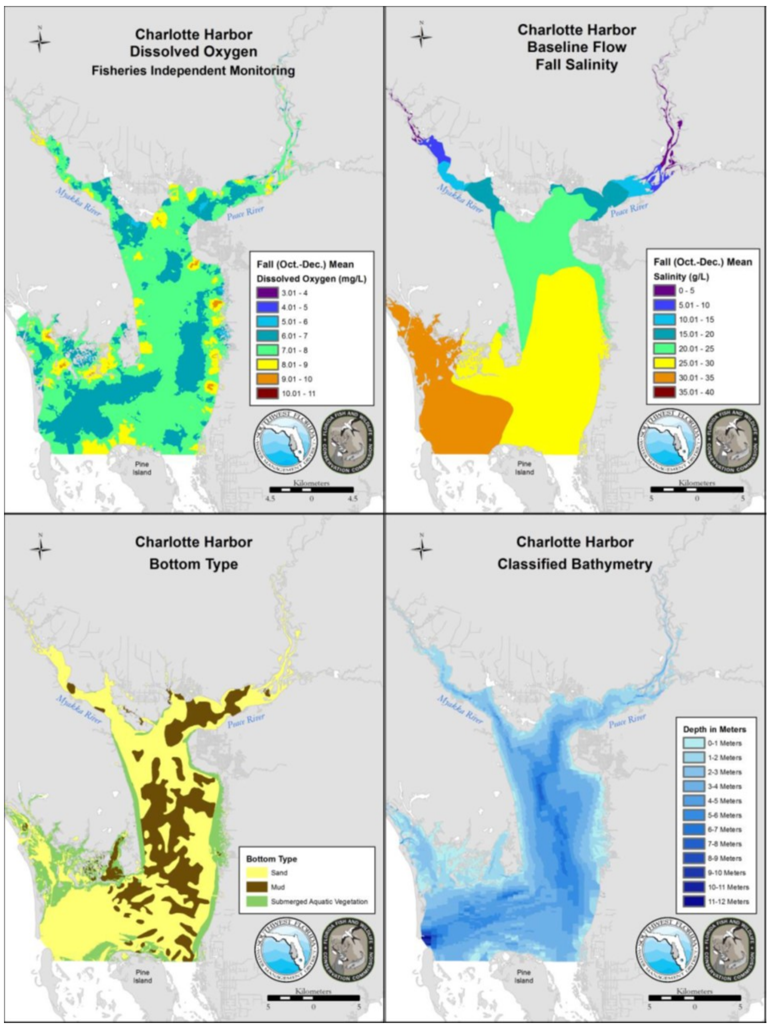

Figure 5-11. Example habitat information used for habitat suitability modeling (HSM) for fish and an invertebrate in the Lower Peace River/Shell System and Charlotte Harbor: a) seasonal (fall) dissolved oxygen concentrations from Florida Fish and Wildlife Conservation Commission Fisheries Independent Monitoring sampling in 1966 through 2013; b) seasonal (fall) salinity based

on District hydrodynamic modeling for the period from 2007 through 2014; c) bottom type from a National Oceanic and Atmospheric Administration database; and d) District bathymetric data collected to support hydrodynamic modeling.

5.5.4. Water Quality Modeling

As part of the District's efforts to assess the impacts of recommended minimum flows for the Lower Peace River and Lower Shell Creek on water quality, Janicki Environmental, Inc. through Applied Technology and Management, Inc. (ATM) was contracted to evaluate relationships between flows to the Lower Peace/Shell System and observed water quality in the system. As detailed in the Janicki Environmental, Inc. (2019) water quality report, included as Appendix F to this document, the following steps were undertaken to evaluate the recommended minimum flows.

1. Screening methods were used to detect potential outliers or possibly erroneous data in the various datasets explored. The screening methods included robust regression analysis implemented using the RobustReg procedure in SAS® software.
2. Descriptive evaluations of the screened time-series data were conducted. The evaluations included comparison of water quality prior to and after implementation of the previously established minimum flow rule for the Lower Peace River, with January 1, 2011, used to differentiate the pre- and post-minimum flow implementation periods.
3. Statistical models (logistic regression, non-parametric regression, and conditional inference trees) were developed to examine relationships between flow and dissolved oxygen, chlorophyll, total nitrogen, and total phosphorus concentrations.
4. Spearman's rank correlation was conducted between the constituent of interest and lag-average flows between 2 and 60 days to determine the temporal scale on which these constituents might be correlated (e.g., 10, 30, 60 days) in the Lower Peace/Shell System.
5. Skillful regressions were used to evaluate the potential effects of flow reductions associated with the recommended minimum flows for the Lower Peace River and Lower Shell Creek on water quality.

CHAPTER 6 – RESULTS OF THE MINIMUM FLOW ANALYSES

The District approach for setting minimum flows is generally habitat-based and involves assessment of sensitive ecological resources that provide protection to all relevant environmental values identified in the Water Resource Implementation Rule for consideration when establishing minimum flows or levels.

For the Lower Peace River and Lower Shell Creek, the District's approach for determining minimum flows involved development and use of baseline flow (i.e., flows expected in the absence of withdrawal impacts) records for the Lower Peace River and Lower Shell Creek and a series of flow records reflecting incremental decreases from the baseline flow records. Using these flow records, the percent-of-flow method and 15% change in habitat criteria were used to develop minimum flow recommendations for the Lower Peace River and Lower Shell Creek. For the Lower Peace River, the minimum flow analysis also includes development of a low flow threshold and a maximum daily withdrawal that are applicable throughout the year.

6.1. Low Flow Threshold

Results from model simulations that relate flows to ecological criteria in the Lower Peace/Shell System did not exhibit breakpoints or inflections at low flows. A low flow threshold based on ecological criteria could, therefore, not be established.

However, a low flow threshold of 130 cfs for the sum of the flows from Peace River at Arcadia, Joshua Creek at Nocatee, and Horse Creek near Arcadia is required to maintain freshwater at the withdrawal intake at the PRMRWSA Peace River Water Treatment Facility. This low flow threshold is an operational criterion and has been used since August 2010. Its continued inclusion in minimum flows for the Lower Peace River is recommended.

A low flow threshold was not identified for Lower Shell Creek, as the City of Punta Gorda is permitted to withdraw water from Shell Creek Reservoir, above Hendrickson Dam.

6.2. Maximum Withdrawal Threshold

A maximum diversion of 400 cfs from Lower Peace River was included in the Lower Peace River minimum flows rule that became effective in August 2010. Staff recommend continued use of the 400 cfs maximum diversion rates for withdrawals from the Lower Peace River. This will ensure that high flows are protected while meeting the water needs of the PRMRWSA service area over the next 20 years. It is important to note that the 400 cfs withdrawal limit is only for withdrawals from the Lower Peace River.

A maximum withdrawal limit was not identified or recommended for Lower Shell Creek. The City of Punta Gorda is permitted to withdraw water from Shell Creek Reservoir upstream of

Hendrickson Dam, not directly from the lower portion of Shell Creek. For this reason, development of a maximum withdrawal rate is not considered necessary for Lower Shell Creek.

6.3. Salinity Habitat Results

Potential flow related changes in salinity-based habitats were evaluated using the District's UnLESS model (Chen 2020). Isohaline locations expressed as river kilometers were used to calculate the extent of shoreline, river bottom area and water volume habitat associated with specified salinities using cumulative physical metrics described in Section 5.5.1. Baseline and eight reduced-flow simulation results were compared to identify potential flow reductions associated with more than a 15% reduction in habitat.

Isohaline locations move upstream and downstream in the river channel with mixing driven by both tide and freshwater inflows. As described in Section 5.4.3., the < 2, < 5, < 10, < 15, and < 20 psu isohalines were selected for the minimum flow analyses to represent the boundaries of salinity habitats that are important to shoreline plant communities, benthic macroinvertebrates, zooplankton and nekton, i.e., floating and free-swimming fish and invertebrates.

Scenario simulations were conducted for the eight-year period from 2007 through 2014 using UnLESS. Model scenarios included baseline flows (0% reduction), and reductions from baseline flows ranging from 1% up to 40%. For each flow reduction scenario, the daily quantities for each respective salinity habitat in the Lower Peace River and Lower Shell Creek were combined to yield system-wide totals that were assessed by flow-based blocks. Comparison of baseline and reduced-flow scenario results and, when necessary, linear interpolation were used to identify flow reductions associated with a 15% decrease in each salinity habitat.

The water volume associated with salinity less than 2 psu habitat was the most sensitive salinity-habitat criterion and a linear relationship (R^2 = 0.99) was observed between percent-of-flow reductions and decline in water volume for Blocks 1 through 3 (see Tables 8 through 10 in Appendix C for salinity-habitat values for all modeled flow scenarios). Based on this criterion, percent-of-flow reductions corresponding to a 15% decrease in habitat from baseline yielded potentially allowable flow reductions of 13%, 23% and 40%, respectively, for Blocks 1, 2 and 3. Table 6-1 provides the absolute value reductions in < 2, < 5, < 10, < 15 and < 20 psu water volume, bottom area and shoreline length salinity habitats and percentage changes due to flow reductions of 13% in Block 1, 23% in Block 2 and 40% in Block 3.

Table 6-1. Summary less than 2 psu, 5 psu, 10 psu, 15 psu and 20 psu salinity habitats in the Lower Peace/Shell System by block relative to the baseline scenario.

Block 1									
	Water Volume (Million m^3)			Bottom Area (Million m^2)			Shoreline Length (km)		
Salinity (< psu)	Baseline Flow	Min. Flow	% Change	Baseline Flow	Min. Flow	% Change	Baseline Flow	Min. Flow	% Change
2	10.8	9.1	15.0%	7.3	6.4	12.4%	44.1	38.2	13.3%
5	18.2	16.8	7.5%	11.2	10.3	7.3%	69.0	64.7	6.2%
10	25.8	24.7	4.0%	15.0	14.5	3.5%	88.9	86.8	2.4%
15	31.4	30.6	2.4%	18.1	17.7	2.3%	96.4	95.9	0.5%
20	43.5	42.2	3.2%	24.0	23.4	2.5%	99.9	99.9	0.1%
Block 2									
	Water Volume (Million m^3)			Bottom Area (Million m^2)			Shoreline Length (km)		
Salinity (< psu)	Baseline Flow	Min. Flow	% Change	Baseline Flow	Min. Flow	% Change	Baseline Flow	Min. Flow	% Change
2	21.5	18.3	15.0%	13.2	11.5	12.8%	78.5	69.3	11.8%
5	26.4	24.2	8.2%	15.7	14.5	7.2%	89.3	85.0	4.8%
10	31.4	29.8	5.2%	18.4	17.5	4.9%	95.7	94.2	1.6%
15	40.1	37.5	6.7%	22.5	21.3	5.2%	99.5	98.9	0.7%
20	60.7	56.0	7.8%	31.2	29.3	5.9%	101.8	101.5	0.3%
Block 3									
	Water Volume (Million m^3)			Bottom Area (Million m^2)			Shoreline Length (km)		
Salinity (< psu)	Baseline Flow	Min. Flow	% Change	Baseline Flow	Min. Flow	% Change	Baseline Flow	Min. Flow	% Change
2	32.9	28.0	15.0%	19.6	16.9	13.9%	94.1	88.0	6.5%
5	38.4	32.7	14.8%	21.8	19.1	12.5%	97.8	94.1	3.8%
10	49.2	41.9	14.8%	26.2	23.0	12.0%	100.5	98.8	1.8%
15	65.0	55.2	15.0%	32.6	28.6	12.0%	102.4	101.3	1.1%
20	85.1	76.9	9.7%	41.8	37.9	9.4%	103.4	103.1	0.3%

For all blocks, the decrease in < 2 psu water volume habitat is 15% as expected, since the recommended minimum flows were established based on 15% decrease in the most restrictive habitat, i.e., the < 2 psu water volume. The decrease in < 2 psu bottom area habitat associated with the recommended minimum flows ranged from 12.4% in Block 1 to 13.9% in Block 3, while the decreases are 13.3% in Block 1, 11.8% in Block 2 and 6.5% in Block 3 for the < 2 psu shoreline length habitat.

During Block 1, 13% reductions in baseline flows could reduce the salinity volume habitats by 3.2% to 15%, the bottom area habitats by 2.5% to 12.4% and the shoreline length habitats by 0.1% to 13.3%. Under medium-flow conditions associated with Block 2, 23% reductions in baseline flows could reduce the salinity volume habitats by 7.8% to 15%, the bottom area habitats by 5.9% to 12.8% and the shoreline length habitats by 0.3% to 11.8%. Salinity habitats were found to be relatively less sensitive to flow reductions under high-flow conditions associated with Block 3. Forty-percent reductions in baseline flows during Block 3 reduced the salinity volume habitats by 9.7% to 15%, the bottom area habitats by 9.4% to 13.9% and the shoreline length habitats by 0.3% to 6.5%.

6.4. Floodplain Inundation Results

The floodplain wetlands habitat criterion for the Lower Peace/Shell System was evaluated by analyzing time-series of inundated areas in the Lower Peace River portion of the system simulated with the UnLESS model (Chen 2020). Iterative analyses of hourly inundated floodplain wetlands area were conducted for all days of the year for the 2007 through 2014 baseline flow period and for a series of reduced baseline flow conditions. Reductions in average wetland inundation area corresponding to various flow reductions for the eight-year simulation period are provided in Table 6-2.

Table 6-2. Reduction in average inundated area of floodplain wetlands in a portion of the Lower Peace River associated with various flow reductions from the baseline condition from 2007 through 2014.

Flow Reduction Scenarios	Average Stage (ft, NAVD 88)	Inundation Floodplain Wetland Area (acre)	Change in Inundation area Relative to Baseline (%)
Baseline	0.07	129.3	-
5%	0.067	128.1	0.9
10%	0.063	126.8	2.0
15%	0.061	125.9	2.6
20%	0.059	124.9	3.4
25%	0.055	123.7	4.3
30%	0.051	122.3	5.4
35%	0.048	121.3	6.2
40%	0.046	120.3	7.0

The analysis shows that a 40% flow reduction could occur without exceeding a 7% decrease in the total inundated floodplain wetland area associated with the baseline flow condition. Considering only the percent-of-flow reductions in Block 3, a 40% reduction from baseline flows would be associated with a 10% decrease in inundated floodplain wetland habitat (Table 6-3). The 10% reduction in inundation area attributable to the proposed 40% withdrawal during high flow period is unlikely to alter the structure and functions of the floodplain wetland community in the Lower Peace River. This criterion is less sensitive than the salinity habitats discussed in Section 6.3 and was therefore not directly used to identify specific allowable percent-of-flow reductions that would be included in the recommended minimum flows for the Lower Peace River and Lower Shell Creek.

Table 6-3. Reduction in average inundated floodplain wetland area in a portion of the Lower Peace River associated with various flow reductions from baseline conditions for high flow season (July to October) from 2007 through 2014.

Flow Reduction Scenarios	Average Stage (ft, NAVD 88)	Inundation Floodplain Wetland Area (acre)	Change in Inundation area Relative to Baseline (%)
Baseline	0.30	189.4	-
5%	0.29	186.7	1.40%

10%	0.29	183.9	2.90%
15%	0.28	181.7	4.00%
20%	0.28	179.8	5.10%
25%	0.27	177.0	6.50%
30%	0.26	174.0	8.10%
35%	0.25	171.8	9.30%
40%	0.25	169.7	10.40%

6.5. Summary of Recommended Minimum Flows

To support development of recommended minimum flows for the Lower Peace River and Lower Shell Creek, flow requirements associated with maintaining 85% of salinity-based habitats associated with a baseline flow condition were evaluated for three flow-based blocks corresponding with low (Block 1), medium (Block 2) and high (Block 3) flow ranges that collectively include the full hydrologic regime of the system. For the Lower Peace River portion of the Lower Peace/Shell System, effects of potential flow reductions from baseline flow condition were also evaluated for floodplain habitats for the entire year and during Block 3. In addition, a recommended Low Flow Threshold and Maximum Withdrawal Limit were developed.

Among the habitat-based analyses assessed for the Lower Peace River portion of the Lower Peace/Shell System, salinity water volume associated with < 2 psu was the most sensitive metric. Based on this most sensitive criterion, recommended minimum flows for the Lower Peace River that include block-specific, allowable percent-of-flow reductions in the combined flow at the USGS Peace River at Arcadia (No. 02296750), Horse Creek near Arcadia (No. 02297310), and Joshua Creek at Nocatee (No. 02297100) gages adjusted for upstream withdrawals were identified. As discussed in Section 5.2, ranges of flows used to define minimum flow blocks for the Lower Peace River are 0 to 297 cfs (Block 1), 298 to 622 cfs (Block 2), and > 622 cfs (Block 3) and are based on the combined, adjusted gaged flows for the previous day.

The recommended minimum flows for the Lower Peace River (Table 6-4) include a low flow threshold of 130 cfs, and a maximum daily withdrawal limit of 400 cfs. Inclusion of the low flow threshold addresses water quality concerns associated with withdrawals from the river at the PRMRWSA Peace River Water Treatment Facility and offers protection to the ecology of the river, while the maximum daily withdrawal limit ensures protection of extremely high flows while meeting the water needs of the region.

Each flow-based block used for the recommended minimum flows for the Lower Peace River is further sub-divided into defined flow ranges. For example, when the previous day's combined, adjusted flow is less than the low flow threshold of 130 cfs, the recommended Block 1 minimum flow is the combined flow. For additional protection of the low flow threshold, when the combined flow from the previous day ranges from 131 cfs to 149 cfs, the Block 1 minimum flow is 130 cfs. For combined, adjusted flows from the previous day that range from 150 to 297 cfs, the recommended Block 1 minimum flow is 87% of the combined flow, which allow for a 13% flow reduction.

For a low range of combined, adjusted Block 2 flows, from 298 cfs to 335 cfs, the recommended minimum flow is 258 cfs. This flow corresponds to the minimum flow associated with the high-end of the Block 1 minimum flows and was calculated as 87% of the upper Block 1 flow boundary of 297 cfs. Use of this minimum flow for the lower range of Block 2 flows smooths the transition from Block 1 to Block 2 minimum flows, which are, respectively, 87% and 77% of the combined flows. The recommended minimum flow for a higher range of combined Block 2 flows (336 cfs to 622 cfs) is 77% of the combined flow on the previous day, which allows for a 23% flow reduction.

For Block 3 flows ranging from 623 cfs to 798 cfs, the recommended minimum flow is the combined, adjusted flow on the previous day minus 479 cfs. This flow corresponds to the minimum flow associated with the high-end of the Block 2 minimum flows and was calculated as 77% of the upper Block 2 flow boundary of 622 cfs. Use of this minimum flow for the lower range of Block 3 flows smooths the transition from Block 2 minimum flows, which are 77% of the combined flows, to Block 3 minimum flows, which are 60% of the combined flows. For flows exceeding 798 cfs, minimum flow is 60% of the combined flows, which allow for a 40% flow reduction. However, the daily maximum withdrawal is limited to 400 cfs.

Table 6-4 summarizes the recommended minimum flows for the Lower Peace River and includes information concerning potentially allowable flow reductions that correspond with the recommended minimum flows. Formulas that may be used to implement surface-water withdrawals in accordance with the recommended minimum flows are also provided.

Table 6-4. Summary of minimum flows and potentially allowable percent-of-flow reduction for the Lower Peace River for flow-based blocks determined from combined, adjusted flows for the previous day at the USGS Horse Creek near Arcadia, Joshua Creek near Nocatee and the Peace River at Arcadia gages. Adjusted flow is defined as flow that would exist in the absence of withdrawal impacts. Formulas that could be used to calculate potentially allowable flow reductions are also provided.

Flow-Based Block	If Combined Flow in Cubic Feet per Second (cfs) on the Previous Day, Adjusted for Upstream Withdrawals is:	Minimum Flow is:	Potentially Allowable Flow Reduction is:	Formula for Calculation of Potentially Allowable Flow Reduction (Q_{Red}) based on Combined, Adjusted Flow on Previous Day (Q_{Prev})
1	≤ 130 cfs	Combined, adjusted flow on the previous day	0 cfs	Q_{Red} = 0 cfs
	> 130 cfs and ≤ 149 cfs	130 cfs	Combined, adjusted flow on the previous day minus 130 cfs	QRed = QPrev - 130 cfs

	> 149 cfs and ≤ 297 cfs	87% of combined, adjusted flow on the previous day	13% of combined, adjusted flow on the previous day	QRed = QPrev * 13%
2	> 297 cfs and ≤ 335 cfs	258 cfs	Combined, adjusted flow on the previous day minus 258 cfs	QRed = QPrev - 258 cfs
	> 335 cfs and ≤ 622 cfs	77% of combined, adjusted flow on the previous day	23% of combined flow on the previous day	QRed = QPrev * 23%
3	> 622 cfs and ≤ 798 cfs	479 cfs	Combined, adjusted flow on the previous day minus 479 cfs	QRed = QPrev – 479 cfs
	> 798 cfs	60% of combined flow on the previous day	40% of combined, adjusted flow on the previous day[a]	QRed = QPrev * 40%

[a] 400 cfs maximum daily withdrawal

Minimum flows recommended for Lower Shell Creek (Table 6-5) were based on potential changes in the < 2 psu water volume identified as the most sensitive metric for the Lower Peace/Shell System. The minimum flows for Lower Shell Creek specify block-specific required percent-of-flow releases in baseline flows at the outfall of Hendrickson Dam, where with support from the District, the USGS maintains the Shell Creek near Punta Gorda, FL gage (No. 02298202). By requiring specific percentages inflows to flow past the Hendrickson Dam, the recommended minimum flows also identify potentially allowable flow reductions that would be expected to be compliant with achieving the minimum flows (Table 6-5).

Specifically, the recommended minimum flows for Lower Shell Creek are based on daily average flow at the USGS Shell Creek near Punta Gorda, FL Gage, adjusted for withdrawals and agricultural runoff. The necessary adjustments include addition of the City of Punta Gorda’s previous day’s withdrawals from Shell Creek Reservoir to the measured flow or volume of water impounded in the reservoir, and subtraction of estimated agricultural flows introduced to the creek watershed above Hendrickson Dam as runoff of pumped groundwater.

Table 6-5. Summary of allowable percent-of-flow release for Lower Shell Creek based on flow measured at the outfall of Hendrickson Dam and withdrawals from Shell Creek Reservoir by the City of Punta Gorda.

Block	If Adjusted Flow, in Cubic Feet per Second (cfs) on the Previous Day is:	Minimum Flow is:	Potentially Allowable Flow Reduction is:

1	< 56 cfs	87% of adjusted flow on the previous day	13 % of adjusted flow on the previous day
	56 cfs – 137 cfs	77% of adjusted flow on the previous day	23 % of adjusted flow on the previous day
3	> 137 cfs	60% of adjusted flow on the previous day	40% of adjusted flow on the previous day

6.6. Evaluation of the Recommended Minimum Flows

As described in Section 5.4, the recommended minimum flows for the Lower Peace River and Lower Shell Creek were evaluated to assess potential effects on fish and invertebrate populations and water quality in the Lower Peace/Shell System and Charlotte Harbor. These environmental value assessments involved analysis of two scenarios, one with no freshwater flow reductions or withdrawals (i.e., the baseline condition) and the other with reduced flows based on the maximum withdrawals allowed by the recommended minimum flows.

6.6.1. Fish Habitat Results

Habitat suitability models (HSMs) developed by Rubec et al. (2018) were run for the baseline flow condition and a minimum flows scenario that included the maximum withdrawals that would be allowed by the recommended minimum flows for the Lower Peace River and Lower Shell Creek. This minimum flows scenario, did not, however, include the maximum withdrawal cap or limit that is included in the recommended minimum flows for the Lower Peace River portion of the Lower Peace/Shell System.

The HSMs were applied to seven fish species life-stages and a specific size-class of Blue Crab which are known to exhibit preferences for low to moderate salinities and are abundant in the Lower Peace/Shell System and Charlotte Harbor.

For the HSM simulations, habitat zones were categorized into Low, Moderate, High, and Optimum zones by percentages based on natural break classification in ArcGIS. Table 6-6 presents seasonal habitat zone percentages and differences between the baseline and minimum flows scenarios for the assessed taxa. Black colored percent change values indicate the percentages for the minimum flows scenario were less than the corresponding baseline percentages. Red colored percent change values indicate the percentages for the minimum flows scenario were greater than the corresponding baseline percentages.

Table 6-6. Seasonal percent of HSM zones for species life stages in the Lower Peace/Shell System and Charlotte Harbor for Baseline (BL) and Minimum Flows (MF) scenarios. Note that the MF scenario was based on maximum percent-of-flow reductions associated with the recommended minimum flows but did not include a maximum flow-reduction cap, i.e., limit, for withdrawals from the Lower Peace River.

Species Life-Stage	Fall			Winter			Spring			Summer		
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
HSM Zone	BL	MF	Change	BL	MF	Change	BL	MF	Change	BL	MF	Change
Juv-Adult Hogchoker												
Low	96.10	96.41	0.31	90.51	91.50	0.99	94.01	94.99	0.98	94.63	95.23	0.60
Moderate	2.55	2.42	0.13	8.11	7.33	0.78	4.51	3.78	0.73	2.64	2.31	0.33
High	1.15	0.99	0.16	1.12	0.98	0.14	1.21	1.02	0.19	1.47	1.25	0.22
Optimum	0.20	0.18	0.02	0.26	0.20	0.06	0.28	0.21	0.07	1.27	1.21	0.06
Juvenile Sand Seatrout												
Low	87.93	89.62	1.69	95.53	96.31	0.78	43.78	45.68	1.90	62.99	70.07	7.08
Moderate	10.14	8.55	1.59	3.81	3.07	0.74	25.66	26.39	0.73	22.91	20.48	2.43
High	1.60	1.52	0.08	0.56	0.53	0.03	18.53	16.58	1.95	12.87	8.53	4.34
Optimum	0.33	0.32	0.01	0.10	0.09	0.01	12.04	11.35	0.69	1.22	0.93	0.29
Juv-Adult Blue Crab												
Low	80.75	81.73	0.98	49.72	51.65	1.93	91.26	91.81	0.55	46.60	50.51	3.91
Moderate	7.90	7.98	0.08	27.72	27.15	0.57	3.20	2.88	0.32	28.06	27.22	0.84
High	8.75	7.89	0.86	13.74	12.88	0.86	3.57	3.55	0.02	15.75	14.97	0.78
Optimum	2.60	2.41	0.19	8.82	8.32	0.50	1.97	1.75	0.22	8.59	7.30	1.29
Early-Juvenile S. Kingfish												
Low	85.69	87.49	1.80	48.44	50.33	1.89	90.15	91.02	0.87	62.18	69.12	6.94
Moderate	5.82	5.16	0.66	29.05	29.24	0.19	5.34	4.99	0.35	21.96	19.24	2.72
High	6.76	5.88	0.88	16.98	15.86	1.12	3.93	3.58	0.35	12.03	8.78	3.25
Optimum	1.73	1.46	0.27	5.52	4.57	0.95	0.58	0.41	0.17	3.83	2.86	0.97
Juvenile Bay Anchovy												
Low	54.76	57.53	2.77	57.70	59.34	1.64	67.69	69.04	1.35	52.87	55.54	2.67
Moderate	25.86	24.44	1.42	21.31	20.67	0.64	16.07	15.50	0.57	22.03	20.53	1.50
High	10.75	9.83	0.92	12.75	12.25	0.50	9.58	9.12	0.46	15.23	15.29	0.06
Optimum	8.62	8.20	0.42	8.24	7.74	0.50	6.65	6.34	0.31	9.87	8.64	1.23
Adult Bay Anchovy												
Low	54.76	57.53	2.77	56.75	58.23	1.48	67.70	69.04	1.34	52.86	55.54	2.68
Moderate	25.86	24.44	1.42	26.02	25.32	0.70	16.07	15.50	0.57	22.04	20.53	1.51
High	10.75	9.83	0.92	10.14	9.53	0.61	9.58	9.12	0.46	15.23	15.29	0.06
Optimum	8.62	8.20	0.42	7.09	6.92	0.17	6.65	6.34	0.31	9.87	8.64	1.23
Early-Juvenile Red Drum												
Low	51.97	52.28	0.31	44.47	44.85	0.38	48.43	48.43	0.00	43.92	46.76	2.84
Moderate	19.62	19.37	0.25	27.35	26.98	0.37	26.65	26.65	0.00	23.43	23.26	0.17
High	17.65	18.06	0.41	18.38	18.31	0.07	15.00	15.00	0.00	27.83	26.11	1.72
Optimum	11.12	10.28	0.84	9.80	9.86	0.06	9.93	9.93	0.00	4.81	3.87	0.94
Early-Juvenile Spot												
Low	68.74	65.02	3.72	45.70	46.18	0.48	65.43	65.65	0.22	39.49	34.58	4.91
Moderate	23.78	26.60	2.82	25.46	25.45	0.01	24.18	24.37	0.19	40.42	39.80	0.62
High	6.16	6.70	0.54	18.27	18.49	0.22	7.78	7.63	0.15	17.20	22.03	4.83
Optimum	1.33	1.68	0.35	10.56	9.89	0.67	2.60	2.35	0.25	2.89	3.59	0.70

As expected, the percentage of predicted Optimum, High, and Moderate zone areas for resident species were mostly higher for the Baseline condition than for the minimum flows condition. However, predicted changes in zonal areas were small: all were < 7% and most were < 3%. In addition, differences in Optimum and High zones between the baseline and minimum flows condition were all < 5%, with most < 1%. Collectively, these results indicate effects of flow reductions associated with the recommended minimum flows for the Lower Peace River and Lower Shell Creek on representative fish habitats in the Lower Peace/Shell System are not significant. In addition, these results can be considered conservative for the resources, as the implementation of minimum flows that include the recommended maximum withdrawal limit for the Lower Peace River would be associated with smaller reductions in flows to the Lower Peace/Shell System and Charlotte Harbor.

Based on these fish habitat assessment results, the recommended minimum flows for the Lower Peace River and Lower Shell Creek are not expected to adversely affect the local abundances of fish and Blue Crab in the Lower Peace/Shell System. Appendix E provides additional information on the HSM modeling.

6.6.2. Water Quality Results

Predictive modeling conducted by Janicki Environmental Inc. (2019) concluded that there was no evidence that flow reductions associated with the recommended minimum flows for the Lower Peace River and Lower Shell Creek would have significant negative effects on water quality in the Lower Peace/Shell System. As was the case for the fish and Blue Crab habitat assessment, the water quality assessments may be considered conservative as the minimum flows condition used in the analyses did not include the maximum withdrawal cap or limit included in the recommended minimum flows for the Lower Peace River portion of the Lower Peace/Shell System.

Nutrient concentrations (total nitrogen and orthophosphate) and color were positively related to flows irrespective of season. These results suggest that flow reductions would not increase the risk to ecological components of the system that may be susceptible to high nutrient concentrations and color.

Correlations between dissolved oxygen (DO) saturation and flows were generally weak in the dry season. However, a relatively strong negative correlation was observed in the wet season as increased flows were associated with decreased DO percent-saturation at all sampling stations. This result suggests flow reductions associated with the recommended minimum flows would not be expected to adversely affect DO levels in the Lower Peace/Shell System.

An example of predictions for exceedance of water quality criterion for DO saturation at a bottom-sampling station at river kilometer 6.6 is provided in Figure 6-1. Janicki Environmental Inc. (2019), included as Appendix F to this document, includes comparable results for other sites and other water quality constituents.

Chlorophyll concentration response to flows varies across the Lower Peace/Shell System as a function of seasonally variable flows. A nonparametric statistical model developed for estimating chlorophyll based on site location and natural-log transformed flows indicated that highest chlorophyll concentrations in downstream areas are associated with high flows and highest concentrations in the upstream area of the system are associated with low flows. These findings can likely be associated with differences in residence times, tidal mixing, and light penetration in different portions of the system.

The statistical models developed as part of this analysis indicate that chlorophyll levels reductions associated with flow reductions are likely to reduce chlorophyll concentrations in one portion of the system and increase chlorophyll levels in another section, resulting in a net-zero change for the system. Figure 6-2 clearly illustrates this result, with cumulative distribution function (CDF) curves for the baseline and minimum flow scenarios that are nearly indistinguishable.

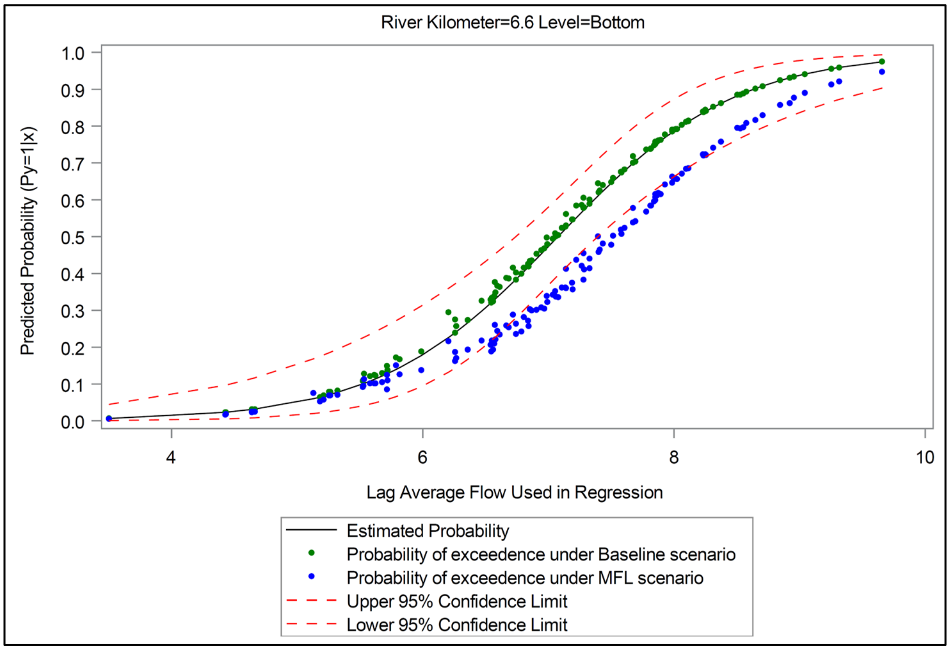

Figure 6-1. Wet season logistic regression predictions for bottom dissolved oxygen (% saturation) exceedances under baseline and minimum flow scenarios at the RKm 6.6 location (see Figure 3-1) in the Lower Peace/Shell System.

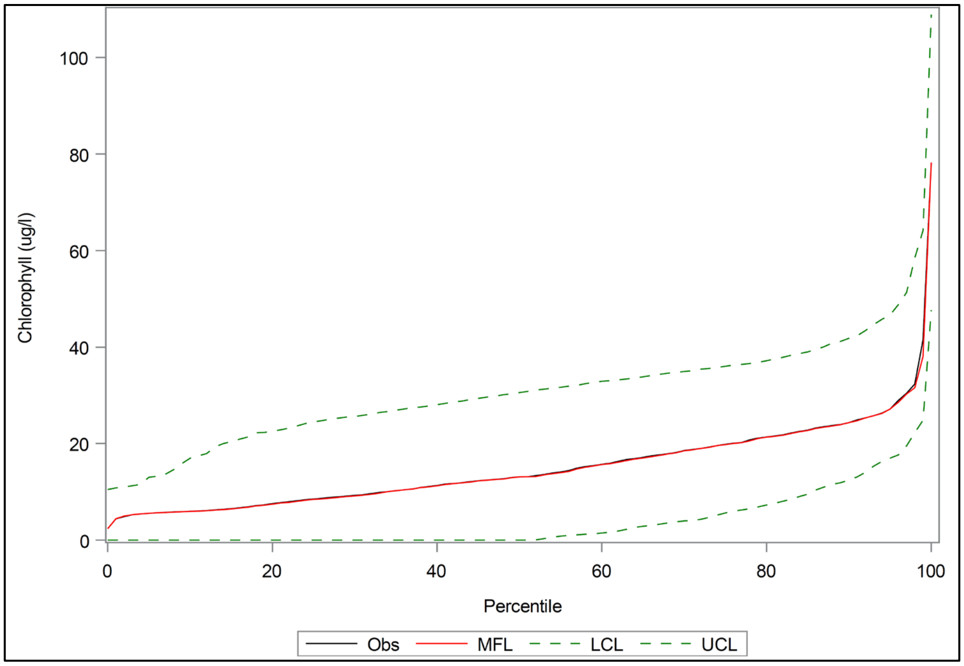

Figure 6-2. Cumulative distribution frequency curves for chlorophyll concentrations for baseline (Obs) and minimum flows (MFL) scenarios. The green dashed lines are upper and lower 95% confidence limits.

Overall, Janicki Environmental Inc. (2019) concluded that there is no evidence that the recommended minimum flows for the Lower Peace River and Lower Shell Creek would have a significant effect on water quality, to the extent it would pose any additional risk to the ecological components in the system.

6.7. Consideration of Environmenal Values

Within the Water Resource Implementation Rule, Rule 62-40.473, F.A.C., requires that when establishing minimum flows and levels *"consideration shall be given to natural seasonal fluctuations in water flows or levels, nonconsumptive uses, and environmental values associated with coastal, estuarine, riverine, spring, aquatic and wetlands ecology, including: (a) Recreation in and on the water; (b) Fish and wildlife habitats and the passage of fish; (c) Estuarine resources; (d) Transfer of detrital material; (e) Maintenance of freshwater storage and supply; (f) Aesthetic and scenic attributes; (g) Filtration and absorption of nutrients and other pollutants; (h) Sediment loads; (i) Water quality; and (j) Navigation."*

Primary factors considered for development of the recommended minimum flows for Lower Peace River and Lower Shell Creek included potential, flow-related changes in salinity-based habitats, floodplain wetland inundation, fish and Blue Crab habitats and water quality. Based on assessments associated with these factors, the recommended minimum flows are protective of all relevant environmental values identified for consideration in the Water Resource Implementation in Rule as well as those included in the Water Resources Act of 1972 that pertain to the establishment of minimum flows and minimum water levels.

6.7.1 Recreation in and On the Water

Recreation in and on the water was considered through characterization of water depths, and assessment of potential changes in water levels, salinities, floodplain inundation, fish and invertebrate habitats, and water quality.

Bathymetric information used for consideration of water depths in the Lower Peace/Shell System and upper portion of Charlotte Harbor is summarized in Section 2.4. Water levels in the system are strongly influenced by tides (see Section 2.6) and were modeled as described in Sections 5.4.3, 5.4.4, 5.5.1, 5.5.2, 5.5.3, 6.3, 6.4 and 6.6.1. These analyses predicted average water level reductions of less than 0.1 ft in the Lower Peace River for maximum flow reductions associated with the recommended minimum flows. These minor changes in water levels are not expected to adversely impact recreation in and on the water within the Lower Peace/Shell System (Section 6.4, Tables 6-2 and 6-3).

Some recreational activities, including fishing, wildlife and natural system observation and study, and swimming can be associated with water salinities. These activities were, therefore, considered through use of a hydrodynamic model to evaluate potential changes in salinities ranging from 2 to 20 psu. Results from the modeling efforts were used to develop minimum flow recommendations and proposals that are expected to support maintenance of natural salinity distributions throughout the Lower Peace/Shell System.

Assessments of potential changes in floodplain inundation patterns (Sections 5.4.4, 5.5.2 and 6.4) indicated that flow reductions of up to 40% reduction could occur without exceeding a 10% decrease in the total inundated floodplain wetland area associated with the baseline flow condition in the Lower Peace River. The criterion is less sensitive than the salinity habitat used for development of the recommended minimum flows for the Lower Peace River and r Lower Shell Creek and is considered protective of the wetland resource.

Assessments of potential effect of flow reductions that could occur with implementation of the recommended minimum flows also indicated that habitats for several important fish species and Blue Crab (Sections 5.4.5, 5.5.3 and 6.6.1) and water quality constituents other than salinity (Sections 5.4.6, 5.5.4, 6.6.2) are not expected to be adversely impacted by implementation of the minimum flows.

6.7.2 Fish and Wildlife Habitats and the Passage of Fish

Information concerning fish and invertebrate nekton and plankton, and benthic macroinvertebrates was summarized in Chapter 4 to support consideration the environmental value, fish and wildlife habitats and the passage of fish. These biological assemblages include taxa that populate the Lower Peace/Shell System based in part on their tolerance of narrow and/or broad ranges of salinities.

Modeling of spatial and temporal distributions of habitats based on water volume, shoreline length and bottom area associated with salinities ranging from 2 to 20 psu with a hydrodynamic model (Sections 5.4.3, 5.5.1 and 6.3) provided a means for evaluating potential flow-related changes in habitats for fish and other taxa. Results from these analyses were used to identify block-specific percent-of-flow reductions that are protective of these salinity-habitats and were used to develop recommended minimum flows for the Lower Peace River and Lower Shell Creek.

In addition, Habitat Suitability Modeling and associated mapping were conducted to evaluate effects of maximum flow reductions that could be associated with the recommended minimum flows on seven fish species life stages and a specific size-class of Blue Crab (Sections 5.4.5, 5.5.3, and 6.6.1). Results from the analyses indicated the recommended minimum flows are not expected to cause any substantial changes to the local abundance of the assessed taxa in the Lower Peace/Shell System.

In low-gradient systems, fish passage is primarily a function of water depth. As discussed for the environmental value Recreation in and on the Water (Section 6.7.1), water levels in the Lower Peace/Shell System are primarily influenced by tides and are predicted to be only minimally affected by the maximum flow reductions associated with the recommended minimum flows. Implementation of the minimum flows is, therefore, not expected to adversely affect fish passage within the Lower Peace River or Lower Shell Creek.

6.7.3 Estuarine Resources

Estuarine resources were considered for development of recommended minimum flows for the Lower Peace River and Lower Shell Creek through data collection, characterization, and analysis of physical, hydrological, chemical, and ecological aspects of the system.

Physical and hydrological characterizations of the system were included in Chapter 2. Information concerning water quality characteristics of the Lower Peace/Shell System, other than salinity, and relationships between selected water quality constituents and flow was summarized in Chapter 3 and Sections 5.4.6, 5.5.4, and 6.6.2.

Summaries of ecological resources of concern, including vegetation assemblages, fish and invertebrate nekton and plankton, and benthic macroinvertebrates and responses of these assemblages to changes in flows to the Lower Peace/Shell System were provided in Chapter 4 and Sections 5.4, 5.5, 6.4, 6.6.1 and 6.6.2.

Assessment of potential, flow-related changes in the spatial and temporal distributions of salinity-based habitats, including water volumes, shoreline lengths and bottom areas associated with salinities ranging from 2 to 20 psu with a hydrodynamic model was a primary means for considering estuarine resources in the Lower Peace/Shell System. Sections 5.5.1 and 6.3 (and Section 6.7 that follows this discussion of environmental values considerations) summarize findings from these analyses, which were ultimately used to support development of the minimum flows recommended for the Lower Peace River and Lower Shell Creek.

In addition, Habitat Suitability Modeling and associated mapping was used for evaluating effects of maximum flow reductions that could be associated with the recommended minimum flows for seven estuarine fish species life-stages and Blue Crab (Sections 5.5.3 and 6.6.1).

6.7.4 Transfer of Detrital Material

Detrital material in rivers and estuaries includes dead, particulate organic material that may originate from upland, floodplain, and in-channel areas. Detrital transfer occurs laterally and longitudinally in flowing water bodies as a function of water levels, flows, velocities, and residence times. Transport processes may be especially strong during periods of high-water levels and flows when hydrologic interactions between the floodplain and the channel are strongest and large quantities of suspended materials may be moved through the system.

The transfer of detrital material was considered for development of recommended minimum flows for the Lower Peace River and Lower Shell Creek through use of a percent-of-flow approach intended to maintain characteristics of the baseline flow regime and associated salinity-based habitats (Sections 5.4.2, 5.5.1, and 6.3) and patterns of floodplain inundation (Section 5.4.4, 5.5.2 and 6.4) expected in the absence of withdrawal impacts. Maintenance of salinity-based and floodplain habitats is expected to support their structural and functional contributions to detrital transfer processes, including roles as sources or sinks for detritus generation, export, and use.

Transfer of detrital material in rivers and estuaries is also dependent on water velocities and residence time. Like water surface elevation, water velocities are not expected to vary much in the Lower Peace/Shell System, based on strong tidal effects.

6.7.5 Maintenance of Freshwater Storage and Supply

Maintenance of freshwater storage and supply is protected through implementation of the District's Water Use Permitting Program based on the inclusion of conditions in water use permits which stipulate that permitted withdrawals will not lead to violation of any adopted minimum flows or levels, as well as the cumulative impact analysis that occurs for new permits or increased allocations for existing permits.

This environmental value was also considered for development of the recommended minimum flows for the Lower Peace River and Lower Shell Creek through use of the PRIM for predictions of withdrawal impacts on groundwater levels and stream flows that were used to develop baseline flow information for the minimum flow analyses. Information on surface water withdrawals from the Peace River by the PRWMRWSA and from Shell Creek by the City of Punta Gorda were similarly used for baseline flow development.

The value was also considered through development of minimum flows that include block-specific, allowable percent-of-flow reductions that can be easily used to develop permit conditions for existing and future surface-water withdrawals.

Inclusion of a low flow threshold and maximum withdrawal cap in the recommended minimum flows for the Lower Peace River portion of the system can also be associated with consideration of the maintenance of freshwater storage and supply.

6.7.6 Aesthetic and Scenic Attributes

Aesthetic and scenic attributes of the Lower Peace/Shell System are inextricably linked to other values such as recreation in and on the water, fish and wildlife and the passage of fish, estuarine resources, transfer of detrital material, filtration and absorption of nutrients and other pollutants, sediment loads, water quality and navigation.

As discussed in previous and subsequent sub-sections of this chapter, all of these environmental values have been considered and, in some cases associate with specific criteria used in habitat-based methods to develop minimum flow recommendations for the Lower Peace River and Lower Shell Creek. As a consequence, the recommended minimum flows ensure that the aesthetic and scenic attributes of the system are protected.

6.7.7 Filtration and Absorption of Nutrients and Other Pollutants

Filtration and absorption of nutrients and other pollutants were considered by assessing system bathymetry, vegetation characterizations, floodplain inundation, water quality characterization, and salinity-based water column, river bottom and shoreline habitats.

Many of these factors are shared with considerations associated with and discussed in previous and subsequent sub-sections of this chapter, including those associated with recreation in and on the water (6.7.1), fish and wildlife and the passage of fish (6.7.2), estuarine resources (6.7.3), transfer of detrital material (6.7.4), sediment loads (6.7.8) and water quality (6.7.9).

6.7.8 Sediment Loads

As with the transfer of detrital material, sediment loads are not expected to be reduced in the Lower Peace/Shell System in response to potential flow reductions associated with implementation of the recommended minimum flows for the Lower Peace River and Lower Shell Creek. Sediment loads typically increase during flood events, when floodplains are inundated, and large flows transport large quantities of sediment during these infrequent events.

Sediment loads in rivers and estuaries are also dependent on water velocities and residence time. Like water surface elevation, water velocities are not expected to vary much in the system, based on strong tidal effects on velocities relative to the effects associated with inflows.

Sediment loads were considered for development of recommended minimum flows for the Lower Peace River and Lower Shell Creek through use of a percent-of-flow approach intended to maintain characteristics of the baseline flow regime and associated salinity-based habitats (Sections 5.4.2, 5.5.1, and 6.3) and patterns of floodplain inundation (Section 5.4.4, 5.5.2 and

6.4) expected in the absence of withdrawal impacts. Maintenance of salinity-based and floodplain habitats is expected to support their structural and functional contributions to detrital transfer processes, including roles as sources or sinks for detritus generation, export, and use. Any changes in sediment loads associated with implementation of the recommended minimum flows are expected to be negligible.

6.7.9 Water Quality

Consideration of water quality was discussed in Chapter 3 and Sections 5.4.3, 5.4.6, 5.5.1, 5.5.4, 6.3 and 6.6.2. As noted in Section 6.6.2, water quality constituents in the Lower Peace/Shell System are not expected to substantially change in response to flow reductions associated with implementation of the recommended minimum flows. The recommended minimum flows for the Lower Peace River and Lower Shell Creek are, therefore, not expected to negatively affect water quality or impair the water designated use of either water body.

If water quality parameters are protected, many other environmental values that can be associated with water quality are also afforded protection. As discussed in previous sub-sections of the report, this protection can be extended to recreation in and on the water (Section 6.7.1), fish and wildlife habitat and the passage of fish (Section 6.7.2), estuarine resources (Section 6.7.3), transfer of detrital material (Section 6.7.4), maintenance of freshwater storage and supply (Section 6.7.5), aesthetic and scenic attributes (Section 6.7.6), and filtration and absorption of nutrients and other pollutants (Section 6.7.7).

6.7.10 Navigation

Commercial and recreational boating in the Lower Peace/Shell System is extensive. Swett et al. (2012) identify five marinas in the Lower Peace River downstream from the I-75 bridge and 8 existing or planned public boat ramps in the lower Peace River and Lower Shell Creek.

As described in Section 6.7.1 for the environmental value recreation in and on the water, navigation was considered by mapping water depth and physical characteristics of the system (Section 2.4), considering tidal fluctuations (Section 2.6), and modeling and assessment of potential changes in water levels (Sections 5.4.3, 5.4.4, 5.4.5, 5.5.1, 5.5.2, 5.5.3, 6.3, 6.4 and 6.6.1).

Consideration of this information showed that water level reductions of < 0.1 ft were predicted for potential flow reductions that could occur in association with implementation of the recommended minimum flows for the Lower Peace River and Lower Shell Creek. Based on these potential changes and because water depth necessary for navigation in the Lower Peace/Shell System is strongly affected by tidal, seasonal, and long-term sea level trends and variation, navigation is not expected to be affected by the allowable reductions in flow associated with the recommended minimum flows.

6.8. Potential Impacts of Sea Level Rise

Sea level rise (SLR) may alter available habitat for species with narrow salinity tolerances by decreasing bottom friction and shifting isohaline wedges further upriver (Obeysekera et al. 2011; Chen 2020). Near the Lower Peace/Shell System, at the NOAA Fort Myers station, sea level has increased at a rate of 3.11 mm per year (equivalent to 1.02 feet for a 100-year period) between 1965 and 2018 (NOAA 2020).

The upstream movement of isohalines associated with rising sea level will affect salinity-based habitats under both baseline and withdrawal-impacted flows by shifting isohalines upstream. For minimum flow status assessments, the District (SWFWMD 2015) has typically used sea level change projections recommended by the United States Army Corps of Engineers (USACE) as guidance for the design of projects along the Florida Gulf coast. The USACE (2019) recommends three levels of SLR scenarios. A low scenario based on continuing historical linear increases, an intermediate scenario (National Research Council [NRC] Curve I) and a high scenario (NRC Curve III). Based on information available from the low, intermediate, and high estimates of SLR at the NOAA Ft. Myers station for the period from 2010 to 2035 are 0.20, 0.33, and 0.76 feet, respectively. We used these three SLR predictions to evaluate potential SLR effects on the Lower Peace/Shell System.

A recent NOAA project, the US Global Change Research Program 2017 (Sweet et al., 2017), provides higher SLR estimates at the NOAA Ft. Myers station, with low, intermediate, and high SLR estimates of 0.38, 0.68, and 1.14 feet, respectively predicted for the period between 2010 and 2035. Following a suggestion by the review panel convened to evaluate the District's recommended minimum flows for the Lower Peace River and Lower Shell Creek, we also used the NOAA 2017 SLR estimates for assessment of potential SLR effects on the Lower Peace/Shell System. These estimates are based on more up-to-date information that that used for estimates derived using the USACE (2019) approach.

For these analyses, effects of the two sets of three SLR scenarios on low-salinity habitat were compared with the baseline condition used to develop the minimum flows recommended for the Lower Peace River and Lower Shell Creek. For the comparisons, 0.20 and 0.38-foot, 0.33 and 0.68-foot, and 0.76 and 1.14-foot water level increases associated with the low, intermediate and high SLR scenarios were added to the water boundary conditions of the UnLESS model with the assumption that the added water would have the same salinity and temperature values as the top-layer of the model (Chen 2020). The SLR scenario simulations were conducted under baseline flow conditions, i.e., with high sea levels but no-withdrawal impacts, for the period 2007 through 2014. Results from the SLR scenarios were compared with the previously completed baseline conditions scenario associated with current (i.e., recent) sea level conditions.

Greater relative changes from the baseline, current condition was predicted for habitats associated with < 2 psu than for the habitats associated with salinities of < 5, < 10 and < 15 psu. Table 6-7 shows the changes in baseline habitats associated within < 2 psu for the low, intermediate, and high SLR scenarios, relative to the current sea level scenario.

Habitats associated with the low flow Block 1 were the most strongly affected by changing sea level, with the largest decrease predicted for water column volume and shoreline length habitats. Decreases ranging from 13 to 27% were predicted for these two sensitive salinity habitats for the low SLR scenario during Block 1, with habitat decreases from 49 to 70% predicted for the high SLR scenario. Bottom area associated with < 2 psu water during Block 1 was also predicted to decrease with increased SLR, with decreases ranging from 4 to 36% relative to the no-SLR condition.

Changes in baseline low salinity habitats associated with increasing SLR scenarios during Blocks 2 and 3 were more moderate than those predicted for Block 1. However, reductions of up to 26% and 34% were simulated for water volume and shoreline length habitats, respectively, under high SLR conditions during Block 2. In addition, baseline low-salinity water volume and bottom area habitats increases of up to 2% and 24% were, respectively predicted during Block 3 under high SLR conditions.

Table 6-7. Percent change in less than 2 psu baseline habitat simulated for the three sea level rise (SLR) scenarios relative to a current sea level scenario by low (Block 1), intermediate (Block 2) and high (Block 3) flow blocks for the Lower Peace/Shell System for the period from 2007 through 2014, using the UnLESS hydrodynamic model. Percent change values based on USACE-recommended SLR predictions and in parentheses, NOAA-recommended SLR predictions.

Scenarios	Percent (%) Change in < 2 psu Salinity Habitat								
	Volume			Bottom Area			Shoreline		
	Block 1	Block 2	Block 3	Block 1	Block 2	Block 3	Block 1	Block 2	Block 3
Low SLR	-13 (-26)	-3 (-7)	0 (0)	-4 (-10)	+2 (+4)	+3 (+7)	-14 (-27)	-5 (-10)	0 (-1)
Intermediate SLR	-22 (-45)	-6 (-14)	0 (+1)	-8 (-19)	+4 (+6)	+6 (+14)	-24 (-46)	-8 (-19)	-1 (-1)
High SLR	-49 (-65)	-17 (-26)	+1 (+2)	-22 (-36)	+7 (+7)	+16 (+24)	-52 (-70)	-21 (-34)	-2 (-3)

Simulations based on flow reductions from the baseline conditions associated with the low, intermediate and high SLR scenarios were also conducted for the period from 2007 through 2014 to assess whether the percent-of-flow reductions associated with the < 2 psu salinity habitats that were used for development of the recommended minimum flows for the Lower Peace River and Lower Shell Creek may be exceeded in the future, based on the SLR projections.

Table 6-8 provides habitat changes associated with the recommended minimum flows for the Lower Peace River and Lower Shell Creek relative to corresponding baseline conditions under low, intermediate and high sea level rise projections for habitats associated with salinities of < 2 psu. Water volume habitats associated with a salinity of < 2 psu exhibited the most sensitive response to the combined effect of sea level rise and flow reductions associated with the recommended minimum flows.

Reducing the baseline conditions projected for each SLR scenario by the 13%, 23% and 40% allowable percent-of-flow reductions associated with the recommended minimum flows, for Blocks 1, 2 and 3, respectively is predicted to result in 26% to 36%, 20% to 36%, and 13% to 18% decreases in water volume habitat with a salinity of < 2 psu. Decreases in bottom area and shoreline length associated with salinities of <2 psu are also predicted to exceed an allowable 15% change from baseline conditions during Blocks 1 and 2 for all assessed SLR scenarios.

Results from these analyses suggest that SLR will amplify effects of flow reductions on salinity-based habitats during Blocks 1 and 2. The effect of SLR during Block 3 is, however, within the 15% reduction habitat limit except for water volume < 2 psu under high SLR scenario, which decreased by 16% and 18%, respectively, based on SLR estimates derived using USACE and more up-to-date NOAA-recommendations. Given the differences between the USACE and NOAA SLR projections, it is important to acknowledge that there is uncertainty in climate models regarding sea level rise projection. Nevertheless, these findings indicate that minimum flows established for the Lower Peace River and Lower Shell Creek may need to be reevaluated within 10 to 15 years after they are adopted into rule, to establish new baseline flow conditions that may occur as a result of SLR.

Table 6-8. Percent change in less than 2 psu baseline habitats for three sea level rise (SLR) scenarios for simulated flow reductions associated with the minimum flows recommended for the Lower Peace River Lower Shell Creek. Habitat changes were predicted for low (Block 1), intermediate (Block 2) and high (Block 3) flow blocks for the period from 2007 through 2014, using the UnLESS hydrodynamic model. Percent change values based on USACE-recommended SLR predictions and in parentheses, NOAA-recommended SLR predictions.

Scenarios	Percent (%) Change in < 2 psu Salinity Habitat								
	Volume			Bottom Area			Shoreline		
	Block 1	Block 2	Block 3	Block 1	Block 2	Block 3	Block 1	Block 2	Block 3
Low SLR	-26 (-31)	-20 (-23)	-13 (-14)	-21 (-23)	-16 (-18)	-12 (-12)	-23 (-27)	-16 (-20)	-5 (-6)
Intermediate SLR	-30 (-32)	-22 (-27)	-14 (-15)	-23 (-25)	-18 (-21)	-12 (-13)	-26 (-30)	-19 (-24)	-6 (-8)
High SLR	-33 (-36)	-29 (-36)	-16 (-18)	-26 (-30)	-22 (-26)	-13 (-13)	-31 (-33)	-26 (-34)	-8 (-11)

CHAPTER 7 - MINIMUM FLOW STATUS ASESSMENT AND IMPLEMENTATION

Flow regimes of the Lower Peace River and Lower Shell Creek were assessed to determine whether flows in the river are currently and are projected over the next twenty years to remain above limits associated with the recommended minimum flows for the Lower Peace River and Lower Shell Creek. These assessments were completed because the Florida Water Resources Act of 1972 stipulates that if the existing flow or level in a water body is below, or projected to fall within 20 years below, an applicable minimum flow or level, the FDEP or the respective governing board as part of the regional water supply plan shall adopt or modify and implement a recovery or prevention strategy to either achieve recovery to the established minimum flow or level as soon as practical or prevent the existing flow or level from falling below the established minimum flow or level.

7.1. Minimum Flows Status Assessment for the Lower Peace River

The initial step in the minimum flow status assessment for the Lower Peace River required an understanding of historic and current flow conditions and evaluation of the extent to which withdrawals or other anthropogenic factors have affected flows in the river. As briefly noted in Section 5.5.2, anthropogenic impacts have not resulted in much change in Lower Peace River flows, based on flow reductions estimated for the Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee gages. Estimated monthly flow reductions in the combined flows from these three gages due to withdrawal-related effects generally ranged from 0.2% in March to 0.9% in October for a 13-year assessment period. This information indicated the recommended minimum flows for the Lower Peace River are currently being met.

The previously adopted minimum flows rule adopted for the Lower Peace River in 2010, , identified minimum five-year and ten-year moving mean and median flow statistics as a tool for assessing whether flows in the Lower Peace River remain above flow rates that are expected to occur with implementation of the minimum flows. To assess the status of the recommended minimum flows in the Lower Peace River, five-year and ten-year moving mean and median flow statistics were computed for a zero-withdrawals (baseline) scenario using the daily baseline flows for the period 1950 through 2018. The analysis was repeated for two other scenarios; one associated with existing withdrawals (i.e., the baseline flows minus withdrawals from the river by the PRMRWSA) and the other with minimum flows-based withdrawals (i.e., baseline flow minus withdrawals allowed by the minimum flows recommended for the Lower Peace River).

Computed five-year and ten-year moving mean and median flow values for the three scenarios are provided in Table 7-1. The flow statistics calculated for the existing withdrawals scenario are higher than the corresponding flow statistics calculated for minimum flows-based withdrawal scenario, further supporting the determination that the recommended minimum flows for the Lower Peace River are being met.

Table 7-1. Five-year and ten-year moving mean and median flow statistics for zero-withdrawals (baseline), existing withdrawals and minimum flows-based withdrawals scenarios for the Lower Peace River for the period from 1950 through 2018.

Period	Statistics	Zero- Withdrawals Scenario (cfs)	Existing Withdrawals Scenario[a] (cfs)	Minimum Flows-Based Withdrawals Scenario[b] (cfs)
Annual	5-Yr Mean	1180.4	1163.9	1001.0
	10-Yr Mean	1182.3	1166.7	1003.5
	5-Yr Median	522.9	506.2	379.6
	10-Yr Median	523.5	507.7	379.4
Block 1	5-Yr Mean	294.8	287.2	266.3
	10-Yr Mean	302.8	295.3	274.2
	5-Yr Median	248.1	241.0	224.2
	10-Yr Median	256.1	249.1	232.1
Block 2	5-Yr Mean	491.2	471.2	380.8
	10-Yr Mean	495.9	476.7	384.8
	5-Yr Median	449.3	428.5	339.2
	10-Yr Median	452.1	432.2	341.5
Block 3	5-Yr Mean	2140.9	2115.9	1797.2
	10-Yr Mean	2134.2	2110.7	1792.7
	5-Yr Median	1531.9	1507.1	1155.3
	10-Yr Median	1518.5	1494.9	1144.4

[a] Baseline flows minus withdrawals by the PRMRWSA at the Peace River Facility.

[b] Baseline flows minus the maximum allowable percent-of-flow reductions associated with the recommended minimum flows for the Lower Peace River, with inclusion of the recommended 400 cfs maximum daily withdrawal rate

Hydrographs of median daily flows in the Lower Peace River for the zero withdrawals, existing withdrawals and minimum flows-based withdrawal scenarios (Figure 7-1) clearly indicate flows associated with the existing-withdrawals condition are above flows that would be required to meet the recommended minimum flows.

Collectively, these findings indicate that development and concurrent adoption and expeditious implementation of a recovery strategy would not be necessary for adoption of the recommended minimum flows for the Lower Peace River.

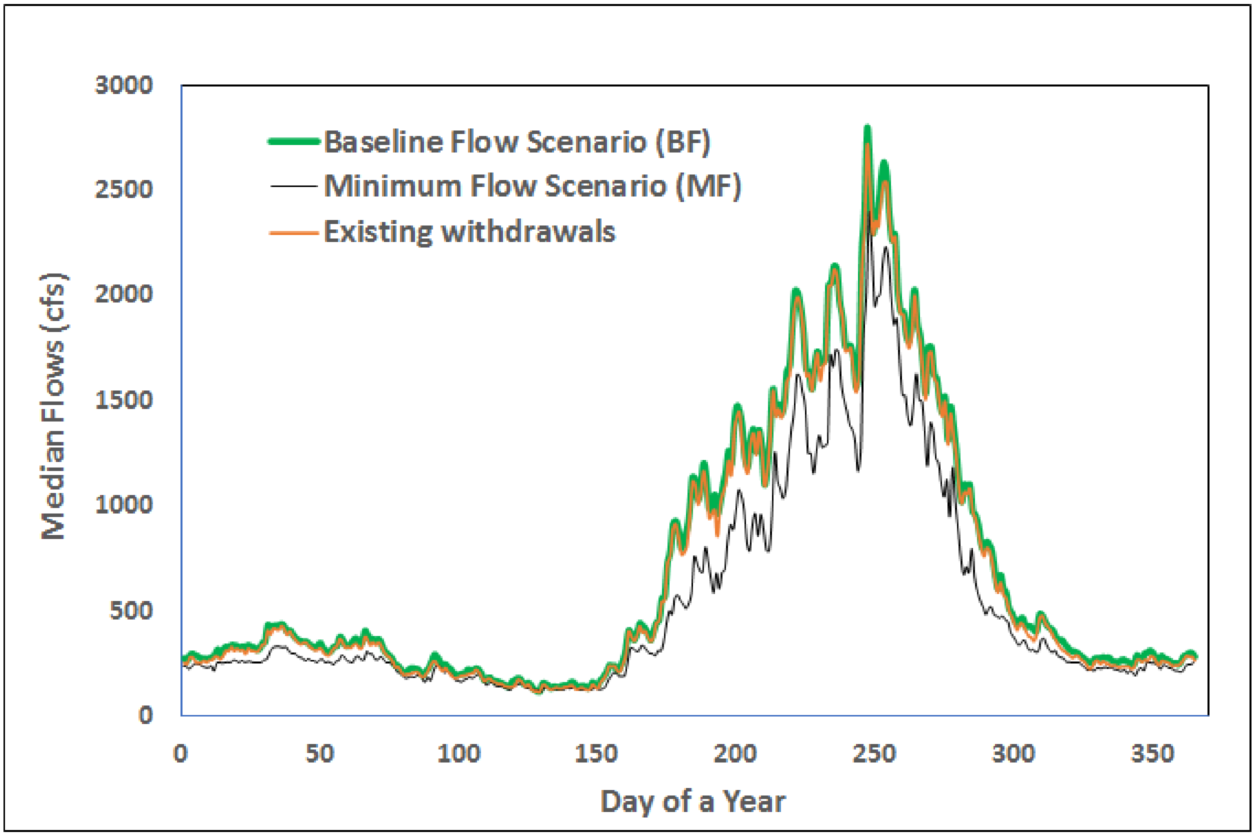

Figure 7-1. Median daily Lower Peace River flows for the zero-withdrawals (i.e., baseline; dashed black line), minimum flow-based withdrawals (solid red line) and existing withdrawals (solid green line) scenarios.

On December 15, 2020, the District Governing Board approved initiation of rulemaking for establishment of the recommended minimum flows for the Lower Peace River described in this report. The recommended minimum flows became effective on April 12, 2021, replacing the previously established minimum flows for the lower river. Following adoption of the recommended minimum flows for the Lower Peace River, the permit issued to the PRMRWSA for withdrawals from river was modified on July 19, 2021, to incorporate withdrawal limitations consistent with the updated minimum flows. No changes to the authorized allocation or permit expiration date were included in the revised permit (i.e., Water Use Permit No. 20010420.011).

Given the inclusion of withdrawal limitations consistent with the adopted minimum flows in the current permit issued to the PRMRWSA and the expectation that any other withdrawals that may affect flows in the river are or will similarly be conditioned to ensure compliance with adopted minimum flows, the minimum flows currently established for the Lower Peace River are expected to be met over the next 20 years and beyond. Development of a specific prevention strategy for the river is, therefore, not necessary at this time.

Because water withdrawals, climatic variation, structural alterations and other changes in the watersheds and contributing groundwater basin can influence river flow regimes, minimum flow status assessments for the Lower Peace River are and will continue to be completed by the District on an annual basis, on a five-year basis as part of the regional water supply planning process, and on an as-needed basis in association with permitting and project-related activities. In addition, consideration of these factors that affect river flows as well as additional information relevant to the minimum flows that may become available, the District is committed to the periodic reevaluation and as necessary revision of the minimum flows established for the Lower Peace River.

In support of this commitment, the District, in cooperation with the USGS and the PRMRWSA, will continue to monitor and assess the status of flows in the Lower Peace River as well as other portions of the watershed, and continue to work with others on refinement of tools such as the Peace River Integrated Model (PRIM) that were used for development and assessment of the recommended minimum flows.

7.2. Minimum Flow Status Assessment for Lower Shell Creek

The observed discharge from Shell Creek reservoir across the Hendrickson Dam to Lower Shell Creek has been increased or augmented by excess irrigation flow associated with groundwater pumped for agricultural purposes and decreased by City of Punta Gorda withdrawals from the reservoir (see Section 5.3.3).

To account for these factors and support assessment of the status of the recommended minimum flows for Lower Shell Creek, a spreadsheet-based mass balance model was developed for the reservoir based on daily historical flows in Shell Creek for a 47-year period, from 1972 through 2018. For model development and use we assumed that historical flows provided a reasonable basis for estimating future flows. Several factors were accounted for in the model, including configuration of the in-stream, Shell Creek Reservoir, the configuration of Hendrickson Dam, withdrawal records, and withdrawal restrictions associated with the recommended minimum flows for Lower Shell Creek. Water quality was also accounted for in the model, as elevated levels of chloride and other ions that in combination exceed the secondary drinking water standard of 500 mg/l for total dissolved solids (TDS) have historically occurred in the reservoir and limited withdrawals.

Shell Creek Reservoir has a usable volume of approximately 320 million gallons (personal communication with City of Punta Gorda staff). Hendrickson Dam is a rectangular, sharp-crested weir with free overflow. Water flowing into the reservoir from the Shell Creek and Prairie Creek is retained up to the crest elevation of the dam, which is approximately 5 ft. Downstream flows to lower Shell Creek occur only when water levels exceed the dam crest elevation.

Under these existing structural conditions, initial modeling results based on gaged flows, indicated the recommended minimum flows for Lower Shell Creek would not have been met approximately 20% of days in the 47-year simulation period. Similar results were predicted for both the current water-use demand of 5.4 mgd and the demands projected over the next 20 years. Days the minimum flows would not have been met occurred most often during low flow periods, i.e., in Block 1, during the dry season (Figure 7-2). Suppression of flows to Lower Shell Creek by the dam and increased occurrence of low reservoir water levels resulting from withdrawals contributed to the simulated, non-compliance with the recommended minimum flows.

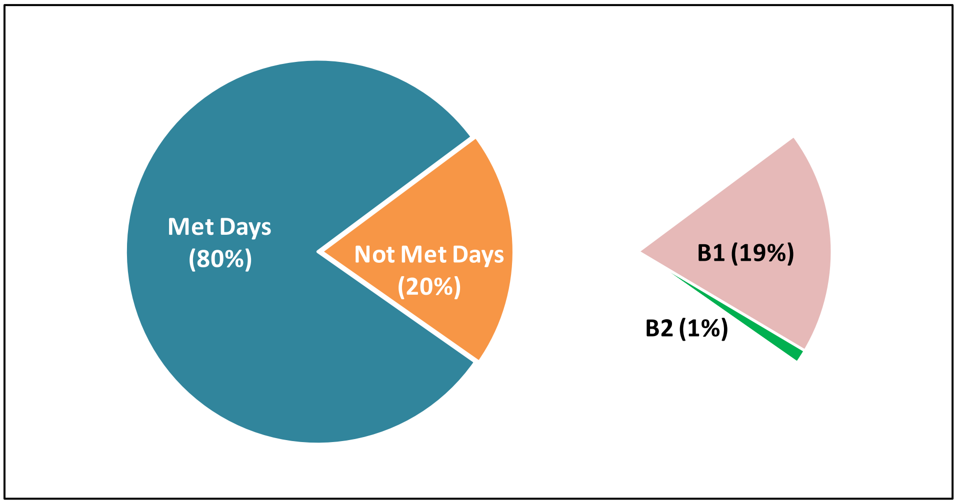

Figure 7-2. Results from an initial status assessment, showing the percentage of days recommended minimum flows for Lower Shell Creek would have been met and would not have been met for a 47-year evaluation period, from 1972 through 2018; the pie slice on the right illustrates the days the recommended minimum flows would not have been met during low-flow periods (B1 = Block 1 and B2 = Block 2; see Table 6-8 for block-specific flow ranges).

At the time of this initial assessment, the District identified two recovery projects that would individually or in combination prevent the Lower Shell Creek minimum flows from being violated due to consumptive water use. The projects are the cooperatively-funded Punta Gorda Reverse Osmosis (RO) Water Treatment Facility Project N780 (RO Project), and the PRMRWSA Regional Loop Phase 1 Interconnect Project N734/N416 (Phase 1 Interconnect Project), which connects the PRMRWSA Peace River Water Treatment Facility and City of Punta Gorda Shell Creek Water Treatment Plant. Both projects were anticipated to minimize reliance on the Shell Creek flows when water in the reservoir is insufficient to meet both minimum flows and allow for blending of water to ensure that the City will meet future water demands and the secondary maximum TDS drinking water standard for finished water.

In August 2020, the District received information from the City of Punta Gorda regarding the completion of the RO and Phase 1 Interconnect projects, and how the City would use these projects to enhance water supply reliability and meet the minimum flows recommended for Lower Shell Creek. In addition, the City provided its updated 2040 water demand projection and monthly withdrawal peaking ratios.

Investigations of Lower Shell Creek minimum flows status using this updated information and other factors that affect flows in the creek were completed in March 2021. The updated assessments included use of the mass-balance model for Shell Creek Reservoir to determine days the recommended minimum flows would be met during the low-flow Block 1, the intermediate-flow, Block 2 and the high-flow, Block 3. The UnLESS hydrodynamic model for the Lower Peace/Shell System was also used for the updated assessments, to ensure that 85% of the low salinity (2 psu or lower) habitat would be maintained in the lower creek during all three flow blocks.

Results from the updated status assessments indicated the recommended minimum flows for Lower Shell Creek are being met and the low salinity habitat in the Lower Peace River/Shell Creek system is being maintained above 85% of the baseline habitat conditions. Based on this information, a recovery strategy for the recommended minimum flows for Lower Shell Creek was not deemed necessary.

The results based on projected 2040 water demands indicated the need for a prevention strategy to ensure the recommended minimum flows would be met during a 20-year planning horizon. The analyses also indicated, however, that a modification of the City's water use permit that imposes withdrawal limitations consistent with the recommended minimum flows for Lower Shell Creek would obviate the need for a prevention strategy. These withdrawal limitations are based on consideration of the City's use of the RO and Phase I Interconnect projects. The City has now modified its water use permit consistent with the recommended minimum flows for Lower Shell Creek. Compliance with the modified permit conditions ensures the Lower Shell Creek minimum flows are met over the next 20 years and a prevention strategy is not required at this time.

Because water withdrawals, climatic variation, structural alterations and other changes in the watersheds and contributing groundwater basin can influence flow regimes, minimum flow status assessments for Lower Shell Creek will be completed by the District on an annual basis, on a five-year basis as part of the regional water supply planning process, and on an as-needed basis in association with permitting and project-related activities. In addition, consideration of these factors that affect flows as well as additional information relevant to the minimum flows that may become available, the District is committed to the periodic reevaluation and as necessary revision of the minimum flows established for Lower Shell Creek.

In support of this commitment, the District, in cooperation with the USGS and the City of Punta Gorda, will continue to monitor and assess the status of flows in Lower Shell Creek as well as other portions of the watershed.

7.3. Minimum Flows Implementation

Ongoing, periodic status assessments, like those described in the preceding section of this report will be an important component of minimum flows implementation for the Lower Peace River and Lower Shell Creek. Compliance with permitted withdrawals will also ensure the minimum flows continue to be met. Information presented in this section provides examples regarding how the minimum flows may be implemented to prescribe permitted withdrawals.

7.3.1 Implementation for Lower Peace River

As discussed in Sections 2.9 and 6.5, combined flows from Horse Creek near Arcadia, Joshua Creek at Nocatee and the Peace River at Arcadia gages have been and will be used to potentially limit permitted surface water withdrawals from the Lower Peace River. Several examples are provided below to illustrate how these gaged flows and the recommended minimum flows for Lower Peace River (see Table 6-4) may be implemented.

If the previous day's combined flow from Horse Creek, Joshua Creek and the Peace River at Arcadia gages adjusted for upstream withdrawals is less than 130 cfs, no water should be withdrawn from the Lower Peace River. During Block 1, the allowable withdrawal can range up to 13% of the combined flow but cannot reduce the combined flow below a low flow threshold of 130 cfs. So, if the previous day's combined flow was 151 cfs, the allowable withdrawal would be 13% of 151 cfs or 20 cfs. However, if the combined flow was 135 cfs, only 5 cfs would be withdrawn to maintain the 130 cfs low flow threshold.

Similar flow-related contingencies would be applicable to withdrawals under Block 2 flow conditions. If, for example, the previous day's combined, adjusted flow was 340 cfs, within the higher range of flows identified for Block 2, a withdrawal of 78 cfs (23% of 340 cfs) would be allowed. However, if the combined, adjusted flow was 330 cfs, in the lower range of flows identified for Block 2, the allowable withdrawal would be 72 cfs, calculated as 330 cfs minus 258 cfs, rather than 76 cfs, calculated at 23% of 330 cfs.

Withdrawals would also be variably constrained under Block 3 flow conditions. For example, if the previous day's combined, adjusted flow was 1,100 cfs, within the highest range of flows identified for Block 3, a withdrawal would be subject to the daily maximum limit of 400 cfs. However, if the previous day's flow was 850 cfs, a withdrawal of 340 cfs, calculated as 40% of 850 cfs, would potentially be allowed. Alternatively, if the previous day's combined, adjusted flow was 650 cfs, within the lower range of flows identified for Block 3, the withdrawal would be limited to 171 cfs, calculated as 650 cfs minus 479 cfs, rather than 260 cfs calculated as 40% of 650 cfs.

7.3.2 Implementation for Lower Shell Creek

The recommended minimum flows for Lower Shell Creek are also flow-dependent (i.e., block-specific) minimum flows that specify allowable reductions in flows (see Table 6-5). For Lower Shell Creek, the allowable reductions would be calculated based on the adjusted previous day's flow measured at the USGS Shell Creek near Punta Gorda, FL gage (No.02298202). The previous day's flow in cubic feet per second (cfs) would be converted to million gallons per day (mgd) and adjusted by adding the City of Punta Gorda's previous day's withdrawal (mgd) from Shell Creek Reservoir and subtracting the monthly estimated excess agricultural runoff (mgd) provided in Table 7.2.

Table 7-2. Estimated excess agricultural runoff (mgd) for Lower Shell Creek flow adjustments for minimum flows implementation.

Month	Agricultural runoff (mgd)
January	8.5
February	11.0
March	14.7
April	8.7
May	6.8
June	27.0
July	10.1
August	0.0
September	0.0
October	0.7
November	5.3
December	6.0

CHAPTER 8 – LITERATURE CITED

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