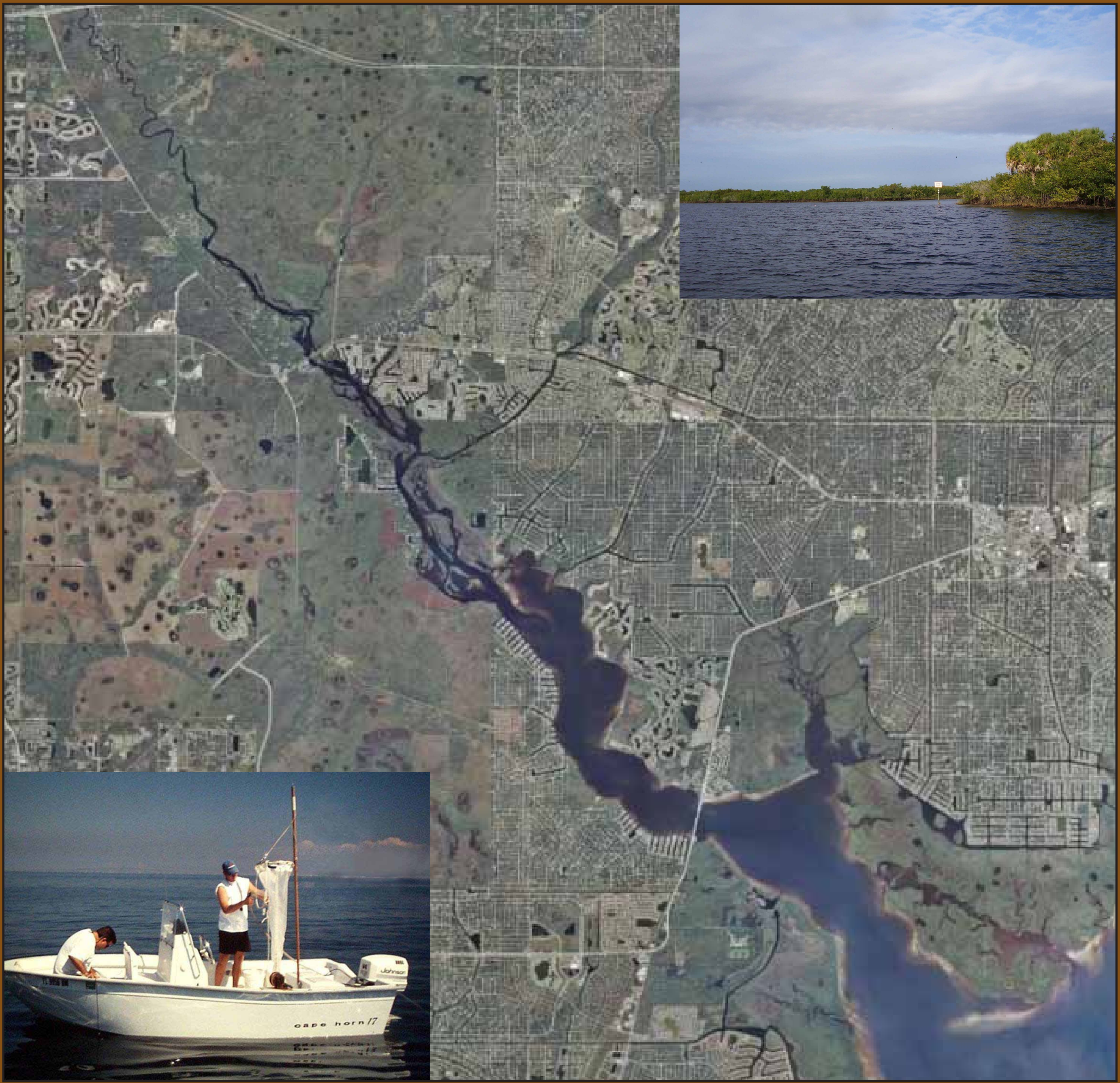
The Determination of Minimum Flows for the Lower Myakka River

Report of the
Southwest Florida Water Management District

Peer Review Draft - August 24, 2010



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Southwest Florida
Water Management District
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List of Acronyms

µg/l	micrograms per liter
3D	three dimensional
CPUE	catch per unit effort
DO	dissolved oxygen
DPS	Deer Prairie Slough
EAV	emergent aquatic vegetation
EDT	eastern daylight time
EST	eastern standard time
FDEP	Florida Department of Environmental Protection
FFWCC	Florida Fish and Wildlife Conservation Commission
FLUCCS	Florida Land Use Land Cover Classification System
FMRI	Florida Marine Research Institute
FSC	free-surface correction
FWRI	Florida Water Resources Institute
GIS	Geogrpahic Information System
HSPF	Hydrologic Simulation Program for Fortran
Km	kilometer
LAMFE	laterally averaged model for estuaries
mg/l	milligrams per liter
MML	Mote Marine Laboratory
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PCU	platinum cobalt units
PEST	parameter estimation software package
PRMRWSA	Peace River Manasota Regional Water Supply Authority
psu	practical salinity units
RK	fire kilometer
SAV	submeged aquatic vegetation
SFWMD	South Florida Water Management District
SWFWMD	Southwest Florida Water Management District
TN	total nitrogen
TP	totan phosphorus
UCH-LPR-LMR	Upper Charlotte Harbor - Lower Peace River - Lower Myakka River
USF	University of South Florida
USGS	United States Gelogical Survey

Acknowledgements

The completion the minimum flows project for the Lower Myakka River involved the efforts of many people in addition to those who are listed as authors or contributors to this report. Sincere appreciation is expressed to the following people for the important roles they played in supplying valuable data, information, analyses and ideas to the District for the minimum flows evaluation.

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The minimum flows analysis relied on extensive bathymetric data provided by Dr. Ping Wang of the University of South Florida (USF) Department of Geology and ichthyoplankton and zooplankton analyses generated by Dr. Ernst Peebles and staff at the USF College of Marine Science. Tim MacDonald, Marin Greenwood, and other staff at the Florida Fish and Wildlife Conservation Commission's Wildlife Research Institute collected the seine and trawl data and produced valuable analysis.

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Lastly, Lisann Morris of District staff and John Loper of Interflow Engineering LLC played a critical role by providing data review and advice on application of the findings of the Myakka River Watershed Initiative and the MIKE SHE modeling effort in the upper river sub-basin to the minimum flows analysis for the Lower Myakka River.

Executive Summary

The Myakka River watershed covers approximately 1559 square kilometers (602 square miles) in predominantly Manatee and Sarasota counties, with small portions extending into Hardee, DeSoto, and Charlotte counties. Along with the Peace River, the Myakka River is one of the two rivers that contributes flow to Upper Charlotte Harbor, which is considered to be one of the most pristine and valuable estuaries in Florida. The Myakka River is similarly a very highly valued natural resource, with portions of it designated as either an Outstanding Florida Water, a State of Florida Wild and Scenic River, and/or an Aquatic Preserve.

Minimum flows are defined in Florida Statutes as “the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area”. Minimum flows essentially establish how much the flow of a stream or river can be reduced by water use without causing unacceptable impacts to the resources of that stream or river including its ecological characteristics. Minimum flow rules can be established for both freshwater streams and freshwater inflow to estuaries and are important regulations that affect natural systems protection, water supply planning, and water use regulation.

For management purposes, the Myakka River watershed can be divided into upper river and lower river sub-basins with the divide at the outlet to Lower Myakka Lake. This report establishes minimum flows for the Lower Myakka River, or the 52 kilometer reach of the river that lies within the lower river sub-basin. The Lower Myakka River is tidally affected over much of its length and the ecological resources of concern in the lower river include estuarine species and communities that are closely linked with the biological resources of Charlotte Harbor. Minimum flows for the freshwater reach of the Myakka River in the upper river sub-basin were established by a previous District project.

The establishment of minimum flows for both the freshwater and tidal reaches of the Myakka River have taken into account that flows in the river have increased significantly due to human activities. It has been well documented that changes in land use in the upper river sub-basin, particularly an increase in irrigated agricultural crops, has resulted in increased flows in the main river channel and a number of upstream tributaries. These increased flows have in turn resulted in tree die-off in the Flatford Swamp and impacts to other freshwater riverine wetlands. To address these impacts, the District has pursued a Myakka River Watershed Initiative (MRWI) project to develop management plans to reduce or remove the excess flows in the upper river sub-basin.

As part of the MRWI, a highly detailed integrated surface water / ground water model for the upper river sub-basin above the long-term Myakka River near Sarasota gage was developed using the MIKE SHE modeling platform. Using hydrologic simulations that included both historical and existing land use, the model allowed for the prediction of excess flows the river received on a daily basis for a twelve-year period from May 1994 through April 2006. These modeling estimates are being used as hydrologic targets in management plans to reduce the excess flows in the upper river sub-basin and restore more natural hydrologic conditions to Flatford Swamp and other freshwater systems.

Given these findings for the upper river sub-basin, the determination of minimum flows for the Lower Myakka River evaluated the effects the removal of these excess flows would have on the ecology of the lower river. To address this question, the minimum flows analysis used the existing flow regime of the lower river as the baseline against which to evaluate the effects of flow reductions. This approach was warranted because there have been other historic modifications in the lower river sub-basin that have reduced freshwater flows to the Lower Myakka River. These are the construction of the Blackburn Canal, which primarily diverts some water away from the lower river to Roberts Bay near Venice, and the modification of Cowpen Slough drainage basin, which diverted almost ten percent of the historic watershed of the Lower Myakka River toward Dona Bay.

The supplementation of flows in the upper river sub-basin and these historic modifications in the lower river sub-basin have counteracted each other to some extent to result in the existing flow regime of the Lower Myakka River. The water quality and ecological characteristics of the Lower Myakka River are currently both in excellent condition, and the biological communities in the lower river have become adapted to the lower river's existing flow regime. Because of its high natural resource value and healthy ecological condition, the District considered the existing flow regime of the lower river as the baseline against which to measure the effects of withdrawals or other flow reductions.

To determine the minimum flows for the Lower Myakka River the District evaluated a series of potential flow reduction scenarios. The first was to simulate the maximum permitted water supply withdrawals by the City of North Port from Myakkahatchee Creek, which is a major tributary to the lower river. These withdrawals were then combined with removal of all the excess flows from the upper river sub-basin above the Myakka River near Sarasota gage. Scenarios were then run which simulated the withdrawal of different percentages of the flow remaining at that gage after removal of the excess flows.

The effects of these flow reduction scenarios were evaluated by running a series of mechanistic and empirical models to predict changes in salinity distributions and a number of biological parameters in the lower river estuary. Reductions in the bottom area and water volume of biologically important salinity zones were simulated using a linked two-dimensional / three-dimensional hydrodynamic model of the Upper Charlotte Harbor – Lower Peace River – Lower Myakka River system. A regression model of the location of the 2 psu surface water isohaline was used to evaluate the effects of flow reductions on sensitive low salinity and freshwater marshes that occur between river kilometers 22 and 29. Regression models were also used to simulate changes in the distribution and abundance of key fish and invertebrate species in the river, with emphasis on a dominant fish species in low salinity areas and a crustacean that is an important prey from juvenile fishes.

The estuarine analyses found that the maximum withdrawal of water by the City of North Port had very little effect on the ecological resources of the Lower Myakka River and were well within acceptable limits. When these withdrawals were combined with the removal of the excess flow from the upper river, it was found that reductions in ecological resource indicators were most pronounced at low flows, largely because the excess flows can comprise very high percentages of the low flow of the river. In minimum flow studies of other rivers the District has used a 15% reduction in resource indicators as a threshold for identifying significant harm. Reductions in resources in excess of 15% were predicted in the Lower Myakka River at low flows, especially in the spring dry season. Reductions in resource indicators less than 15% were common at higher flows that typically occur in the summer, winter, and fall.

Based on these findings, the proposed minimum flows for the Lower Myakka River are that flow reductions should not exceed water quantities that are hydrologically equivalent to the excess flows that were simulated for this minimum flows report, until daily flows at the Myakka River near Sarasota gage exceed a flow rate of 400 cfs. The removal of excess flows should be capped at 130 cfs at all rates of river flow. Removing these excess flows will return flows in the river to conditions like those that existed before the late 1970s, when human effects on increased flows in the river were much less. Although construction of the Blackburn Canal and the modification of the Cowpen Slough basin have reduced freshwater flow to the lower river, the effects of these modifications are most pronounced at higher flows, and are typically exceeded by excess flows at low flow rates.

It was concluded from the estuarine analyses that withdrawals by the City of North Port will be in compliance with the proposed minimum flows, as these withdrawals have a very small effect on the ecosystem of the Lower Myakka River. Also, the proposed minimum flows allow for withdrawal of ten percent of the daily flow at the Myakka River near Sarasota gage that remains after removal of the excess flows, if daily flows at that gage exceed a rate of 400 cfs. This provision is warranted because reductions in resource indicators in the lower river are less than 15% at high flow rates, even when the excess flows and ten percent of the remaining flow at the gage are removed.

The simultaneous application of restoration plans for the Upper Myakka River sub-basin and minimum flows for the Lower Myakka River will require an adaptive management strategy in which the excess flows that are removed and remaining flow at the Myakka River near Sarasota gage will have to be closely monitored to ensure that compliance with the minimum flows for the lower river are achieved. It is unlikely that removal of all the excess flows in the upper river sub-basin can be achieved in the short term, and reductions of the excess flow may be done incrementally over time. This will allow for the effectiveness of the minimum flows for the lower river to be periodically reviewed, while restoration plans for the upper river sub-basin are developed and implemented.

Even with this incremental approach, the removal of excess water within the proposed minimum flows will cause substantial reductions in the existing low flow characteristics of the Lower Myakka River. These flow reductions will in turn result in shifts in salinity distributions and reductions in the abundance of some species and biological communities in the lower river during prolonged periods of low flow. These changes will be most pronounced in the spring dry season, which is an important time for fish nursery use and increasing biological productivity in the lower river estuary.

Management options for other hydrologic features that affect freshwater flow to the Lower Myakka River could be pursued to at least partially offset the reductions in low flows in the dry season. These could include modifications or water storage options that involve the Blackburn Canal, the Cowpen Slough drainage basin, or the Tatum Sawgrass area. However, the removal of excess flows from the upper river sub-basin and compliance with minimum flows for the Lower Myakka River would not be contingent upon such management plans.

Finally, minimum flows for Myakkahatchee Creek should be established within a five years. This time frame will allow for the inclusion of streamflow data from relatively new gages on Myakkahatchee Creek and the Cocoplum Waterway. The minimum flow evaluation for Myakkahatchee Creek could also incorporate improvements to the District’s hydrodynamic model of the Upper Charlotte Harbor – Lower Peace River – Lower Myakka River system that will be applied with the scheduled reevaluation of the minimum flows for the Lower Peace River within this same time frame.

Chapter 1

Purpose and Background of Minimum Flows and Levels

1.1 Overview

The Southwest Florida Water Management District (District) is responsible for permitting the consumptive use of water within the District's boundaries. Within this context, the Florida Statutes (Section 373.042) mandate that the District protect water resources from "significant harm" through the establishment of minimum flows and levels for streams and rivers within its jurisdiction. The purpose of minimum flows and levels (MFLs) is to create hydrologic and ecological standards by which either permitting or water resource planning decisions can be made concerning withdrawals from surface or ground waters.

Along with the Peace River, the Myakka River is one of the two major rivers in the District that drain to Charlotte Harbor, and the Myakka is a very highly valued natural resource in the region. The river is approximately 106 kilometers (66 miles) long and has both freshwater and estuarine reaches. Minimum flows and levels have been adopted for the freshwater portion of the Myakka River between Myakka City and State Road 72 (SWFWMD 2005a). Minimum flows for the Lower Myakka River, or the predominantly tidal portion of the river that lies below the outlet of Lower Myakka Lake, are proposed in this report. In determining these minimum flows, the District evaluated to what extent flows in the river can be reduced by withdrawals without causing significant harm to the downstream ecosystem. The determination of minimum flows for the Lower Myakka River was a rigorous technical process in which extensive physical, hydrologic, and ecological data were collected and analyzed.

This chapter provides an overview of how the District applied legislative and water management directives in the determination of minimum flows for the Lower Myakka River. The rationale of the District's technical approach is also summarized. Greater details regarding this technical approach, including data collection programs and analytical methods used to determine the minimum flows, are provided in subsequent chapters that conclude with the proposed minimum flows for Lower Myakka River.

1.2 Legislative Directives

As part of the Water Resources Act of 1972, the Florida Legislature mandated that the five water management districts establish MFLs for surface waters and aquifers within their jurisdictions (Section 373.042, F.S.). Although this Section has been revised in subsequent years, the definitions of MFLs that were established in 1972 have remained the same. Minimum flows are defined as "*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.*" As defined, "*the minimum water level shall be the level of groundwater in an aquifer and the level of surface water at which further* *withdrawals would be significantly harmful to the water resources of the area*." It is generally interpreted that ecological resources are included in the "water resources of the area" mentioned in the definition of minimum water level. The establishment of MFLs for flowing watercourses can incorporate both minimum flows and minimum levels. However, the establishment of MFLs for the largely estuarine Lower Myakka River involved only a flow component, and the term minimum flows is used in this report with specific reference to Lower Myakka River.

Section 373.042 F.S. further states that MFLs shall be calculated "*using the best information available. When appropriate, minimum flows and levels may be calculated to reflect seasonal variations. The Department [of Environmental Protection] and the governing board [of the relevant water management district] shall also consider, and at their discretion may also provide for, the protection of non-consumptive uses in the establishment of minimum flows and levels*."

Guidance regarding non-consumptive uses of the water resource to be considered in the establishment of MFLs is provided in the State Water Resources Implementation Rule (Chapter 62-40.473, Florida Administrative Code), which states that "*consideration shall be given to the protection of water resources, natural seasonal fluctuations in water flows or levels, and environmental values associated with coastal, estuarine, aquatic and wetlands ecology, including:*

(1) Recreation in and on the water;
(2) Fish and wildlife habitats and the passage of fish;
(3) Estuarine resources;
(4) Transfer of detrital material;
(5) Maintenance of freshwater storage and supply;
(6) Aesthetic and scenic attributes;
(7) Filtration and absorption of nutrients and other pollutants;
(8) Sediment loads;
(9) Water quality; and
(10) Navigation."

Florida Statues further state that "*When establishing minimum flows and levels pursuant to 373.042, the department or governing board shall consider changes and structural alterations to watersheds, surface waters and aquifers and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of the affected watershed, surface water, or aquifer, provided that nothing in this paragraph shall allow significant harm as provided by s. 373.042(1) caused by withdrawals*" (Section 373.0421(1)(a) F.S.). In essence, the District is to evaluate and account for existing structural alterations on a watercourse when assessing the potential for withdrawals to cause significant harm.

Given this suite of legal directives, the basic function of MFLs remains to ensure that the hydrologic requirements of natural systems are met and not jeopardized by excessive water withdrawals. In turn, establishment of MFLs is important for water supply planning and regulation, since it affects how much water from a water body is available for withdrawal. Because of the central role that

MFLs play in natural resource protection and water supply management, the methods, data and analyses on which MFLs are based should be comprehensive and technically sound. For this reason, it is District practice to have an independent peer review conducted on the draft technical report upon which a set of proposed MFL rules are based. This process commences upon the publication a draft report by District staff that provides the technical analyses and justification for the proposed MFLs. Pending the findings of this peer review, the Governing Board may choose to adopt the proposed MFLs or pursue further analyses and possible revision of the proposed minimum flows.

1.3 General Technical Approach for Determining Minimum Flows for the Lower Myakka River

Recent assessments of MFLs for flowing water courses by the state's water management districts have emphasized the maintenance of natural flow regimes, which include seasonal variations of low, medium, and high flows that reflect the climatic and watershed characteristics of a particular stream or river system (Hupalo et al. 1994, Mattson 2002b, SWFWMD 2005a, SWFWMD 2005b). As described in the MFL report for the freshwater reach of the Alafia River (SWFWMD 2005b), this approach endorses the concept that the biotic makeup, structure, and function of an aquatic ecosystem depends largely on the hydrologic regime that shaped its development (Hill et al. 1991, Richter et al. 1997, Poff et al. 1997, Instream Flow Council 2002, National Research Council 2005).

Given that protection of a river's flow regime is critical to protecting the biological communities associated with that system, the District has employed a percent-of-flow method in determining minimum flows and levels. The percent-of-flow method determines percentage rates that flows can be reduced without causing significant harm. In both the evaluation and application of the minimum flows, these percentage limits are applied to daily flow records at or very near the time of withdrawal. MFLs determined for the freshwater reaches of the Middle Peace, Myakka, Alafia and Upper Hillsborough rivers which used the percent-of-flow method have all received independent scientific peer review, which generally supported this technical approach (Cichra 2005, 2007; Shaw et al. 2005).

In coastal areas such as Florida, the management of streamflow must also take into account the ecological health of downstream estuaries. It has been repeatedly shown that the physicochemical characteristics and biological structure and productivity of estuaries are also closely linked to seasonal changes in timing and volume of freshwater inflow (Longley 1994, Drinkwater and Frank 1994, Sklar and Browder 1998, Alber 2002). Based on these findings, the protection of natural seasonal variations of freshwater inflows to estuaries has been a priority in District scientific, regulatory, and water supply planning programs for over two decades (Flannery et al. 2002).

Based largely on assessments of the inflow needs of downstream estuaries, the percent-of-flow method has been applied to the regulation of major water use permits from three unimpounded rivers in the region (Peace, Alafia and Little Manatee). It either has been or is being used to determine minimum flows for these three rivers, which will potentially affect all water users from those sources. In keeping with these precedents, the percent-of-flow method was used to determine minimum flows for the Lower Myakka River based on the freshwater inflow requirements of the natural resources associated with the lower river.

One major exception to the percent-of-flow method for the Lower Myakka was how excess flows in the river were evaluated. It has been well documented that flows in the upper Myakka River have increased due to land use changes in the watershed, particularly large increases in agriculture and crop irrigation (Coastal Environmental 1998, SWFWMD 2005a, and Interflow Engineering 2008b). These excess flows have in turn increased freshwater inflow to the lower river. As will be discussed in Chapter 2, an extensive effort using the MIKE SHE continuous simulation water budget model was conducted to identify the quantities of excess flow the upper river now receives due to land use changes in the watershed. As discussed in Chapters 7 and 8, the initial flow reduction scenarios examined by the District was removal of these excess flows to the lower river. Subsequent flow reduction scenarios then involved removing percentages of the remaining adjusted flows using the percent-of-flow approach.

The steps that were critical to the determination of minimum flows for the Lower Myakka River are described in the following chapters of this report. Salinity distributions and biological resources of concern in the lower river were identified and analytical methods were developed to evaluate how these characteristics and resources would change if freshwater inflows are reduced. Modeling scenarios that correspond to removal of the excess flows and a series of percentage flow reductions were then performed to determine the maximum rate of withdrawal that would not cause significant harm to the resources of concern.

1.4 Content of Remaining Chapters

The organization of the following chapters is as follows. Chapter Two describes the physical and hydrologic characteristics of the Lower Myakka River watershed, including major sources of tributary flow and changes in the flow regime of the river. Chapter Three describes the physical characteristics of the Lower Myakka River estuary. Chapter Four describes the salinity and water quality characteristics of the lower river and presents a series of empirical models to predict salinity distributions as a function of freshwater inflow. Chapter Five discusses a mechanistic hydrodynamic model of the lower river that was used to assess changes in salinity distributions, while Chapter Six describes the lower river's biological characteristics. Chapter Seven discusses the District's approach for determining minimum flows for the lower river, including identification of the ecological resources of concern and methods by which changes in these resources were assessed. Chapter Eight presents the findings of modeling scenarios that examine the effects of different flow reductions and presents the proposed minimum flows for the Lower Myakka River. The report concludes with the Literature Cited. The Appendices to the report are provided separately as a pdf file on CD, or may be downloaded along with a pdf of this report from the documents and publications tab on the District web site - http://www.swfwmd.state.fl.us.

Chapter 2

Physical and Hydrological Characteristics of the Lower Myakka River Sub-Basin

2.1 Introduction

Located in southwest Florida, the Myakka River flows southerly for 106 kilometers (66 miles) from Myakka Head to Charlotte Harbor (Figure 2-1). The river's watershed has a drainage area of approximately 1559 square kilometers (602 square miles), which lies principally in Manatee and Sarasota Counties with small drainage areas extending into Hardee, Desoto, and Charlotte counties. Along with the Peace and Caloosahatchee rivers, the Myakka is one of the three rivers that provide freshwater inflow to the Charlotte Harbor estuarine system, which is considered to be one of the most pristine and valuable estuaries in Florida. The mouth of the Myakka River is located approximately 31 kilometers (km) by water from the Gulf of Mexico at Boca Grande (Figure 2-1).

The Myakka River watershed may be divided into upper and lower river sub-basins at the outlet of the Lower Myakka Lake. The lower river is tidally affected and brackish over much of its length, whereas the upper river is non-tidal and fresh. The lower river sub-basin is larger than the upper river sub-basin, covering 922 km^2 or about 59 percent of the entire river watershed (Figure 2-1).

This chapter focuses on the physical and hydrological characteristics of the Lower Myakka River sub-basin. A companion document, “Proposed Minimum Flows and Levels for the Upper Segment of the Myakka River, from Myakka City to SR 72” (SWFWMD 2005a), presents detailed information on the Upper Myakka River sub-basin. Some basin-wide information for the Myakka River watershed discussed below is taken from that report.

2.1.1. Designations

Significant regions of the coastal watershed and shoreline of the Lower Myakka River are owned and managed for natural resource conservation by the State of Florida, the Southwest Florida Water Management District, Sarasota County, or private organizations. The Myakka River in Sarasota County has been designated a Wild and Scenic River by the State of Florida. Waters of the Lower Myakka River, including its estuarine portions, are Class II and III Waters of the State and have been designated an Outstanding Florida Water by the Florida Department of Environmental Protection (FDEP). The lower Myakka River is also part of the Gasparilla Sound-Charlotte Harbor Aquatic Preserve. All of the Myakka River and its watershed are designated as part of the Charlotte Harbor National Estuary Program.

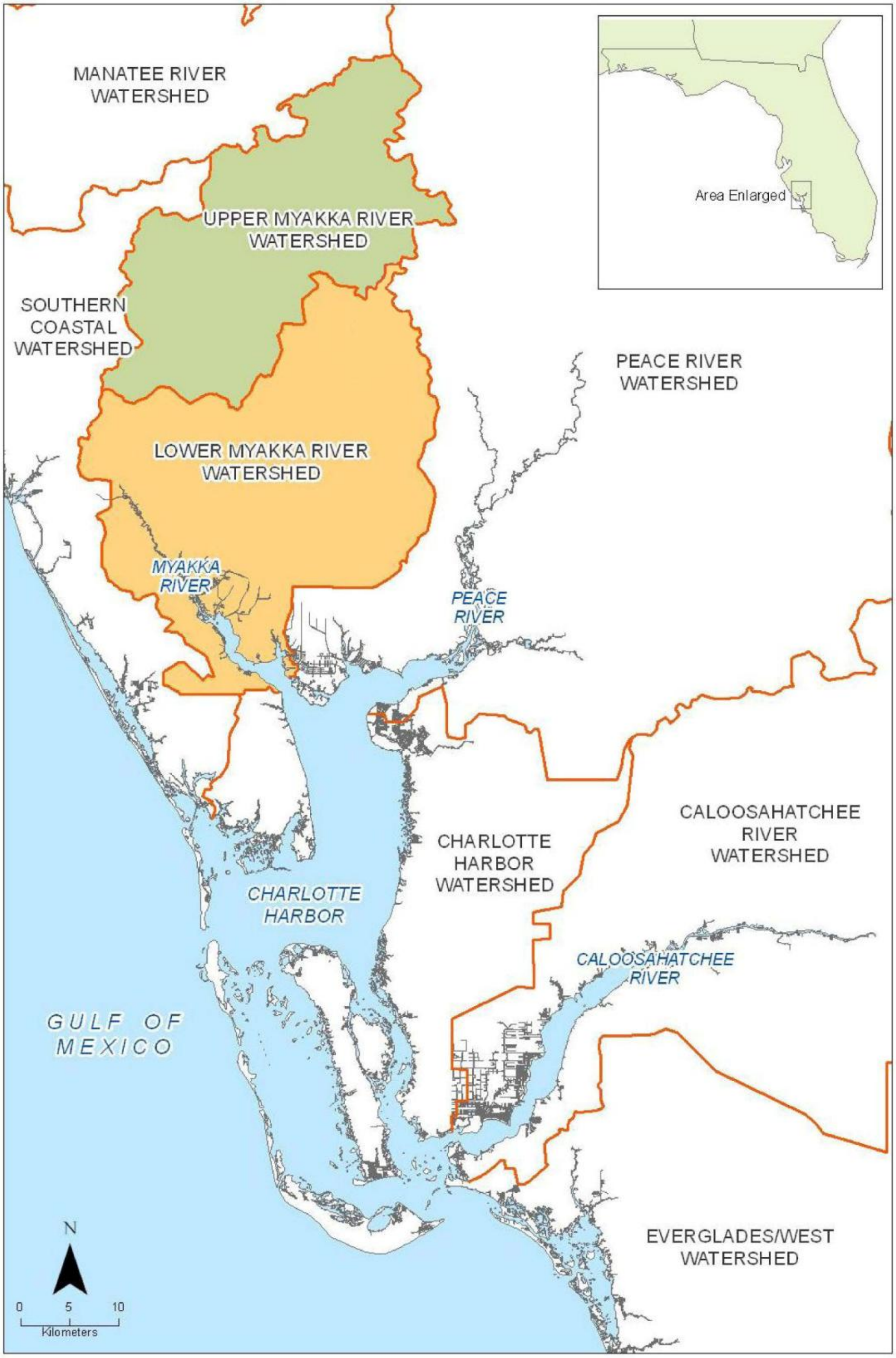

Figure 2-1. Map of Charlotte Harbor showing the location of the Myakka River watershed and upper and lower river sub-basins.

2.2 Climate and Physical Characteristics of the Myakka River Watershed

2.2.1. Climate

The climate of west-central Florida is described as humid subtropical. Mean annual air temperature within Sarasota County is 73 degrees Fahrenheit, with a mean daily temperature range of 84^o F in summer to 61^o F in winter (SWFWMD 2004). Along the coast, temperatures are slightly higher in winter and lower in summer due to the moderating effect of the Gulf of Mexico. The average annual rainfall, based on a number of rainfall stations in the area, is approximately 53 inches. Approximately 60 percent of annual precipitation falls during the months of June, July, August and September and is caused by convective storms that move across the area (Figure 2-2). Periods of very heavy rainfall associated with the passage of tropical low pressure systems may occur during the summer and early fall. Lowest rainfall occurs during the month of November with another seasonal low typically occurring in April.

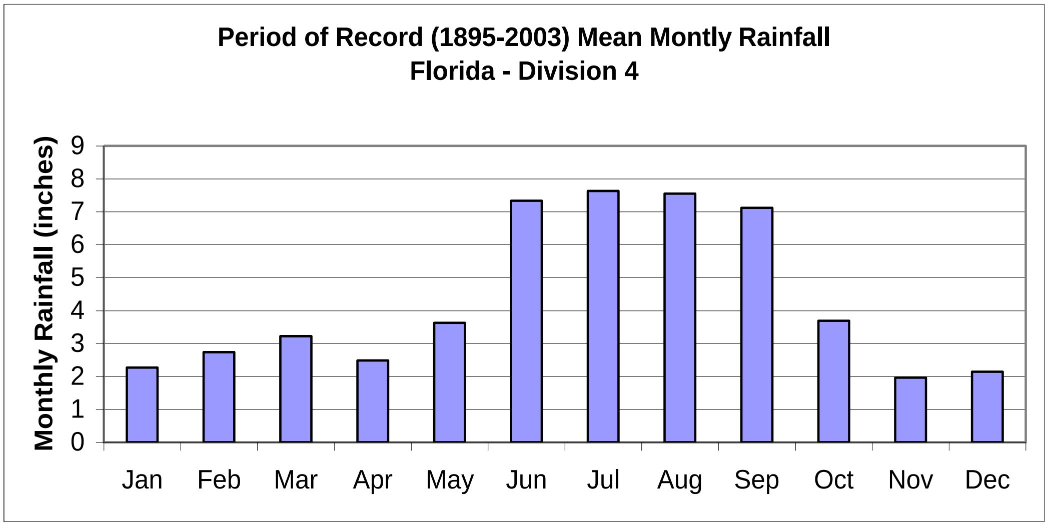

Figure 2-2. Mean monthly rainfall for the Myakka River watershed (Florida – Division 4) for 1895 – 2003.

2.2.2. Physiography

The Myakka River watershed lies within three subdivisions of the central or mid-peninsular physiographic zone of Florida, predominantly the Gulf Coastal Lowlands with the upper portion of the river within the DeSoto Plain and a small part of the headwaters in the Polk Upland unit (White 1958). The Gulf Coastal Lowlands are characterized by flat topography with elevations generally below 40 feet and sandy, shelly, and silty sand soils with little organic matter. The DeSoto Plain consists of generally white sandy soils at elevations from 40 to 100 feet. The maximum watershed elevation is 116 feet above the National Geodetic Vertical Datum of 1929 (NGVD) in the northeastern part of the basin where terraces have eroded into rolling hills. The southwestern part of the basin is less than 20 feet above NGVD and has little local relief.

2.2.3 Hydrogeology

The Myakka River watershed is located within the Southern West-Central Florida Ground-Water Basin, one of three distinct ground-water basins within west-central Florida (SWFWMD 1993). No significant ground-water flow crosses the basin boundaries; hence, all surficial ground water is derived from recharge by rainfall within the basin. Upper Floridan aquifer flow in the basin is derived primarily from rainfall recharge that occurs outside the Myakka River watershed in the Lake Wales Ridge area to the east and on a limited basis from the Green Swamp. Down-gradient of these areas, ground-water flows west and southwest toward and into the Gulf of Mexico.

Within the basin, the ground-water system is divided into three main aquifers: the surficial, the intermediate and the Floridan. Each aquifer is separated by a confining layer of variable thickness and areal extent. The uppermost aquifer, the surficial, is largely undeveloped due to its small thickness and low permeability, except near the coast and in Charlotte County where ground water from deeper aquifers is too mineralized for potable use. The surficial aquifer occurs in the undifferentiated sands that overlie the watershed and generally varies from less than 25 feet in the southern areas to more than 50 feet in thickness in the northeastern areas of Manatee County. These sands yield limited quantities of water, primarily used for lawn irrigation, and are economically mined for their silica and shell hash content.

Underlying the surficial aquifer is the intermediate or secondary artesian aquifer system, which occurs in the Hawthorn Group. The intermediate aquifer system is a moderately prolific but highly developed source of water, and is widely used for domestic and public supplies south of Polk County. Within the basin, the intermediate aquifer averages 700 feet in thickness in southern Charlotte County, but thins toward the north. Within the Myakka River watershed, the intermediate aquifer varies in thickness from less than 200 feet, to more than 350 feet. The upper Hawthorn consists of a green sand and clay containing black phosphate grains. This upper unit is sometimes included with the Bone Valley member and targeted for open pit phosphate mining. The lower Hawthorn is yellow to white sand, clay, and limestone residual from carbonate rock. The fine sand is quartz with black or brown phosphate. Lenses of pure limestone, clay and sand exist throughout the formation and domestic water well production occurs from the porous limestone layers.

The lowermost and most productive aquifer is the Floridan aquifer system. The Floridan aquifer is the primary artesian aquifer throughout Florida and much of the southeastern United States. It consists of two transmissive zones, the Upper Floridan and lower Floridan aquifer, which are separated by the middle confining unit. This aquifer consists of a thick sequence of sedimentary rocks of Eocene to Miocene age. These chemically precipitated deposits of limestone and dolomite contain shells and shell fragments of marine origin, which accumulated throughout the Tertiary period. The Floridan aquifer system thickens from approximately 1,200 feet in the northern areas of the watershed to more than 1,800 feet to the south. Generally, water quality in the Upper Floridan aquifer is good but tends to deteriorate due to increasing mineralization as ground water moves south and toward the coast. The Upper Floridan is the major source of water for agriculture, industry and public supply, except in southern DeSoto and Charlotte counties and the coastal areas of Manatee and Sarasota counties where water quality is relatively poor.

2.2.4 Land Use in the Myakka River Watershed

(Adapted from SWFWMD [2005a], which may be consulted for methods and additional details.)

It is informative to discuss the entire Myakka River watershed to get an appreciation of the major land uses/covers and the changes that have occurred during the 30 plus years for which land use data are available. A list of major land use/covers from 1972 and 1999 is given in Table 2-1 and a land use/cover map for 1999 for the Lower Myakka River sub-basin is shown in Figure 2-3.

Table 2-1. Land use and land cover percentages in the Myakka River watershed for three time periods: 1972, 1990, and 1999.

	1972	**1990**	**1999**
Urban	7.8	13.4	14.2
Citrus	0.8	1.0	1.7
Other Agriculture	25.8	25.5	25.6
Uplands	53.0	36.2	34.0
Wetlands	10.5	21.5	21.0
Water	0	0.2	0.6
Mines	2.0	2.3	2.8

These data indicate there has been a substantial decrease in uplands and an increase in wetlands from 1972 to 1999. However, these apparent changes may be partly due to differences in how the land covers were categorized between periods. Still, relatively large decreases in uplands have occurred in some sub-basins in the watershed. It is helpful when interpreting these trends to view the sum of the wetlands and uplands as natural area, and the changes in this total as a measure of conversion to some other more intensive land use (e.g, agriculture, mining, urban).

Based on the 1999 data, a significant amount of the watershed remains in fairly natural land cover, as uplands and wetlands together comprise approximately 55 percent of the watershed area. On a percentage basis, considerably more of Myakka River watershed remains in a relatively undisturbed state compared to either the Alafia or Peace River watersheds, where the combined acreages of uplands and wetlands are 32 percent and 20 percent of the total watershed area, respectively (SWFWMD 2005b, 2005c).

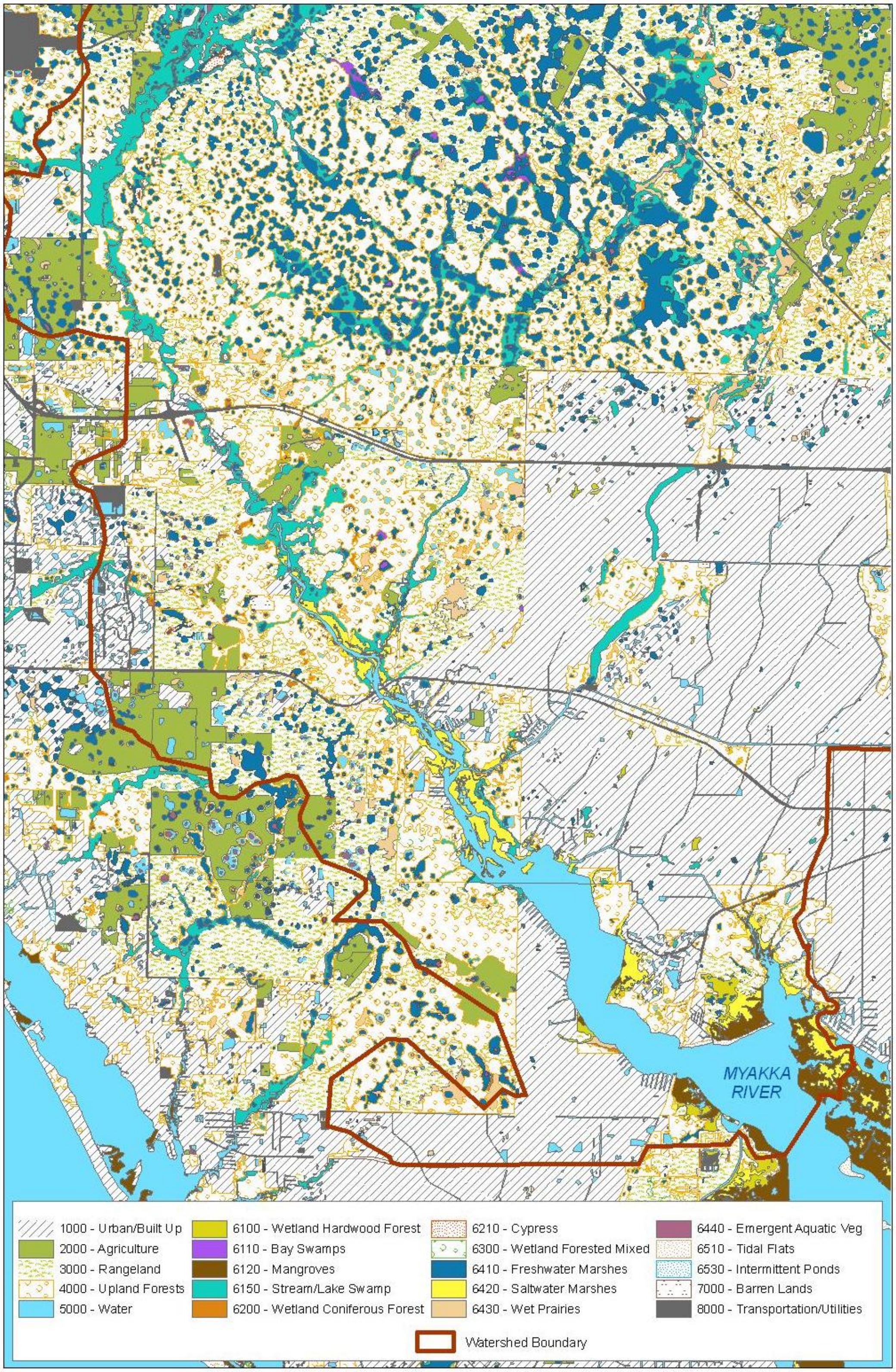

Figure 2-3. Land cover / land use in the Myakka River watershed downstream of Myakka River State Park.

Fourteen percent of the Myakka River watershed was in urban land use as of 1999. Of all the major land use categories, the amount of land converted to urban uses has shown the single greatest increase, with most of this increase occurring in the southern part of the watershed which drains most directly to the lower Myakka River. Only a small portion (0.6 percent) of the Myakka watershed has been mined.

Agriculture represents a major land use in the Myakka River watershed (27 percent). Table 2-1 indicates there has been very little change in the total area of agricultural land use from 1972 to 1999, with citrus showing the greatest change from 0.8 to 1.7 percent. However, several agricultural land use types were combined in the other agriculture category for the change analysis. As a result, changes in land use reported for 1972-1999 may not reflect shifts which have occurred from less intensive types of agriculture to those requiring greater amount of irrigation. For example, the conversion of pastureland to row crops would not be shown as a change in total agricultural lands, but such a conversion could result in greater quantities of irrigation.

As discussed later in this chapter, several lines of evidence indicate that considerable quantities of excess water are now discharged from agricultural lands to the Myakka River due to conversion of agricultural lands that required small amounts of irrigation to agricultural land uses that require greater water use.

2.3. Hydrographic Characteristics of the Lower River Sub-Basin

The hydrographic characteristics of the Myakka River watershed differ considerably between the upper and lower river sub-basins. The river in the upper sub-basin contains two large, shallow, instream lakes (Figure 2-4). The most downstream lake was formed by a man-made sill which creates the Lower Myakka Lake at the southern end of Myakka River State Park. The Lower Myakka River sub-basin begins at the outlet from the lower lake. There are no similar backwater lakes between the outlet and the mouth of the river.

Whereas the Myakka River is situated centrally within the upper river sub-basin, the lower river runs close by the western boundary of the lower sub-basin, with tributaries extending to the northeast (Figure 2-4). The hydrographic characteristics of major tributaries in the lower river sub-basin are described in the following section. The soils, land uses, and surface water features of the lands east and west of the lower river differ considerably and are summarized separately.

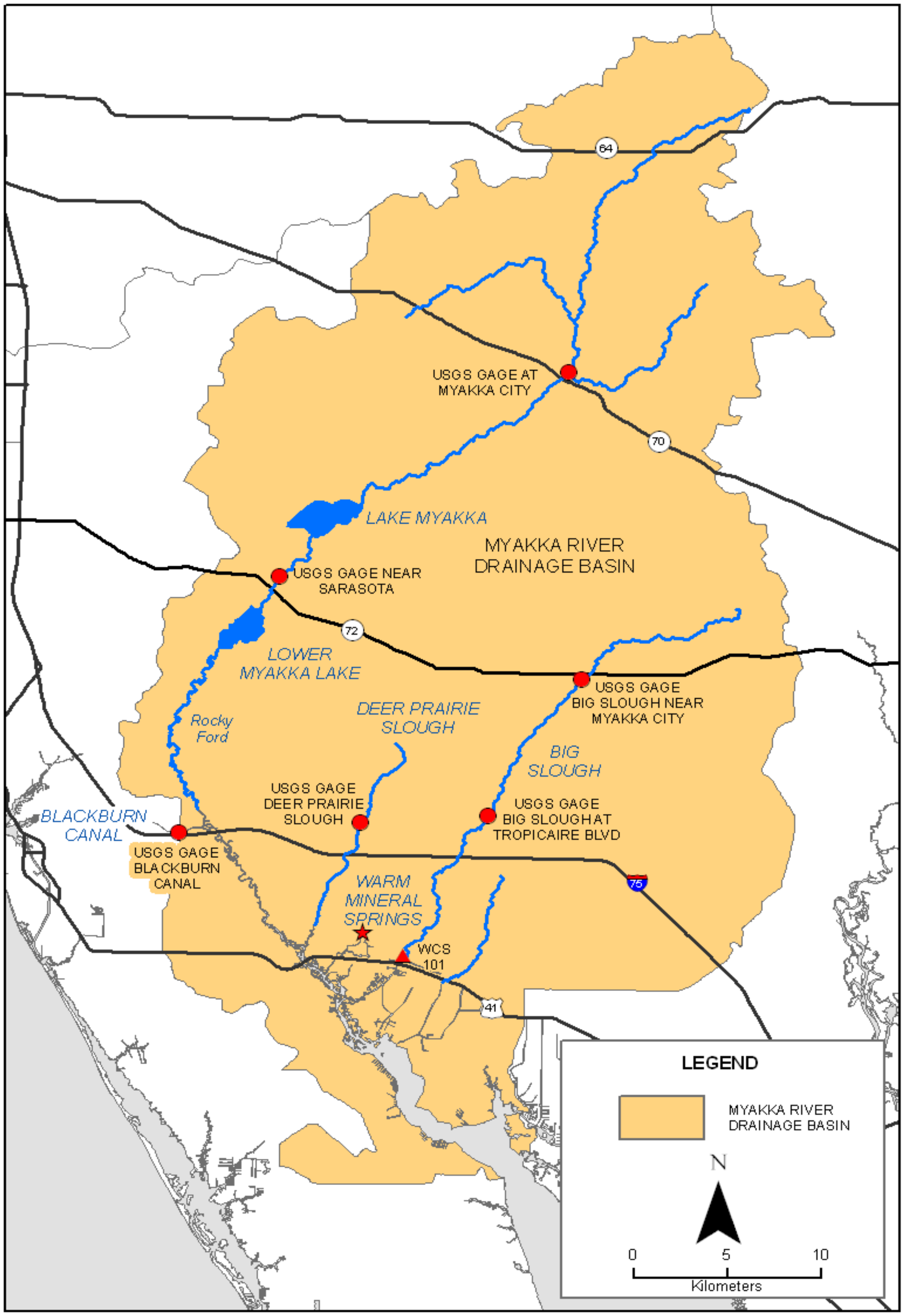

Figure 2-4. Map of the Myakka River watershed showing the Myakka River main stem and tributaries, highways, selected USGS streamflow gages operating prior to 2007, Warm Mineral Springs, and Water Control Structure 101

2.3.1 Drainage West of the Lower River

The watershed west of the river channel and downstream of Myakka River State Park is relatively narrow. A majority of soils west of the river are shallow, poorly drained, and overlay alkaline material or organic hardpan. Upland forest, rangeland and agriculture are the primary land covers and uses in Sarasota County, and each supports low to moderate amounts of isolated freshwater marsh. In lands draining from the west in Charlotte County are largely in suburban development.

No major tributaries presently enter the Lower Myakka River from the west. However, the drainage characteristics of the watershed west of the river have been altered considerably from what were predevelopment conditions. Two major drainage projects, the modification of Cowpen Slough and construction of the Blackburn Canal, have changed the quantity of freshwater flow reaching the Lower Myakka River. The physical nature of these modifications are summarized below.

Modification of Cowpen Slough

Historical surveys of Sarasota County show a large wetland system known as Cowpen Slough flowed from north to south, eventually turning east to join the Lower Myakka River near Rocky Ford (Figure 2-5). A smaller, adjacent drainage basin for Salt and Shakett Creeks flowed to Dona Bay to the west. Between 1916 and 1920, a drainage ditch was excavated through Cowpen Slough to connect it to Salt Creek, presumably for mosquito control and pasture conversion (Kimley-Horn Associates and others [KHA et al. 2007). As a result, runoff that used to flow toward the Myakka River was diverted to Salt Creek, which in turn flows to Shakett Creek and finally Dona Bay.

The drainage area diverted from the Myakka River watershed to Dona Bay covered approximately 152 km^2 (KHA et al. 2007), equal to about 10 percent of the current watershed area of the entire Myakka River. In later decades, a series of channels were excavated to improve drainage in this re-routed basin. Around 1950, a 12 km channel was excavated along the lower reaches of Cowpen Slough by a group of nine ranchers with technical assistance from the Soil Conservation Service (KHA et al. 2007). As part of a multi-agency watershed improvement plan in the early 1960s, the Cowpen Slough Canal was excavated through Cowpen Slough to connect it directly to Shakett Creek (KHA et al. 2007, SWFWMD 2009). This canal had three flood control structures, though the uppermost structure failed in 1967 and it has since been bypassed by a gully. The lowermost structure serves as a salt barrier that separates the freshwater and tidal portions of Shakett Creek, near where it flows into Dona Bay.

As a result of these modifications, Dona Bay receives much more freshwater flow than in predevelopment conditions. The District has established minimum flows for the Cowpen Slough/Shakett Creek system (SWFWMD 2009). The minimum flow analysis for Cowpen Slough concluded that increased freshwater flow to Dona Bay has resulted in impacts to the bay, including decreased seagrass coverage and increased oyster mortality. The goal of the Cowpen Slough minimum flows was therefore to return freshwater flows to Dona Bay to a more historical condition, similar to that prior to the major re-routing and channelization of Cowpen Slough.

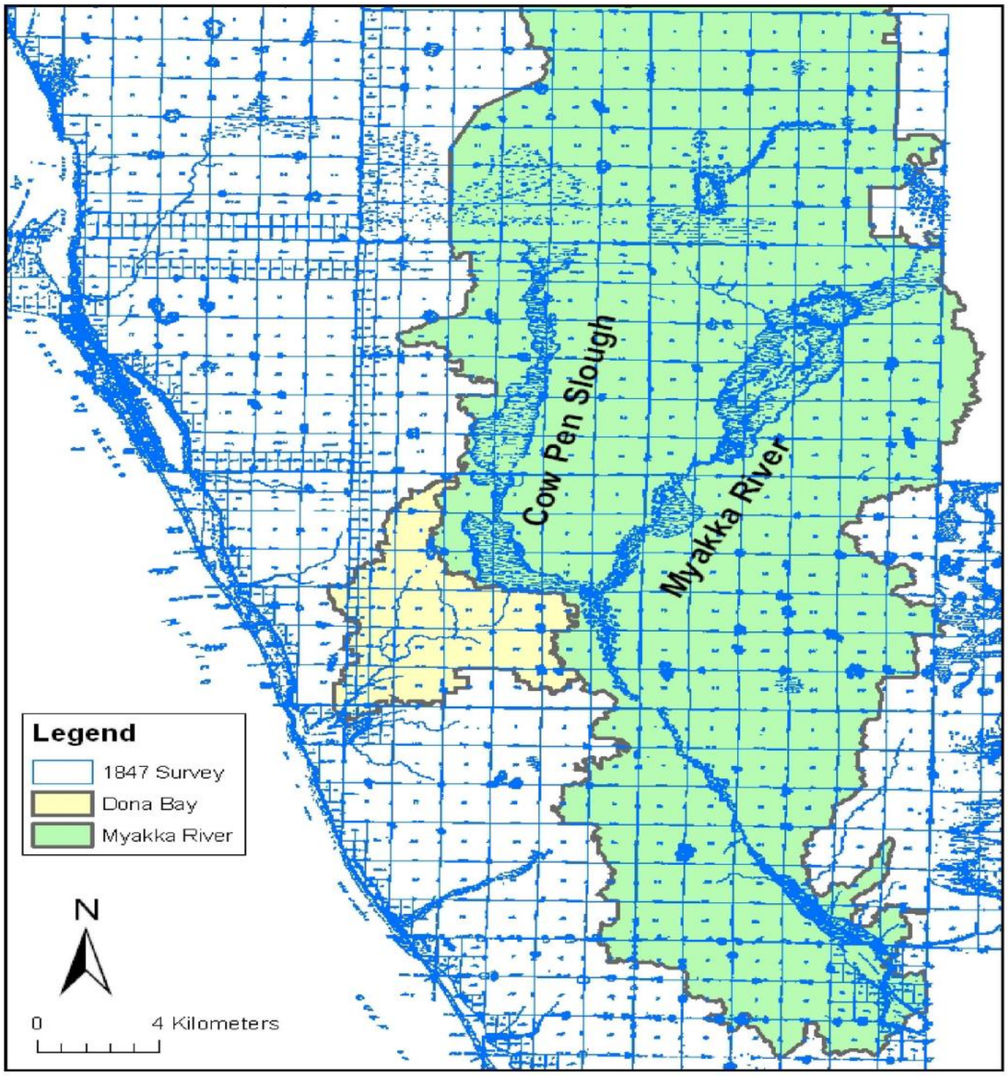

Figure 2-5. Historical watershed boundaries of Dona Bay (yellow) and the Myakka River (green) in the area of Sarasota County taken from the 1847 survey of the region.

To accomplish this goal, a HSPF surface water model (Hydrologic Simulation Program - FORTRAN) was developed for the Dona Bay watershed by Intera Inc. (2007). The HSPF model was used to simulate runoff to the bay given the current land use and hydrographic characteristics of the Cowpen Slough basin. In addition, in order to approximate a more historical baseline flow condition, land use data taken from 1948 aerial photography were entered into the model along the watershed delineations of the Cowpen Slough and Salt Creek/Shakett Creek systems adjusted to its historic boundaries. Using rainfall data for a 21-year period from 1985-2005, runoff to Dona Bay was then simulated for two conditions; the basin under current conditions and the basin under historical baseline conditions. Comparison of these simulations was then used to estimate the quantity of excess flow that Dona Bay receives due to land use changes and modifications of its drainage basin.

Conceivably, much of the excess water that now flows to Dona Bay flowed to the Myakka River. Since the watershed area that was diverted from the Myakka was near ten percent of the entire river watershed, it can be assumed that the flows that were lost from the Lower Myakka were significant.

Blackburn Canal

Another alteration to the lower river's surface water hydrology was the construction of the Blackburn Canal, which intersects the lower river at km 32.3 near the I-75 bridge (Figure 2-4). Completed in 1959 for the purpose of relieving flooding in rangelands near the river, the canal extends west to connect the Myakka River to Curry Creek and Roberts Bay. Roberts Bay is located adjacent to Dona Bay, and these bays are often referred to collectively as Dona/Roberts Bay.

The Blackburn Canal was excavated at or below sea level and water levels in the canal fluctuate with tides (DeLeuw et al. 1959). It had been suggested that flows in the canal can flow either toward, or away from, the Myakka River depending on local rainfall patterns and differences in tidal water levels in Roberts Bay and the Lower Myakka River. However, as discussed in greater detail in Section 2.4.1.1, streamflow data collected in the Blackburn Canal since 2004 show that water primarily flows from the Myakka River toward Robert’s Bay, although brief periods of flow toward the Myakka periodically occur. As a result, similar to the effect of the Cowpen Slough modification, the Blackburn Canal has principally resulted in reduced flows in the Lower Myakka River and increased flows to Dona/Roberts Bay.

2.3.2 Drainage East of the Lower River

The watershed east of the Lower Myakka River and south of the state park is comprised of a large expanse of uplands, wetlands and drainage channels. The largest drainage networks, Deer Prairie Slough, Warm Mineral Springs/Salt Creek, and Big Slough/Myakkahatchee Creek, flow southwesterly to the river (Figure 2-4). Soils in the eastern drainage are similar to soils west of the river, but also include shallow, poorly to very poorly drained wetland soils over alkaline material. In Sarasota County outside of the City of North Port, freshwater marshes, upland forest, rangeland and agriculture are the primary land covers and uses, as considerable lands are managed for conservation as the T. Mabry Carlton, Jr. Reserve. Within the reserve, agricultural and range lands are fallow. Interior wetlands are divided from the river channel by upland forest, principally pine flatwoods. In Charlotte County, eastern lands are largely developed or are currently being developed for suburban land use.

Deer Prairie Creek

(*Adapted from Kimley-Horn and Associates, 2006*)

The Deer Prairie watershed heads in Manatee County and trends southwesterly toward the river. The watershed contains 97 km^{2,} with most (66 percent) of the area lying in Sarasota County and 86 percent of the area in both counties in public ownership. The watershed is one of Sarasota County's and southwest Florida's most natural. The largest alteration is a manmade dam that was built in the 1950s at a location 1.7 km upstream of the creek's confluence with the Myakka River. The dam has a crest elevation of 1.0 m and impounds about 3.4 hectares (8.3 acres) of surface water.

Warm Mineral Springs

Warm Mineral Springs is located east of the river and north of U.S. Hwy 41 (Figure 2-4). The spring discharges over a limestone dam to tidal waters of Salt Creek. Salt Creek is approximately three kilometers long and flows southwesterly through urbanized land to enter the river near river kilometer 17. Its discharge from the deep boulder zone of the Floridan aquifer is highly mineralized and sulfurous, with temperatures ranging from 29-32^{o} C. Discharge measured irregularly over a period from the 1940s to the 1970s averaged 10 cfs (Rosenau et al. 1977). The spring is recognized as an important archaeological site and is presently used for commercial recreation (Champion and Starks 2001). Salt Creek meanders through residential lands and salt marshes and is regarded as a primary warm water refuge for the threatened manatee, *Trichechus manatus latirostris,* as well as Sarasota County's single most-important year-round manatee area (Gorzelany 2003).

Big Slough/Myakkahatchee Creek

Big Slough is the name given to an interior wetland system that ran southwesterly approximately 34 km as a meandering stream system, entering the Myakka River about 15 kilometers upstream of the river mouth. The Big Slough watershed contains 530 km^{2,} or about a third of the entire Myakka River watershed. Named tributaries in its upper reach include Wildcat, Bud, and Mud Lake Sloughs. Farmland drainage projects and development of North Port and Port Charlotte led to successive drainage, channelization, and impoundment modifications to the system. Big Slough is now largely a channelized system, which is now referred to as Myakkahatchee Creek in its lower reaches.

Myakkahatchee Creek is used for potable water supply by the City of North Port Utilities at a site near US 41, located 4.1 kilometers upstream of the creek's confluence with the Myakka River (Figure 2-4). A concrete water control structure (WCS 101) located just downstream of the City's water supply intake separates the freshwater and tidal portions of Big Slough/Myakkahatchee Creek. About 0.5 kilometers below WCS 101 the Myakkahatchee Creek receives flow from the Cocoplum Waterway, which is comprised of a series of canals that drain highly urbanized lands in the North Port area. A similar water control structure (WCS 106) located near the mouth of the Cocoplum Waterway separates fresh and tidal waters in that channel. The effective catchment area above WCS 106 has not been determined. The tidal reach of Myakkahatchee Creek downstream of U.S. 41 is a box-cut channel with spoils, with remnants of meanders and oxbows. Based on early soil surveys, the stream south of U.S. Hwy 41 was tidally influenced.

The City of North Port water supply facility is the only permitted surface water withdrawal in the Myakka River watershed. The City maintains intake pipes on both the Myakkahatchee Creek and the Cocoplum waterway, but the Myakkahatchee is the primary water source with the Cocoplum used only as a back-up source. The City's facility is linked to the water supply system of the Peace River Manasota Regional Water Supply Authority (PRMRWSA), and the City can receive treated potable water from the PRMRWSA or transfer treated water to it. During times of low flow, the City discontinues withdrawals from the Myakkahatchee Creek due to high sulfates in the creek and receives treated water from the PRMRWSA.

The City's water use permit was renewed by the Southwest Florida Water Management District in July 2006 for a period of ten years. By the conditions of this permit, the City's withdrawals from Myakkahatchee Creek cannot exceed an annual average withdrawal rate of 4.4 million gallons per day (mgd) and a peak month average rate of 6.6 mgd, which are equivalent to flow rates of 6.8 cubic feet per second (cfs) and 10.2 cfs, respectively. In order to protect the low freshwater flows to the creek below WCS 101, the 2006 permit renewal required that maximum daily withdrawal rates be linked to the rate of flow in the creek. Daily withdrawals cannot exceed 2.08 mgd (3.2 cfs) when flows at WCS 101 are less than 10 cfs, 4 mgd (6.2 cfs) when flows at WCS 101 are between 10 cfs and 30 cfs, and 6 mgd (9.3 cfs) when flows are greater than 30 cfs. The City uses a relationship of relationship of water levels in the creek to flows at WCS 101 established by Boyle Engineering (2003).

2.4. Streamflow Characteristics of the Lower Myakka River

A critical part of the determination of minimum flows for any river or estuary is an evaluation of the flow regime of that system. Such evaluations typically involve quantifying the timing and volume of freshwater inflows at various locations in the watercourse. In most cases, these evaluations are based on long-term gaged streamflow records, although hydrologic modeling may be necessary where gaged records do not cover long periods of time or account for only a small proportion of the watershed.

Where possible, it is the practice of the SWFWMD to evaluate trends in daily flow records to see if any components of a stream or estuary's flow regime have changed due to climatic or anthropogenic influences. Based on such assessments, a baseline period is chosen to evaluate the effects of potential new withdrawals on the flow regime and ecology of a river or estuary. If evidence indicates that previous water use or other anthropogenic effects have altered the flow regime of a stream or estuary, those effects are taken into account in the selection of or numerical adjustment of the baseline period.

Data from the gaged streams that contribute flow to the Lower Myakka River are summarized below, including typical seasonal variations of streamflow. Where gaged streamflow records are long enough to be meaningful, trends in flow are examined and compared to trends in seasonal rainfall. As will be discussed, a number of lines of evidence indicate that flows to the Lower Myakka River have increased due to changes in land and water use in the upper river sub-basin.

Modeled and estimated flows from ungaged areas in the lower river sub-basin are also described. Because accurate long-term hydrologic records are not available to assess possible changes in ungaged flows, these estimates were not used to determine or adjust the baseline flow regime for the lower river. Ungaged flows, however, are a major component of the inflow regime of the Lower Myakka River, and ungaged flow estimates were used to calibrate and construct a hydrodynamic salt-transport model of the lower river.

2.4.1 Gaged Inflows

Compared to other rivers in the region, a comparatively small proportion of the Myakka River watershed is gaged for streamflow. Until recently, approximately 52% of the watershed area of the Myakka River was gaged for flow. New gages installed by the USGS and Sarasota County since 2005 have increased the percent area gaged to at least 61 % of the river watershed.

The sources of gaged flow data for the Lower Myakka River are described below. In some cases, the recent gages were installed too late to be effectively used in the minimum flows analysis. However, these sites are described below as they can be used to assess freshwater inflows to the lower river in future analyses.

The drainage areas, periods of record, and mean flows from 14 gaged sites that contribute flow to the Lower Myakka River are listed in Table 2-2, including sites that are currently active and sites that have been discontinued. Sites measured by either the USGS or Sarasota County are included in the discussion.

2.4.1.1 Currently Active Streamflow Gages

Myakka River near Sarasota

The USGS gage Myakka River near Sarasota is the principal source of long-term freshwater inflow data for the lower river. The gage is located at State Road 72 between the Upper and Lower Myakka Lakes in the upper-river sub-basin (Figure 2-4). It measures flow from 593 km^2 (229 mi^2) or 38 percent of the entire Myakka River watershed. Daily flow records begin in August 1936 and continue to present. The average flow for this site is 256 cfs, equivalent to 15.2 inches of runoff per year over its drainage basin (Table 2-2). This is a relatively high runoff rate for streams in west central Florida. By comparison, average runoff rates for Horse Creek near Arcadia is 11.8 inches/year, while the Peace River at Arcadia is 10.6 inches/year.

Table 2-2. Drainage areas, periods of record, and summary statistics for active and discontinued USGS streamflow gaging sites in the Lower Myakka River watershed. Mean and median values calculated for data from the beginning of record through September 2007 at each site. Mean and median flow values reported for the Blackburn Canal are for flows away from the Myakka River to Curry Creek. Information also listed for four active stream gages operated by Sarasota County.

Gage	Gage Number	Drainage area	Period of Record	Mean Flow	Median Flow
Units		**(Km^2)**		**(cfs)**	**(cfs)**
Active USGS Gages					
Myakka River nr. Sarasota, FL	02298830	593	Aug. 1936 – present	256	80
Myakka River Control nr. Laurel	02298830	655	Oct. 2007 – present	Not calculated due to limited data	
Big Slough Canal nr. Myakka City, FL	02299410	95	Oct. 1980 – present	40	6
Big Slough Canal at Tropicaire Blvd.	02299450	210	June 2001 –present	88	14
Blackburn Canal nr. Venice	02299692	n/a	March 2004 - present	29	7
Big Slough Canal at West Price Blvd.	02299472	222	July 2007 - present	Not calculated due to limited data	
Cocoplum Waterway At North Port, FL.	02299482	undetermined	July 2007 - present	Not calculated due to limited data	
Discontinued USGS Gages					
Deer Prairie Slough nr. North Port Charlotte	02299160	86	April 81 – Sep. 92	23	3
Deer Prairie Slough at Power Line nr. N. Port	02299120	83	Oct. 93 – Jan. 03	37	3
Deer Prairie Slough nr. Myakka City, FL	02299060	undetermined	Oct. 93 – Jan. 03	9	0.3
Tributary to Myakka River nr. Venice, FL	02298928	0.5	Oct. 93 – March 03	12	0.3
Active Sarasota County Gages					
Myakka River at Interstate 75	MY-1	736	July 2006 to present	Not calculated due to limited data	
Myakka River at Border Road	MY-2	721	April 2005 to present	Not calculated due to limited data	
Curry Creek near Capri Isle	CUR-2	undetermined	April 2005 to present	Not calculated due to limited data	
Tributary to Myakka River (same as USGS)	MS-6	0.5	1999 to present	10	0.1

Despite this comparatively high average rate of yearly runoff, the Myakka River has frequent periods of very low flow. A cumulative distribution function of daily stream flow in the Myakka is shown in Figure 2-6. The maximum daily flow rate of 10,800 cfs was recorded in June 2003, while the median flow rate is 80 cfs. Based on the long-term record, flows were less than 1 cfs occurred approximately 10 percent of the time. However, as discussed later in this chapter, the low flows in the river have increased significantly since the late-1970s.

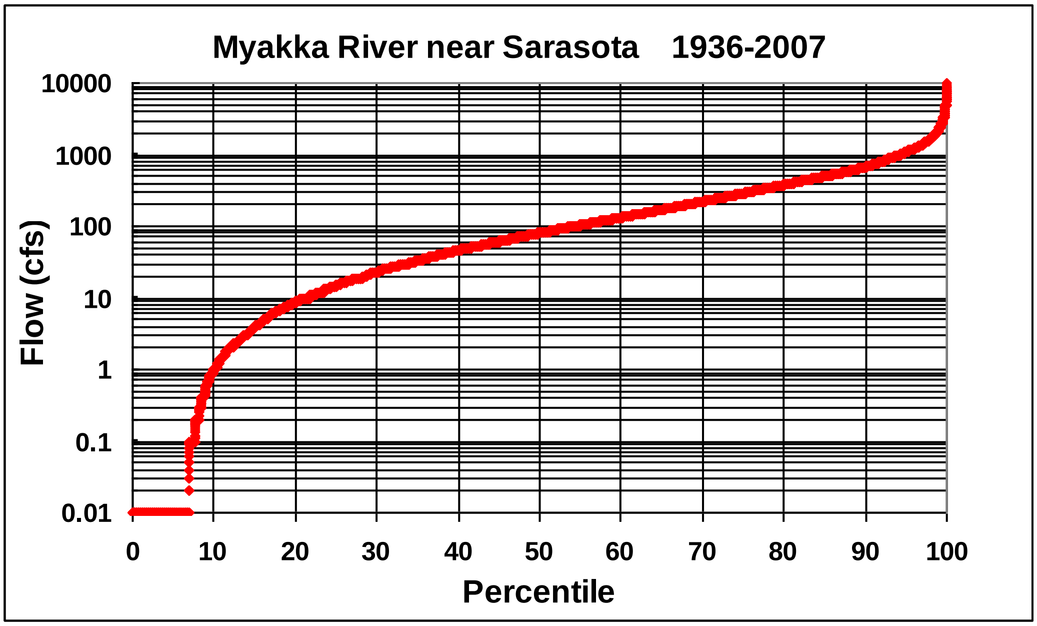

Figure 2-6. Cumulative distribution function of daily flows for the Myakka River near Sarasota. A maximum value of 10,800 cfs was set to 10,000 cfs and values of 0 cfs were set to 0.01 cfs for plotting purposes.

A bar graph of average monthly flows at the Myakka River near Sarasota gage is shown in Figure 2-7, while the percent of yearly rainfall and streamflow that occurs at this site is shown in Figure 2-8. Streamflow shows a lagged response to seasonal changes in rainfall. Although rainfall totals are fairly similar from June through September, monthly streamflow peaks near the end of the summer wet season as soils become saturated and storage in wetlands and depressions is filled. High streamflow often persists into October, even though rainfall totals fall considerably during that month.

Low flows typically occur during a winter-spring dry season that extends from November until mid-June. A minor peak in dry-season flow often occurs in March due to the passing of cold fronts that bring sustained rains. Flows then sharply decline in the spring as air temperatures and evapotranspiration rates increase, resulting in dry soil conditions and low groundwater levels.

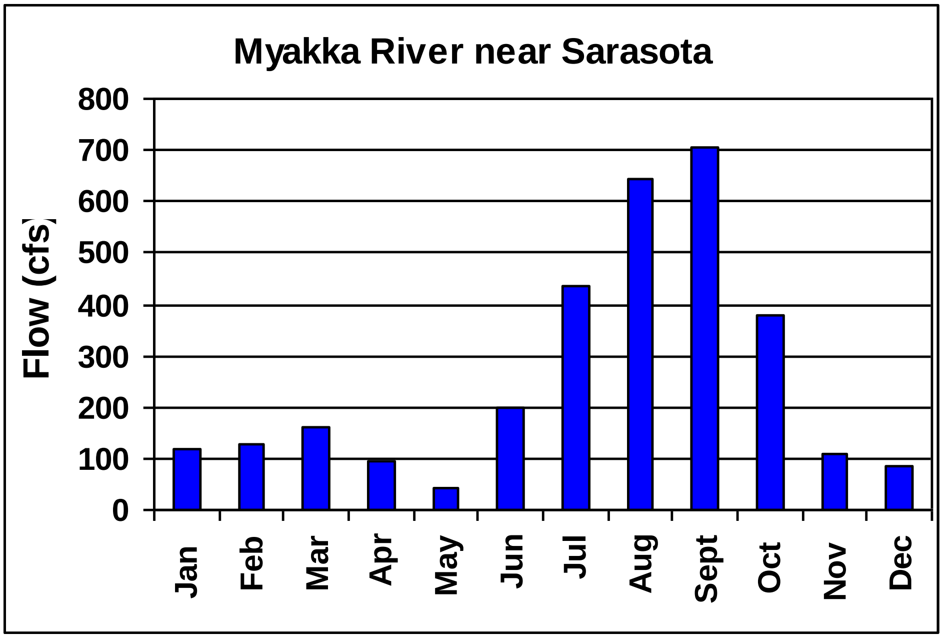

Figure 2-7. Average monthly flows for the USGS Myakka River near Sarasota gage

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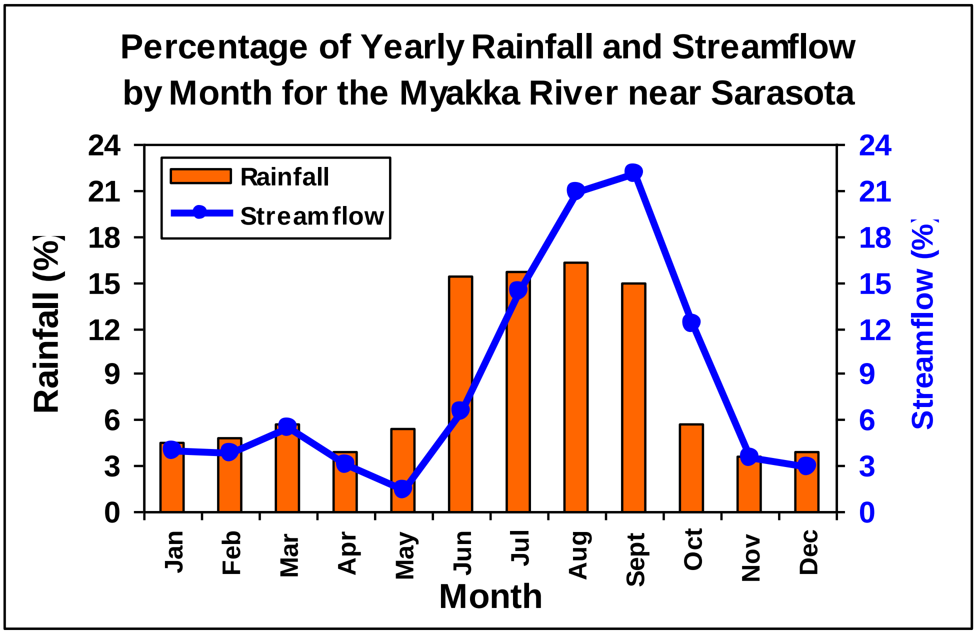


Figure 2-8. Average values for percentages of yearly rainfall and streamflow that occur each month. Rainfall data are from the Myakka River State Park National Weather Service station; streamflow data are from the USGS Myakka River near Sarasota gage.

Depending on when the summer rains begin, low flows can persist into June with the lowest daily flow rates of the year often occurring in late May or early June. This seasonal streamflow pattern is also illustrated in Figure 2-9, in which the 10th, 50th (median), and 90th percentile flows for each day of the year are plotted. The decline of streamflow in the spring and the initiation of the summer wet season in mid-June is apparent. Although this is the typical seasonal pattern for the Myakka River, notable exceptions sometimes occur. In particular, a strong El Nino climatic cycle during the winter of 1997-1998 caused flows to be the highest during November 1997 through March 1998 of those two years.

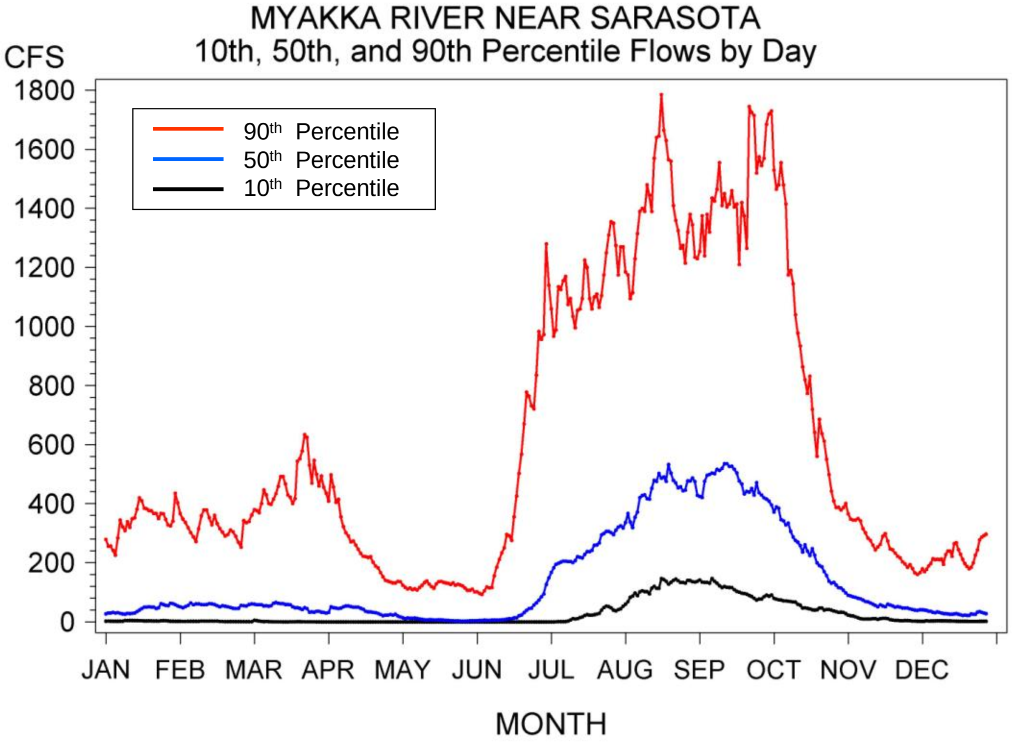


Figure 2-9. Time series plot of the 10th, 50th, and 90th percentile flows calculated for each day of the year for the Myakka River near the Sarasota gage.

Due largely to its watershed characteristics, differences in wet and dry season flows in the Myakka River are among the highest in west-central Florida (Estevez et al. 1991). Natural groundwater flow to the river is usually very low, as the streamflow records from earlier decades (1940s-1960s) had many days of zero flow at the Myakka River near Sarasota gage (discussed further in Section 2.4.2.2). Conversely, runoff rates in the wet season are very high, due to high surficial aquifer levels and many shallow wetlands in the watershed that readily transmit water when their depressional storage is filled.

This variation in seasonal flows is reflected in the large differences between the mean and median flows for the Myakka River near Sarasota gage, as the mean value (256 cfs) is greater than the median value (80 cfs) by over a factor of three (Table 2-2). The mean is heavily influenced by high flow volumes in the summer, whereas the magnitude of high flows does not affect the median statistic. Differences between mean and median flows are even greater of the smaller gages listed in Table 2-2 (Big Slough, Deer Prairie Slough). Baseflow rates are very low for these small sub-basins, but large quantities of water can be transmitted from these sub-basins in the wet season.

Myakka River at Control near Laurel

In October 2007 the USGS installed a stream gage at the Myakka River at Control near Laurel, Florida (# 02298900), located in the lower river about 45.8 kilometers above the river mouth (see Figure 2-11 on page 2-21). Water level data at this site show that tidal variations are minor and an acoustic velocity meter technique is used by the USGS to compute flow. The increase in watershed area represented by this gage compared to the long-term gage near Sarasota is only about 10%, but the Laurel gage is below the Lower Myakka Lake, so it captures the hydraulic effect of the lake on flow to the lower river. Daily mean discharge values for the Myakka River near Laurel are available from March 2008 to present, though final approved values were only available through September 30, 2009 when this report was prepared.

A time series graph of flows at the Myakka River near Sarasota and the Myakka River near Laurel sites is shown in Figure 2-10 for the nineteen-month period for which approved flow data near Laurel were available. The flow values closely agree, but the flows at the downstream site were lower during the spring and early summer of 2008. Caution should be used to not over-interpret these limited data. Continuation of Myakka River near Laurel gage will allow for better quantification of flows to the lower river in the future.

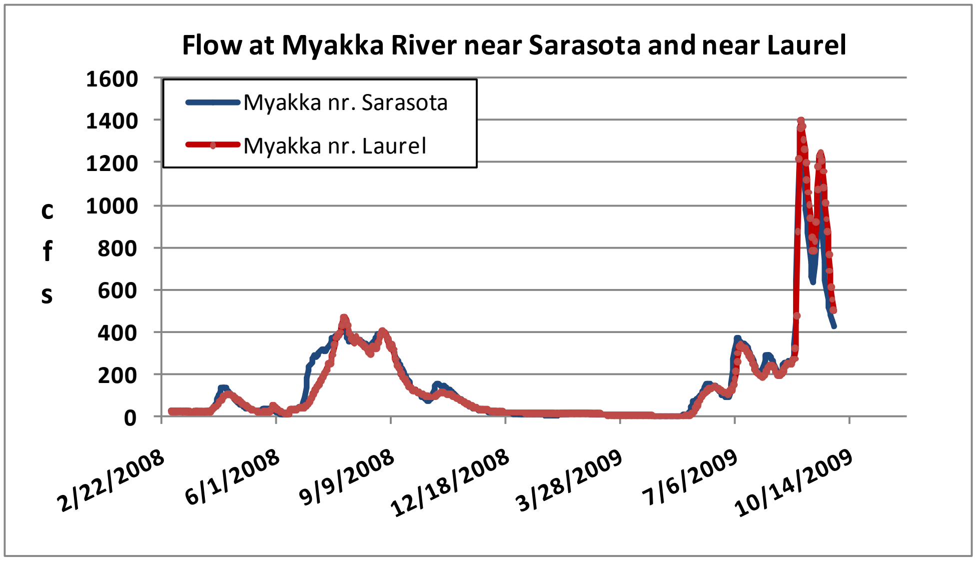


Figure 2-10. Time series plot of flows at the Myakka River nr. Sarasota and Myakka River at control nr. Laurel for the period March 6 through September 30, 2008.

Sarasota County gages on the main stem near Border Road and Interstate 75

The Sarasota County Water Resources Department has also implemented a program of measuring water levels and flow at a number of sites in the County. Administered by County staff, the data collection and reporting is conducted by consultants experienced in hydrologic data collection, some of whom are retired USGS employees. The County program has established two gages on the main stem of the river: one at Border Road near kilometer 33.3 and one near Interstate 75 near kilometer 32.1. The Blackburn Canal intersects the river between these two gages, which may be why they were placed so close together (Figure 2-11).

Streamflow data for the Border Road site begins in April 2005, while data for the site at Interstate 75 begins in July 2006. Tidal water level fluctuations are strong at both locations, requiring the use of an index velocity method that employs Acoustic Doppler Current Profilers. During periods of very low freshwater inflow, negative (upstream) flows are sometimes reported at these gages due to the actions of winds and tides. During periods of high freshwater inflow, consistent downstream flows are reported. These gages provide valuable data for flow in the river downstream of the long-term gage near Sarasota, although interpretation of the data is confounded by winds and tides during low flows. Data from these gages were initiated too late to be of use in the minimum flows analysis, for much of the data for dependent variables (salinity, biological data) in the estuary were collected before these gages were in operation. However, continuation of these gages, especially the gage below the Blackburn Canal, could be important for future assessments of freshwater inflow in the lower river.

Big Slough Canal / Myakkahatchee Creek

The other active gaged sites that contribute flow to the Lower Myakka River are located on the Big Slough Canal, which is also known as Myakkahatchee Creek (Figures 2-4 and 2-11). Daily flow records at the USGS Big Slough Canal near Myakka City gage begin during October, 1980. This site measures flow from an area of 95.5 km^2 (36.5 mi^2). The average flow for the period 1980 - 2007 was 40 cfs, equivalent to 14.9 inches of runoff over the basin. Daily records at the more recent USGS gage Big Slough at Tropicaire Blvd. site begin in June, 2001. This site measures flow from 208 km^2 (81 mi^2), or about 90 percent of the entire drainage basin above the City of North Port's water control structure (WCS 101). The average flow for the 2001 through 2007 at this site was 88 cfs, equal to 14.8 inches of runoff.

Until recently, the sum of the drainage areas at the USGS gages on Big Slough at Tropicaire Blvd. and the Myakka River near Sarasota represented the total area of the Myakka River watershed was gaged for flow (803 km^2). However, in July 2007 the USGS installed a velocity index meter in Big Slough Canal at West Price Blvd., which is located downstream of the Tropicaire gage, about 3.4 km upstream of WCS 101 (Figure 2-11). This new gage includes flow from the Snover Waterway (which enters Big Slough below the Tropicaire gage), bringing the total gaged area of Big Slough up to about 222 km^2. Combining this gage with the Sarasota County gage near I-75 brings the total gaged area of the Myakka River watershed to 958 km^2, or 61% of the entire watershed area of the Myakka River. However, this does not include the area drained by a gage on the Cocoplum Waterway, which is described on following pages.

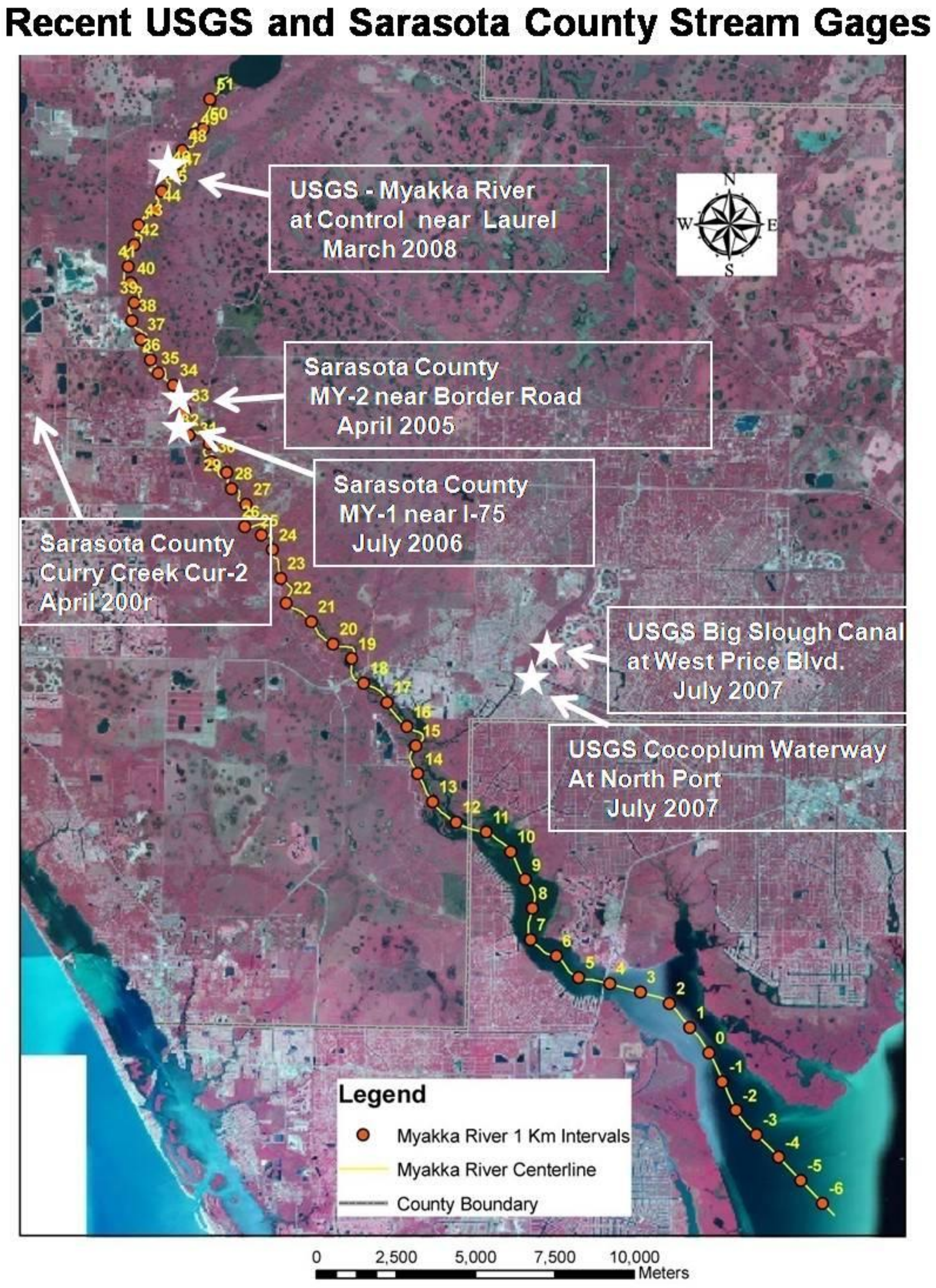


Figure 2-11. **Location and month and year of beginning of daily streamflow records for recent gages in the lower river sub-basin operated by the USGS or Sarasota County. Not shown is County gage MS-6 on a tributary to the lower river near kilometer 32.**

Daily flow records are now available for the Big Slough West Price Blvd. site dating back to July 2007. The USGS has also installed an index velocity meter on the Cocoplum Waterway just upstream of WCS 106, with flow data reported back July 2007. The drainage area of the Cocoplum Waterway is undetermined, as water from Big Slough can go through the Cocoplum Waterway depending on water levels in the system and the status of various upstream gates. Regardless, these new gages have been installed so that better data are available to quantify the total flow in the Myakkahatchee Creek/Cocoplum system for water supply and natural resource management purposes.

Water level (stage) records are available for Big Slough at WCS 101, and stage discharge relations can be used to estimate flows at that site. However, operation of the gates on WCS 101 affect stage-discharge relationships at the structure, and gate operations records have not been available to reconstruct long-term flow records at this site. Also, the elevation of tidal waters downstream of WCS 101 affects head gradients and rates of flow through the gates when they are open. Acknowledging these limitations, the District requested the City of North Port develop rating curves for WCS 101 and construct a flow record to the extent practical, given the status of the poor operations records and lack of water level data below the structure. The City contracted Boyle Engineering to investigate the development of flow rating curves for Myakkahatchee Creek and estimate historical flows at WCS 101. Boyle (2003) produced an estimated daily flow record for WCS back to 1993 from inferred gate operations records, but stated those values were very approximate due to uncertainly in the gate operations records.

Boyle Engineering did indicate that the gate operations records after February 2003 were more reliable and put more emphasis on those flow estimates. Subsequent analyses by PBS&J (2006a) for the period 2002-2005 indicated there was fairly good correlation between the estimated flows at WCS 101 and flows at the USGS Tropicaire gage when the flow estimates at WCS 101 were below 50 cfs. However, the agreement between these two terms was poor at higher rates of flow, due to the poor operation records the gates at WCS 101 during high flows or the influence of flows to Big Slough downstream of the Tropicaire gage.

The District compared flow estimates reported at WCS 101 after February 2003 with flows reported by the USGS at the upstream Big Slough Canal gages near Myakka City and Tropicaire Blvd. The District eliminated outliers from the WCS 101 flow estimates based on apparent incongruity with upstream flows. Using this edited data set, the District contracted the firm of HSW Engineering, Inc. (HSW) to develop a piecewise regression between the estimated flows at WCS and the USGS gage near Myakka City (Appendix 2A). This regression was then used to predict flows at WCS back to 1980, which is when daily flow records began at the USGS gage.

Another estimate of flows in Big Slough was generated for the District by the firm of Janicki Environmental by developing a regression to predict flows at the USGS Tropicaire Blvd gage as a function of upstream gage near Myakka City (Appendix 2B). Measured data from both gages for the period 2001 – 2007 were used to develop the regression, which was then used to generate a record predicted flows at Tropicaire Blvd. back to 1980.

Estimated flows from Big Slough were included as hydrologic input in the hydrodynamic model of the Lower Myakka River developed by District staff. Estimated flow terms were also incorporated as independent variables in separate regression models to predict salinity distributions in the lower river by Mote Marine Laboratory and the abundance and distribution of fish and invertebrate populations in the river as function of freshwater inflow (Peebles et al. 2006). The use of the specific estimated flow terms for Big Slough is discussed with each of these applications later in the report.

Water Use from Myakkahatchee Creek (Big Slough Canal)

Withdrawals from the City of North Port's facility on Myakkahatchee Creek have averaged 1.3 mgd (2.1 cfs) over the most recent five-year period for which complete records are available (2005 – 2009). These withdrawals are substantially less than the 4.4 mgd (6.8 cfs) annual average withdrawal that was allocated to the City in the most recent permit renewal, but expansion of the City's water supply system is anticipated. As discussed on page 2-13, withdrawals from Myakkahatchee Creek by the City are now linked to estimated flows in the creek in order to limit impacts to low flows to the tidal creek below WCS 101. The effects of withdrawals allowed under the City's renewed permit have been evaluated in monitoring reports submitted by the City as part of their water use permit (PBS&J 2006a, 2009).

Until recently, the most reliable USGS gaged streamflow values against which to measure the effects of the City of North Port’s withdrawals were at the USGS Big Slough Canal at Tropicaire Blvd. gage, where records go back to 2001. Based on data collected between 2004 and 2008, the median value for percent of flow at the Tropicaire Blvd. gage comprised by actual withdrawals by the City was 6 percent, while the median value for the maximum possible withdrawals is 33 percent. The actual withdrawals equaled all of the flow at the Tropicaire gage 9 percent of the time, while the maximum possible withdrawals, had they occurred, would have consumed all the flow 22 percent of the time. It is reiterated, however, that these are the maximum possible withdrawals and the City actually often ceases pumping from the creek during low flows due to water quality concerns. During these times the City receives water from the Peace River Manasota Regional Water Supply Authority facility on the Peace River.

Equally important, recent data collected at the newer USGS sites in the Myakkahatchee Creek show that flows at Tropiciare Blvd. represent a fairly small fraction of the total streamflow in Myakkahatchee Creek system. Hydrographs of daily flows at the Tropicaire gage and the more recent USGS gages on the Cocoplum Waterway and the Big Slough Canal at West Price Blvd. are shown in Figure 2-12. Based on 628 days between July 2007 and June 2009 when there were no missing records at any of the sites, the average flow at the Tropicaire gage (13.9 cfs) was 71% of the average flow at West Price Blvd. gage (19.4 cfs), and 48% of the average flow at Cocoplum Waterway gage (28.7 cfs). The average flow at Tropicaire was only 29% of the average of the combined flow from these other two downstream gages.

The post-2007 flow data at these new sites provide new perspective on the relative effects of the City of North Port’s withdrawals on flows in Myakkahatchee Creek system. The City is required to monitor the effects of their withdrawals on salinity distributions and water quality in

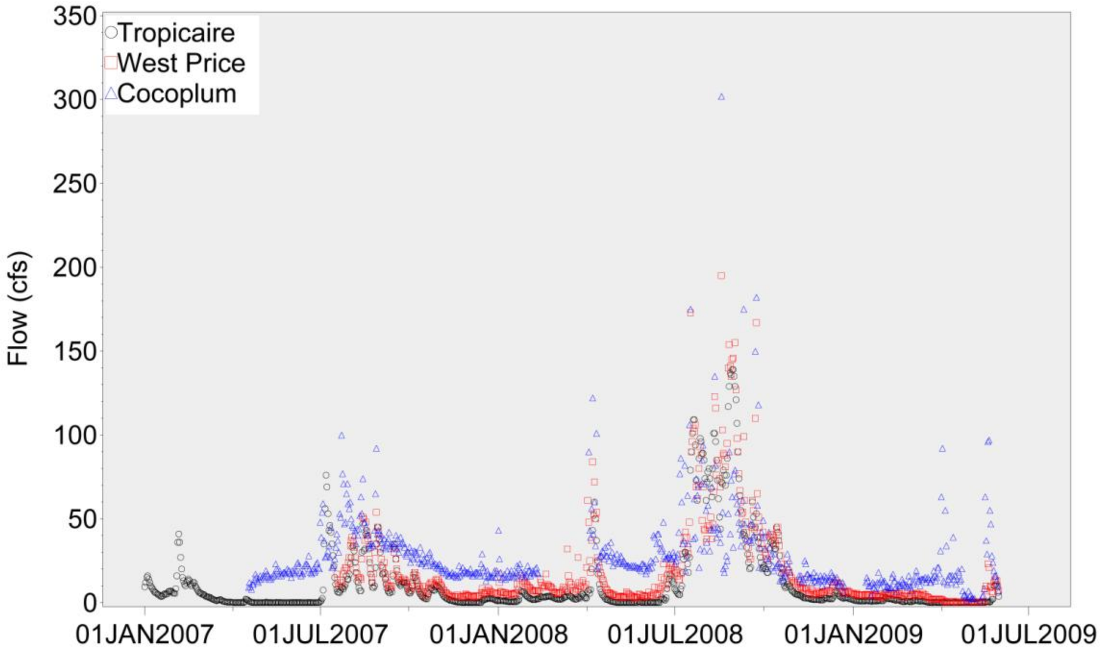


Figure 2-12. Hydrograph of daily flows at the USGS gages Big Slough Canal at Tropicaire Blvd., Big Slough Canal at West Price Blvd., and the Cocoplum Waterway for January 2007 – June 2009 (reprinted from PBS&J [2009]).

the creek and present their findings in monitoring reports that are regularly submitted to the District (PBS&J 2006a, 2009). In the most recent report, PBS&J (2009) presented preliminary relationships between flows at Tropicaire gage and the other gages in the system, but remarked that the record after July 2007 when all three of these gages were operating was unusually dry. They therefore suggested that any predictive regressions between these gages be developed at a future data after high flows in Myakkahatchee Creek system have occurred.

Blackburn Canal

As described in Section 2.3.1, the Blackburn Canal intersects the Lower Myakka River near kilometer 32.3 and connects the lower river to Curry Creek, which flows to Dona/Roberts Bay. The USGS established a streamflow gage on the Blackburn Canal in March, 2004. This gage, Blackburn Canal near Venice FL (02299692), is located about 1.5 kilometers west of the Myakka River. An automated Acoustic Doppler Current Profiler is used at this site to measure flows in the canal every fifteen minutes. Flows from the Myakka River toward Curry Creek are reported as positive values, while flows from Curry Creek toward the Myakka River are reported as negative values. Tidally filtered daily residual flows that represent the net movement of water over a calendar day are also reported by the USGS.

In May 2005 Sarasota County established a similar streamflow gage on Curry Creek, which is what the Blackburn Canal called as it approaches Roberts Bay (much of the canal was excavated in the channel of Curry Creek). This site is located approximately 5 kilometers measured along the creek west of the USGS Blackburn gage. The County site also employs an

Acoustic Doppler Current Profiler to measure flow in this tidally affected water body. As with the USGS data, positive values represent flows away from the Myakka River toward Roberts Bay. At the time of this report, published (approved) daily net residual flow values for the USGS and County sites on the Blackburn Canal and Curry Creek were available through September 2008. A time series plot of daily flows from both sites is presented in Figure 2-13. The USGS data started about 14 months sooner, capturing high flows that occurred in the summer of 2004. The two gages generally showed the same seasonal patterns after the County site began in 2005, though the USGS site was no operable during a period of high flows in 2006.

At both gages the majority of flows were positive, meaning the Blackburn Canal primarily acts to divert water from the Myakka River to Curry Creek and Roberts Bay. At the USGS gage, 12.5% of the flow values were negative, while 10.3% of the flow values were negative at the county gage. Most of the negative values were small (–5 to 0 cfs), indicating slow, tidally driven flows toward the river. The average flow for the USGS gage was 24.5 cfs, equal to 11.2% of the flow of the Myakka River near Sarasota on days when data were recorded in the canal. The average flow for the County gage was 28.1 cfs, equal to 18.7% of the flow of the Myakka River near Sarasota on days were recorded at the County gage. These results confirm that the excavation of the Blackburn Canal was a significant hydrologic modification that primarily acts to divert freshwater inflow from the lower Myakka River estuary.

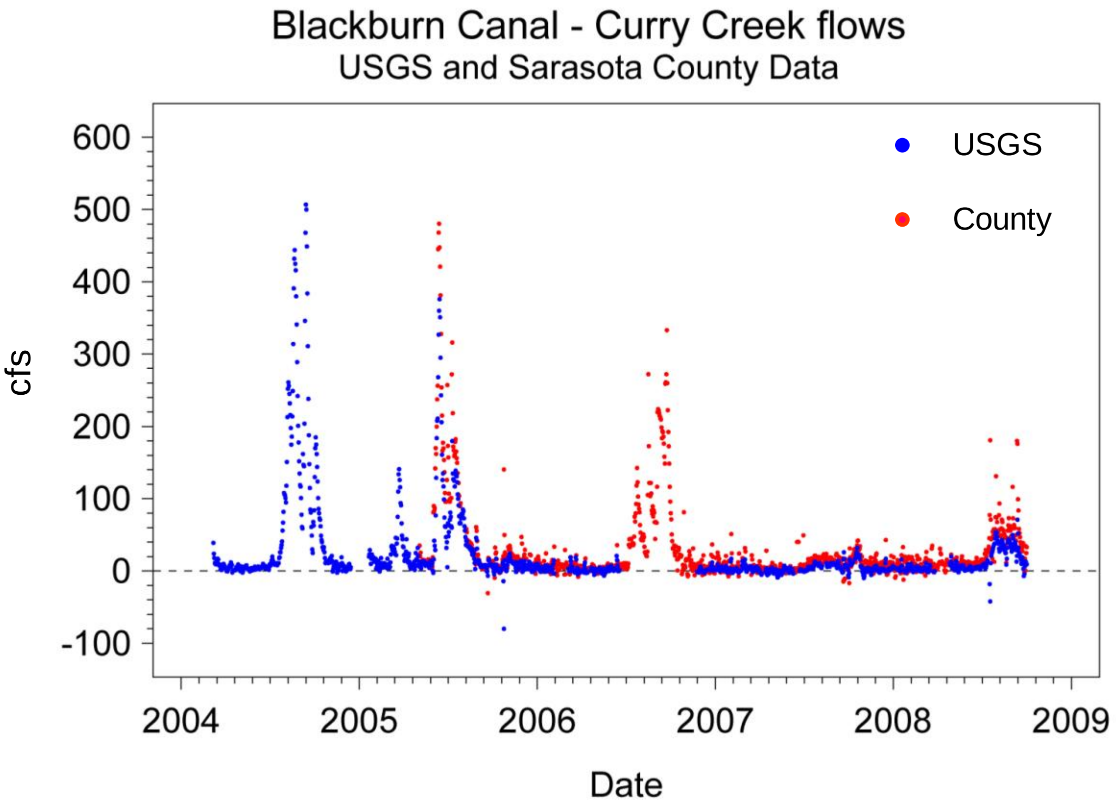


Figure 2-13. Time series of all approved data for the USGS gage Blackburn Canal near Venice, FL and the Sarasota County gage on Curry Creek near Capri Isle.

In a District funded project, Intera (2007) investigated the relationship of flow in the Blackburn Canal at the USGS gage to flow in the Myakka River near Sarasota and observed a two-phased relationship, with an inflection in the relationship between 400 and 500 cfs (Figure 2-14). Below this inflection, flows in the Blackburn increase slowly with increased flow in the Myakka, as tides exert a major effect on water levels in the Myakka and resulting flows through the Blackburn Canal. Above about 400 cfs, flows from the Myakka down the Blackburn increase more quickly, as water levels in the Myakka becomes high enough to more effectively push water through the canal.

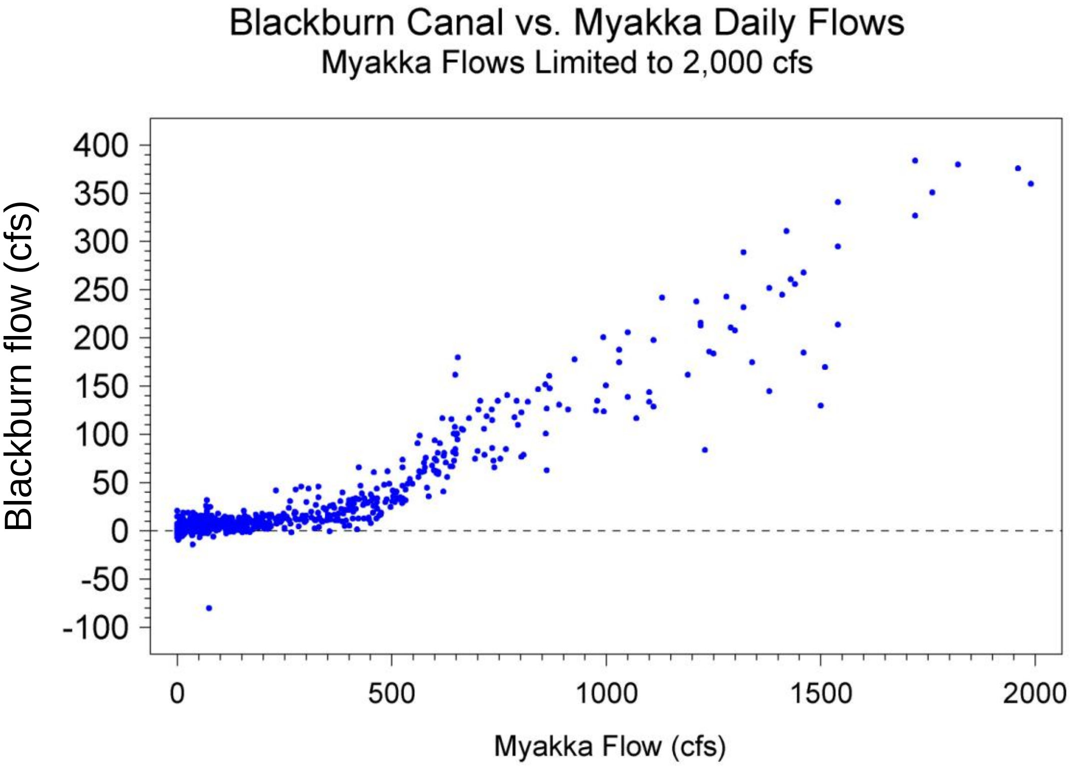


Figure 2-14. Relationship of same-day flows for the USGS streamflow gages at the Blackburn Canal at Venice FL and the Myakka River near Sarasota FL. Data limited to days when flows at the Myakka River gage were less than 2,000 cfs.

Intera (2007) developed a piecewise regression to predict flow in the Blackburn Canal as function of stage at the Myakka River near Sarasota gage. A time series plot of predicted and observed flows in the canal is presented in Figure 2-15. This relationship was used to predict flows in the Blackburn Canal prior to the initiation of USGS flow records for the canal in 2004 (Fig. 2-16). These predictions were included as hydrologic input to the District's hydrodynamic model of the Lower Myakka River for purposes of simulating salinity distributions in years prior to 2004. Flows in the Blackburn Canal were not included in the regression analyses of salinity or fish and invertebrate populations, as data from the canal were not available when those analyses were begun.

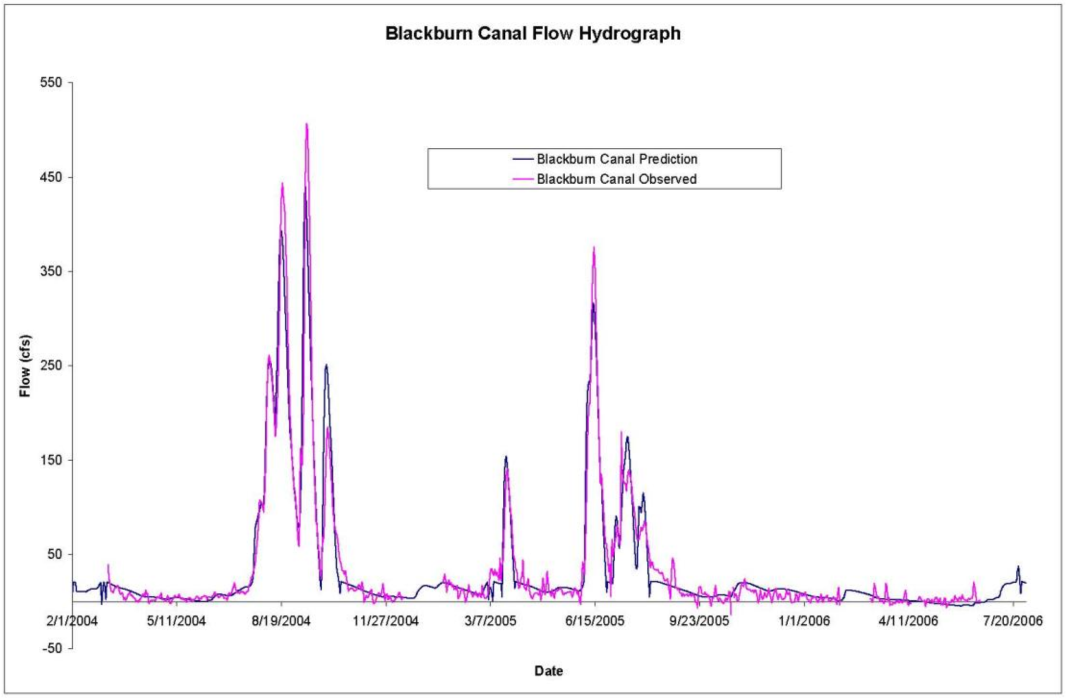


Figure 2-15. Time series graph of daily flows in the Blackburn Canal reported by the USGS and flows predicted by the regression, reprinted from Intera (2007).

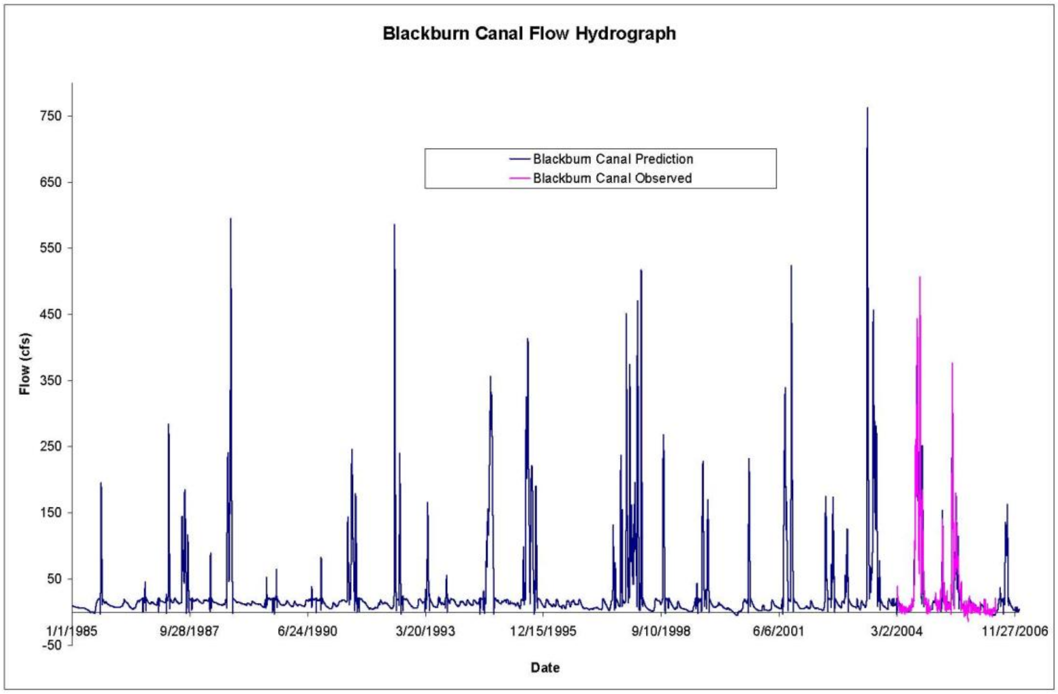


Figure 2-16. Time series graph of estimated flows in the Blackburn Canal for 1985 through 2006 predicted by regression along with flows reported by the USGS from March 2004 though 2006, reprinted from Intera (2007).

2.4.1.2 Discontinued streamflow gaging sites

A series of gaged streamflow sites on other tributaries that have been operated by the USGS in the lower river basin in the past are described below, along with limited periodic flow measurements from Warm Mineral Springs. Water levels either have been or are currently measured at other sites in the lower river sub-basin, but they are not discussed because streamflow rating curves have not been developed for those sites.

Deep Prairie Slough

The second largest tributary in the lower river sub-basin for which historic flow records are available is Deer Prairie Slough, which is also referred to as Deer Prairie Creek. The USGS has operated three gages in recent decades on Deer Prairie Slough (DPS). Flows were reported for DPS near North Port Charlotte from April 1981 to September 1992. This gage was located 4.2 miles upstream of the mouth of the slough, and measured flow from 86 km^2, or about 88 percent of the entire drainage basin of DPS. Mean flows for this period of record were 22.5 cfs, equal to 6.8 inches of runoff for the basin.

Streamflow data were collected at a more recent gage, DPS at Power Line near North Port, from October 1993 through January 2003. This site was located about 2.5 km upstream from the previous station described above and had a similar catchment area (83 km^2). The mean flow for the period of record was 36.7 cfs, equal to 15.6 inches of runoff for the basin. As previously discussed, the difference between the mean and median flow for this small sub-basin is very large (37 cfs vs. 3 cfs), and a bar graph of average monthly flows show vary large variation between the dry and wet season flows (Figure 2-17).

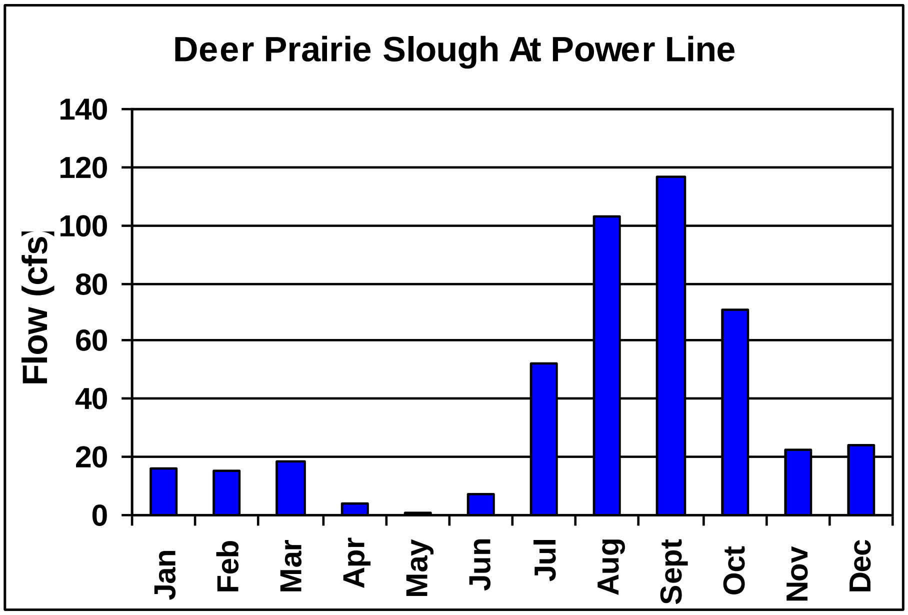


Figure 2-17. Average monthly flows for the USGS gage Deer Prairie Slough at Power Line near North Port, FL for the period 1993-2003.

The higher runoff rate for the 1993-2003 DPS at Power Line record compared to the earlier record at DPS near North Port Charlotte was largely due to generally wetter conditions during the latter period. A third site, DPS near Myakka City, operated for a near identical period between 1993 and 2003. Though the catchment size for this gage was undetermined, it was located considerably further upstream and measured less flow, with a mean flow of 9 cfs for the period of record.

Because the recent gages were discontinued in 2003, flows from DPS were not included in the predictive empirical models for salinity or fish and invertebrate populations in the lower river presented later in this report, since those efforts included field data collected through 2004 (Peebles et al. 2006, Chapter 4 of this report). Flows from the DPS, however, were included the flow records produced by Ross et al. (2005) for the lower river sub-basin for years prior to 2003. Consideration should be given to reinstituting flow measurements at the Deer Prairie Slough site in the future.

Tributary to Myakka River near Venice

The USGS operated a gage on a small tributary to the Myakka River just upstream of I-75 during, which was named Tributary to the Myakka River near Venice FL. The period of record was very similar to the recent gages on Deer Prairie slough (1993 - March 2003). This site measured flow from catchment area reported at only 0.5 km^2, although this area estimate is very approximate as the area contributing runoff could increase during periods of heavy rainfall. A mean flow of 11.6 cfs was reported for the period from 1993-2003. This mean, however, appears to be heavily influenced by brief periods of high flow, as the median flow was only 0.3 cfs. Daily flow rates in excess of 500 cfs were periodically reported from this gage, indicating that brief periods of high flow can occur from this small basin during heavy rainfall events.

Sarasota County has maintained a gage on this same tributary since 1997, moving their gage to the location of the former USGS gage when it was discontinued in 2003. Similar to the USGS data, flows for the County gage are usually low with brief periods of high flow. Based on data recorded between January 1997 and September 2008, a mean flow of 9.7 was recorded at the county gage, but the median flow was practically zero (0.1cfs) with 62 percent of the daily mean values below 1 cfs. Peak flows at this gage, in the range of 200 to 698 cfs, occurred during storm events between December and March in the El Nino winter of 1997-1998.

Warm Mineral Springs

Flows from Warm Mineral Springs have been measured only sporadically in the past, with no measurements during the last 30 years. In the Florida Bureau of Geology report Springs of Florida, Rousenau et al. (1977) lists flow rates measured on ten dates between 1942 and 1974. Flows from the spring were very stable, averaging 9.7 cfs, with nine of the measured flow rates ranging between 9.0 and 11.2 cfs. Though recent flow rates are not available, visual evidence indicates that Warm Mineral Springs continues to flow. As with Deer Prairie Slough, the initiation of flow measurements from Warm Mineral Springs should be considered for the future, as it likely contributes a significant proportion of inflow to the lower river during the dry season.

2.4.2 Trend analyses of rainfall and gaged flows

Trend analyses of rainfall and gaged flow records from long-term sites were examined to determine if flows to the Lower Myakka River have changed significantly over time. Trends in streamflow that are not accompanied by similar changes in rainfall can be evidence of anthropogenic effects on flow. In addition to the complete daily flow record, trends were examined on various flow statistics to discern if any components of the river's flow regime have changed.

The District has identified three seasonal blocks for the assessment of minimum flows on rivers in the District (SWFWMD 2005a, 2005b, 2005c). These blocks are based on typical seasonal variations of daily flows at long-term streamflow gages in the region, and are assigned to a spring dry season (Block 1), a fall and winter medium flow period (Block 2), and the summer wet season (Block 3). Median flows calculated for each day of the year at the Myakka River near Sarasota gage were presented in Figure 2-8 (page 2-18), along with daily 10th and 90th percentile flows at that site. Based on this typical seasonal variation of flows at the Myakka River near Sarasota, the ranges of dates initialed selected for the assessment of minimum flows for the Lower Myakka River are as listed below. Trends in rainfall and flows were examined for these seasonal blocks in addition to annual data. However, as described in Chapter 7, the beginning of Block 1 was moved to March 1 for the estuarine modeling to account for the effects of preceding flows in the spring.

Block 1 - April 20 to June 20,
Block 2 - October 28 – April 19,
Block 3 - June 21 – October 27

2.4.2.1 Rainfall

There are a number of active rainfall stations in southwest Florida in or near the Myakka River watershed, but the only site in the watershed with records that extend back to the 1940s is the National Weather Service (NWS) rainfall station at the Myakka River State Park, located near the Upper Myakka Lake. Because of its length of record and its central location in the watershed, the analysis of long-term rainfall trends for the Myakka River watershed was restricted to that site.

The mean annual rainfall for the period of complete years from 1944-2006 is 56.3 inches. Yearly rainfall totals have ranged from 32 inches in 1989 to 78 inches in 1959 (Figure 2-18). Another time series of yearly rainfall is portrayed in Figure 2-19, where the yearly deviations from the average yearly rainfall value is plotted along with the moving three-year average rainfall. Although some substantial inter-annual variations in yearly rainfall have occurred, a Kendall Tau trend test indicates there has been no overall trend in yearly rainfall totals over the period of record.

However, results presented by Interflow (2008a) for this station and the Ft. Green NWS rainfall station indicate that climate cycles associated with the Atlantic Multi-decadal Oscillation (AMO) that was discussed by Kelly (2004) and SWFWMD (2005a), resulted in generally higher rainfall amounts prior to 1960 and after 1992, with a generally dry period between during 1960 - 1992. Interflow also points out the rainfall totals at the state park site differed from some other nearby stations in the mid-1980s, and suggests that caution be used in interpreting data for the state park site. Regardless, hydrographs for the Myakka River State Park site are shown in Figures 2-18 and 2-19 to give some idea of long-term variation in rainfall the upper river sub-basin watershed.

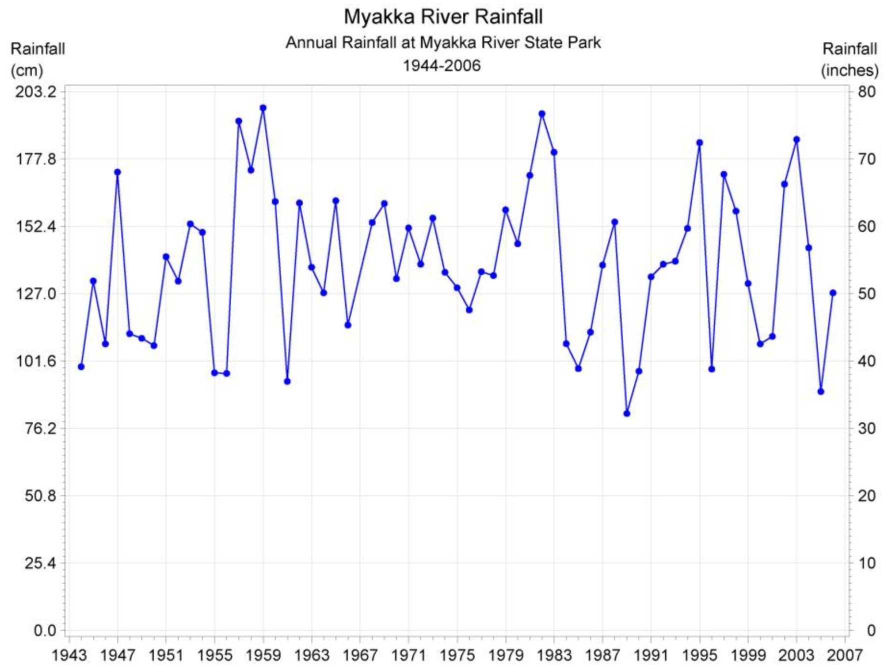


Figure 2-18. **Time series of yearly rainfall totals for the Myakka River State Park station for 1944 - 2006.**

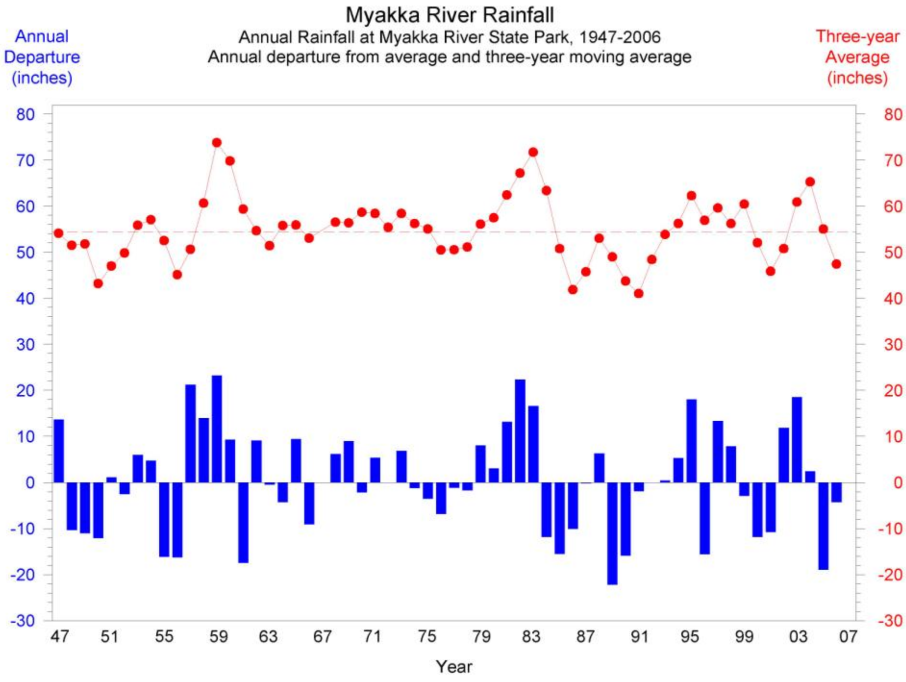


Figure 2-19. **Time series of three-year moving average rainfall and deviation from average for yearly values for the Myakka River State Park site.**

Time series plots of yearly rainfall totals within the three seasonal blocks at the State park site are presented in Figures 2-20 A-C (each value for block 2 spans two years; for example fall 1992 – winter 1993). The graphs indicate there have been no long-term trends in rainfall for any of the seasonal blocks, which is supported by trend tests which showed no indication of significant trends (Table 2-3). However, although there have been some marked multi-year patterns in rainfall variation at the Myakka River State Park site over the last six decades, there have been no significant long-term trends in either yearly or seasonal rainfall totals at this site.

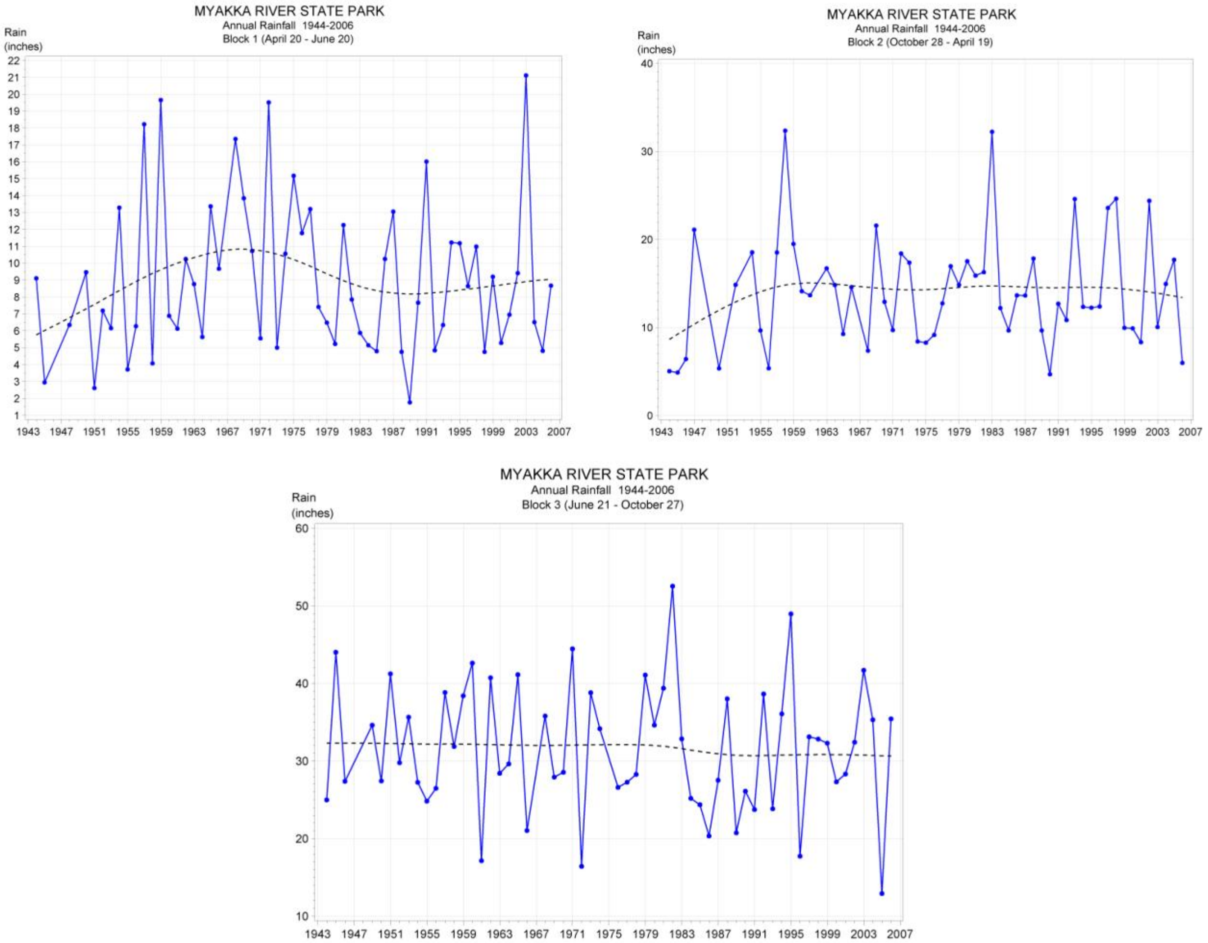


Figure 2-20. Time series plots of seasonal rainfall totals per year at the Myakka River State Park for Blocks 1 (A), 2 (B), and 3 (C) for 1944 – 2006.

Table 2-3. Results of Kendall Tau tests for trends in annual rainfall by seasonal block for the Myakka River State Park gage for the period 1944-2006.

Block (Dates)	Tau Statistic	P value	Slope
Block 1 (April 20 – June 20)	-0.006	0.953	-0.003
Block 2 (October 28 – April 19)	0.035	0.705	0.017
Block 3 (June 21 – October 27)	-0.052	0.565	-0.032

2.4.2.2 Streamflow Trends at the Myakka River near Sarasota Gage

Trends in various streamflow parameters were examined for two gages in the watershed; the Myakka River near Sarasota and Big Slough Canal near Myakka City. The intent of this analysis was to determine if any components of the flow regime of the lower river have changed over time. Flow trends at the Myakka River near Sarasota are discussed first, followed by a summary of findings from other studies that have examined flow trends at that gage, including a recent integrated surface water / ground water modeling study of the Upper Myakka River sub-basin.

Streamflow records for the Myakka River near Sarasota extend back to when urban and agricultural development in the Myakka River watershed were very limited. Decades prior to the 1970s can be considered baseline conditions during which time human effects on flows in the upper Myakka River basin were probably very small. Although streamflow records begin 1936 for the Myakka River near Sarasota gage, trends for seasonal blocks were examined for the period after 1944 to coincide with period of rainfall records at the Myakka River State Park. Since rainfall has shown no significant trends over this period, significant changes in various streamflow parameters may indicate anthropogenic effects on flow. However, this analysis is restricted to one site, which as previously discussed, differs somewhat from the NWS station at Ft. Green which has a somewhat shorter record. Data from both stations, however, do not indicate any increasing rainfall trends that would explain the observed increases in streamflow.

A seasonal Kendall trend test indicated there has been a significant increasing trend ($p < .001$) in streamflow for the Myakka River at Sarasota for the period 1937-2006. The seasonal Kendall test is a non-parametric test that is uses all the data collected within the year. Though not directly comparable in a statistical sense, a time series of yearly mean flows is presented in Figure 2-21. This hydrograph does not clearly suggest an increasing trend, but yearly mean values are strongly influenced by flows in the summer wet season. It appears the Seasonal Kendall test was influenced increases in flows during the drier months of the year.

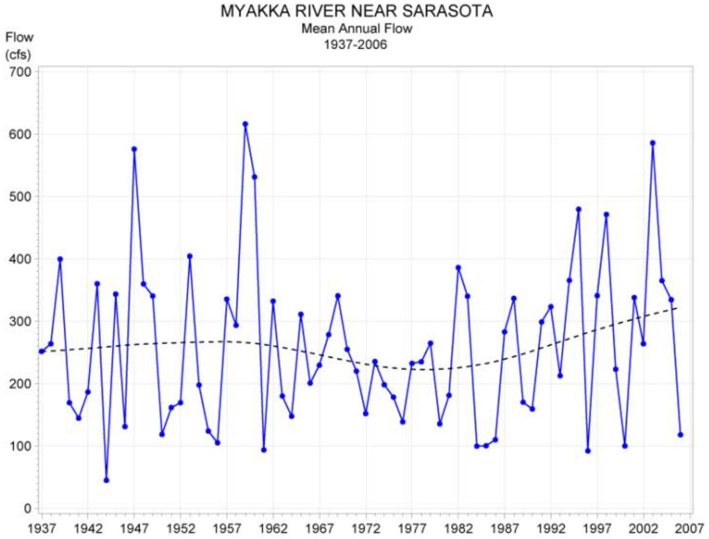


Figure 2-21. Time series plot of yearly mean flows for the Myakka River near Sarasota fitted curvilinear trend line.

Trends for seasonal blocks

Significant trends are apparent for flows at the Myakka River near Sarasota gage when the flow regime is broken into different seasonal components. Kendall Tau tests conducted on yearly median flow values calculated for each seasonal block indicate that flows are increasing for block 1 (spring) and block 2 (fall and winter), with no indication of trends in block 3 wet season flows (Table 2-4).

Table 2-4. Results of Kendall Tau tests for trends in median annual flows by Block for the Myakka River near Sarasota gage (USGS 02298830) for the period 1944-2005.

Block (Dates)	**Tau Statistic**	**P value**	**Slope**
1 (April 20 – June 20)	0.2992	0.001	0.272
2 (October 28 – April 19)	0.237	0.006	0.757
3 (June 21 – October 27)	0.015	0.868	0.206

Hydrographs of these values show that the increase has been most pronounced in block 1 (Figure 2-21A). Prior to 1979, median flows for block 1 were generally less than 10 cfs and were zero cfs in many years. High median flows in block 1 were observed in some wet years (e.g., 1958-1960), but median values exceeded 10 cfs only seven times in the 35 years of record from 1944 through 1978.

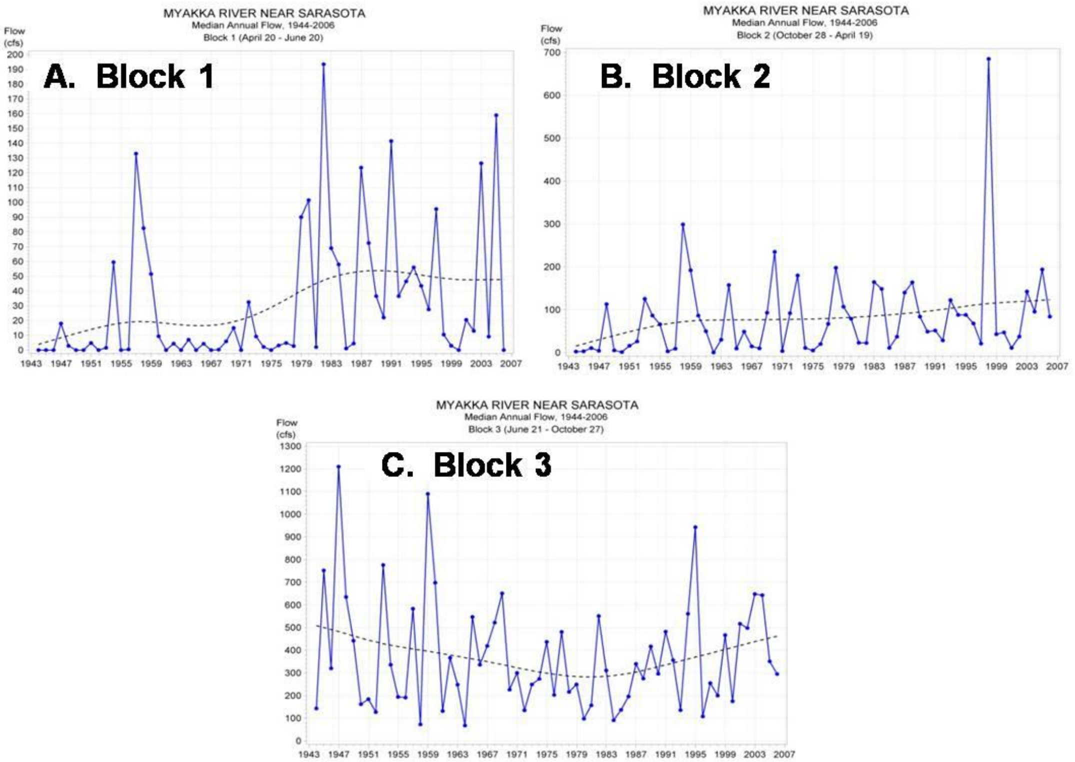


Figure 2-22. Time series plots of median seasonal block flows at the Myakka River at Sarasota gage for Block 1 (A), Block 2 (B) and Block 3 (C).

It is clear that springtime flows from the upper-Myakka River basin have increased substantially since the late 1970s. In 26 years of record since 1979, median flows for block 1 have exceeded 10 cfs nineteen times. Median flows at or near 0 cfs occurred only during the drought years of 1981, 2000, and more recently in 2006. The average flow for block 1 for the period prior to 1979 was 42 cfs, while the average flow for the period after 1979 (95 cfs) was more than double that amount.

Flows in Block 2 have also shown a significant increase (Table 2-4), though proportionately the rise is not a steep as block 1 (Figure 2-22B). The mean flow for block 1 for 1944-1978 was 104 cfs, while the mean flow for 1979-2006 was 155 cfs. The unusually high flow in the winter of 1997-1998 was due to an El Nino event in which 50 inches of rain fell at the Myakka River State Park rain gage from November through March.

The hydrograph of yearly median flows for block 3 indicate that wet-season flows tended to be lowest in the 1970s through the mid-1980s, but have shown a general rise since then (Figure 2-22C). However, in contrast to blocks 1 and 2, median yearly flows for block 3 since the late 1980s are not higher than flows in the 1940s and 1950s and there has been no long-term trend.

Trends in monthly flows

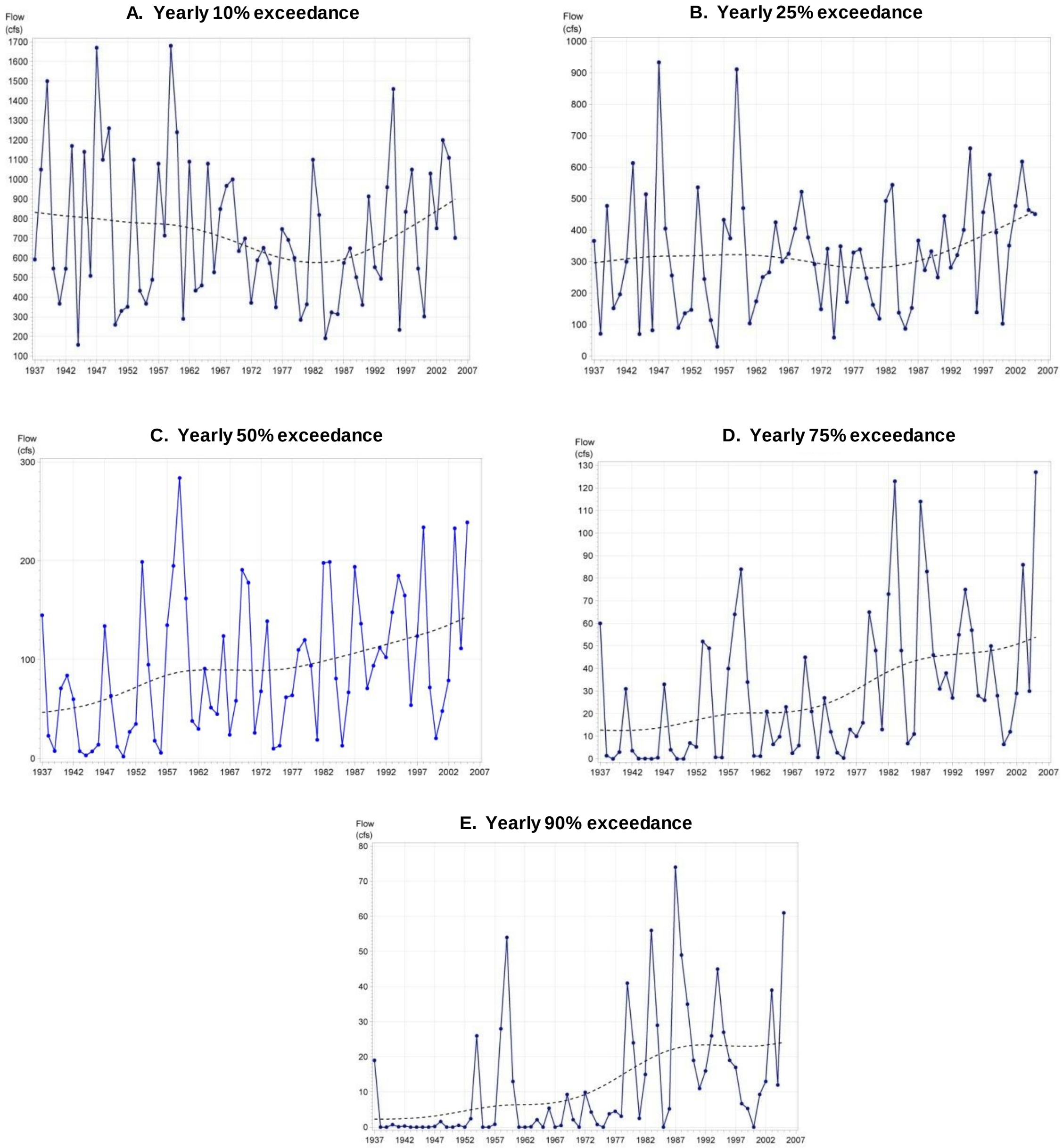
In order to examine changes in flow on smaller time scales, trends were also examined for each month (Table 2-5). Using the same Kendall Tau test on median monthly flows, significant increasing trends at $p<.05$ were observed for all months except July through October. Time series hydrographs of median flows for each month are included in Appendix 2C. Inspection of these graphics indicate the greatest and most consistent increase has occurred in May, during what is normally one of the lowest flow times of year, which further indicates the baseflow of the river has increased.

Table 2-5. Results of Kendall Tau tests for trends in monthly streamflow for the Myakka River near Sarasota gage (USGS 02298830) for the period 1937-2005.

Month	Tau Statistic	P value	Slope
January	0.246	0.003	0.802
February	0.182	0.027	0.640
March	0.223	0.007	0.983
April	0.226	0.006	0.488
May	0.342	0.000	0.303
June	0.176	0.032	0.205
July	-0.031	0.713	-0.433
August	-0.005	0.959	-0.067
September	-0.035	0.671	-0.733
October	0.049	0.558	0.634
November	0.233	0.005	0.827
December	0.242	0.003	0.485

Trends in yearly percent exceedance flows

Trends were also evaluated for yearly percent exceedance flows, or the flows that are exceeded for a percentage of time within each year. A ten percent exceedance value represents a high flow, as flows are higher than that rate only 10 percent of the time, while a 90 percent exceedance value represents a low flow. The 50 percent exceedance flow represents the median flow for each year. The results of trend tests for five yearly percent exceedance flows at the Myakka River near Sarasota gage are listed in Table 2-6. Hydrographs of these values are illustrated in Figure 2-23.


A. Yearly 10% exceedance

B. Yearly 25% exceedance

C. Yearly 50% exceedance

D. Yearly 75% exceedance

E. Yearly 90% exceedance

Figure 2-23. Time series hydrographs of the 10, 25, 50, 75 and 90 yearly percent exceedance flows for the Myakka River near Sarasota gage.

Table 2-6. Results of Kendall Tau tests for trends in yearly percent exceedance flows for the Myakka River near Sarasota gage (USGS 02298830) for the period 1937-2005.

Percent Exceedance Flow	Tau Statistic	P value	Slope
10% exceedance (high flows)	-0.036	0.663	-0.922
25% exceedance	0.140	0.089	1.946
50% exceedance (median flows)	0.269	0.001	1.325
75% exceedance	0.358	0.000	0.489
90% exceedance (low flows)	0.407	0.000	0.202

There was no significant trend for the 10 percent exceedance flows, or the highest 10 percent of flows that occurred each year. However, the fitted smoothed curve indicates that has been an increase in high flows since about 1983, with the lowest flows occurring in the 1970s. This temporal pattern may correspond to the Atlantic multi-decadal oscillation cycle (AMO) described by Enfield et al. (2001) and related to southwest Florida by Kelly (2004). Also, as discussed in Section 2.4.2.3, recent watershed modeling of the upper river sub-basin indicates that changes in land and water use since the late 1970s have acted to increase high flows in the river.

There is also some indication of an increase in the 25 percent exceedance flows, but this was not significant at the p<.05 level (p = 0.089). However, the time series plot indicates there has been some rise in the lowest values of this parameter (Figure 2-23B). Since 1987, only two yearly values of the 25 percent exceedance flow have been below 250 cfs, with these occurring in the very dry years of 1996 and 2000. Prior to 1987, however, yearly 25 percent exceedance flows below 250 cfs were common, with values below 100 cfs sometimes occurring as well.

Significant increasing trends were observed for the 50 (median), 75 and 90 percent exceedance flows, which are graphically displayed by time series hydrographs (Figures 2-23 C, D, and E). Yearly median flows below 20 cfs were fairly common from the late 1930s to the 1950s, but have only been observed once in the last 20 years during the severe drought of the year 2000. Yearly values for both the 75 and 90 percent exceedance flows were at or near zero cfs for many years in during the 1930s to 1950s, with values near zero for the 90 percent exceedance flows extending into the early 1970s (Figure 2-23 E). However, since that time yearly 90 percent exceedance flows have reached zero cfs only twice, during the severe droughts of 1985 and 2000. The median value of the 90 percent exceedance flows prior to 1979 was 0.4 cfs, while the median of these values after 1979 was 18 cfs. These results clearly show the low flow characteristics of the Myakka River near Sarasota are increasing, with the effect extending to yearly median flows for the river as well.

Trends in moving average flows

Trends were also examined for the mean, minimum and maximum values of moving average flows that were calculated within each year. These values provide different information that the percent exceedance flows, which report the total amount of time a flow is exceeded within a year regardless if the flows occurred over continuous or disjunct periods. In contrast, moving-average statistics represent flows that occur over continuous periods. These statistics can be important for assessing flow trends can affect estuarine resources, for many physicochemical and biological variables in estuaries respond to flows that have been received over preceding periods of time.

Moving average flows were calculated for periods of 3, 10, 30, 60, 90 and 120 days. These values were taken from the day within a year that the moving period ended, and in some cases, the moving average period may have extended into the previous year. The results of Kendall Tau tests for yearly values of the mean, minimum and maximum values of moving average flows calculated for each year are listed in Table 2-7. Hydrographs of the mean, maximum, and minimum values of the moving averages calculated for these day intervals are presented in Appendix 2D, with hydrographs for the yearly minimum values also shown in Figure 2-24.

Table 2-7. Results of Kendall Tau tests for trends in mean, minimum, and maximum values of moving average flows calculated over 3, 10, 30, 60, 90, and 120 days within each year for the Myakka River near Sarasota gage (USGS 02298830) for the period 1937-2005.

Statistic	Tau Statistic	P value	Slope
Mean 3-day average flow	0.060	0.472	0.556
Mean 10-day average flow	0.059	0.478	0.557
Mean 30-day average flow	0.054	0.517	0.509
Mean 60-day average flow	0.044	0.594	0.378
Mean 90-day average flow	0.058	0.488	0.380
Mean 120-day average flow	0.049	0.558	0.472
Maximum 3-day average flow	-0.033	0.694	-3.987
Maximum 10-day average flow	-0.032	0.705	-2.928
Maximum 30-day average flow	-0.042	0.615	-1.378
Maximum 60-day average flow	-0.008	0.930	-0.216
Maximum 90-day average flow	0.003	0.971	0.134
Maximum 120-day average flow	-0.012	0.889	-0.213
Minimum 3-day average flow	0.417	0.000	0.066
Minimum 10-day average flow	0.406	0.000	0.081
Minimum 30-day average flow	0.433	0.000	0.135
Minimum 60-day average flow	0.363	0.000	0.212
Minimum 90-day average flow	0.326	0.000	0.363
Minimum 120-day average flow	0.295	0.000	0.577

There were no significant trends for the mean and maximum values for any of the day intervals. There is a period from the mid-1960s to the mid-1980s when the maximum values were relatively low, but a rebound has occurred in the last twenty years. The time series of mean values show a similar temporal pattern.

Significant increasing trends were observed for the yearly minimum values of moving average flows for all the day intervals tested (Table 2-7). Hydrographs of these values show how dramatically the low flow characteristics of the Lower Myakka River have changed (Figure 2-24). Even for the 90-day interval, minimum yearly values of zero or near zero cfs were commonly observed prior to the late 1970s. Since that time however, 90-day flows of near zero have only occurred during the severe droughts of 1985 and 2000. Minimum flows in the 3 to 30-day range have increased at particularly high rates.

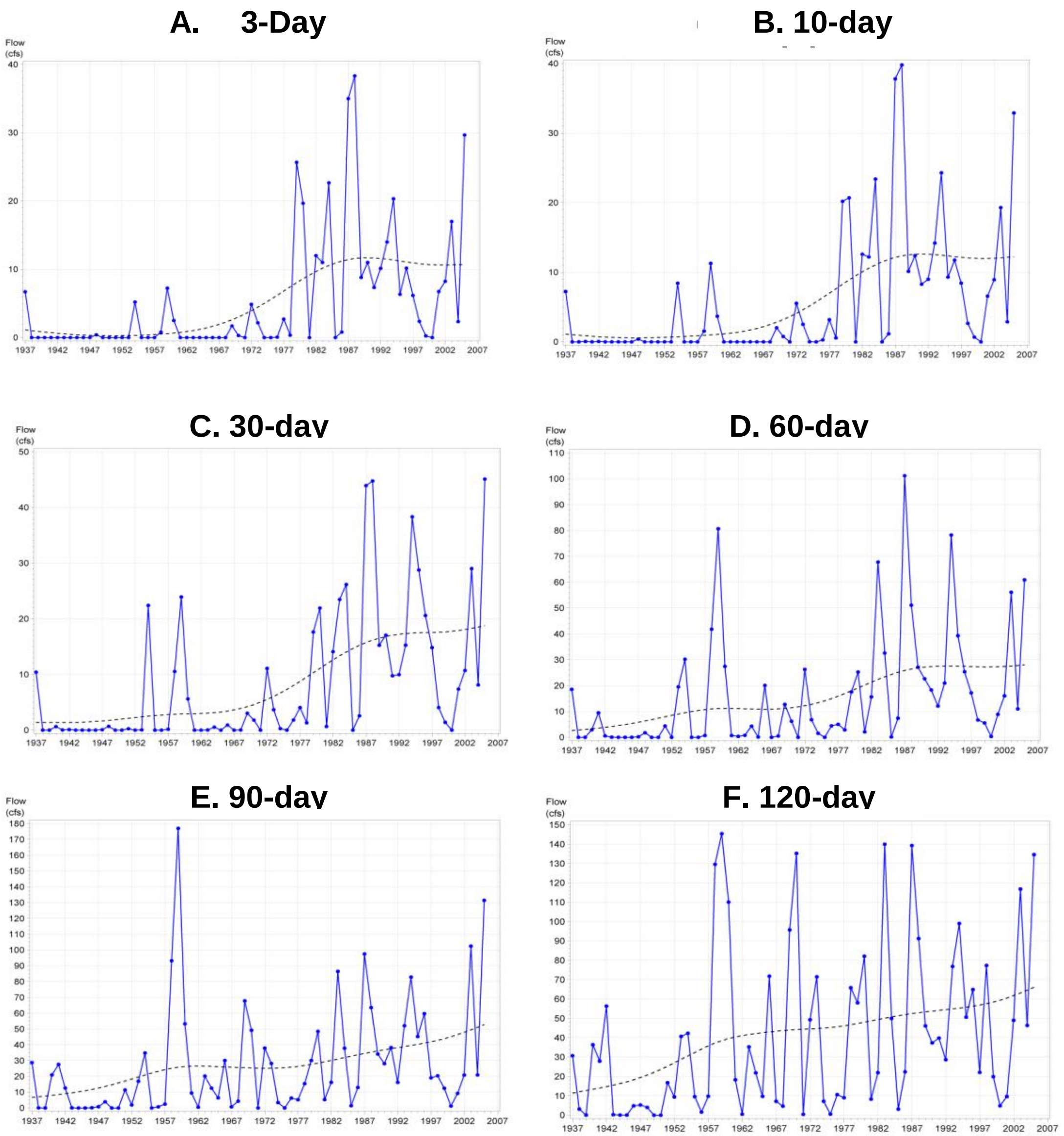


Figure 2-24. Hydrographs of yearly minimum values of the 3, 10, 30, 60, 90 and 120-day moving average flows.

Number of zero flow days

The final graphic presented for trends in flows is the number of zero flow days per year at the Myakka River near Sarasota gage (Figure 2-25). Prior to the mid-1970’s, zero flow days were common in dry years, with a maximum value of 133 days in 1949. However, since the mid-1970s, zero flow days have been much less frequent, restricted to drought years such as 1981, 1985, 2000, 2006 and 2007. These data further reflect the increasing low flow characteristics of the upper river sub-basin.

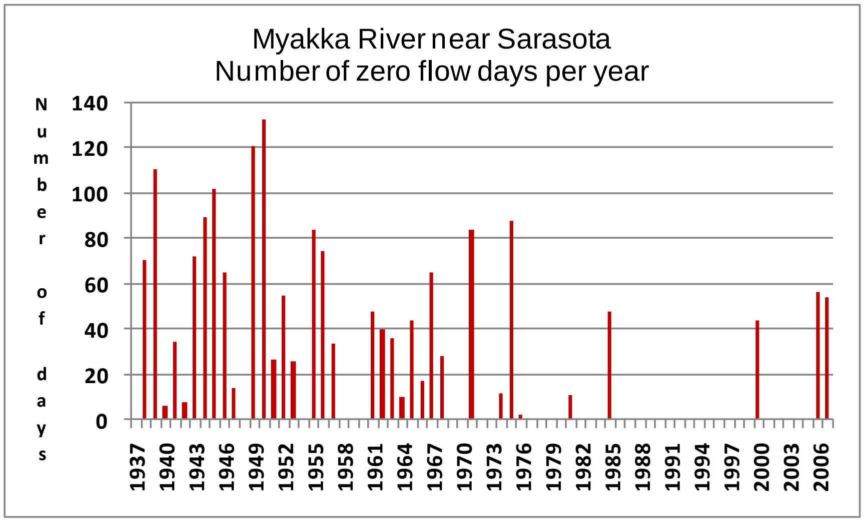


Figure 2-25. Number of zero flow days per year at the Myakka River near Sarasota gage for the period 1937 – 2007.

Zero flow rates occur when water levels at the Myakka River near Sarasota gage fall to about 9 feet NGVD (Figure 2-26). Water levels can continue to fall at zero flow, meaning there is water in the channel but it is not moving downstream. The Myakka River near Sarasota gage is located between Upper and Lower Myakka Lakes (Figure 2-4). Additional work is planned to examine how low flows at the Myakka River near Sarasota gage correspond to flows in the lower river, for example, at the Myakka River at control near Laurel gage, which is located about nine kilometers below the sill on the lower lake (Figure 2 -11). Streamflow data are available for this gage beginning in March 2008 (Figure 2-10).

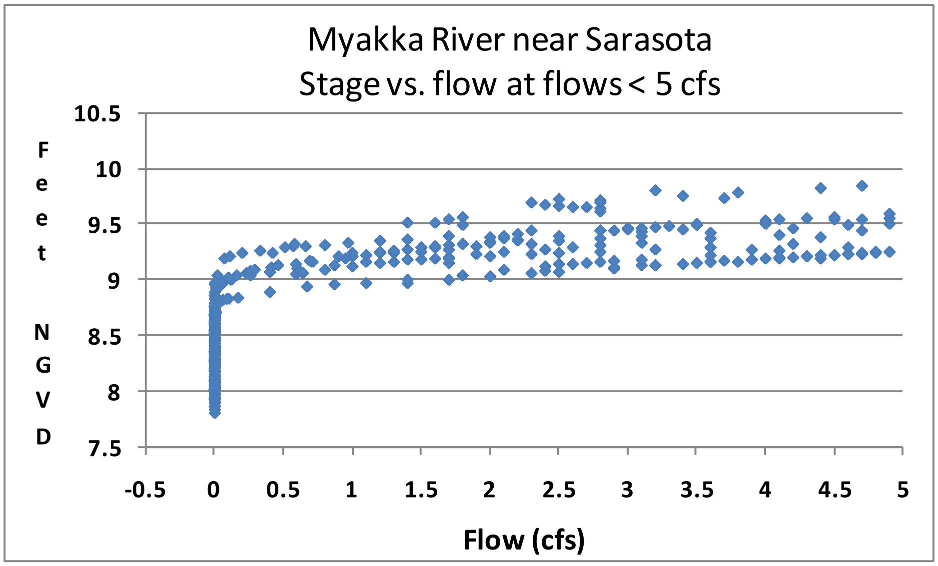


Figure 2-26. Relationship of water levels and flow at the Myakka River near Sarasota for flow rates less than 5 cfs. Data restricted to the period from 1999 – 2008.

2.4.2.3 Findings from other studies, including the Myakka River Watershed Initiative

Other studies have documented an increase in dry season flows in the Myakka River (Coastal Environmental 1998, PBS&J 1999b, SWFWMD 2005a, Interflow Engineering 2008b). Increasing flows first drew attention in the 1990s when it was reported there was tree die-off in the Flatford Swamp, a large wetland area in the upper reaches of the Myakka River basin. In response to these reports, the District sponsored a study of the Flatford Swamp and surrounding areas which concluded that abnormally high tree mortality was occurring in both wetlands and adjacent uplands (Coastal Environmental 1998). Both photographic and dendrochronological evidence indicated the tree die-off had begun in the mid-1980s. A follow-up study found that tree mortality had increased through 1998 (PBS&J 1999b).

These studies concluded that excess flows from agricultural lands and other land use changes in the upper river sub-basin have caused an increase in water levels and prolonged hydroperiods that were detrimental to a variety of wetland and upland tree species. Other evidence has supported the conclusion that excess flows from agricultural lands was a causative factor, and a range of management actions are being investigated in the upper river sub-basin to address the issue of excess flows (Interflow 2009c, 2010a, 2010b).

The minimum flows analysis for the freshwater reaches of the Myakka River also supported the conclusion that increasing flows were attributable to agricultural land and water use (SWFWMD 2005a). Similar to the trend analyses presented in this report, the freshwater minimum flow report examined trends in various streamflow parameters for the Myakka River near Sarasota and also the upstream Myakka River near Myakka City gage. These results were compared to multi-year climatic cycles and flow trends observed for other rivers in the region and it was found the Myakka gages had increasing trends that were not observed at most other sites. The report also observed significant increases in specific conductance and potassium concentrations in the river, which was attributed to increased groundwater inflows to the stream as a result of excess agricultural irrigation.

In determining minimum flows for the freshwater reaches, the District took a seasonal block approach and divided the year into three blocks similar to those described on page 2-34. Based on analyses of flow trends at the Myakka River near Sarasota, the District concluded that flows during block 1 (April 20 to June 24) had been increased by an average flow rate of 22.5 cfs. The District concluded that flows during Block 2 (October 28 to April 19), flows had been increased on average by 26 cfs, but there was no evidence of flow augmentation in the Block 3 summer wet season. The minimum flow recommendations for the Upper Myakka River concluded that removal of these rates of flow in Block 1 (22.4 cfs) and Block 2 (26 cfs) would return the river to a more natural flow regime and not result in significant harm to the freshwater reach of the river between the USGS gages at Myakka City and near Sarasota (SWFWMD 2005a).

As described in the following section, rates of streamflow augmentation in the upper Myakka River basin have been revised based on new hydrologic modeling. These revised flow estimates are described in some detail, for as discussed in Chapters 7 and 8, they play a critical role in the determination of minimum flows for the lower river.

Hydrologic modeling conducted for the Myakka River Watershed Initiative

In 2007 the District began a Myakka River Watershed Initiative (MRWI) to develop management strategies to address water resource issues in the Myakka River watershed. Key among these issues was the increase in dry season flows which had resulted in tree mortality in swamps and uplands in the upper river sub-basin. In addition to remediating these adverse ecological impacts, the water supply and flood protection aspects of increasing flow issue are being evaluated. Specific project elements of the MRWI consist of the generation of improved topographic information, an integrated surface-groundwater model for the watershed, a geodatabase for watershed parameterization, and analyses of alternative best management practices. The District is assisted in the ongoing MRWRI by a consultant team led by Singhofen and Associates, Inc. (SAI).

A central task of the MRWI is the development of a continuous simulation water budget model of the watershed. A MIKE SHE / MIKE 11 integrated modeling platform (MIKE SHE) was selected for the task. The model has been developed and calibrated for the upper Myakka River sub-basin. A principal goal of this modeling effort is to evaluate how changes in land and water use in the Myakka River have affected flows and water levels in various wetlands systems and stream reaches in the upper Myakka River sub-basin. Under sub-contract to SAI, the firm of Interflow Engineering, LLC (Interflow) constructed the MIKE SHE model for the upper river basin and performed a series of hydrologic simulations for the District. Development of the model was based on extensive data for soils, topography, land use/cover, flows, water levels, and irrigation pumpage in the upper river sub-basin. The model was calibrated on combined data collected from May 1999 to April 2006 and was verified against hydrologic data collected between May 1994 and April 1999. The development, calibration, and verification of the MIKE SHE model is described in detail in the report by Interflow in association with SAI (Interflow 2008a).

The objectives of this modeling effort that are relevant to the determination of minimum flows for the Lower Myakka River include:

- Estimate quantities of excess flow in the upper Myakka River.

- Investigate linkages between land use /land practices and excess flows

- Develop time-series of flow rates that are sufficient for pollutant load modeling purposes, which include partitioning the time series into groundwater and surface water sources.

- Evaluate alternative management scenarios for restoring the natural hydrology of the Upper Myakka River watershed.

Excluded from the objectives of the current modeling effort are evaluations of flood protection and water quality. Those objectives will be addressed through concurrent modeling efforts by other members of the consultant team. Interflow (2008a) further states that the current model is a sub-regional model, with spatial and temporal discretization commensurate with a sub-regional scale. The evaluation of alternate management strategies and hydroperiods for individual wetlands or stream reaches in the upper river sub-basin may require the development of one or more local scale models.

The current model is suitable for evaluating alterations of inflows to the Lower Myakka River from the upper river sub-basin. As previously described, historic data for gaged inflows to the lower river are currently limited to the Myakka River near Sarasota gage and two gages on Big Slough. As part of the MRWI effort, Interflow simulated changes in the flows at a number of upstream streamflow gages on river and the UGSG gage Myakka River near Sarasota. As the most downstream long-term gage on the main stem of the river, flows at the Myakka River at Sarasota gage integrate the effects of all the land use and hydrologic factors in that 593 km^2 drainage sub-basin. Inflows that are either measured or modeled at this gage can be considered as net flows to the lower river from approximately 93% of upper river sub-basin, for which the downstream boundary is defined as the outlet to Lower Myakka Lake.

The District utilized output from the model simulations to evaluate the excess flows the lower river has received as a result of changes in land and water use in the upper river sub-basin. Of particular interest was the role of increasing amounts of agricultural irrigation. To address these questions, Interflow (2008b) produced another report that presented model simulations for the following three watershed conditions:

1. Existing conditions, using recent data for land and water use in the upper river sub-basin

2. Existing conditions with no irrigation. All crops in the existing land coverage that are irrigated were converted to unirrigated pasture for this simulation.

3. Historical conditions. This scenario simulated conditions that existed in the early 1950s, which is prior to the occurrence of significant impacts associated with changes in agricultural land and water use and other alterations in the watershed.

Interflow (2008b) ran these simulations for the combined calibration and verification periods which together extended from May 15, 1994 to April 30, 2006. The same rainfall record was used for all simulations, which consisted of Thiessen polygon rainfall totals derived from a series of recorders within the basin for the May 19994 through April 1999 period, and NEXRAD radar rainfall estimates for the May1999 through April 2006 period.

In the time since the MIKE SHE model was calibrated and the initial set watershed of watershed simulations were performed (Interflow 2008a, 2008b), the model has been updated and refined and the watershed simulations rerun. Interflow (2009b) described model refinements that include updating model input parameters that utilize 2007 land use mapping, representation of three irrigation reuse projects in upper-river sub-basin, a conceptual representation of the dike and pump system in the Tatum Sawgrass area, and new survey data for detailed MIKE SHE modeling of the tributaries to Flatford Swamp. This revised model was used to evaluate a series of management alternatives to reduce excess flows to Flatford Swamp (Interflow 2009c).

Additional refinements of the model were applied in the fall of 2009 and revised excess flow estimates were published in December 2009 (Interflow 2009e). This further refined model was then used to characterize potential discharge locations and potential end users of excess flows that go to Flatford Swamp (Interflow 2010a, 2010b). It is expected that further refinements of the MIKE SHE model will be pursued as changes in land and water use occur in the upper river sub-basin.

The excess flows that were used in the minimum flows analysis of the Lower Myakka River were based on refinements of the model that were implemented in late 2008 and provided to the District in January 2009 (Interflow 2009a). As will be described in Chapters 7 and 8, these excess flow values were subtracted from the gaged inflow record to the Lower Myakka River to simulate the effect of removing the excess flows on the salinity and ecological characteristics of the lower river.

It was not possible to redo the minimum flows analysis when the subsequent refinements of the MIKE SHE model were implemented. However, the excess flows at the location of the Myakka River near Sarasota gage that were used in the minimum flows analysis are very similar to the excess flows at that location predicted by the later refinements of the MIKE SHE model, largely because the refinements were changes in localized land use and detail in upstream areas that had only minor effects at the downstream model boundary. It was therefore concluded that the findings that used the excess flow predictions that were generated in late 2008 provided a valid tool to evaluate minimum flows for the Lower Myakka River, knowing that the model had received later refinements and may be refined again in the future.

The statistical and seasonal characteristics of the excess flows are described in the remainder of this section are based on the MIKE SHE simulations conducted in late 2008 (interflow 2009a). While reiterating that these values have since been updated and revised, the following material provides a useful characterization of the magnitude and relation of the excess flows to the current flow regime of the Myakka River. Later publications by Interflow (2009d, 2010a, 2010b) should be consulted for the results of more recent modeling efforts.

Hydrologic characterization of the excess flows

In the latter part of 2008, Interflow ran MIKE SHE simulations for the three watershed conditions described on page 2-43 (existing conditions, existing conditions with no agriculture, and historical conditions) for the combined model calibration and verification periods, which together extended from May 15, 1994 to April 30, 2006. Model output for simulated flows at the location of the Myakka River near Sarasota gage were provided to the District (Interflow 2009a). Duration curves of flows at the gage site for these three scenarios show that flows were highest for the existing scenario, followed by the existing scenario without irrigation, with the historical flows being the lowest (Figure 2-27). These results are supported by trend analyses of flow records at the Myakka River near Sarasota gage which have found that flows in the river have increased over time.

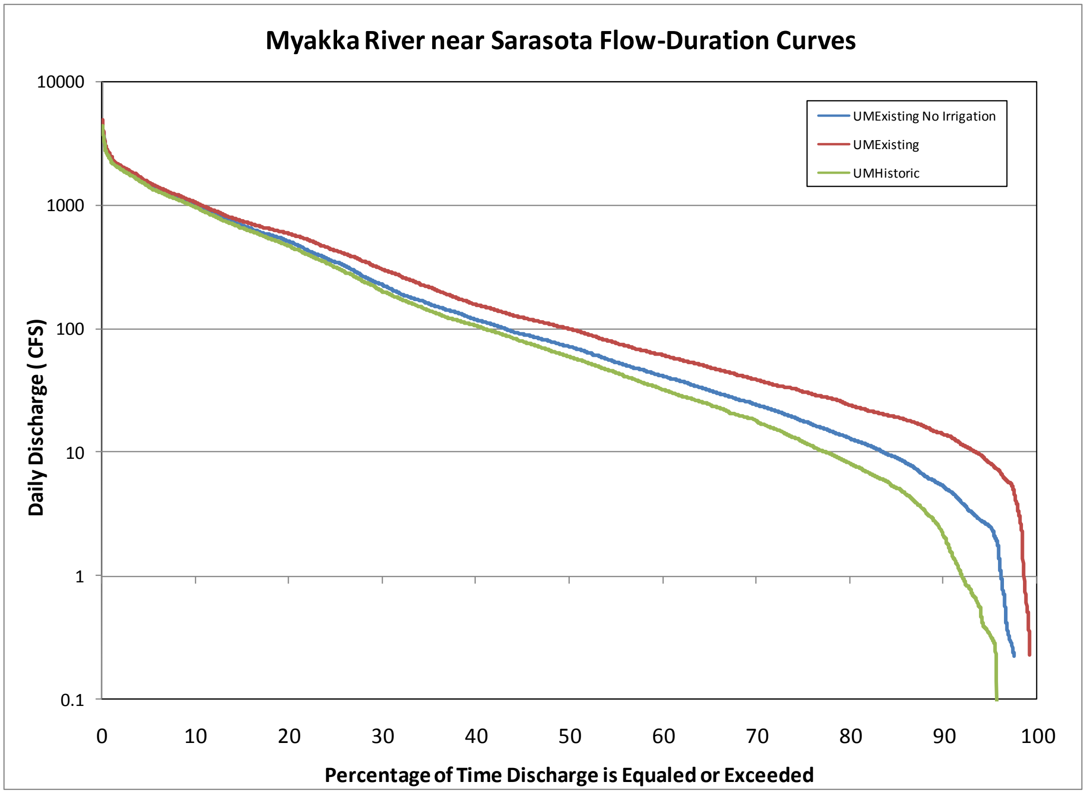


Figure 2-27. Flow duration curve for daily streamflow at the location of the Myakka River near Sarasota gage simulated by MIKE SHE: (A) Flows under existing watershed conditions; (B) existing conditions minus excess water resulting from irrigation in the upper river sub-basin; and (C) historic 1950 conditions with existing rainfall. Reprinted from Interflow Engineering (2009a).

The results of the MIKE SHE modeling provide estimates of the total amount of excess flow the Myakka River receives from all land use changes in upper river sub-basin. The difference between the existing scenario and historic scenario reflect the effects of all land and water use changes in the watershed, including physical alterations such as urbanization, ditching, and channelization. These differences in daily flows between the existing and historic scenarios are termed total excess flows for this minimum flows report.

The MIKE SHE modeling project can also be used to assess the effects of irrigated agricultural lands on flow in the river. The differences in daily flows between the existing scenario and the existing scenario without irrigation were used to estimate the effects of irrigated agriculture lands in the upper-river sub-basin, which are termed agricultural excess flows. Existing land covers for irrigated crops were converted to unirrigated pasture for this scenario, since changes in land cover and soil structure associated with crop conversion can affect runoff rates, regardless of the amount of irrigation. Thus, the objective of this scenario was to examine the total effects on streamflow that have resulted from the conversion of natural land covers to irrigated crops.

The daily quantities of total excess flows and agricultural excess flows are plotted for the 12-year modeling period in Figures 2-28 and 2-29. On almost all days the total excess flow values were positive, meaning the daily flow values for the existing condition scenario were greater than the historic scenario (Figure 2-28). The total excess flow values ranged from negative values for a small number of days to values ranging over 600 cfs during some years. Maximum total excess daily flow values over 180 cfs occurred in the wet seasons of all years for which there were complete records (1995-2005).

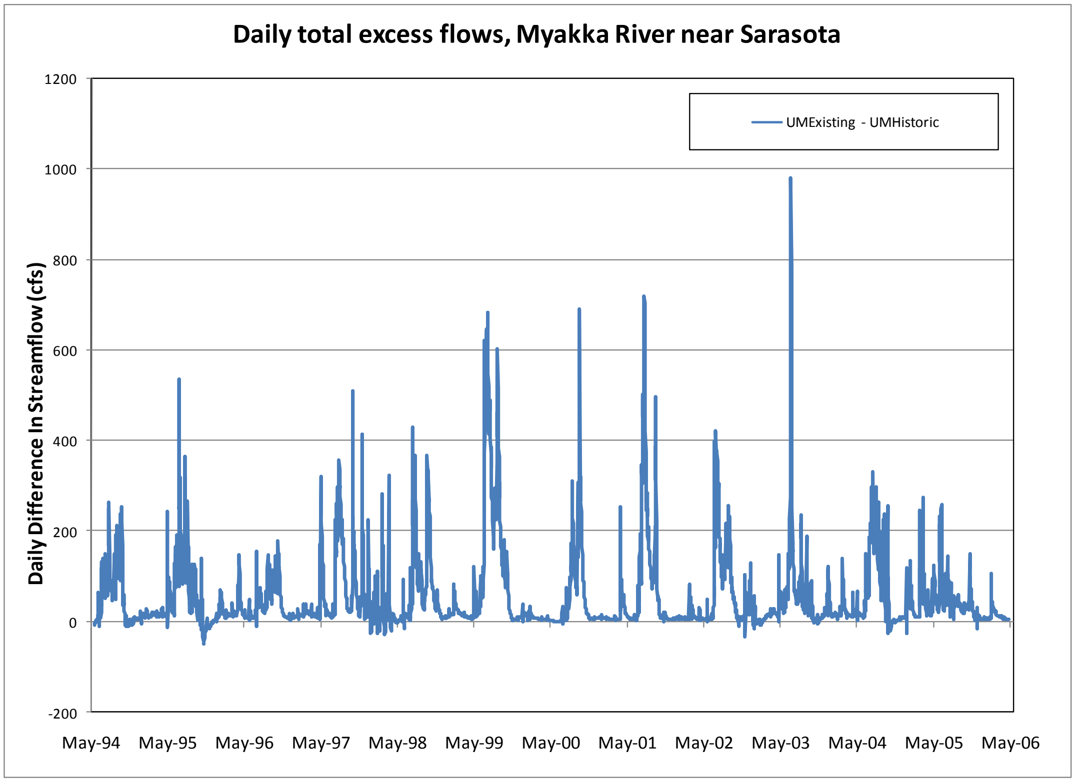


Figure 2-28. Time series of differences in daily flows between the existing conditions scenario and the historic 1950 scenarios simulated by MIKE SHE.

Estimates of excess flows were also developed at several other locations in the Upper Myakka river sub-basin, which showed there is considerable variation in the seasonality an relative amounts of excess flow from one location to another. However, the excess flows at the Myakka River near Sarasota gage are the most relevant for the development of minimum flows for the Lower Myakka River.

The excess flow values resulting from agricultural land use were also positive at the downstream site throughout most of the modeling period (Figure 2-29). The quantity of excess agricultural flows were generally less than the total excess flows, though as discussed later, agricultural excess flows comprised a majority of the total excess flows.

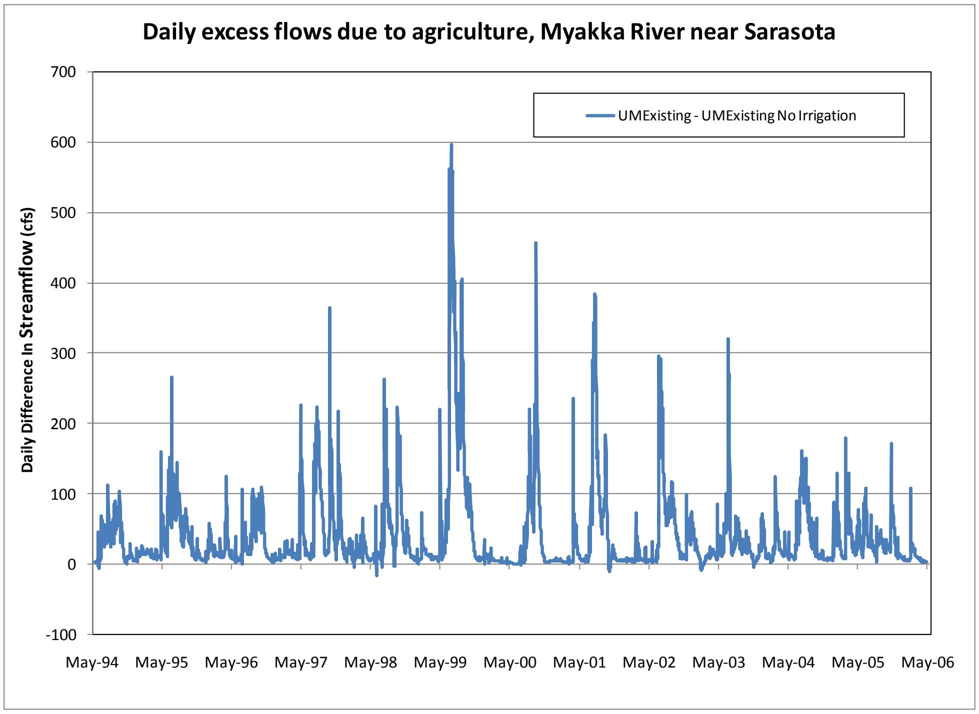


Figure 2-29. **Time series of the difference in daily flows between the existing conditions scenario and the existing condition minus irrigation water scenario as simulated by MIKE SHE.**

In order to examine typical rates of excess flow throughout the year, average and median values of total excess and agricultural excess flows were calculated for each day during the calendar year (days 1 through 365). Average and median daily values for total excess flows are plotted in Figures 2-30 and 2-31. These values show similar seasonal patterns, although the daily averages are generally higher than the medians due to the influence of unusually large daily excess flow values on the averages. Average daily total excess flows range from 100 to over 200 cfs during the wet season from late June through September. During the dry months from November through May, total excess flow values generally varied in the range of 15 to 30 cfs, generally supporting the conclusion by SWFWMD (2005a) that flows in the Myakka River appear to have increased about 22 to 26 cfs on average in the dry season.

The variation of daily median values is generally more subdued than the averages, particularly in the dry season, and it can be considered the median values reflect the typical amount of excess flow the river receives each day of the calendar year. Median daily total excess flows generally ranged between 7 and 15 cfs for the dry season extending from November through early June (Figure 2-31).

Average and median daily excess flows due to agriculture are shown in Figures 2-32 and 2-33. These show similar patterns to the total excess flows, but generally at lesser amounts. Average excess flows due to agriculture range from about 60 to 130 cfs in the wet season, and from about 15 to 25 cfs in the dry season. Median daily flows due to agriculture typically range from about 40 to 110 cfs in the wet season, and from about 7 to 15 cfs in the dry season.

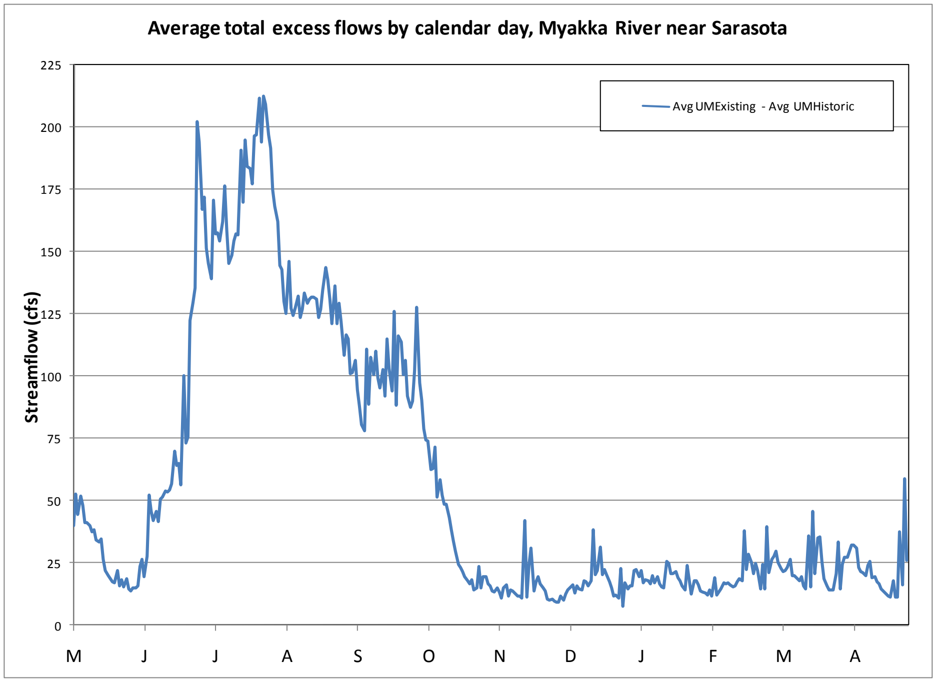


Figure 2-30. Average daily values for total excess flows at the Myakka River near Sarasota gage based a MIKE SHE simulation of the upper river sub-basin for May 1994 through April 2006

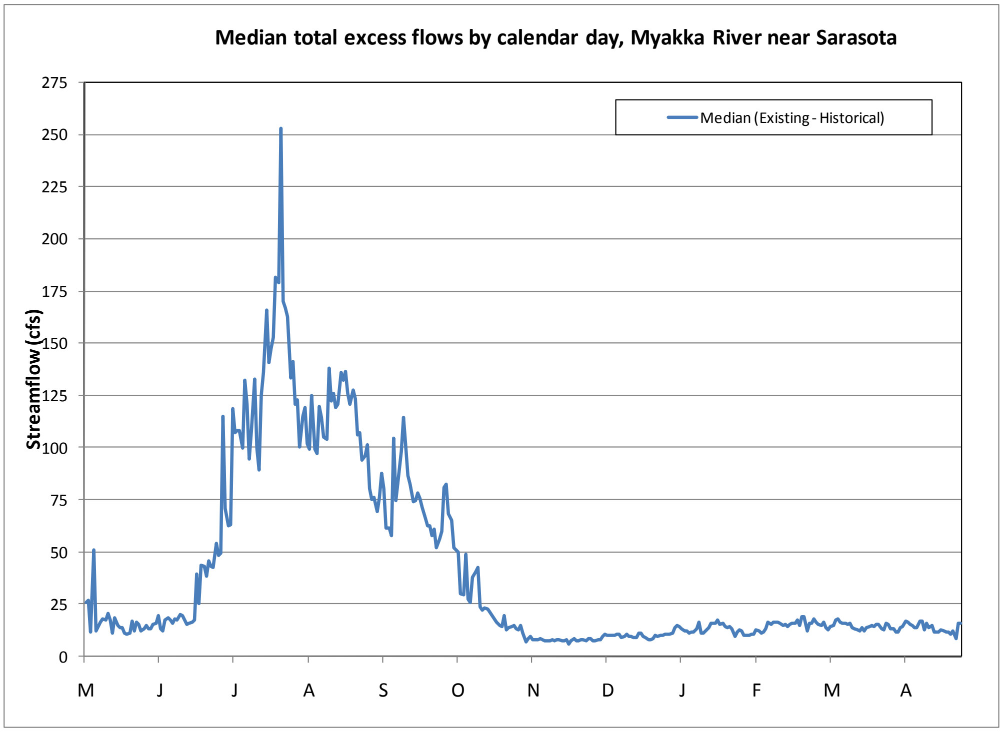


Figure 2-31. Median daily values for total excess flows at the Myakka River near Sarasota gage based a MIKE SHE simulation of the upper river sub-basin for May 1994 through April 2006

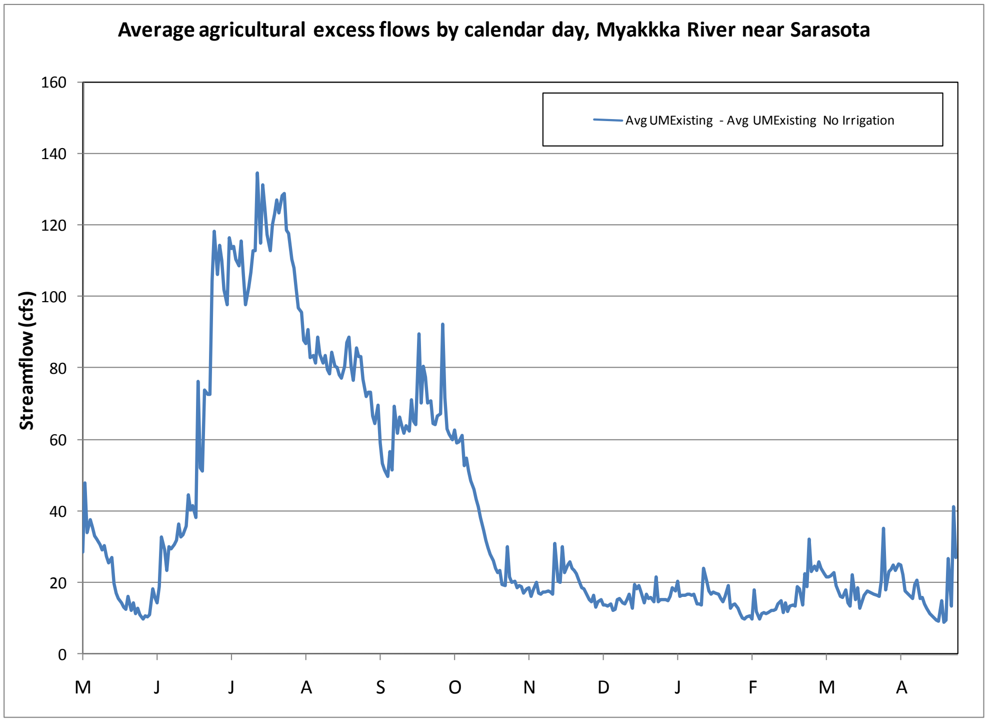


Figure 2-32. Average daily values for excess flows due to agriculture at the Myakka River near Sarasota gage based a MIKE SHE simulation of the upper river sub-basin for May 1994 through April 2006

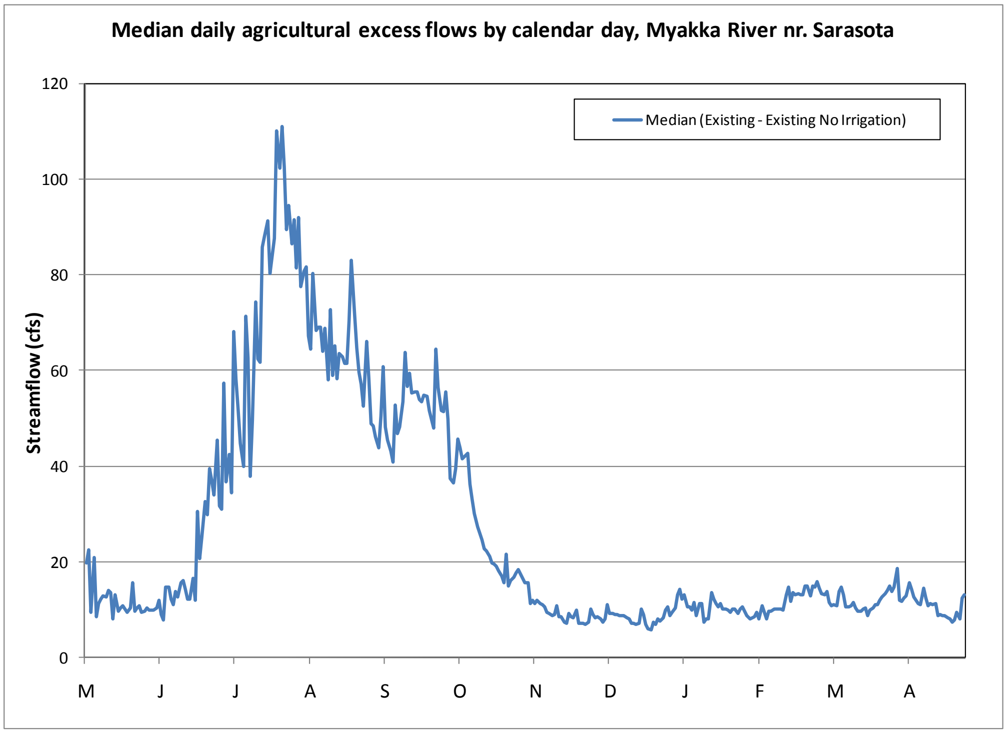


Figure 2-33. Median daily values for total excess flows due to agriculture at the Myakka River near Sarasota gage based a MIKE SHE simulation of the upper river sub-basin for May 1994 through April 2006.

Summary statistics were generated to characterize the amount of excess flow the river receives in relation to flow at the Myakka River near Sarasota gage (Table 2-8). Baseline flows at the gage location are listed for the predicted flows under the existing conditions scenario and the measured flows by the USGS. If the model perfectly predicted the flow for the existing condition, then the predicted values would be the same as the measured gaged values. The model performed well, but the mean flow for the existing conditions scenario (346 cfs) was about 5% greater than the mean flow for the gaged flows (329 cfs).

Due to the timing of various flow events routed through the system, and use of recorded daily stage values for the downstream model boundary, the model predicted negative flows for the existing conditions scenario for some days, as reflected by the negative minimum value in the second column in Table 2-8. This cannot happen in nature, but these periods of negative modeled flows were brief (< 1 % of total days), with modeled flows quickly returning to positive values. Negative values for the total excess and agricultural excess flow represent days when the historical conditions scenario had greater flows than the corresponding existing conditions scenario. Though still relatively rare, this genuinely could occur on some days.

Table 2-8. Summary statistics for gaged flows at the Myakka River near Sarasota and the following variables predicted by MIKE SHE model of the upper river sub-basin: existing flow conditions at the gage: total excess flows; and excess flows due to agriculture. All values in cfs for the period May 15, 1994 through April 30, 2006.

	Mean	Std	Min	Max
Myakka River near Sarasota gaged	329	593	0	10,800
Modeled existing flows at gage	346	547	-76	4,992
Modeled total excess flows	56	92	-48	980
Modeled excess flows due to agriculture	40	62	-16	597

Total excess flows averaged 56 cfs, equivalent to 16% of the predicted mean flow for the existing conditions scenario and 17% of the actual gaged flow for 1994-2006 modeling period (Table 2-8). The mean value for agricultural excess flows (40 cfs) was 71% of the mean for total excess flow, indicating that agriculture has had a very strong effect on the observed increasing flow trends.

Mean monthly values for gaged flow and modeled flow terms are shown in Figure 2-34 and listed in Table 2-9. The monthly mean values for total excess flows ranged from 14.7 cfs in November to 174 cfs in July. In contrast to the minimum flows report for the upper river (SWFWMD 2005a), which concluded that excess flows had not increased in the wet season, the MIKE SHE model indicates that considerable quantities of excess flow are generated during the rainy season from June through September. It should be noted, however, the conclusions of the upper river minimum flows report were based on statistical analyses of flow data alone, in which the effects of changes in rainfall were not directly assessed. Potentially, changes in rainfall could mask the effects of watershed changes. In contrast, the MIKE SHE modeling effort employed a highly detailed physical based model in which identical rainfall data sets were used to assess the effects of watershed changes.

Agricultural excess flows comprised the majority of the modeled total excess flows throughout the year, especially in the dry season from October through May, when the mean values for agricultural excess flows ranged from 74% to in excess of 100% of the mean total excess flows. Mean values for agricultural excess flows were greater than means for total excess flows in October and November.

The results for October and November simply mean the average difference in flows between the existing conditions scenario was greater for the existing conditions with no irrigation scenario than for the historic scenario. Excess flows not due to agriculture peaked in the summer wet season due to storm generated runoff. Agricultural excess flows ranged between 65 and 66% of the mean total excess flow values for the rainy months of June through September.

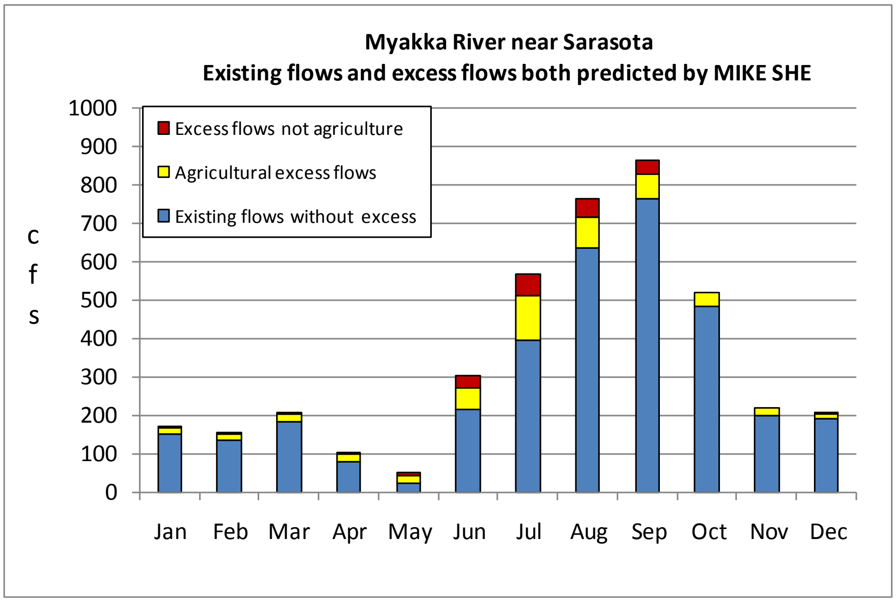


Figure 2-34. Monthly mean values for agricultural excess flows, excess flows not due to agriculture, and gaged flows not including excess flows. The sum of these three groups represent the total predicted flow at the Myakka River near Sarasota gage.

Table 2-9. Monthly mean values for gaged flows at the Myakka River near Sarasota gage, plus the following terms predicted at the gage by MIKE SHE; existing flows, total excess flows, excess flows from agriculture, and excess flows not from agricuture. All values in cfs for the period May 15, 1994 - April 30, 2006.

Month	Myakka River nr. Sarasota	Existing flow at gage	Total excess flow	Agricultural excess flow	Excess flow not from Ag.
Jan	213	171	18.3	16.1	2.2
Feb	188	157	19.1	14.2	4.9
Mar	210	207	22.9	19.3	3.6
Apr	78	102	22.1	18.0	4.1
May	65	52	27.6	21.0	6.6
Jun	315	304	88.5	56.6	31.9
Jul	511	570	174.2	144.8	59.4
Aug	723	763	126.4	80.8	45.6
Sep	742	863	100.1	66.4	33.7
Oct	440	529	36.1	37.0	0.0
Nov	238	215	14.7	19.7	0.0
Dec	202	209	16.9	15.3	1.6

It is also informative to view the proportion of flow at the Myakka River near Sarasota gage comprised by excess flows on a daily basis. Monthly box and whisker plots of these daily percentages show that both total and agricultural excess flows comprise the highest proportion of gaged flows in the months from April through June (Figures 2-35 and 2-36). The boxes represent the data between the 25th and 75th percentiles, while the tops and bottoms of the whiskers are at the 5th and 95th percentiles.

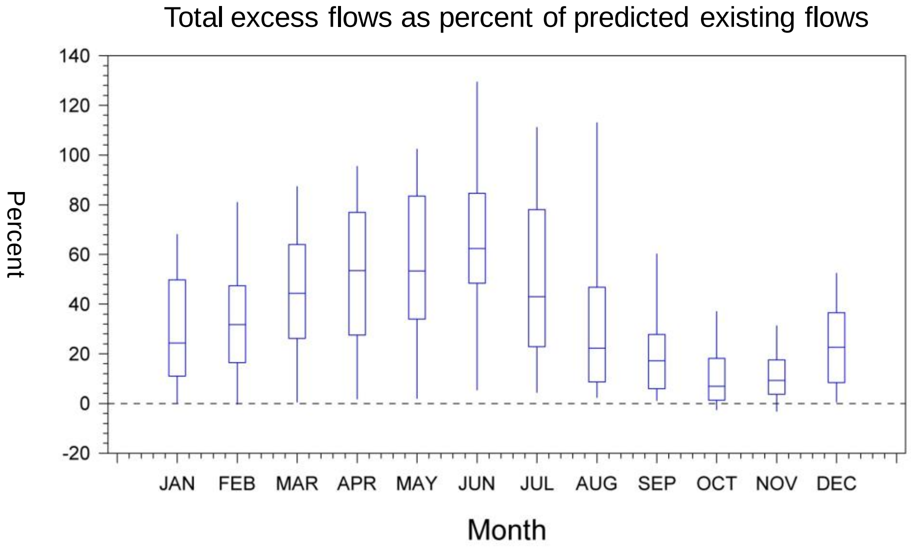


Figure 2-35. Monthly box and whisker plot of the percent of predicted flows at the Myakka River near Sarasota gage comprised by total excess flows predicted by MIKE SHE for the period Mary 15, 1994 through April 30, 2006.

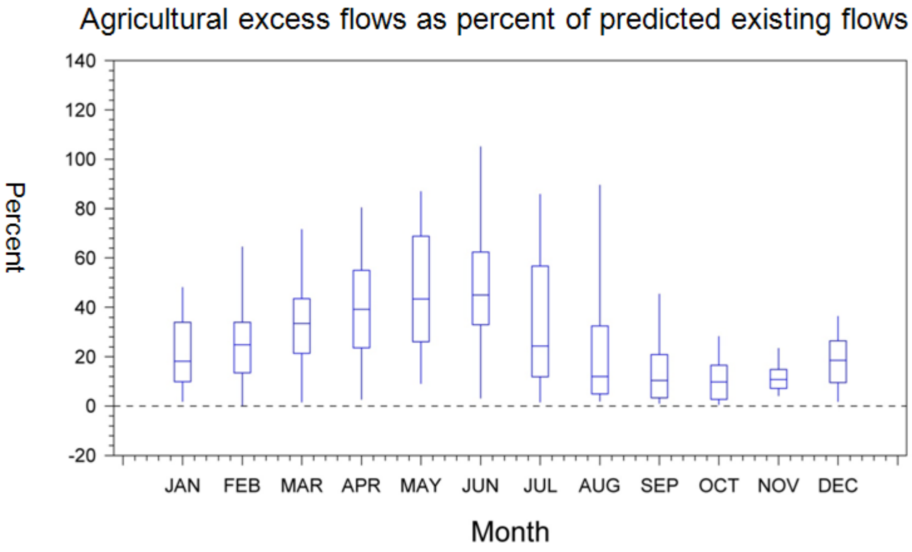


Figure 2-36. Monthly box and whisker plot of the percent of predicted flows at the Myakka River near Sarasota gage comprised by total excess flows predicted by MIKE SHE for the period Mary 15, 1994 through April 30, 2006.

The results of the MIKE SHE modeling efforts (Interflow 2008b, Interflow 2009a) agree with the findings of other studies, which have reported increasing flows in the Upper Myakka River sub-basin, with agricultural land conversion and irrigation being key factors contributing to these trends. During dry periods, low flows in the river are increased by the addition of excess irrigation water, either as direct runoff from irrigated fields or as increased baseflow from the surficial aquifer. The increasing trend of specific conductance in the Myakka River reported by SWFWMD (2005a) also indicates that irrigation waters are entering the river, as ground waters pumped from deep aquifers have higher specific conductance than surface runoff or shallow ground water. An increase in specific conductance has been observed in other streams in the southern part of the District where low flow parameters have been increasing due to agricultural water use (Flannery et al. 1991, PBS&J 2007).

The MIKE SHE modeling also indicates that flows in the river are supplemented in the wet season. This likely results from the combined effect of changes in land and water use. The change of land cover from native forests and range to row crops affects runoff coefficients and evapotranspiration rates, regardless of irrigation. In addition, irrigation can contribute to greater runoff from storm events by raising the water table, increasing soil saturation, and reducing soil storage. On a percent of flow basis, the effects of irrigation on increasing surface runoff is probably greatest in the dry season when the irrigation is occurring. However, elevated water tables may persist for sometime after the irrigation has ceased, contributing to increased flows in the summer wet season. A change from native land covers to urban lands would also increase runoff rates.

As described in Chapter 7, the District accounted for these excess flows from the upper river sub-basin in the determination of minimum flows for the Lower Myakka River. Excess flows were not calculated for the lower river sub-basin because: long-term streamflow records are much more limited; a detailed integrated surface / ground water model has not been constructed for the lower river sub-basin; land uses in the lower river sub-basin have not shown the dramatic increase in agricultural land use; and there are no reports of related trends that indicate that increasing agricultural flows are a concern.

As described in the following section, a hydrologic characterization of flow from the lower river sub-basin was restricted to trend analyses of a single long term gage on Big Slough and the simulation of flows from ungaged areas within the lower river sub-basin.

2.4.2.4 Trend analyses of Big Slough near Myakka City Gage

Big Slough Canal is the only major tributary to the Lower Myakka River that is currently gaged for streamflow and trend tests of flows in Big Slough are presented below. These results, however, are not as informative as for the Myakka River near Sarasota because period of record at longest-term gage on Big Slough only extends back to 1980. Trend tests and time series hydrographs for this gage are strongly influenced by variations in rainfall since that time and were not used to assess any potential anthropogenic effects on flow. The data do, however, illustrate how flows in Big Slough have varied over the last three decades.

Selected hydrographs of different streamflow parameters at the Big Slough near Myakka City are presented below, with the complete suite of hydrographs for all parameters tested for trends included in Appendices 2E, 2F, and 2G. It is reiterated this gage only represents seven percent of the area of Myakka River watershed. Flows have probably varied similarly at the more downstream Big Slough at Tropicaire Blvd. gage (15 percent of watershed area), but flow records at this site extend only to 2000, thus trend tests were not conducted for that site.

A hydrograph of yearly mean flows at the Big Slough at Myakka City gage for the period 1981 – 2006 is presented in Figure 2-37. The lowest yearly mean flows on record were occurred in 1985 and 1989. The mean annual flow for the drought year 2000 was considerably higher than eight yearly mean flows during the 1980s and 1990s.

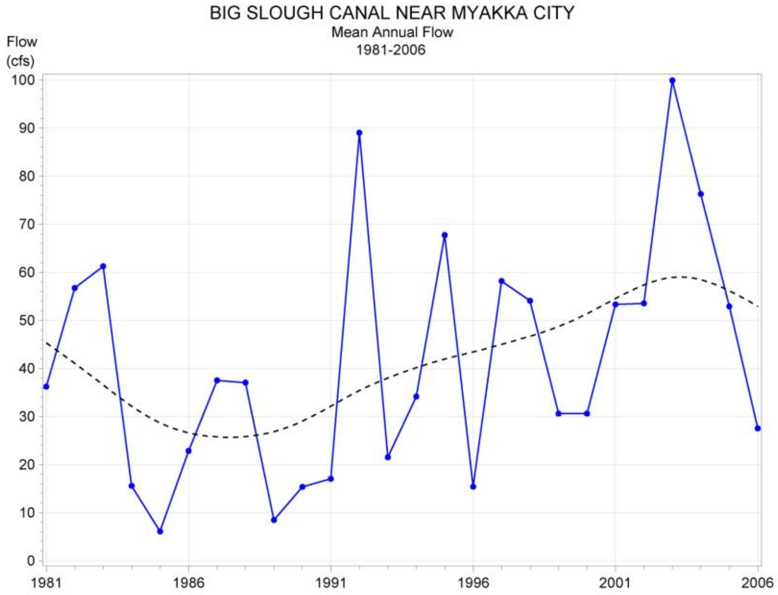


Figure 2-37. Time series plot of mean annual flows for the USGS gage Big Slough Canal near Myakka City for 1981-2006.

There have been no significant trends in any of the three seasonal blocks (Table 2-10). Hydrographs of yearly median flows within each block indicate that block 1 flows were very low during the dry period from 1999 through the spring of 2002, similar to other gages in the region (Figure 2-38A). Block 3 flows peaked in the wet year of 1995, and were fairly high during the years from 1999 – 2004, with low years in 2005 and 2006.

Table 2-10. Results of Kendall Tau tests for trends in median annual flows by Block for the Big Slough Canal Near Myakka City gage (USGS 02299410) for the period 1981-2006.

Block (Dates)	Tau Statistic	P value	Slope
1 (April 20 – June 20)	-0.212	0.134	-0.075
2 (October 28 – April 19)	-0.052	0.724	-0.067
3 (June 21 – October 27)	0.182	0.201	0.871

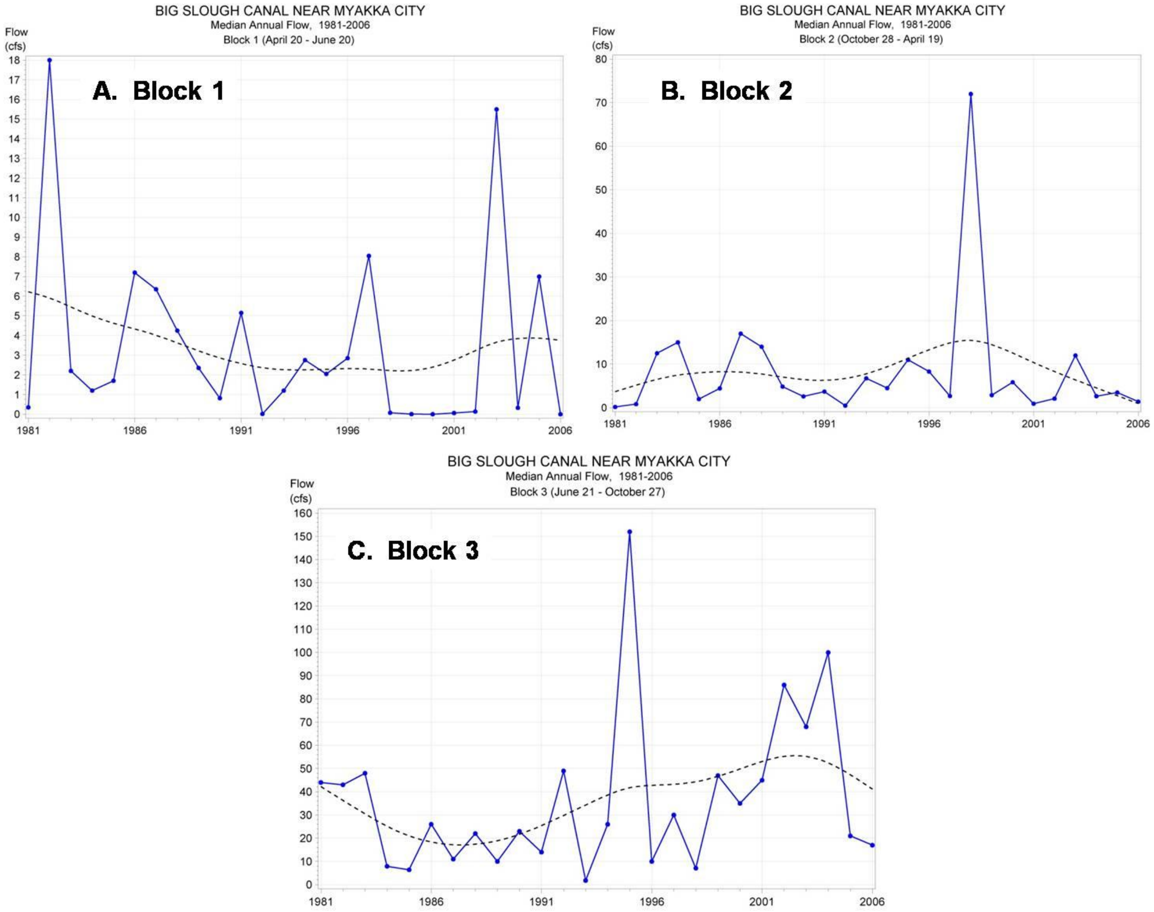


Figure 2-38. Time series plots of yearly median flows for seasonal blocks 1, 2, and 3 for Big Slough Canal near Myakka City.

Trend tests for flows within individual months did not indicate any consistent patterns (Table 2-11, Appendix 2E). A significant decreasing trend for April and increasing trend for July were found, with some evidence of an increasing trend for January.

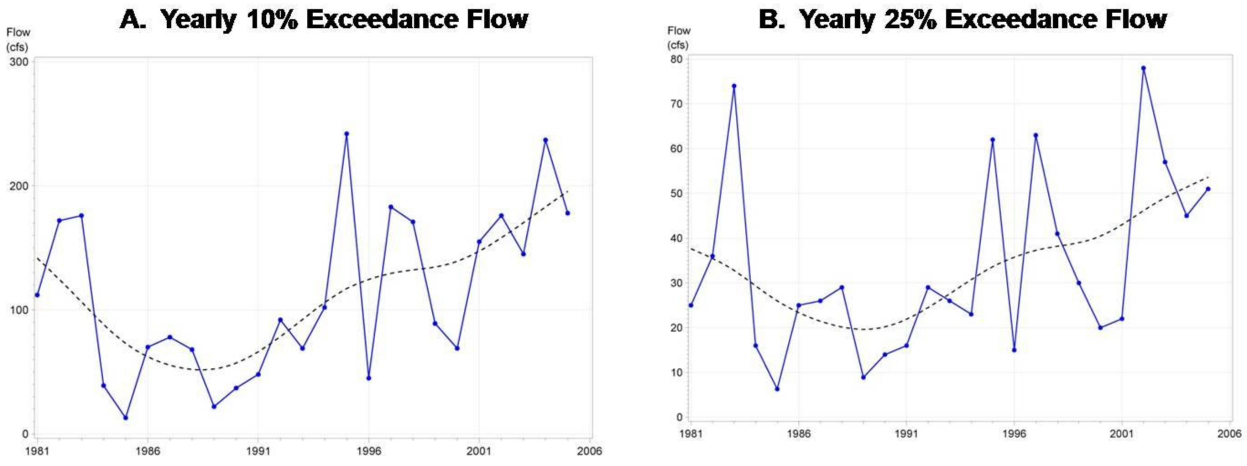
Trend tests on yearly on yearly percent exceedance flows indicate that the high flows on the Big Slough have been increasing, while low and medium flows have shown no trends (Table 2-12, Appendix 2F). Time series plot of the 10 and 25 percent exceedance flows indicate the wet season flows of Big Slough have been increasing (Figure 2-39), which may be due to patterns in wet season rainfall. There has not been a hydrologic assessment of land use changes in the Big Slough watershed, so no assessment of any potential land use effects is possible.

Table 2-11. Results of Kendall Tau tests for trends in monthly Streamflow for the Big Slough Canal Near Myakka City gage (USGS 02299410) for the period 1981-2005.

Month	Tau Statistic	P value	Slope
January	0.253	0.080	0.201
February	-0.020	0.907	-0.023
March	-0.070	0.640	-0.110
April	-0.403	0.005	-0.261
May	-0.140	0.337	-0.023
June	0.087	0.559	0.113
July	0.327	0.023	2.971
August	0.223	0.123	1.792
September	0.027	0.870	0.212
October	0.003	1.000	0.011
November	-0.067	0.657	-0.050
December	0.120	0.414	0.080

Table 2-12. Results of Kendall Tau tests for trends in yearly percent exceedance flows for the Big Slough Canal Near Myakka City gage (USGS 02299410) for the period 1981-2005.

Percent Exceedance Flow	Tau Statistic	P value	Slope
10% exceedance (high flows)	0.307	0.033	4.909
25% exceedance	0.260	0.072	1.000
50% exceedance (median flows)	0.087	0.559	0.047
75% exceedance	-0.063	0.674	-0.037
90% exceedance (low flows)	-0.120	0.412	-0.010



A. Yearly 10% Exceedance Flow

B. Yearly 25% Exceedance Flow

Figure 2-39. Time series plot of yearly values of the 10 and 25 percent exceedance flows for the Big Slough Canal near Myakka City.

Trend tests on moving average flows within years indicated there was a tendency for increasing trends in both the mean and maximum values, while there were no trends for minimum values. Hydrographs of the yearly mean, minimum, and maximum values for the 90-day flow interval are presented in Figure 2-40. Although a significant trend in yearly mean values was observed only for the 120-day flow, significance levels near the p <. 05 threshold were observed for the other day intervals tested (Table 2-13). Similarly, significant trends were observed for four of the six intervals tested for maximum yearly values, with p values for the other two intervals near the p < .05 significance threshold. The hydrograph of the 90-day maximum values clearly indicates the wet season flows in Big Slough have been increasing over the last twenty-five years. In contrast, there were no significant trends in the minimum values for any of the day intervals tested, which are supported by hydrographs of these values (Figure 2-40C and Appendix 2G).

The combined trend tests for the Big Slough show very different results than the Myakka River near Sarasota, where there are increasing trends in dry season flows but no evidence of trends in wet season flows. These differences in results are likely due to yearly rainfall variations over the different lengths of record at these gages and differences in land use between the upper river and lower river sub-basins.

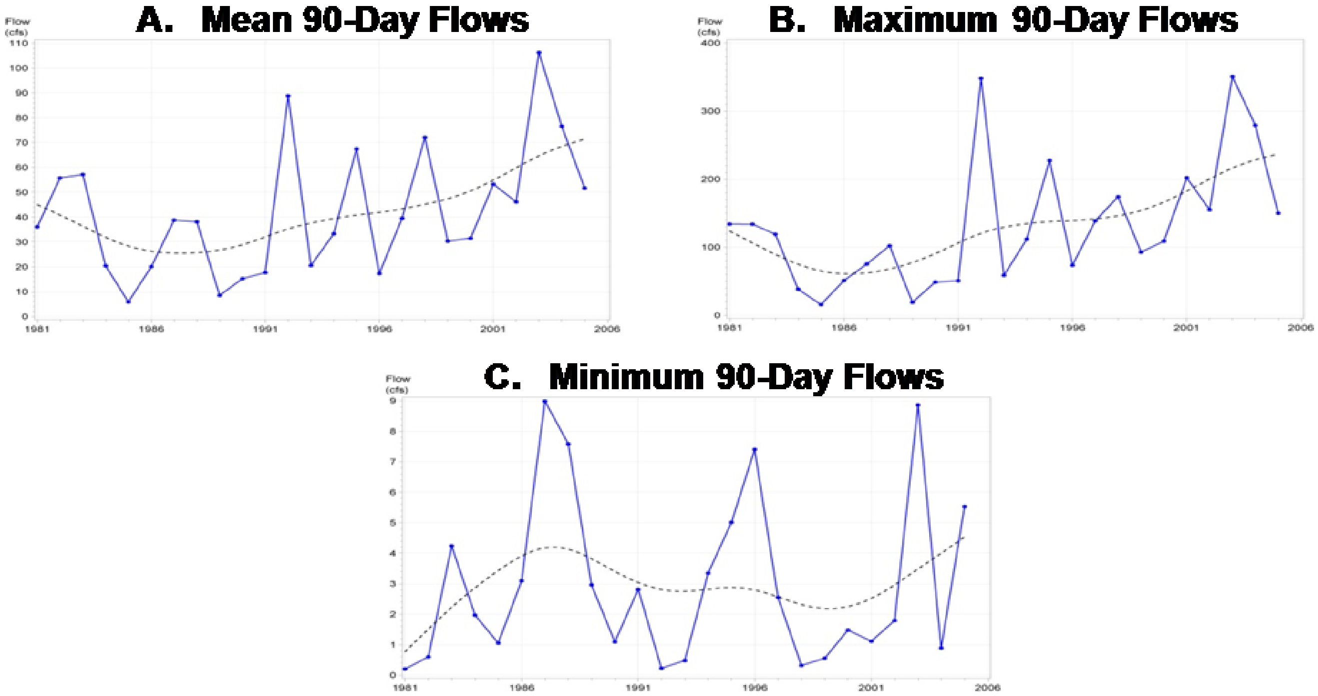


Figure 2-40. Time series plots of yearly mean, minimum, and minimum values of moving average 90-day flows within years for the Big Slough Canal near Myakka City.

Table 2-13. Results of Kendall Tau tests for trends in mean, minimum, and maximum values of moving average flows calculated over 3, 10, 30, 60, 90, and 120 days within each year for the Big Slough Canal Near Myakka City gage (USGS 02299410) for the period 1981-2005.

Statistic	**Tau Statistic**	**P value**	**Slope**
Mean 3-day average flow	0.247	0.088	1.526
Mean 10-day average flow	0.233	0.107	1.543
Mean 30-day average flow	0.273	0.059	1.507
Mean 60-day average flow	0.280	0.053	1.529
Mean 90-day average flow	0.280	0.053	1.536
Mean 120-day average flow	0.293	0.042	1.575
Maximum 3-day average flow	0.247	0.088	18.279
Maximum 10-day average flow	0.293	0.042	15.110
Maximum 30-day average flow	0.273	0.059	7.610
Maximum 60-day average flow	0.373	0.010	6.550
Maximum 90-day average flow	0.380	0.008	5.926
Maximum 120-day average flow	0.333	0.021	3.713
Minimum 3-day average flow	-0.140	0.326	0.000
Minimum 10-day average flow	-0.127	0.379	-0.004
Minimum 30-day average flow	-0.067	0.656	-0.004
Minimum 60-day average flow	0.027	0.870	0.004
Minimum 90-day average flow	0.060	0.691	0.021
Minimum 120-day average flow	0.133	0.362	0.080

2.4.3 Ungaged flows to the Lower River

Approximately 39% percent of the drainage area to the Lower Myakka River is currently not gaged for streamflow. However, two recent efforts have estimated flows from these ungaged areas. Along with gaged flows, a combination of ungaged flow estimates from these two efforts were used as hydrologic input for the construction of hydrodynamic salt transport models of Charlotte Harbor and the Lower Peace and Myakka Rivers prepared by the University of Florida (Sheng et al. 2006) and District staff (Appendix 5A). A summary of the two methods for estimating ungaged flows is presented below, with a brief discussion of how these were utilized to serve as input to the estuarine models.

2.4.3.1 HSPF modeling

The District contracted the University of South Florida Center for Modeling and Aquatic Systems to construct a surface-water model to predict ungaged flows to Upper Charlotte Harbor, including the Lower Myakka River. Ungaged flows were simulated using an HSPF model (Hydrologic Simulation Program – FORTRAN, Bickell et al. 2001). A detailed discussion of the HSPF modeling effort by is presented in a report by Ross et al. (2005).

HSPF requires that the watershed be divided into three groups: pervious land, impervious land, and channels or reaches. Based on land cover data from 1999, the implementation of HSPF for this project divided pervious land into five subgroups or land segments; 1) urban, 2) irrigated, 3) grass/pasture 4) forested and 5) mined and disturbed. Each of the five pervious land segments had associated hydrologic parameters. Assigned irrigation rates were developed from metered and estimated irrigation rates obtained from the District.

The sub-basins used in the project were derived from the USGS basin delineations, but sub-basins along the Myakka and Peace River were subdivided into smaller units where interest in detailed inflow was desired. The sub-basin delineations used in the project, including those in the Lower Myakka River, are shown in Figure 2-41. After the initial sub-basins were constructed, two addition sub-basins were added near Deer Prairie Slough, producing 74 total sub-basins delineated for the project, of which 36 were in the Lower Myakka River.

Major conveyances of water through the model domain, including the major rivers and tributaries, were classified as routing reaches. Runoff from the basins was routed through the routing reaches. There were 48 routing reaches identified for the ungaged Charlotte Harbor model, of which 19 were in the watershed of the Lower Myakka River. Rainfall inputs for the model were derived from nine rain gages in the region based on a defined set of selection criteria.

The HSPF model was calibrated to data collected between January 1, 1989 and September 20, 2004. The calibration was performed in a two-step procedure, the first of which used traditional manual calibration techniques. The second step was to refine the initial calibration with a parameter estimation software package (PEST, Doherty 2001). The model was calibrated to three available USGS flow gages, two of which are in the Lower Myakka River watershed; Deer Prairie Slough at Power Line nr. North Port Charlotte and Big Slough Canal at North Port Charlotte. A third calibration site, Gator Slough at SR 765 at Cape Coral, was located in the southern Charlotte Harbor area. A number of plots and statistics supporting the calibration and validation of the model are presented by Ross et al. (2005). After calibration, the HSPF model was used to produce a record of predicted daily ungaged flows for all the sub-basins and routing reaches in the model domain for the years 1989-2004. Flows reported for each reach included both the gaged and ungaged flows, but the gaged flows could be subtracted to determine the total ungaged flow.

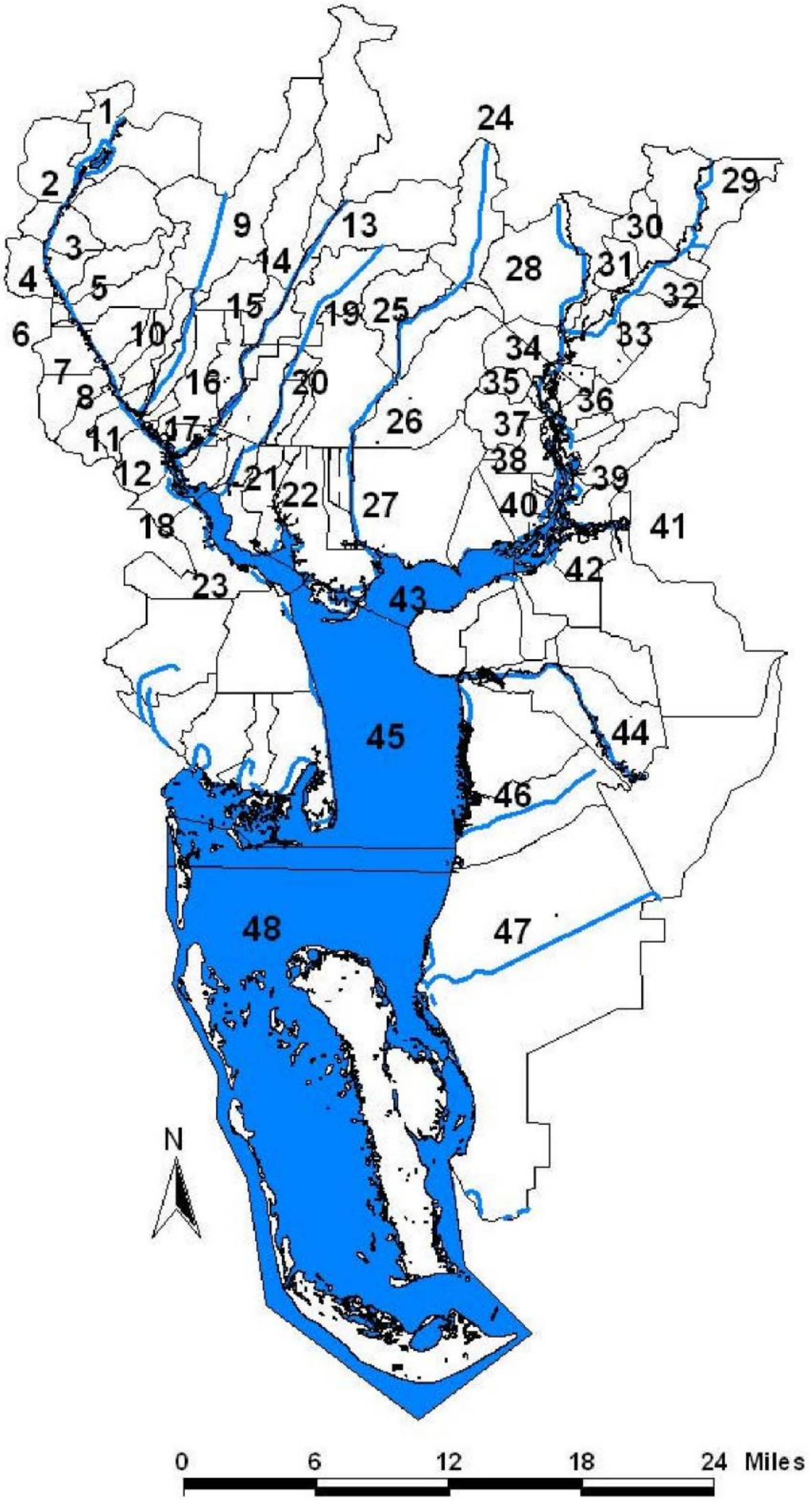


Figure 2-41. Map of stream reaches for HSPF modeling of ungaged areas to Charlotte Harbor, reprinted from Ross et al. (2005).

2.4.3.2 Ungaged flow estimates prepared by SDI Environmental Services, Inc.

The firm of SDI Environmental Services, Inc. (SDI) also generated estimates of ungaged flow to the Charlotte Harbor, including the Lower Myakka River. Though not funded by the District, these values were supplied to the District for evaluation in the minimum flows project. In order to estimate unit area runoff rates from ungaged rural and urban areas draining to Charlotte Harbor, SDI compared flows from two gaged drainage basins in the region. Walker Creek near Sarasota (USGS gage # 02299861) was considered to be representative of an urban drainage basin, and Big Slough Canal near Myakka City was considered to be representative of a rural drainage basin. At the time of the comparison, the periods of record were 8/1/1991 to 9/30/2002 for Walker Creek and 10/1/1980 to 9/30/2002 for Big Slough Canal. Daily flow values for each gage were expressed in inches of runoff per day.

The average flows for the comparable periods-of-record (8/1/1991 to 9/30/2002) were calculated for each basin. The ratio of the overall mean flows from Walker Creek to Big Slough was 1.08. To estimate flows from ungaged basins in the Charlotte Harbor watershed, it was assumed that daily flows in inches per day from Big Slough were representative of daily flows from rural land covers. Multiplication of the Big Slough daily flows by 1.08 was used to estimate daily flows from urban land covers. Using GIS, either rural or urban codes were assigned to land covers within each of the delineated ungaged sub-basins in Charlotte Harbor watershed. Depending on the land code, daily flows from Big Slough, with or without the 1.08 adjustment, were applied to the respective areas of rural or urban land cover in each of the ungaged sub-basins to generate daily flows in inches of runoff for those basins. These values were converted to daily flows in cfs and used as hydrologic input in the hydrodynamic models.

The initial calibration of the UF Charlotte Harbor model, which was based on a twelve month calibration period during 2003 and 2004, incorporated HSPF generated flows provided by Ross et al. (2005). However, assessments of model performance indicated the ungaged flow values predicted by the HSPF model might be too high, as the estuarine model tended to under-predict salinity. Also, the daily HSPF estimates were generally greater than flow estimates produced by SDI for the same ungaged sub-basins during the calibration period.

To test performance of the estuarine model to reduced ungaged inflow, the time series of daily flows predicted by the HSPF model were adjusted by constant coefficients derived by comparing the mean ungaged flow values generated by HSPF to mean flow values produced by SDI. Based on these comparisons, daily ungaged flows predicted by HSPF in the Peace River watershed were multiplied by 0.387, while daily ungaged flows predicted by HSPF in the Myakka River basin were multiplied by a factor of 0.507 to arrive at the final adjusted ungaged flows within each river watershed. Ungaged flows along the western shore of Charlotte Harbor were multiplied by the adjustment factor for the Myakka River, while ungaged flows along the eastern side of the harbor were multiplied by the factor for the Peace River.

These adjusted ungaged flow values resulted in improved performance of the UF Charlotte Harbor model. As described in Chapter 5, output from the UF model along a two-dimensional cross-section in Charlotte Harbor was used as a boundary condition for the District model of the Upper Harbor and the Lower Myakka and Peace Rivers. Calibration of the District model also indicated that the original HSPF ungaged flow estimates were too high, as the adjusted ungaged flow values improved model performance. As a result, the adjusted ungaged flow values described above were used for the final calibration of both the UF and District models. However, as described in Chapter 5, application of the District estuarine model to different gaged inflow scenarios for the years 1999-2002 used ungaged flow values computed directly by the SDI method.

Chapter 3

Physical Characteristics of the Lower Myakka River Estuary

3.1. Physiography

The Lower Myakka River extends approximately 52 kilometers (32 miles) from the sill at the downstream end of Lower Myakka Lake to the mouth of the river at Cattle Dock Point (Figure 3-1). The lower river flows southwesterly along a controlling fracture to Rocky Ford near river kilometer (RK) 41, where it intercepts another fracture and runs southeasterly near the western boundary of its catchment area to Charlotte Harbor (Evans et al., 1989). Three geomorphic reaches of the Lower Myakka River were created by drowning of the river floodplain by sea level rise:

> (1) The river mouth features broad fringing mangroves at Hog Island and Tippecanoe Bay, but the river is otherwise a wide, shallow embayment with upland banks shaped by relict meanders. Deep water extends 1-2 kilometers (km) from Charlotte Harbor to near Tippecanoe Bay. The bottom shallows and then deepens to a 2-3 km scour feature near El Jobean. Sediments associated with former wetland islands in this reach have been eroded, distributed, and mineralized by sea level rise. Upstream of El Jobean the bottom is comprised of level, medium to fine sands with variable organic content, with shoals occurring near the top of the embayment.
>
> (2) Beginning near RK 12 (Sarasota-Charlotte county line), mangrove and salt marsh islands dissect the stream into a mixture of parallel and braided channels. Fringing wetlands are common on most river banks and salt marsh extends farther upriver than mangroves. For the next 10 km the river narrows with upstream distance, widening downstream of three principal tributaries (Big Slough/Myakkahatchee Creek; Warm Mineral Springs, and Deer Prairie Creek). A natural but shallow thalweg runs across otherwise shoal bottoms and eventually ends at a sand glide upstream of Deer Prairie Creek.
>
> (3) Upstream of RK 22 the stream runs to Rocky Ford as a single, highly-meandered channel. The upstream half of this reach is a deep (2-3 m) incised stream with outcrops of rock and indurated shell on its banks and bottom. The downstream half is a slowly widening reach flanked by perfect and imperfect levees and increasing amounts of bottomlands. Small marshes occur at creek mouths and on point bars. Below RK 25 pocket marshes with high plant diversity increase in number and size downstream. The reach shallows with downstream distance; sediments are mostly poorly-sorted and low in organic content.

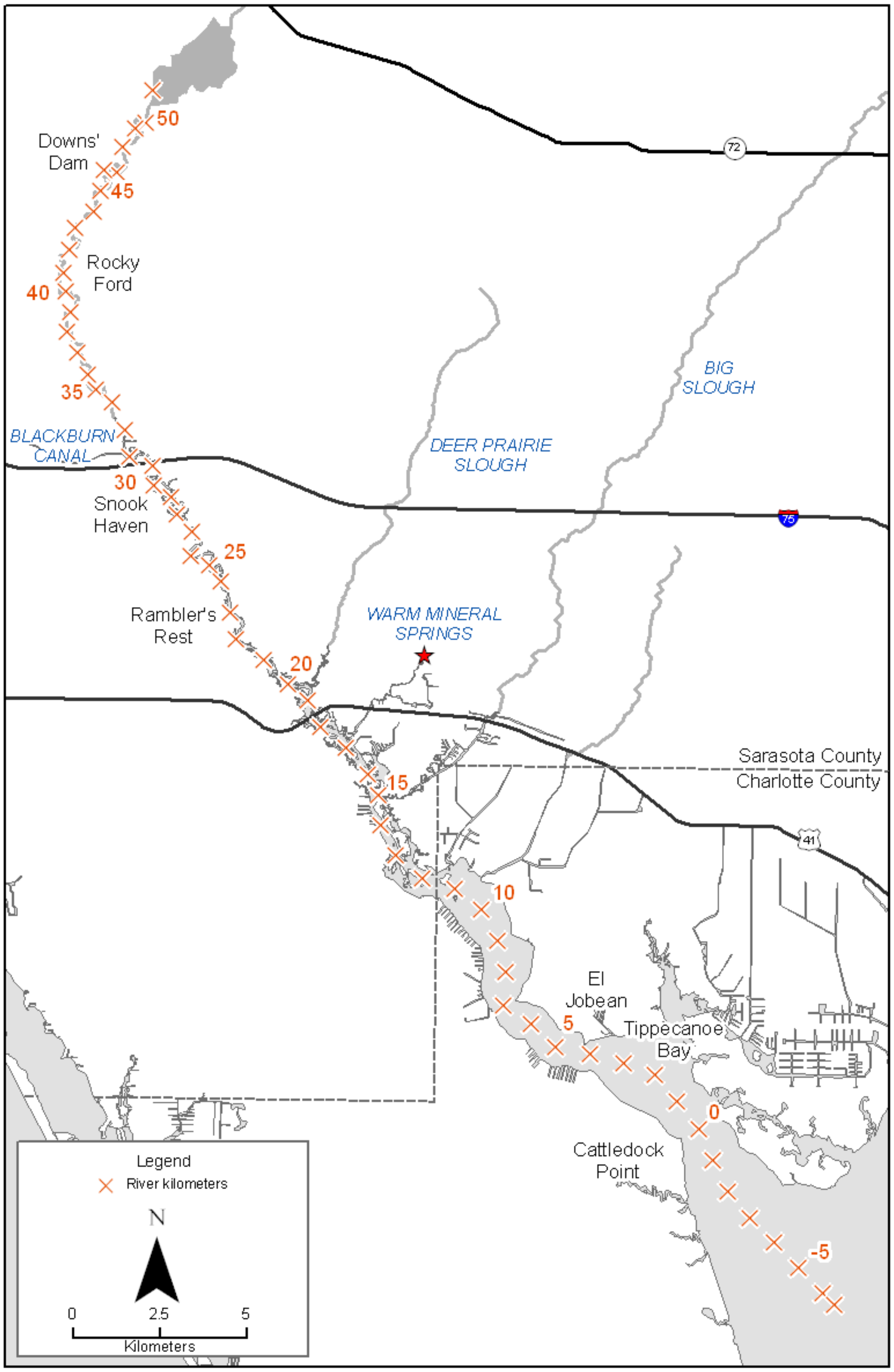


Figure 3-1. Map of the lower Myakka River showing the river-kilometer (RK) system used in this report. The mouth of the river (RK 0.0) is taken as Cattle Dock Point near Charlotte Harbor.

3.2 Tides

The waters of nearly all of the Lower Myakka River are affected by astronomical tides. Tidal effects extend upriver and include the presence and concentration of salt, tidal reversals of current, and water level (stage) variations. Effects vary as a function of river discharge, but under most flow conditions current reversals extend farther upstream than salt, and stage variations extend farther upstream than current reversals. Under low flow conditions, tidal stage variations extend upstream to near Rocky Ford (RK 41.6) with backwater effects extending to Downs' Dam (RK 46). Sea level intercepts the bed of the Myakka River at Rocky Ford (Bie 1916, US Geological Survey 1973).

Tides at the river mouth are mixed (diurnal and semidiurnal components) with a diurnal range of 58 cm relative to mean lower low water (International Marine, 2006; http://tidesandcurrents.noaa.gov). At El Jobean (NOAA/NOS Station ID 8725769; RK 4.0) mean sea level and mean tide level occur at 33 cm relative to mean lower low water, or 16 cm below the North American Vertical Datum of 1988. According to Hammett (1992), there is about a 150 minute lag between high tide at El Jobean and high tide at Snook Haven (RK 26.5), with high tides farther upstream occurring at about the same time as tides at Snook Haven. On the other hand, there is about a 180 minute lag in low tide from El Jobean to Snook Haven, and then about a 60 minute lag from Snook Haven to near Laurel (RK 41). Hammett (1992) estimated the tide range at Snook Haven to be approximately 75% of the tide range at El Jobean. Recent tidal data measured during the course of the minimum flows investigation are discussed in Chapter 4.

3.3 Geometry of the Lower River

The in-bank river channel is only a few meters wide in its uppermost reaches, and is more than 3 km wide in its lowest reach where the northeast bank falls away into Tippecanoe Bay. The total surface area of the lower river is approximately 2,200 hectares at mean tide. Overall river area is greatest from RK 0 to RK 14, upstream of which river area decreases significantly (Figure 3-2). The river area at two meters depth is much less than at the surface, due to the shallow nature of the lower river. The area of bottom at depths $\geq$ 2 m is greatest near the river mouth and decreases upstream to RK 10. The bottom area at depths > 2 m is relatively small (Figure 3-3).

River depths were extracted from bathymetric files provided to the District by the Department of Geology, University of South Florida (Wang, 2004). Relative to chart depth (mean lower low water), the tidal river has an average depth of about 1.5 m (Figure 3-4). Although not visible in the depth chart of Figure 3-4, the river between RK 23 and RK 33 is actually deeper on average than the river mouth area, because the lower river has broad shallow areas whereas the upper river is an incised channel.

Figure 3-5 depicts average and maximum depths by river kilometer and illustrates the deep reach between RK 23 and RK 33. Another deep area occurs at the confluence of Big Slough – Myakkahatchee Creek with the river, although this deep spot may be an artifact of dredging when the tributary was channelized. Maximum depths average about 3 m for the entire river, with maximum depths greater than 4 m occurring between Cattle Dock Point and El Jobean, near the mouth of Big Slough, and in the Big Bend area (RK 35 – 37).

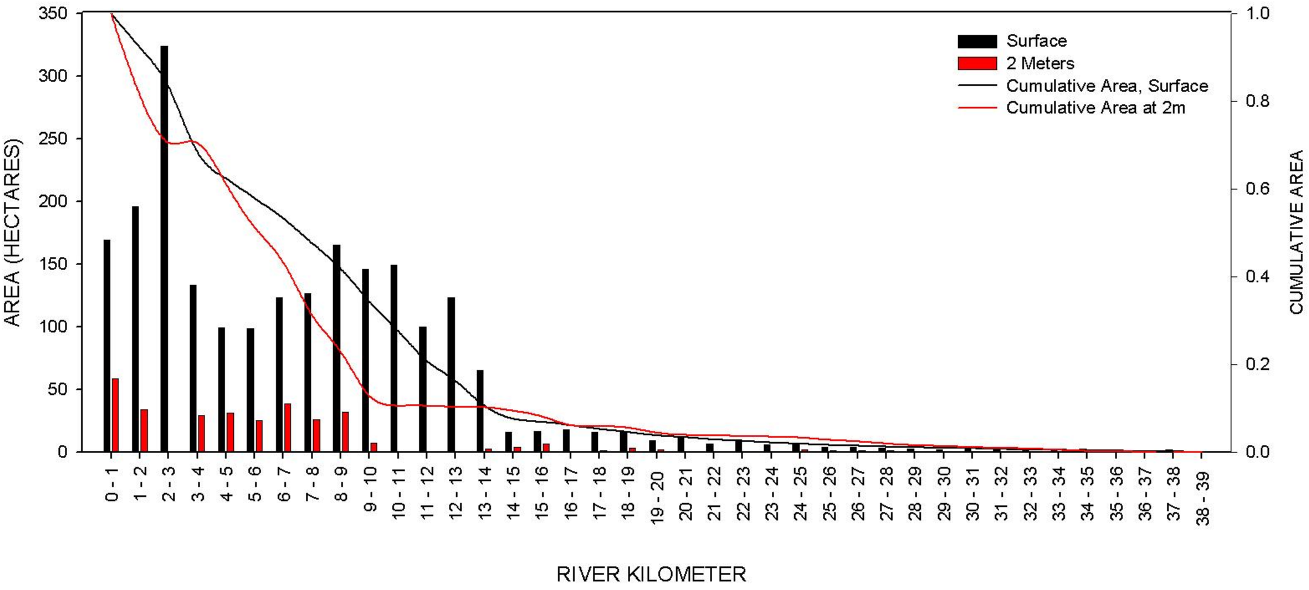


Figure 3-2. Graph of river area (hectares) by one-kilometer intervals and by cumulative area for the river surface (black symbols) and for the river bottom at a depth of two meters (red symbols). Depths are in meters relative to the National Geodetic Vertical Datum (NGVD 1929).

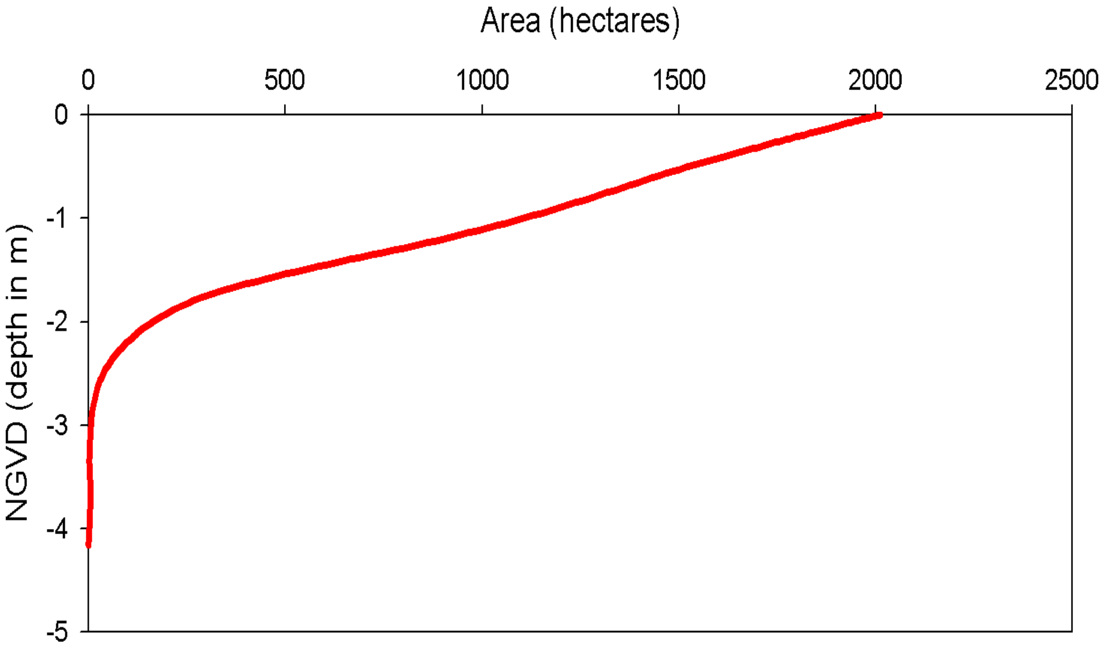


Figure 3-3. Hypsograph depicting the area of river bottom as a function of river depth in meters relative to NGVD.

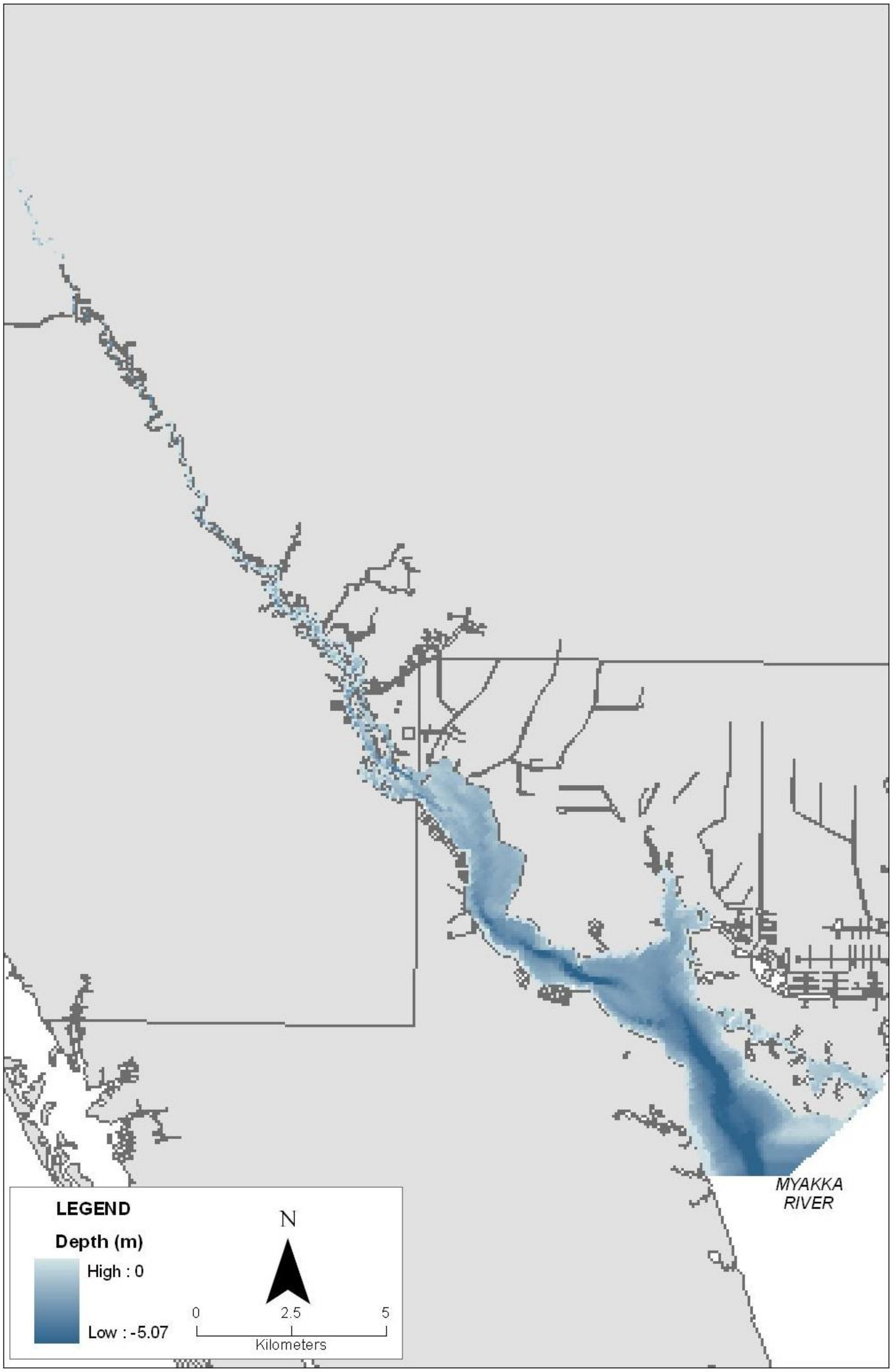


Figure 3-4. Map of the lower Myakka River depicting shallow (light blue) and deep (dark blue) bottom areas relative to NGVD. Adapted from Wang (2004).

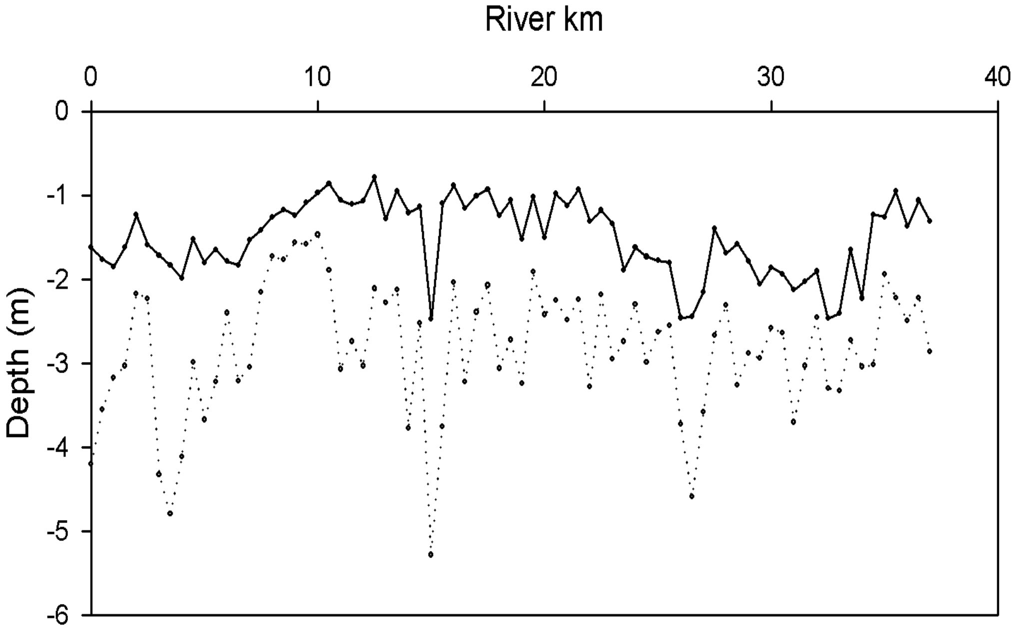


Figure 3-5. Mean depth (solid line) and maximum depth (broken line) of the lower river at half-kilometer intervals. Depths are in meters relative to NGVD.

An important shoal reach of the lower river occurs between Deer Prairie Creek and Rambler's Rest, particularly in the RK 20-22 area. There, shallow water runs from bank to bank and the entire channel may be only a few decimeters deep during winter low tides.

River widths and depths combine to create an overall river volume of approximately 28 million cubic meters in the first 14 river kilometers, with comparatively small additional volume added with upstream distance beyond RK 14 (Figure 3-6). Based on the frequency distribution of volume relative to depth (Figure 3-7), the tidal prism represents approximately half of the lower river's average volume.

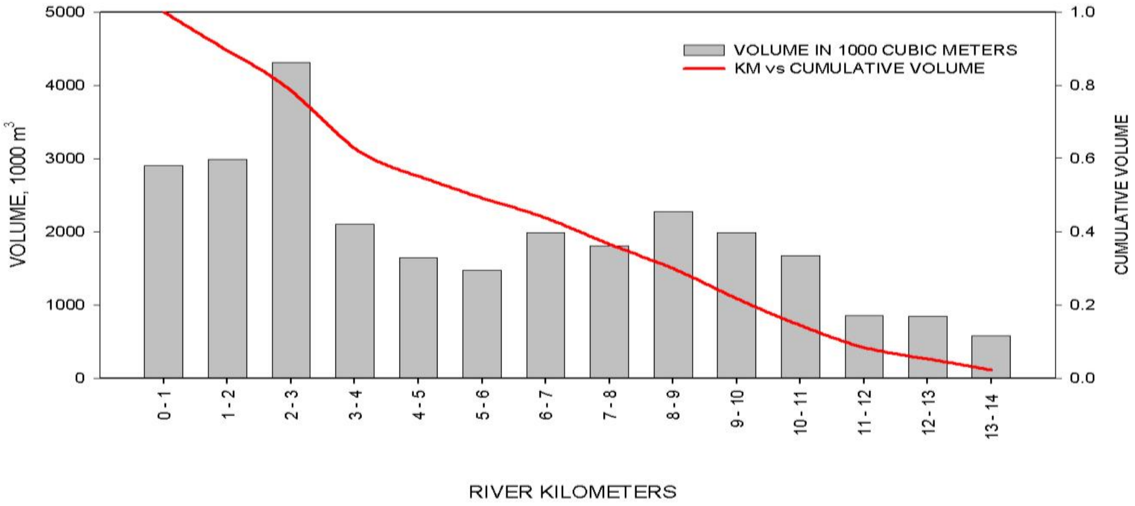


Figure 3-6. Graph of river volume (1000 cubic meters) by one-kilometer intervals and by cumulative volume for the first 14 river kilometers. River volume upstream of RK 14.0 approaches zero at 10^3 m^3 scale.

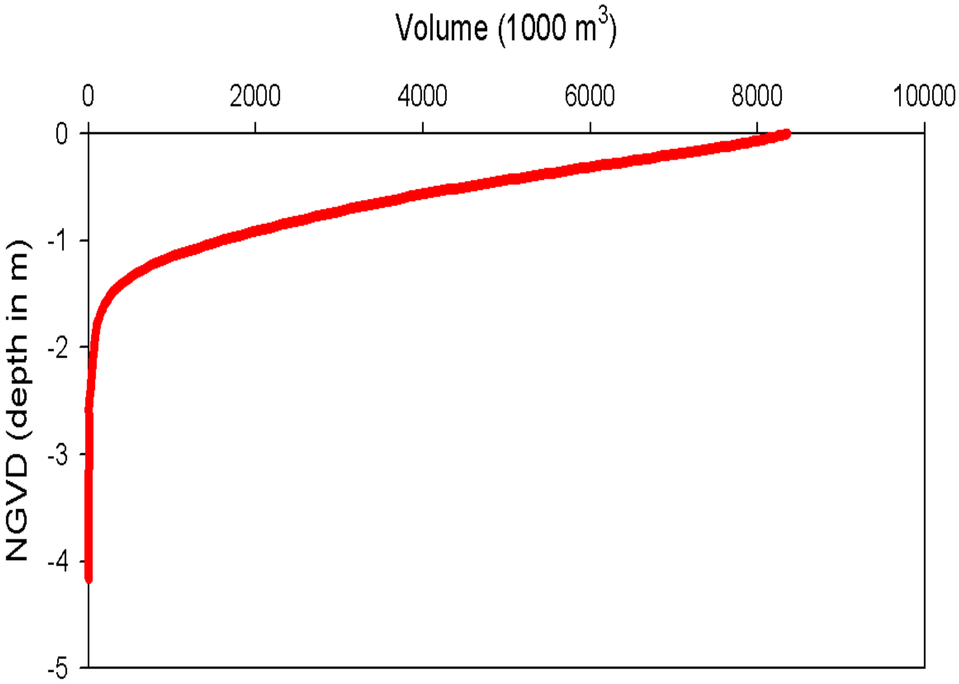


Figure 3-7. Hypsograph depicting river volume as a function of river depth in meters relative to NGVD.

3.4 Shorelines and Wetlands

Shorelines can be described in terms of the wetted lengths of natural and altered land covers and land uses in the lower river. Estevez et al. (1990) inventoried shorelines of the tidal river in Sarasota and Charlotte Counties, using shoreline lengths to classify the condition of the river banks in Sarasota County. Because of the extensive edges associated with marshes, islands and tributaries, they found that there was approximately 13 km of shoreline per kilometer of river within the tidal reach. Hardened shores comprised 12.4% of the total. By length, exotic species were present along more than one-third of tidal river shorelines, with Brazilian pepper (*Schinus terebinthifolius*) constituting 93% of the exotic cover, by species.

Shoreline features of the lower river are mapped in Figure 3-8. More detail is given in Figure 3-9 and Figure 3-10. For natural land covers, there is a distinct zonation of wetland community shorelines in the lower river (Figure 3-9), with mangroves dominant in the downstream-most third of the river; "saltwater marshes" occupying the middle third, and freshwater marshes and forests dominating the upstream-most third of the river. The species composition and distribution of wetland communties along the lower river are discussed in further detail in Chapter 5.

Superimposed over the pattern of natural communities and shorelines of the lower river are patterns of shoreline alteration. Urbanization of shorelines is the dominant form of alteration (Figure 3-10) and it is noteworthy that on a shoreline length basis, significant amounts of shoreline in Sarasota County as well as Charlotte County have been urbanized. On balance, much of the urbanization of upriver shoreline has occurred with the development of upland areas along the river, rather than wetlands.

3.5 Sediments

The Myakka is a blackwater river and as such transports suspended inorganic sediments only during periods of extremely high flow. Bed transport occurs at moderate to high flow (Grace, 1977). River sediments are primarily poorly-sorted, fine-grained quartz sands derived from the reworking of terrestrial soils of the floodplain being drowned by sea-level rise.

Details of river sediments are provided in Chapter 6, although it is interesting to note that silts and clays are low (<5%) in sediments of the upper 22 km of the river, but below RK 21 the silt-clay content of bottom sediments increases several-fold (Figure 3-11). As explained in Chapter 6, the RK 21-22 reach represents a narrowing of the channel and also a transition from down-river salt marshes dominated by *Juncus roemerianus* to up-river marshes characterized by tidal-freshwater and oligohaline plant species.

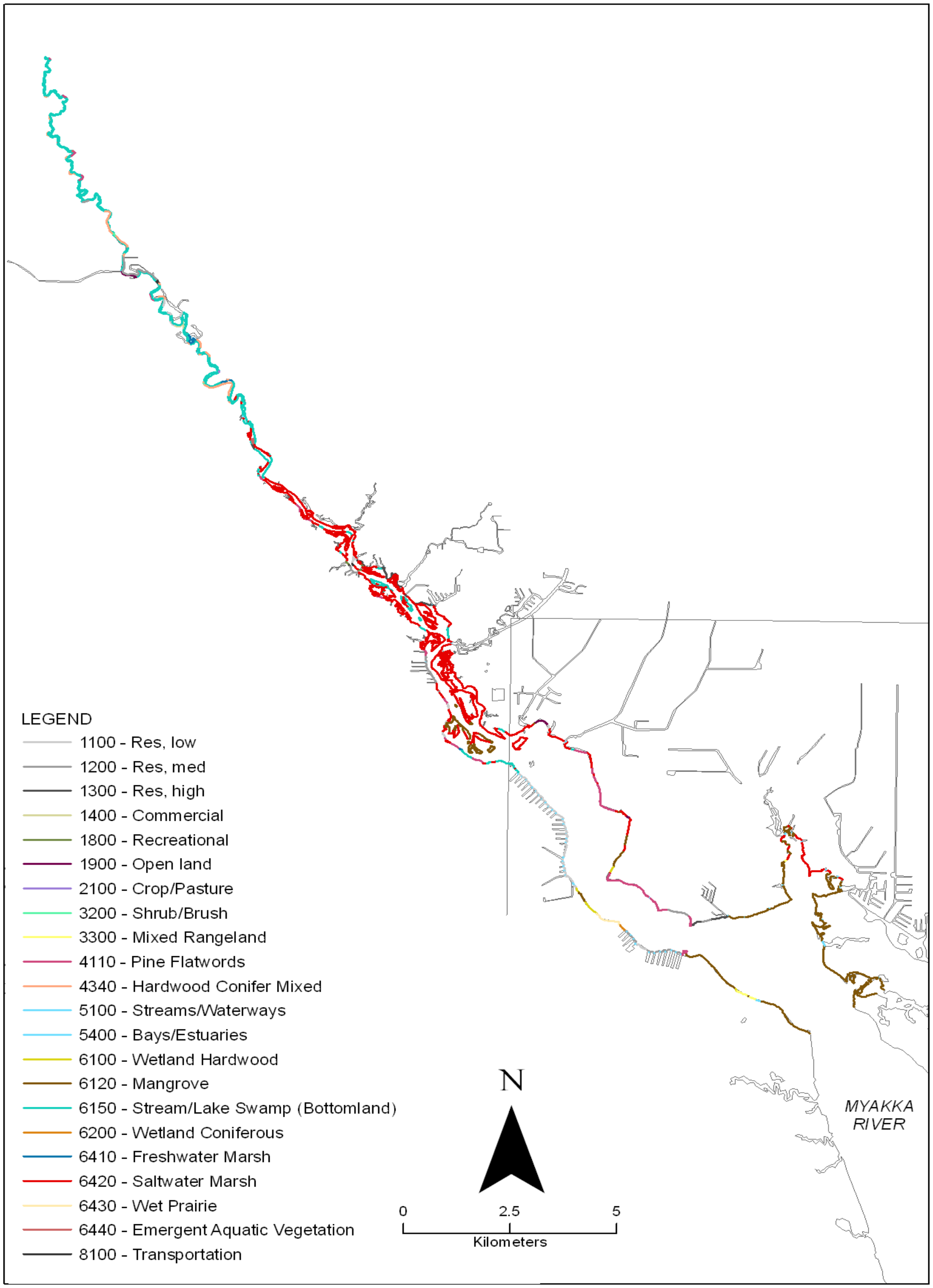


Figure 3-8. Map depicting major land cover and land use types of shoreline on the lower Myakka River.

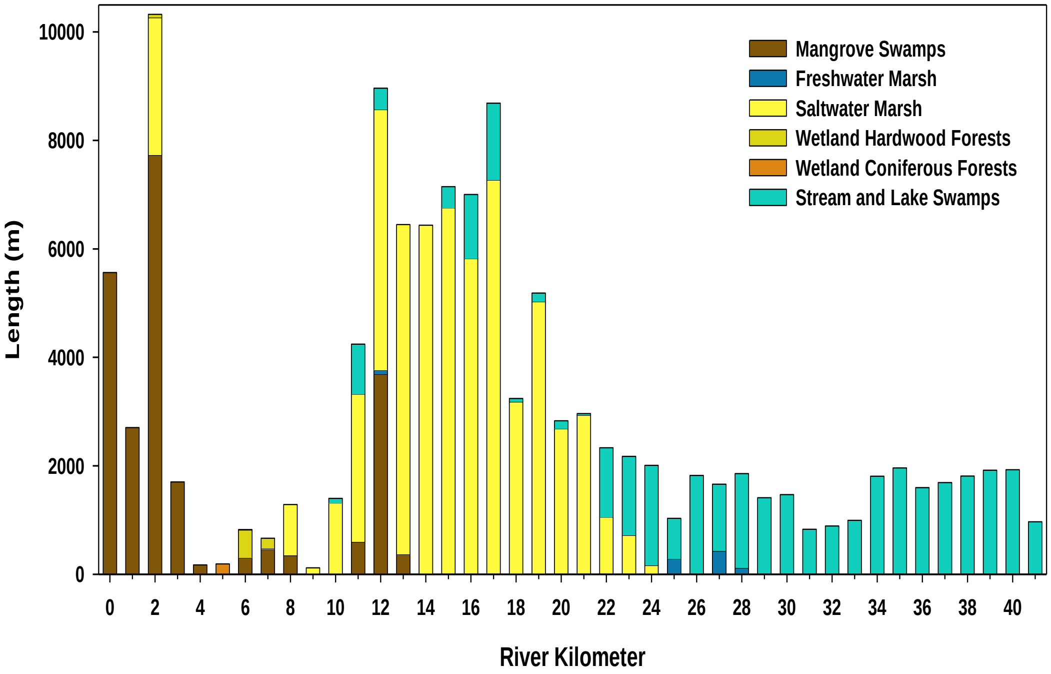


Figure 3-9. Length of shoreline by river kilometer that has been classified as wetlands (600) with sub-classifications delineated.

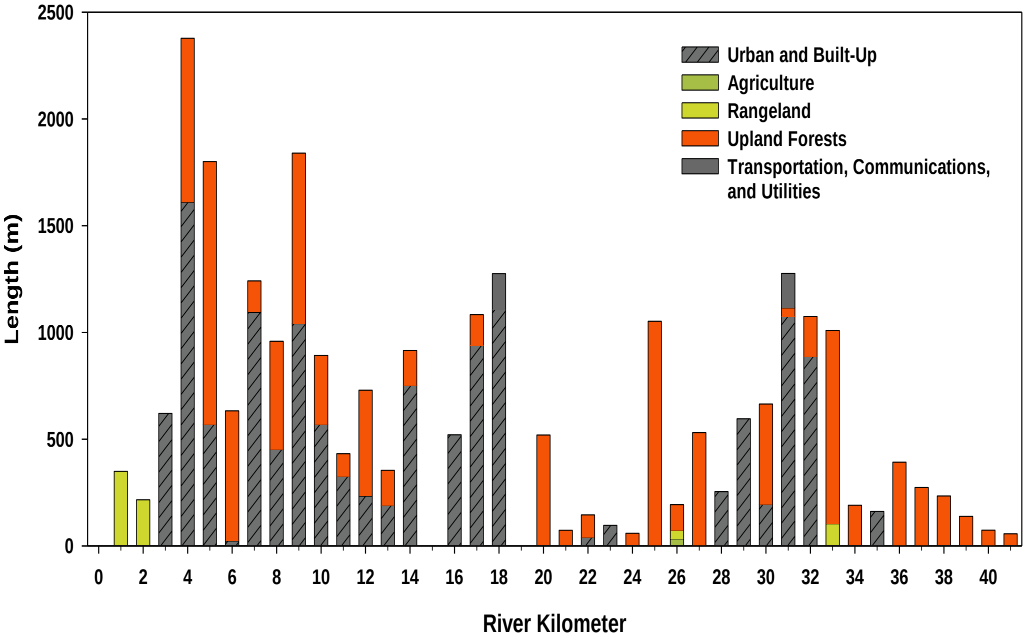


Figure 3-10. Length of non-wetland shoreline types by river kilometer.

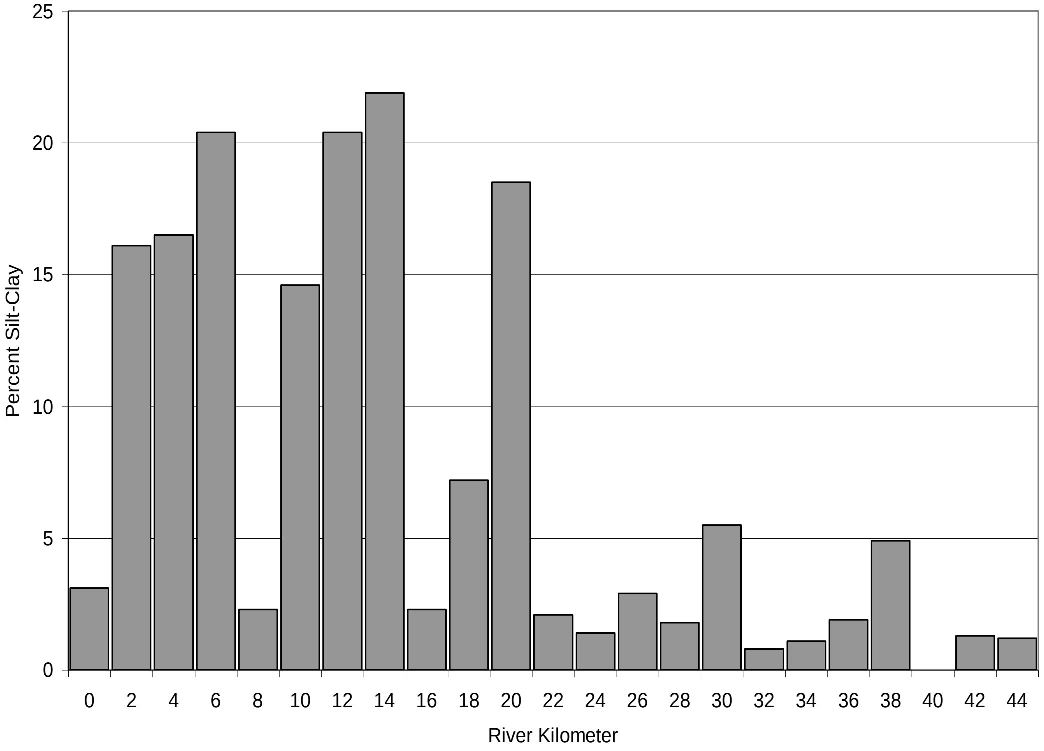


Figure 3-11. Percent silt-clay in sediment samples from the Myakka River. June, 2004.

Chapter 4

Salinity, Empirical Model Development, and Water Quality

4.1 Introduction

The salinity and water quality characteristics of the Lower Myakka River and their relationships with freshwater inflow are described in the following chapter, with salinity discussed first below. In addition to summarizing actual salinity observations, selected isohalines were also computed (through linear interpolation) and their behavior and general distribution described. Where salinity or isohaline positions were described as a function of flow, all available data were generally incorporated. Where salinity gradients were described, data were generally limited to 1995 to present, the period in which the entire length of the study area was routinely sampled. Ultimate modeling efforts generally ranged from 1980 to present, the period when data were available for all major flows to the river. The various descriptions of salinity, therefore, refer to specific time periods which should be referenced to the climatological influences in effect at the time and the timing of the various anthropogenic hydrologic alterations.

The quantitative analysis of salinity in the Myakka River centered on developing regression models which would reproduce the flow-related behaviors of selected isohalines and which would reproduce salinity at selected representative stations along the river. Input data were limited to flows below the 99th percentile and to data collected above river kilometer 0.0 to optimize regression utility for low flow, upriver conditions. The regressions were then employed under a variety of flow alterations to predict changes in salinity and isohaline position.

In addition to flows of the Myakka River, weather, tide, and flow variables from the Peace River and from Myakkahatchee Creek were also included as potential independent variables in regression analyses. When significant, the inclusion of weather and tide variables provided a more constrained estimate of flow dependence. Modeling of the various flow scenarios, however, used mean weather and tide conditions to extend the time period which could be modeled, and so that differences due to flow alterations could be more directly observed.

4.2 Methods

4.2.1 Data Sources

Data sources included in the following analyses of salinity and water quality appear in Appendix 4-A. Data were obtained from the listed sources with an original retrieval area between 26.870º and 27.250º N and 82.128º and 82.375º W, or between Upper Lake Myakka and extending into Charlotte Harbor. The resulting data ranged from river kilometer -9.0 to 45.6. If unspecified, nutrient parameters were assumed to be the total rather than dissolved and time references were assumed to be local time (EST or EDT). Reasonable assumptions regarding sampling depth were used where appropriate.

The stations were plotted to assign a river kilometer and distance from centerline using the river centerline supplied by the District (revised 5/20/2005). Stations in waterbodies off of the main stem of the Myakka River (Tippecanoe Bay, Blackburn Canal, Myakkahatchee Creek, etc.) were excluded. FWCC-FWRI Fisheries Independent Monitoring (FIM) data were generally 1-2 m shallower than other sampling programs at equivalent river kilometers, and so bottom data from this program were also excluded.

Data were also retrieved from continuous recorders operated by the U.S. Geological Survey (Figure 4-1). Stations were designated as 02298955 Myakka River at Snook Haven (27.1000° N, 82.3336° W, 28.3 km), 02299230 Myakka River at North Port Charlotte (27.0447° N, 82.2933° W, at U.S. 41, 18.5 km), and 02299496 Myakka River at El Jobean (26.9578° N, 82.2128° W, 4.2 km). These data were available as daily values and as 15 minute data. The more recent data began in January 2003, March 2003, and August 2002, for Snook Haven, North Port Charlotte, and El Jobean, respectively, with some older data available from 1983-1985. In addition to stage data, the recent installations included fixed sensors for near surface and near bottom temperature and salinity.

4.2.2 Isohalines

Isohalines of interest were selected by the District based on biological significance determined in other literature and included 2, 4, 8, 12, 16, and 28 psu. In addition, 1, 20, and 24 psu were also examined as the amount of data for 28 psu was minimal within the study area and did not permit significant analysis.

Isohaline positions, distance from centerline, and estimated times were calculated as linear interpolations between adjacent pairs of salinity data. When a very shallow station (<1.0 m) had a single mid-depth reading, these data were included in both the surface and bottom categories. For isohaline regression modeling, input data were limited to positions calculated from successive stations separated by no more than 6 km and 7 psu as a compromise between the uncertainty of computed isohaline positions and number of retained data. Data were also limited to isohaline positions upstream of river kilometer 0.0 to emphasize lower flow conditions. To reduce serial correlation, a single value per month was selected for modeling while remaining data were retained for regression verification.

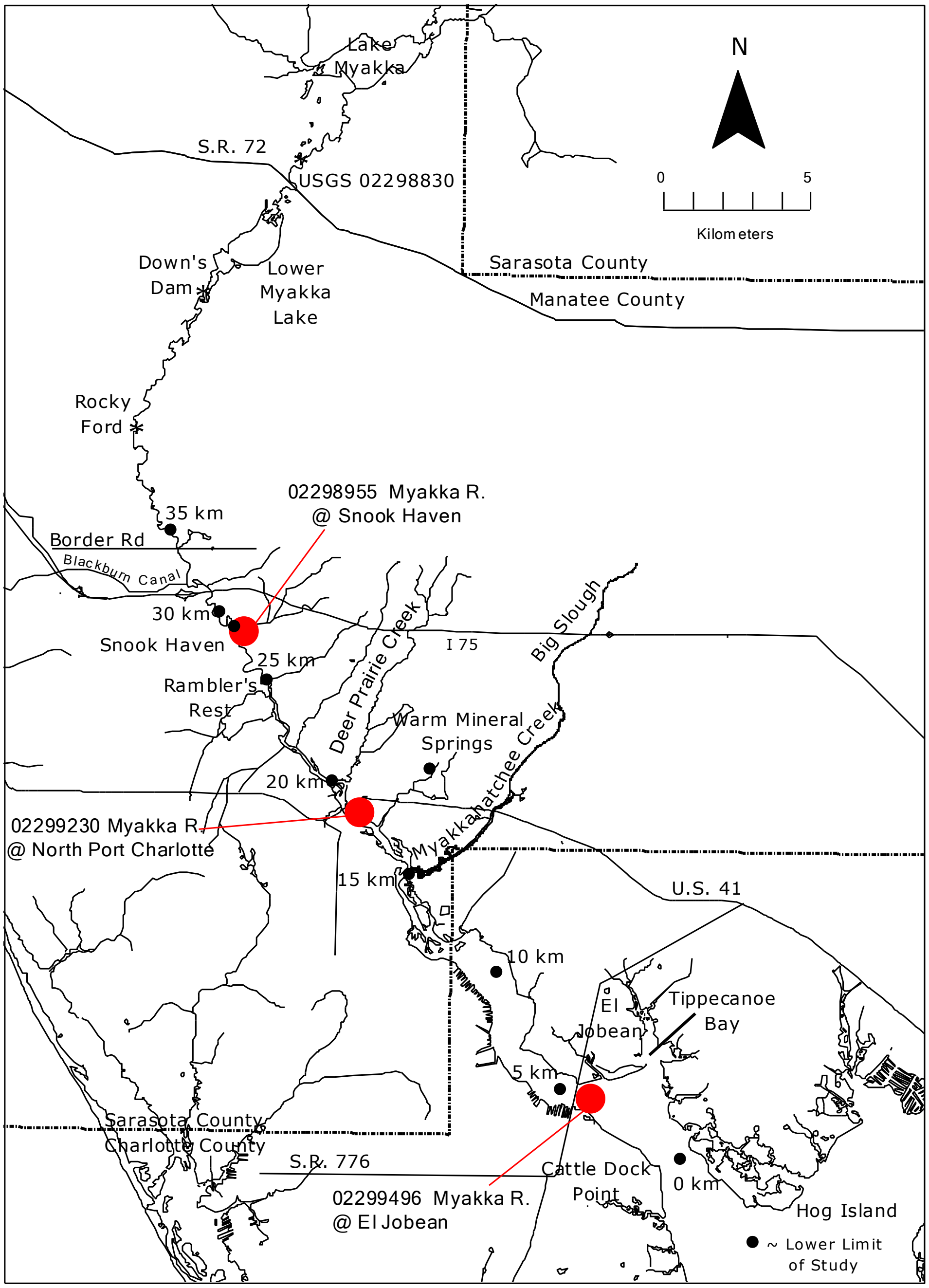


Figure 4.1 Selected continuous recorders operated by the U.S. Geological Survey within the Myakka River study area.

4.2.3 Fixed Stations

Frequencies of observations per kilometer were examined and the 1 km intervals with the most observations (Figure 4-2) were identified. Five intervals were selected (Figure 4-3, Table 4-1) for regression modeling. A single value per month was again identified to reduce serial correlation.

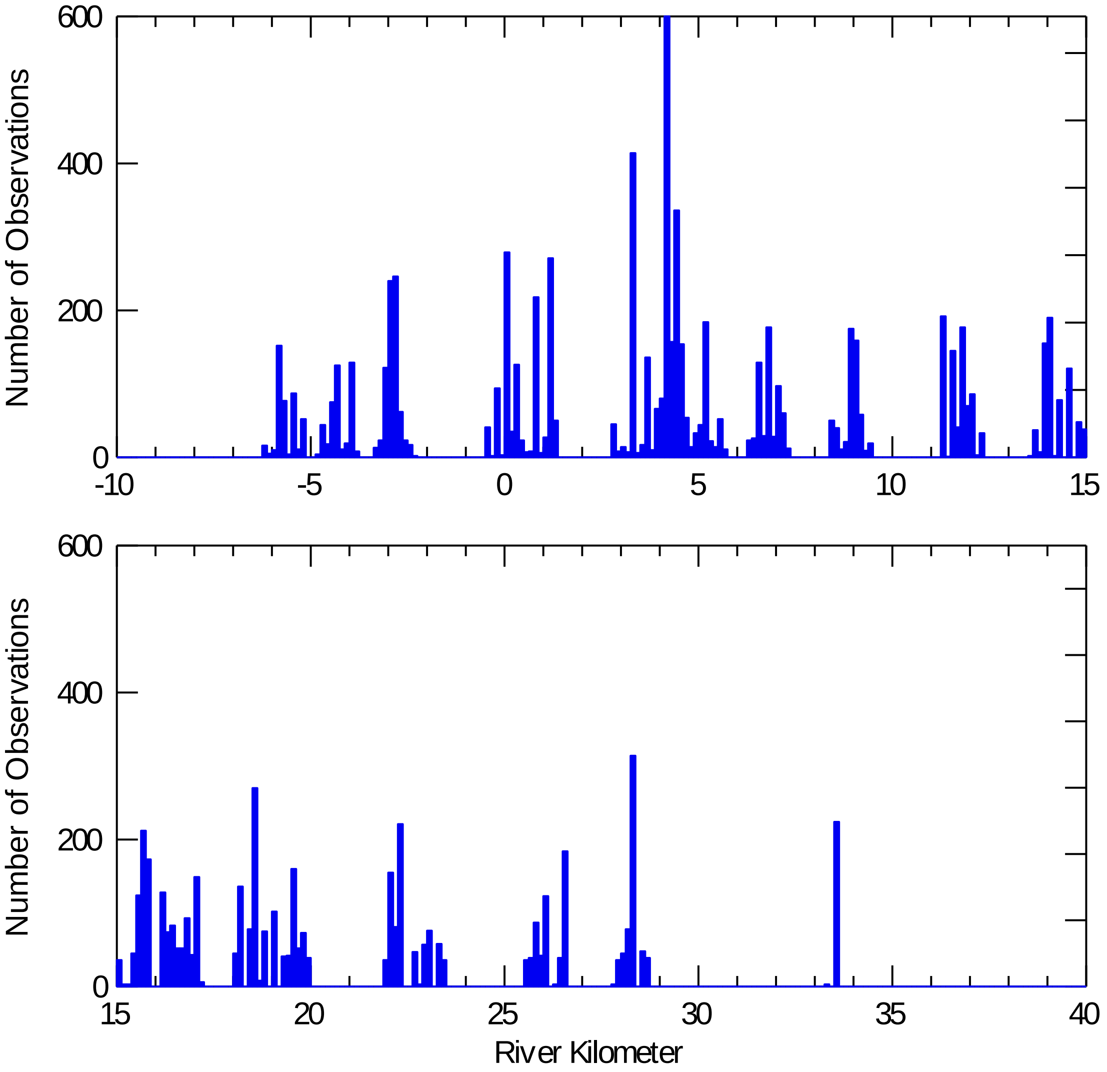


Figure 4-2. The one kilometer river intervals with the highest number of salinity observations, 1962 to 2005, all depths pooled.

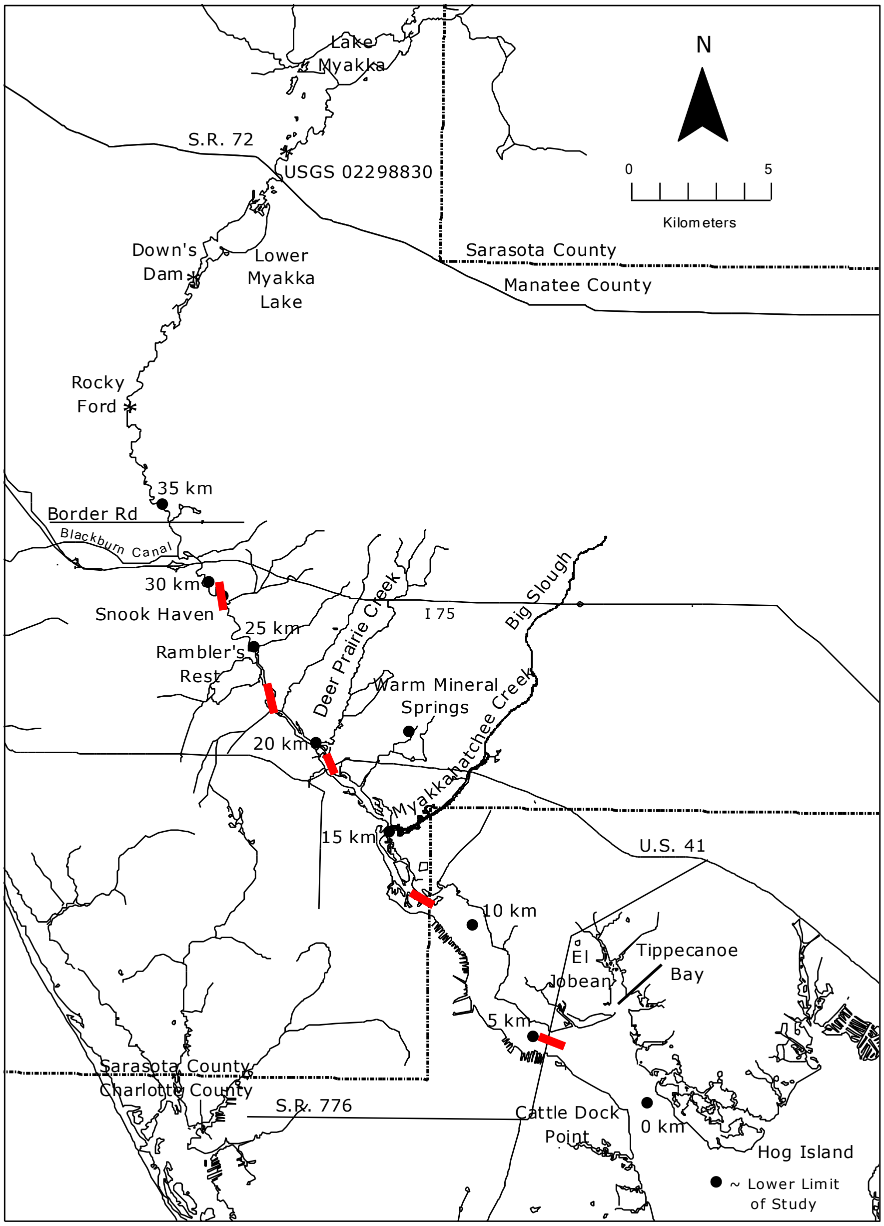


Figure 4-3. One kilometer river segments of high data density (red bars) to be used for fixed station salinity regressions.

Table 4-1. Location, approximate place name, designation, and number of salinity observations at stations selected for fixed station salinity regression modeling.

Km	Location	Km / Designation	n=
3.7 - 4.7	El Jobean	4 - EJ	1546
11.3 - 12.3	Sarasota-Charlotte County Line	12 - CL	620
18.0 - 19.0	U.S. 41	18 - 41	450
21.8 - 22.8	Rambler's Rest	22 - RR	354
27.8 - 28.8	Snook Haven	28 - SH	475

4.2.4 Regression Analyses

The goal of regression analyses was to develop a model which would calculate daily salinity or isohaline locations using altered flow scenarios. Modeling over an extended time period was desired in order to capture a wide variety of flows and flow combinations. However, not all significant variables would be available over the period of the initiating data, therefore tidal variables were simulated from harmonics derived from continuous records collected over a few years. Weather data which might affect salinity and stage were available for a substantial period of time, but not for the entire period for which modeling was desired. As a result, specific data were used for regression development, while model runs to evaluate differing flow scenarios used mean weather conditions over the entire modeled period. Details of regression analyses, listing of input variables, and flow weighting calculations appear in Appendix 4-B in detail.

Weather and Tides

Independent variables included weather influences (barometric pressure, wind direction and wind stress parameters recorded as hourly data at Venice, approximately 10 km to the east of the Myakka River; Table 4-2). Tidal influences were investigated using predicted tides based on harmonics extracted from the U.S. Geological Survey's continuous gauge at El Jobean during a low flow period (May-June, 1985) and accumulated over periods from hours to an entire day (Table 4-3). Correspondence between observed and the resulting predicted timing and tidal elevation was excellent, with an average RMS error ranging from 0.15 (Figure 4-4) to 0.34 feet during selected low flow periods.

Table 4-2. Weather variables investigated during regression analyses.

BAR	Barometric pressure, millibars or hectopascals
BAR3	Mean barometric pressure of last 3 hours
BAR6	Mean barometric pressure of last 6 hours
COS_WD	Cosine of wind direction, (see text for transformation)
COS_WD3	Mean cosine transformed wind direction of last 3 hours
COS_WD6	Mean cosine transformed wind direction of last 6 hours
COS_WDS2	Wind stress = transformed wind direction *(wind speed in m/sec)^2
COS_WDS23	Mean wind stress of last 3 hours
COS_WDS26	Mean wind stress of last 6 hours

Table 4-3. Predicted tidal variables at El Jobean investigated during regression analyses. Heights are in meters.

<u>Time specific variables</u>

PRED_M_SEA	Predicted stage in m, with seasonal sea level added back in, based on 1985 harmonics
DELTA_M	Change in stage per hour, over last hour
TIDE_M1	Stage 1 hour earlier
TIDE_M2	Stage 2 hours earlier
TIDE_M3	Stage 3 hours earlier
TIDE_P1	Stage 1 hour later
TIDE_3M	Mean stage of last 3 hours
RATE_3M	Mean rate of change (DELTA_M) of last 3 hours
MAXRATE_3	Maximum rate of change of last 3 hours
MAXTIDE_3	Maximum stage of last 3 hours
MINTIDE_3	Minimum stage of last 3 hours
TIDE_6M	Mean stage of last 6 hours
RATE_6M	Mean rate of change of last 6 hours
MAXRATE_6	Maximum rate of change of last 6 hours
MAXTIDE_6	Maximum stage of last 6 hours
MINTIDE_6	Minimum stage of last 6 hours

<u>Day specific variables</u>

MIN_TIDE	Minimum stage of the day
MAX_TIDE	Maximum stage of the day
RANGE_TIDE	Range of stage for the day
TIDE_MEAND	Mean tide for the day
TIDE_MEANL	Mean tide during typical sampling hours (1000-1600 hours UTC inclusive)
MIN_RATE	Minimum rate of change for the day
MAX_RATE	Maximum rate of change for the day
RANGE_RATE	Range of rate of change for the day
RATE_MEAND	Mean rate of change for the day
RATE_MEANL	Mean rate of change for typical sampling hours (1000-1600 hours UTC, inclusive)

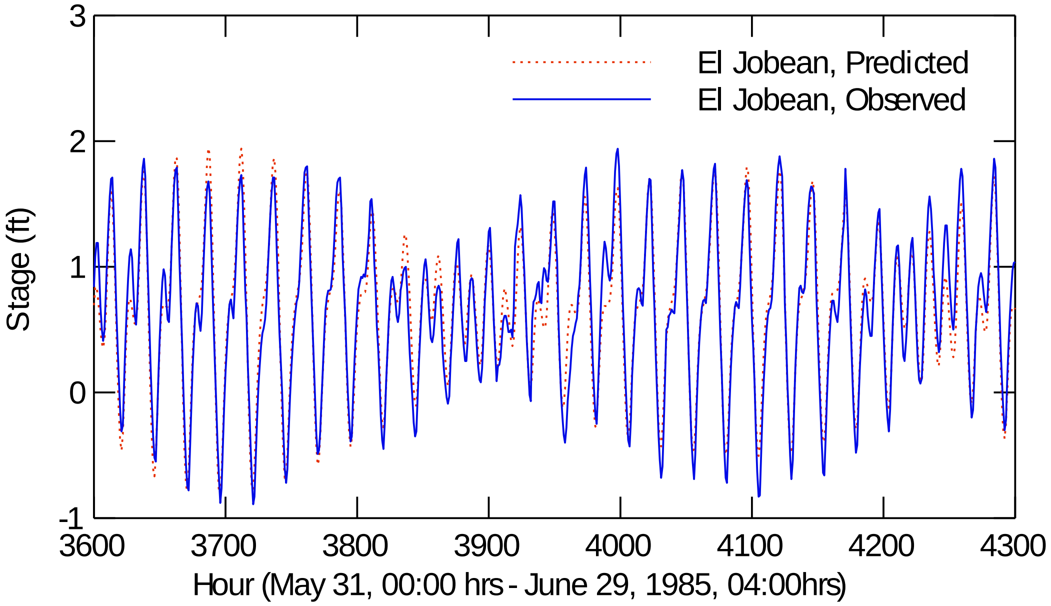


Figure 4-4. Correspondence of observed and modeled tide heights at El Jobean during the period of the initiating data.

Flows

The reference flow station used for evaluating salinity in the Myakka River was the U.S. Geological Survey station 02298830, "Myakka River near Sarasota, FL" (27.2403 º N, 82.3139 º W) with a drainage area of 593 km^2 (229 mi^2), located between the Upper and Lower Lake Myakka. The period of record available extended from September 1, 1936 through December 31, 2005 for this project. References to flows in the Myakka River refer to this site exclusively unless specified otherwise.

Myakkahatchee Creek flows were developed from a variety of sources (Appendix 4-B) to provide a record from October 1, 1980 through December 31, 2004. As an indicator of end member conditions affecting the lower Myakka River (i.e. salinity in Charlotte Harbor), flows from the Peace River at Arcadia (U.S. Geological Survey station 02296750, 27.2219 º N 82.8761 º W) were also examined as a potential independent variable. The site captures approximately 3,541 km^2 (1,367 mi^2) or roughly 60% of the total gauged flow of the Peace River watershed with average flows slightly over three times that of the Myakka River. Myakka River, Peace River, and Myakkahatchee Creek flows were all subjected to a variety of flow weighting techniques to generate potential independent variables (Table 4-4) during regression development. The details of computations appear in Appendix 4-B.

Regression Development

Models of both isohaline position and of salinity at fixed station locations were developed as forward interactive regressions, using $p<0.05$ as criteria for inclusion and maintenance in the model and including a constant term. Once a flow term from a river or creek was included, no other flow term from the same river was used. Weather and tide variables were generally included subsequent to flow terms and were also limited to one parameter for each category. The sign of the individual regression coefficients and constancy of sign with the inclusion of additional variables were examined to prevent spurious correlations. Due to the inclusion of wind and tide terms, the constant term is not necessarily synonymous with isohaline position at zero flow.

All regression models were subjected to both residuals analysis and verification with details of the techniques in Appendix 4-B. Verification consisted of applying the previously derived regression equations to data not used in the development of the regressions. The 95% confidence interval of estimated values as a function of observed values was computed for both the initiating and non-initiating data. The overlap of the two confidence intervals indicated robustness of regression coefficients.

Table 4-4. Flow variables considered as independent variables in regression analyses.

FLOW	Daily flow, Myakka River.
DAYS	Days required to fill river volume between 50.0 and isohaline km at the daily flow.
VWT45	Variable weighted flow over maximum of DAYS or 45 days
VWT30	Variable weighted flow over maximum of DAYS or 30 days
VWT15	Variable weighted flow over maximum of DAYS or 15 days
VEXWT	Variable exponentially weighted flow over maximum of DAYS or 45 days
EXWT3	Exponentially weighted flow over the prior 3 days
EXWT5	Exponentially weighted flow over the prior 5 days
EXWT7	Exponentially weighted flow over the prior 7 days
LNFLOW	Natural log transformation of (FLOW+10)
LNVWT45	Natural log transformation of (VWT45+10)
LNVWT30	Natural log transformation of (VWT30+10)
LNVWT15	Natural log transformation of (VWT15+10)
LNVEXWT	Natural log transformation of (VEXWT+10)
LNEXWT3	Natural log transformation of (EXWT3+10)
LNEXWT5	Natural log transformation of (EXWT5+10)
LNEXWT7	Natural log transformation of (EXWT7+10)
FLORATE3	Change in flow rate, method 1, 3 days prior
FLORATE3B	Change in flow rate, method 2, 3 days prior
FLORATE5	Change in flow rate, method 1, 5 days prior
FLORATE5B	Change in flow rate, method 2, 5 days prior
LAGDAYS	Daily flow, DAYS (see above) prior
LAG_5DAYS	Daily flow, DAYS/2 prior
LAG_25DAYS	Daily flow, DAYS/4 prior
LAG_1	Daily flow, Myakka River, 1 day prior
LAG_2	Daily flow, Myakka River, 2 days prior
LAG_3	Daily flow, Myakka River, 3 days prior
LAG_5	Daily flow, Myakka River, 5 days prior
LAG_7	Daily flow, Myakka River, 7 days prior
LAG_10	Daily flow, Myakka River, 10 days prior

PFLOW	Daily flow, Peace River at Arcadia
PVWT45	Variable weighted flow over maximum of DAYS or 45 days
PVWT30	Variable weighted flow over maximum of DAYS or 30 days
PVWT15	Variable weighted flow over maximum of DAYS or 15 days
PVEXWT	Variable exponentially weighted flow over a maximum of DAYS or 45 days
PEXWT3	Exponentially weighted flow over the prior 3 days
PEXWT5	Exponentially weighted flow over the prior 5 days
PEXWT7	Exponentially weighted flow over the prior 7 days
LNPFLOW	Natural log transformation of (PFLOW+10)
LNPVWT45	Natural log transformation of (PVWT45+10)
LNPVWT30	Natural log transformation of (PVWT30+10)
LNPVWT15	Natural log transformation of (PVWT15+10)
LNPVEXWT	Natural log transformation of (PVEXWT+10)
LNPEXWT3	Natural log transformation of (PEXWT3+10)
LNPEXWT5	Natural log transformation of (PEXWT5+10)
LNPEXWT7	Natural log transformation of (PEXWT7+10)
BSFLOW	Daily flow, Myakkahatchee Creek
BSDAYS	Number of days required to fill Creek and a portion of the river volume (see text).
BVWT45	Variable weighted flow over maximum of BSDAYS or 45 days
BVWT30	Variable weighted flow over maximum of BSDAYS or 30 days
BVWT15	Variable weighted flow over maximum of BSDAYS or 15 days
BVEXWT	Variable exponentially weighted flow over maximum of BSDAYS or 45 days
BEXWT3	Exponentially weighted flow over the prior 3 days
BEXWT5	Exponentially weighted flow over the prior 5 days
BEXWT7	Exponentially weighted flow over the prior 7 days
LNBSFLOW	Natural log transformation of (BSFLOW+10)
LNBVWT45	Natural log transformation of (BSVWT45+10)
LNBVWT30	Natural log transformation of (BSVWT30+10)
LNBVWT15	Natural log transformation of (BSVWT15+10)
LNBVEXWT	Natural log transformation of (BSVEXWT+10)
LNBEXWT3	Natural log transformation of (BSEXWT3+10)
LNBEXWT5	Natural log transformation of (BSEXWT5+10)
LNBEXWT7	Natural log transformation of (BSEXWT7+10)

Regression Modeling

Weather data were not available for the entire period for which flow data existed or which simulations were desired. In order to calculate isohaline positions over an extended period, the weather variables were set to constant values (the mean conditions observed in the initiating data) for all simulations. The approach provided weather-neutral simulations of isohalines and allowed for comparisons between the positions of different isohalines whose raw observations may have been collected on different days and under different weather conditions.

A similar approach was followed for the predicted tidal variables, replacing any significant tidal terms with fixed values. Inclusion of weather and tide variables in the original regressions almost always enhanced regression significance, resulting in greater confidence that all major variables affecting isohaline position or salinity had been represented. As weather and tides will not be management issues, however, fixing weather and tide variables allowed regression results between measured flows and altered flow scenarios to concentrate on salinity changes that may result from altered flows alone.

4.2.5 Inflow Scenarios

Regression results, together with mean weather conditions, were used to generate a daily record of isohaline positions and salinity at fixed stations. October 1, 1980 through December 31, 2004, was established as the modeled period for all simulations, and was limited by the duration of available Myakkahatchee Creek flow data. The simulation performed using the observed flows during this period was termed the 'baseline' simulation.

As discussed in Sections 2.4.2.2 and 2.4.2.3, increasing trends in streamflow at the Myakka River near Sarasota gage have been attributed to the effects of changes in land and water use in the upper Myakka River sub-basin, particularly a large increase in irrigated crops. Minimum flow studies on the upper Myakka River (SWFWMD 2005a) approximated this influence at 26 cfs and 22 cfs in the fall/winter and spring seasonal blocks, respectively, at the Myakka River near Sarasota gage. However, daily estimates for excess flows at the gage site that were predicted by a detailed MIKE SHE integrated model of the upper river sub-basin were available when the minimum flow analysis for the Lower Myakka River was conducted.

Model generated values for total excess flows and excess flows due to agriculture for the period May 15, 1994 to April 30, 2006 were provided to Mote Marine by the District, after adjusting these values as described in Sections 8.2.1 and 8.2.2. Agricultural and total excess flows applied during periods before modeled data were available were constructed as the 7-day moving average of the day-of-the-year median modeled values from May 15, 1994 to April 30, 2006, and ranged from 7 to 100 cfs. Though these estimated excess inflow values were used in the regression models to predict salinity in the river before May 15, 1994, the District only used results from 1995-2004 that included the adjusted excess flows from the MIKE SHE model to determine the minimum flows.

The adjusted excess flow values were subtracted from the gaged records at the Myakka River near Sarasota gage to evaluate the effect of removing the excess flows on the salinity characteristics of the estuary. Additional scenarios involved removing percentages of the remaining flows at the Myakka River near Sarasota gage. A more detailed discussion of the selection of the baseline period and the flow reduction scenarios that were used in the minimum flows analysis is presented in Sections 7.4 through 7.6.

The Myakka River has been subjected to other hydrologic alterations that would not be expected to be visible in the gage record at the Myakka River near Sarasota. These alterations are not presently included in the following evaluations. Flow decreases of approximately 20% likely occurred in the river below Rocky Ford due to the diversions of 152 sq. km of upper Cowpen Slough from the Myakka River to Dona Bay in 1916-1920 (the gage area of the Myakka River near Sarasota is 593 sq. km). As discussed in Section 2.4..1.1 (pages 2-24 through 2-27), the Blackburn Canal has diverted additional water from the river with the rate of diversion increasing with increased Myakka flow. It should be kept in mind that regressions were developed from data primarily collected when all three alterations were in effect (1995-2005), but only the increased excess flows were quantified and accounted for in the gage data used as the primary independent variable in the salinity regressions.

4.3 Tides

The entire study area downstream of river kilometer 28 was tidal (although not necessarily saline), with mixed, semi-diurnal tides (Figure 4-5). Using data from the three U.S. Geological Survey continuous recorders, median stage levels for 2004 were 0.77, 1.04, 1.06 feet (NGVD29) for El Jobean, North Port Charlotte (U.S. 41), and Snook Haven respectively. Median diurnal ranges of stage were 2.22, 2.07, and 1.65 feet, for the three stations during the same period. Lags of tidal maxima and minima varied between the three stations but ranged from one to two hours (Figure 4-6).

Stage elevations due to increased flow were clearly apparent at Snook Haven (Figure 4-7). Despite the high water levels, a tidal signal remained apparent, although was reduced once elevations exceed 4 ft. A more modest stage elevation due to flow appeared at North Port Charlotte. Stage fluctuations remained dominated by tidal signals, even under high flow conditions.

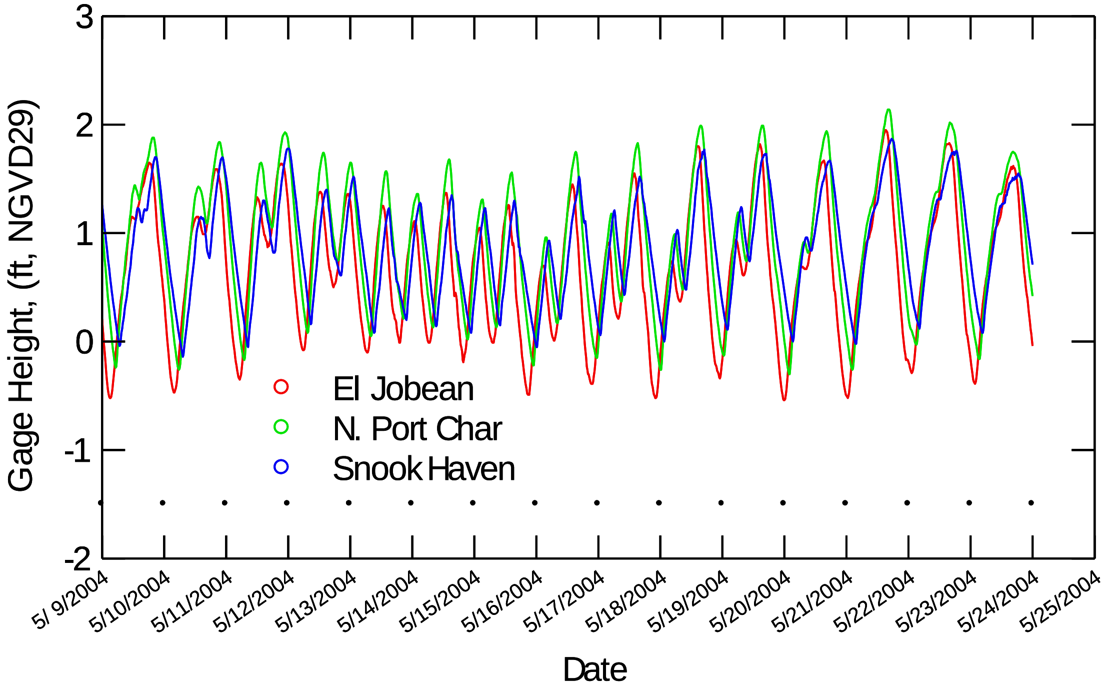


Figure 4-5. Mixed, semi-diurnal tides of the Myakka River and concordance between stations. Dots indicate midnight.

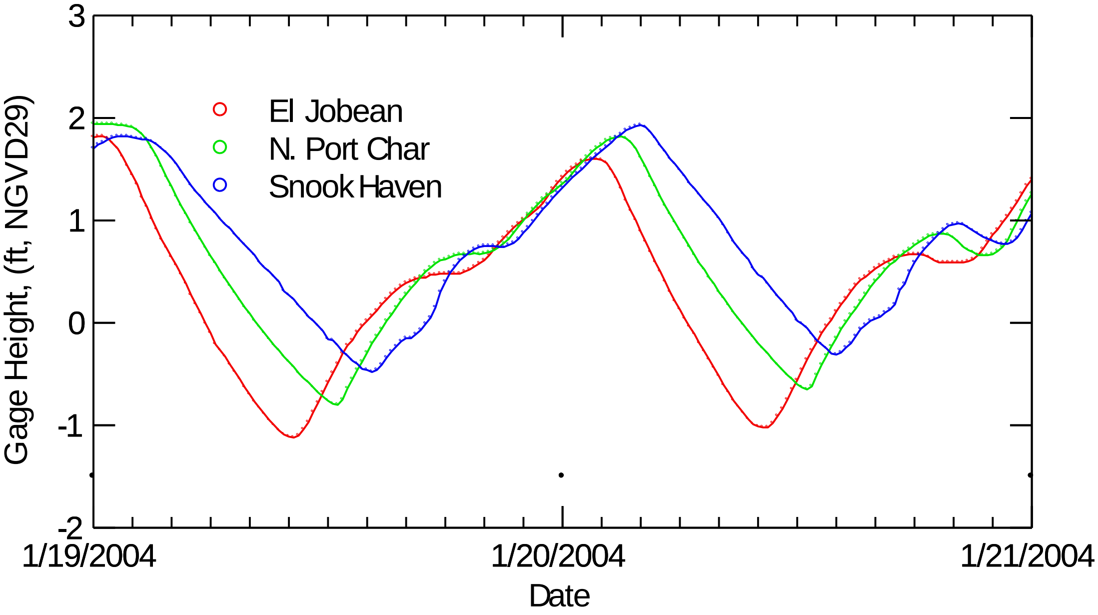


Figure 4-6. **Representative differences between stations in the timing and amplitude of tides on the Myakka River.**

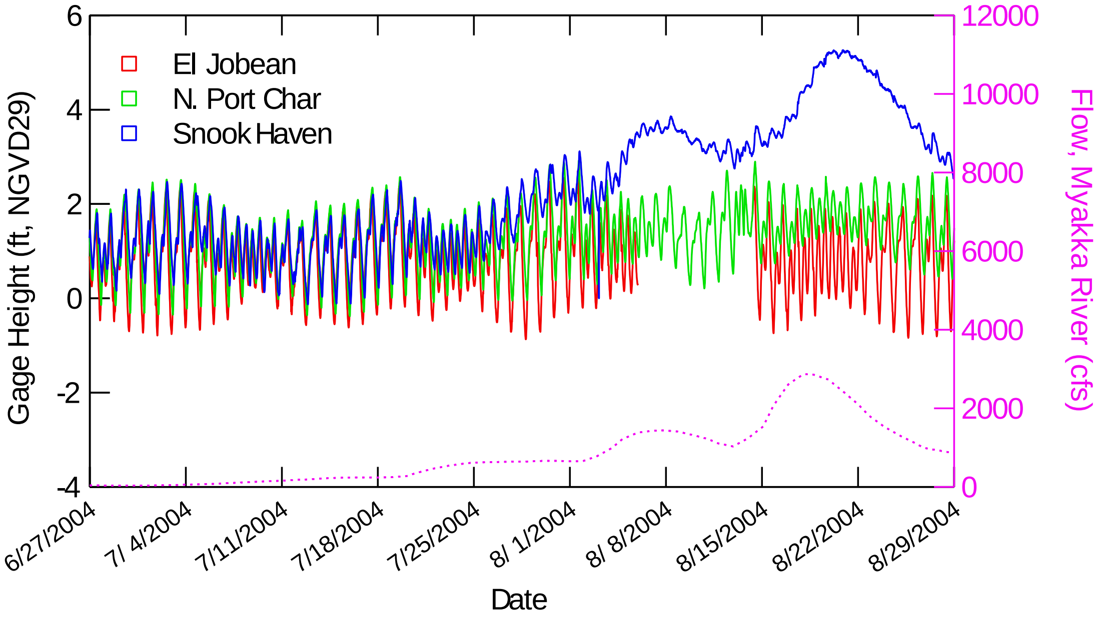


Figure 4-7. **Tide and flow related changes in stage along the Myakka River**.

4.4 General Hydrology

Daily flows for the Myakka River period of record are illustrated in Figure 4-8. The log scale depiction clearly indicates the reduced incidence of flows below 10 cfs since the late 1970's. The increase in flow is not accompanied by any monotonic trend in annual rainfall amounts (1950-2000), although longer term climatic variations were noted (Wade, et al., 2003). No step-trend in dry season (November through June) rainfall was apparent. Lack of overall rainfall trends, coupled with significant increases in specific conductance in the dry season, have resulted in dry season flow increases being attributed to groundwater contributions to the River from reject agricultural irrigation (SWFWMD 2005a).

Time series plots of daily flows were also examined for the seasonal blocks described on page 2-30. These results indicate that the incidence of flows less than 10 cfs had declined in all seasons (Figure 4-9), not just during the spring dry season (Block 1). The issue is complicated by apparent increases in wet season rainfall (Figure 4-10) linked to global scale climatic indices (Atlantic Multidecadal Oscillation, or AMO, see Enfield, et al. 2001).

Approximate flow percentiles for the entire period of record for the Myakka River, Peace River, and Myakkahatchee Creek appear in Table 4-5. Values of flow percentiles for the 1980-2005 period were somewhat higher, except in the highest percentiles. Daily correspondence of flow between the Myakka River, Peace River, and Myakkahatchee Creek vary widely (Figure 4-11), indicating complexity of watershed influences and spatial variability of rainfall events. Normalized for watershed area, calculations of annual runoff from the Peace and Myakka basins (at the respective gauge locations) indicate a general correspondence early in the record, with a divergence (increasing runoff in the Myakka River, decreasing runoff in the Peace River), which began in the early 1960's (Figure 4-12).

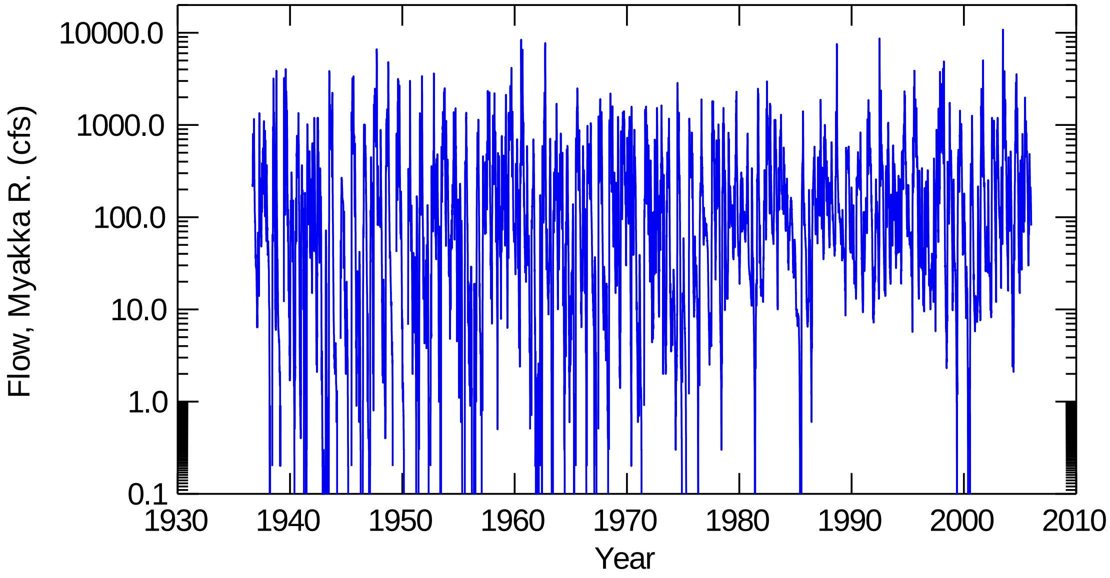


Figure 4-8. Time series of daily flow for the Myakka River near Sarasota (U.S.G.S. Gage 02298830), period of record, log scale.

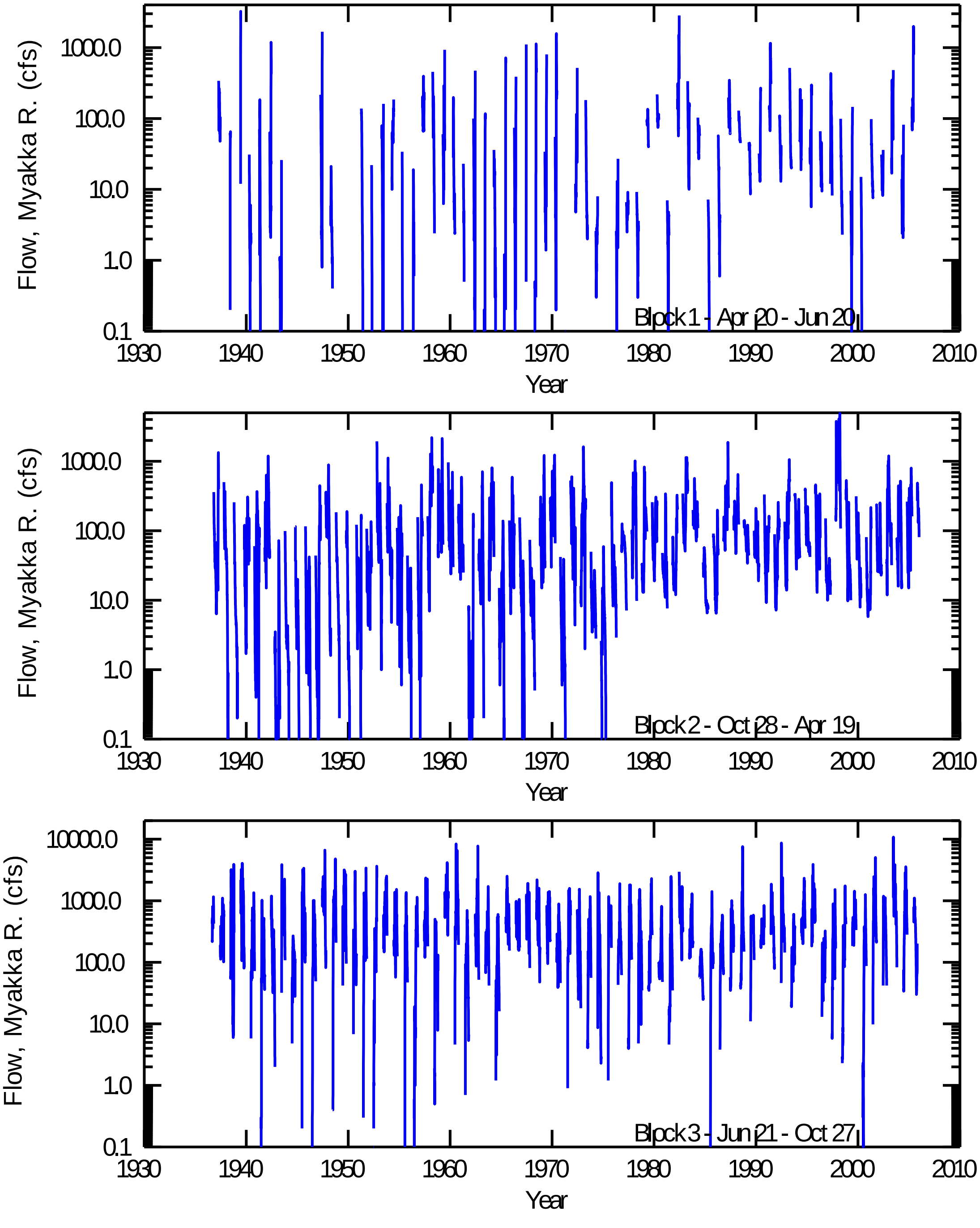


Figure 4-9. **Time series of daily flow for the Myakka River near Sarasota USGS Gage 02298830), segregated by blocks (see text), log scale.**

Table 4-5. Flow percentiles for selected stations (cfs). Period of record for Myakkahatchee Creek (10/1/1980-12/31/2004) is less than that used for the Peace or Myakka Rivers (9/1/1936 – 12/31/2005).

Percentile	Myakka R. near Sarasota 1936-2005	Myakka R. near Sarasota 1936-1979	Myakka R. Near Sarasota 1980-2005	Peace R. near Arcadia 1936-2005	Myakkahatchee Cr. 1980-2004
1	0	0	0	41	8
5	0	0	7	88	8
10	1	0	13	121	9
20	9	3	27	184	12
25	15	6	35	213	14
30	24	11	45	247	15
40	48	31	72	342	20
50	83	64	109	478	26
60	136	116	153	685	38
70	226	207	253	1010	59
75	295	276	315	1240	78
80	386	376	400	1570	108
90	690	719	648	2791	214
95	1103	1141	1020	4300	359
99	2265	2280	2226	8382	795

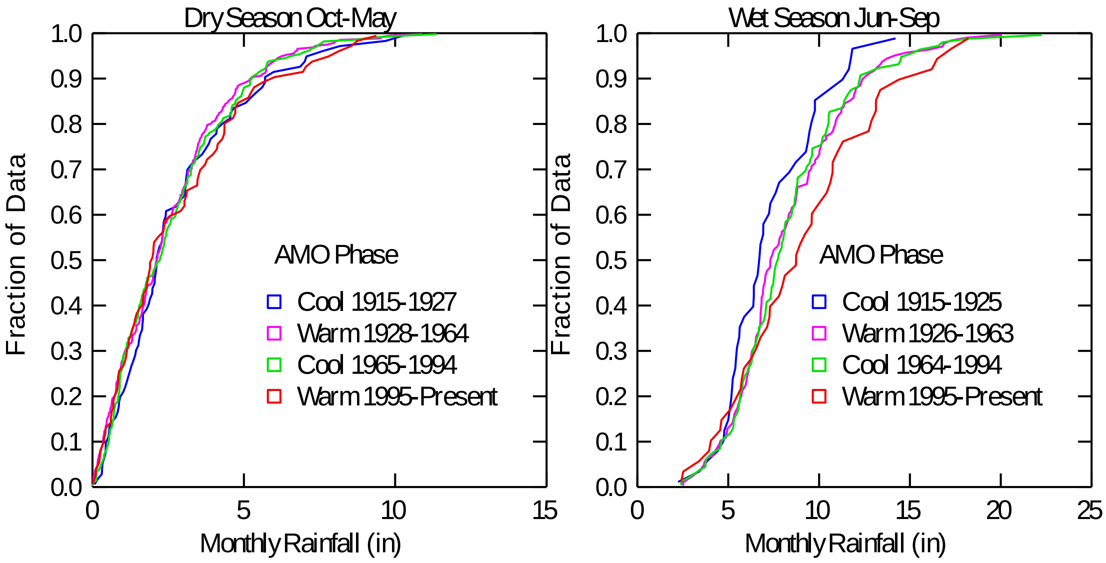


Figure 4-10. Apparent increase in monthly rainfall during the wet season over the period of record from 1915 to present[1].

[1] Data source: River basin rainfall summaries on the SWFWMD web site http://www.swfwmd.state.fl.us/data/wmdbweb/rainfall_data_summaries.php. These data represent estimated long-term rainfall records in which the data used to calculate basin rainfall totals can vary between time periods based on the rainfall gages in operation. Basin totals may be calculated from gages near, but not within, the drainage basin**.**

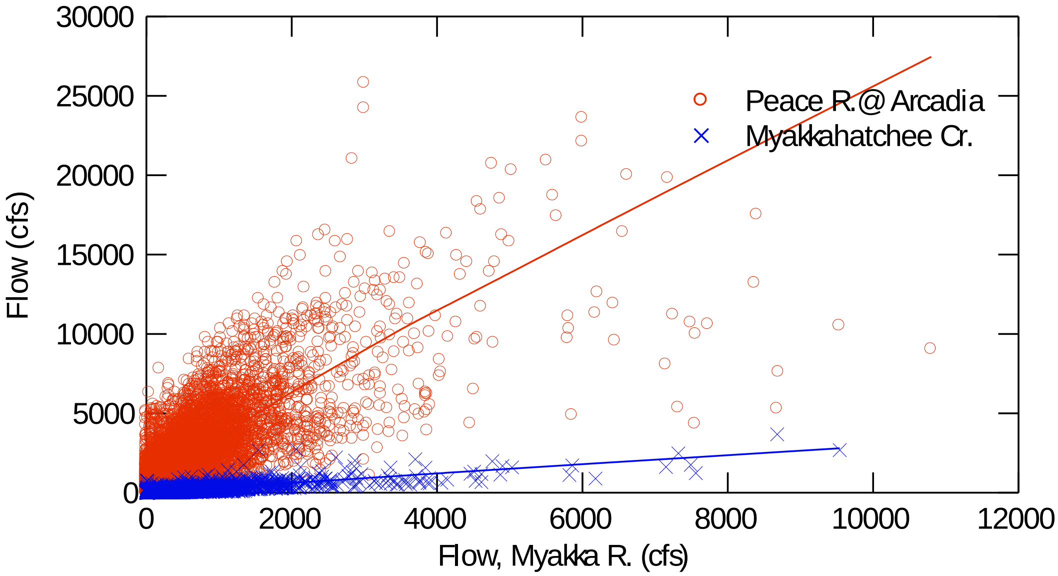


Figure 4-11. **Correspondence of daily flows between the Myakka and Peace Rivers (1936 to 2005) and Myakkahatchee Creek (1980-2005), with linear smooths illustrated.**

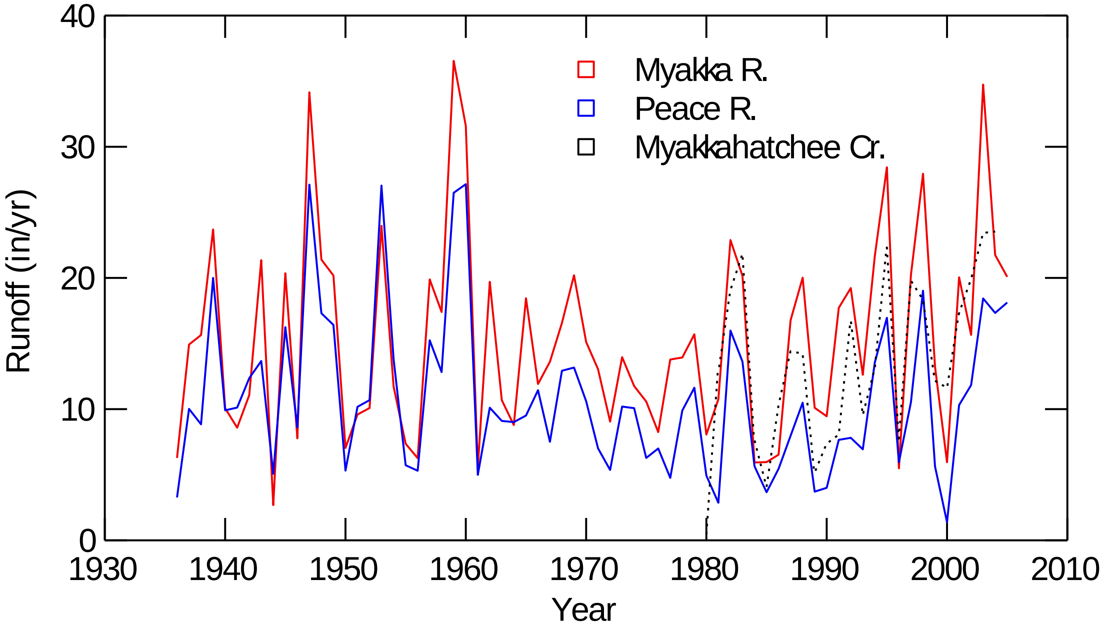


Figure 4-12. **Annual runoff from the Peace, Myakka, and Myakkahatchee Creek basins (at the respective gage locations).**

Runoff from the Myakkahatchee Creek basin (seen in flow data available since October,1980) was generally between that of the Peace or Myakka Rivers. These patterns were reproduced in the decadal compilations of annual runoff values (Figure 4-13).

Plots of daily Myakka River flow against time (Figure 4-14) revealed the typical annual pulses of rainfall and flow. Annual patterns of rainfall resulted in flows which included a small wet season in January-March and a larger wet season which peaked in August-September, but which could start as early as June and could continue through October during wet years. Daily flow percentiles (Figure 4-15) indicated a substantial variation between years in the extreme high flows, and with median flows not exceeding 600 cfs. On an annual basis, median flows were almost always below 200 cfs (Figure 4-16), but generally above 25 cfs.

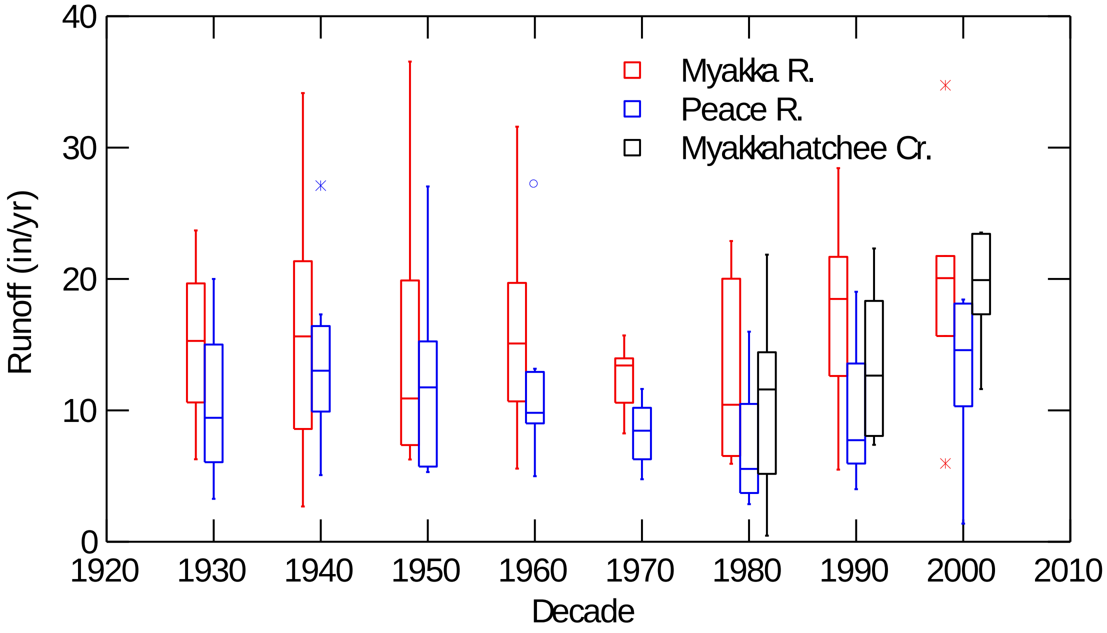


Figure 4-13. Time series of annual runoff values compiled by decade and watershed.

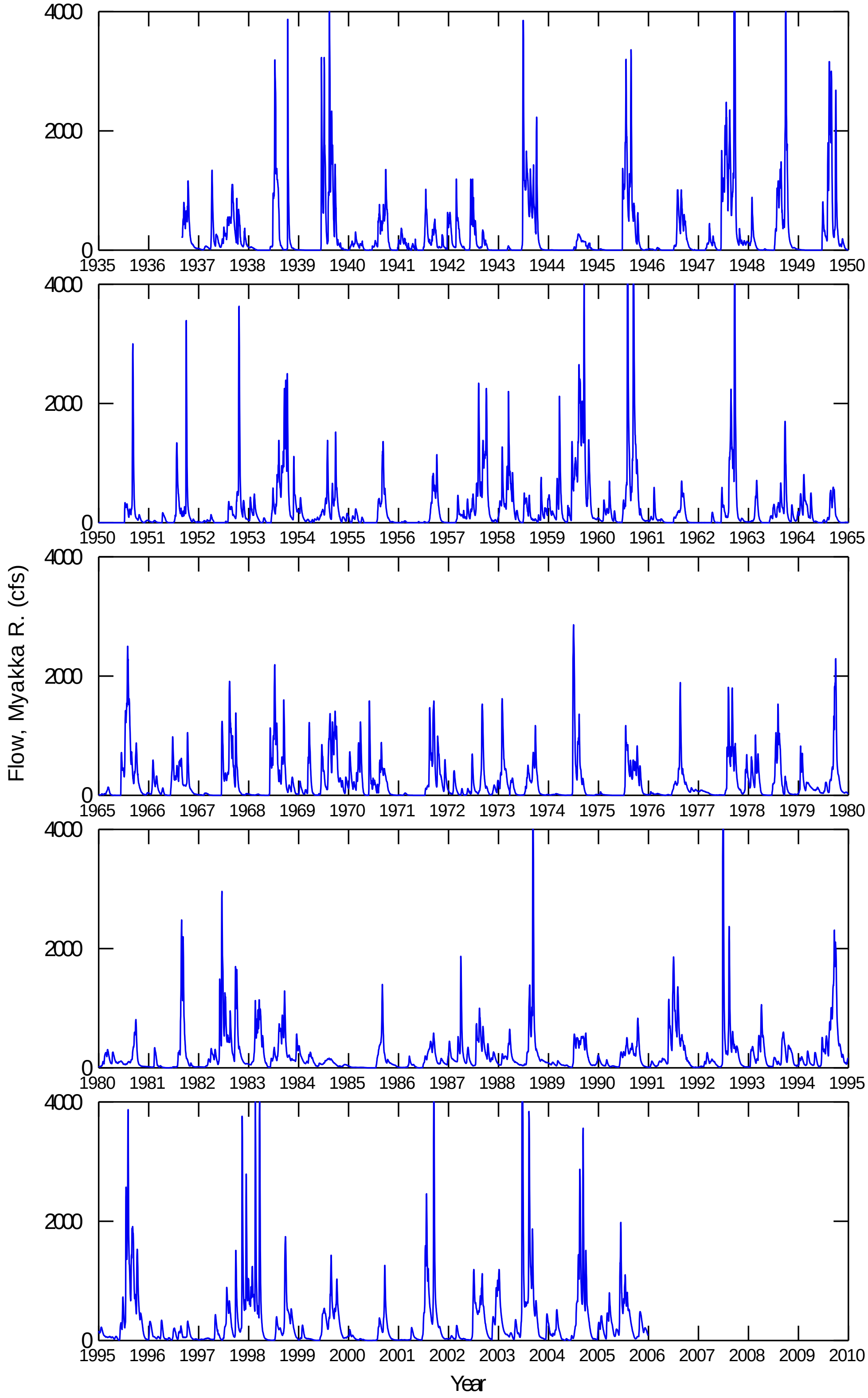


Figure 4-14. Daily flow at U.S.G.S. Station 02298830, Myakka River near Sarasota.

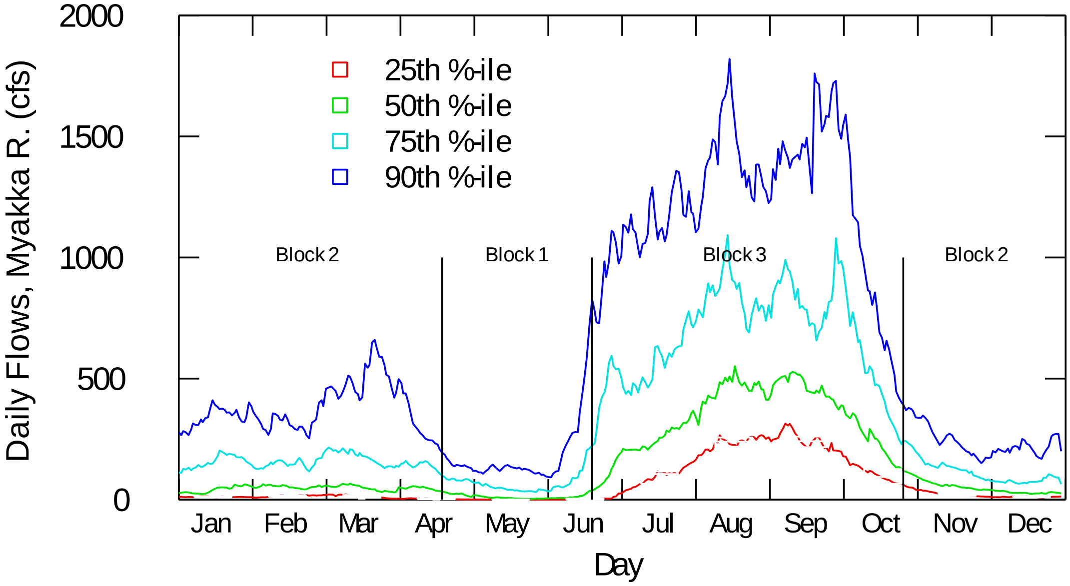


Figure 4-15. Selected daily flow percentiles for the Myakka River.

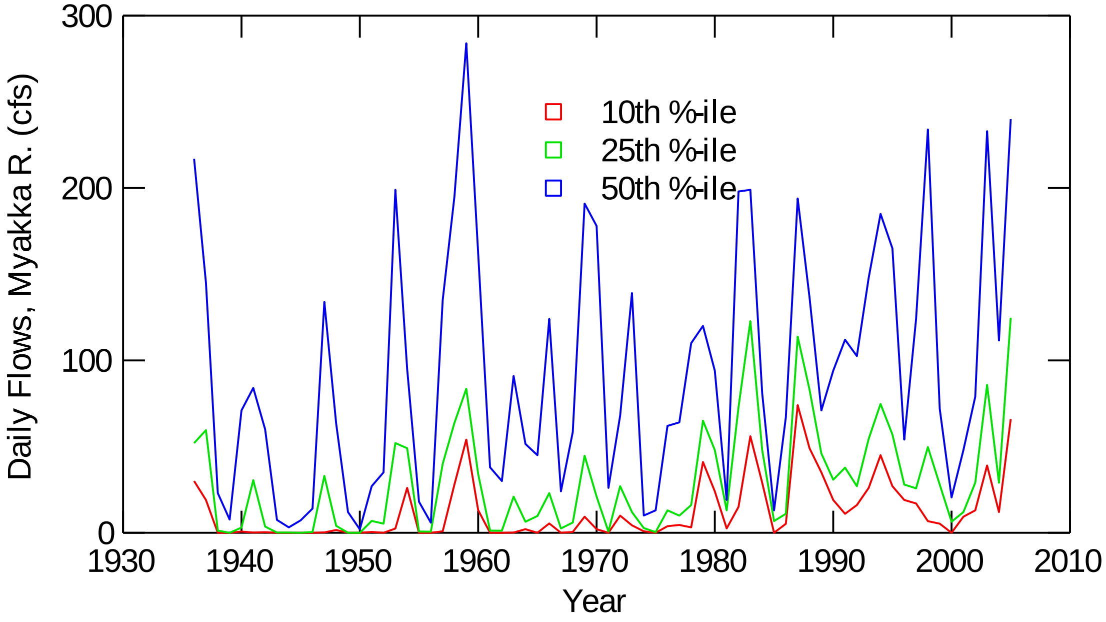


Figure 4-16. Time series of selected annual flow percentiles of the Myakka River.

4.5 Salinity

4.5.2 Observed Salinity Distributions

Over 18,000 salinity observations at discrete depths and locations were retrieved for the general study area. Truncation of data to stations within the spatial selection criteria and to surface and bottom observations resulted in over 9,700 data points. Data were collected between 1972 and 2005 on approximately 1,600 dates and ranged across river kilometers -6.2 to 33.5.

Examination of river kilometer sampled for salinity as a function of time (Figure 4-17) indicated that early sampling in the Myakka River (with short exceptions) was generally limited to a few stations and not appropriate for depicting whole river salinity conditions. Sampling over the entire study area was most consistent from 1996-2005 and therefore was used predominantly in the following illustrations of seasonal and spatial distributions. Flows on the sampling days from 1996-2005 were compared with the entire period of record (Figure 4-18) and indicated that low flows were slightly higher during 1996-2005 samplings when compared to 1936-2005. The salinity and isohaline distributions described for 1996-2005, therefore, were likely shifted downriver relative to the entire period of record.

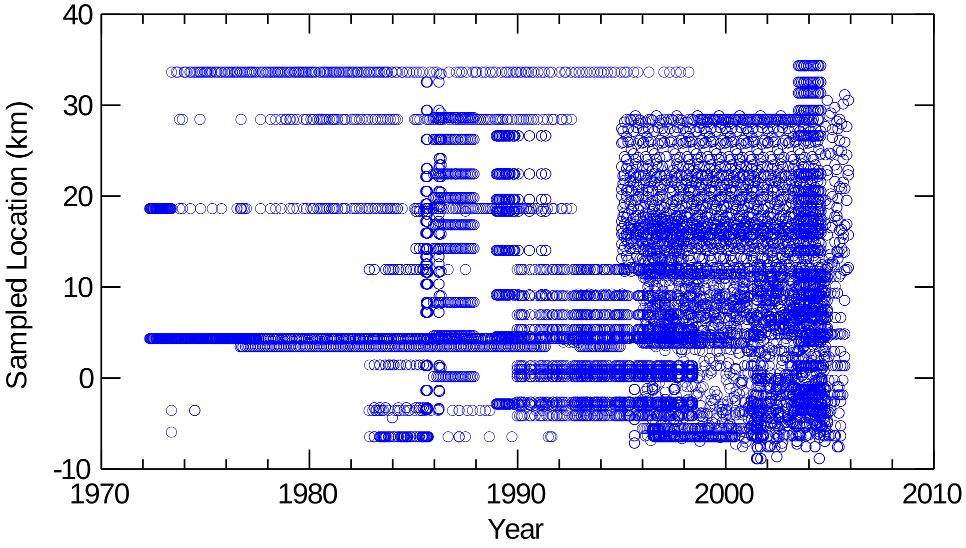


Figure 4-17. Date and river kilometer of salinity sampling in the Myakka River.

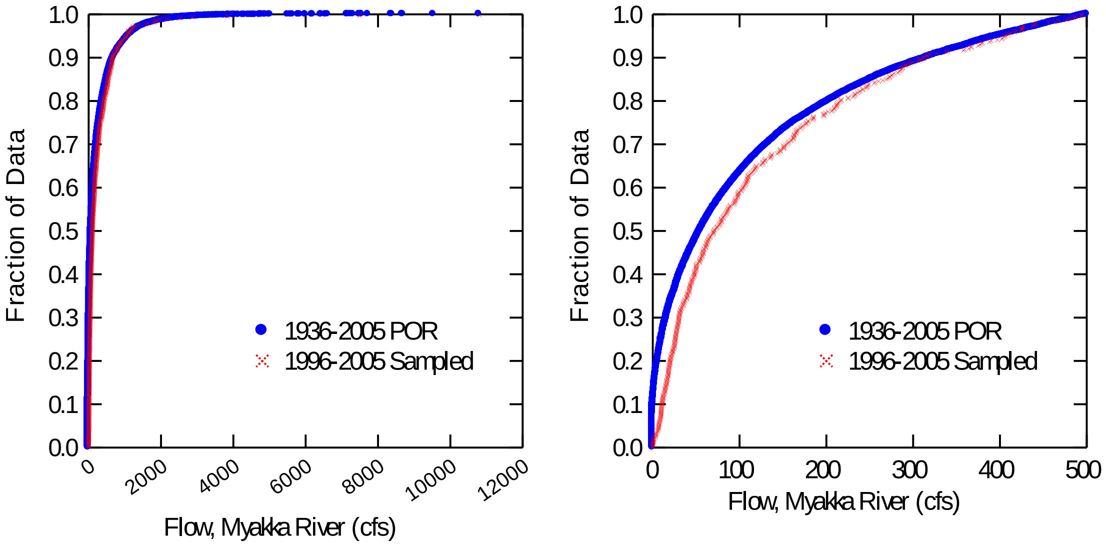


Figure 4-18. **Relative distribution of Myakka River daily flows between the period of record (1936-2005) and the sampled flows in 1996-2005.**

The temporal pattern of salinity in the Myakka River was extremely variable. The entire study area (roughly -6 to 28 km) could at times be completely dominated by either salt or fresh water (Figure 4-19). On a seasonal basis, May and June experienced the most saline conditions (Figure 4-20) while August and September were the least saline, but interannual variation was high.

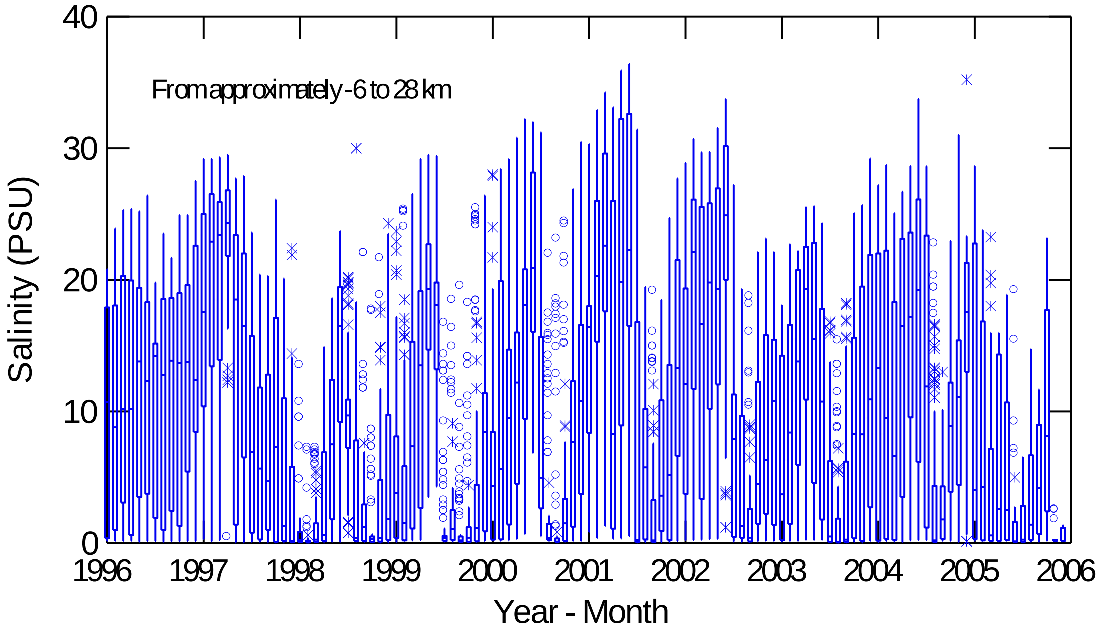


Figure 4-19. **Distribution of salinity within the Myakka River study area, by year and month.**

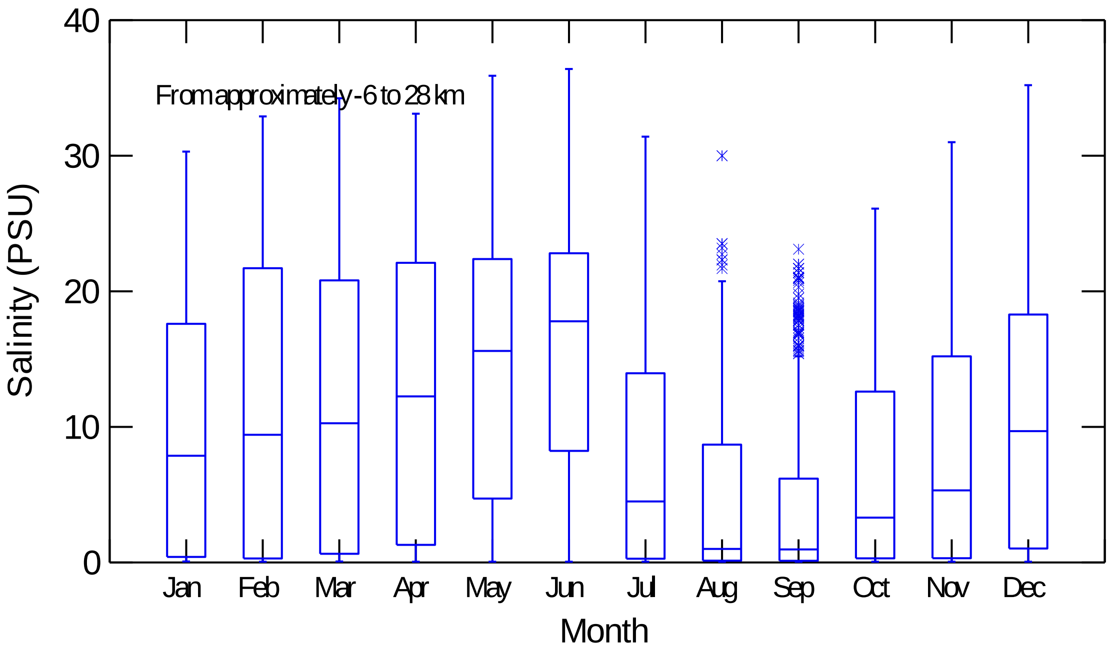


Figure 4-20. Distribution of salinity within the Myakka River study area, by month, 1996-2005.

A monthly time series of salinity data by 5 km river segments (Figures 4-21 and 4-22) and by month (Figure 4-23 and 4-24) emphasized both spatial and temporal variability. For the lower river, January through June experienced the highest salinities. The upper river, however, generally experienced salinity maxima restricted to May and June, with the most saline conditions generally recorded in June.

The 1996-2005 period, however, did not include the furthest upriver penetration of salinity in the entire database. In May of 1975 and May of 1976, salinity near 9.0 psu was recorded at Border Road (33.5 km). Salinity near 8.0 psu was recorded in July 1985. No other salinity above 1.0 psu was ever recorded above 33.5 km. Salinity distributions by block (Figure 4-25) indicated that the largest seasonal range in salinity occurred near the 5 to 10 km region of the river.

Diurnal tidal variation in salinity (1996-2005) was approximated from the database of discrete salinity observations as the standard deviation among salinities of a given station and depth category on any given day. Standard deviations were always less than 4.0 psu and had median values of less than 1.0 psu, with relatively consistent behavior over the length of river and the flow conditions sampled. From data collected on two dates which sampled fixed stations on a successive high and low tide, salinity variation was 5-10 psu between tides, with reduced variation at both upriver and downriver regions.

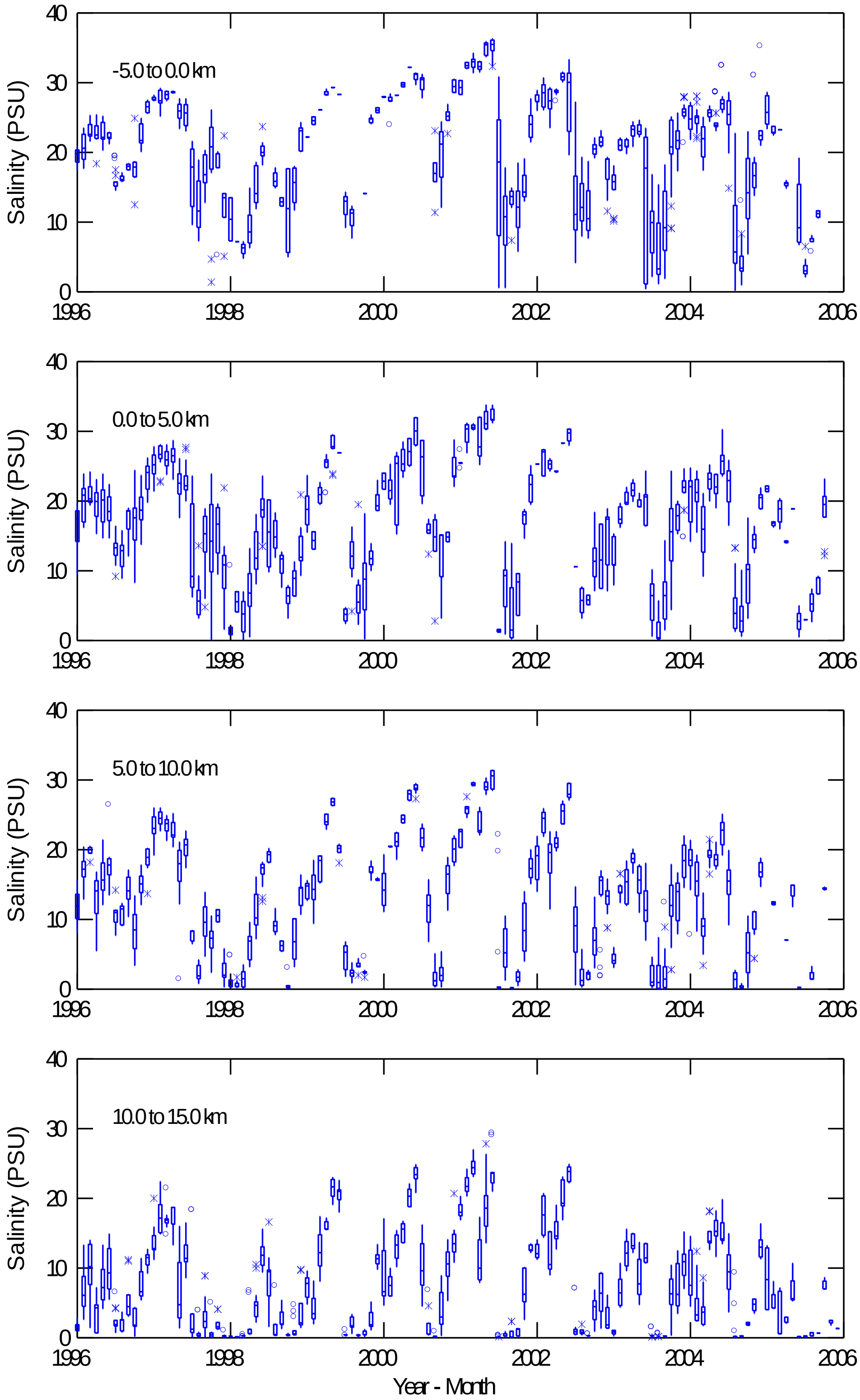


Figure 4-21. **Monthly time series of salinity distribution for selected segments of the Myakka River.**

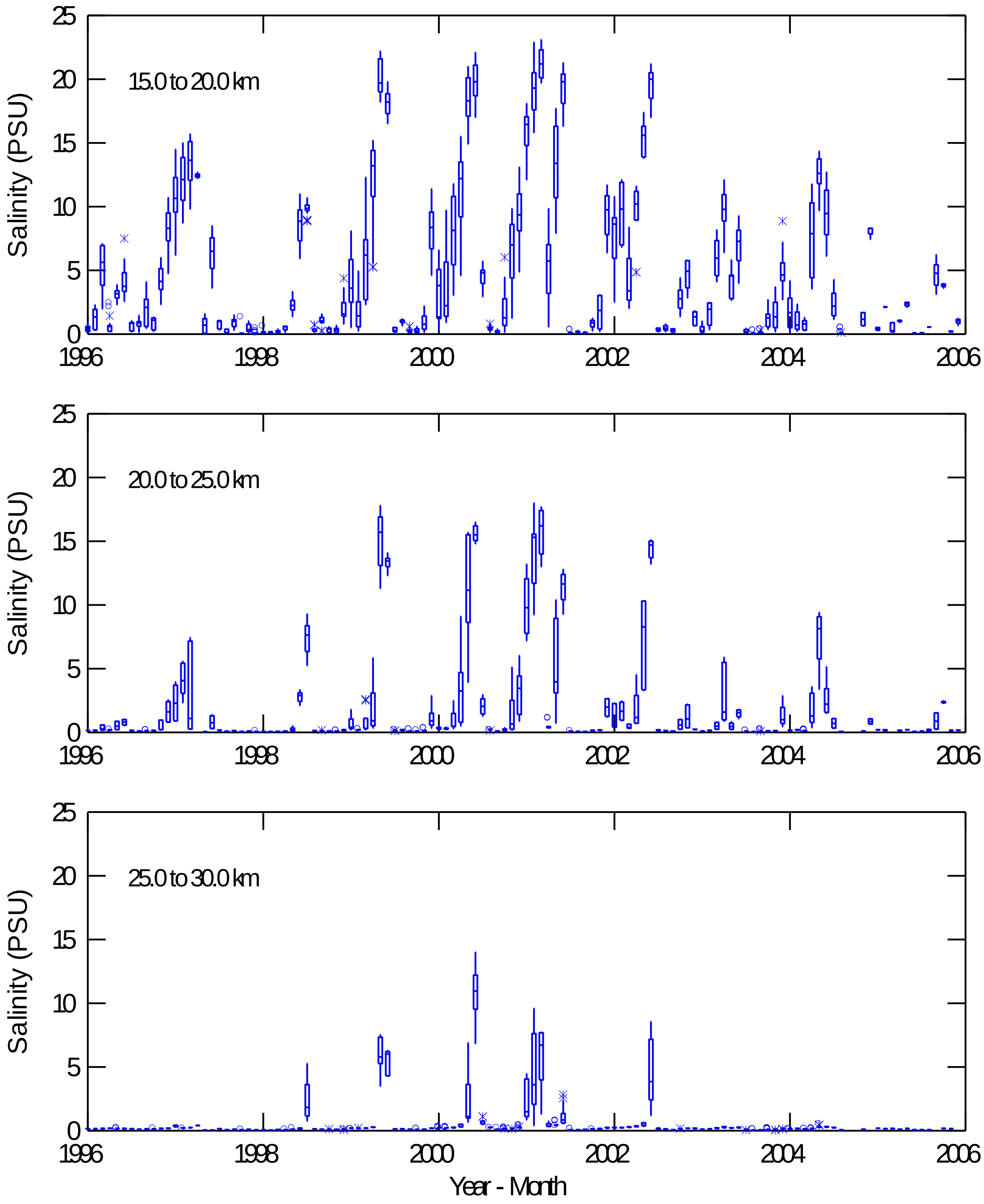


Figure 4-22. Monthly time series of salinity distribution for selected segments of the Myakka River, continued

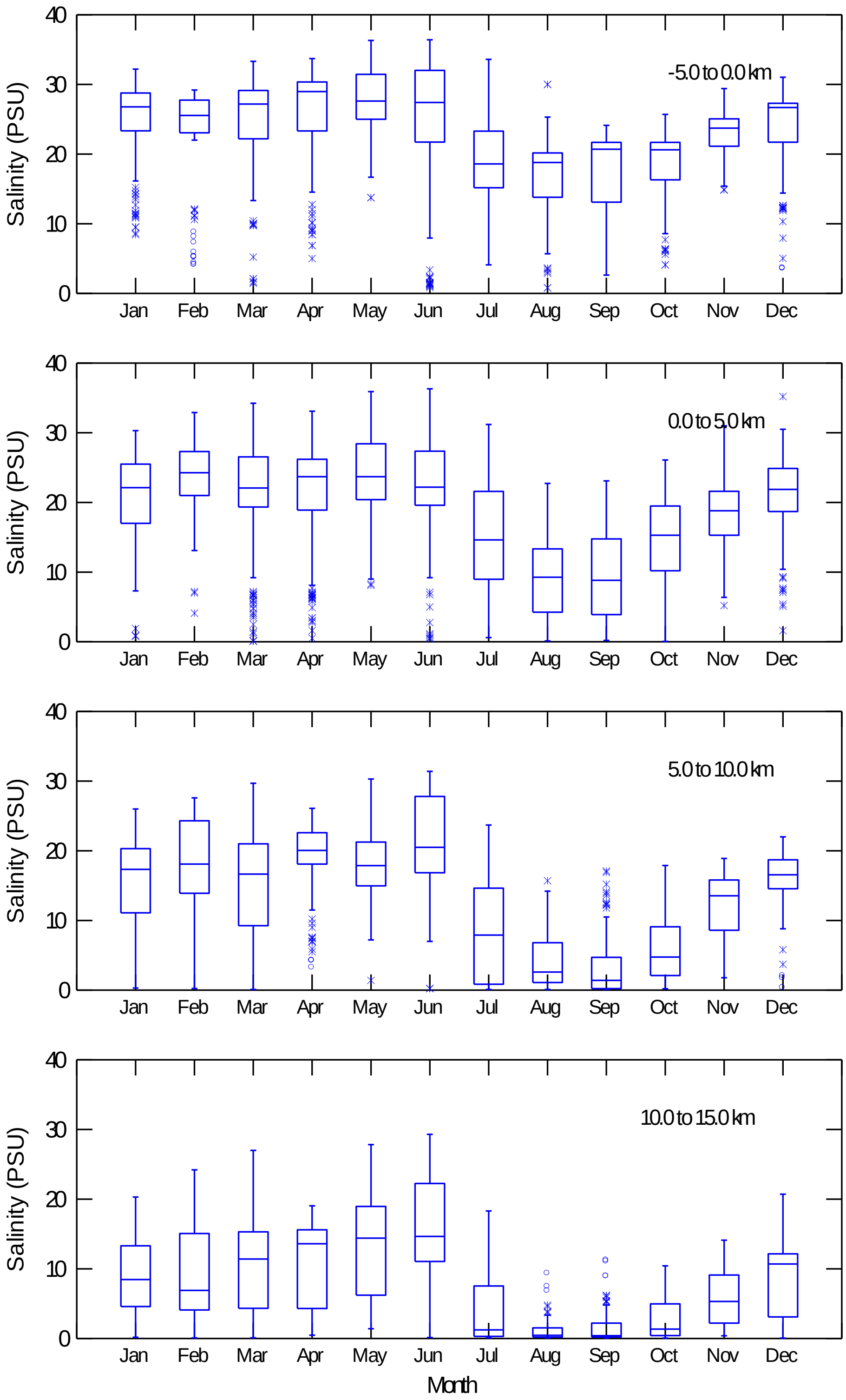


Figure 4-23. Monthly distribution of salinity for selected segments of the Myakka River, 1996-2005.

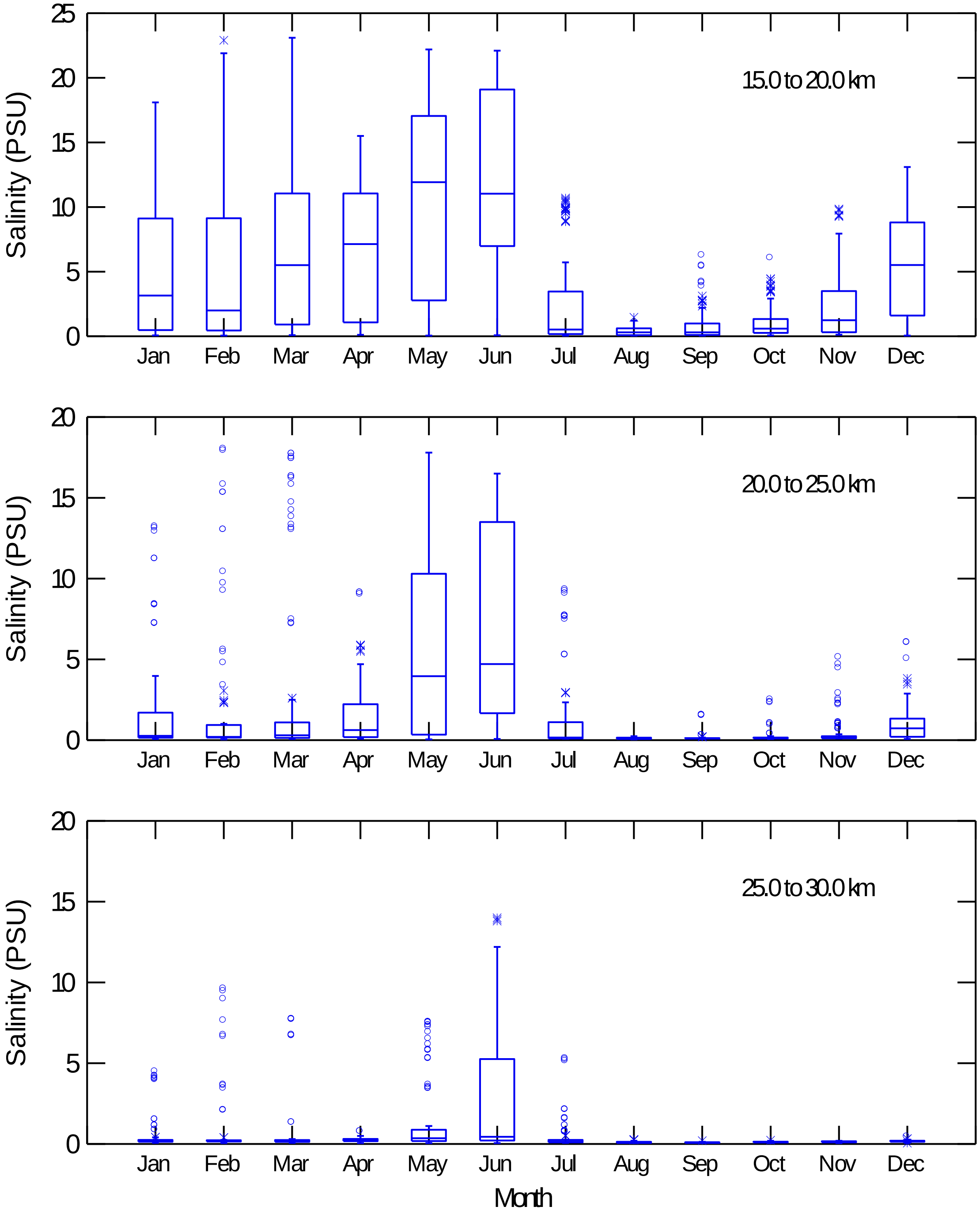


Figure 4-24. Monthly distribution of salinity for selected segments of the Myakka River, 1996-2005, continued.

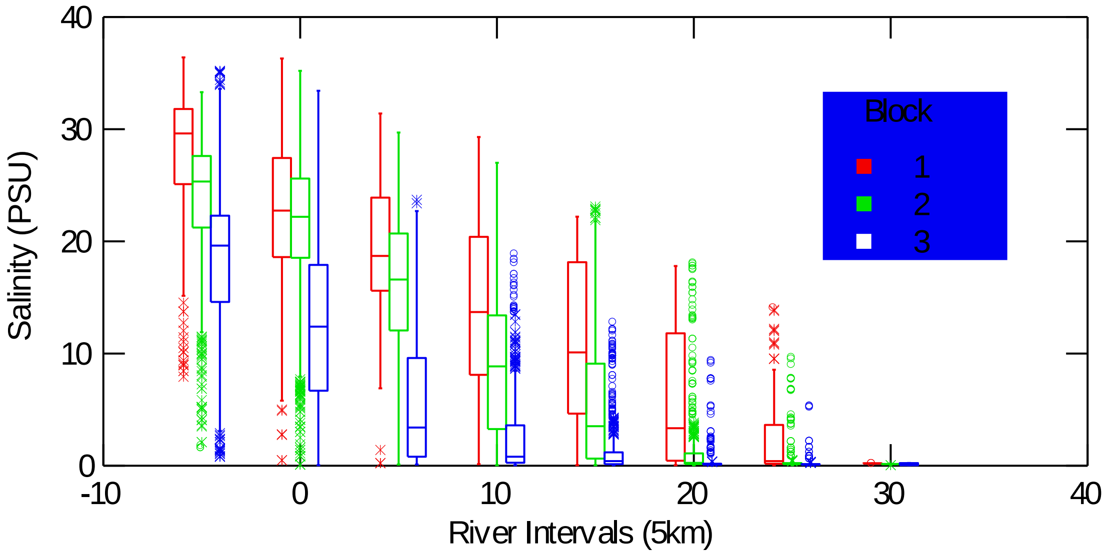


Figure 4-25. Seasonal distribution of salinity within the Myakka River study area, by selected river intervals, 1996-2005.

Diurnal variation measured by continuous recorders (15 minute data; Figure 4-26) was comparable to that estimated from the discrete samples, with median diurnal variations of 5 psu at El Jobean and 3 psu at U.S. 41 (North Port Charlotte). Tidal variations in salinity declined during higher flow periods (after February 22 in Figure 4-26) as salinities reached less than 1 psu, and were seldom observed at Snook Haven. Variation in daily mean salinity (Figure 4-27) was lower than that determined from the continuous data at the respective stations and was typically the lowest under the least saline conditions.

Salinity stratification data (1996-2005) indicated that stratification was modest with minimal stratification above 14.0 km and values generally less than 1-2 psu for stations below 14.0 km (Figure 4-28). Frequent stratification of 5.0 psu or greater was generally limited to below river kilometer 1.0 and to flows at or above the 80th percentile (386 cfs) (Figure 4-29). Stratification above 10.0 psu was generally limited to below 0.0 km and to flows at or above the 90th percentile (690 cfs). Figure 4-30 summarized the relationship of stratification with both flow and location and also illustrated that, under high flow conditions, the zone of little stratification moved downstream as the river became exclusively fresh in the upper reaches.

Stratification at continuous recorders displayed similar patterns, generally 1.0 psu or less at the U.S. 41 bridge, and 5-6 psu or less at El Jobean (Figure 4-31). Stratification at Snook Haven was negligible. At El Jobean, stratification when flows were above 1300 cfs was minimal due to the prevailing fresh conditions. The fresh water threshold where no further stratification was observed was reached at ~500 cfs for the North Port Charlotte gage. Daily variation in stratification observed in 15 minute data (Figure 4-32) was comparable to that observed from daily mean values.

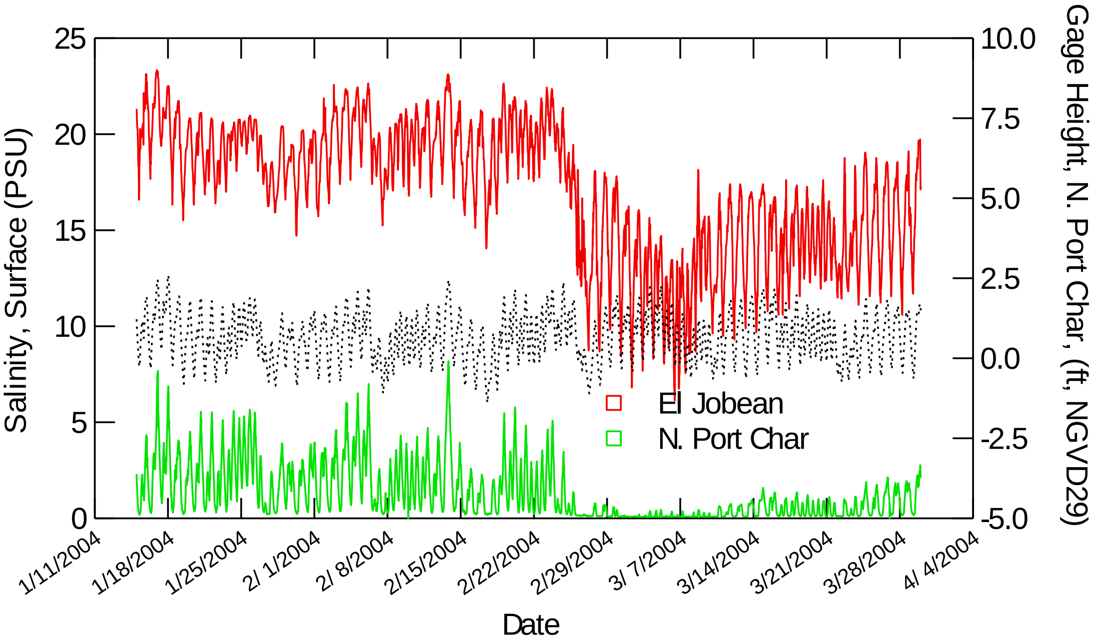


Figure 4-26. **Tidal variation in salinity at El Jobean (red) and North Port Charlotte (green) , relative to tidal variation in stage at El Jobean (black). (Note the depressed salinities after February 22 with little alteration in stage at El Jobean.)**

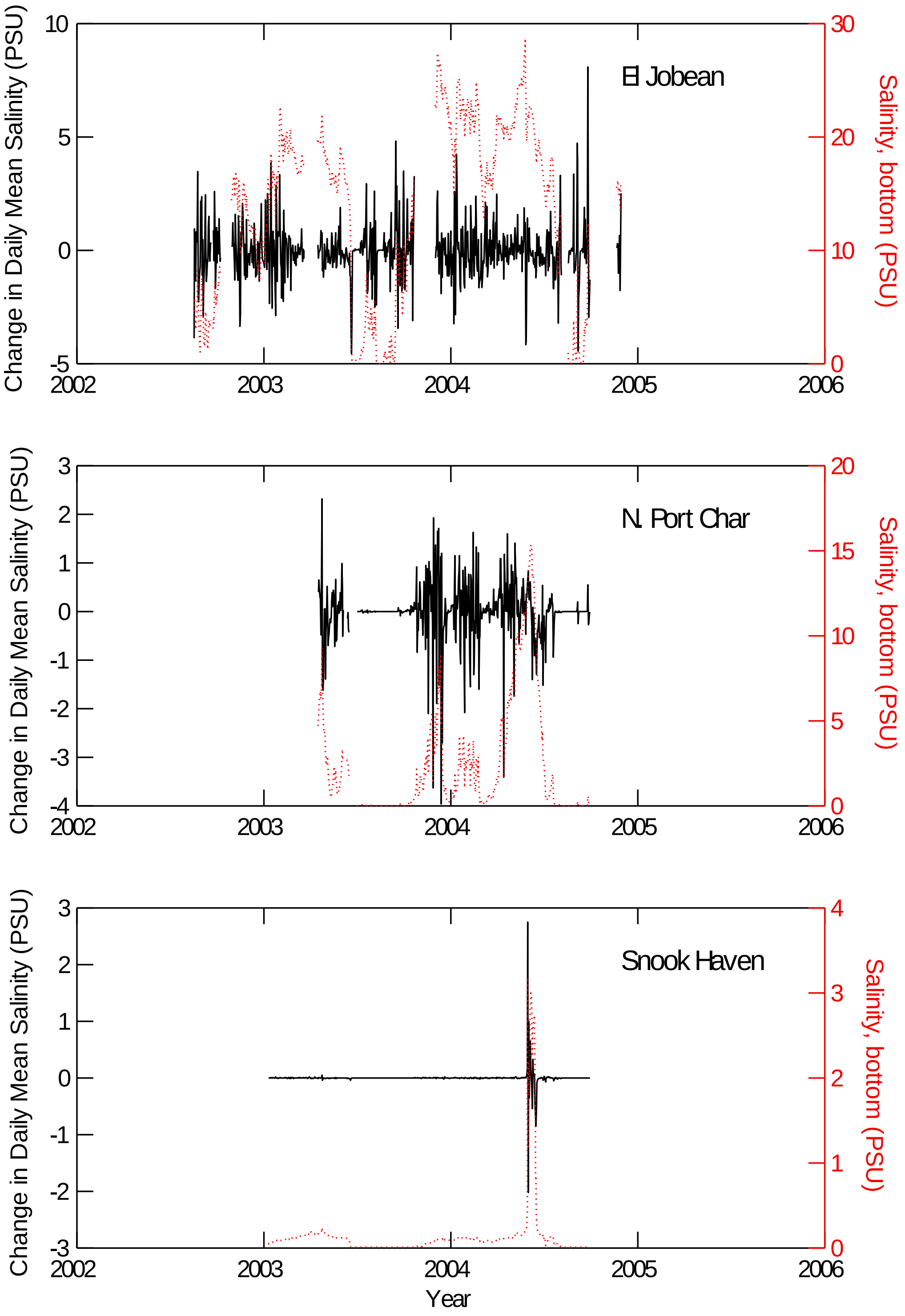


Figure 4-27. **Time series of daily mean salinity (red) and change in daily mean salinity (black) at three selected locations. Note scale change between figures.**

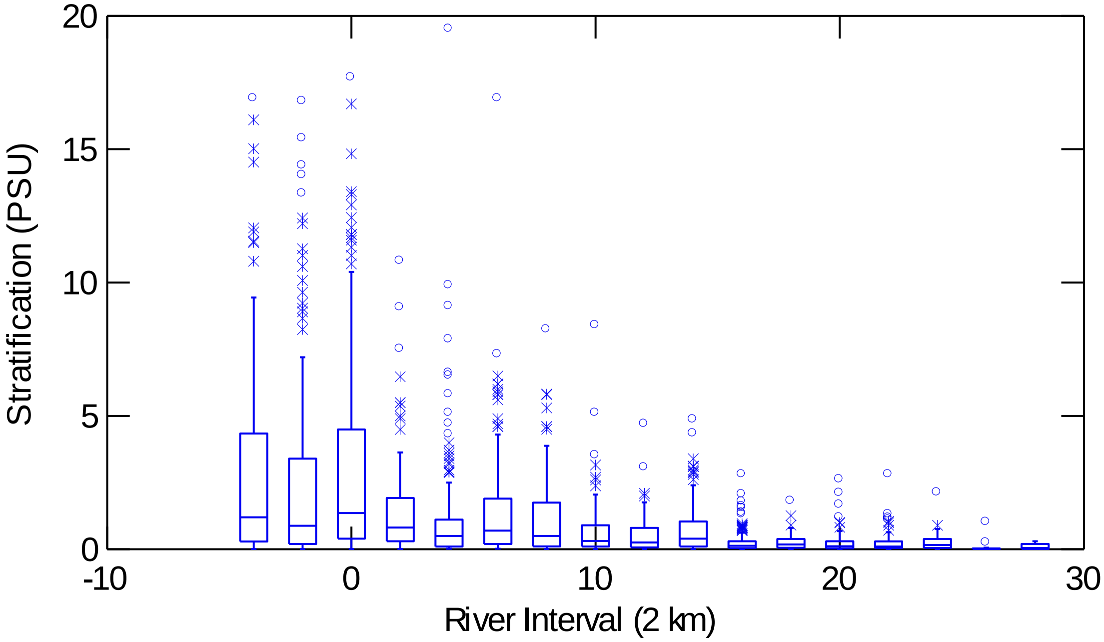


Figure 4-28. Distribution of salinity stratification by river kilometer, 1996-2006.

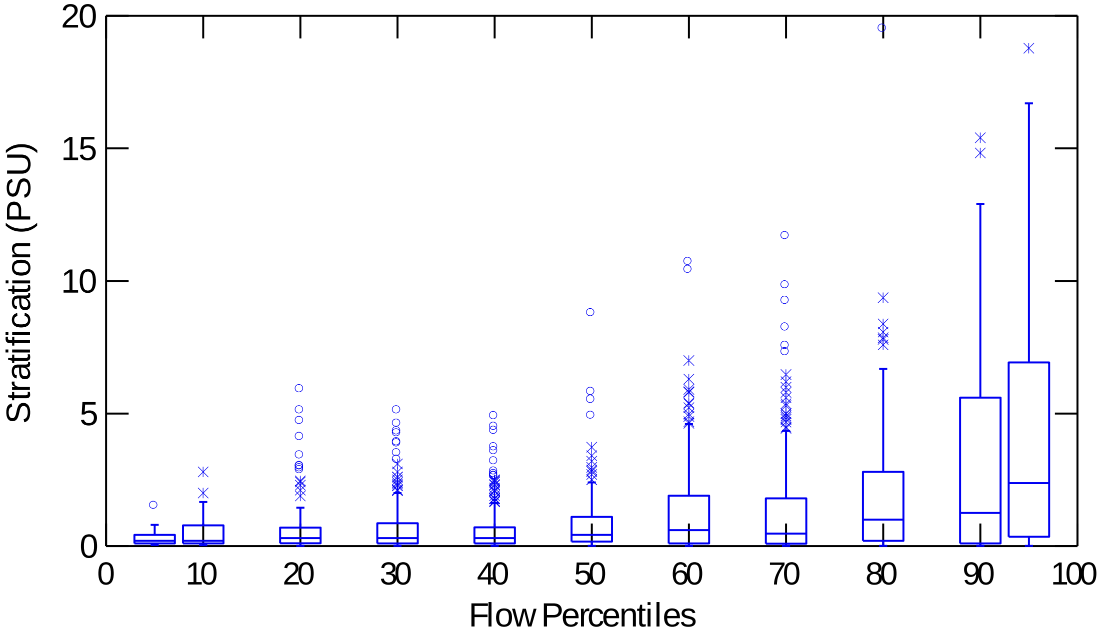


Figure 4-29. Distribution of salinity stratification by flow percentile, 1996-2005.

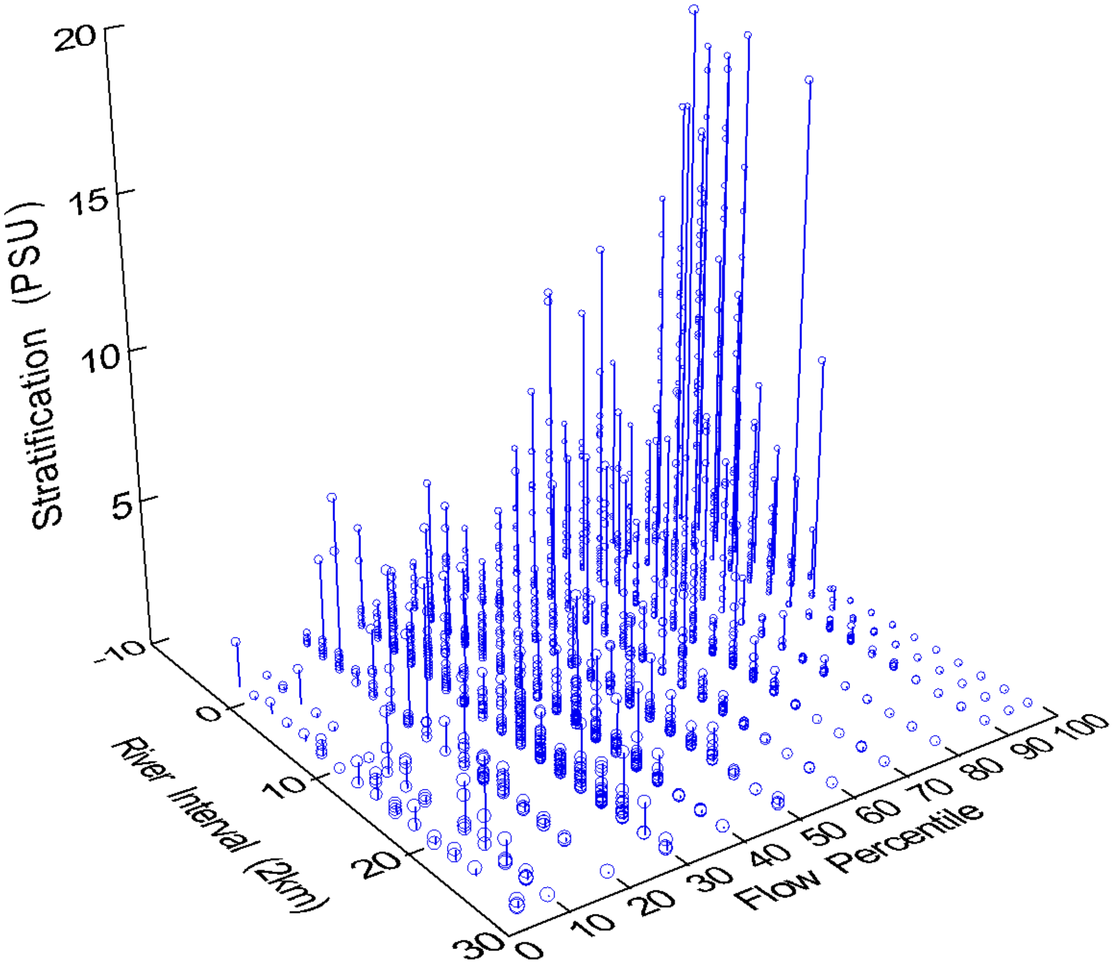


Figure 4-30. Distribution of salinity stratification by river kilometer and flow percentiles, 1996-2005.

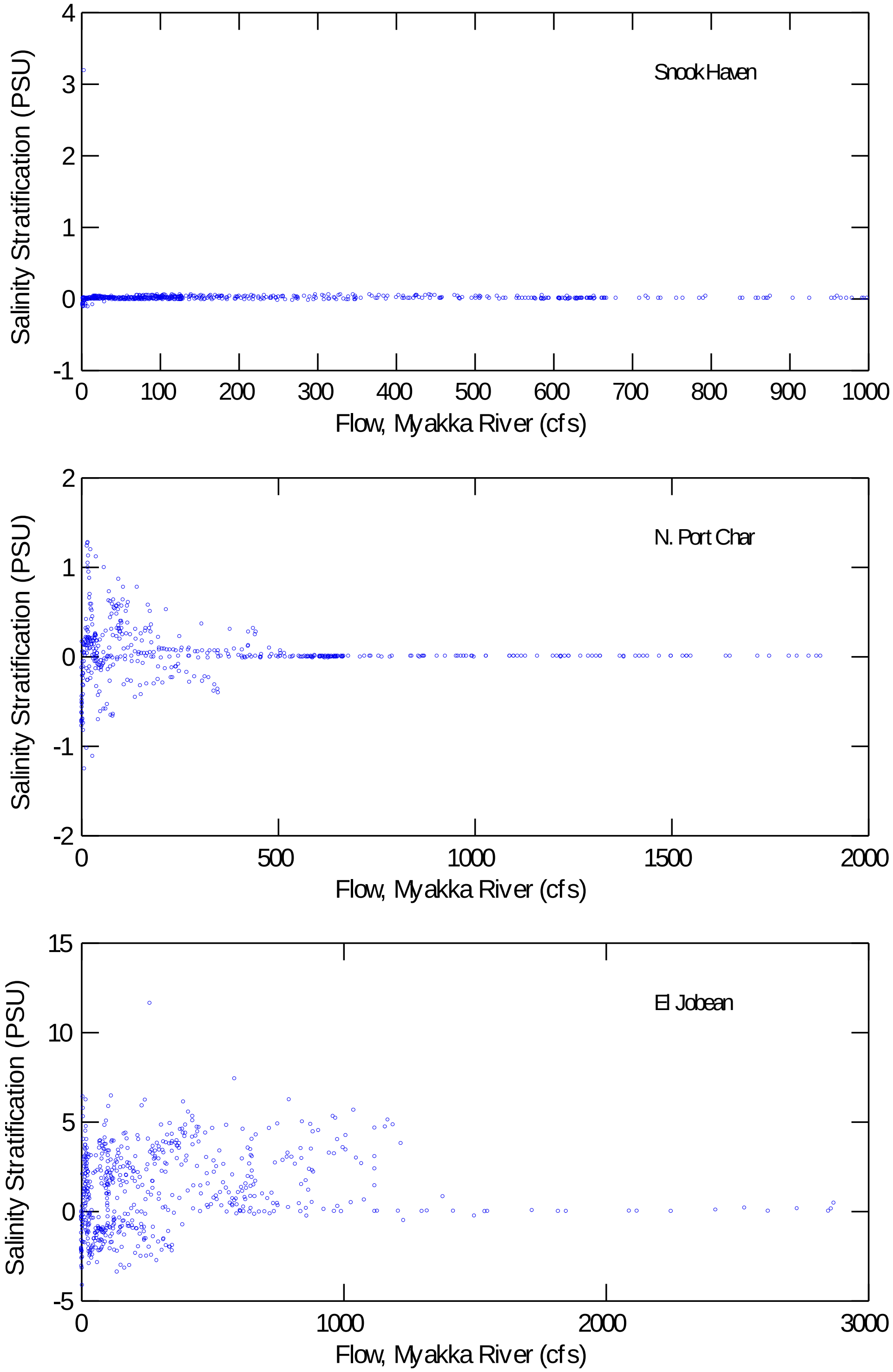


Figure 4-31. **Salinity stratification as a function of flow at three selected locations.**

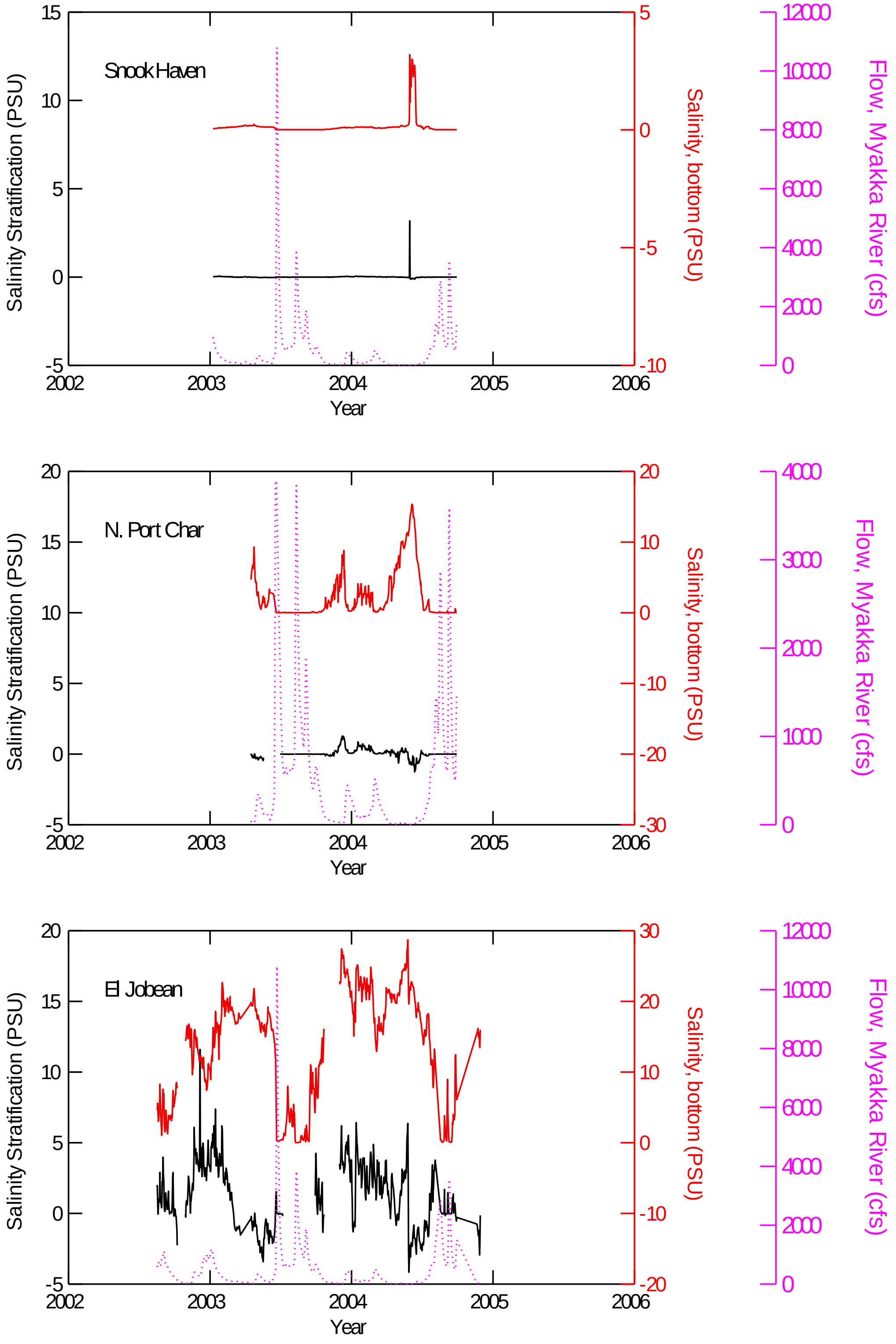


Figure 4-32. Continuous record of bottom salinity (red), stratification (bottom minus surface salinity, black), and Myakka River flow (magenta) at three selected locations.

4.5.3 Interpolated Isohaline Positions

Distributions of interpolated isohaline positions from 1996-2005 appear in Figure 4-33 and emphasize the wide range of conditions experienced by the entire river. Modest stratification values produced surface isohaline positions slightly downstream from bottom isohaline positions. Distributions of isohaline position within a given month (Figures 4-34 to 4-35) indicated a broad range of salinity conditions even within a particular season. The 24.0 psu isohaline did not appear in the study area in August and September of 1996-2005. Relationships of relative isohaline positions with respect to flow percentiles (Figure 4-36) were as expected.

4.5.4 Isohaline Regressions

From the salinity data described above, over 5,400 isohaline locations were computed, of which over 3,500 met the criteria of having been computed from two successive stations separated by 6 km or less and 7 psu or less. Data restricted by these criteria were collected between 1983 and 2005 and distribution of data among isohalines appeared in Figure 4-37. The relatively few observations of the 28 psu isohaline were clearly evident and justified eliminating this isohaline from consideration. The 24 psu isohaline was present within the study area only during low flow periods, indicated by the reduced number of observations relative to other isohalines.

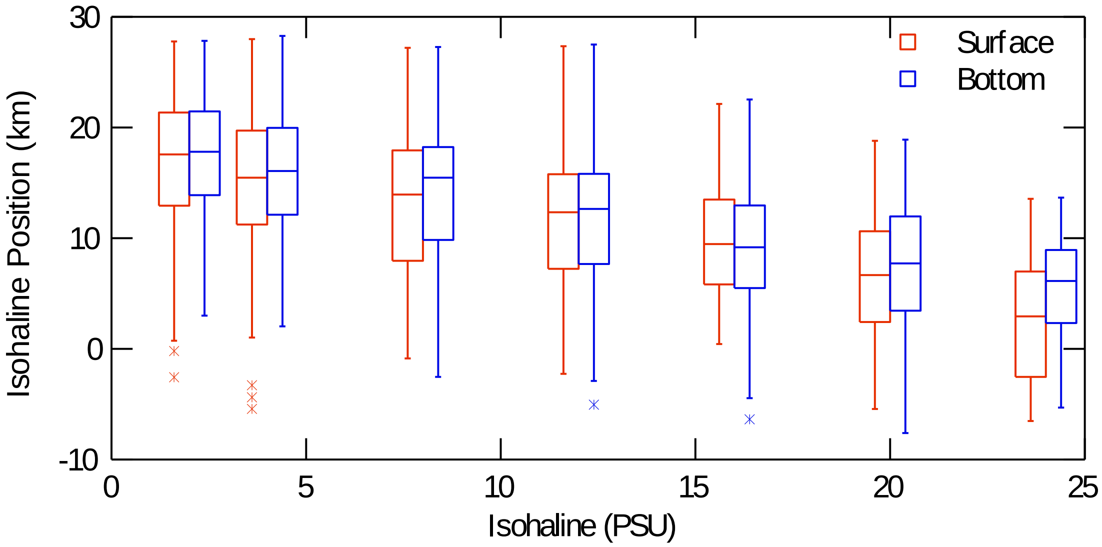


Figure 4-33. Distribution of calculated surface and bottom isohaline positions, 1996-2005 (1.0 psu not shown).

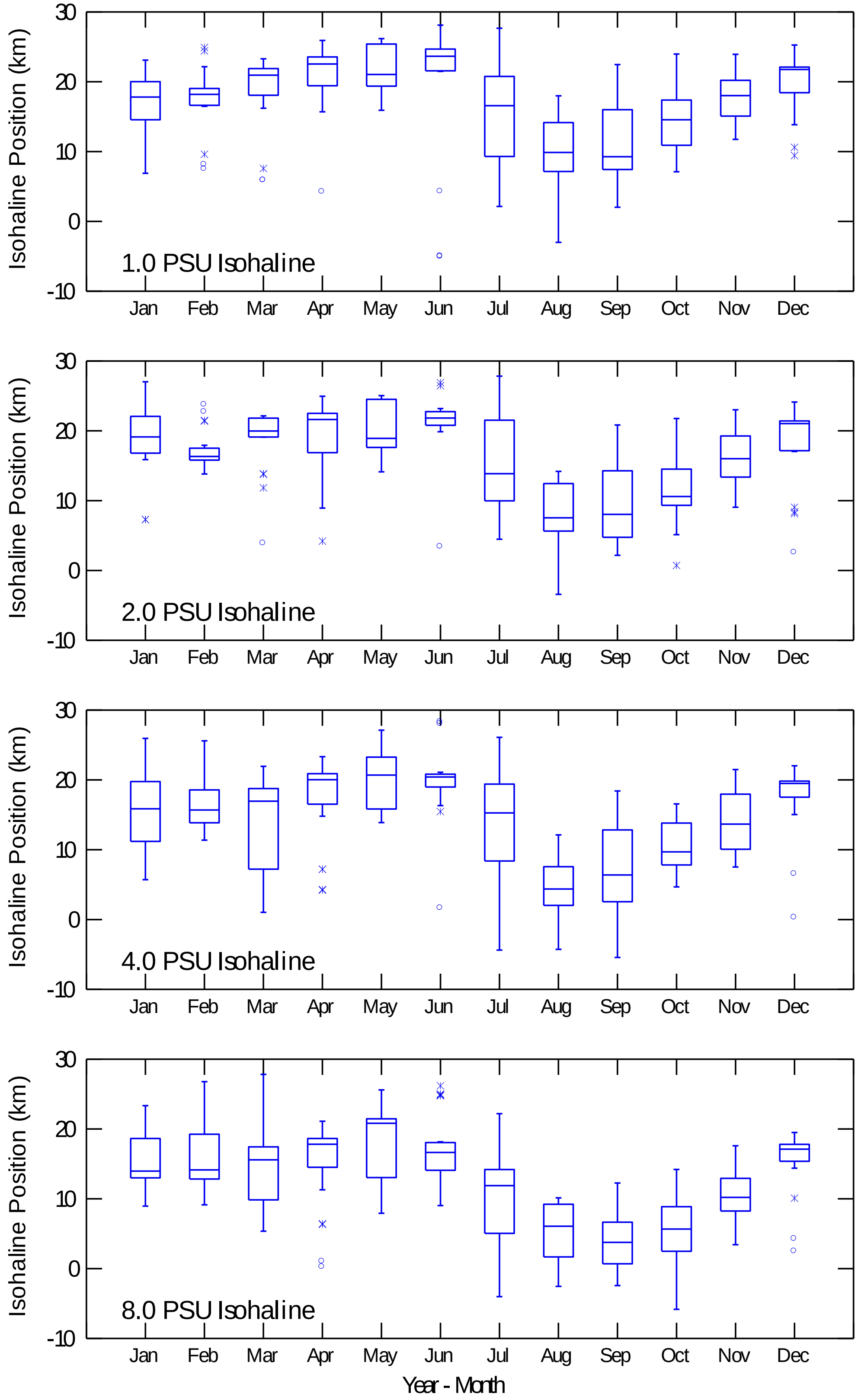


Figure 4-34. Monthly distributions of isohalines, surface and bottom combined, 1996-2005.

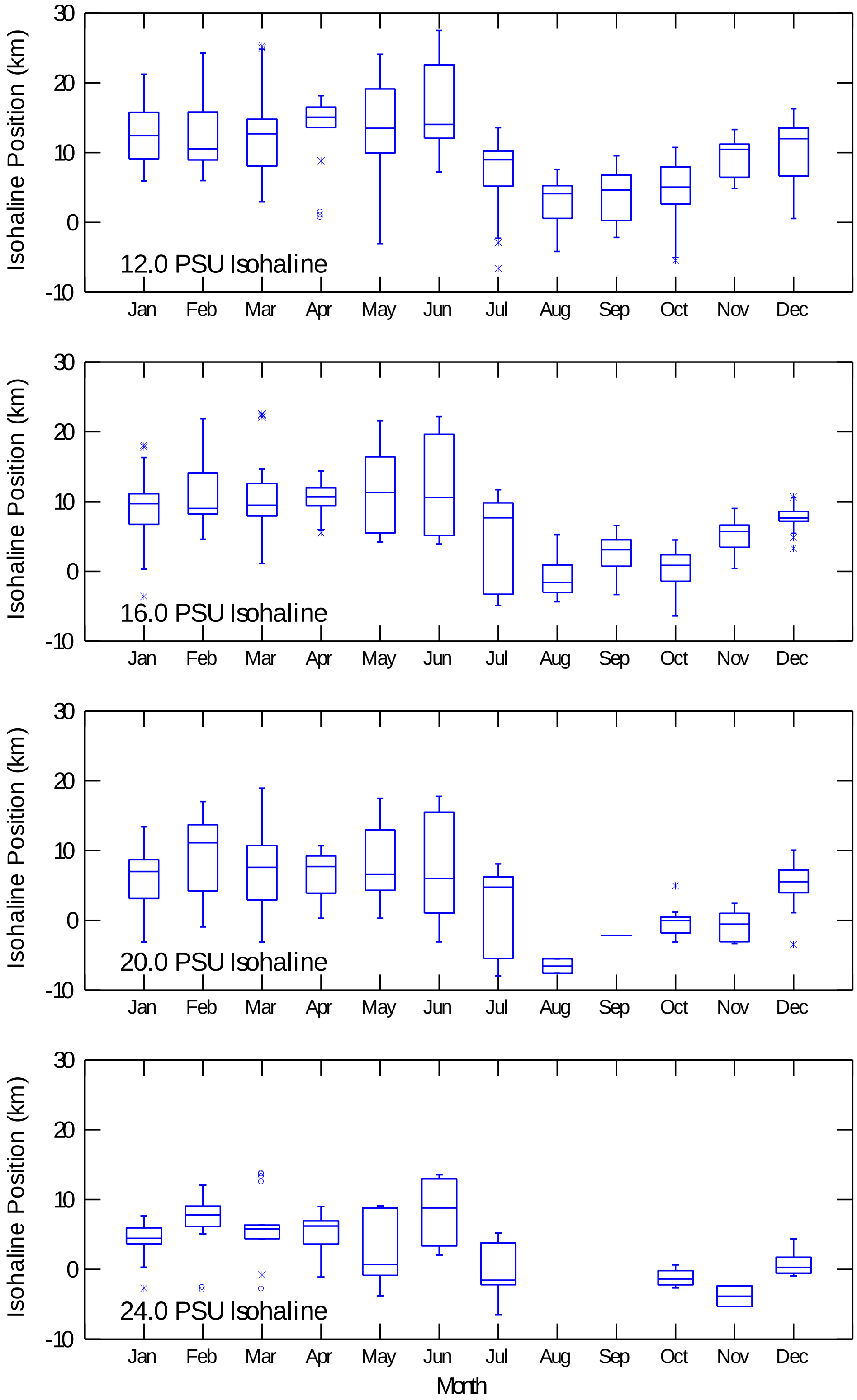


Figure 4-35. Monthly distributions of isohalines, surface and bottom combined, 1996-2005, continued.

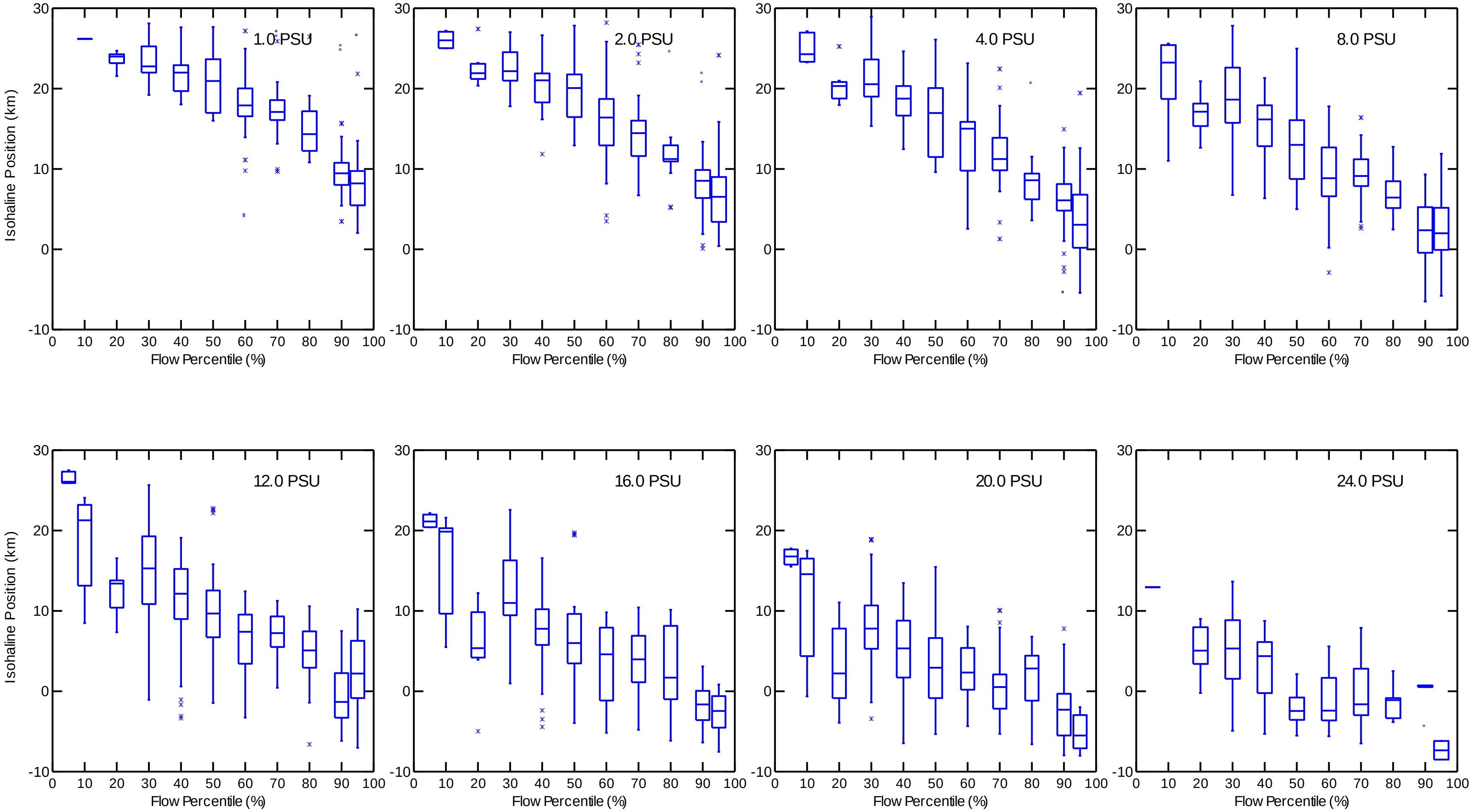


Figure 4-36. Distribution of selected isohalines by flow percentiles, surface and bottom combined, 1996-2005.

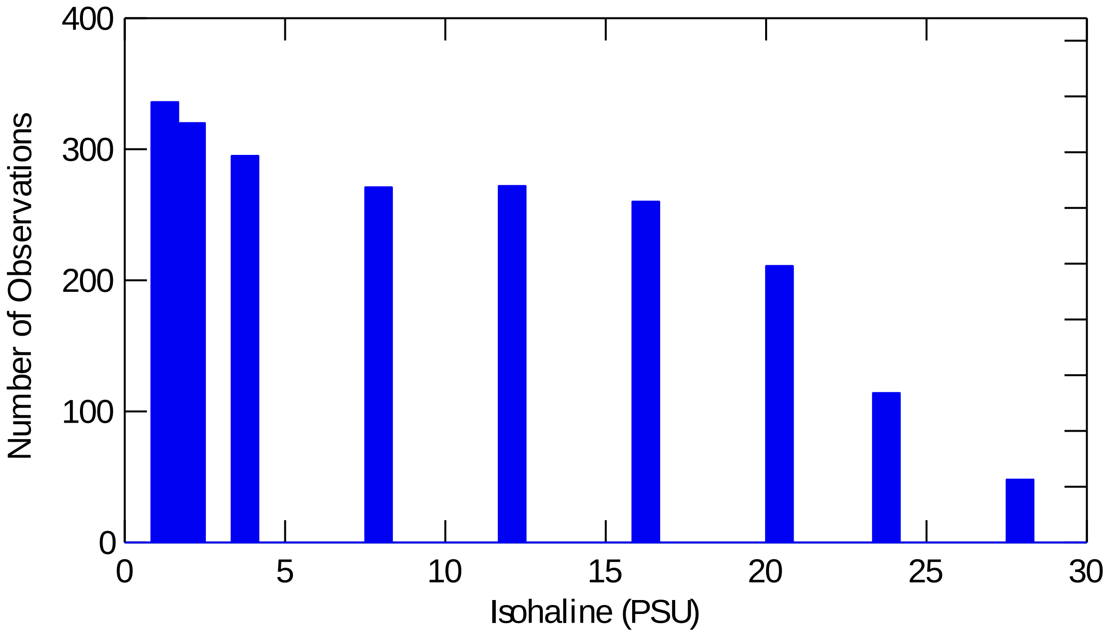


Figure 4-37. Distribution of data available for regression analyses, by isohaline, surface and bottom combined.

For isohaline position, linear model form was optimized with a river kilometer to *ln*(flow) relationship (Figure 4-38 to 4-39). Preliminary regressions indicated that isohaline position estimates, while generally excellent, tended to be underestimated at low flow (estimated too far downstream relative to observed) and over estimated at high flow (not downstream enough). This result was attributed to river volume estimates constructed from a single datum (mean sea level) extrapolated the length of the river. In actuality, water level elevations were expected to increase slightly upstream as a result of both topography and control structures such as Rocky Ford and Downs Dam. Therefore, the effective river volume of the upper river may actually be larger (and flow weighting periods longer) than estimated. River volume is included in the regression indirectly as a component of the DAYS parameter (see Appendix 4-B).

Under high flow conditions, position estimates were often located further upstream than observed. This effect could be attributed to an effective reduction in river volume produced by salinity stratification (bottom minus surface salinity). While stratification appeared downstream of river kilometer 10.0 (the County line), surface and bottom separation of salinity increased greatly downstream of 0.0 km (Cattle Dock Point). Both locations are marked by a widening of the river. As stratification is dependent on buoyancy and shear forces and is also strongly affected by bathymetric features, stratification was not calculated as part of the isohaline position calculation and therefore could not be included isohaline regressions.

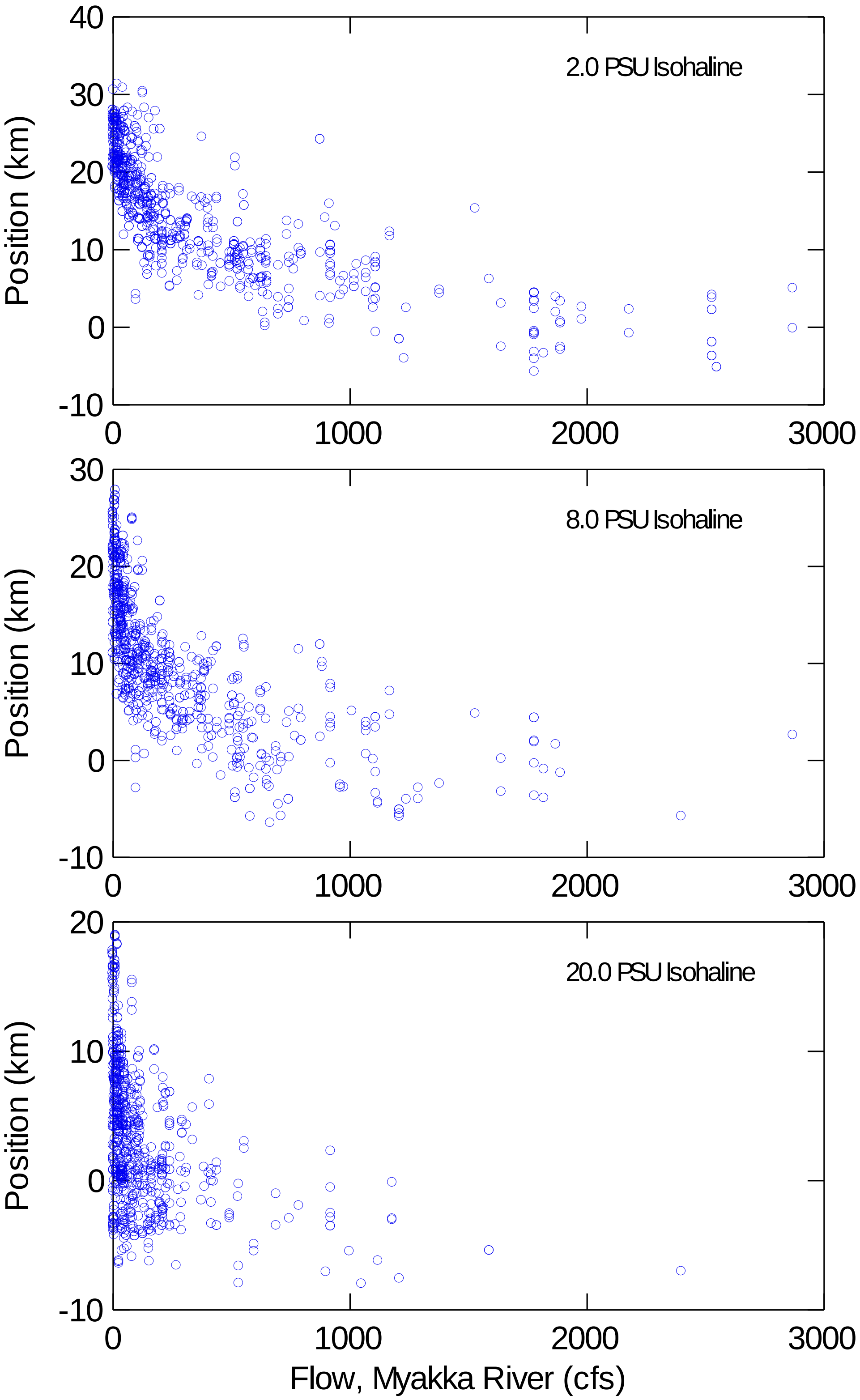


Figure 4-38. **Salinity to flow relationships of selected isohalines illustrating a varying response to flow and leading to differences in model form.**

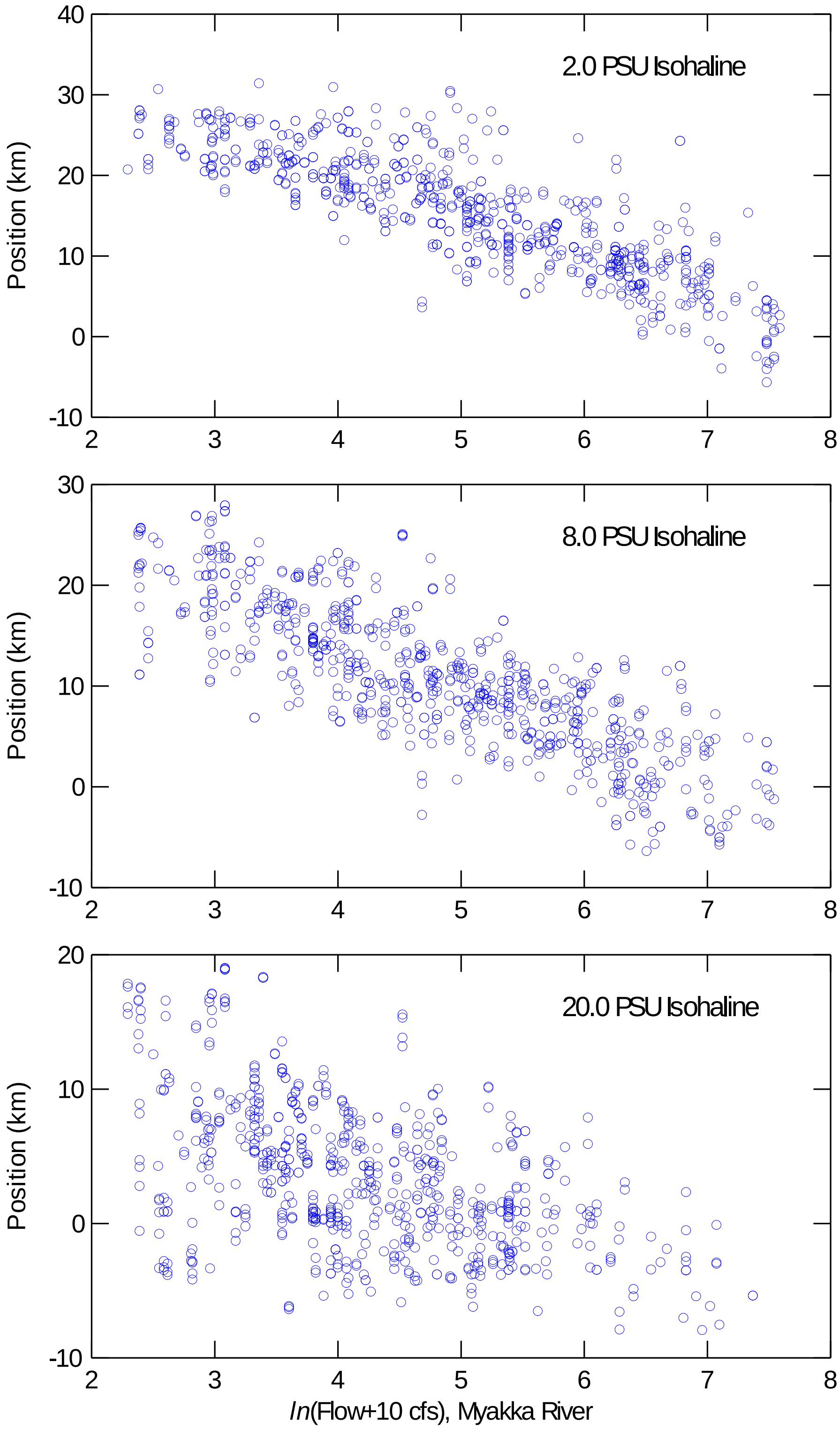


Figure 4-39. Salinity to flow relationships of selected isohalines illustrating differences in model form even after natural log transformation of flow.

Additionally, significant flow terms in the preliminary regressions of higher isohalines were limited to those from the Peace River. In an effort to limit bias in estimated isohaline positions and to maximize the detection of potential influence of the Myakka River on isohaline position, isohaline regressions and simulations were limited to above 0.0 km. Limiting the spatial scope of the regression model improved correlation coefficients for the higher isohalines, most likely by limiting stratification effects as the higher isohaline relationships remained dominated by Peace River flow terms.

Final results of isohaline regressions appear in Table 4-6 as significant independent variables and adjusted multiple r^2 for each isohaline and depth. Regression coefficients were standardized to allow for the comparison of the relative importance of the individual terms. All terms were significant at the p=0.05 level or better. Regressions were significant at p<0.001. Standard errors of the estimate ranged from 2.0 km for the 1.0 psu isohaline to 3.5 km for the 24.0 psu isohaline and generally increased with salinity. Regression verifications uniformly indicated that regression coefficients were robust for the remainder of the isohaline data. Tabulated regression coefficients, detailed regression outputs, residuals analyses, and graphic results of regression verifications appear in Appendix 4-C.

Wind stress or direction was significant for all surface isohaline positions except for 20 and 24 psu. For bottom data, wind stress or direction was significant for the 8.0 psu and lower isohalines. A tidal parameter was significant for all surface isohalines and for many of the bottom isohalines as well. Myakka River flow (as the natural log transform of the variably weighted flow to a maximum of 45 days) was significant for all isohalines of 12.0 psu and below. When Myakka River flow was included as a significant term, it appeared to be the most dominant, based on standardized coefficients, with the exception of 12.0 psu. The natural log transform of the variably weighted flow of the Peace River at Arcadia was significant for all isohalines modeled (1.0 through 24.0 psu), with an increased weight at the higher isohalines, indicating the importance of boundary conditions. Isohalines of 16.0 or greater displayed no significant relationship with Myakka River flows and were correlated with Peace River flows alone. The 8.0 and 12.0 psu surface and bottom isohalines displayed a dependence on change in Myakka River flow rates as well. Flows from Myakkahatchee Creek proved to be significant only for the surface 8.0 psu isohaline.

Table 4-6. Regression models of surface and bottom isohalines in the Myakka River. Regression coefficients are standardized, to indicate relative importance of each term.

Isohaline/Depth	**1.0 S (Surface)**		**2.0S**		**4.0S**		**8.0S**		**12.0S**		**16.0S**		**20.0S**		**24.0S**	
Wind	COS_WD6	0.15	COS_WD6	0.12	COS_WDS26	0.11	COS_WDS26	0.09	COS_WDS23	0.18	COS_WD	0.18	-	-	-	
Tide	-	-	RATE_3M	0.09	RATE_6M	0.10	RATE_6M	0.14	MAXRATE_6	0.10	RATE_3M	0.18	MIN_RATE	-0.23	PRED_M_SEA	0.48
Myakka flow	LNVWT45	-0.73	LNVWT45	-0.69	LNVWT45	-0.60	LNVWT45	-0.53	LNVWT45	-0.33	-	-	-	-	-	-
Peace Flow	LNPVWT45	-0.17	LNPVWT45	-0.24	LNPVWT45	-0.33	LNPVWT45	-0.24	LNPVWT45	-0.54	LNPVWT45	-0.75	LNPVWT45	-0.78	LNPVWT45	-0.76
Myakkahatchee Flow	-	-	-	-	-	-	LNBSVEXWT	-0.23	-	-	-	-	-	-	-	-
Change in Flow	-	-	-	-	-	-	FLORATE5B	0.23	FLORATE5B	0.18	-	-	-	-	-	-
n=		96		88		84		84		83		71		84		30
Adj Mult R^2		0.80		0.85		0.87		0.86		0.81		0.74		0.66		0.49
S.E.of Estimate		2.3		2.1		2.2		2.2		2.7		3.1		2.9		3.2
Isohaline/Depth	**1.0 B (Bottom)**		**2.0B**		**4.0B**		**8.0B**		**12.0B**		**16.0B**		**20.0B**		**24.0B**	
Wind	COS_WD6	0.18	COS_WD6	0.15	COS_WDS26	0.15	COS_WDS23	0.16	-	-		-	-	-	-	-
Tide	RATE_MEANL	0.09	RATE_6M	0.09	RATE_6M	0.11			RATE_MEANL	0.13		-	MAXRATE_3	0.16	-	-
Myakka flow	LNVWT45	-0.74	LNVWT45	-0.74	LNVWT45	-0.60	LNVWT45	-0.54	LNVWT45	-0.47		-	-	-	-	-
Peace Flow	LNPVWT45	-0.15	LNPVWT45	-0.18	LNPVWT45	-0.32	LNPVWT45	-0.36	LNPVWT45	-0.44	LNPVWT45	-0.80	LNPVWT45	-0.77	LNPVWT45	-0.60
Myakkahatchee Flow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Change in Flow	-	-	-	-	-	-	FLORATE5B	0.15	FLORATE5B	0.09	-	-	-	-	-	-
n=		97		89		81		73		116		118		68		39
Adj Mult R^2		0.84		0.88		0.87		0.86		0.78		0.64		0.63		0.34
S.E.of Estimate		2.0		1.9		2.1		2.2		3.0		3.3		3.3		3.5

4.5.5 Isohaline Modeling and Response to Flow

Using the derived regression coefficients, flow records from the Myakka River, Peace River, and Myakkahatchee Creek, and the mean weather and tide variables of the initiating isohaline data, isohaline positions were modeled from October 1, 1980 through 2004, the maximum period for which all three flow variables were available. The baseline simulation period had the advantage of capturing the extremely dry period of 1984-1985, as well as a number of high flow periods. The use of mean weather and tide conditions as inputs were further indicated as the weather and tide variables used for regression development were in hourly time steps while flow data were daily values. In addition, by using mean weather and tide condition values, modeled isohaline positions were both weather and tide neutral and could be compared with one another (but no longer corresponded precisely to interpolated isohaline positions from which regressions were developed). Modeling isohalines with mean weather and tide conditions also permitted a ready comparison of isohaline behavior under possible flow alteration scenarios. Distribution of flow between the period of record (1936-2005) and the baseline period (1980-2004) was illustrated in Figure 4-40 and indicated that modeled isohaline distributions may have been dislocated downstream relative to the entire period of record and indicated that 1980-2004 experienced higher low flow values than did 1936-2005, consistent with the increases in base flows noted since the 1970's.

Isohaline modeling was limited spatially to above river kilometer 0.0. Limits placed on flow variables during regression modeling and range of the initializing data further limited modeling to the maximum flows listed in Table 4-7. The maximum modeled Myakka River flow of 2,115 cfs was selected based on the 99th percentile of the parameter within the initiating data.

Table 4-7. Maximum flows (and parameter designations) for isohaline regression models.

Flow Term	Maximum cfs
Variably weighted flow, Myakka River, 45 day maximum (VWT45)	2,115
Change in flow rate, Myakka River (FLORATE5B)	+/- 200
Variably weighted flow, Peace River, 45 day maximum (PVWT45)	8,000
Variably weighted flow, Myakkahatchee Creek, 45 day maximum (BSVWT45)	600

A time series of selected isohalines modeled with mean weather and tide appears in Figures 4-41 to 4-43 together with observed isohalines. Lack of a modeled isohaline may be due to missing Myakkahatchee Creek flow data or any flow data exceeding the flow terms described in Table 4-7, above. While recalling that isohalines are modeled with mean weather and tide data while observed isohaline position was subject to specific conditions, the agreement between observed and modeled provides visual confirmation of the strength of the regressions. Surface and bottom modeled isohaline positions were typically offset to the small degree expected for the minimal stratification in the river.

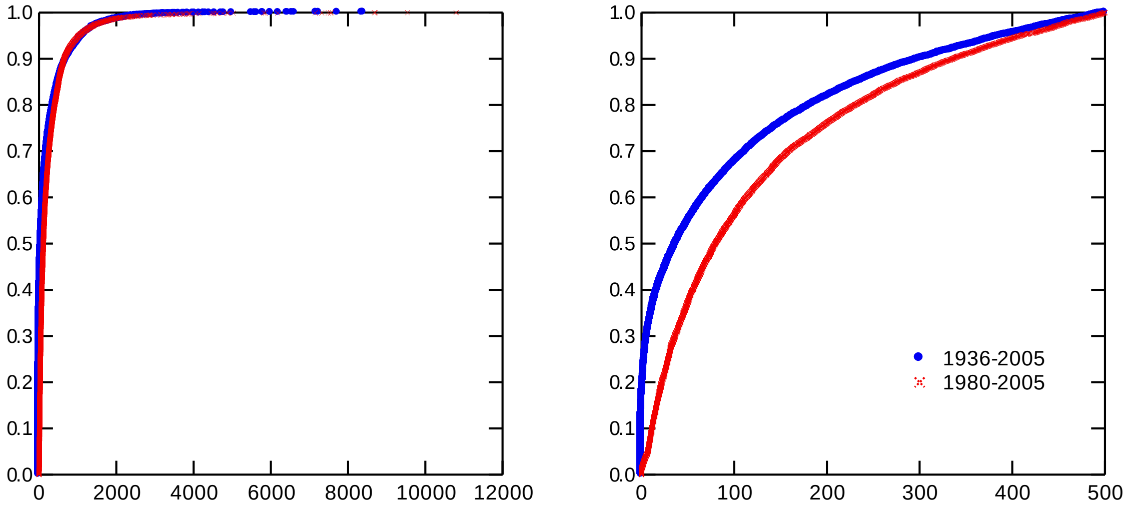


Figure 4-40. **Comparison of daily flow distribution between the period of record (1936-2005) and the modeled baseline period (1980-2005).**

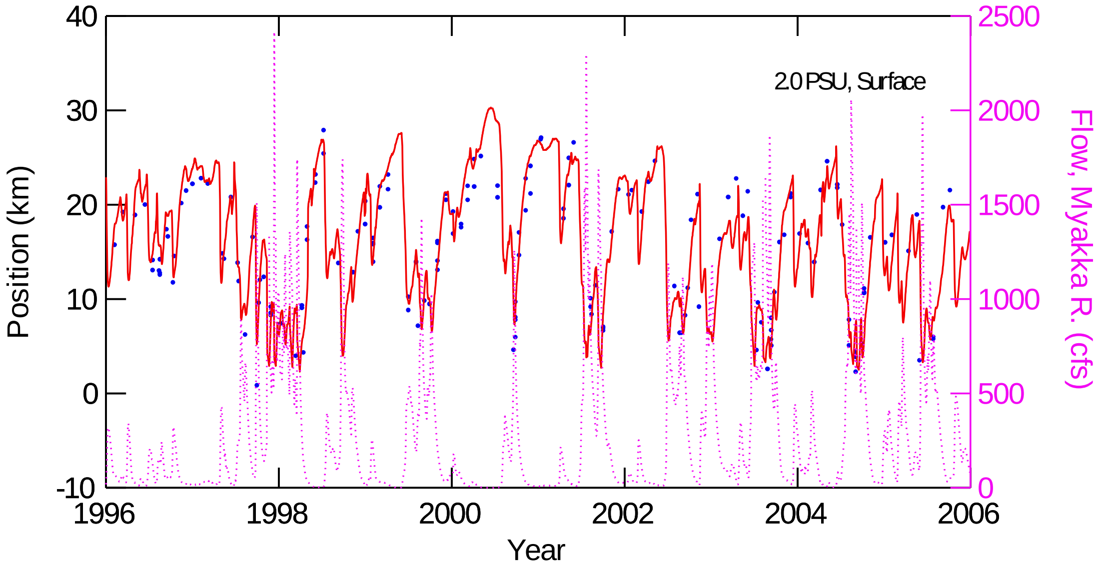


Figure 4-41. **Modeled surface 2.0 psu isohalines (weather and tide neutral), daily flow of the Myakka River, and observed isohaline position (blue circles, with specific weather and tide).**

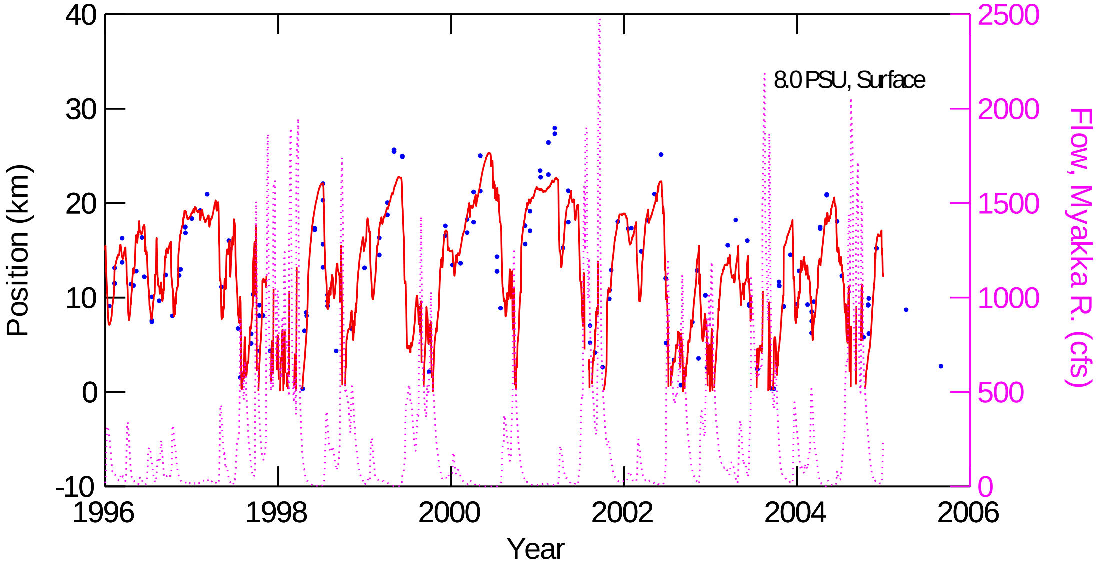


Figure 4-42. Modeled surface 8.0 psu isohalines (weather and tide neutral), daily flow of the Myakka River, and observed isohaline position (blue circles, with specific weather and tide).

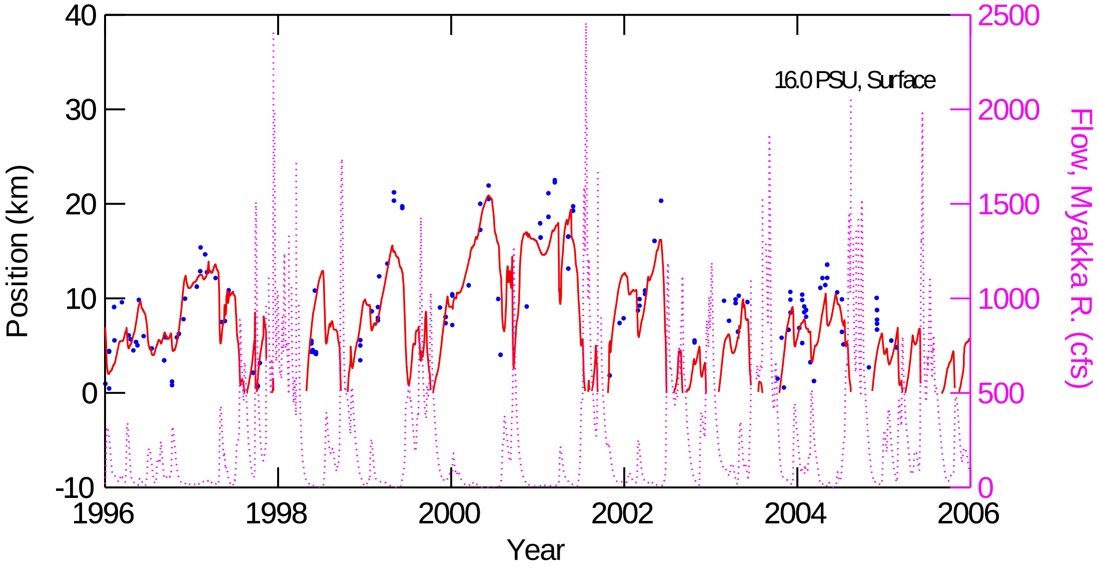


Figure 4-43. Modeled surface 16.0 psu isohalines (weather and tide neutral), daily flow of the Myakka River, and observed isohaline position (blue circles, with specific weather and tide).

Selected modeled surface isohalines and time periods were illustrated in Figures 4-44 to 4-47. Myakka flows were truncated at or below 2115 cfs. Even during the extremely dry period of 1984, the 24.0 psu isohaline was only present above 0.0 km for some portions of the year. All isohalines did not display precisely the same timing of amplitudes, due to the differing flow variables in each regression model. In 1997, all isohalines were not simulated throughout the year as the latter part of 1997 was extremely wet and exceeded the flow ranges from which regressions were developed. Despite being constructed from differing variables, however, modeled isohalines generally responded in a coherent fashion, as illustrated in early April and early September, 1997.

Similarly, modeled data from 2002 displayed an appropriate response to flow increases. In August, however, the 16.0 psu isohaline was illustrated as further upstream than the 8.0 psu isohaline. The modeled transposition of isohalines was the result of flow increases in the Peace River that were not mirrored in either the Myakka River or Myakkahatchee Creek and the differing variables contained within each regression. Similar transpositions of modeled isohalines occurred when flow records or even ratios of flow deviated substantially from the typical initiation condition values or ratios.

4.5.6 Fixed Station Regressions

Regressions of fixed station salinity at the surface and bottom, residuals analyses, verifications and modeling of salinity estimates were conducted, similarly to those described for isohaline regressions. Regression input data were again limited to weighted Myakka flows of 2115 cfs or below. Some differences in optimum linear model form were present as above certain flows, salinities reached zero and no longer varied with increasing flow, particularly for upper river stations (Figures 4-48 to 4-50).

For salinity at fixed stations, salinity to *ln*(flow) provided the best results at the most downriver station, while the remainder of the stations exhibited best fits with *ln*(salinity) to *ln*(flow) forms. Even with this alteration, distributed residuals were present for stations at and above U.S. 41 (~12 km). Residuals indicated a critical value of Myakka River flow above and below which relationships were more linear but differed from one another. Regressions were therefore conducted piecewise, with flow breakpoints of 400 cfs for surface data at the County line (~12 km), 120 cfs for surface and bottom data near Rambler's Rest (~22 km), and 50 cfs near Snook Haven (~28 km). As salinities were very low, with little variation under the higher flow conditions, regressions of the upper flow range often resulted in no significant Myakka River flow terms.

The drawback to the *ln*(salinity) model form, however, arose in the back transformation of salinity. While the model minimized the residuals of *ln*(salinity), the difference between observed and modeled salinity ($e^{(ln[\text{salinity}])}$) was greatest for the high salinity portion of the model, at times computing physically unreasonable values. Regardless of this shortcoming, the models captured the breakpoints in flow at which low salinity values began to rise (Figure 4-51). As such, the *ln*(salinity) forms of fixed station models were judged to provide a useful tool for determining threshold flows for the Myakka River and for establishing monitoring stations and station-specific salinity criteria.

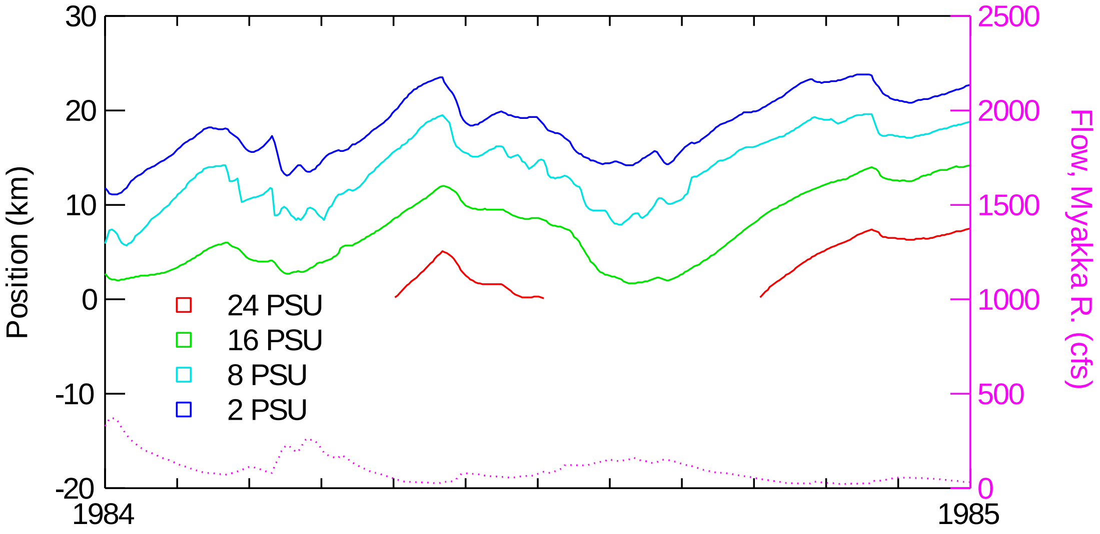


Figure 4-44. **Modeled time series of selected isohalines and Myakka River flow during 1984.**

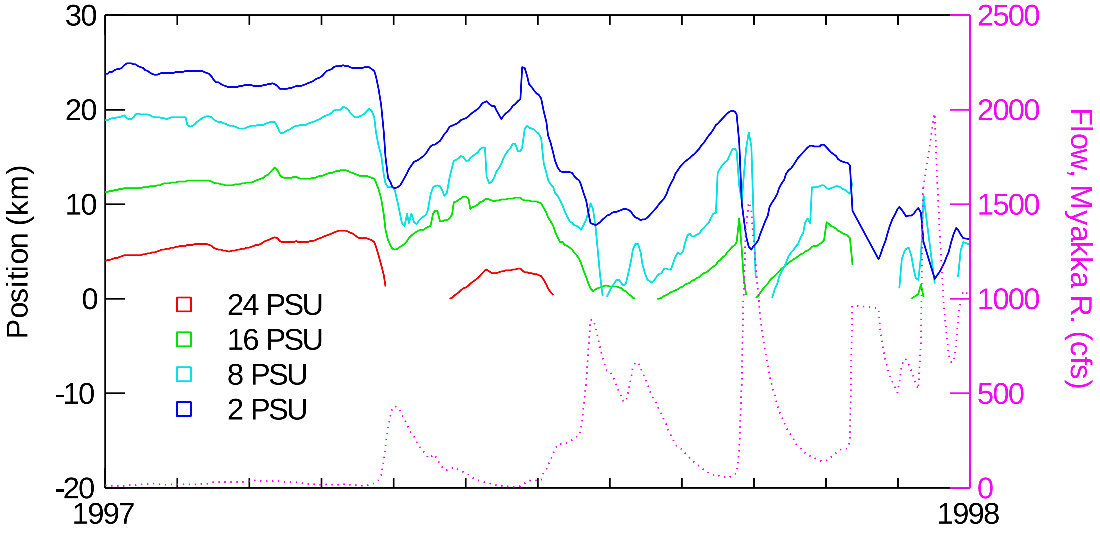


Figure 4-45. **Modeled time series of selected isohalines and Myakka River flow during 1997.**

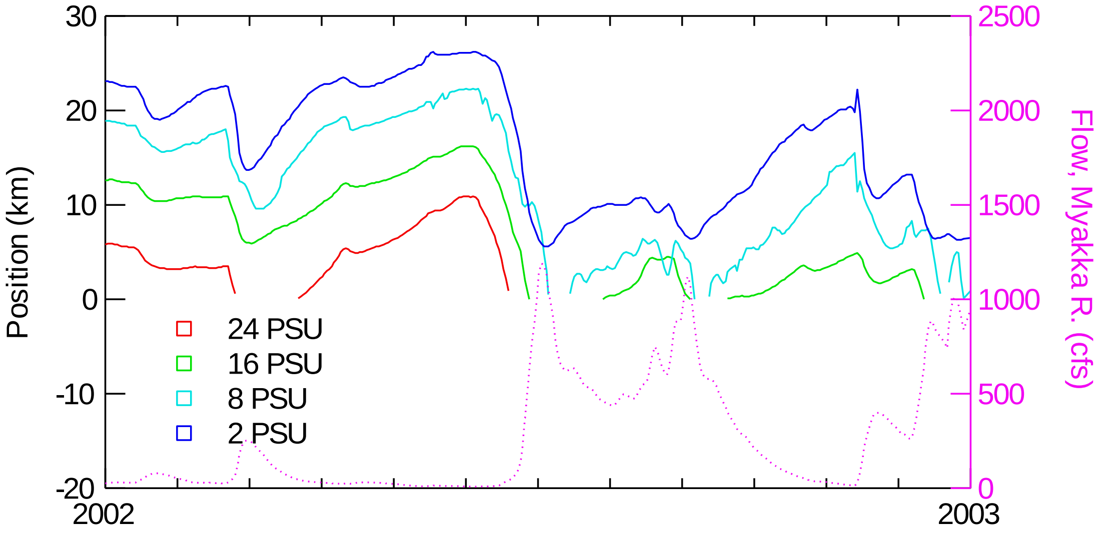


Figure 4-46. Modeled time series of selected isohalines and Myakka River flow during 2002.

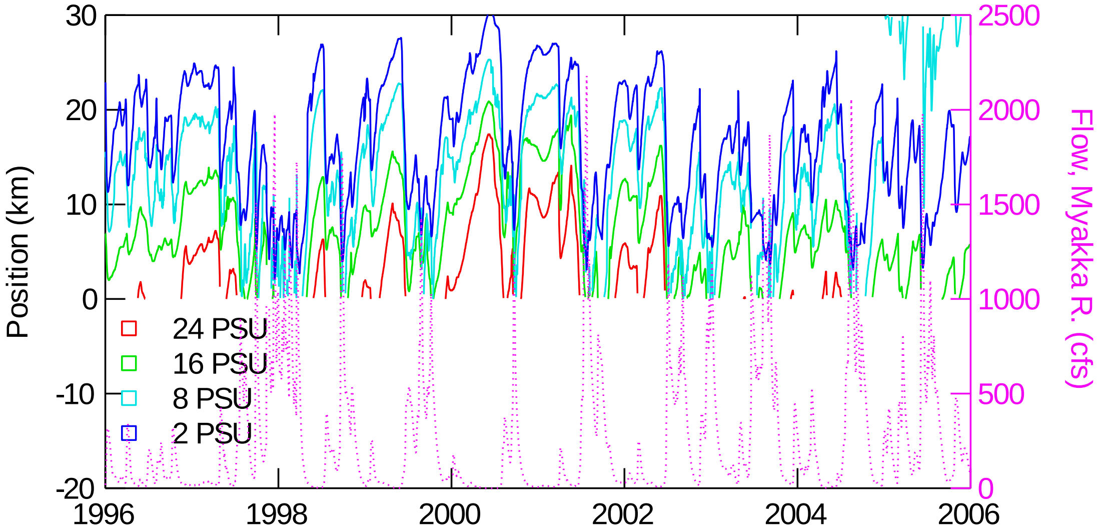


Figure 4-47. Modeled time series of selected isohalines and Myakka River flow during 1996-2006.

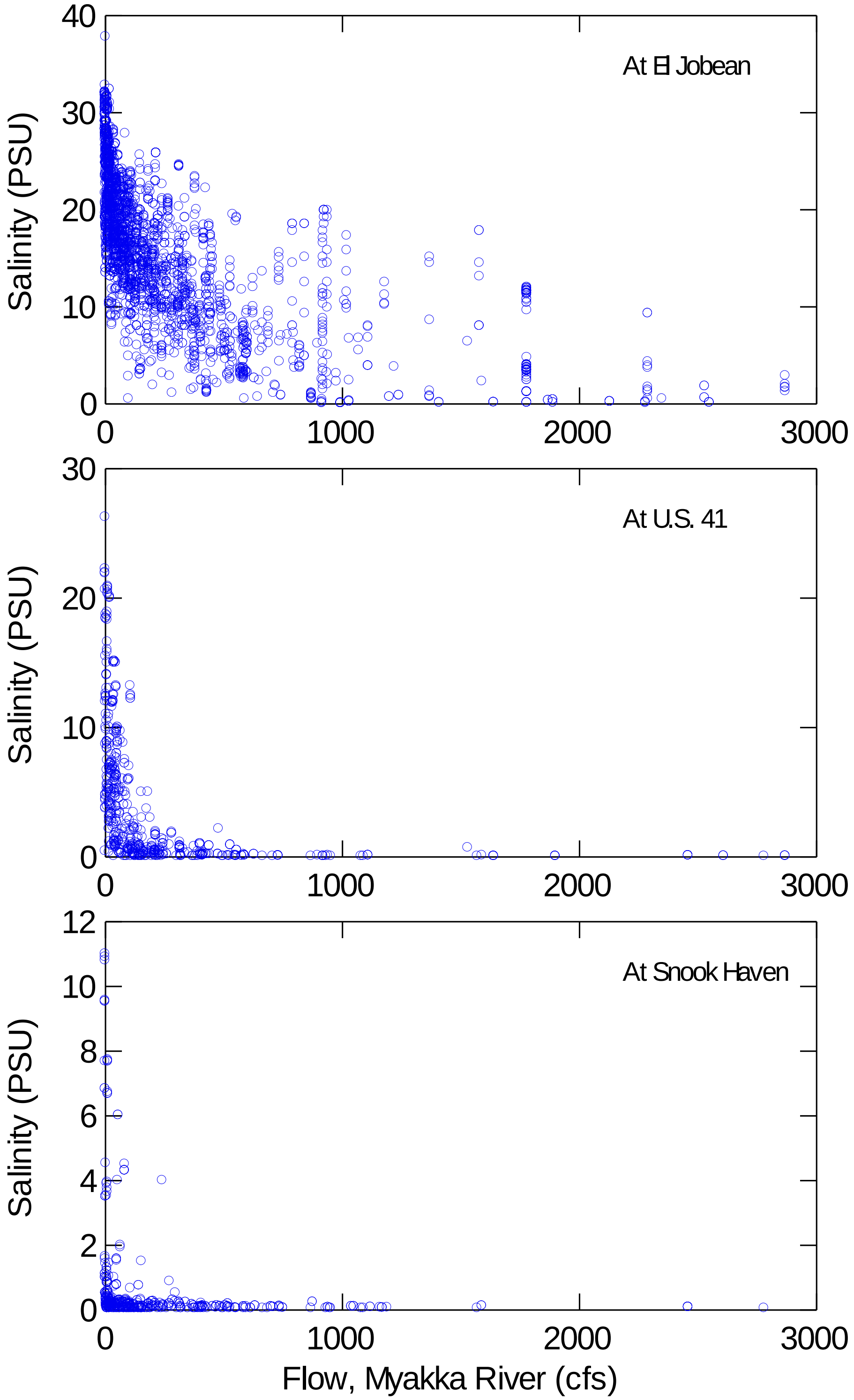


Figure 4-48. **Selected fixed station salinity to flow relationships illustrating differences in model form.**

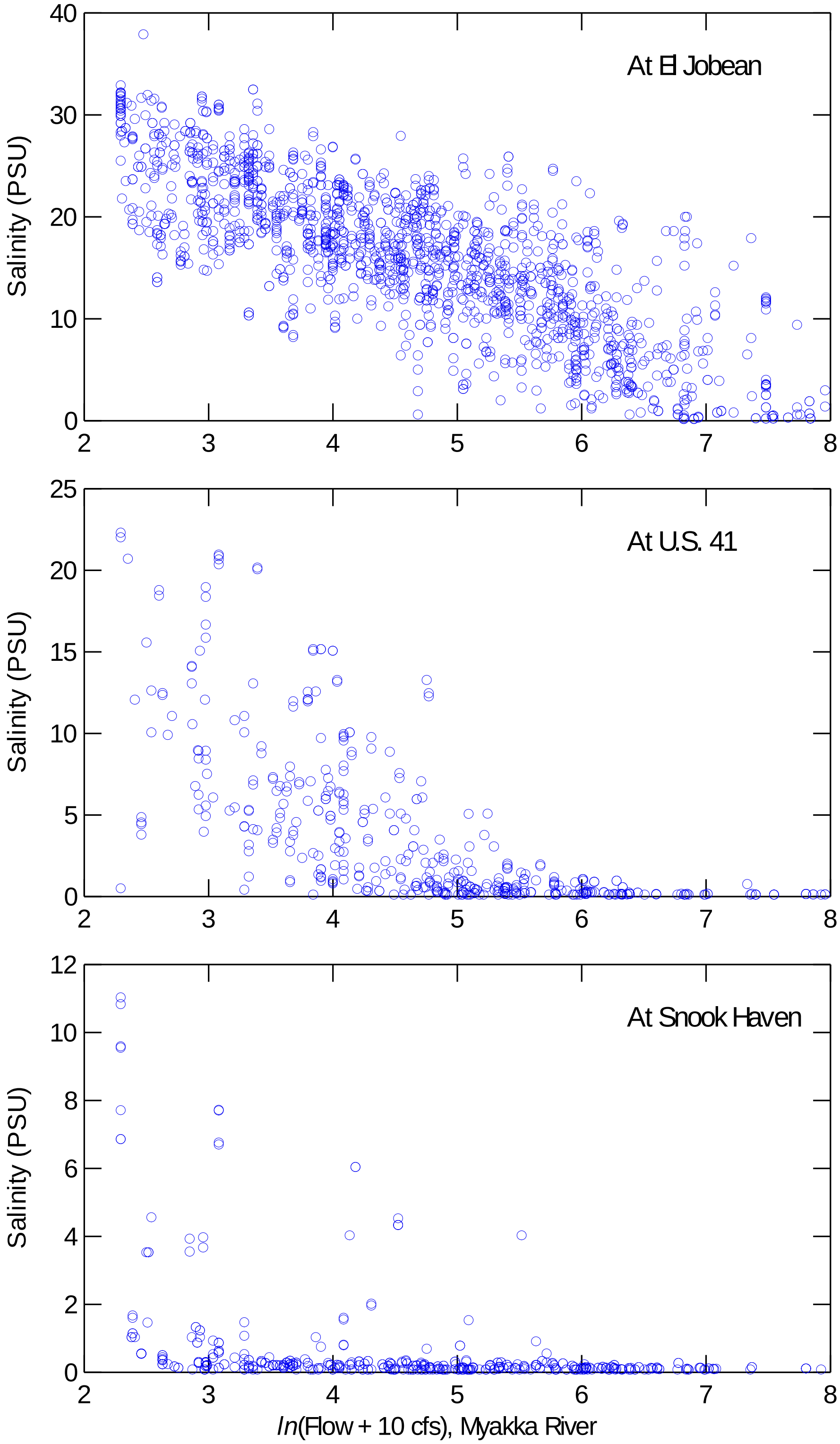


Figure 4-49. Selected fixed station salinity to ln(flow) relationships illustrating differences in model form.

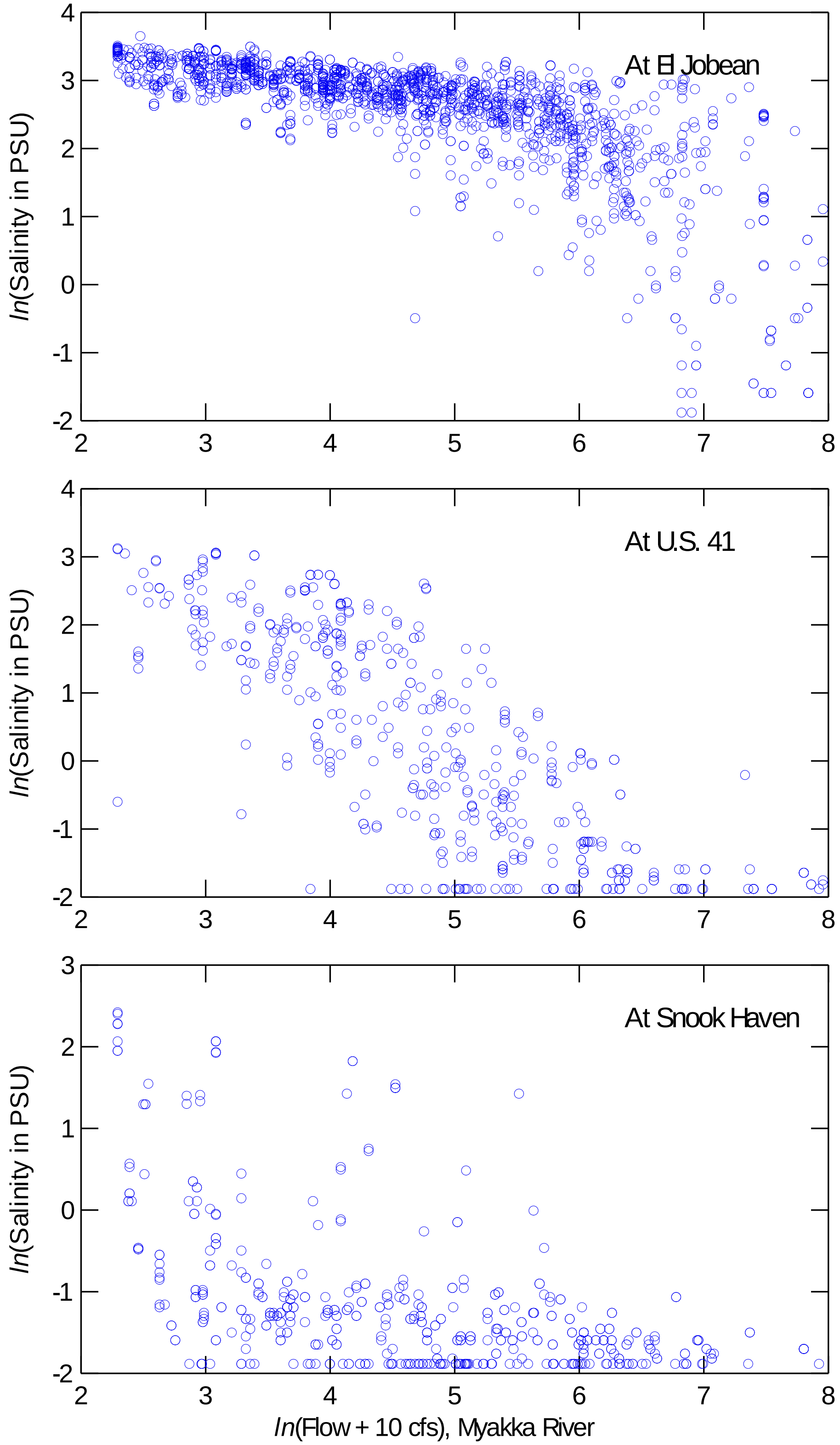


Figure 4-50. **Selected fixed station ln(salinity) to ln(flow) relationships illustrating differences in model form.**

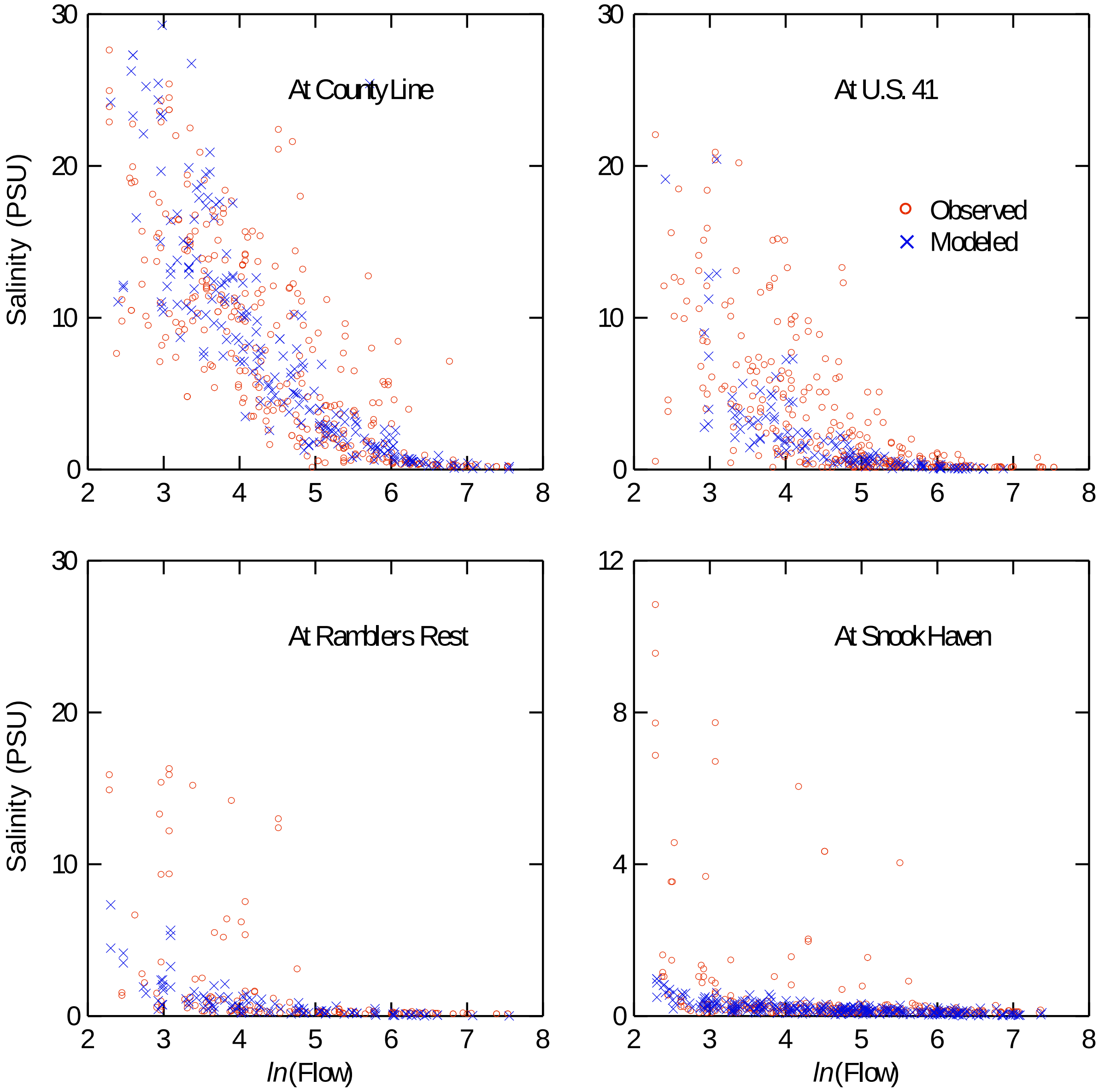


Figure 4-51. **Comparison of observed and back transformed modeled salinity as a function of the natural log transformation of variably weighted flows at the four stations where ln(salinity) to ln(flow) model forms were the most appropriate.**

Results of fixed station salinity regressions appeared in Table 4-8 as standardized coefficients. Appendix 4-D contains detailed regression outputs, residuals analyses, and model verification results, analogous to that provided for isohaline modeling.

Significant flow variables for salinity modeling were more varied between stations than was observed for the isohaline modeling. A portion of this result was attributable to the more varied data set used for input. As data were selected based only on geographic location, many agency efforts were included, even efforts where only a single station was sampled in a day. These data necessarily captured a larger variety of flows. Isohaline modeling, on the other hand, was restricted to those computed from pairs of stations relatively close together. These data, therefore, were generally collected during efforts in which multiple stations were sampled on the river, with a number of isohalines sampled under similar flow conditions.

Tide and wind variables were significant at many stations and depths. Flows from the Myakkahatchee Creek were significant for the surface of the stations at U.S. 41 and downstream. Since U.S. 41 is upstream of the confluence of Myakkahatchee Creek with the river, this was another example of downstream flows influencing boundary conditions for upstream stations. The Peace River flows were again significant for stations in both the upper and lower river. Myakka River flows generally were not significant for the higher flow regressions of surface data at U.S. 41 and above. When significant, Myakka River flows typically accounted for the most variation in salinity. The change in flow rate of the Myakka River was a significant variable for surface salinity at Snook Haven under low flow conditions.

4.5.7 Fixed Station Modeling and Response to Flow

Modeling of salinity at the selected fixed stations was conducted analogously to isohaline position modeling with the exception that, as kilometer positions were fixed, no iterative process was required to compute the required flow weighting terms. Based on the limits placed on Myakka River flow in the input data (2,115 cfs, 99%-ile of input flows), modeling limits for all flow terms were established and were listed in Table 4-9. Modeling was performed for 1980-2005.

Table 4-8. Regression models of fixed station salinity in the Myakka River. Regression coefficients are standardized.

Km – Designation	**28 - SH**		**28 – SH**		**22 - RR**		**22 – RR**		**18 – 41**		**18 - US41**		**12 - CL**		**4 - EJ**	
Flow Range	50-2115		0-49		120-2115		0-119		400-2115		0-399		0-2115		0-2115	
Dependent Variable	LNSAL		LNSAL		LNSAL		LNSAL		LNSAL		LNSAL		LNSAL		SAL_PSU2	
Wind	-	-	COS_WDS26	0.35	-	-	COS_WD	0.27	COS_WD6	0.43	COS_WDS26	0.17	COS_WD	0.10	-	-
Tide	MAXRATE_3	0.23	RANGE_TIDE	-0.23	-	-	MAXRATE_6	0.33	-	-	RATE_MEANL	0.17	TIDE_MEANL	-0.18	RATE_6M	0.22
Myakka Flow	-	-	LNVWT45	-0.51	-	-	LNVWT45	-0.50	-	-	LNEXWT7	-0.75	LNEXWT7	-0.57	-	-
Peace Flow	LNPVEXWT	-0.50	-	-	LNPEXWT7	-0.63	-	-	-	-	-	-	-	-	LNPVEXWT	-0.57
Myakkahatchee Flow	-	-	-	-	-	-	-	-	LNBSVWT30	-0.52	-	-	LNBSEXWT7	-0.29	LNBSVWT45	-0.33
Change in Flow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
n=		205		49		45		47		18		82		120		147
Adj Mult R^2		0.27		0.42		0.38		0.53		0.35		0.62		0.81		0.82
S.E. of Estimate		0.72		0.73		0.20		0.94		0.38		0.98		0.62		3.02

Km – Designation	**28 - SH**		**28 – SH**		**22 - RR**		**22 – RR**		**-**	**-**	**18 - US41**		**12 - CL**		**4 - EJ**	
Depth	B		B		B		B				B		B		B	
Flow Range	50-2115		0-49		120-2115		0-119		-	-	0-2115		0-2115		0-2115	
Dependent Variable	LNSAL		LNSAL		LNSAL		LNSAL		-	-	LNSAL		LNSAL		SAL_PSU2	
Wind	-	-	-	-	-	-	COS_WDS23	0.37	-	-	COS_WDS2	0.22	-	-	-	-
Tide	MAXTIDE_6	0.36	-	-	-	-	MAXRATE_6	0.27	-	-	TIDE_MEANL	-0.14	MAXRATE_6	0.26	RATE_6M	0.22
Myakka Flow			LNVWT45	-0.59	LNEXWT7	-0.67	LNVWT45	-0.33	-	-	LNVEXWT	0.51	LNEXWT7	-0.50	LNVEXWT	-0.41
Peace Flow	LNPVWT45	-0.64	-	-	-	-	LNPVEXWT	-0.32	-	-	LNPEXWT7	-0.34	-	-	LNPEXWT7	-0.25
Myakkahatchee Flow	-	-	-	-	-	-	-	-	-	-	-	-	LNBSVWT30	-0.41	LNBSVEXWT	-0.21
Change in Flow	-	-	FLORATE3	0.39	-	-	-	-	-	-	-	-	-	-	-	-
n=		32		22		38		35				57		69		111
Adj Mult R^2		0.28		0.43		0.43		0.67				0.81		0.85		0.74
S.E. of Estimate		0.50		0.85		0.20		0.78				0.67		0.55		3.28

Table 4-9. Maximum flows for fixed station salinity regression models.

Flow Term	Maximum cfs
Variably weighted flow, Myakka River, 45 day maximum (VWT45)	2,115
Change in flow rate, Myakka River (FLORATE3)	+/- 500
Variably weighted flow, Peace River, 45 day maximum (PVWT45)	8,000
Variably weighted flow, Myakkahatchee Creek, 45 day maximum (BSVWT45)	600

Mean weather (wind and tide) conditions from the initiating data were used for modeling to produce weather-neutral modeled salinity. Where the dependent variable was *ln*(salinity), back-transformations were performed to present modeled data in salinity units. Figures 4-52 to 4-53 illustrated the 1996-2005 modeled, weather-neutral surface salinity together with salinity observations under specific weather conditions to illustrate the degree of fit of final regressions. General patterns are well captured and when salinity was elevated, the modeled bottom salinity was generally greater than the surface salinity, consistent with observed data.

A final verification was possible by superimposing regression modeled, weather neutral, daily salinity on the daily values provided by the U.S. Geological Survey's continuous recorders (Figures 4-54 and 4-55). These data are completely independent and indicate an excellent overall fit at stations in the upper, middle, and lower river.

Due the larger variety of flow terms in the fixed station regressions (i.e. linearly weighted flow for one station, exponentially weighted flow for another), there were more salinity transpositions (the modeled salinity of a station higher than the salinity of a station further downstream on a given day) than for the isohaline modeling. Without forcing the use of the same flow variable(s) for each station and suffering the degradation in r^2 values, this result was unavoidable. Distributions of the modeled data (Figure 4-56) indicated that the overlap was relatively minimal and generally limited to higher salinity values. For the regressions which contained only a single flow variable of either the Myakka River or Myakkahatchee Creek, modeled salinity could plateau and remain fixed when the respective flows reached and remained at 0.0 cfs.

4.5.8 Fixed Station Response to Flow and Other Variables

The most value of the continuous recorders was in capturing a unique series of climatic events in 2004 (Figure 4-57) which illustrated a combined response to weather-driven stage, rainfall, and flow. The decreases in barometric pressure indicated the nearby passage of hurricanes Charley (A), Frances (B), and Jeanne (C). While the stage record was not available for Hurricane Charley at El Jobean, the other two storms resulted in abrupt increases in stage from wind driven water level increases. Flow and subsequent stage increases from rainfall then followed the passage of Charley and Frances, and to a lesser extent, Jeanne. Hurricane Ivan (D) passed the region farther offshore rather than crossing the state, and resulted in slight wind-driven stage increase with little attendant rainfall.

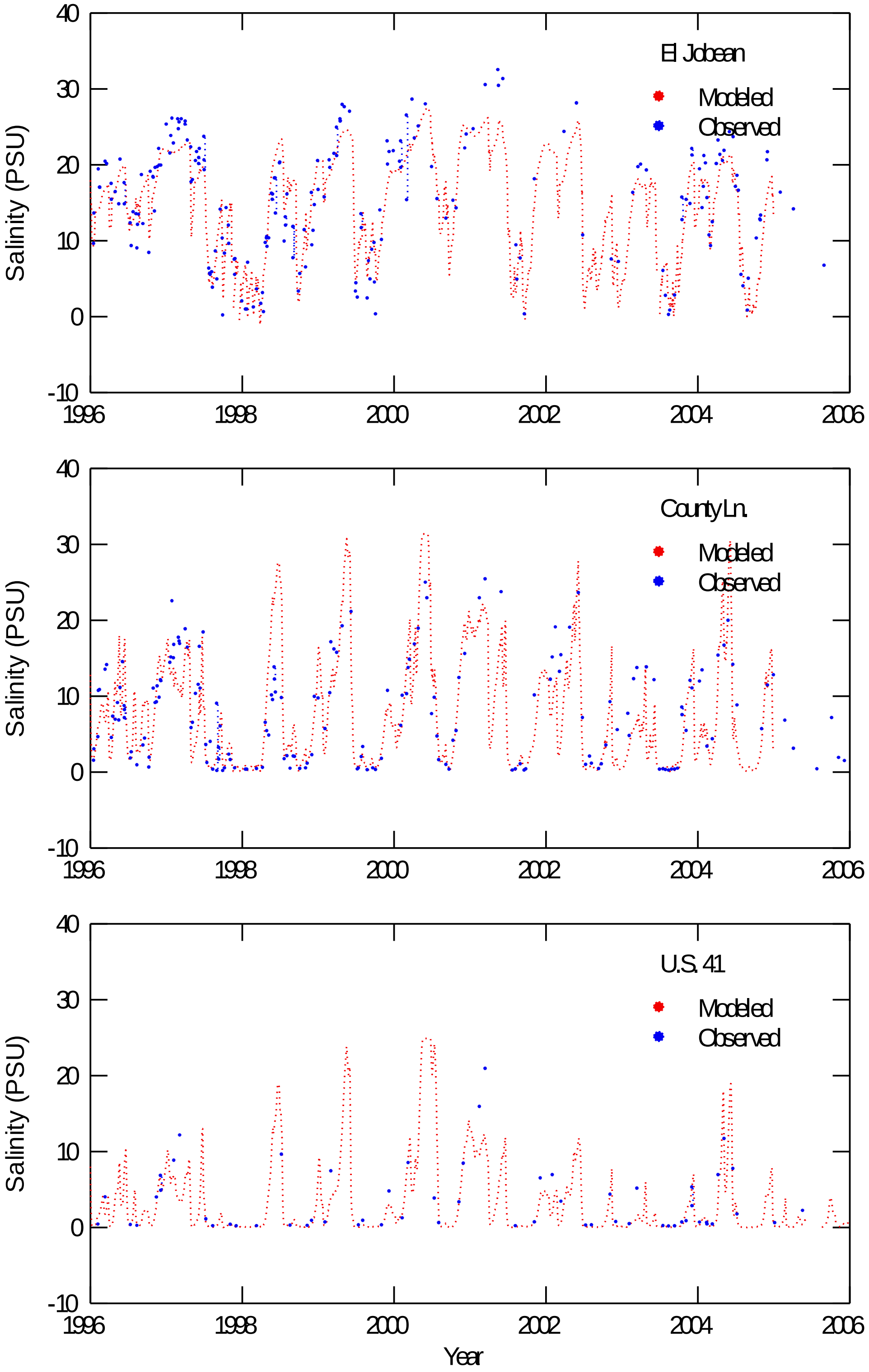


Figure 4-52. **Modeled surface salinity at fixed stations (weather neutral) compared to salinity observations (circles, under specific weather conditions).**

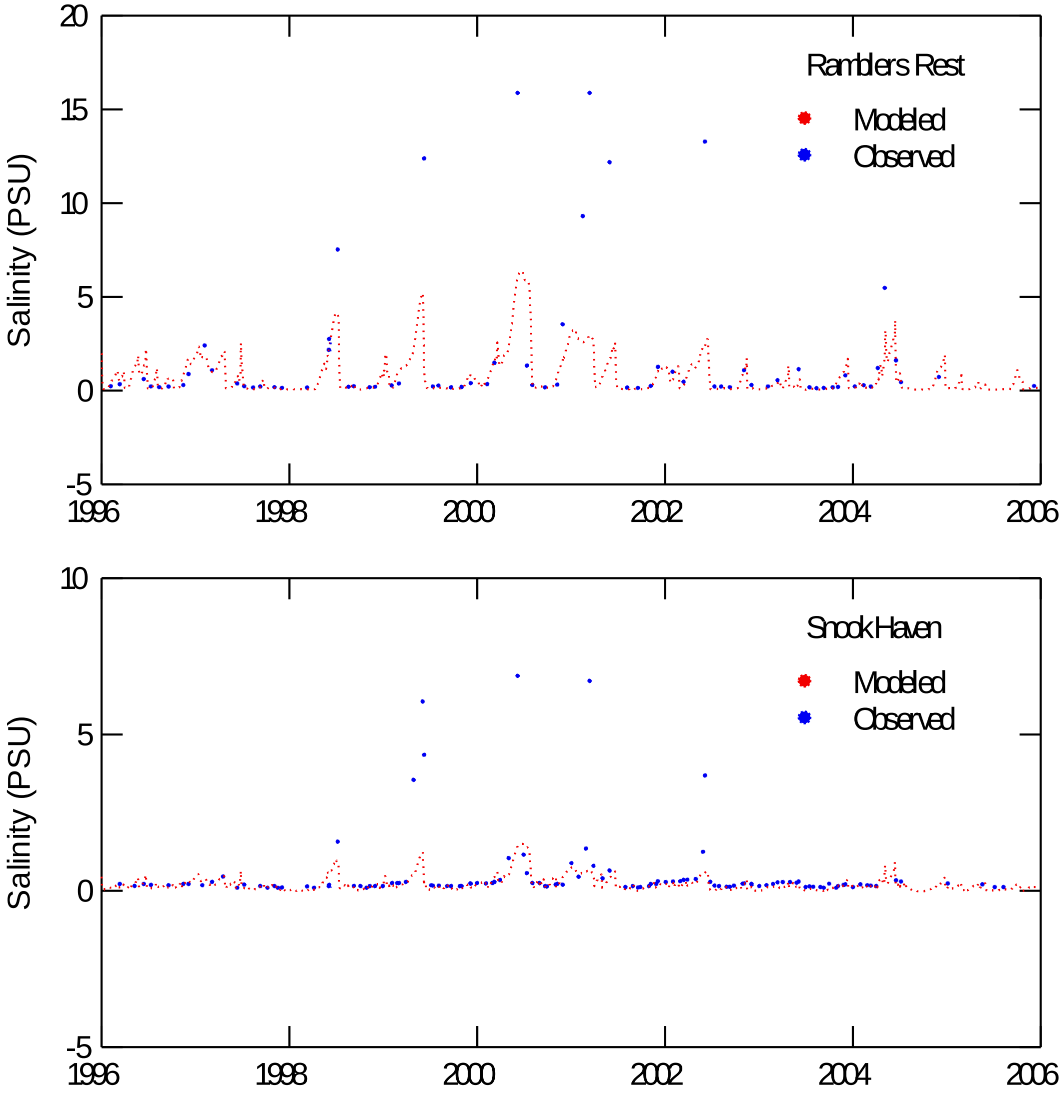


Figure 4-53. **Modeled surface salinity at fixed stations (weather neutral) compared to salinity observations (circles, under specific weather conditions), continued. Note scale change among figures and relative to prior figure.**

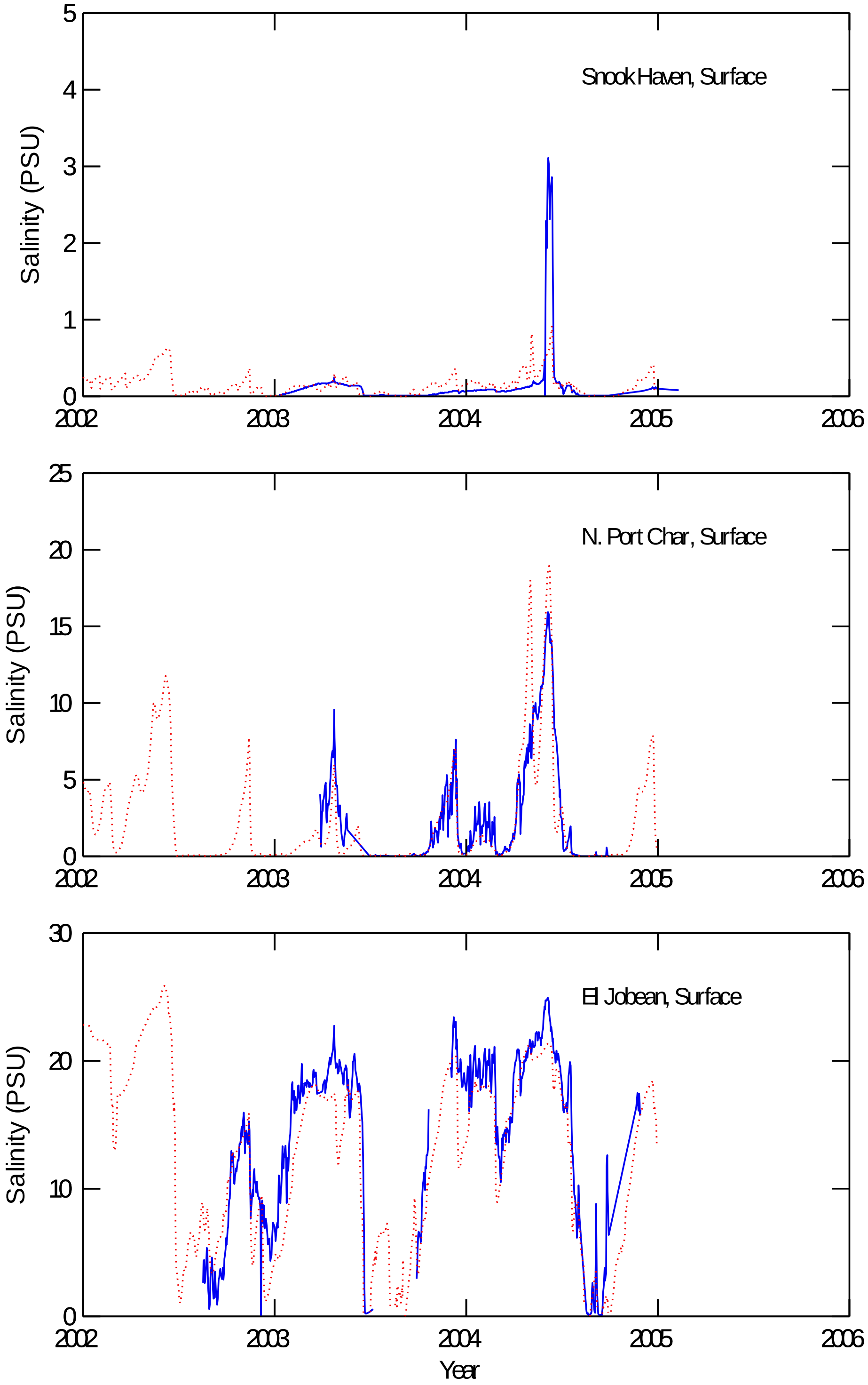


Figure 4-54. **Modeled daily surface salinity at fixed stations (weather neutral, dashed) compared to continuous salinity observations (specific weather conditions, solid). Note scale change.**

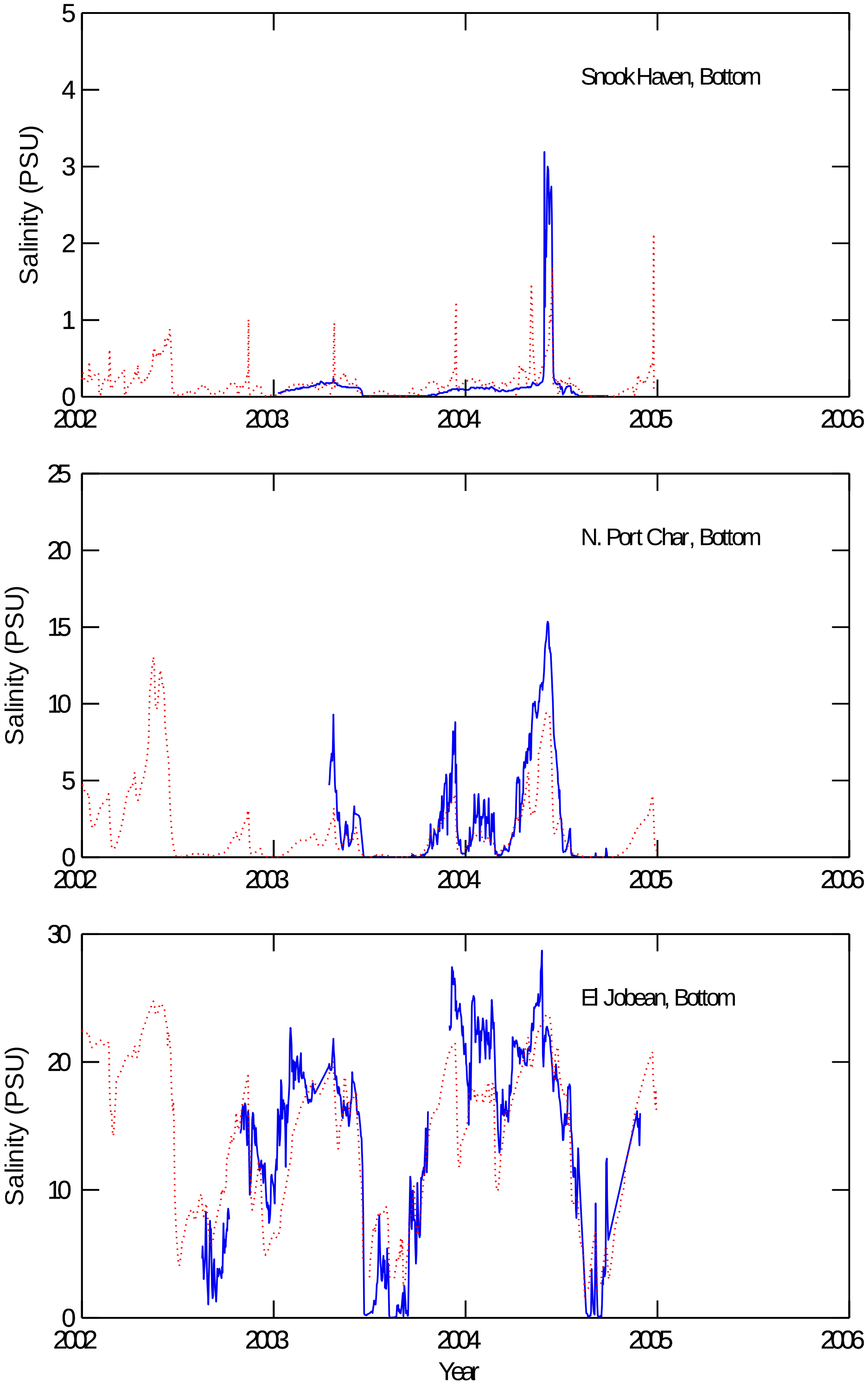


Figure 4-55. Modeled daily bottom salinity at fixed stations (weather neutral, dashed) compared to continuous salinity observations (specific weather conditions, solid). Note scale change.

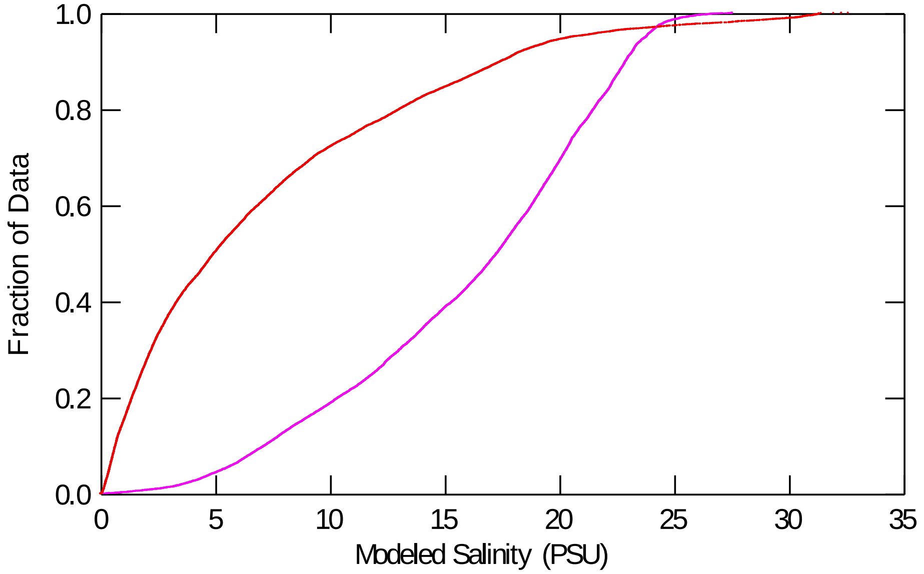


Figure 4-56. Distribution of modeled salinity, 1980-2005, by fixed station examined.

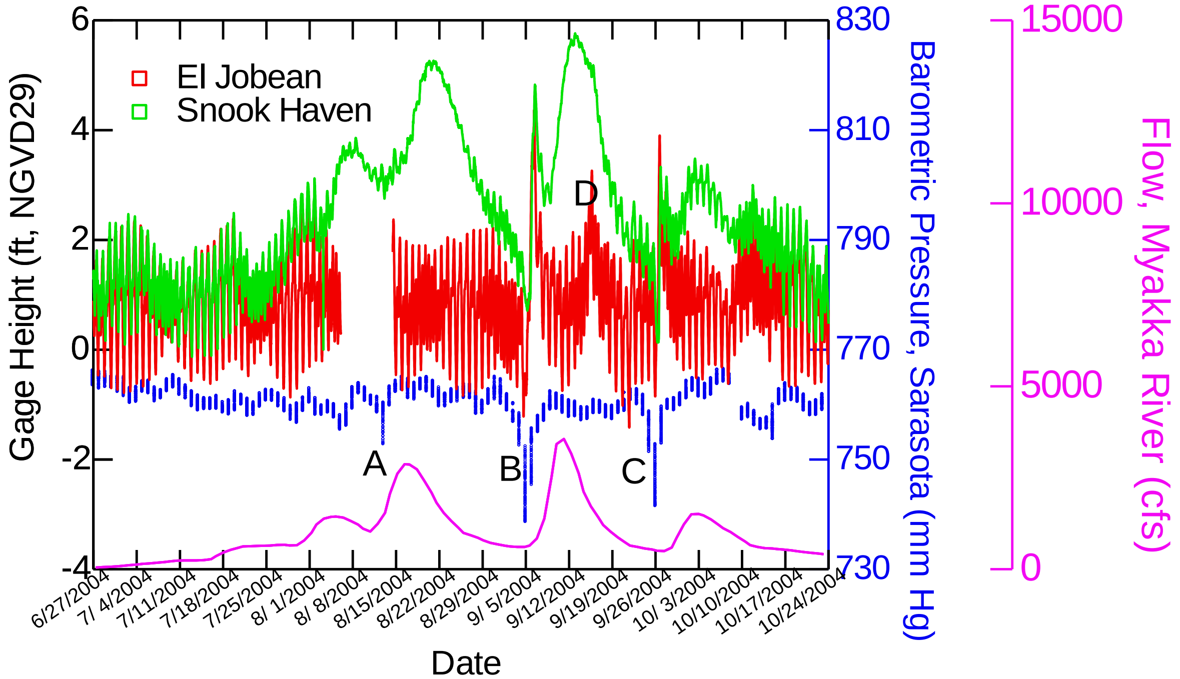


Figure 4-57. Time series of stage, weather, and flow during an active hurricane season (A – Charley, B – Frances, C – Jeanne, D – Ivan).

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Examination of the data above in more detail, together with salinity records (Figure 4-58) was interesting in that salinity increases resulted from the wind-driven stage increase in **advance** of Hurricanes Frances (A) and Jeanne (B). The higher tidal stage from Ivan (C), however, was insufficient to increase salinity in the presence of high flow levels produced by rainfall from Frances, and salinity remained low at EL Jobean. Additional observations were that high flows at the reference gage site (September 10-11) preceded maximum stages recorded at Snook Haven by two to three days. The series of observations was a clear example of the necessity of including weather parameters in any complete simulation of salinity, as salinity increased from 0 to 15 psu during a time when flow increased only marginally.

4.4 Temperature

Observed Temperature

Monthly temperature distributions (1996-2005) appear in Figure 4-59 and indicated that June, July, and August were the warmest months. The winter months exhibited a larger range of temperature. On a quarterly basis there was no significant variation in temperature between river intervals although the median temperatures of the upper river appeared slightly warmer in the colder months (Figure 4-60). Over the longer term data set, annual maximum temperatures from 1975-2005 (Figure 4-61) appear to display an increasing trend of up to 3° C, a trend not accounted for by any changes in the time of day of sampling.

Continuous temperature data did not indicate a consistent difference between upriver and downriver locations (Figure 4-62), in accordance with the discrete observations discussed above. While seasonally specific patterns might be inferred from small sections of Figure 4-62 above, further examination of both Figure 4-63 and discrete sampling data over multiple years indicated that the pattern of temperature with kilometer was far from uniform during either warm or cold months. Figure 4-63 illustrates both negligible differences during September 2004, and a warmer downstream in August (by approximately the level of diurnal changes). During any individual month or sampling, temperature differences between upstream and downstream locations were generally 2-3 ^{o}C or less, but varied as to the warmer location, and did not provide a consistent relationship with either season or time of day of sampling.

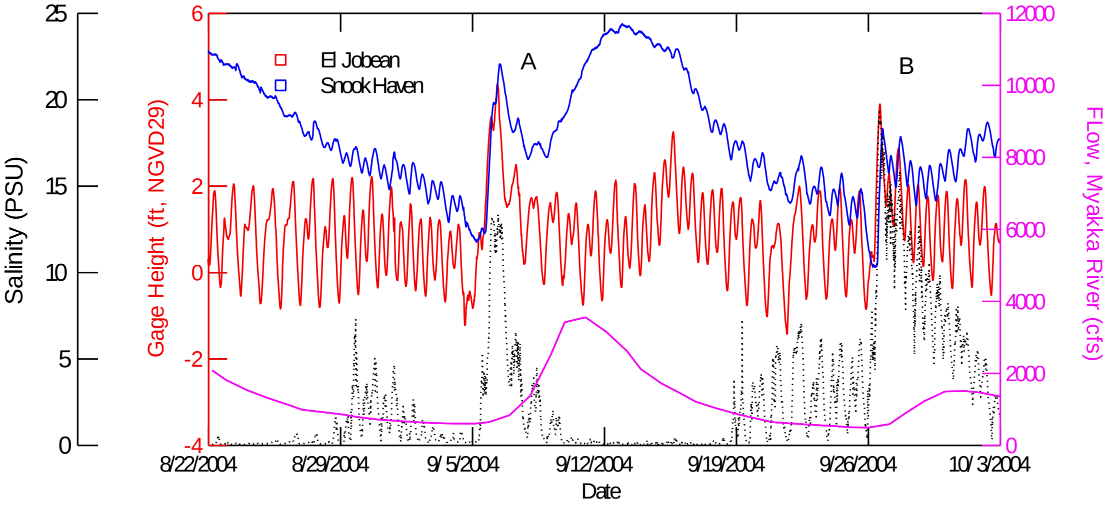

Figure 4-58. **Detail from previous figure with a time series of salinity, stage, and flow during the passage of three hurricanes.**

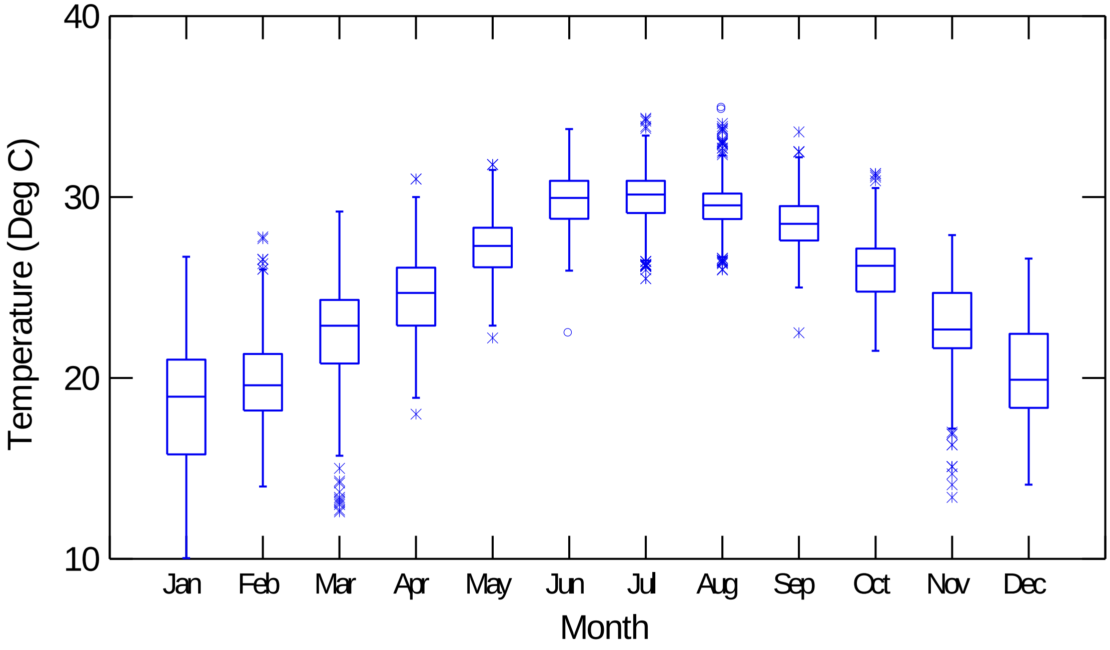

Figure 4-59. **Distribution of temperature by month.**

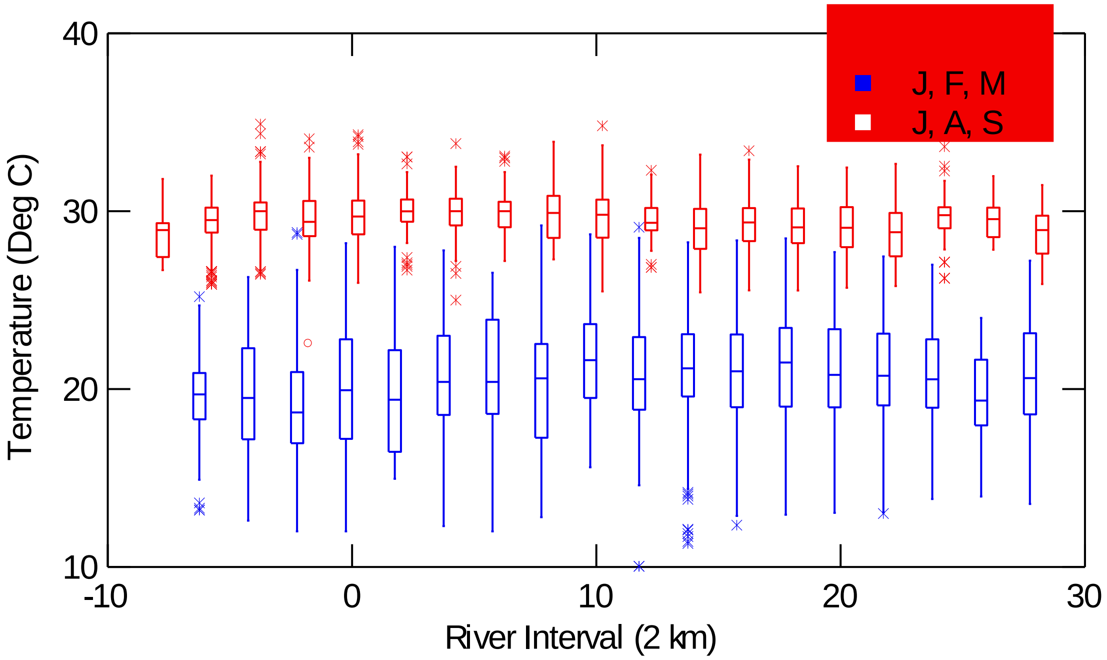

Figure 4-60. **Distribution of temperature by river kilometer during the warmest and coolest quarters of the year.**

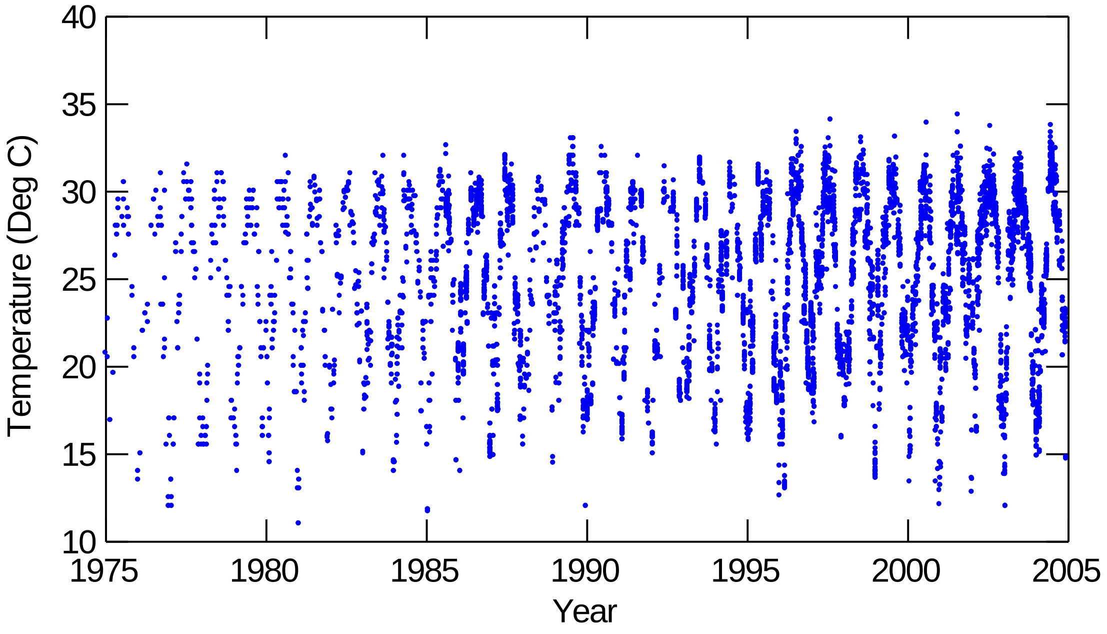

Figure 4-61. **Time series of temperature data collected in the Myakka River.**

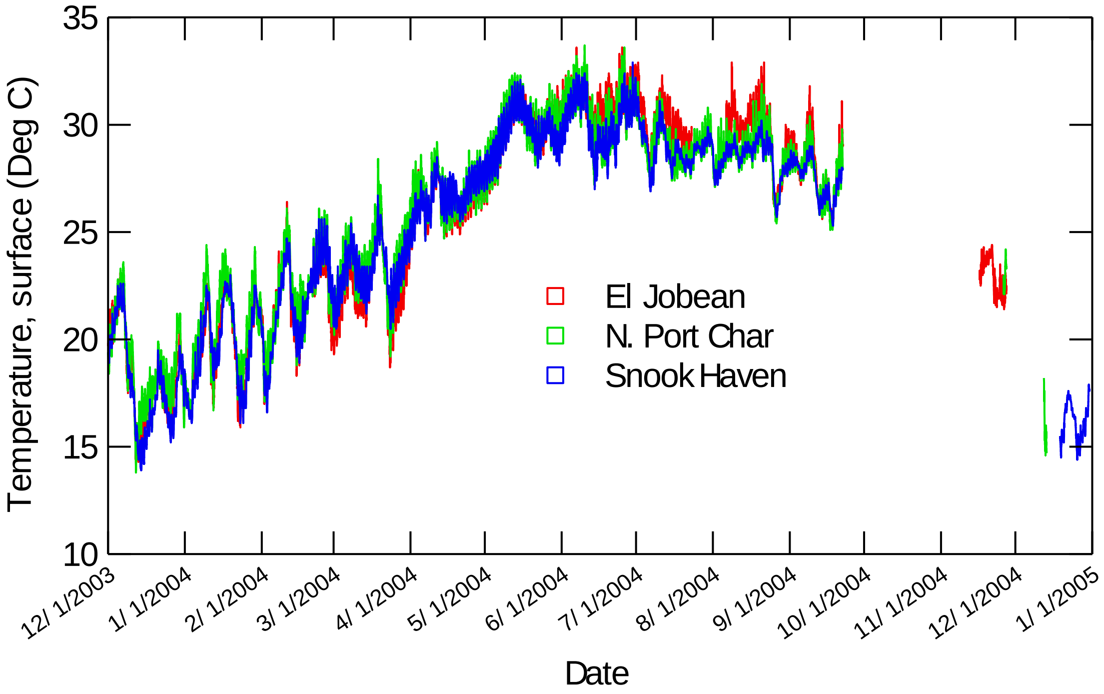

Figure 4-62. Time series of continuous temperature data from three selected locations in the Myakka River.

Periodic depressions of temperature during the colder months (Figure 4-62, above) were on the order of ~5-7ºC, but relationships with forcing functions were complex and undoubtedly include the combined effects of reduced insolation, increased wind speed, increased and then decreased cloud cover, rainfall, reduced air temperature, and reduced river volume (stage) that resulted with the passage of a frontal weather system. Within the temperature fluctuations during cooler months (Figure 4-63), diurnal patterns are as expected with ranges of 0.5-3ºC and maximum values near 1600-1700 hours local time. Periodic temperature excursions were less marked during the warmer months, with dominant forcing functions likely to be insolation, rainfall, residence time, and stage. Similar diurnal variations were observed in the warmer months, generally between 2-3 ºC.

Predictive models of temperature were not developed. However, to the extent that a withdrawal scenario significantly reduced stage and river volume and increased residence time, flow reductions might be expected to increase the diurnal, periodic, and seasonal variations in temperature. The effect would be complex, as many of the forcing functions reinforce one another.

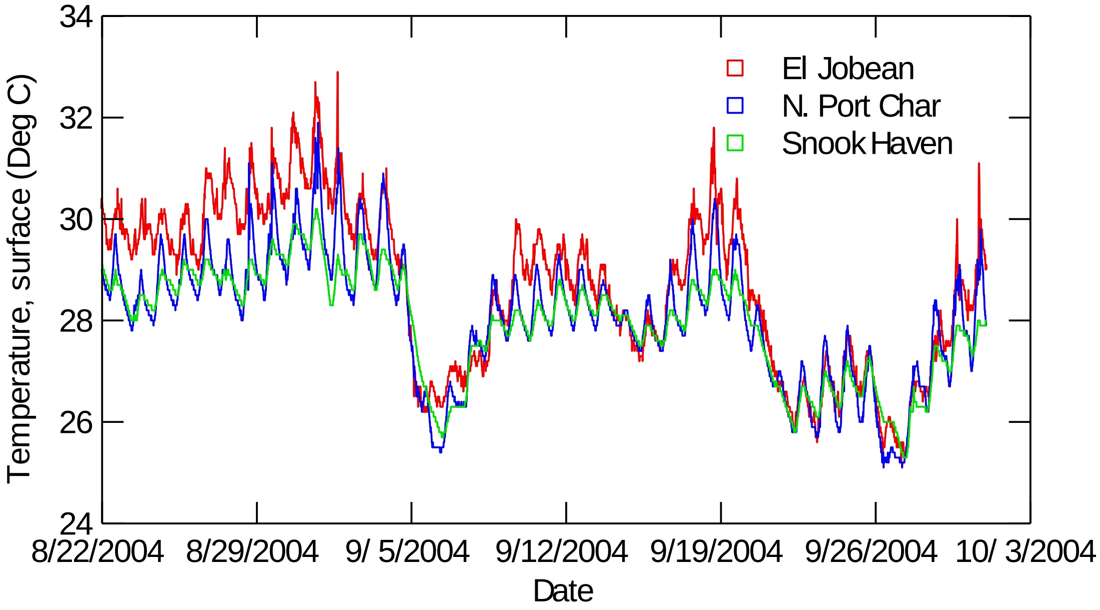

Figure 4-63. Diurnal variations in temperature at three selected locations in the Myakka River.

4.5 Water Quality

Selected water quality parameters, including dissolved oxygen, chlorophyll *a*, Secchi depth, attenuation coefficient, color, total nitrogen, total phosphorus, and inorganic nitrogen, are illustrated in Appendix 4-F for river intervals as a function of time, season (month), salinity, temperature, and daily flow of the Myakka. Many of the seasonal, temperature, salinity, and flow related variations were the direct result of summer wet season injections of fresh water which contained both nutrients and high concentrations of colored dissolved organic matter (humic and fulvic acids from decomposing soils and vegetation).

4.5.1 Dissolved Oxygen

General seasonal patterns in dissolved oxygen (DO) appear in Figure 4-64. Depressed DO (below 4.0 mg/l) was a regular seasonal phenomenon (Figure 4-65) and often extended the length of the study area. On average, upriver stations (above ~10 km) experienced lower DO by 1-2 mg/l (Figure 4-66). Depressions persisted throughout the year but were particularly marked in the warmer months of July through September when upriver concentrations were as much as 3 mg/l lower. The effect was not the result of warmer temperatures and reduced gas solubility, as the seasonal and spatial patterns were present in percent saturation data as well. Any diurnal bias from sampling up river stations later in the day would have had a tendency to produce higher DO values upstream, and so the up river depressions were considered to be a true depiction of river conditions.

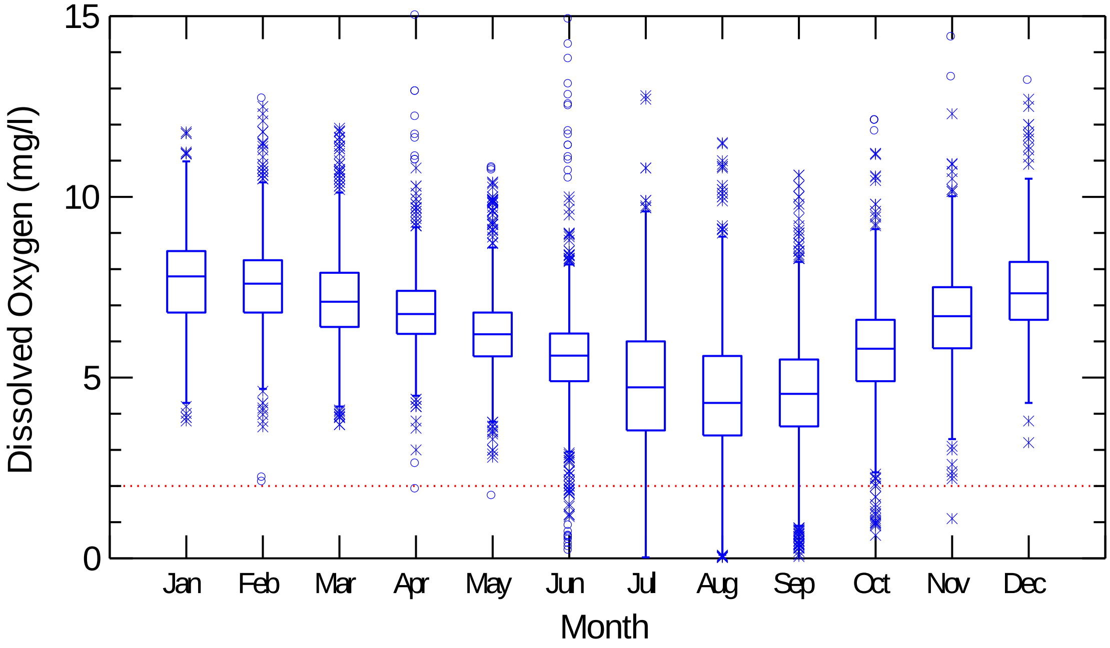

Figure 4-64. Seasonal patterns of dissolved oxygen in the Myakka River.

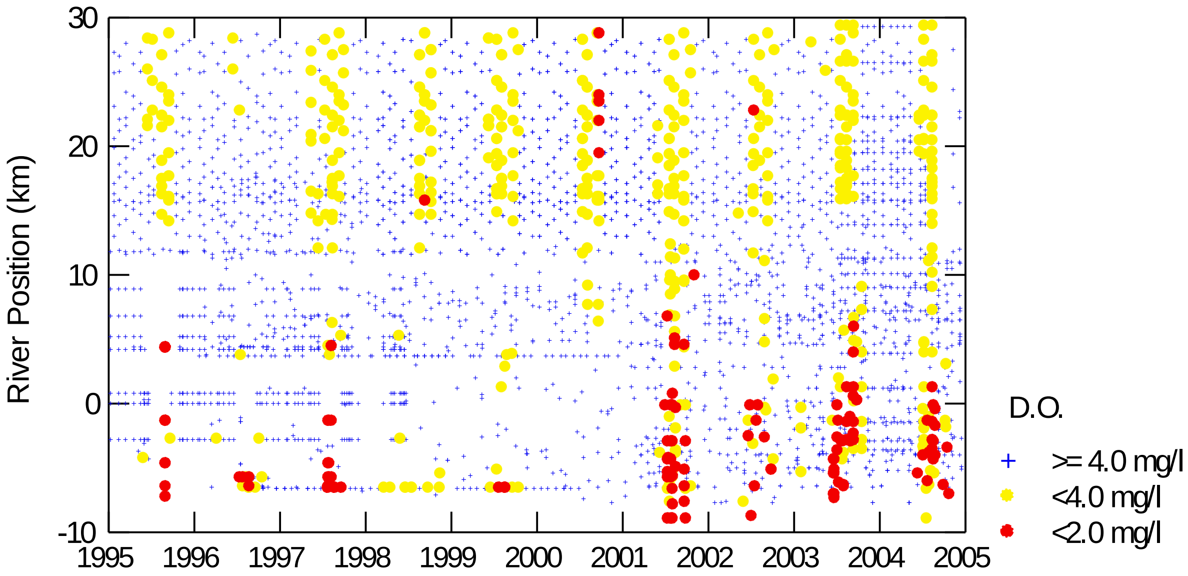

Figure 4-65. Time series of bottom DO in the Myakka River.

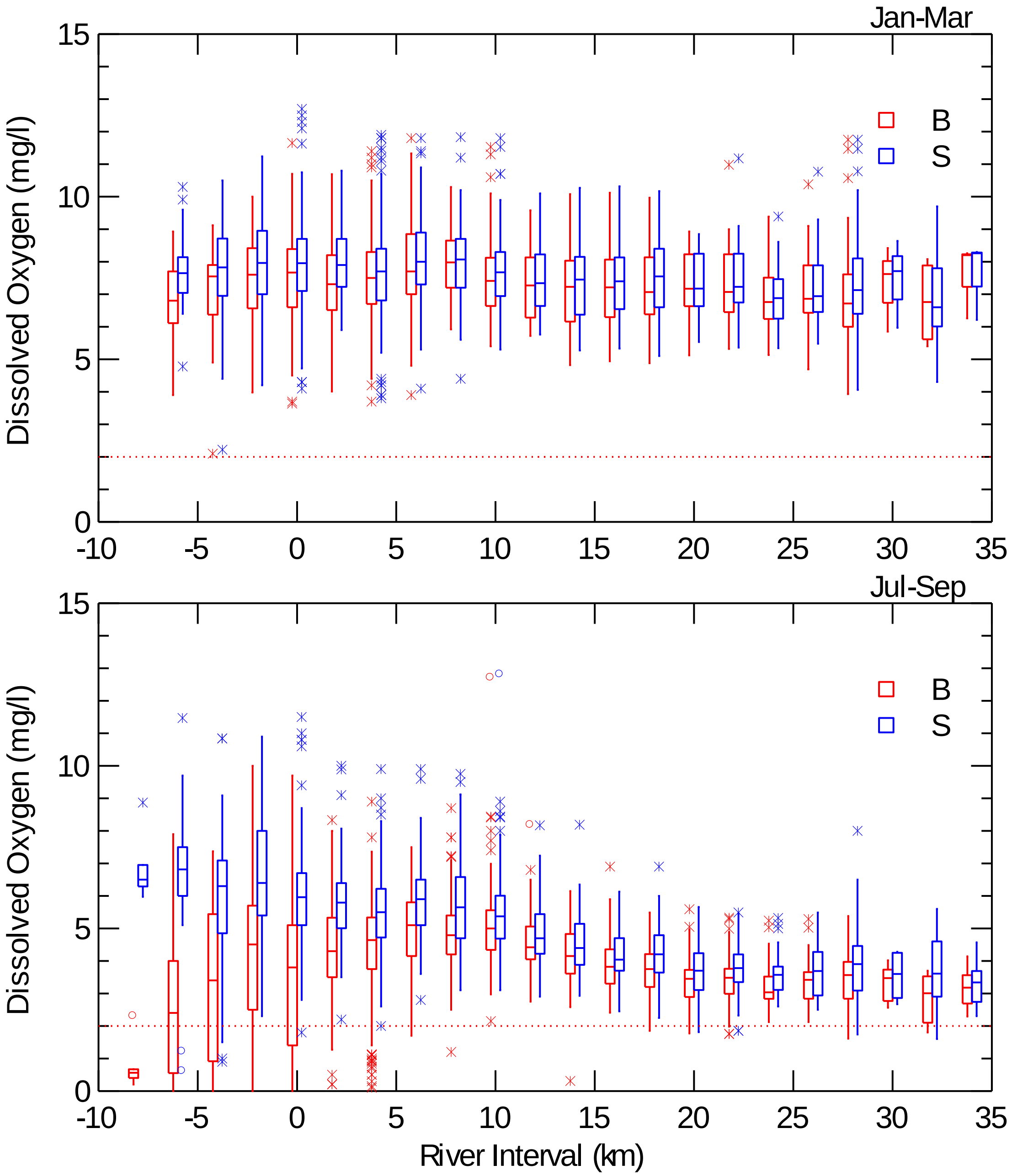

Figure 4-66. Spatial distributions of surface and bottom dissolved oxygen during cool and warm seasons.

Examination of the DO concentrations of low salinity waters (Figure 4-67) indicated that depressed values in the upper river (which only occasionally reached hypoxic levels) were generally limited to below 0.5 psu salinity and to July through September when temperatures and colors were high. The fact that DO increased as salinity increased to near 0.5 psu, and that the depressions displayed no pattern with either time of sampling or water temperature, indicated that the upriver DO depressions were the result of recent

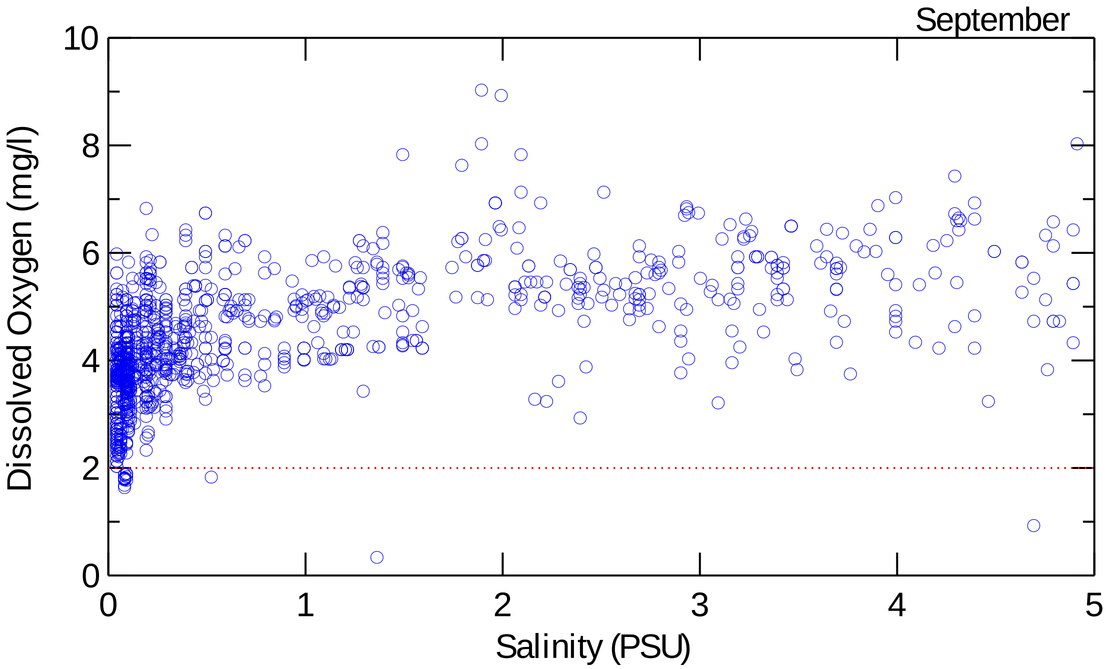

Figure 4-67. Distribution of DO with respect to salinity for low salinity stations during September.

additions of low DO, high color, low conductance water, i.e. from floodplain surface water storage adjacent to the river. Increased DO with the relatively small increase in salinity was likely the result of turbulence and subsequent re-aeration within the river.

Surface to bottom differences in DO were minimal during the cooler months, but bottom concentrations during the warmer months often reached hypoxic levels (2 mg/l) and below, particularly downstream of river kilometer 5.0, and generally in association with salinity stratification. Hypoxia in Charlotte Harbor has been noted in many years, primarily associated with salinity stratification during the higher flow events of summer months (Camp Dresser & McKee, 1998; Heyl, 1998). These hypoxic events have often extended into the Myakka River study area as well, and while present between June and October, were generally most severe between July and September.

Further examination of Myakka River hypoxic conditions indicated that, of the surface observations, nearly all hypoxic surface observations were of very low salinity, and some distance upstream, as described above. For mid-depth and bottom observations, however, while there were a modest number of near-hypoxic conditions upriver, the most observations and most depressed DO levels occurred when salinities were at 10 psu and above and when stratification between surface and bottom salinities exceeded 5 psu (Figure 4-68).

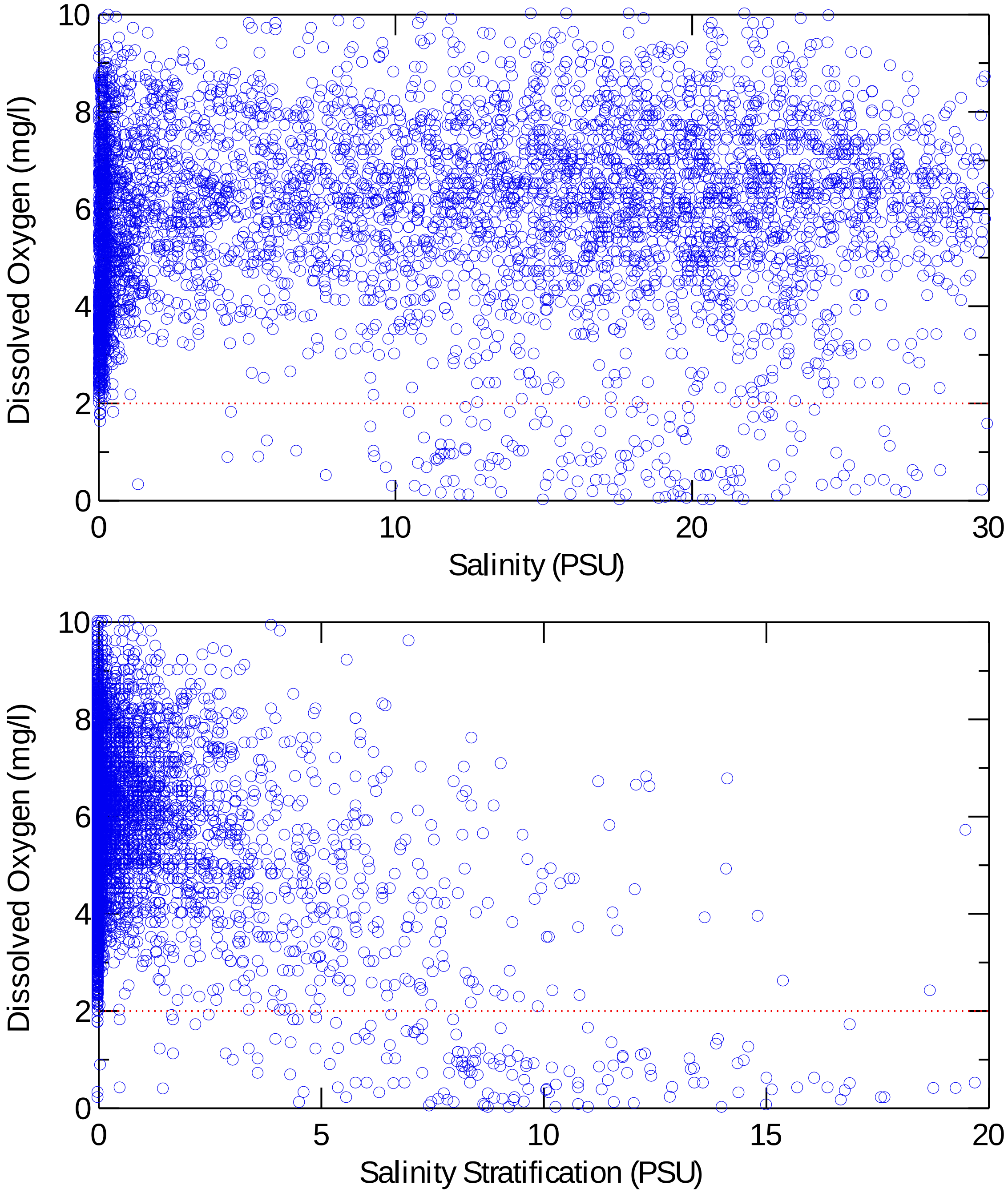

Figure 4-68. Distribution of DO with respect to salinity and salinity stratification in the Myakka River.

Examining data from all seasons, it was clear that elevated temperatures (>25ºC) in addition to stratification were required to produce hypoxic conditions (Figure 4-69). In the few instances for which high flows occurred during winter (15-20ºC), significant stratification did not generally result in hypoxic conditions. Depressed oxygen levels below the halocline were not associated with unsatisfied water column biochemical oxygen demand (MML, unpublished data). Hypoxia appeared to be linked to temperature enhanced sediment respiration and sediment oxygen demand when oxygen demands were unrelieved by reaeration thru the physical barrier of the halocline.

Spatially, the required stratification conditions and resultant hypoxia generally occurred below river kilometer 5.0. Below kilometer 0.0, hypoxic conditions were recorded over a wide variety of flows (Appendix F, Figure 4F-1), while for kilometers 0-5, depressed oxygen was generally limited to 400 cfs and above (Appendix F, Figure 4F-9), when the requisite stratification had been produced.

Sampling density, in both space and time, has varied in the region, but since 1990, hypoxia was recorded during the wet seasons of 1990, 1992, 1994, 1995, 1997, 2001, 2002, 2003 and 2004. From year to year, similar flow events (see 2000, and 2002, Figure 4-70) resulted in lesser or greater degrees of stratification, with hypoxia either avoided or produced. An explanatory variable may have been the rapidity of onset of the wet season. In this and in other instances it appeared that if flows increased gradually as in 2000, then salinity in the lower river was depressed and the resulting plume from additional higher flows had insufficient relative buoyancy to result in stratification. Alternatively, if the wet season began abruptly (2002), then the lower river was relatively saline, and a moderate increase in flow would have resulted in a buoyant plume of fresh water, stratification, and subsequent hypoxia.

Multiple linear regressions of DO as a function of both physical and chemical variables produced complementary results to the above discussion. Surface values of DO were significantly ($p<0.001$) correlated with temperature, river kilometer, time of day, chlorophyll *a*, salinity, color, and weighted flow, in order of decreasing significance, with an adjusted multiple r^2 of 0.45 and a standard error of the estimate of 1.1 mg/l. For bottom DO observations, significant ($p<0.001$) regressions employed temperature, stratification, chlorophyll *a*, depth of the observation and river kilometer for an adjusted multiple r^2 of 0.63 and standard error of the estimate also at 1.1 mg/l. Results of these regressions appear in Appendix 4-E.

Although DO data were not analyzed for predictive modeling purposes, the above discussion can be summarized to estimate the impact of any future flow reductions on DO levels in the river. Flow reductions are unlikely to impact the low salinity, upriver hypoxic DO levels if these are the product of the addition of DO depressed water from adjacent flood plain storage (unless reduction techniques include shallow groundwater withdrawals). Downriver (river kilometer -5 to 5) hypoxic events could be modified by flow reductions if withdrawals modify the establishment of stratification. Hypoxic events would likely be reduced if withdrawals either reduced the total flow (perhaps below 400 cfs) or if the rapid increase in flow at the onset of the rainy season is attenuated such that stratification does not form as rapidly.

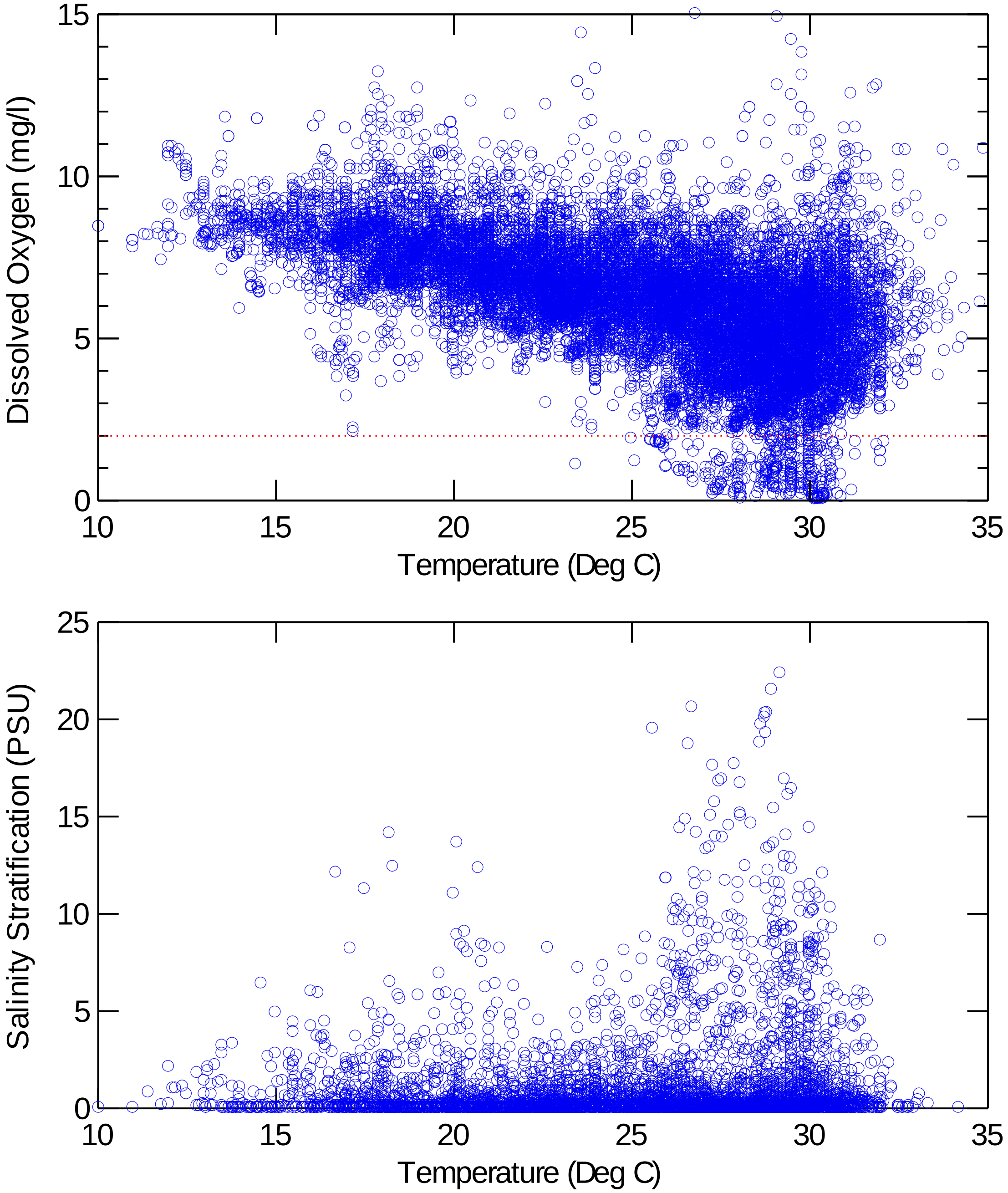

Figure 4-69. Distribution of DO and salinity stratification with respect to temperature in the Myakka River.

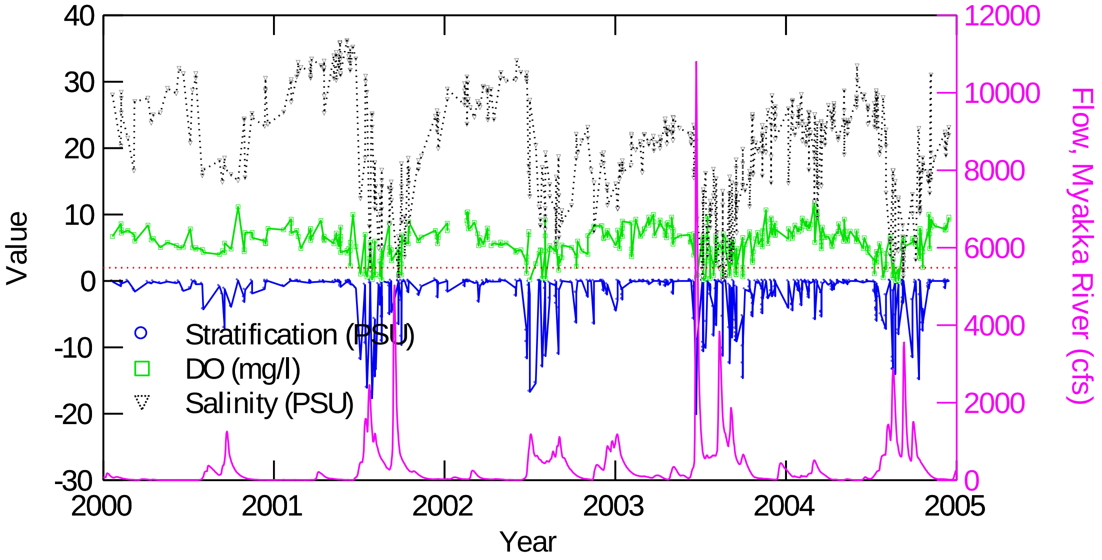

Figure 4-70. Time series of salinity, DO, stratification and flow from observations between river kilometer 5.0 and 0.0. Salinity stratification is plotted as surface minus bottom values for graphic clarity. Hypoxia is indicated by the red dashed line at 2.0 mg/l.

4.5.2 Nutrient and Light Related Parameters

Amounts of color in the Myakka River varied seasonally. Fresh water during January through June averaged near 100-120 PCU (Figure 4-71). With the onset of the wet season, fresh water color increased abruptly to between 220 and 270 PCU in July through October (Figure 4-72). Some instances of color higher than 400 PCU were observed. Color generally increased with flow but increase flow during the wet season produced higher colors than flow increases at other times of the year. Downriver, 20 psu waters were generally near 50 PCU, except during September when color values were nearer 100 PCU. Due to the dominant influence of dissolved humics and color on water clarity (Figure 4-73) in the Myakka River, seasonal and flow related patterns were quite similar for secchi depths and for attenuation coefficients.

General observations on nutrient concentrations included the following points. Dominant nitrogen forms were organic rather than inorganic. Total nitrogen values averaged near 1.0 mg/l and declined slightly in the downstream direction with increasing dilution and increasing salinity (Figure 4-74). Seasonal patterns were present with elevated values in July through October, but inter-annual variation was high (Figure 4-75). For freshwater stations (salinity ≤ 1.0 psu), both ammonium-nitrogen and nitrate-nitrite-nitrogen concentrations were generally less than 0.1 mg/l and were comparable in the middle and upper river. Ammonia concentrations were slightly higher on average during the warmer, wet season months, while nitrate-nitrite-nitrogen (Figure 4-76) exhibited slightly reduced values overall during the dry season months of April, May, and June. Below

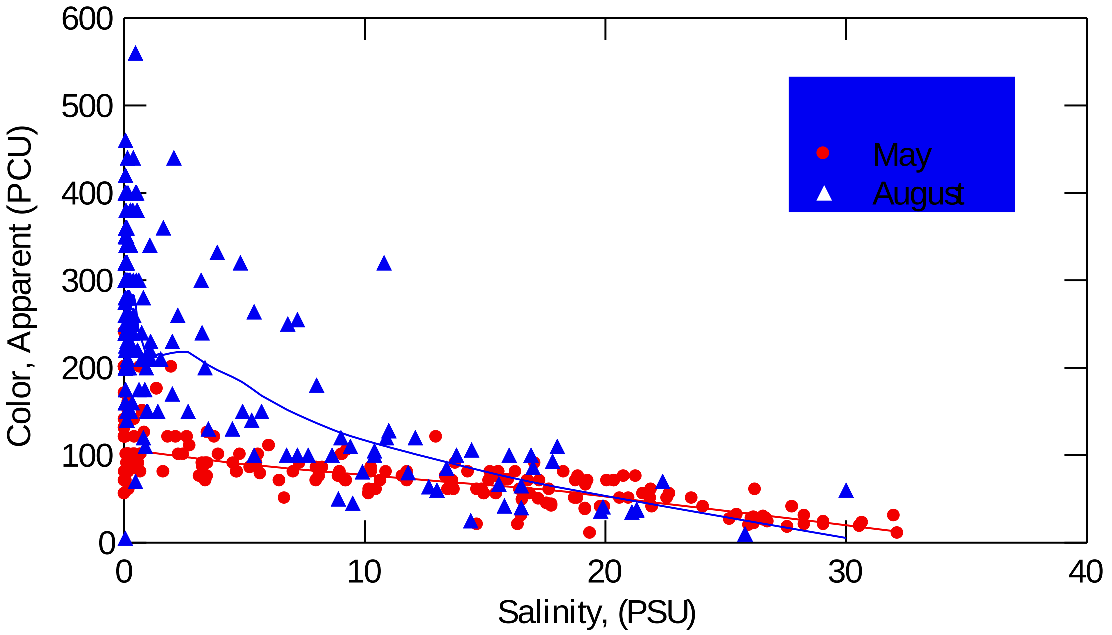

Figure 4-71. Seasonal relationship of color with respect to salinity in the Myakka River. Lines indicate LOWESS smoothes.

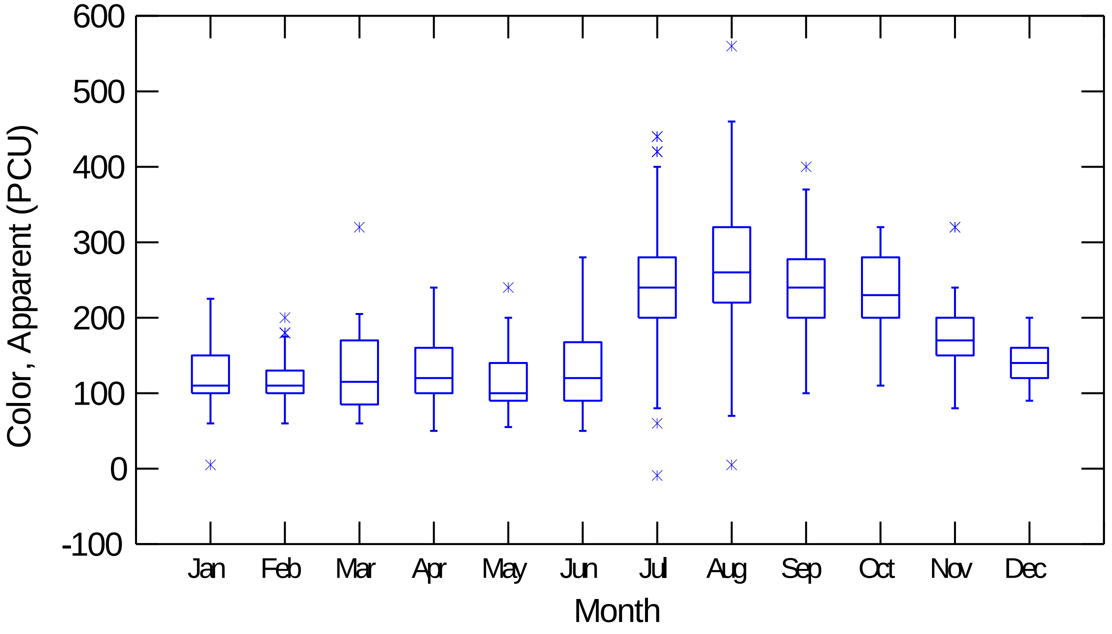

Figure 4-72. Seasonal distribution of color in the freshwater stations (salinity less than 1 psu) of the Myakka River.

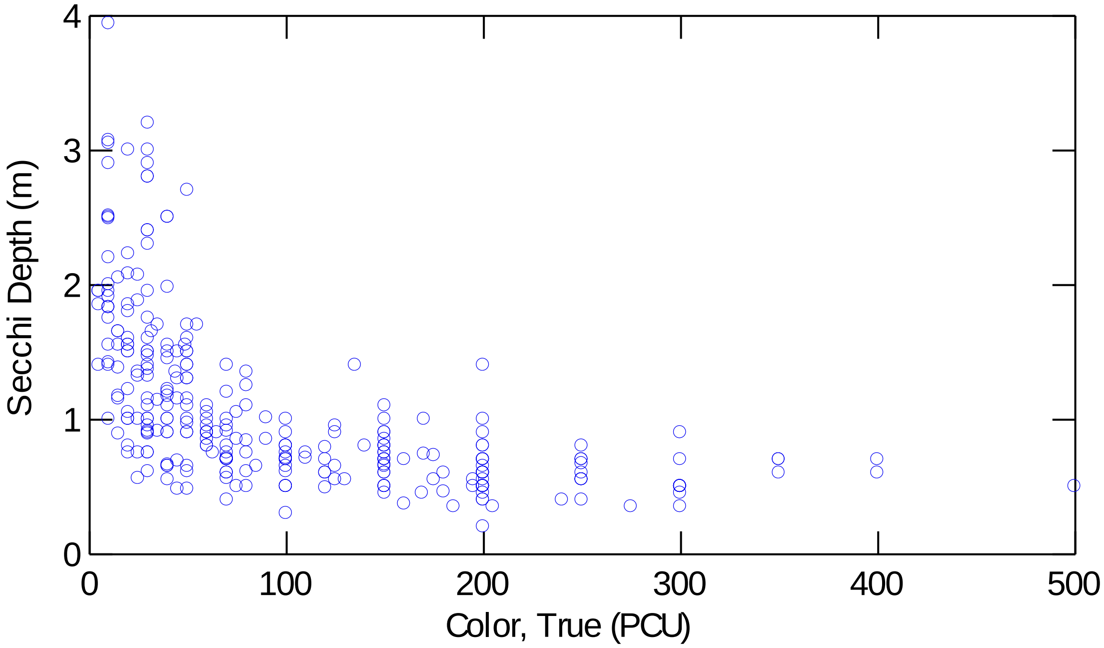

Figure 4-73. **Water clarity (secchi depths) as a function of water color in the Myakka River.**

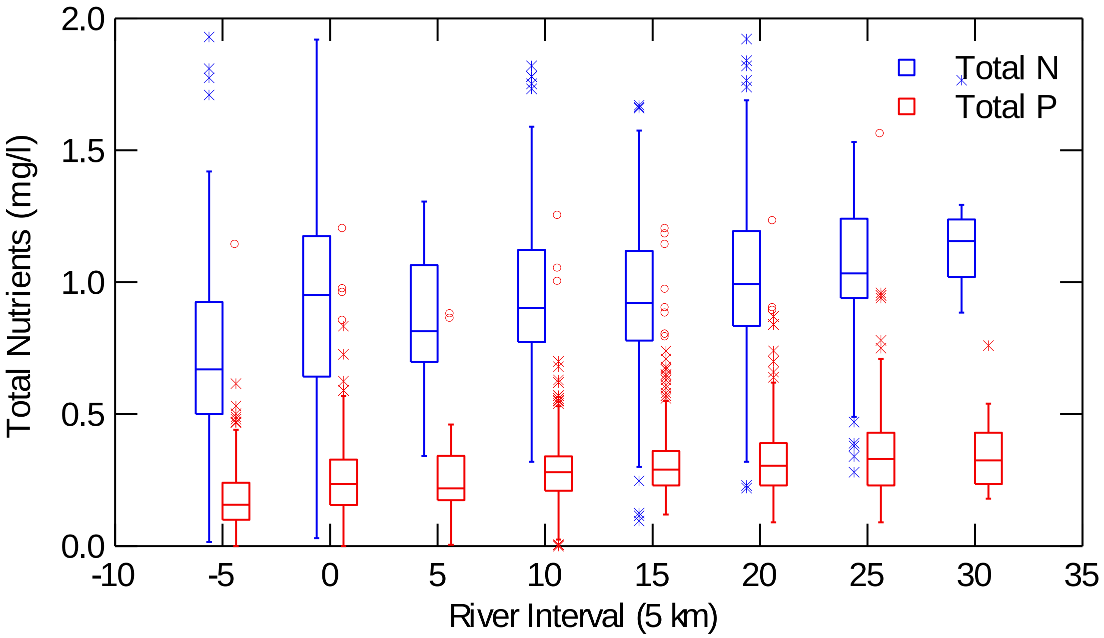

Figure 4-74. **Spatial distribution of total nitrogen and phosphorus in the Myakka River**.

river kilometer 0.0, ammonium forms were the dominant inorganic nitrogen species (Figure 4-77). Nitrite concentrations were minimal relative to nitrate concentrations. The increase in inorganic nitrogen concentrations above river kilometer 10 was approximately coincident with a decrease in salinity below 20 psu. A few instances of high inorganic nitrogen concentrations (>0.5 mg/l) were observed and were typically found near river kilometer 5.0. Ammonia displayed little coherent behavior with flow or salinity, but nitrate-nitrite-nitrogen concentrations were generally highest (above 0.1 mg/l) when flows were below 500 cfs and when salinities were less than 5 psu (Figure 4-78). Inorganic nitrogen (ammonia plus nitrate-nitrite-nitrogen) was generally below 0.3 mg/l.

Similar to nitrogen, phosphorus levels were seasonally elevated during the wet season and declined with distance downstream and with increasing salinity. Total phosphorus concentrations averaged near 0.25 mg/l. Seasonal increases in tital phosphorus were not as marked and occurred earlier on average than did the seasonal nitrogen increases (Figure 4-75).

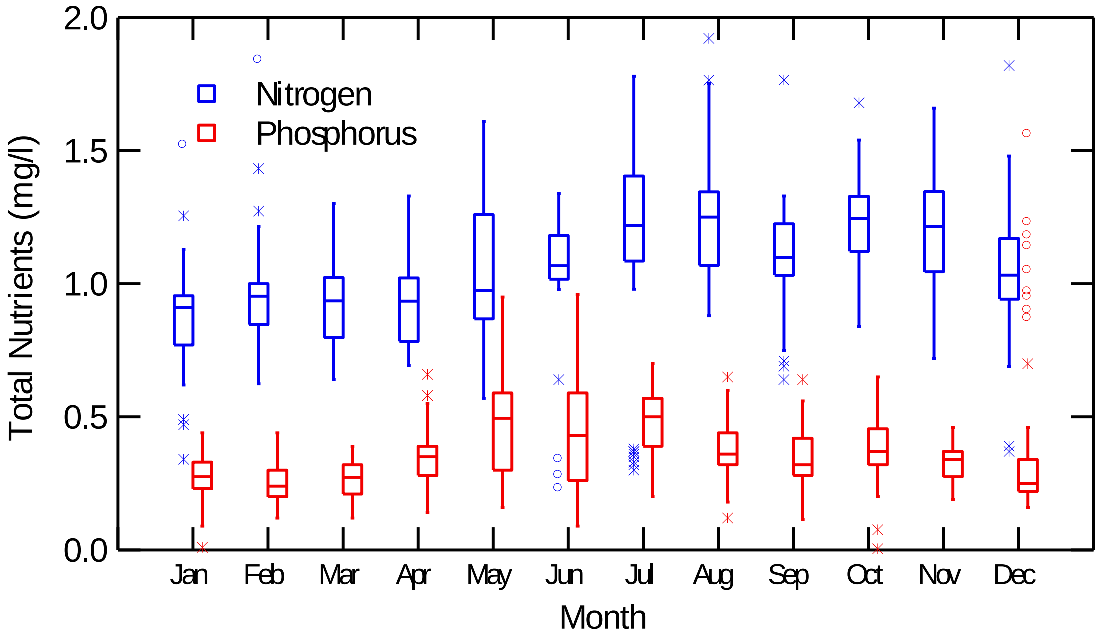

Figure 4-75. Seasonal variation of total nitrogen and phosphorus in the freshwater stations of the Myakka River. (Salinity less than or equal to 1.0 psu.)

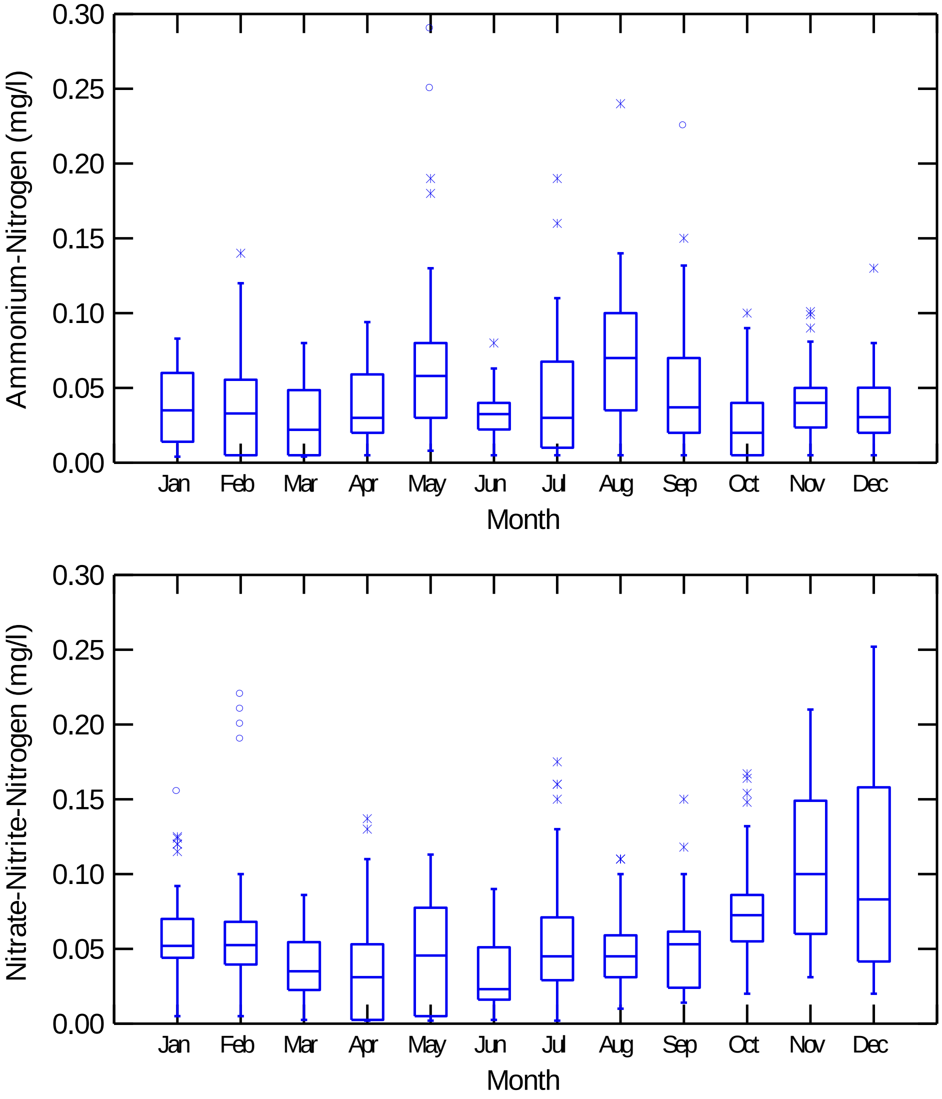

Figure 4-76. **Seasonal distributions of ammonium-nitrogen and nitrate-nitrite-nitrogen in the freshwater stations of the Myakka River. (Salinity less than or equal to 1.0 psu.)**

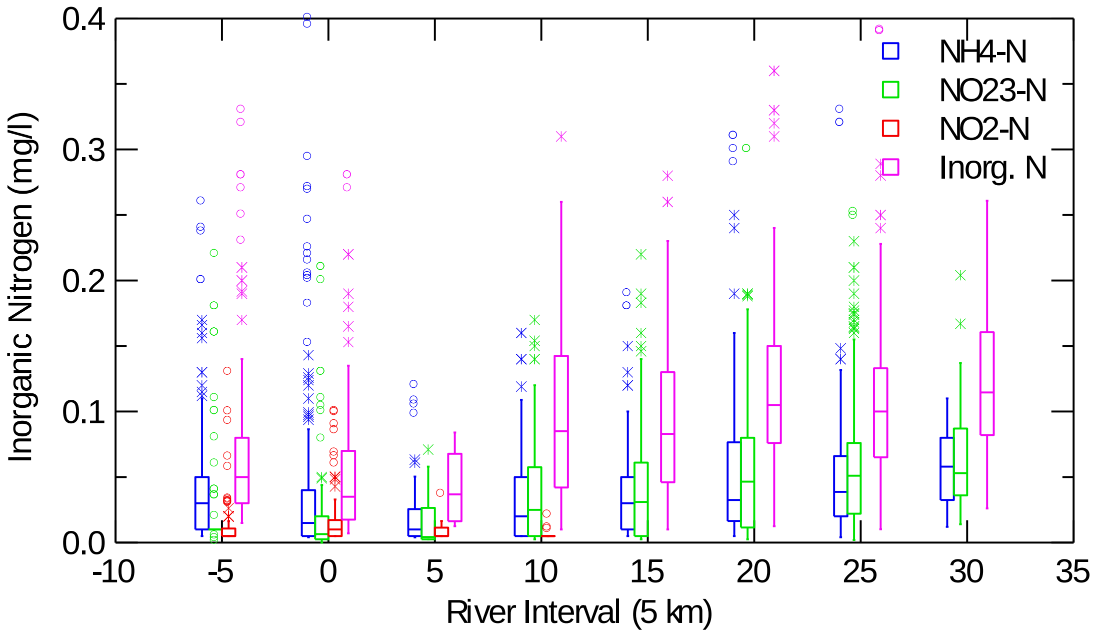

Figure 4-77. Spatial distribution of inorganic nitrogen in the Myakka River.

Orthophosphorus formed a large fraction of the total phosphorus in the river and averaged near 85%. When total phosphorus was high (>0.6 mg/l), nearly all phosphorus was in the orthophosphorus form. Ratios of orthophosphorus to total phosphorus did not vary appreciably with salinity, indicating that little transformation occurred between forms as dilution with more saline waters occurred. Orthophosphorus displayed similar seasonal patterns as did total phosphorus, with declines in orthophosphorus above 20 psu and increasing orthophosphorus with increasing flow (Figure 4-79). The higher phosphorus concentrations (>0.6 mg/l) displayed no strong seasonal, salinity, or flow related relationships, occurred periodically throughout 1970-2005, and was present along the length of the study area.

Ratios of total nitrogen to total phosphorus averaged near 5:1 on a weight:weight basis. Relative to an ideal ratio of 7.2:1 (mg:mg) to support phytoplankton growth, data indicated that the ultimate limiting nutrient for phytoplankton might be expected to be nitrogen. Inorganic nitrogen and phosphorus supported this as mean IN:IP ratios were almost always below 2:1 and averaged less than 0.5:1. There were no salinity, flow, seasonal, or spatial patterns evident in either IN:IP or TN:TP ratios.

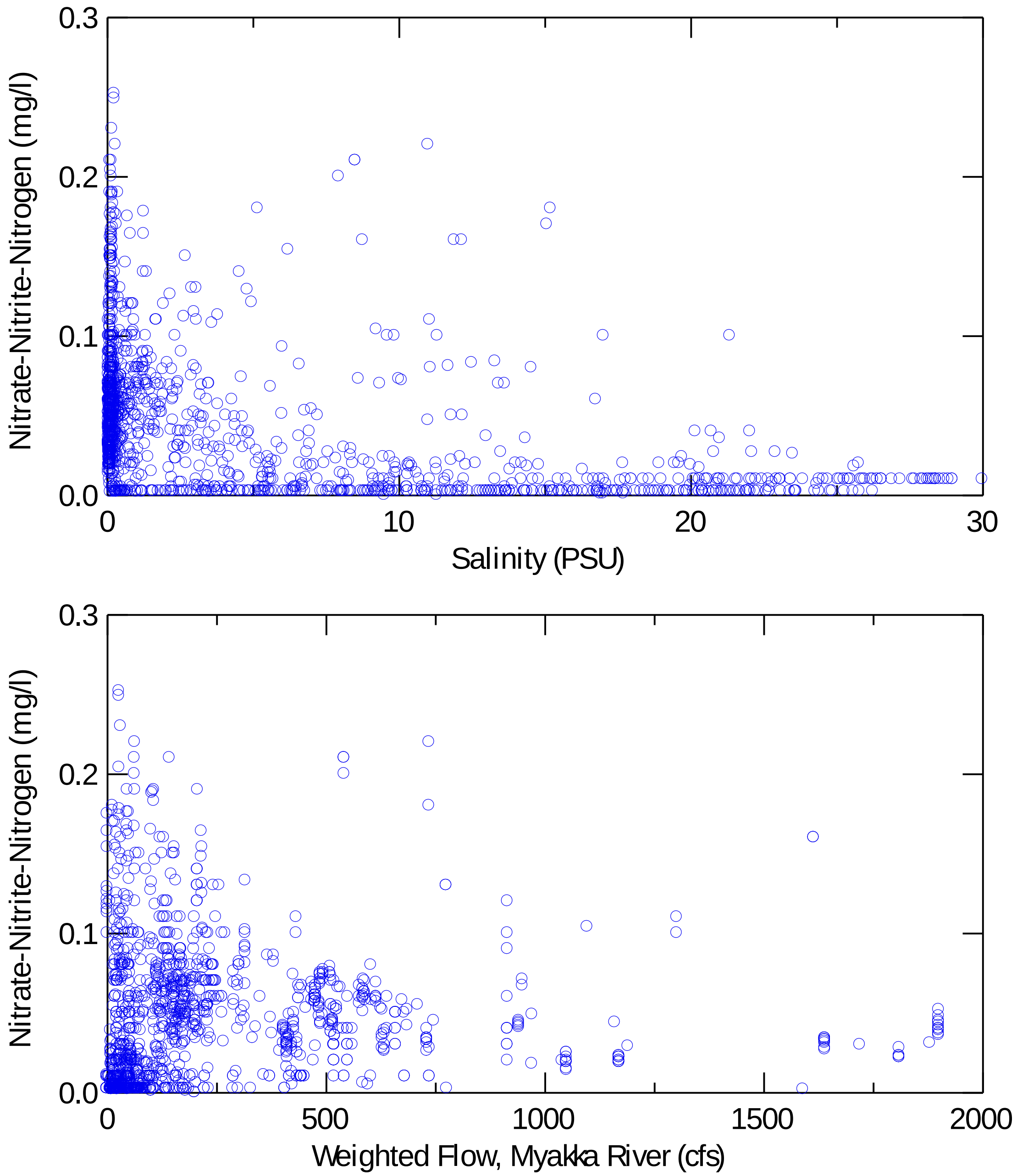

Figure 4-78. Nitrate-nitrite-nitrogen in the Myakka River, as a function of salinity and weighted flows.

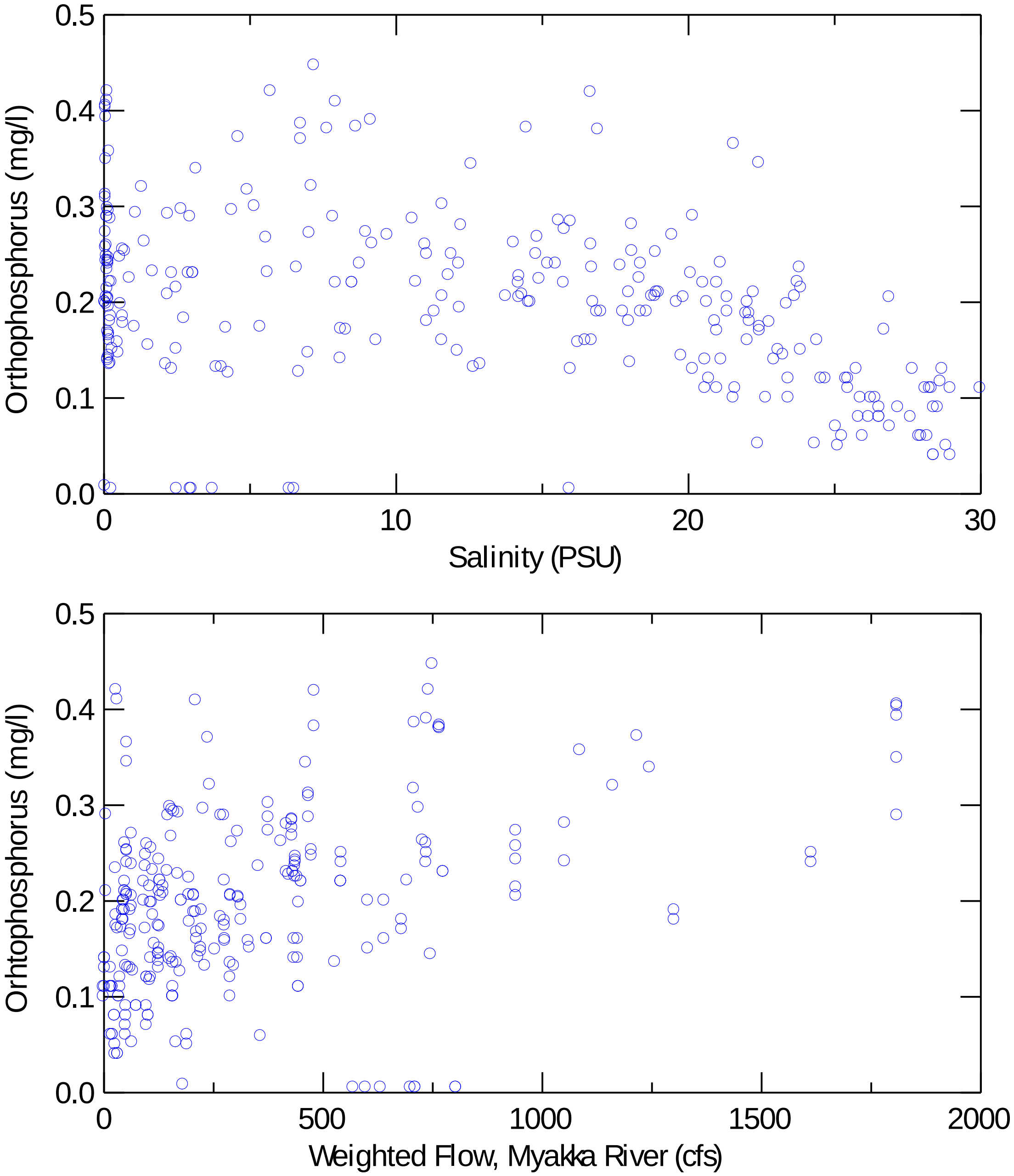

Figure 4-79. Orthophosphorus in the Myakka River, as a function of salinity and weighted flows.

4.5.3 Chlorophyll *a*

The maximum corrected chlorophyll *a* value observed in the river was 120 µg/l, recorded in 1989 near El Jobean. Mean and median values were much lower, 7.2 µg/l and 5.0 µg/l, respectively. Since 1995, there were very few instances of chlorophyll *a* greater than 50 µg/l and, in general, values seldom exceeded 20 µg/l.

Chlorophyll *a* displayed interesting seasonal patterns in the Myakka River that varied by river section (Figure 4-80). Upriver (above 15 kilometers), the larger chlorophyll *a* values were generally observed in March through July, after seasonal increases in insolation but before the increase in wet season flows. During this low flow time, residence times (as approximated by the DAYS parameter) were comparatively high and color values low. Maximum values of upriver chlorophyll were observed in June, while values were generally low in August and September. Another increase in upriver chlorophyll *a* was also noted in October through December.

At mid-river (10-15 kilometers), highest values were primarily in June and July, and were higher overall than at upriver locations. Below river kilometer 10.0, higher chlorophyll *a* values were typically observed later in the year (July through November), when flows and presumably nutrient loads were at a maximum. There were some instances of high chlorophyll *a* values (>20 µg/l) above 10.0 km, but most were downstream. Overall distributions recorded the highest chlorophyll *a* concentrations near mid-river, roughly between 5 and 15 kilometers. (Figure 4-81).

The differences in seasonal chlorophyll *a* maxima for the upriver and downriver sections indicate that phytoplankton community structure as well as community response to forcing functions may differ between the upper and lower river. Seasonal variation in insolation, salinity, nutrient loadings and light attenuation (color) associated with wet season flows, washout of blooms from standing water upstream, increased turbulence and reduced residence times under higher flow conditions, and tidal translocation of blooms from downstream all likely play a contributing role. As a result of 1) the inverse covariation between flow and residence time, 2) the more variable, seasonally-dependent, non-linear relationships of color with flow and nutrients with color or flow, and 3) the non-linear response of phytoplankton growth with light levels, it is difficult to allocate the individual effects of either increased color, increased nutrients, or reduced residence time under higher flow conditions with the existing data.

For descriptive purposes, as illustrated with data from May to October for a period when there was the most spatial and temporal variation, chlorophyll *a* increased with increasing color (with the addition of fresh water and associated nutrients) and declined as color increased beyond 200 PCU (Figure 4-82). Similar relationships, highest chlorophyll *a* at a midrange of color, were generally present even when data were segregated by month or river interval. Complementary graphic examinations of May-October chlorophyll *a* as a function of either flows or DAYS (as an approximation for residence time), revealed similar patterns i.e. maximum chlorophyll *a* values occurring at a modal midrange value, with only slight variations between either months or river intervals. Salinity, on the other hand, while resulting in a mid-range, optimum value for high chlorophylls in Figure 4-82, did vary markedly between upstream and downstream river intervals.

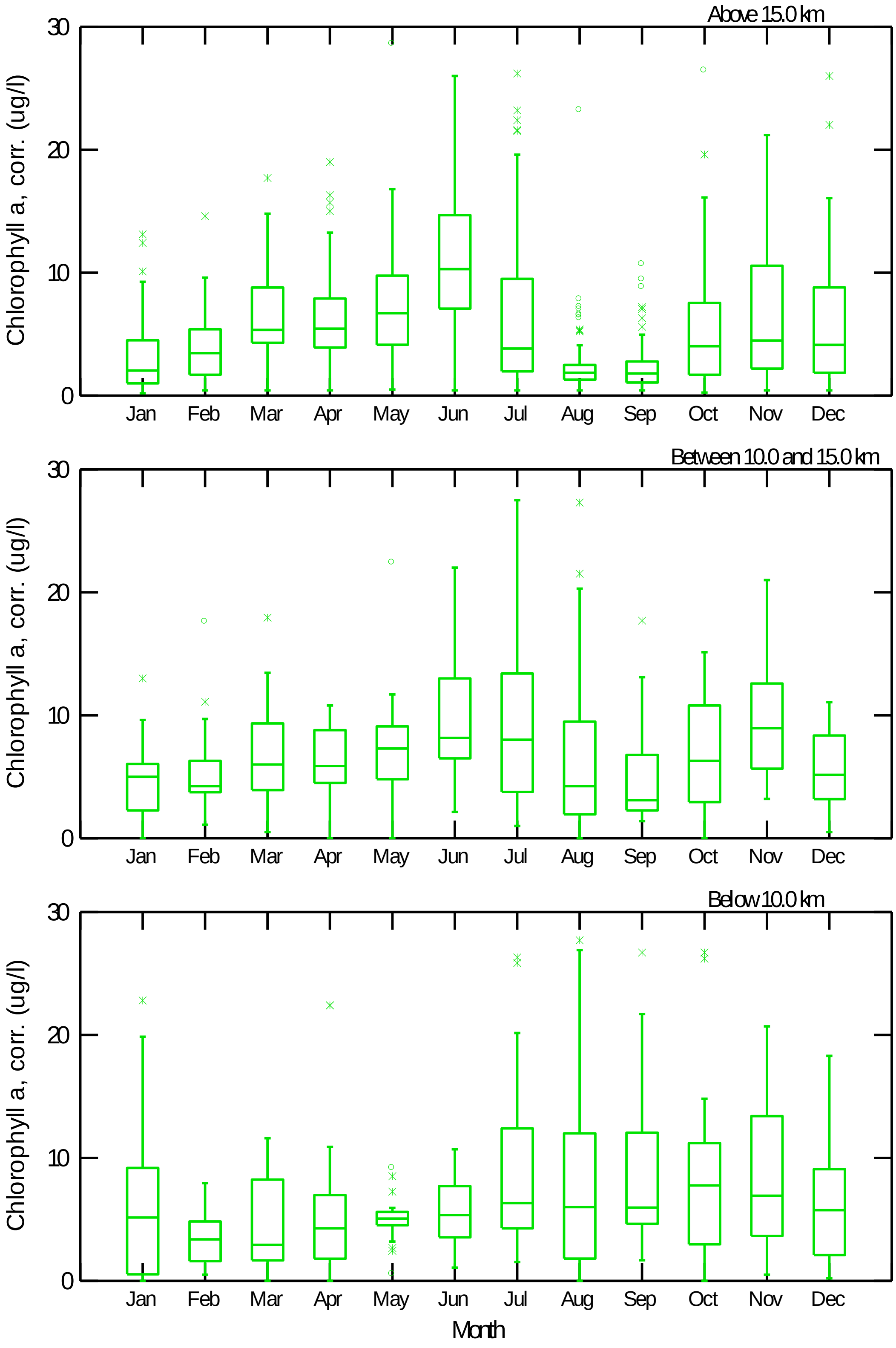

Figure 4-80. Seasonal distribution of chlorophyll *a* at selected locations in the Myakka River.

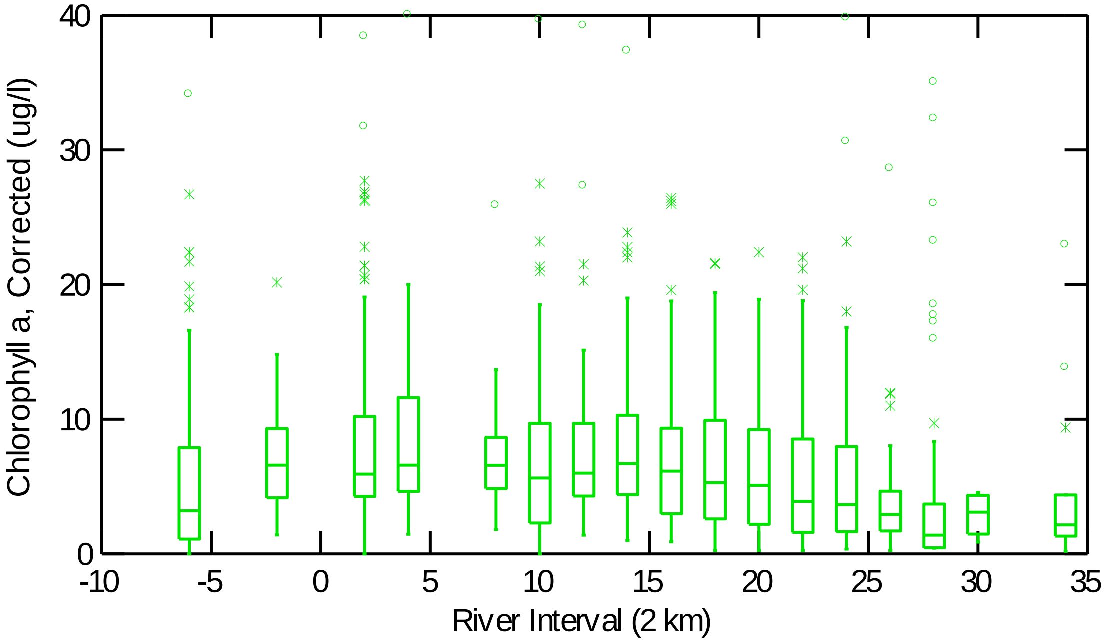

Figure 4-81. Spatial distribution of chlorophyll *a* in the Myakka River.

Figure 4-83 and 4-84 illustrate the spatial differences in May through October chlorophyll *a* concentrations of downriver and upriver locations. Table 4-10 summarizes those regions water quality values both for the May-October data set and for those instances of chlorophyll *a* greater than 20 µg/l. While the modal ranges of color, flow, and DAYS (as approximate residence time) associated with the higher chlorophyll *a* concentrations (>20 µg/l), can be identified for both upriver and downriver intervals, relationships with salinity differ between regions. Below river kilometer 10, optimal salinities were generally in the 10-25 psu range with somewhat lower chlorophylls outside of the interval. For data collected above river kilometer 15, however, chlorophyll *a* displayed a more linear relationship with salinity. The regression was significant ($p<0.001$, S.E. ~ 5.5 µg/l) and directly correlated with the log of salinity values, although with a few outliers of high chlorophyll *a* in a compressed region of low salinity (~0.2-0.3 psu).

While the observed relationship of chlorophyll *a* with salinity in the upper river may be useful for coarse predictive purposes, however, it does not further isolate the dominant forcing functions for chlorophyll *a* in this portion of the river. Higher chlorophyll *a* associated with high salinity could represent some combination of in situ growth under long residence times and reduced color, or chlorophyll entrained with the more saline waters from downstream. The outliers to the relationship with salinity may have represented a washout of standing surface water and associated algal bloom into the river with the onset of the wet season (when the associated DAYS parameter is on the order of 1-3 days) or could be in situ growth when the DAYS parameter indicates longer residence times.

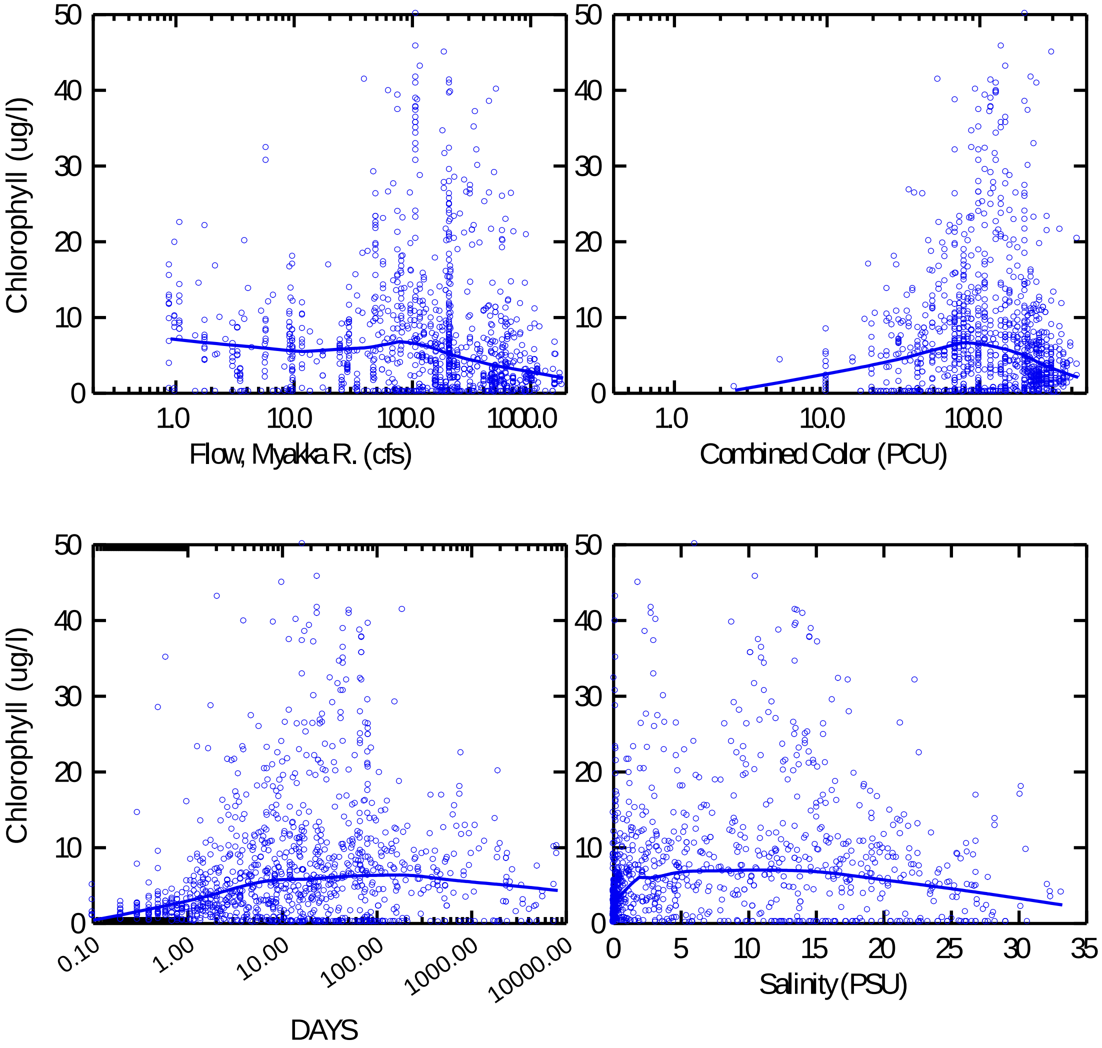

Figure 4-82. Chlorophyll *a* as a function of flow, color, DAYS, and salinity in the Myakka River. May through October, from river kilometer -5 to 35.

Due to the dominance of modal relationships, there were no other significant univariate relationships of chlorophyll *a* with forcing functions detected. Not surprisingly, multiple linear regressions of chlorophyll *a* (under a variety of transformations) produced some significant relationships with coefficients that in general were supportive of the above discussion (positive correlations with temperature, inverse correlations with river kilometer and flow). Standard errors, however, were generally larger than median chlorophyll *a* concentrations and relationships did not appear useful.

Chlorophyll *a* concentrations were also examined with respect to nitrogen and phosphorus concentrations. As was expected, due to the geology of the upper river and phosphorus supplies of the region, phytoplankton growth appeared nitrogen-limited, as the highest chlorophyll occurred when inorganic nitrogen:inorganic phosphorus ratios (weight:weight) were less than 0.5.

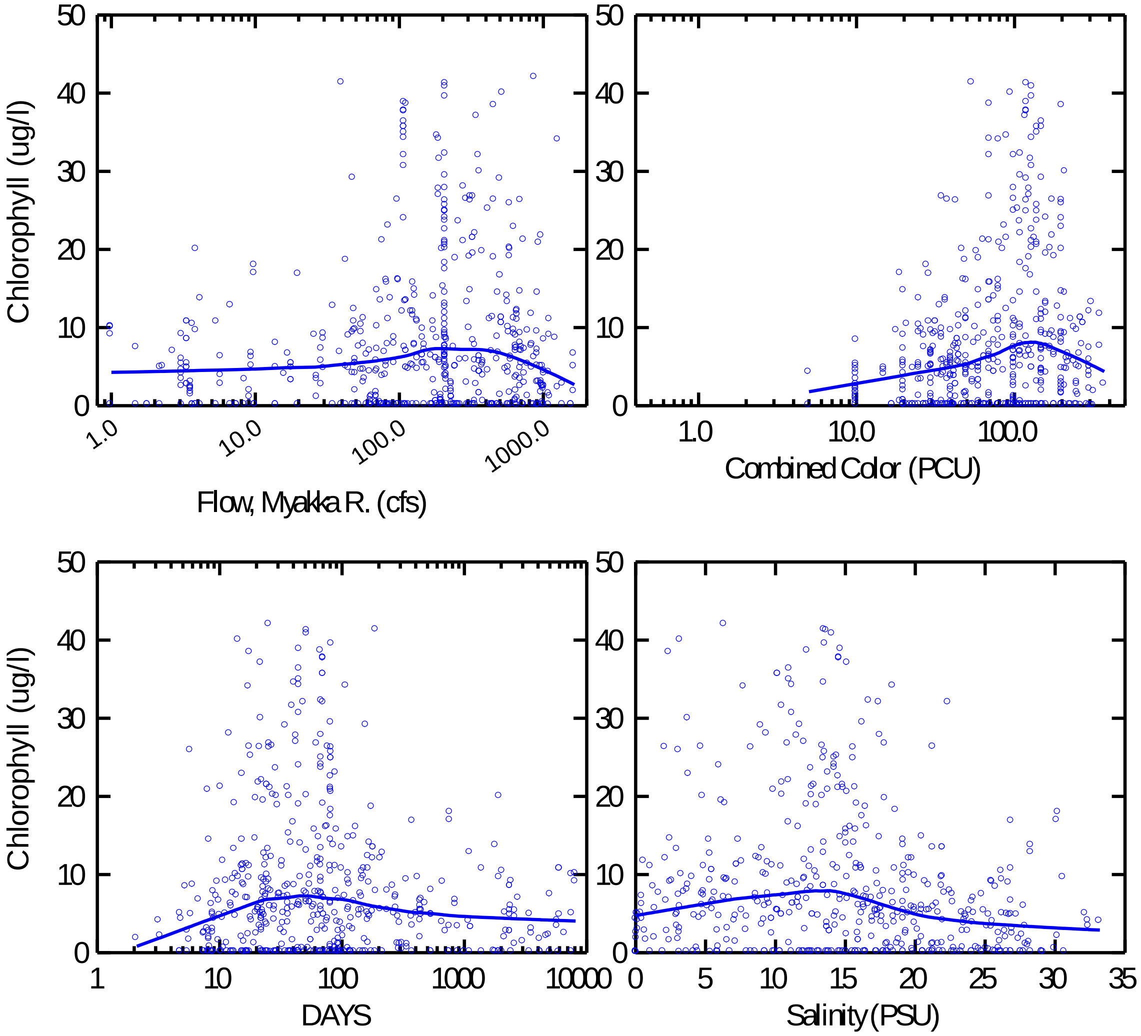

Figure 4-83. Chlorophyll *a* as a function of flow, color, DAYS, and salinity in the Myakka River. May through October, from river kilometer -5 to 10.

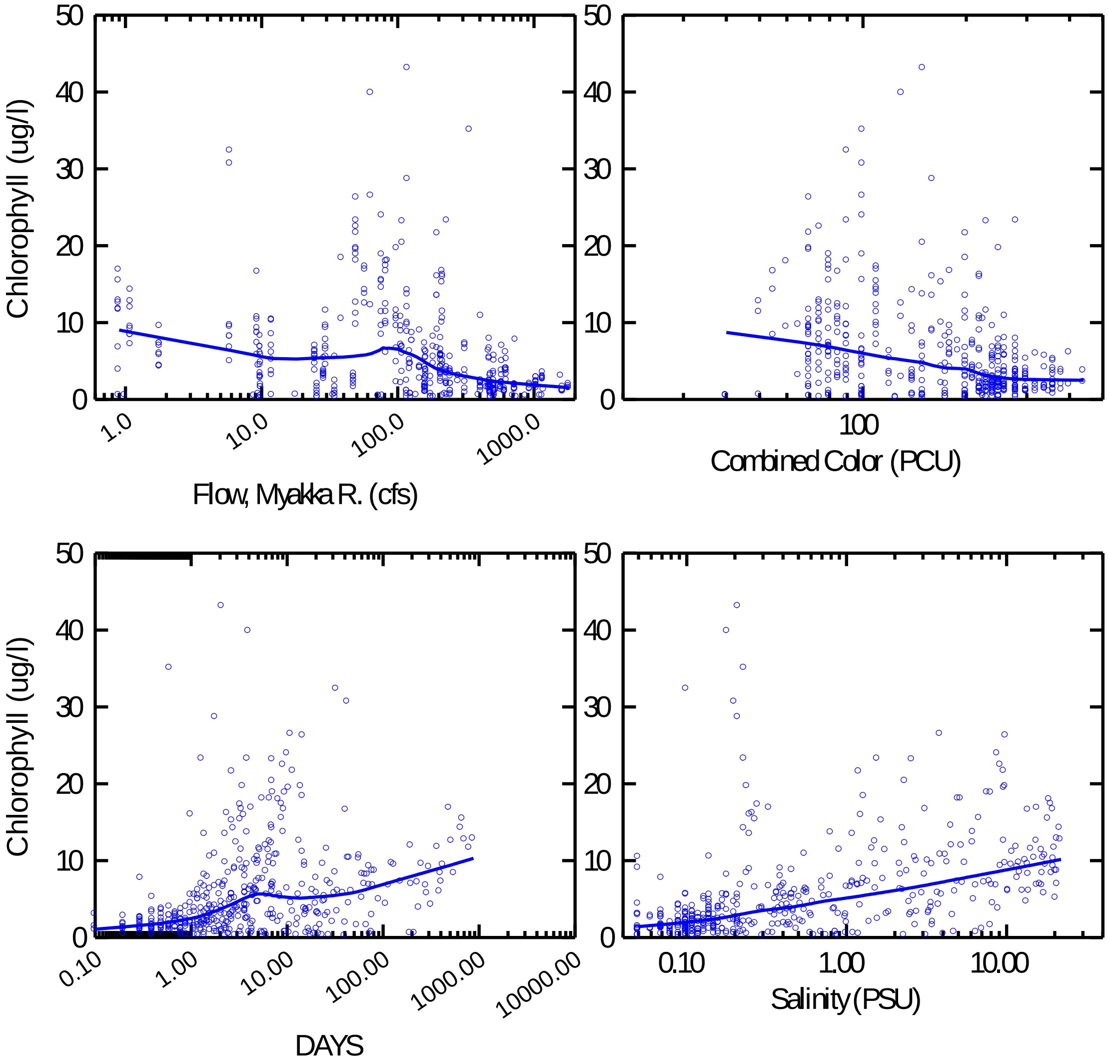

Figure 4-84. Chlorophyll *a* as a function of flow, color, DAYS, and salinity in the Myakka River. May through October, from river kilometer 15 to 35.

Table 4-10. Water quality percentiles for upriver (km>15) and downriver (km<10) intervals under all conditions and under high chlorophyll *a* (>20 ug/l) conditions.

	n=, Percentiles	**km>15**	**km>15, chl a>20**	**km<10**	**km<10, chl a>20**
Chlorophyll *a*, combined (ug/l)	n=	520	16	284	19
	10%	0.0	21.7	0.0	21.2
	25%	0.9	23.1	1.5	21.8
	50%	2.4	26.1	4.6	26.3
	75%	6.8	31.5	8.5	32.5
	90%	13.4	39.3	14.6	47.2
Flow (cfs)	n=	520	16	284	19
	10%	9	6	4	190
	25%	48	50	57	315
	50%	177	61	232	458
	75%	519	119	657	573
	90%	941	228	981	672
DAYS (days, see text)	n=	520	16	284	19
	10%	0.3	1.3	8.9	14.8
	25%	0.8	2.0	20.2	18.6
	50%	2.3	6.6	47.7	25.8
	75%	10.1	13.2	182.6	39.8
	90%	65.3	41.7	2386.8	54.8
Color, Combined (PCU)	n=	520	16	280	19
	10%	75	70.5	20	53.8
	25%	100	90	35	75
	50%	200	100	70	130
	75%	250	150	150	200
	90%	320	196	245	200
Nitrate-nitrite,N (mg/l)	n=	467	16	39	2
	10%	0.003	0.003	0.003	0.003
	25%	0.007	0.005	0.003	0.003
	50%	0.039	0.014	0.010	0.004
	75%	0.069	0.059	0.036	0.006
	90%	0.090	0.078	0.050	0.006
Salinity (psu)	n=	520	16	277	19
	10%	0.1	0.2	2.5	2.7
	25%	0.1	0.2	6.6	4.1
	50%	0.2	0.7	14.3	10.5
	75%	1.8	7.8	21.2	12.6
	90%	10.1	9.6	25.6	17.0

Other riverine investigations have explored the river position of the chlorophyll *a* maximum with respect to physical variables (flow and pulse residence time). While pulse residence times were unavailable for the Myakka River, the parameter was approximated by the DAYS parameter used in isohaline regressions. The DAYS parameter, as the number of days required to fill the river volume between 50.0 km and the sample location at the daily flow, while not accounting for previous flow history or tidal flushing and sequential dilution, does account for the varying morphology of the river. Under similar flows, a location upstream will have a much smaller DAYS value than a location downstream and so represents an approximate residence time.

There were 166 samplings with sufficient stations to compute a chlorophyll *a* maxima and location for the date. Maximum values were centered near 10.8 µg/l, while median values for chlorophyll *a* minima were 2.2 µg/l. The salinity at the chlorophyll *a* maxima had a median value of 3 psu and a median location of 15.7 km (but ranged from -5 to 35 km). Chlorophyll *a* maxima were similar to chlorophyll overall in that higher maxima were associated with higher color values (increased fresh water), up to near 150 PCU. At higher colors, maximum chlorophyll *a* values were depressed and likely represented light limitation.

Chlorophyll *a* maxima greater than 20 µg/l in any portion of the river were typically limited to when flows were less than ~600 cfs. The amplitude and location of the chlorophyll *a* maxima as a function of flow (Figure 4-85) or salinity (Figure 4-86) alone were both significant, although standard errors in each case were on the order of 12-13 µg/l and 6-7 km, respectively, and so relationships were not pursued for predictive purposes. The maximum values of chlorophyll *a* on any given day are undoubtedly a complex function of the numerous forcing factors described above.

Any effects of freshwater withdrawals on chlorophyll *a* will likely depend on the method of withdrawal. In-stream removals at an upriver location would not be expected to reduce color values in the freshwater portion but may reduce downstream color values and downstream nutrients, including the translocation of the saline mixing zone upstream. Off-stream withdrawals, of either surface storage or shallow groundwater, by preventing the contribution of highly colored surface waters at the onset of wet season, may reduce color values along the entire length of the river. Either withdrawal mode would also be expected to increase residence times for locations below the withdrawal point and increase salinity, as discussed elsewhere in this document.

Based on Figure 4-83, freshwater withdrawals could have a variable effect below river kilometer 10, either enhancing or decreasing chlorophyll *a* concentrations although the degree of change cannot be quantified from the present information. Upstream of river kilometer 15 (Figure 4-84), withdrawals, to the extent which flow and color would be reduced and residence time and salinity increased, could generally be expected to increase chlorophyll *a* concentrations. The most useful predictor of chlorophyll *a* appeared to be the resulting salinity distributions in the upper river. Based on Figure 4-85, chlorophyll *a* maxima may be expected to increase and translocate upriver under reduced flows, although, as for all chlorophyll *a,* the degree of change is uncertain.

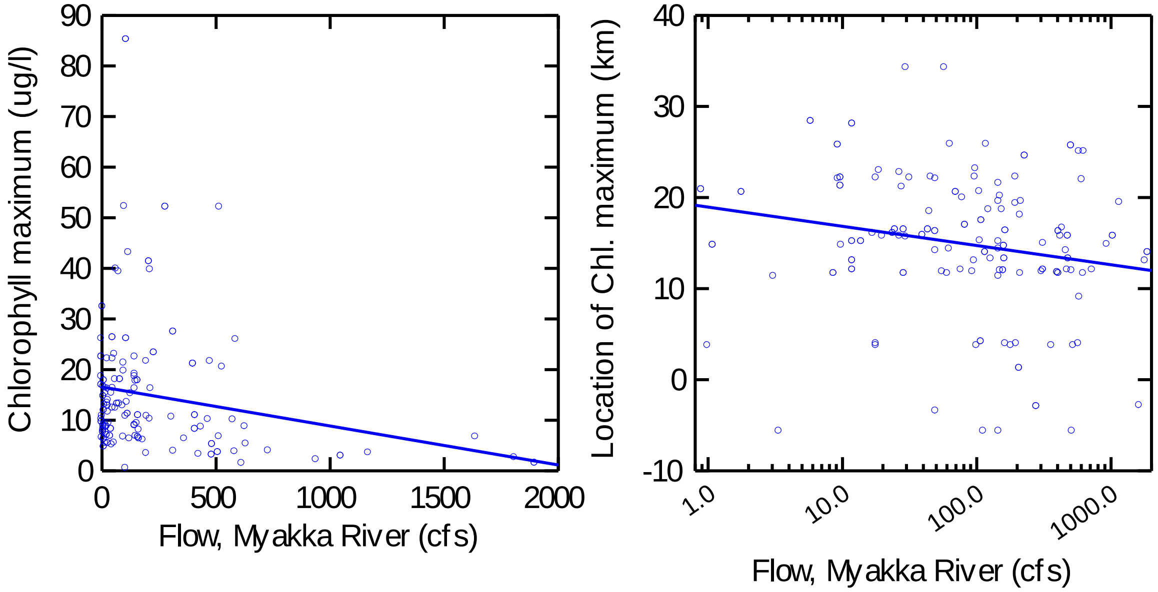

Figure 4-85. Amplitude and location of the chlorophyll *a* maxima as a function of daily flows.

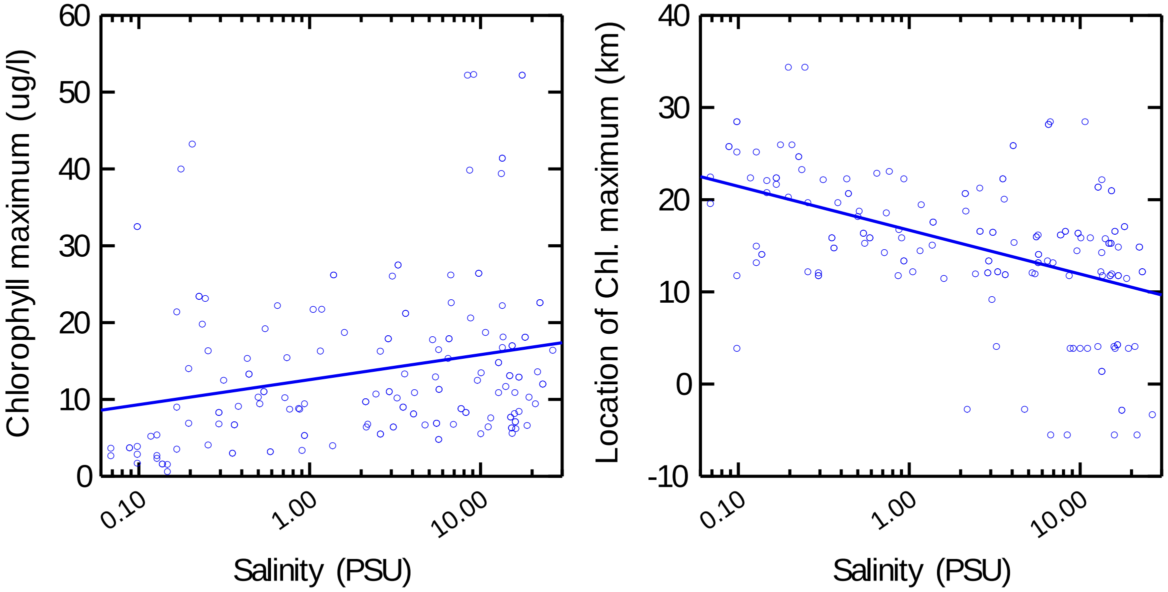

Figure 4-86. Amplitude and location of the chlorophyll *a* maxima as a function of the salinity at the maxima.

Chapter 5

Hydrodynamic Modeling of the Lower Myakka River

5.1 Introduction

A hydrodynamic model that was developed for Upper Charlotte Harbor, including the tidal reaches of the Peace and Myakka Rivers, was used to simulate changes in salinity distributions in the Myakka River for purposes of determining minimum flows. This model was also recently used to simulate changes in salinity distributions for the determination of minimum flows for the Lower Peace River (SWFWMD 2010b). The Peace and Myakka Rivers enter Upper Charlotte Harbor in close proximity (Figure 2-1) and flows from each river can affect salinity in both the upper harbor and the adjacent rivers. For this reason, the model domain for the determination of minimum flows was extended to include the upper harbor and the two rivers that comprise the Upper Charlotte Harbor – Lower Peace River – Lower Myakka River (UCH-LPR-LMR) system.

The downstream model boundary in the upper harbor was linked to model output from a model of the greater Charlotte Harbor system and nearshore Gulf developed by the University of Florida (Sheng et al. 2006). The interaction of these two models allows the District to evaluate the combined effects of reductions in freshwater flow from both rivers on the salinity and circulation in the greater Charlotte Harbor system, as well as in each of the tidal rivers.

Details about the development of the model and its calibration and verification against measured field data collected in the UCH-LPR-LMR system can be found in Appendix 5A and SWFWMD (2010b). This chapter briefly describes the hydrodynamic model used in the study and its application to the UCH-LPR-LMR system in support of the determination of minimum flows for the Lower Myakka River.

5.2 Model Equations

The hydrodynamic model used for the UCH-LPR-LMR system is a dynamically coupled 3D-2DV model called LESS (Chen 2003c, 2005a, 2007) which involves a two-way coupling of the laterally averaged 2D hydrodynamic model LAMFE (Chen and Flannery 1997, Chen et al., 2000, Chen 2003a and 2004a) and the 3D hydrodynamic model LESS3D (Chen 1999, 2003b, 2004b). While LESS3D is needed for the Upper Charlotte Harbor and the most downstream portions of the LPR and LMR where flow patterns are three-dimensional, LAMFE is much more efficient in dealing with narrow and meandering upstream reaches of the system where flow patterns are basically two-dimensional (vertical and longitudinal).

In the LAMFE model, the following governing equations are solved:

$$\frac{\partial ub}{\partial x} + \frac{\partial wb}{\partial z} = v \tag{1}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + w\frac{\partial u}{\partial z} = -\frac{\tau_{wx}}{\rho_o b} - g\frac{\partial \eta}{\partial x} - \frac{g}{\rho_o}\int_z^{\eta}\frac{\partial \rho}{\partial x}d\zeta + \frac{1}{b}\frac{\partial}{\partial x}(bA_h\frac{\partial u}{\partial x}) + \frac{1}{b}\frac{\partial}{\partial z}(bA_v\frac{\partial}{\partial z}) \tag{2}$$

$$b\frac{\partial c}{\partial t} + \frac{\partial ubc}{\partial x} + \frac{\partial wbc}{\partial z} = \frac{\partial}{\partial x}(bB_h\frac{\partial c}{\partial x}) + \frac{\partial}{\partial z}(bB_v\frac{\partial c}{\partial z}) + vc_t + S_s \tag{3}$$

where *t* is time; *x* is the horizontal coordinate along the river/estuary, *z* is the vertical coordinate, *u* and *w* denote velocity components in *x*- and *z*-directions, respectively; *v* is the lateral velocity from lateral inputs (sheet flow of direct runoff, tributary, etc.); *b*, *p*, *g*, and η denote the width, pressure, gravity acceleration, and the free surface elevation, respectively; ρ_o is the reference density; τ_{wx} represents the shear stress due to the friction acting on the side wall (= $\rho C_w u[u^2+w^2]^{1/2}$, where C_w is a non-dimensional frictional coefficient for side walls); A_h and A_v are eddy viscosities in the *x*- and *z*-directions, respectively; *c* is concentration (can be temperature, salinity, suspended sediment concentrations, nutrient concentrations, etc.); c_t is concentration in lateral inputs; B_h and B_v are eddy diffusivities in the *x*- and *z*-directions, respectively; S_s denotes source/sink terms; and ρ is density which is a function of salinity and temperature (UNESCO 1983). In the above transport equation, if the material simulated involves settling, *w* in the advective term includes the settling velocity of the material.

In the LESS3D model, the governing equations are:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{4}$$

$$\begin{aligned} \frac{\partial u}{\partial t} + \frac{\partial uu}{\partial x} + \frac{\partial vu}{\partial y} + \frac{\partial wu}{\partial z} &= fv - \frac{1}{\rho_o}\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}(A_h\frac{\partial u}{\partial x}) + \frac{\partial}{\partial y}(A_h\frac{\partial u}{\partial y}) + \frac{\partial}{\partial z}(A_v\frac{\partial u}{\partial z}) \\ \frac{\partial v}{\partial t} + \frac{\partial uv}{\partial x} + \frac{\partial vv}{\partial y} + \frac{\partial wv}{\partial z} &= -fu - \frac{1}{\rho_o}\frac{\partial p}{\partial y} + \frac{\partial}{\partial x}(A_h\frac{\partial v}{\partial x}) + \frac{\partial}{\partial y}(A_h\frac{\partial v}{\partial y}) + \frac{\partial}{\partial z}(A_v\frac{\partial v}{\partial z}) \end{aligned} \tag{5}$$

$$p = g\int_z^{\eta}\rho d\zeta \tag{6}$$

$$\frac{\partial c}{\partial t} + \frac{\partial uc}{\partial x} + \frac{\partial vc}{\partial y} + \frac{\partial wc}{\partial z} = \frac{\partial}{\partial x}(B_h\frac{\partial c}{\partial x}) + \frac{\partial}{\partial y}(B_h\frac{\partial c}{\partial y}) + \frac{\partial}{\partial z}(B_v\frac{\partial c}{\partial z}) + S_s \tag{7}$$

where *x*, *y*, and *z* are Cartesian coordinates (*x* is from west to east, *y* is from south to north, and *z* is vertical pointing upward); *u*, *v*, and *w* are velocities in the *x*-, *y*-, and, *z* directions, respectively; *f* denotes Coriolis parameter; and A_h and A_v represent horizontal and vertical eddy viscosities, respectively; and B_h and B_v are horizontal and vertical eddy diffusivities, respectively. Again, if the material simulated in Equation (7) involves settling, *w* in the advective term includes the settling velocity of the material.

Both the LAMFE and LESS3D models solve their governing equations using a flux-based finite difference method which is basically a finite volume method. Both models employ a semi-implicit scheme called the free-surface correction (FSC) method (Chen 2003a, 2003b) which is very efficient, as it is unconditionally stable with respect to gravity waves, wind and bottom shear stresses, and vertical eddy viscosity terms. The dynamic, two-way coupling of LAMFE and LESS3D was done through the FSC method by merging a water elevation correction matrix for LAMFE with that for LESS3D and solving the merged matrix. By doing so, the surface elevations in both the 3D and 2DV sub-domains are found simultaneously. Details on how LAMFE and LESS3D are dynamically coupled are presented in Chen (2007).

5.3 Data Used for Model Development

Because flow and salinity distributions in the UCH-LPR-LMR system are mainly controlled by bathymetry, freshwater inflows to the upstream areas, and tides and salinity conditions at the downstream boundary, boundary conditions should be specified at all the boundaries before the boundary value problem (Equations 1 – 7) can be solved. Therefore, data required for a successful simulation of hydrodynamics in the UCH-LPR-LMR system include bathymetry, freshwater inflows at upstream boundaries, estimates of freshwater loadings from ungauged portions of the watershed, downstream boundary conditions (water level, salinity, and temperature), and meteorological data (wind, solar radiation, air temperature, and air humidity). To calibrate and verify the model, field data measured inside the simulation domain are also needed.

Flow data used in this modeling study were collected by the US Geological Survey at: (1) Peace River at Arcadia (02296750), (2) Joshua Creek at Nocatee (02297100), (3) Horse Creek near Arcadia (02297310), (4) Shell Creek near Punta Gorda (02298202), (5) Big Slough Canal at Tropicaire (02299450), (6) Myakka River near Sarasota (02298830), (7) Deer Prairie Slough near Myakka City (02299060), and (8) Blackburn Canal near Venice (02299692). These USGS flow data were used, either directly or indirectly, as the gauged portion of the total freshwater loading to the UCH-LPR-LMR system.

The ungaged portion of the freshwater loading to the system was estimated by Ross et al (2005) using the Hydrological Simulation Program - FORTRAN (HSPF) (Bicknell et al. 2001). However, these values were adjusted by coefficients derived by comparisons of the HSPF modeled flows to other ungaged estimates generated by SDI (see section 2.4.3.2). Another factor influencing the total freshwater budget of the system is freshwater withdrawals from the

LPR by the Peace River Manasota Regional Water Supply Authority and from Shell Creek by the City of Punta Gorda (the later is included in the Shell Creek flow).

For the boundary conditions at the downstream boundary (the red dashed line in Figure 5-1), simulated results of water elevation, salinity and temperature of a larger scale hydrodynamic model by University of Florida (Sheng et al. 2006) were used. The UF model covered the entire Charlotte Harbor and a coastal area almost 45 km offshore into the Gulf of Mexico.

At the free surface, wind shear stresses and heat fluxes need to be specified. Wind data measured at the UF station (Figure 5-1) were used to calculate shear stresses at the free surface. The heat exchange with the atmosphere at the free surface was calculated based on measured solar radiation, wind, and air temperature data at the UF station and a SWFWMD station near the Peace River Manasota Regional Water Supply Authority.

Inside the simulation domain (Figure 5-2), real-time data of water level, salinity, and temperature at eight stations (see asterisks in Figure 5-1) were available for model calibration and verification. These eight stations are: (1) the University of Florida station in the Upper Charlotte Harbor near the mouth of the Myakka River, (2) USGS Peace River at Punta Gorda (02298300), (3) USGS Peace River at Harbor Heights (02297460), (4) USGS Peace River at Peace River Heights, (5) USGS Myakka River at El Jobean (02299496), (6) USGS Myakka River at North Port (02299230), (7) USGS Myakka River at Snook Haven (02298955), and (8) USGS Shell Creek Tidal near Punta Gorda (02298208). The USGS real-time data were collected with a time interval of 15 minutes, while the UF data had a time interval of 30 minutes. At the UF station, velocity components at several water depths were also measured.

As mentioned by Chen (2008), the quality of the available real-time water level, salinity, and temperature data measured at the eight stations is just average. Several stations had many missing data periods. Some of the salinity and temperature data appeared to possibly contain some unexpected error . Nevertheless, these are the best data available for this modeling study.

5.4 Model Calibration and Verification

To apply the LESS model to the UCH-LPR-LMR system, the entire simulation domain was split into a 3D sub-domain and a 2DV sub-domain. The 3D sub-domain includes the Upper Charlotte Harbor, the downstream 15.5 kilometers of the Lower Peace River, the downstream 13.8 kilometers of the Lower Myakka River, and the most downstream 1.74 km portion of the Shell Creek. A rectilinear grid system was used to discretize the 3D simulation domain with 108 grids in the *x*-direction, 81 grids in the *y*-direction, and 13 layers in the *z*-direction. The grid size in the 3D domain varies from 100m to 500m in both the *x*- and *y*-directions, while the spacing varied between 0.3m and 1.0m in the vertical direction. The 2DV sub-domain includes three main parts: (1) the LPR from river-km 15.5 to Arcadia, (2) the LMR from river-km 13.8 to river-km 38.4, and (3) and the Shell Creek from river-km 1.74 to the dam. Also included in the 2DV sub-domain were the downstream 4.16km of the Myakkahatchee Creek (up to a salinity barrier called structure WC101) and major branches of the LPR and the Shell Creek. The 2DV sub-domain was discretized with 356 longitudinal grids and 17 vertical layers. The longitudinal length for 2DV grids varied between 200m and 400m. To make the 3D-2DV coupling simple, the first 13 layers for the 2DV domain is set to be the same as the 13 layers used for the 3D domain.

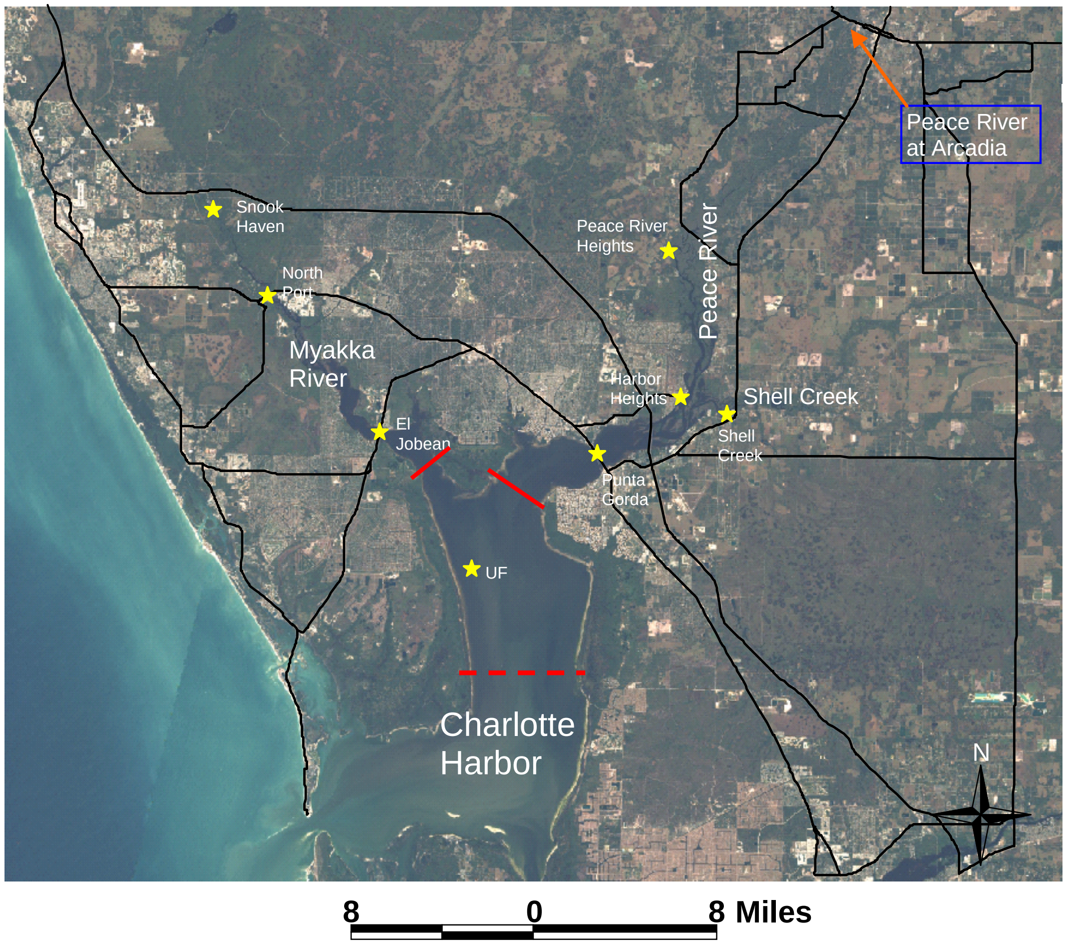

Figure 5-1 Aerial photo of the UCH-LPR-LMR system. Yellow asterisks denote the locations where real-time data were collected. The two red bars are the locations of the starting points (river kilometer 0) for the Peace and Myakka River estuaries. The red dashed line is the downstream boundary of the modeling domain.

Figure 5-2 is the mesh of the UCH-LPR-LMR model, including model grids for both the 3D and 2DV sub-domains. The red portion of the mesh represents land grids in the 3D sub-domain, while the black portion represents water grids. Only water grids are included in the computation at each time step. Land grids are kept inactive and not included in the computation. As the water level rises, shorelines also change. As a result, some land grids may become water grids and will be treated as active grids in the computation at the new time step.

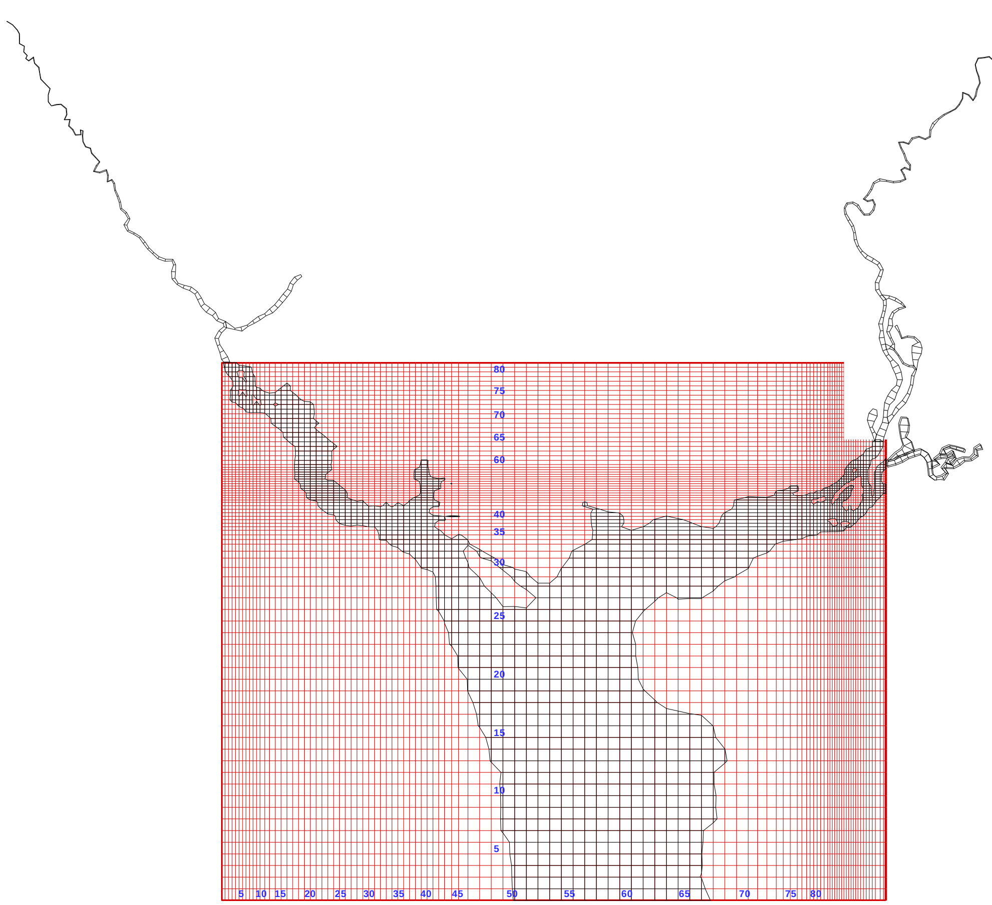

Figure 5-2 Model grids used in the UCH-LPR-LMR model. The red portion of the mesh represents land grids that are inactive in the computation in the 3D domain.

Model simulations were conducted for a 13-month period between June 13, 2003 and July 12, 2004, during which the first 30 days, from June 13 to July 12, 2003 were used for model spin-up because no initial conditions on June 13, 2003 were available.

Considering the quality of available data and errors associated with the estimation of un-gauged flows during extreme conditions, a three-month period from January 10, 2004 to April 9, 2004 was chosen for model calibration. During the model calibration process, key model parameters (e.g., bottom roughness, background vertical eddy viscosity and diffusivity, various advection schemes, etc.) were adjusted to obtain the best fit between model results and measured data at the eight stations in the UCH-LPR-LMR system. Because the initial conditions for the calibration period were also unknown, a 30-day spin-up period was included in the model calibration. Therefore, the calibration run was actually performed for a four-month period from December 12, 2003 to April 9, 2004, with the model results during the first 30 days being excluded in calibrating the model. After the model was calibrated, it was verified against field data measured at the eight stations during a six-month period before the calibration period (July 12, 2003 – January 9, 2004) and a three-month period after the calibration period (April 19 – July 11, 2004).

Detailed comparisons between model results and field data at the eight real-time stations for both the calibration and verification periods are presented in Chen (2008). A quantitative assessment of the model performance was also conducted and reported in Chen (2008). It includes calculating mean errors, mean absolute errors, coefficients of determination (R^2), and skills of model results in comparison with measured real-time data. Here the skill is an assessment parameter introduced by Wilmott (1981) to judge the agreement between model results and measured data and takes the following form

$$\text{Skill} = 1 - \frac{\sum (y^M - y^D)^2}{\sum (|\, y^M - \overline{y^D}\,| + |\, y^D - \overline{y^D}\,|)^2} \tag{8}$$

where y^M and y^D are simulated and measured variables (surface elevation or salinity) and $\overline{y^D}$ and $\overline{y^M}$ are means of y_l^D and y_l^M, respectively. Skill in Equation (8) varies between 0 and 1: a perfect agreement between simulated results and measured data yields a skill of one and a complete disagreement yields a skill of zero.

Table 5-1 summarizes the overall performance of the model for the UCH-LPR-LMR system. It can be seen from the table that the model performance is good.

Table 5-1. Average mean errors, mean absolute errors, q^2-values, and skills of simulated water levels, velocities, salinities, and temperatures in comparison with real-time data at eight stations in the LPR – LMR – UCH system during model calibration and verification periods

Parameter	ME	MAE	R^2	Skill
Stage (cm)	-5.07	11.33	0.82	0.91
Velocity (cm/s)	-0.04	3.69	0.53	0.84
Salinity (ppt)	0.23	1.51	0.79	0.87
Temperature (C^o)	-1.23	1.61	0.91	0.95

In addition to comparing model results with data collected at the eight real-time stations, a comparison of simulated salinities with a salinity profile data set compiled by the Mote Marine Laboratory was also done for further model verification. These salinity profile data were collected by several government agencies and private entities at 13 locations in the LPR and 10 locations in the LMR. As shown in Chen (2008), comparisons of model results with salinity profiles data in both the LPR and LMR are good. Table 5-2 lists mean errors, mean absolute errors, coefficients of determination, and skills of simulated salinities in comparison with the salinity profile data for both the LPR and LMR. Again, it can be seen that the errors are relatively small and q^2-values and skills are quite high.

Table 5-2. Mean errors, mean absolute errors, q^2-values, and skills of simulated salinities in comparison with salinity profile data compiled by the Mote Marine Laboratory during model calibration and verification periods in the LPR and LMR.

	Depth	ME	MAE	R^2	Skill
Peace River	All Depths	-0.06	1.69	0.89	0.99
	< 1m	0.28	1.51	0.91	0.98
	≥ 1m	-0.23	1.79	0.89	0.97
Myakka River	All Depths	-0.97	1.36	0.94	0.98
	< 1m	-0.95	1.50	0.92	0.97
	≥1m	-0.99	1.26	0.96	0.98

Chapter 6

Biological Characteristics of the Lower Myakka River

6.1 Introduction

The determination of minimum flows for the Lower Myakka River included investigations of tidal wetlands, benthic invertebrates, zooplankton and fishes in the lower river. Relationships of freshwater inflow and salinity with the abundance and distribution of these organisms were assessed to evaluate how reductions in freshwater inflows might affect various species and communities. These relationships were then used to develop biologically relevant metrics by which the effects of freshwater inflow reductions could be assessed. The characterization of biological communities in the lower river and relationships with freshwater inflow and salinity are presented in this chapter. The ecological metrics chosen for the minimum flows analysis are discussed in Chapter 7. Simulations of the effects of various rates of freshwater inflow reductions on these metrics are presented in Chapter 8 along with the proposed minimum flows.

6.2 Tidal Wetlands

Wetlands often dominate tidal river landscapes and sustain river ecosystem functions of mass and energy storage and flux, fish and wildlife nursery and habitat, and biodiversity reservoirs (Seaman 1985, Kusler and Daly 1989, Myers and Ewel 1990, Mitsch and Gosselink 2000, Keddy 2000). The combined effects of freshwater inflows and tides on vegetation in tidal rivers are manifested through water stage variations, current reversals, and the presence of saline water (McPherson and Hammett 1991). In the Myakka River, tidal stage variations occur upstream to a lithified sill called Rocky Ford, near river kilometer (RK) 41.6 (Bie 1916, US Geological Survey 1973). Weak tidal current reversals may occur to near RK 36 during periods of low stream flow. Salt penetration into the river rarely reaches RK 30 (See Chapter 4).

Modern land cover and use along the Myakka River downstream of Rocky Ford to U.S. Highway 41 (U.S. 41; RK 18.4) is generally undeveloped coniferous forests (pine flatwoods) and wetlands, with substantial areas in public ownership for conservation (Myakka Conservancy, 1994). From U.S. 41 downstream to the river's mouth, land cover and use become progressively more urban (Myakka River Management Coordinating Council 1990), with the densest areas of urbanization occurring between RK 5 and RK 12 (Figure 6-1).

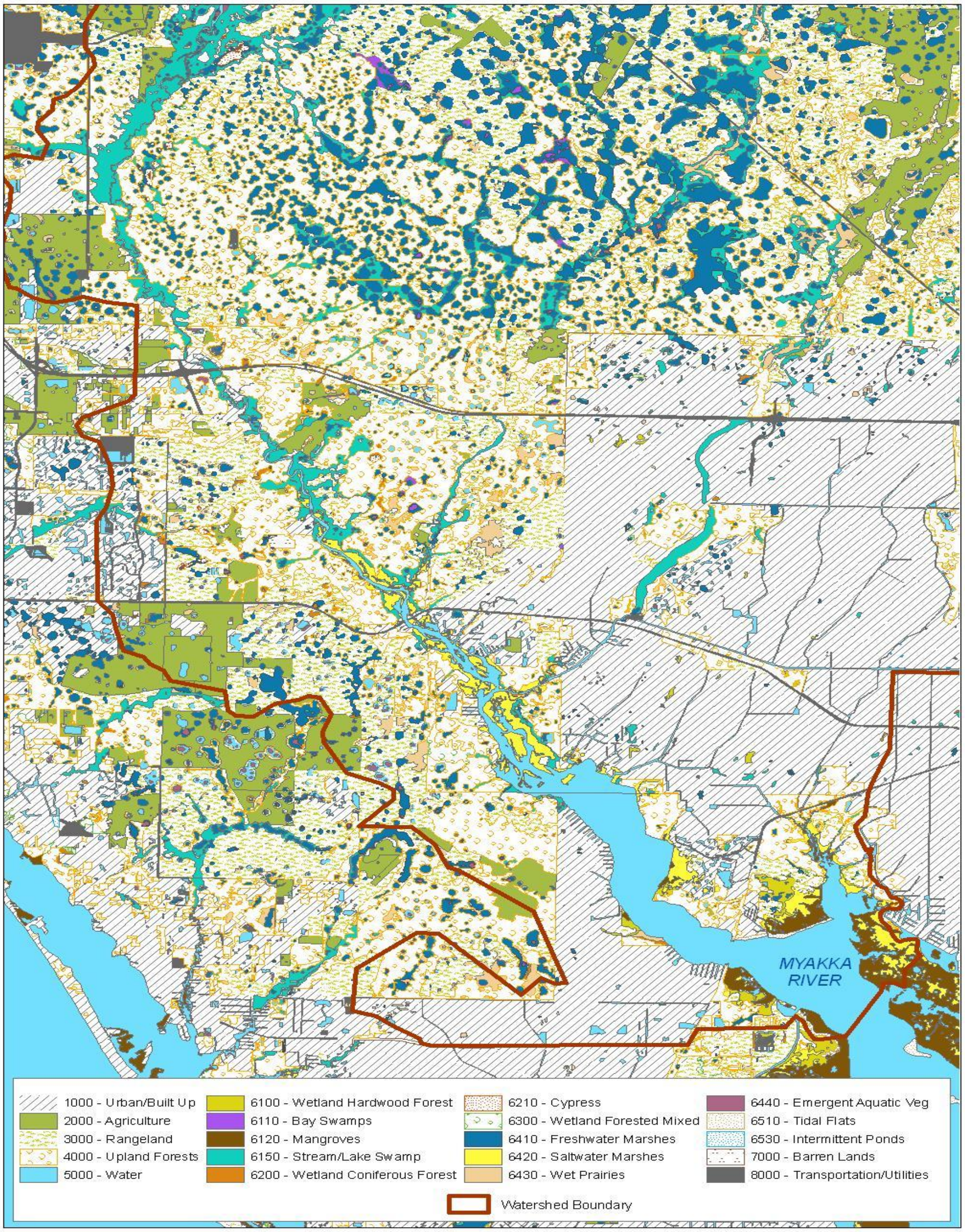

Figure 6-1. Composite land use-land cover map of the lower Myakka River and Watershed.

Based on interpretations of field notes from the General Land Office Survey made during Florida's 1843-1849 survey and other historical sources, Wharton (1985) concluded, "The lower Myakka appears much like it did in presettlement times. The upstream extent of estuarine conditions, as reflected in brackish-water conditions and brackish-type vegetation, has probably not shifted from its presettlement situation. Both freshwater and brackish-water vegetation communities retain in large part their original configuration along the lower river corridor." (page 44).

Although river environments have been conserved at large scale, shorelines, including wetlands, have been affected by development and biotic competition. Estevez et al.'s (1990) survey of the tidal river from its mouth to Interstate 75 (RK 31) found that hardened shorelines and invasive, exotic species occupied 12.4% and 36.7% of total shoreline length, respectively. They noted that much of the altered shoreline in Charlotte County (lower 12 kilometers) was originally uplands. In contrast, most of the island and fringing wetlands in Sarasota County remained intact, especially upstream of US 41 (RK 18.4).

In the tidal Myakka River, wetlands potentially affected by salinity changes are typically contiguous to the river, although some are less directly connected being separated from the river by another wetland type (e.g. freshwater marsh located on the backside of a saltwater wetland that is contiguous to the river). These generally include mangrove forests, herbaceous marshes, and some freshwater forested wetlands. This chapter characterizes tidal wetlands and assesses their risk if salinity is significantly changed by reductions of freshwater inflow.

As described below, Myakka River wetlands can be divided into four broad groups– a downstream system dominated by mangroves; a middle-river system with widespread saltmarsh that is typically dominated black needle rush (*Juncus roemerianus*); and an upriver system where high-diversity oligohaline and tidal-freshwater marshes are replaced upstream by floodplain forests and bottomland hardwoods (Figure 6-2). Our emphasis will be on oligohaline and tidal freshwater marshes located in the upriver system as indicators of potential changes resulting from altered salinities. As shown in Chapter 4, the low-salinity reach of the Myakka River exhibits the largest changes in salinity relative to change in river flow.

6.2.1 Wetlands Characterization Sources

(Adapted from Estevez et al. 1990)

Descriptions of the modern flora of the Myakka Corridor have been given by the Soil Conservation Service (1959), Miller (1979), the National Wetlands Inventory (U.S. Fish and Wildlife Service 2010), Harris et al. (1983), Hussey (1985), the Florida Department of Natural Resources (Hunter Services, Inc., 1990), Clewell et al. (1990), Estevez et al. (1990), Florida Marine Research Institute (1999), and Clewell et al. (2002). When appropriate, river miles cited in other works have been converted to river kilometers.

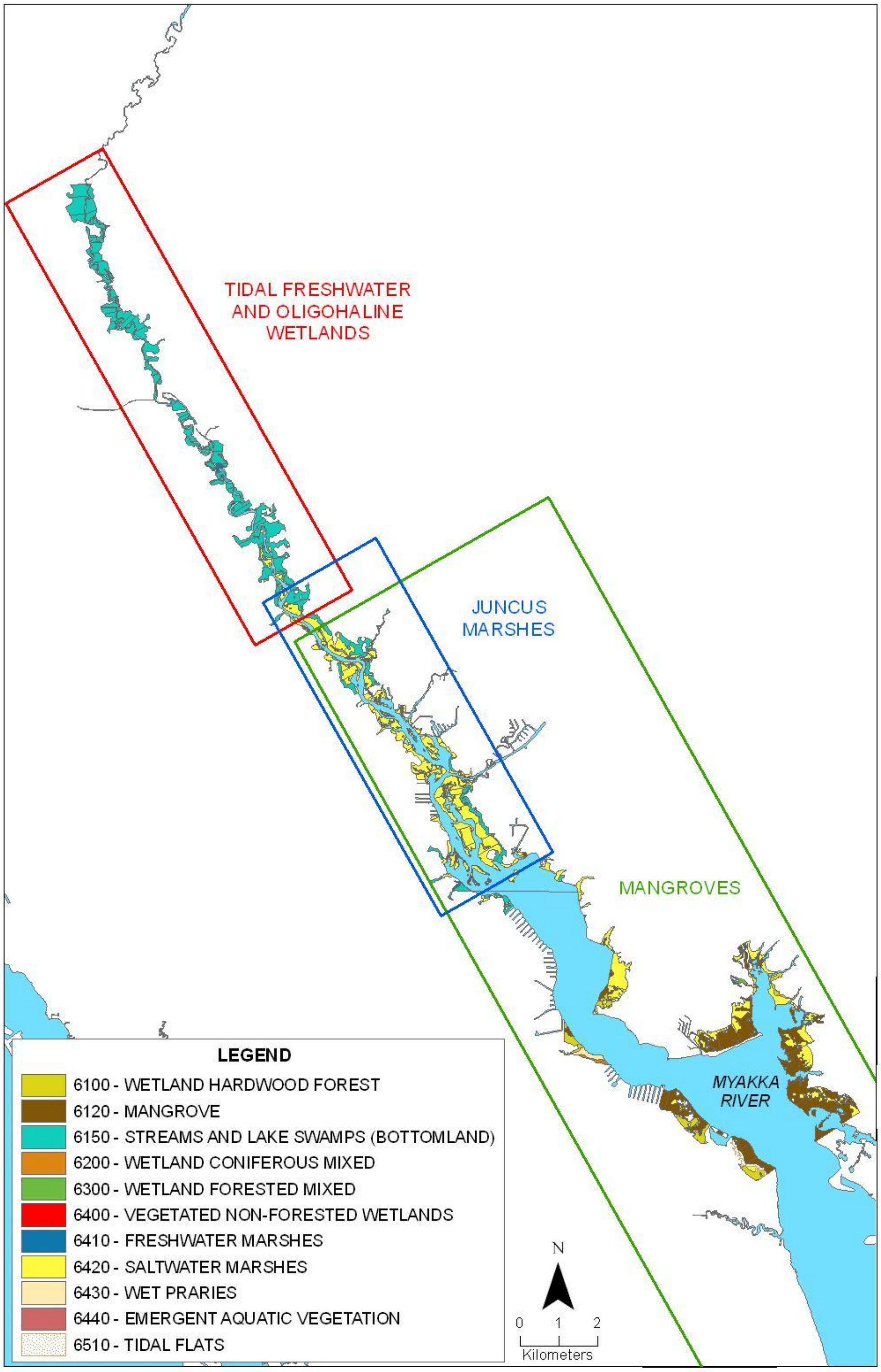

Figure 6-2. Ten wetland forms identified from FLUCCS aggregated into three principal zones characterized by dominant vegetation communities on the Lower Myakka River. A fourth zone, freshwater floodplain forests, lies upstream.

The Soil Conservation Service (SCS) actually described soils of Sarasota County based on aerial photography and ground-truthing performed in the 1940s and 1950s. SCS maps depict sandy alluvial soils along the river below the Park, downstream to the Big Bend area where that soil type pinches out at RK 24.6 and is replaced by a widening band (downstream) of tidal marsh soil.

For the river's reach in Sarasota County, Miller (1979) recognized eight plant associations in three groups: river-independent, man-disturbed, and river-related. The latter group contained low upriver (near the Park), low downriver (tidal), and oak-cabbage-palm hammock associations. The low upriver associations, generally small in extent, included popash heads, mixed meadows of buttonbush, popash, and water locust, and willow points. The low downriver associations included "brackish" marshes, salt marshes, and mangrove swamps, which first appear "just south of Snook Haven", and include bulrush, cordgrass, leather fern, and cattail. Miller (1979) stated that mangroves first appear about a mile north of the U.S. 41 bridge (RK 18.4).

Wetlands were hierarchically defined and mapped into five ecological systems and numerous subsystems, classes, and subclasses by the National Wetland Inventory via the interpretation of high resolution (1:80,000) aerial photographs following Cowardin et al.'s (1979) structural classification system. The photography was acquired in 1972. Nearly all of the tidal wetlands downstream of U.S. 41 were classified "Estuarine Intertidal" and constitute marshes or mangrove forests. Only three small wetland patches bearing the palustrine forest or palustrine marsh labels appear downstream of the Highway, on the Myakka River topographic quadrangle. Upstream of the Highway (RK 18.4), to Rambler's Rest Resort (RK 23.0), estuarine marshes dominated. From the Resort upstream to Big Bend, wetlands were a mixture of palustrine forests and emergent marshes. Upstream of Big Bend, the National Wetland Inventory reported palustrine forests comprised of "broad-leaved evergreens" (cabbage palms) and the first occurrences (heading upriver) of open-water tributaries bearing the "Riverine Lower Perennial" label were mapped.

Harris et al. (1983) reported on fishery habitat distribution, abundance and trends since 1945 for the Charlotte Harbor area, including the "El Jobean" topographic quadrangle that encompasses the tidal Myakka River upstream to the Charlotte-Sarasota County line. In 1982, this area contained 1749 ha (4,321 ac) of mangrove, 618 ha (1,528 ac) of salt marsh, and 362 ha (894 ac) of seagrass. Since 1945, the spatial extent of mangroves increased by 26%, while saltmarsh and seagrass decreased areally by 13% and 45%, respectively. Harris et al. (1983) attributed saltmarsh loss to urbanization and noted that mangrove areal increases coincided with a 255 ha (631 ac) decrease (-83%) in unvegetated tidal flats.

As part of a wet-season characterization of the tidal Myakka River, Hussey (1985) used transects to depict wetland composition along the salinity gradient downstream of the T. Mabry Carlton Reserve (RK 30.0). Seventy-two species were identified. Black needle rush was the most common species, followed by cabbage palm, Brazilian pepper, and wax myrtle. Distribution of the 20 most common species bore no relation to salinity although the distribution of 12 salinity-sensitive species followed a pattern consistent with the effects of saltwater penetration. Eight physiographic shoreline types were identified along the tidal river. Forested freshwater shorelines occurred upstream of RK 24. Tidal freshwater marsh was very rare in this river reach and all occurred on the east bank between RK 27.2-31.9.

“Brackish marshes” contained mixtures of salt marsh plants and freshwater species that are tolerant of low salinities (e.g. *Typha domingensis*, *Scirpus californicus*); these were found between RK 10.8-26.7 (east bank) and 15.1-20.4 (west bank). The influence of tributaries was noted in localized mixtures of freshwater species in salt marsh or mangrove swamp in the river, near the mouth of each tributary. Admixture was particularly high at the mouth of Deer Prairie Creek. Overall, Hussey recognized RK 9.7-20.9 as floristically transitional between the estuarine/marine and riverine plant communities. The presence of only one patch of sawgrass was noted.

Clewell et al. (1990) reported on a botanical survey of the upper part of the tidal river, between Snook Haven (RK 27.9) and the State Park (RK 41.0), performed as part of a Myakka River basin study by Sarasota County. The river flora was found to be depauperate (147 species) relative to northern and southern coastal rivers. Four vegetation types were recognized, hydric hammocks, mesic evergreen hammocks, marshes, and sloughs. Hydric hammocks contained live oak, cabbage palm, laurel oak, sweetgum, American elm, loblolly pine, red maple, ironwood, water oak and red cedar. Mesic evergreen hammocks contained live oak and cabbage palm with a saw palmetto undergrowth and few epiphytes. Sloughs were numerous in the upriver half of their study area. Most shoreline marshes were small and occupied low flats or sand bars near sloughs. Shoreline marshes downstream of RK 40 (former Cow Pen Slough confluence) were small to large, contained more species, and were more numerous than marshes upstream of that point. Six shoreline species were found within the lower river reach that are characteristic of tidal influence and another six were found to be common upstream and absent downstream.

Hunter Services, Inc. (1990) provided descriptions of major plant communities and maps of the river reach designated as a Florida Wild and Scenic River, including extensive "saltwater marsh" downstream of Rambler's Rest Resort (RK 24) and patches of "freshwater swamp" between Rambler's Rest Resort and the mouth of Deer Prairie Creek (RK 19.5). A patch of sawgrass (*Cladium jamaicense*) was mapped in marshes across the stream from Deer Prairie Creek, apparently the same occurrence of the species mapped by Hussey (1985). Upriver patches of freshwater swamp were mapped near Snook Haven Fish Camp and downstream of Laurel Road.

Estevez et al. (1990) inventoried shorelines of the tidal river in Sarasota and Charlotte Counties, for Sarasota County, using shoreline lengths to classify the condition of the river banks.

Because of the extensive edges associated with marshes, islands and tributaries, they found that there were ~13 km of shoreline per kilometer of river within the tidal reach. Hardened shores comprised 12.4% of the total. By length, exotic species were present along more than one-third of tidal river shorelines, with Brazilian pepper (*Schinus terebinthifolius*) constituting 93% of the exotic cover, by species.

In 1999, the Florida Marine Research Institute developed GIS-based maps to determine the status and trends of oligohaline vegetation in the tidal Peace and Myakka rivers (Florida Marine Research Institute, 1999). The map for the Myakka depicted salt marshes dominated by *Juncus roemerianus* switching to salt marsh without *Juncus* at RK 22.0. The *Juncus* attribute was an overlay meant to depict its dominance in the more general “salt-marsh” mapping unit.

Clewell et al. (2002) mapped vegetation communities in seven tidal rivers in west central and southwest Florida, including the Myakka River, where salinity data allowed comparisons of plant distributions to salinity gradients. They noted that in tidal rivers of southwest Florida generally, that while "...all tidal marsh species respond to the salinity regime, their distribution and abundance are determined in concert with other factors" such as interspecific competition, and resilience to disturbance. They noted that while vegetation breaks were generally apparent from vegetation maps, the precise break points were difficult to determine from shoreline associated species-specific data. Also noted was that the floral species composition of riverbank vegetation and/or forest assemblages located short distances inland and on slightly higher topography could differ markedly from that at the riverbank.

In the Myakka River Clewell et al. (2002) surveyed the lower 40 km of this tidal river and recorded a total of 57 wetland and stream-bank plant species (Appendix 6A, List 3). Among the most common were three species in the lower third of the river, five species in the middle third (to near RK 24), and eight species in the upper third of the tidal reach. For all species combined, 40% were found upstream of RK 24, where mean and surface salinity was 1.2 ± 3.1 psu (n=19).

To recapitulate, the Myakka River has been relatively well described in terms of major wetland plant communities, from State Road 64 in Manatee County downstream to Charlotte Harbor. Progressing downstream from the Myakka River State Park, a hydric hammock with numerous sloughs grades into mesic evergreen hammocks with few sloughs. Marsh-dominated wetlands are scarce. Downstream of RK 30 small marshes begin to appear in bank cuts, creek mouths, ephemeral point bars, and muddy banks. For the next 10-15 river kilometers these marshes become more numerous, and larger. Although their specific floristic composition varies with season and year, they are basically a mixture of tidal freshwater marshes, oligohaline marshes, and emergent aquatic plant communities. Near RK 22.0 the river turns abruptly and widens, opening onto a wide, long salt marsh dominated by *Juncus roemerianus*. *Juncus* marshes continue nearly to the river mouth although mangrove forests become common downstream of US 41 (RK 18.4).

6.2.2 Submerged and Emergent Vegetation

The National Wetland Inventory mapped submerged (SAV) and emergent aquatic vegetation (EAV) within the tidal river, with the only intertidal or subtidal aquatic beds of estuarine or marine character reported for the El Jobean quadrangle, downstream of Cattle Dock Point. Harris et al. (1983) mapped 1945 and 1982 SAV in this same area. The first attempt to map SAV within the tidal river above Cattle Dock Point was reported by Hussey (1986); a dry season characterization performed by Mote Marine Laboratory for Sarasota County. The survey was made during a relatively wet 1986 spring season following a 2-year drought that ended abruptly with the passage of Hurricane Elena (September 1985).

Four SAV/EAV zones were recognized within the tidal river: 1) “freshwater” zone – the river upstream of Snook Haven defined by the dominance of dwarf arrowhead (*Sagittaria subulata*) ; 2) “low salinity” zone – delineated by Snook Haven upstream and Rambler's Rest Resort downstream, this area was dominated by wild celery (*Vallisneria americana*) ; 3) “brackish” zone – the tidal river between Rambler's Rest and the El Jobean Bridge that was dominated by widgeon grass (*Ruppia maritima*); and 4) the “marine” zone – an area dominated by shoal grass (*Halodule wrightii*) that extends from Charlotte Harbor upstream to a point about RK 2.5 km above the El Jobean Bridge (note this zone overlapped the brackish zone). Tributaries often contained species less tolerant of elevated salinities than the prevailing conditions at the confluence of the stream and river, e.g., the *V. americana* found within Deer Prairie Creek.

6.2.3 Wetlands associated with the tidal Myakka River

Reported Species A total of 134 species of plants has been recorded in wetlands and on shorelines of the tidal river. Appendix 6A lists species by study and includes a master list of species. Of these, 99 (74%) species are listed in Section 62-340.450 of the Florida Administrative Code as obligate or facultative wetland plants, or submerged aquatic vegetation (Table 6-1).

Table 6-1. Wetland plant species reported from the Lower Myakka River classified by the F.S. Section 62-340.450 vegetative index as obligate (O) or facultative (F) wetland species with S denoting submerged aquatic species.

Acrostichum danaeifolium	O	*Ludwigia repens*	O
Acrostichum aureum	O	*Lycium carolinianum*	O
Alternanthera philoxeroides	O	*Lythrum alatum*	O
Amaranthus floridanus	O	*Lythrum lineare*	O
Andropogon glomeratus	F	*Melanthera nivea*	F
Avicennia germinans	O	*Micranthemum glomeratum*	O
Baccharis angustifolia	O	*Myrica cerifera*	F
Bacopa monnieri	O	*Osmunda regalis*	O
Bacopa caroliniana	O	*Panicum hemitomon*	O
Batis maritima	O	*Panicum rigidulum*	F
Borrichia frutescens	O	*Paspalum sp.*	O
Carex lupulina	O	*Pluchea odorata*	F
Cephalanthus occidentalis	O	*Pluchea purpurascens*	F
Ceratophyllum demersum	S	*Polygonum hydropiperoides*	O
Chara sp.	S	*Polygonum punctatum*	O
Cicuta maculata	O	*Polypodium polypodioides*	O
Cladium jamaicensis	O	*Pontederia cordata*	O
Conocarpus erectus	F	*Pontederia lanceolata*	O
Coreopsis sp.	F	*Prosperpinaca pectinata*	O
Crinum americanum	O	*Quercus laurifolia*	F
Dichromena sp.	O	*Rhizophora mangle*	O
Diodia virginiana	F	*Rhynchospora colorata*	O
Distichlis spicata	O	*Rhyncospora tracyi*	O
Eleocharis baldwinii	O	*Rumex verticillatus*	F
Eleocharis cellulosa	O	*Ruppia maritima*	S
Eleocharis flavescens	O	*Sabatia calycina*	O
Eupatorium sp.	O	*Sagittaria graminea*	O
Fimbristylis castanea	O	*Sagittaria lancifolia*	O
Fraxinus caroliniana	O	*Sagittaria latifolia*	O
Gratiola virginiana	F	*Sagittaria subulata*	S
Halodule wrightii	S	*Salix caroliniana*	O
Hydrilla verticillata	S	*Samolus ebracteatus*	O
Hydrocotyle umbellata	F	*Samolus valerandi*	O
Hydrophila polysperma	O	*Scirpus californicus*	O
Hypericum fasciculatum	O	*Scirpus tabernaemontani*	O
Hypericum mutilum	O	*Scripus validus*	O
Hypericum h. hypericoides	F	*Senecio glabellus*	O
Ilex sp.	O	*Sesuvium portulacastrum*	F
Iris sp.	O	*Solidago fistulosa*	F
Iris hexagona	O	*Soldiago sempervirens*	F
Isoetees flaccida	O	*Solidago stricta*	F
Iva frutescens	O	*Spartina alterniflora*	O
Juncus effusus	O	*Spartina bakeri*	F
Juncus megacephalus	O	*Spartina patens*	F
Juncus roemerianus	O	*Teucrium canadense*	F
Laguncularia racemosa	O	*Toxicodendron r. radicans*	F
Limonium carolinianum	O	*Typha domingensis*	O
Lobelia feayana	F	*Typha latifolia*	O
Ludwigia peruviana	O	*Utricularia sp.*	O
		Valisneria americana	S

Wetlands Communities - GIS methods that were employed in the characterization of wetland communities associated with the lower river are described in Appendix 6B. Graphs depicting the lengths and areas of all wetlands appear in Figures 6-3 and 6-4. The lowest wetland shoreline length by kilometer occurs in the broad embayment reach of Charlotte County, and the highest shoreline length per kilometer occurs in southern Sarasota County where mangrove and marsh islands are common. Wetland area per kilometer is highest at the river mouth and lowest in the broad embayment reach of Charlotte County, because Tippecanoe Bay adds a large area of wetlands to the lower river but upland habitats form the natural shoreline of the broad embayment.

Four wetland community types comprise the majority of all wetlands in the tidal Myakka River: 1) mangrove forests; 2) *Juncus roemerianus* dominated salt marsh; 3) tidal-fresh and oligohaline marshes, and 4) forested freshwater wetlands. Although they are distinct floristic communities, oligohaline and tidal freshwater communities are considered together for this report because they are the upstream-most mixture of tidal marsh wetlands.

<u>Mangroves</u>: Figures 6-5 and 6-6 depict the shoreline length by kilometer, and area by kilometer, of mangroves. The majority of both attributes occur in the first few kilometers of river. Downstream of the Charlotte-Sarasota County line (RK 12), mangrove swamps are the most conspicuous wetlands. The greatest distribution of mangroves in the river occurs between RK 0 and 2. These trees are taller (to 12 meters) than those found upriver near the county line where individual trees rarely grow taller than 6 or 7 meters. These latter heights are probably maintained by periodic freezes which reduces the height of the canopy. The trees grow as a fringe around marsh islands in the river, without ever reaching an overwash forest aspect (Lugo and Snedaker, 1974). Trees growing along the bank near creek mouths have a wider footprint, but never acquire a fringe, basin, or riverine forest aspect. In Charlotte County, however, fringe and basin forest forms do occur, especially along the shores of Tippecanoe Bay.

Red mangroves (*Rhizophora mangle*) are more common along island edges and creek-banks but nowhere form large monospecific stands. Among the pure stands of red mangrove that occur in Sarasota County, the largest tend to be downriver, especially between Tarpon Point and the county line. This species' typical upriver limit is delineated at an island ~1 km upstream of the mouth of Deer Prairie Creek. At this location the single individual occurs as a shrub that is taller than 2 m after mild winters, or shorter after freezes. It flowers and successfully drops propagules into the surrounding marsh and river. Mangroves, including the red mangrove, also occur farther upriver as newly rooted recruits growing at and behind marsh edges.

Black (*Avicennia germanis*) and white (*Laguncularia racemosa*) mangroves and buttonwood (*Conocarpus erecta*) are much more abundant in Charlotte than Sarasota County, and decrease in occurrence and size upriver. Black mangroves tend to grow toward the interior of large stands, and are separated from open water by fringes of white mangrove or salt marsh.

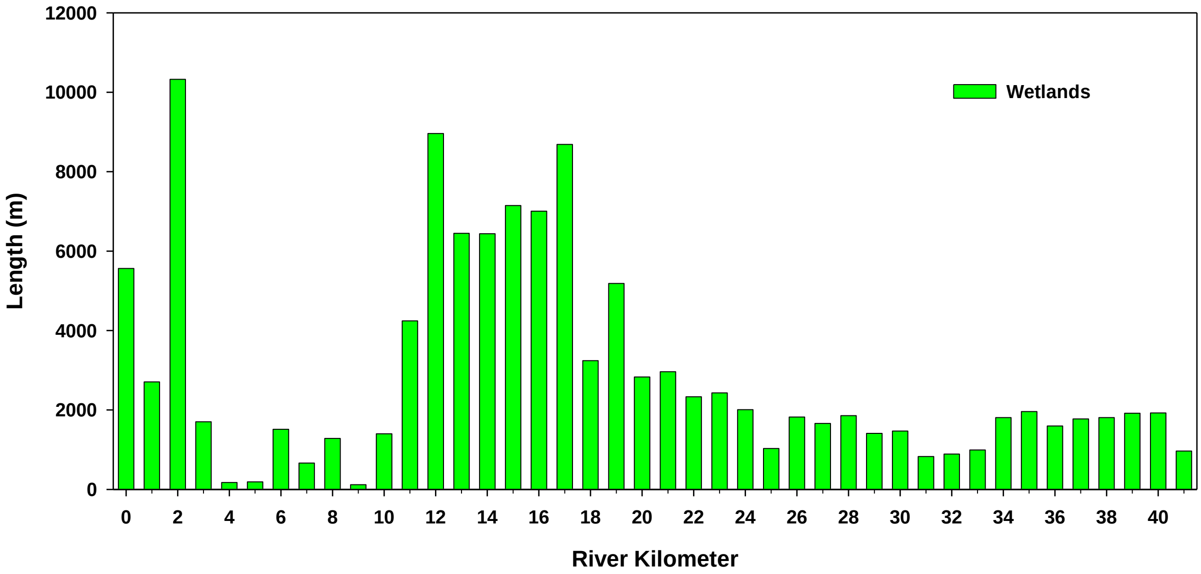

Figure 6-3. Length of shoreline by river kilometer that have been classified as "wetlands"(600). This classification includes hardwood forests (610), mangrove swamps (612), bottomland (615), coniferous forests (620), mixed forests (621), vegetated non-forests (640), and non-vegetated (650) wetlands.

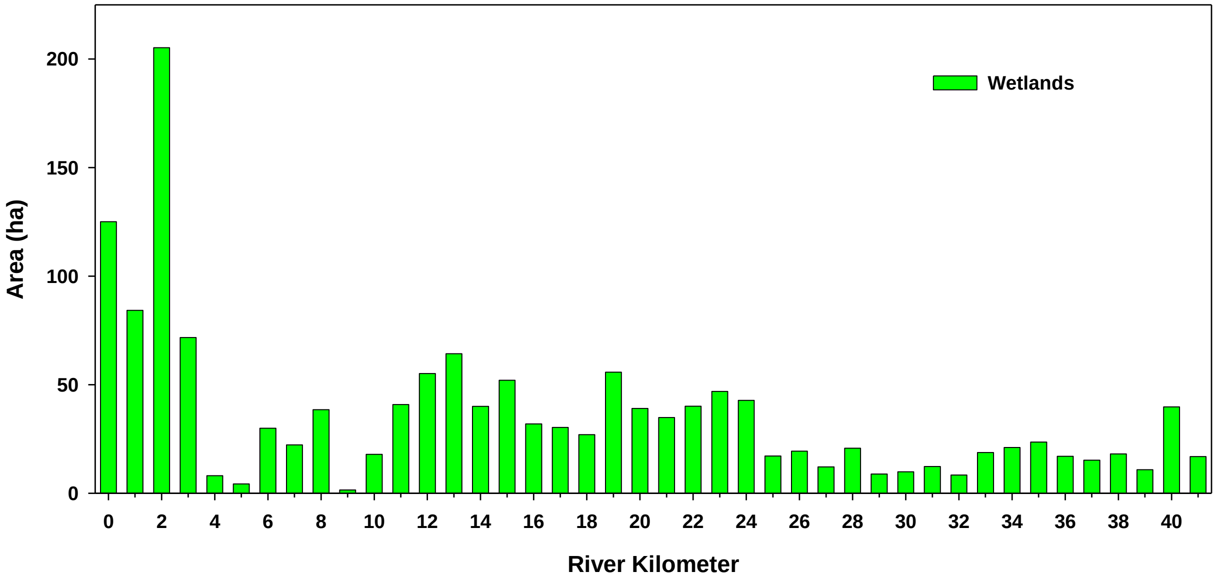

Figure 6-4. Wetland (600) areas associated either directly or indirectly with the river shoreline by river kilometer (includes same classes as Figure 6-3.

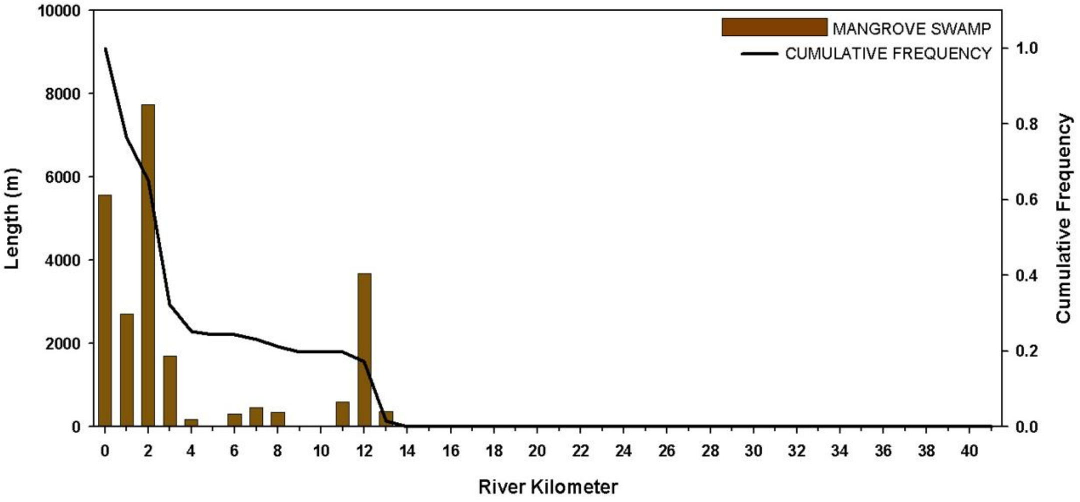

Figure 6-5. Length of mangrove swamp (612) shoreline by river kilometer. Also noted is the cumulative frequency of this shoreline type.

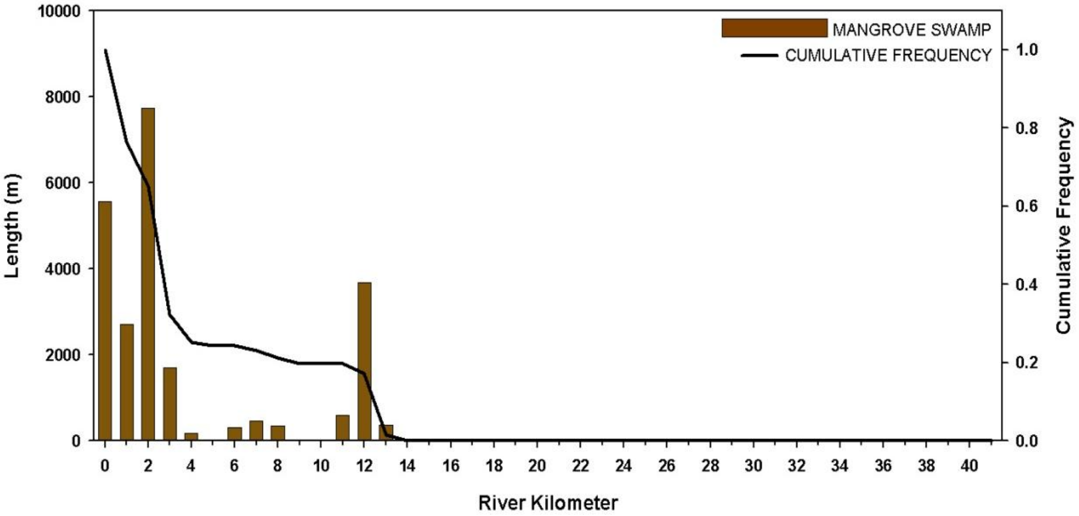

Figure 6-6. Areas classified as mangrove swamp (612) associated with the shoreline by river kilometer. Also noted is the cumulative frequency of classification.

Salt Marshes**:** Figures 6-7 and 6-8 depict the shoreline length and area of salt marshes by kilometer. The majority of both attributes occur in the first 23 kilometers of the river although large marshes occur near the river mouth. These marshes are large but their narrow connections to the river result in low shoreline lengths. Most marsh area per kilometer occurs between RK 10-22.

Juncus roemerianus (black needle rush) is the most common salt marsh species in the tidal river, occurring as broad marsh expanses near the county line, as islands and as mainland fringe upriver to U.S. 41. Black needle rush also forms broad mainland fringing marshes upriver of U.S. 41 to near RK 22.0, and upstream further as elements of low salinity "pocket marshes" growing in small bights.

The upriver limit of *Juncus* marsh occurs near RK 24-25, upstream of Rambler's Rest Resort. This pocket marsh grows on the western bank of the river, three bends downstream of Big Bend. From this point through Big Bend, other pocket marshes are smaller in area and vegetated by tidal freshwater species. Thus, the upriver penetration of *Juncus* into potential marsh habitat appears to be more complete than the penetration of mangroves into potential forest habitat. Individual specimens of *Juncus* may be found farther upriver toward Snook Haven Fish Camp but none is organized into marsh systems. In general, *Juncus* marshes appear to be dissected more by distributaries and braided channels as one proceeds upriver.

Oligohaline and Tidal Freshwater (OTF) Marsh: Oligohaline and tidal freshwater wetlands are separate plant communities that occur within the upper reaches of tidal rivers, but are differentiated by the salt tolerance of different plant species. There is considerable species overlap between these zones, as freshwater species that are in the tidal freshwater may also extend into the oligohaline zone depending on antecedent rainfall and runoff conditions. Clewell et al. (2002) refers to freshwater plants with very little salt tolerance as glycophytes. These species occur in tidal freshwater wetlands where there are tidal water level fluctuations, but exposure to saline water is very infrequent. Tidal freshwater plants that are common in the Myakka River include *Pontedaria cordata, Sagittaria lancifolia, and Polygonum hydropiperoides.*

Oligohaline marshes represent a transition between tidal freshwater marshes and salt marshes, where there is often seasonal exposure to low salinity water (e.g., 1 to 12 psu). These marshes may include a mix of salt marsh species (*Juncus romerianus*) with freshwater species that have some salt tolerance, or may be comprised entirely of these salt-tolerant freshwater species. The most common freshwater plants in oligohaline marshes in the Myakka River are giant bulrush (*Scirpus californicus*) and cattail (*Typha domingensis*). Other freshwater plants may extend partly or wholly into the oligohaline marsh, resulting in fairly high species diversity. These low salinity oligohaline marshes are sometimes referred to as brackish marshes.

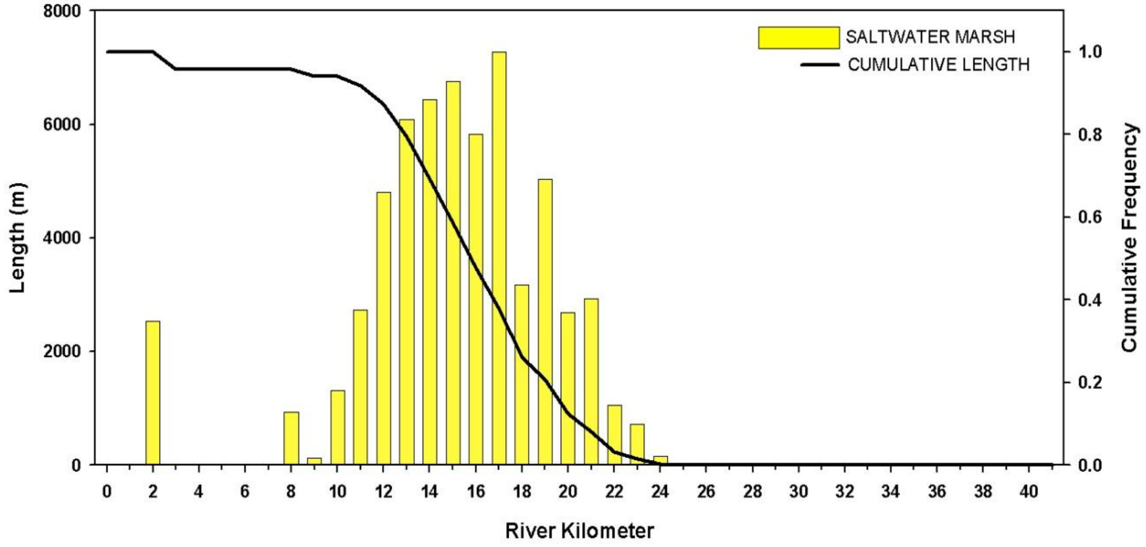

Figure 6-7: Length of saltwater marsh (642) shoreline by river kilometer. Also noted is the cumulative frequency of this shoreline type.

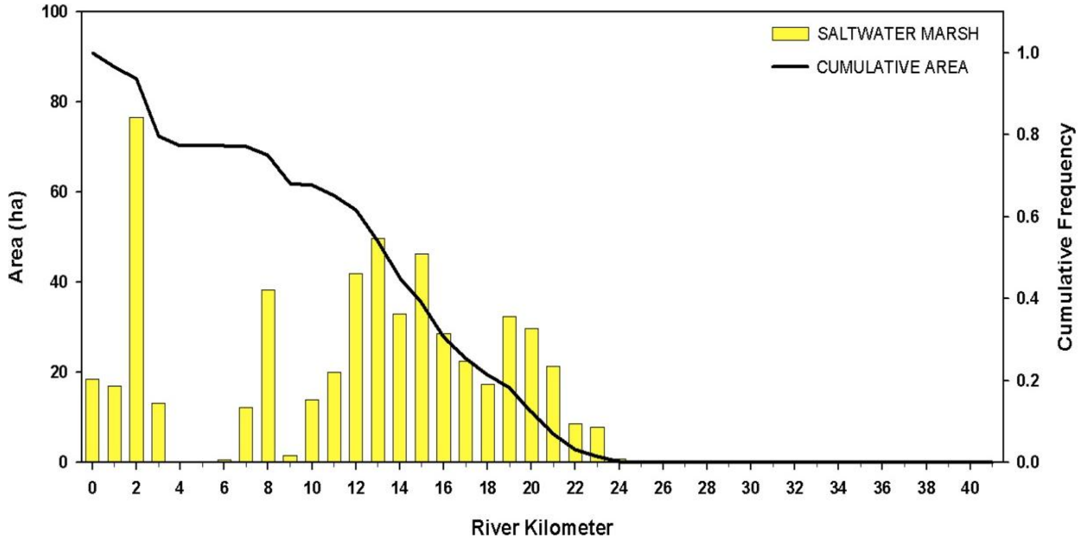

Figure 6-8: Areas classified as saltwater marsh (642) associated with the shoreline by river kilometer. Also noted is the cumulative frequency of classification.

Figures 6-9 and 6-10 depict the shoreline length by kilometer, and area by kilometer, of these marsh types. A relatively large area of OTF marsh occurs from RK 12 to RK 15, in association with Myakkahatchee Creek, but little of it is directly contiguous with open waters of the river. The longest river reach with contiguous kilometer intervals containing OTF marsh begins at RK 22 and extends to RK 29.

Several lines of evidence point to the persistence of an oligohaline to tidal-freshwater marsh system upstream of the river's large *Juncus* marsh system.

A. Transition from alluvial to tidal marsh soils at RK 24.6 (Soil Conservation Service, 1959).
B. Delineation of "emergent marsh" in NWI (Cowardin et al. 1979).
C. Delineation of "fresh marsh" and "brackish marsh" physiographic zones distinct from "salt marsh" (Hussey 1985)
D. Delineation of "tidal freshwater wetland" from upstream of Deer Prairie Creek to near Snook Haven (Estevez et al. 1990)
E. FLUCFCS[1] code 641 ("freshwater marshes") and code 6440 ("emergent aquatic vegetation") mapped upstream of code 6420 ("saltwater marshes") by Florida Department of Transportation (1999).
F. "Oligohalophyte" species number increasing with upriver distance (Clewell et al. 2002).

Species composition of the Myakka River's OTF marshes is detailed in a subsequent section.

Submerged aquatic vegetation (SAV) zonation in the river corresponds with the OTF marsh data. Hussey (1986) and Estevez et al. (1990) found that salt-tolerant freshwater SAV, principally *Vallisneria americana*, had occurred from Snook Haven downstream to US 41 during wet years and downstream to near Ramblers' Rest Resort in normal years.

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[1]/ Florida Land Use, Cover and Forms Classification System, Florida Department of Transportation (1999).

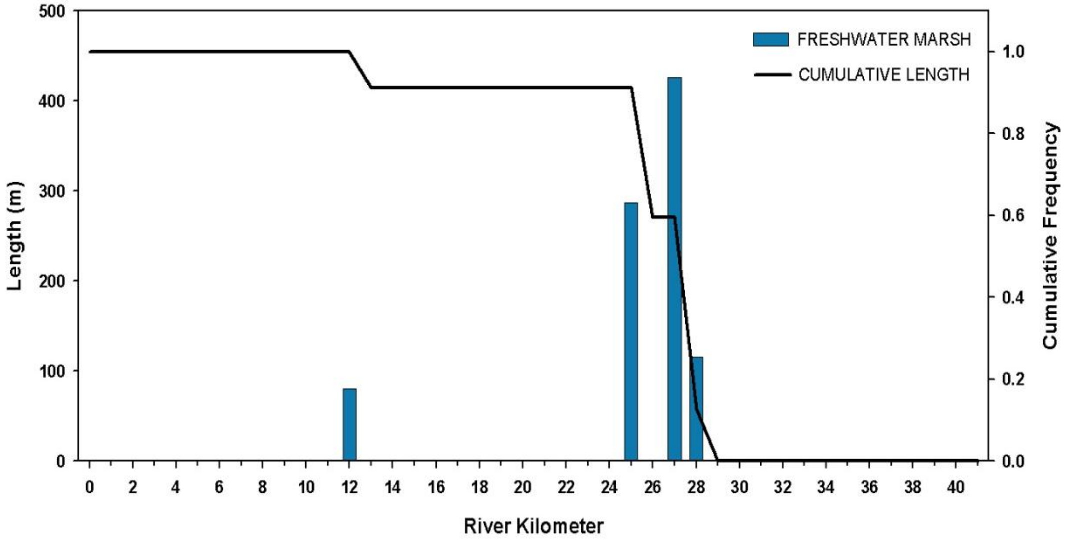


Figure 6-9. Length of freshwater marsh (641) shoreline by river kilometer. Also noted is the cumulative frequency of this shoreline type.

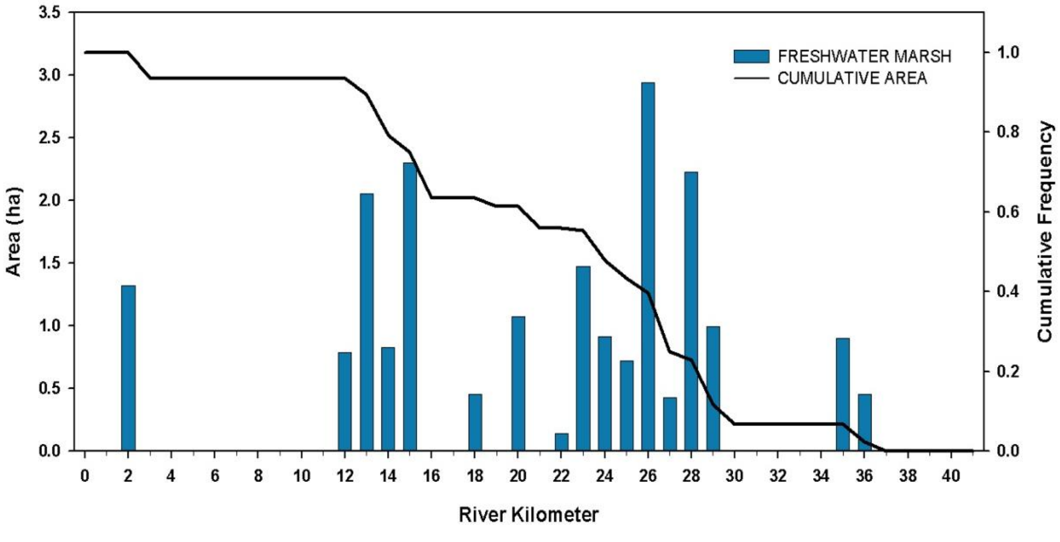


Figure 6-10. **Areas classified freshwater marsh (641) associated with the shoreline by river kilometer. Also noted is the cumulative frequency of classification.**

Freshwater Forested Wetlands: Figures 6-11 and 6-12 depict the shoreline length by kilometer, and area by kilometer, of freshwater forested wetlands. Three types of wetland forest are distinguished: hardwood forests, coniferous forests, and stream and lake swamps. Stream and lake swamps comprise the major form of wetland forests in the lower river, especially upstream of RK 22 for shoreline length, but the area of stream and lake swamps is substantial upstream of its first occurrence at RK 10.

These designated wetlands likely include some wetlands located near, but not connected to, the river channel. Also, some of the forests that are classified as wetlands by the National Wetland Inventory could also be considered uplands that occur near the river. The GIS assessment of the river by the FMRI (1999) found that very few wetland forests were located upstream of RK 24, with upland forest occurring on the more incised banks of the river in this region.

Common species in stream and lake swamps include red maple, water hickory, swamp dogwood, pop ash, willow, sweetbay, swamp bay, live and water oak, buttonbush, and cabbage palm. Bald-cypress (*Taxodium distichum*) is not known to occur naturally within the Myakka River and its watershed.

6.2.4 Basis for Assessing Altered Flow Scenarios

The extent to which altered flows may affect wetlands in the lower Myakka River is evaluated with respect to changes in the spatial overlap of stationary and dynamic habitats (*sensu* Browder and Moore 1981, Estevez and Marshall 1997). In this section, information is presented on oligohaline and tidal freshwater marshes and existing salinity conditions in the tidal river.

Oligohaline and tidal freshwater (OTF) marshes are large in rivers of the Atlantic coast, and relatively well studied (Odum et al. 1984, Livingston 1992, Moore 1992). In Florida, these wetlands are largest in the St. Johns, Suwannee, and panhandle rivers but are present in many peninsular rivers, such as the Myakka River, as well (Livingston 1991). OTF marshes are also common within spring runs or between salt marsh and forested wetlands in some rivers (Estevez et al. 1991).

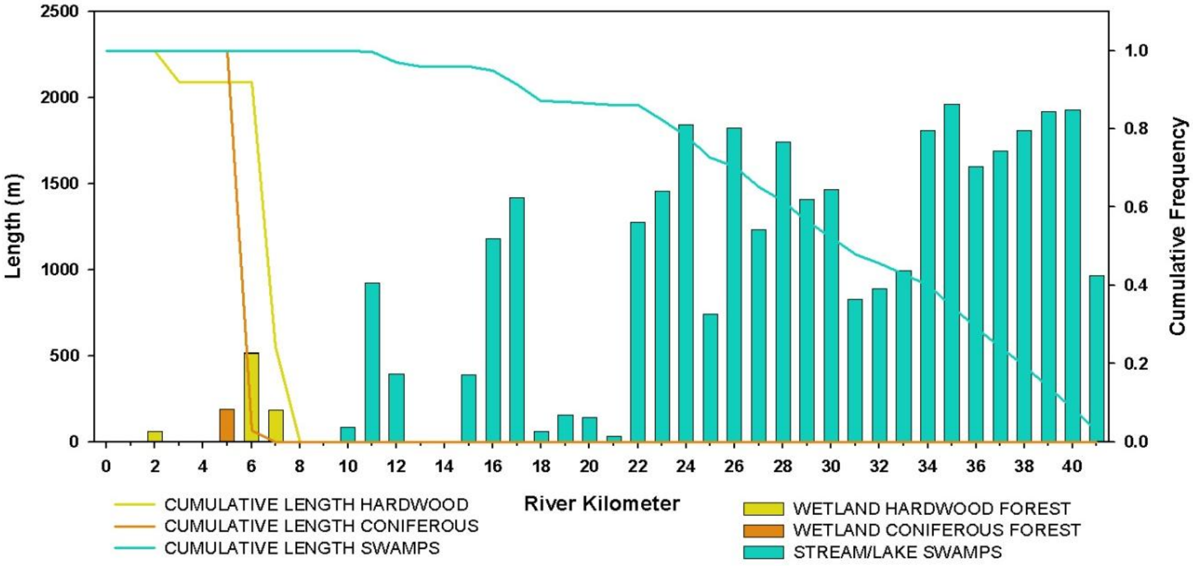


Figure 6-11. Length of shorelines classified as wetland forests (610, 615, 620) by river kilometer and the cumulative frequency of these classifications.

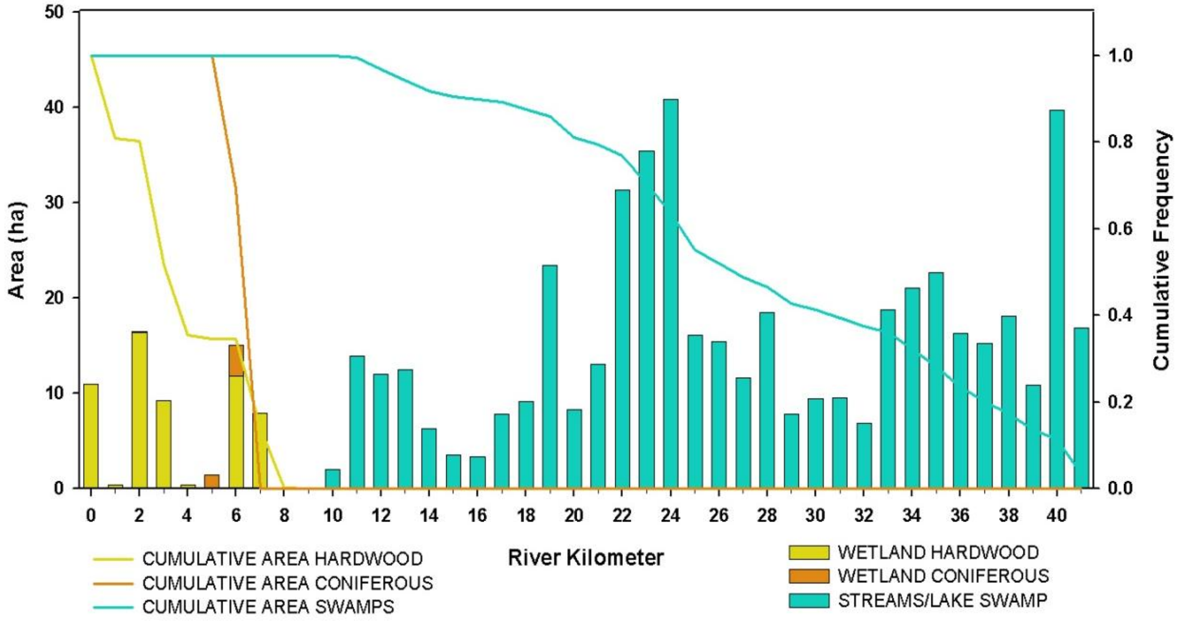


Figure 6-12. Areas classified as wetland forests (610, 615 and 620) associated with the shoreline by river kilometer and the cumulative frequency of these classifications.

Characteristic species found in oligohaline and tidal freshwater marshes of rivers along the west coast of Florida include *Cladium jamaicense, Typha domingensis, Crinum americanum, Pontederia cordata, Polygonum hydropiperoides, Alternanthera philoxeroides,* and two or more species in the genera *Spartina, Scirpus, Acrostichum,* and *Sagittaria* (Clewell et al. 2002).

Oligohaline and tidal freshwater marshes tend to harbor many plant species (Perry and Atkinson 1997, Baldwin 2004) and support a wide range of fish and wildlife (Odum et al. 1984, Florida Fish and Wildlife Conservation Commission 2005). Of coastal tidal rivers FFWCC (2005) “includes the freshwater or brackish portions of a river or stream [that] bridge the freshwater and marine realms, with aquatic communities ranging from tidal freshwater to tidal brackish” (p. 165).

Among mid-Atlantic systems that are better studied than Florida systems, it has been suggested that, “Freshwater tidal marshes… support the greatest diversity of bird species of any marsh type” (Shellenbarger Jones 2007). Consequently, these wetlands are significant in maintaining a high habitat-level of biodiversity and high secondary production in the river ecosystem.

Factors important in the creation and continuance of conditions favorable for OTF marshes include sediment availability (Woerner and Hackney 1997, Lewis 2005b), elevation (Silvestri et al. 2005), inundation (Cavatorta et al. 2003), groundwater flux (Tobias et al. 2001), and the influx of dissolved and particulate nutrients (Odum 1988). Experimental evidence suggests that salt marsh species such as *Juncus* flourish in lower salinity marsh conditions unless native neighbors are present, in which case *Juncus* fails to thrive (Crain et al. 2004). These results indicate that biological processes are also important to the maintenance of a coherent low salinity wetland systems.

However, salinity can be either the primary regulator of OTF marsh systems (Lewis 2005b), or it may act as a conservative covariant of the other physical and/or chemical regulators described above. Upstream movement of high salinity water has been associated with the decline or elimination of OTF marshes, or with their “cryptic ecological degradation” (*sensu* Dahdouh-Guebas et al., 2005). The Loxahatchee River is a prime example of cryptic ecological degradation or the replacement of high diversity upstream wetlands with low diversity downstream wetland species (Van Arman et al. 2005). In the Suwannee River, natural climate events have moved high salinity water into low salinity wetlands resulting in their significant decline and in some cases their extirpation (Mattson 2002a).

6.2.5 OTF Marshes in the Myakka River

Oligohaline and tidal freshwater marshes occur from RK 2 to RK 36; although some occur downstream in association with tributaries, their dominance as a distinct and continuous wetland type associated with the main river channel begins at RK 22, approximately 2.5 km upstream of Deer Prairie Creek (Figure 6-13). OTF marshes are intercalated between large downstream salt marshes and large upstream wetland forests. OTF marsh occupies the upstream-most intertidal shallow areas available as marsh habitat.

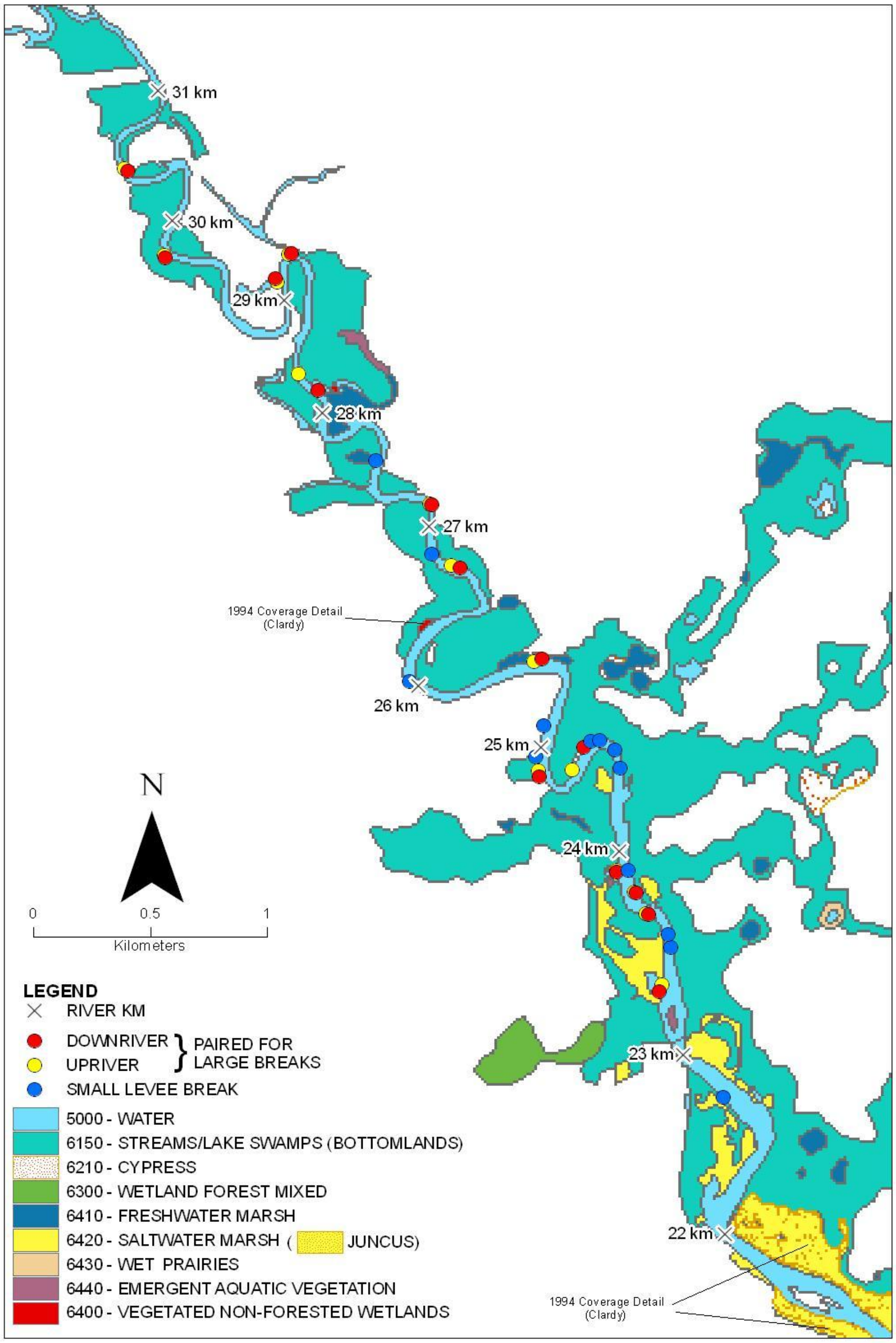


Figure 6-13. Tidal Myakka River between river kilometer 22 and river kilometer 31, depicting wetlands.

The identity and relative abundance of OTF species in this reach changes seasonally and annually depending on rainfall and runoff, but the typical flora includes the following obligate (O) and facultative (F) wetland species and submerged (S) species (Table 6-2). Clewell et al. (2002) provide data on the distribution of several OTF species of interest in the Myakka River expressed in river miles during 1989 and 1990 (Table 6-2; Figure 6-14).

Table 6-2. Typical plant species found in oligohaline and tidal freshwater (OTF) marshes in the Lower Myakka River listed as obligate (O) or facultative (F) wetland species or as submerged aquatic (S) species.

Acrostichum danaeifolium	O		*Panucum rigidulum*	F
Alternanthera philoxeroides	O		*Pluchea odorata*	F
bacopa monnieri	O		*Polygonum hydropiperoides*	O
Carex lupulina	O		*Pontederia cordata*	O
Cephalanthus occidentalis	O		*Rumex verticillatus*	F
Crinum americanum	O		*Ruppia maritima*	S
Diodia virginiana	F		*Sagittaria lancifolia*	O
Eleocharis flavescens	O		*Saggittaria subulata*	S
Hydrocotyle umbellata	F		*Samolus valerandi*	O
Isoetees flaccida	O		*Scirpus californicus*	O
Juncus megacephalus	O		*Scirpus tabernaemontani*	O
Ludwigia repens	O		*Teucrium canadense*	F
Lythrum alatum	O		*Typha domingensis*	O
			Vallisneria americana	S

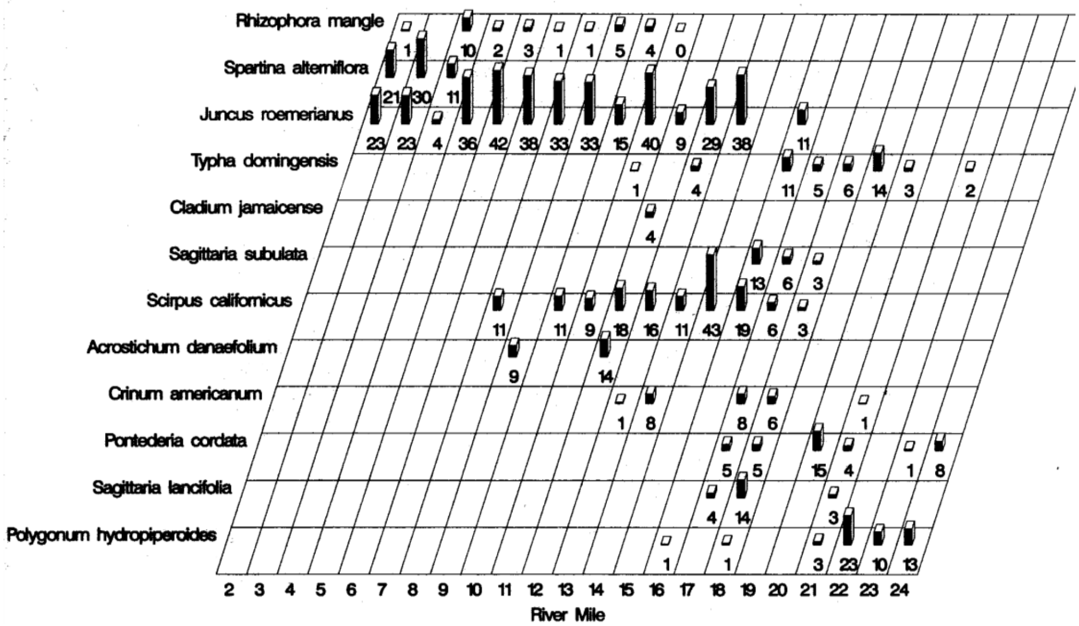


Figure 6-14. Distribution by river mile and percent cover (numerical value, height of glyph) for 12 species along the Myakka River. One river mile equals 1.61 river kilometers. From Clewell et al. (2002).

Table 6-3. Centers of abundance, minimum, and maximum river positions (converted to kilometers) of principal OTF marsh and SAV species reported by Clewell et al. (2002).

Species	Center of Abundance	Minimum	Maximum
Acrostichum danaeifolium	18.35	15.69	2.59
Cladium jamaicense	19.64	19.64	19.64
Spartina bakeri	21.78	21.78	21.78
Samolus valerandi	22.29	18.45	23.86
Scirpus californicus	22.42	13.28	29.94
Aster caroliniana	25.87	25.87	25.87
Pluchea odorata	26.03	21.78	28.77
Bacopa monnieri	26.35	26.35	26.35
Isoetes flaccida	26.77	26.77	26.77
Crinum americanum	27.11	21.78	33.81
Sagittaria subulata	27.37	26.35	29.75
Typha domingensis	28.48	18.45	35.82
Sagittaria lancifolia	29.28	27.54	34.30
Gratiola virginiana	30.21	28.77	34.30
Ludwigia repens	31.21	26.35	34.30
Pontederia cordata	31.79	28.48	39.12
Mikania scandens	32.94	21.78	37.27
Urochloa mutica	33.58	28.77	35.82
Scirpus tabernaemontani	34.98	28.04	39.12

Although numerous studies have identified the location, extent, and community structure of Myakka River OTF marshes in different ways, there is general agreement that marshes upstream of RK 22 are characteristically oligohaline and/or tidally fresh (Soil Conservation Service, 1959; Cowardin et al. 1979; Hussey 1985; Estevez et al. 1990; Florida Department of Transportation 1999, Clewell et al. 2002).

The river wetland system upstream of RK 22 is depicted in Figure 6-13. The upstream-most *Juncus* marsh ends at a river bend at RK 22. Thereafter, brackish marsh without *Juncus* dominating, emergent aquatic vegetation, and freshwater marsh occur along with swamp forests as a continuous wetland system to RK 29 (near Snook Haven). The per-kilometer area of all marsh types combined (as “non-forested wetlands”), and of all forest types combined (“forested wetlands”), are depicted in Figure 6-15.

As described previously, the identity and relative abundance of marsh species in this reach changes seasonally and also annually depending on rainfall and runoff, so for purposes of this assessment all non-forested wetlands are regarded as OTF marsh.

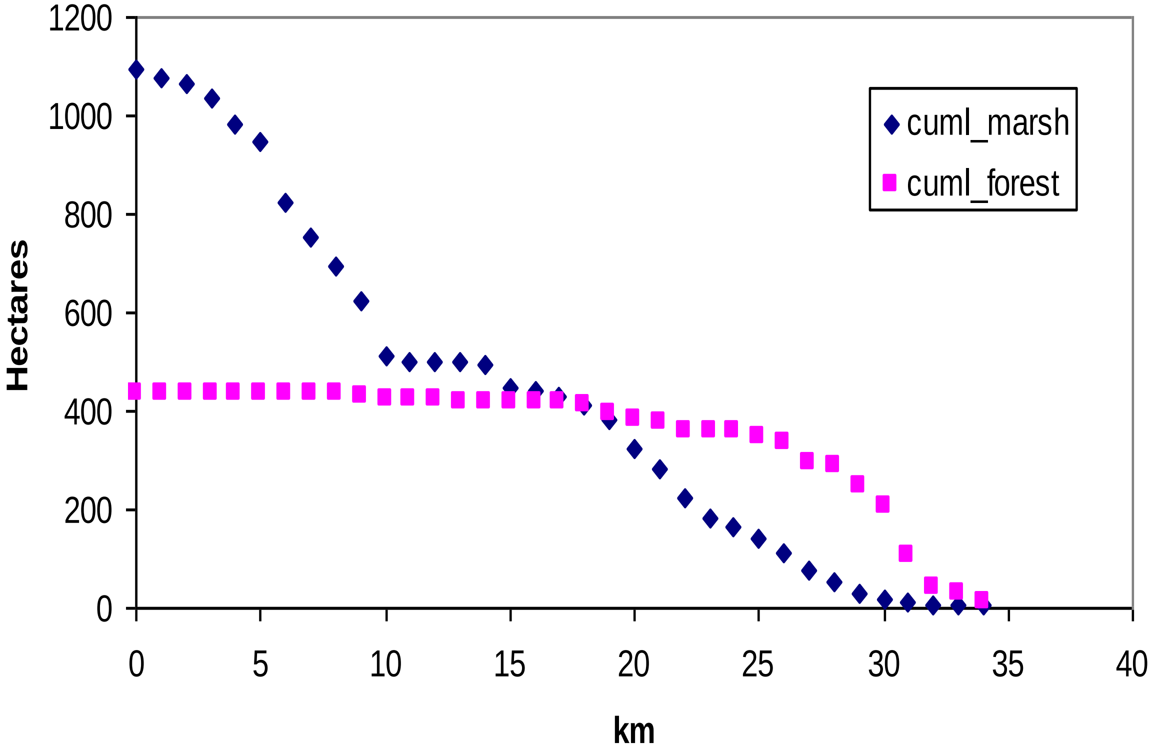


Figure 6-15. Cumulative percentage of total wetland area for forested and non-forested wetlands between RK 0 and RK 34.

6.2.6 Existing Salinity Conditions near Myakka OTF Marshes

The empirical models described in Chapter 4 can be used to describe salinity conditions in kilometers 22 - 29, the reach of interest with respect to oligohaline and tidal freshwater marshes. Median monthly positions of the 1, 2, 4 and 8 psu surface isohalines corroborate ecological evidence that high salinity waters rarely extend into the OTF marsh zone (Figure 6-16). Low salinity isohalines (1, 2, and 4 psu) penetrate furthest upstream during the spring dry season, which can extend into June. Isohalines are transported downstream and the OTF marshes are predominantly fresh in the wet season from July through October.

Horizontal box and whisker plots of all the isohalines modeled during the study are overlain with the distribution of the OTF marshes in Figures 6-17 A and B. The median values for the locations of all the isohalines are downstream of the OTF marshes on a yearly basis (Figure 6-17A). However, when the isohaline locations are examined at the height of the spring dry season (block 1), the median locations of the 1 and 2 psu isohalines occur near the downstream limit of the OTF marshes, with the 4 isohaline penetrating the OTF river zone over 25 percent of the time.

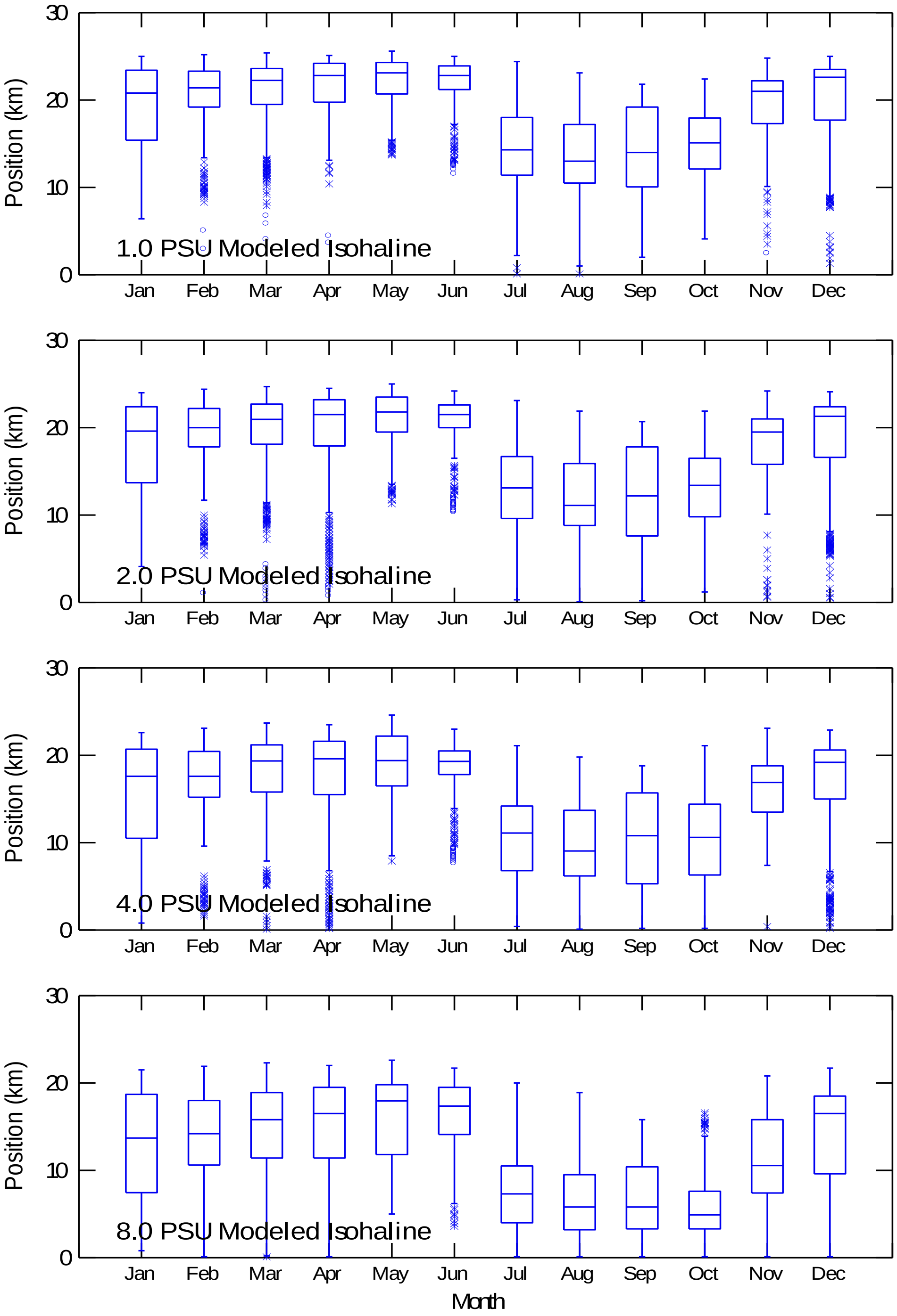


Figure 6-16. Box and whisker plots of predicted monthly locations of the 1, 2, 4, and 8 psu surface isohalines for 1996-2006 generated by the models presented in Chapter 4.

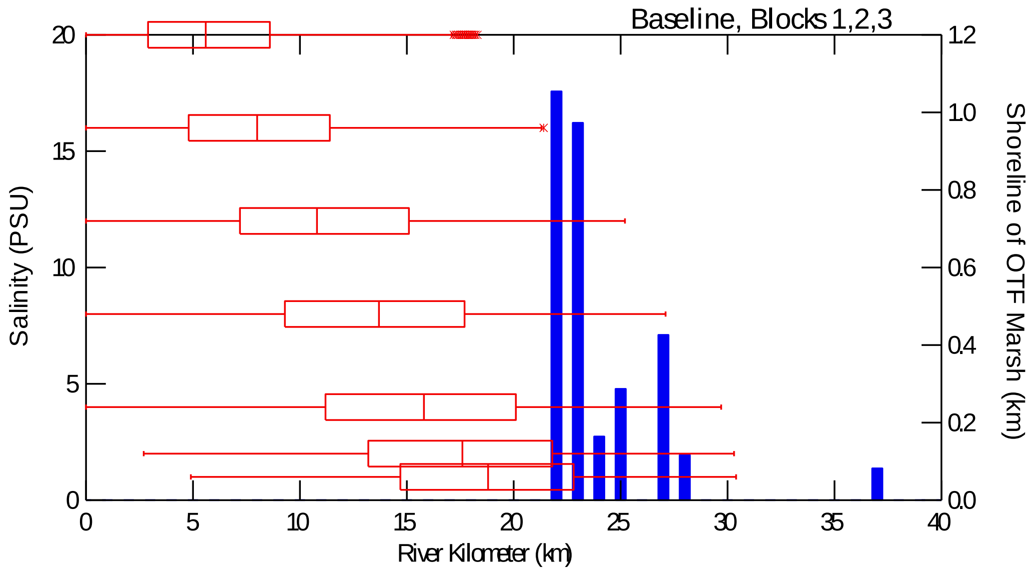


Figure 6-17A. Distribution of OTF marsh shoreline relative to river kilometer, showing box-whisker distributions of (from bottom of graph to top) the 1.0, 2.0, 4.0, 8.0, 12.0, 16.0 and 20.0 psu surface isohalines for 1996-2006).

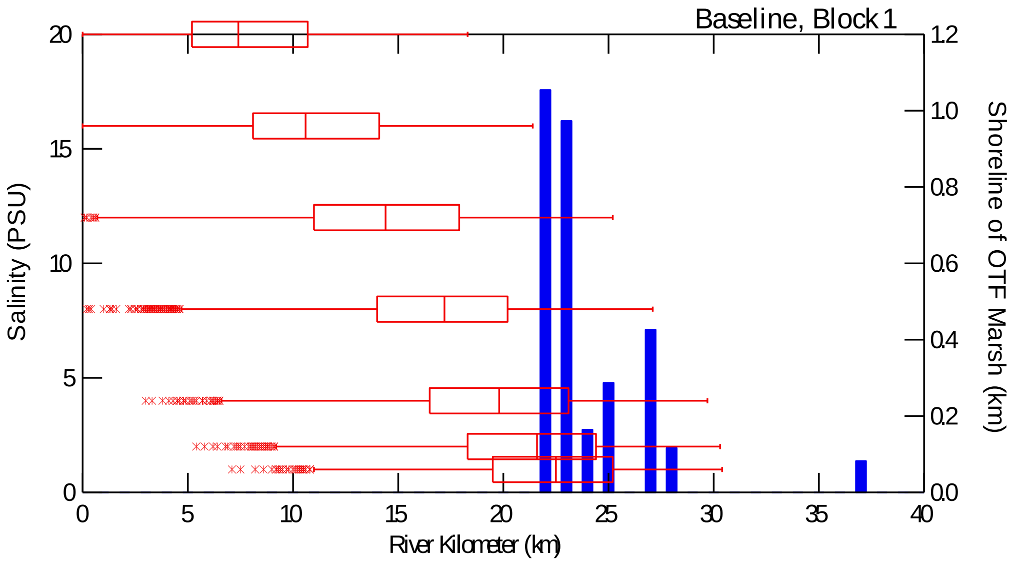


Figure 6-17B. Distribution of OTF marsh shoreline relative to river kilometer, showing box-whisker distributions of (from bottom of graph to top) the 1.0, 2.0, 4.0, 8.0, 12.0, 16.0 and 20.0 psu surface isohalines during the spring dry season for 1996-2006.

Diagnostic Salinities

To protect low salinity environments in other rivers, water managers have proposed using the river kilometer position of specific isohalines as objective functions with respect to wetland assessments. Clewell et al. (1999) proposed using a 7 ppt isohaline for this purpose to protect OTF wetlands in the Suwannee River. Latham (2003) proposed using the 5 ppt isohaline as a primary target for the Suwannee River: "Targeting the position of the 5 ppt isohaline in the lower river is anticipated to meet other species- and habitat-specific targets for minimum flows, including downstream extent of SAV/*Vallisneria americana*, downstream extent of woody vegetation (tidal swamps), *downstream extent of freshwater tidal marshes*, and passage for the federally protected Gulf sturgeon" (Latham 2003, emphasis added).

In a study of seven tidal rivers in west-central Florida, Clewell et al. (2002) found that the abundance of common salt-tolerant freshwater species (cattails, sawgrass, giant bulrush) was greatest where yearly median salinity values were less than 4 ppt, and that glycophytes were most abundant where yearly median salinities were less than 2 psu. The results for the Myakka river presented in this study indicate it is the dry season locations of these isohalines could be related to the distribution of plant species that comprise oligohaline and tidal freshwater marshes.

An annotated bibliography of publications describing salinity effects on tidal freshwater and oligohaline marsh vegetation is provided in Appendix 6C, and summarized in Table 6-4. Existing studies represent a combination of laboratory studies, field experiments, and field observations in a variety of wetland types and geographic areas.

Published accounts of salinity limits should be interpreted conservatively because some pertain to interstitial or pore water salinity rather than the salinity of overlying waters. Furthermore, the effect of salinity on OTF marsh species is clearly affected by other factors such as inundation, sediment quality, seed bank dynamics, and competitive interactions among marsh species. No data specific to the Myakka River or other rivers of southwest Florida exist concerning the effects on marshes of inundation, sediment quality, seed bank dynamics, and competitive interactions.

On balance, the work by Clewell et al. (2002) on salinity relationships of marsh species in southwest Florida rivers, evidence of general salinity limitations from the scientific literature (Table 6-4)**,** and the behavior of present day salinity fields in the Myakka's OTF marsh zone suggest the use of the 1 psu, 2 psu, and 4 psu, isohaline positions could be used as assessment tools for the evaluation of the effects of reduced freshwater inflows and increased salinity plant on the distribution of oligohaline and tidal freshwater wetlands.

Table 6-4. Summary of water or pore-water salinities found to affect the germination, growth, survival, or species richness of oligohaline or tidal freshwater vegetation with empahsis on marshes.

Reference	Location	Wetland Type	Salinity (psu)
	Effect		
Van Armen et al. (2005)	Loxahatchee R.	floodplain swamp	2
	reduced diversity and cypress germination		
Latham et al. (1991)	Savannah R.	tidal freshwater and oligohaline marsh	2 - 3
	reduced species germination and species richness		
Pearlstine et al. (1991)	Savannah R.	tidal freshwater marsh	<4
	restoration of healthy tidal freshwater marsh		
Baldwin et al. (1996)	Coastal LA	oligohaline marsh	4
	reduced seed gemination		
Webb and Mendelssohn (1996)	Coastal LA	oligohaline marsh	4-5
	redced growth		
Latham (2003)	Suwannee R.	tidal freshsater marsh	< 5
	protection of tidal freshwater marsh		
Perry and Atkinson (1997)	York R.	Tidal freshwater	5 - 8
	reduced species richness		
Wetzel et al. (2004)	Savannah R.	tidal freshwater	> 5
	species losses		
Howard and Mendelssohn (1999)	Coastal LA	brackish marsh	6
	species losses, supressed growth		
Clewell et al. (2002)	west-central Florida	tidal freshwater	2
	glycophytes most frequent where median salinity is less < 2		

6.3 Benthic macroinvertebrates

6.3.1 Introduction and Data Sources

For decades, benthic macroinvertebrates have proven to be valuable as indicators of environmental health, primarily because they are relatively immobile and can be abundant. Benthic macroinvertebrates are very important ecologically because they serve as prey for many fishes, motile crustaceans and even birds. Fishery yields and abundance of juveniles of important finfish species are often positively correlated with the quantity of freshwater inflow, probably taking advantage of the increased productivity (including, secondary production of benthic invertebrates) in these locales (Peebles 2005a, Matheson et al. 2005). On the other hand, certain species, such as the blue crab, are themselves valuable commercial fisheries and spend at least part of their life in tidal rivers. Many benthic species are confined to specific habitats while others occupy a wide range of habitat and sediment conditions. Benthic invertebrate species also display different tolerances to pollutants, physical disturbances, and physicochemical parameters, particularly salinity (Sanders et al. 1965, Ristich et al. 1977, Leland and Fend 1998).

Salinity is a primary physical factor responsible for determining the distribution of flora and fauna in a tidal rivers and is especially important in shaping the organization of benthic macroinvertebrate communities (Remane and Schlieper 1971, Wolff 1983, Janicki Environmental 2007, Montagna et al. 2008). Estevez (1985a) determined that salinity was the primary forcing structure of the benthic communities in the Lower Myakka River, and that the major faunal groups (molluscs, crustaceans and annelids) react at different rates to changes in salinity. The salinity gradient will fluctuate on a variety of time scales, from the daily course of a tidal cycle to annual cycles reflected in seasonal rainfall and flow patterns. The range of change in salinity is also dependent upon the different reaches of the river. Typically, the upper reaches of a river generally experience either constant, very low salinity or freshwater condition; the middle reaches have the most pronounced salinity fluctuations, and the lower reaches have higher, but relatively more constant salinities than the upstream counterparts. These regions are not sharply separated and may move either up or downstream in accordance with the abovementioned temporal changes.

Perhaps even more important than salinity fluctuations *per se* is the rate of change in salinity. The distribution of fauna may be determined, not primarily by the salinity gradient, but by the rate and magnitude of salinity change. Thus, a given species would have a wider salinity tolerance in a system with a smaller rate of salinity change. Understanding the relationship between salinity (as it relates to flow) and the structure and distribution of resident benthic communities is necessary in order to evaluate the freshwater flow requirements needed to protect and preserve these natural resources.

The importance of benthic faunal communities to the ecology of the Myakka River and the sensitivity of these organisms to changes in flow form the basis for the analyses presented in this chapter. Additionally, the processes involved in shaping the benthic communities of the Myakka River are the same as those influencing the benthos in the adjacent Peace River. This section discusses the structure of the benthic community in the lower Myakka River and how this structure is related to freshwater flows and river salinity.

A limited data base for the Myakka River benthic communities already exists from previous studies on the ecology of this river. Technical reports containing benthic infauna data were retrieved and the data reviewed in order to describe community structure and species distribution in the lower Myakka River as it relates to salinity. Essentially all of the documents were technical reports produced by Mote Marine Laboratory over the past twenty years. A summary of these reports is presented in Table 6.5.

Two other reports were useful in providing information on benthic communities of the adjacent Peace River and upper Charlotte Harbor. These reports were used to compare faunal structure, species distributions and salinity preferences between these two adjacent rivers. A summary of these reports is also provided in Table 6.5.

The contents of each report are summarized below. Information includes the number and location of stations, sampling frequency, sampling methods, replication, and whether samples were qualitative (undefined sample size) or quantitative.

Culter, J.K. 2004. Dry-season characterization of the benthic fauna of the tidal Myakka River. Southwest Florida Water Management District. Mote Marine Laboratory Technical Report 1030. One-time sampling event. Samples collected during June, 2004; considered a dry season sampling. Stations separated on two kilometer intervals from the mouth of Charlotte Harbor (RK 0) to RK 44. At each station, a single 3” diameter core (infauna) and sweep net (epifauna) sample was collected from both the shallow intertidal and deeper subtidal sediments. A separate core was collected at both shallow and deep locations for sediment analysis. This study was the most comprehensive, quantitative benthic sampling conducted of the Myakka River. Station locations are shown in Figures 6-18.

Estevez, E.D. 1985a. A wet-season characterization of the tidal Myakka River. Submitted to Sarasota County Ringling-MacArthur Reserve Project. MML Technical Report 95A. Nineteen locations were sampled for fauna. Samples collected in September, 1985, and were considered a wet season event. Qualitative samples were collected by bucket dredge and otter trawl; specimens were also hand-picked from salt marshes. Quantitative samples were collected by diver core at only four locations.

Table 6.5. Technical reports containing benthic infauna data, community structure and species distribution in the lower Myakka River.

AUTHOR	DATE	TITLE	CLIENT	REFERENCE
Culter, JK	2004	Dry-season characterization of the benthic fauna of the tidal Myakka River.	Southwest Florida Water Management District	MML Technical Report 1030
Estevez, ED	2004	Molluscan bio-indicators of the tidal Myakka River and inshore waters of Venice Florida	Southwest Florida Water Management District	MML Technical Report 990
Milligan, MR	1990	Myakka River basin biological study: Down's Dam to Snook Haven.	Sarasota County	MML Technical Report 220
Estevez, ED	1985a	A wet-season characterization of the tidal Myakka River	Sarasota County Ringling MacArthur Reserve	MML Technical Report 95A
Estevez, ED	1985b	A dry-season characterization of the tidal Myakka River	Sarasota County Ringling MacArthur Reserve	MML Technical Report 95B
Mote Marine Laboratory	2002	Peace River Benthic Macroinvertebrate and Mollusk Indicators	Peace River Regional Water Supply Authority	MML Technical Report 744
Texas Instruments	1978	Preliminary Biological Report for the Proposed Desoto Site Development	Florida Power and Light	

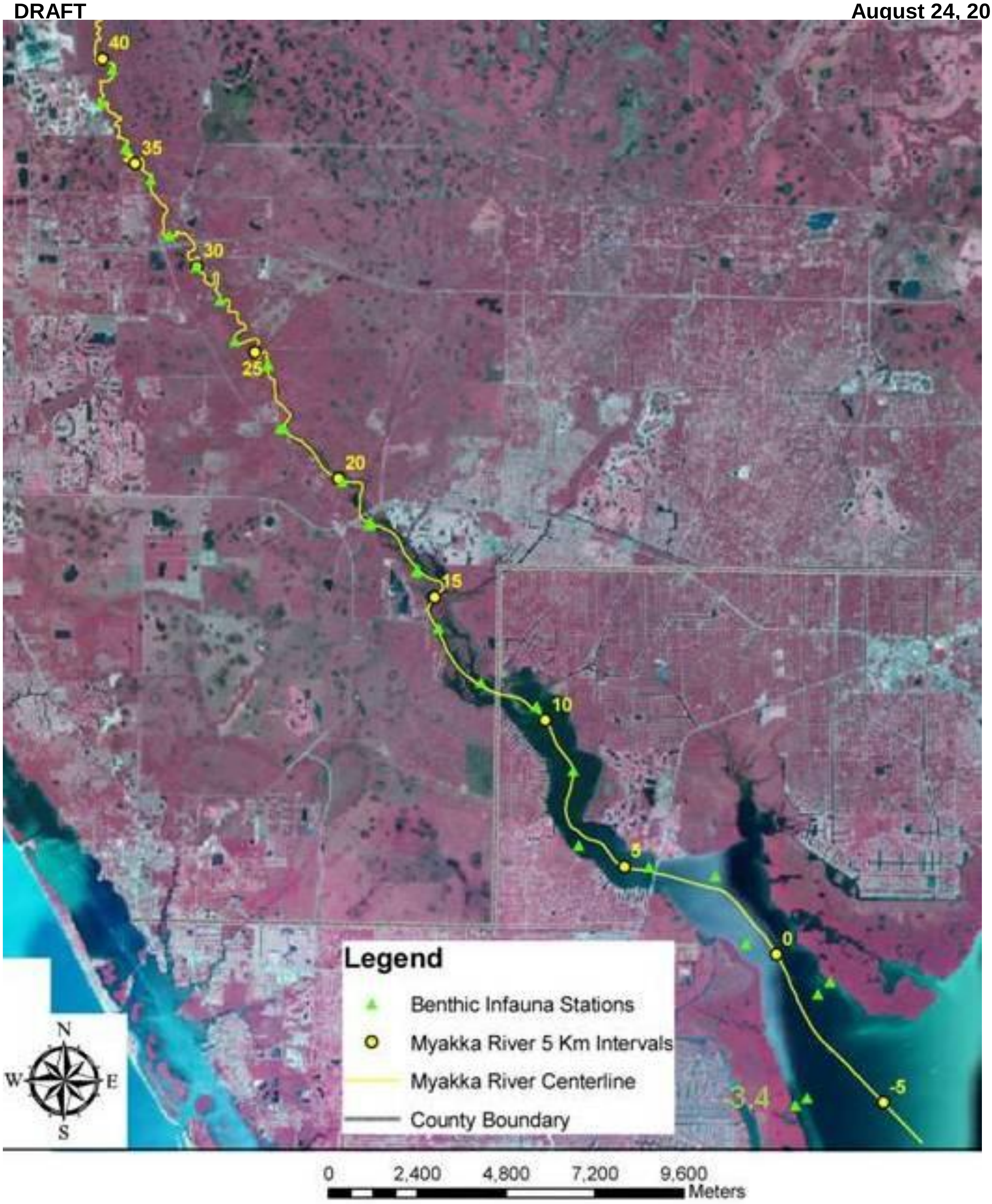


Figure 6-18. Lower Myakka River benthic stations - river kilometers -3.4 through 39.4 sampled by Culter (2004) during June 2004

Estevez, E.D. 1985b. A dry-season characterization of the tidal Myakka River. Submitted to Sarasota County Ringling-MacArthur Reserve Project. Mote Marine Laboratory Technical Report 95B. Qualitative sampling at fourteen locations during April, 1986 (dry season). Samples were collected from a subset (14 of 19) of stations sampled in September, 1985. Benthic surveys focused on the live/dead molluscan assemblage, although crustaceans were collected and recorded as well. Only fauna larger than 2 mm were sampled in this study.

Estevez, E.D. 2005. Molluscan bio-indicators of the tidal Myakka River and inshore waters of Venice Florida. Mote Marine Laboratory Technical Report 990. Semi-quantitative sampling of live and dead molluscan fauna during June, 2004. Samples collected with either a shovel (intertidal) or Ponar grab (subtidal) and sieved on 5 mm mesh screens. Stations on 1.0 km centers from RK 0 to RK 42.

Milligan, M.R. 1990. Myakka River basin biological study: Down's dam to Snook Haven. Final Report to Sarasota County Division of Ecological Monitoring. Mote Marine Laboratory Technical Report 220. Inventory of macroinvertebrate communities of the non-tidal Myakka River south of the Myakka River State Park. Quarterly sampling at seven freshwater stations (Upstream of Snook Haven). Six large (12 x 12 cm) diver-operated cores at each station. Excellent characterization of the predominantly freshwater invertebrates and aquatic insects in this section of the lower Myakka River. All salinity measurements were below 2 psu.

6.3.2 Sediment Characteristics

Table 6-6 lists sediment parameters for subtidal samples collected in June, 2004 (Culter 2004). Sediment characteristics include percent composition, particle size and statistics. The downstream reaches of the lower Myakka River (km -3 to km 20) had a considerably higher percent of silt-clay in the sediments than stations further upstream. Downstream stations also had a higher organic content than upstream stations. The rather abrupt change in sediment characteristics within the Myakka River, which occurred near the US 41 bridge, may be partially attributed to meanders and widening of the river at this location. There are also more tidal creeks in this region which may contribute more organically rich fine sediments to the river.Two stations, RK 26 and RK 34, stood out as notable exceptions to this pattern. Both stations had approximately twice the silt-clay and ten times the organic content than surrounding stations. The cause of anomolous sediment conditions at these two stations is not readily apparent.

Based on data from nine tidal rivers in west central Florida including the Myakka, Janicki Environmental Inc. (2007) found that benthic community structure was generally unchanged as the percent silt-clay increased within a given salinity class. Instead, characteristic taxa were more likely to differ between salinity classes. Montagna et al. (2008) reported similar findings for mollusk communities collected from many of these same tidal rivers.

Table 6-6. Myakka River Sediment Characteristics. Subtidal samples, June 2004. Locations rounded to nearest kilometer.

		Percent Composition						% Silt-Clay	Particle Size (µm)			Statistics		
KM	Texture (Notes)	% Solids	% Moisture	% Organic	% Sand	% Silt	% Clay		Mean	Median	Mode	S.D.	Skewness	Kurtosis
-3	clean sand	79.4	20.6	0.7	96.9	2.2	0.9	3.1	281	311	324	2.4	-2.9	13.3
-1	medium sand	74.8	25.2	1.4	83.9	13.5	2.6	16.1	155	231	269	3.8	-1.6	2.1
1	(no notes)	70.4	29.6	1.6	83.5	14.1	2.4	16.5	139	189	204	3.7	-1.4	2.0
3	(no notes)	66.7	33.3	1.9	79.6	17.7	2.7	20.4	128	185	204	4.0	-1.2	1.1
4	coarse sand	78.2	21.8	0.6	97.8	1.6	0.7	2.3	333	365	391	2.1	-3.7	21.1
6	muddy sand	70.0	30.0	1.4	85.5	12.3	2.3	14.6	143	191	185	3.4	-1.7	2.8
8	soft muddy	61.6	38.4	2.5	79.6	18.4	2.0	20.4	116	153	154	3.5	-1.2	1.5
10	soft muddy sand	59.5	40.5	3.0	78.1	19.6	2.3	21.9	109	140	154	3.7	-1.0	1.3
12	coarse sand	78.2	21.8	0.8	97.6	1.8	0.5	2.3	373	403	391	2.1	-3.3	17.3
14	clean medium sand	73.5	26.5	0.3	92.8	6.3	0.9	7.2	185	226	245	2.3	-3.3	11.6
16	clean medium sand	74.9	25.1	0.4	81.6	16.3	2.2	18.5	176	287	356	4.1	-1.5	1.4
18	coarse sand	76.7	23.3	0.4	97.9	1.8	0.3	2.1	409	440	429	2.0	-4.0	23.7
20	coarse sand, detritus	75.8	24.2	1.0	98.5	1.1	0.3	1.4	393	402	391	1.9	-3.2	20.9
22	clean sand	76.5	23.5	0.5	97.1	2.4	0.5	2.9	292	318	324	2.1	-3.1	15.5
24	coarse sand	77.3	22.7	0.4	98.3	1.8	0.0	1.8	503	548	568	1.9	-2.9	13.6
26	sand/peat	62.1	37.9	3.9	94.4	4.9	0.6	5.5	355	394	429	2.9	-1.7	5.0
28	clean sand	76.2	23.8	0.2	99.2	0.7	0.1	0.8	287	297	296	1.6	-3.5	28.9
30	clean sand	77.4	22.6	0.4	98.9	0.9	0.2	1.1	378	391	391	1.7	-3.5	26.6
32	clean sand	76.9	23.1	0.4	98.1	1.4	0.5	1.9	280	296	296	1.9	-3.2	20.3
34	Rock w/ sand patches	56.9	43.1	4.8	95.0	4.2	0.7	4.9	201	198	204	2.5	-1.1	7.0
36	clean sand	76.0	24.0	0.2	100.0	0.0	0.0	0.0	369	365	356	1.5	0.2	0.8
38	coarse sand/shell	76.9	23.1	0.5	98.7	1.1	0.2	1.3	560	567	517	2.0	-3.0	19.1
39	clean sand	75.9	24.1	0.1	98.8	0.9	0.3	1.2	237	250	245	1.7	-4.1	31.9
	Minimum	56.9	20.6	0.1	78.1	0.0	0.0	0.0	108.9	139.9	153.8	1.5	-4.1	0.8
	Maximum	79.4	43.1	4.8	100.0	19.6	2.7	21.9	560.0	566.9	567.8	4.1	0.2	31.9
	Median	75.9	24.1	0.6	97.1	2.2	0.6	2.9	281.4	296.9	324.3	2.1	-2.9	13.3
	Mean	72.7	27.3	1.2	92.7	6.3	1.0	7.3	278.3	310.6	318.3	2.5	-2.4	12.6
	St.Dev	6.7	6.7	1.3	7.7	6.8	1.0	7.8	126.8	117.8	112.0	0.9	1.2	10.2

6.3.3 Myakka River Benthic Species Inventory

A total of 348 benthic invertebrate species were identified from the Myakka River from all previous surveys (Appendix Table 6D). Efforts were made to reconcile nomenclature differences among studies, and only organisms that could be identified to genus or species were included. Benthic fauna were distributed among the major taxonomic categories as shown in Figure 6-19. Insects and crustaceans had the most species among the major faunal groups in the Myakka River, with polychaetes, oligochates, gastropods and bivalves comprising the other remaining major groups.

The number of species in each major faunal group per river kilometer during June, 2004 are shown in Figure 6-20, while the distribution of species numbers for major faunal groups from September, 1985 are shown in Figure 6-21. Insects occurred mostly in the upper, tidal freshwater sections of the river; the number of crustacean species generally declined moving from the mouth of the river toward the headwaters.

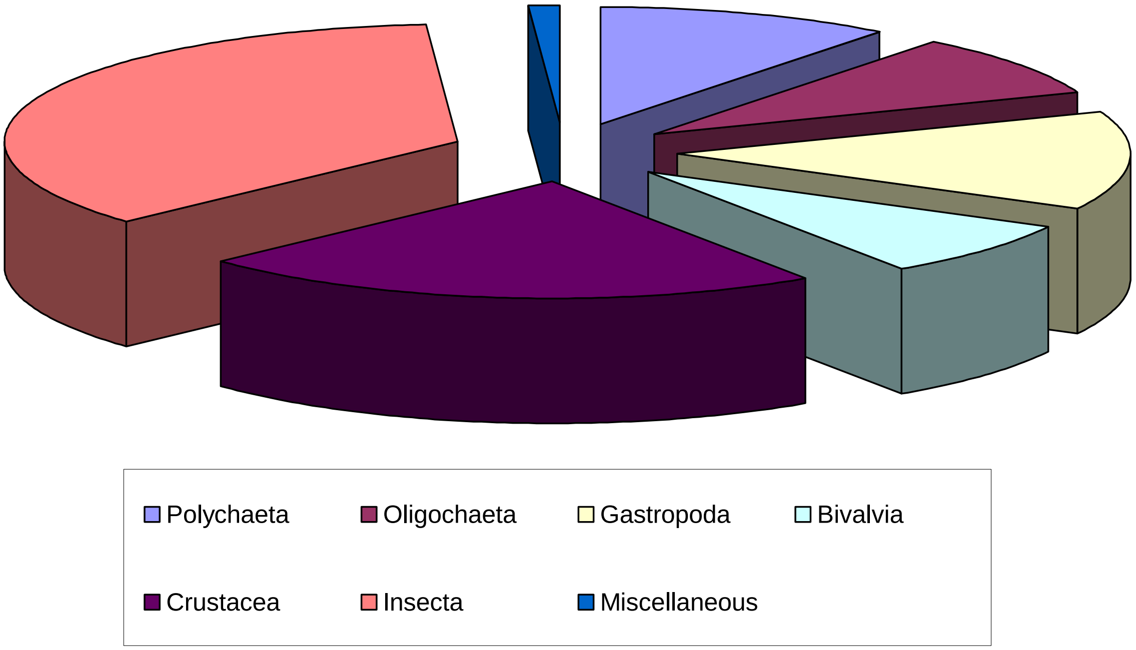


Figure 6-19. Proportion of Myakka River benthic fauna in each major taxonomic category.

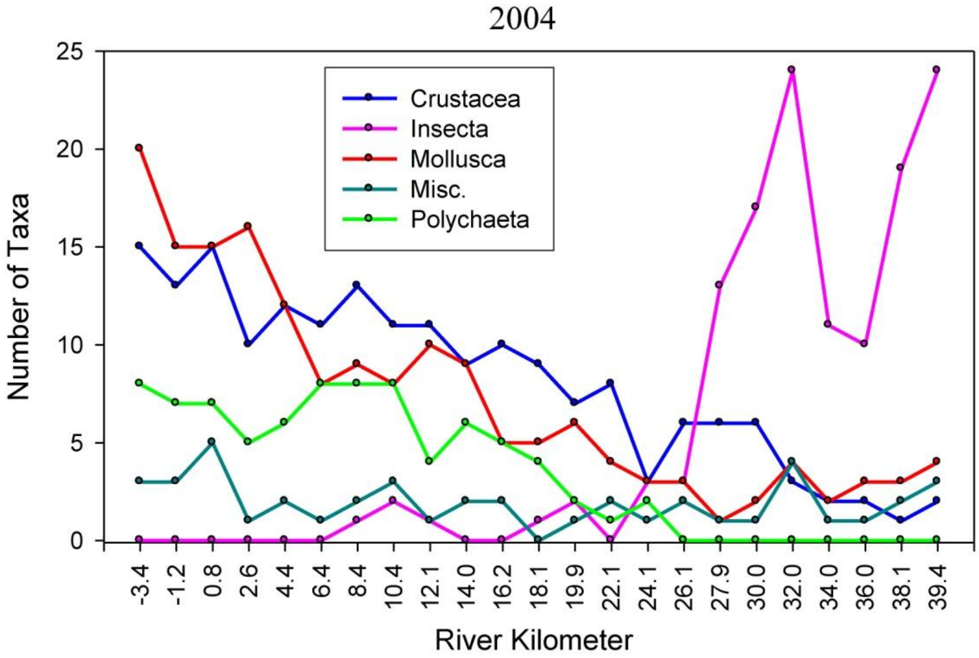


Figure 6-20. Number of species for major faunal groups per river kilometer (June, 2004).

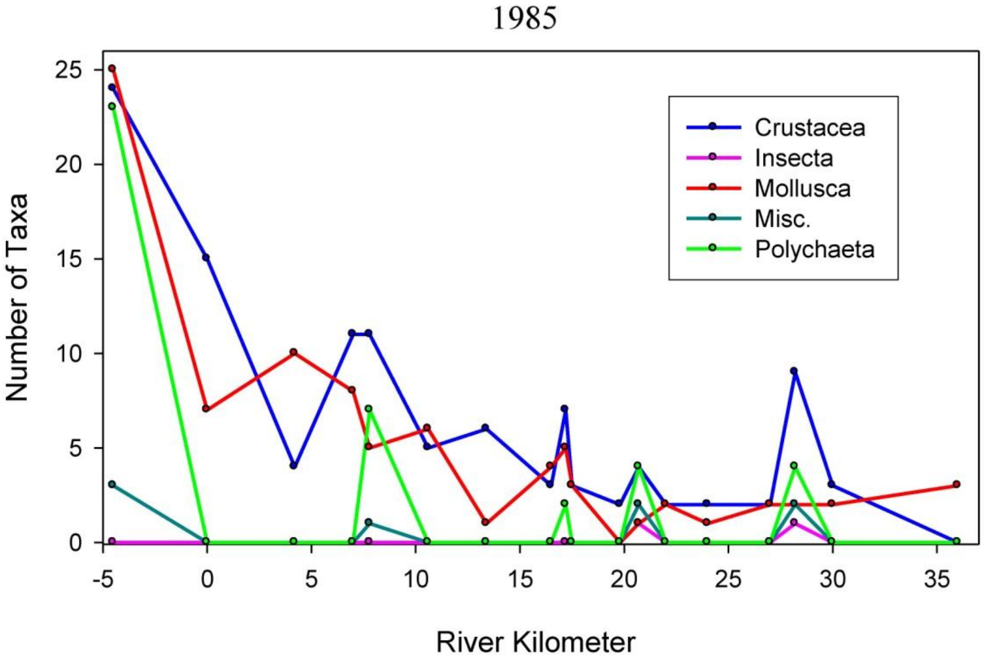


Figure 6-21. Number of species for major faunal groups per river kilometer (September, 1985)

6.3.4 Species Comparisons to Peace River Fauna

Species of benthic invertebrate from the Myakka River were compared to species from the Peace River. The list of species from the Myakka River was accumulated from all previous studies while the Peace River species list was taken from the Mote Marine Lab study of the Peace (Mote Marine Laboratory 2002). This comparison was undertaken in order to identify species that inhabit common salinity zones between the two rivers. This species comparison between the two rivers uncovered the following information:

- In all, a total of 514 species were found from both rivers
- The Myakka River had 348 total species
- The Peace River had 314 total species
- The Myakka River had 271 unique species (not present in the Peace River)
- The Peace River had 168 unique species
- There were 75 species common to both rivers. Common species are in Table 6-7.

This information is presented as a general comparison and should be taken with caution when attempting any analyses between fauna in the two river systems. There were more historical sampling events in the Myakka River which may have lead to the reporting of more species in that river. Peace River sampling, however, was more equitably distributed among seasons.

6.3.5 Faunal Zonation: Bray-Curtis Similarity Index

The Bray-Curtis Index is designed to identify faunal assemblages that are similar/dissimilar to each other. This analysis was performed on Myakka River benthic data to identify resident faunal groupings within a spatial context. Once these faunal groupongs have been identified, then the relationship between benthic community structure and relevant abiotic factors (principally salinity and sediment) can be further evaluated.

Figure 6-22 shows results from the Bray-Curtis hierarchical cluster analysis that was performed on Myakka River data from June, 2004. Three major faunal clusters were evident. The first cluster included stations RK -3 to RK 10. These are the most downstream, or estuarine, stations located from below the mouth of the river to the about 5 kilometers below Myakkahatchee Creek. The second cluster included stations RK 12 to RK 28, and the final cluster included the remaining upstream stations, RK 30 to RK 40. Abiotic factors, salinity and sediment composition that may contribute to structuring these faunal assemblages are discussed in a subsequent section of this report. Spatially, these two breaks between the faunal clusters occured near the Sarasota-Charlotte County line (RK 12) and Interstate 75 (RK 30). These findings indicate the river segment between these two locations supports a distinct faunal assemblage that is neither strictly fresh nor marine. This faunal community, with its respective dominant species, is most likely to be affected by changes in flows in the Myakka River.

Table 6-7. Macroinvertebrate Species Common to the Myakka and Peace Rivers.

CLASS POLYCHAETA

- *Sthenelais sp. A*
- *Eteone heteropoda*
- *Eumida sanguinea*
- *Phyllodoce arenae*
- *Podarkeopsis levifuscina*
- *Sigambra tentaculata*
- *Sigambra bassi*
- *Neanthes succinea*
- *Laeonereis culveri*
- *Glycera americana*
- *Glycinde solitaria*
- *Diopatra cuprea*
- *Aricidea philbinae*
- *Polydora ligni*
- *Paraprionospio pinnata*
- *Streblospio gynobranchiata*
- *Scolelepis texana*
- *Spiochaetopterus costarum*
- *Capitella capitata*
- *Heteromastus filiformis*
- *Asychis elongata*
- *Pectinaria gouldii*

CLASS GASTROPODA

- *Assiminea succinea*
- *Diastoma varium*
- *Astyris lunata*
- *Mitrella lunata*
- *Nassarius vibex*
- *Rictaxis punctostriatus*
- *Acteocina canaliculata*
- *Haminoea succinea*
- *Macoma tenta*
- *Macoma constricta*
- *Tellina texana*
- *Tagelus plebeius*
- *Mytilopsis leucophaeata*
- *Polymesoda caroliniana*
- *Corbicula fluminea*

PHYLUM CHELICERATA

- *Limulus polyphemus*

PHYLUM CRUSTACEA

- *Mysidopsis almyra*
- *Mysidopsis furca*
- *Taphromysis louisianae*
- *Taphromysis bowmani*
- *Oxyurostylis smithi*
- *Almyracuma nr. proximoculae*
- *Cyclaspis varians*
- *Xenanthura brevitelson*
- *Amakusanthura magnifica*
- *Exosphaeroma diminuta*
- *Sphaeroma terebrans*
- *Edotea montosa*
- *Ampelisca abdita*
- *Gitanopsis laguna*
- *Cymadusa compta*
- *Apocorophium lacustre*
- *Apocorophium louisianum*
- *Erichthonius brasiliensis*
- *Grandidierella bonnieroides*
- *Gammarus tigrinus*
- *Gammarus mucronatus*
- *Hyalella azteca*

Table continued on next page

Table 6-7 continued

CLASS BIVALVIA

- *Amygdalum papyrium*
- *Geukensia demissa*
- *Ischadium recurvum*
- *Crassostrea virginica*
- *Mysella planulata*
- *Laevicardium mortoni*
- *Mulinia lateralis*
- *Rangia cuneata*
- *Ensis minor*

ORDER DECAPODA

- *Penaeus duorarum*
- *Palaemonetes pugio*
- *Ambidexter symmetricus*
- *Callinectes sapidus*
- *Rhithropanopeus harrisii*

PHYLUM BRACHIOPODA

- *Glottidia pyramidata*

```
 Km
 -3 --------------------------------------------I------I
  1 --------------------------------------------I      I------------------I
 -1 ---------------------------------------------------I                  I
  3 --------------I-----------I                                        I------I
  8 --------------I           I--------------------------I             I      I
  6 --------------------------I                          I-------------I      I-----I
  4 -----------------------------------------------------I                    I     I
 10 --------------------------------------------------------------------------I     I
 12 --------------------I--------------------I                                      I
 16 --------------------I                    I----------------I                     I
 14 -----------------------------------------I                I------------------I  I---
 18 ------------------I-----------------------I               I                  I  I
 20 ------I-----------I                       I---------------I                  I  I
 22 ------I                                   I                                  I  I
 24 ----------------------------I-------------I                                  I  I
 26 --------------I-------------I                                                I--I
 28 --------------I                                                              I
 30 -------------------------------------------I                                 I
 32 ------------------------I-----I            I-------I                         I
 38 ------------------------I     I------------I       I                         I
 34 ----------I-------------------I                    I-------------------------I
 36 ----------I                                        I
 39 ---------------------------------------------------I
```

Figure 6-22. Bray-Curtis hierarchical cluster analysis. Myakka River, June, 2004

6.3.6 Myakka River Benthic Communities: Statistical Summary

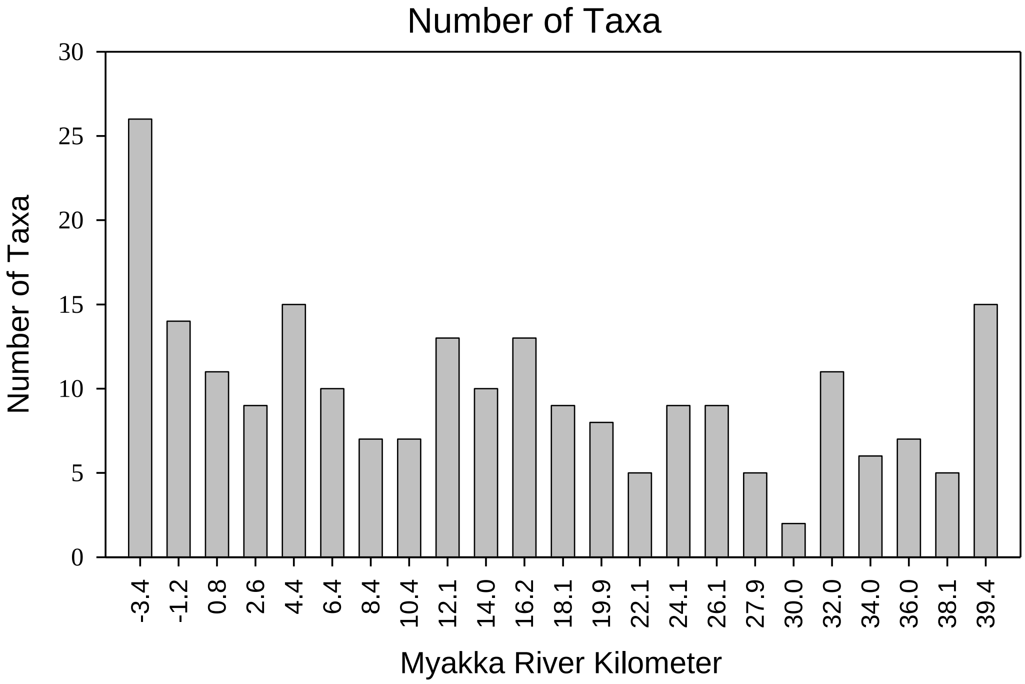
A suite of statistical measures were calculated for the lower Myakka River benthic macroinvertebrate community for the June, 2004 sampling. Statistics and community indices calculated for all samples are listed in Appendix 6E, with results listed separately intertidal and subtidal samples at roughly two kilometer intervals from RK -3.4 to RK 39.4. Statistics generated for each sample include total taxa (i.e., species richness), total abundance as individuals/m^2 (subtidal samples only), species diversity, and several indices describing how the fauna are distributed.

Summary statistics calculated for all samples are presented in Table 6-9. The Myakka River has a very healthy benthic community based on these results. Mean and median abundance values are13,628 and 1,925 individuals per square meter, respectively, which are favorably comparable to other rivers in the region. There were no samples with zero organisms present, which is likely due to the infrequent occurrence of bottom hypoxia in the lower river.

Table 6-8. Benthic fauna statistics for the Lower Myakka River for June, 2004. number per square meter calculated for subtidal core samples only.

	Total Taxa	Number Per m^2	Shannon-Weiner Index H'			Pielou's Index	Margelef's index	Simpson's Index	Gini's Index
			logE	log10	log2				
Mean	11	13,628	1.66	0.72	2.40	0.72	2.46	0.29	0.71
S.D.	6	10,410	0.58	0.25	0.83	0.17	1.09	0.18	0.18
Med	9	1,925	1.66	0.72	2.40	0.75	2.39	0.24	0.76
Min	2	962	0.16	0.07	0.24	0.24	0.31	0.04	0.08
Max	29	44,033	2.96	1.29	4.27	0.95	5.52	0.92	0.96

Figure 6-23 displays the number of taxa and faunal density by river kilometer while Figure 6-24 shows species diversity and species eveness for the same stations (station locations are rounded to the nearest kilometer in the following discussion). Species richness was dramatically highest at RK -3. Many taxa characteristic of higher salinities were only found at this location. Species richness gradually and steadily declined moving upriver until RK 30. At this point, the number of taxa rebounded as the number of freshwater species, mostly insects, increased. Faunal abundance was lowest at two intermediate locations in the river, notably RK 10 and RK 30. These stations roughly correspond to the transitional points between the faunal zones revealed in the Bray-Curtis similarity analysis. Species diversity and evenness, which measure how evenly the number of individuals is spread among the different species, were relatively high along the entire length of the river except for two noticeable exceptions. RK 4 and RK 28 were low in diversity and evenness, suggesting that these stations were dominated by individuals from one or two species. The distributions of individual benthic species are discussed below.



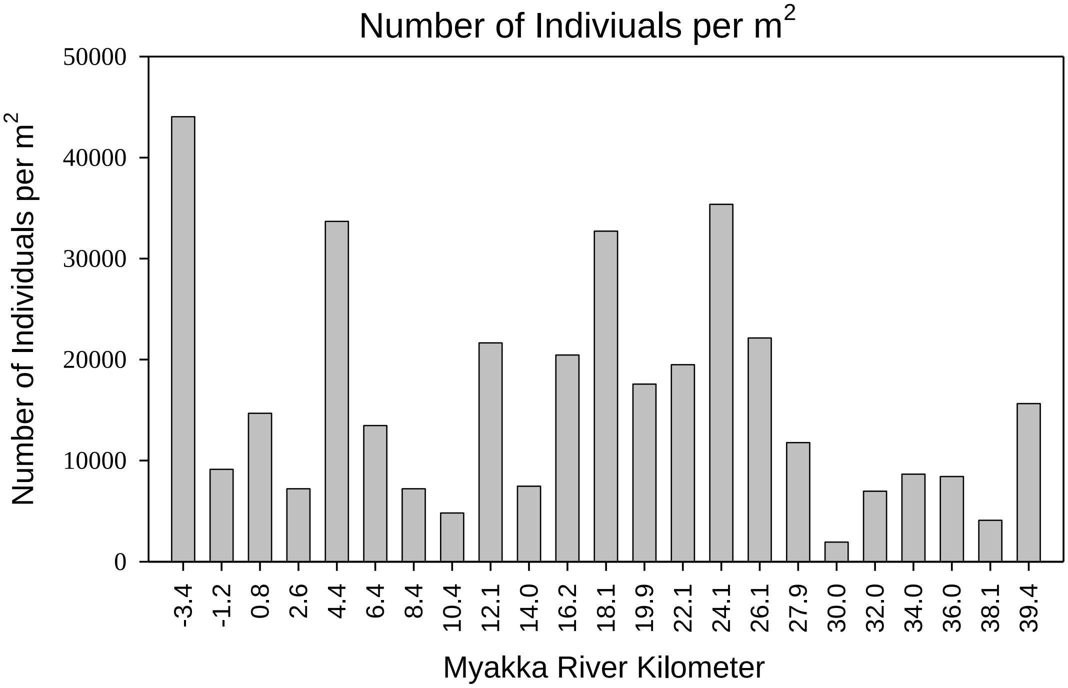


Figure 6-23. Myakka River benthic communities, June, 2004. Number of taxa (top) and number of individuals (bottom).

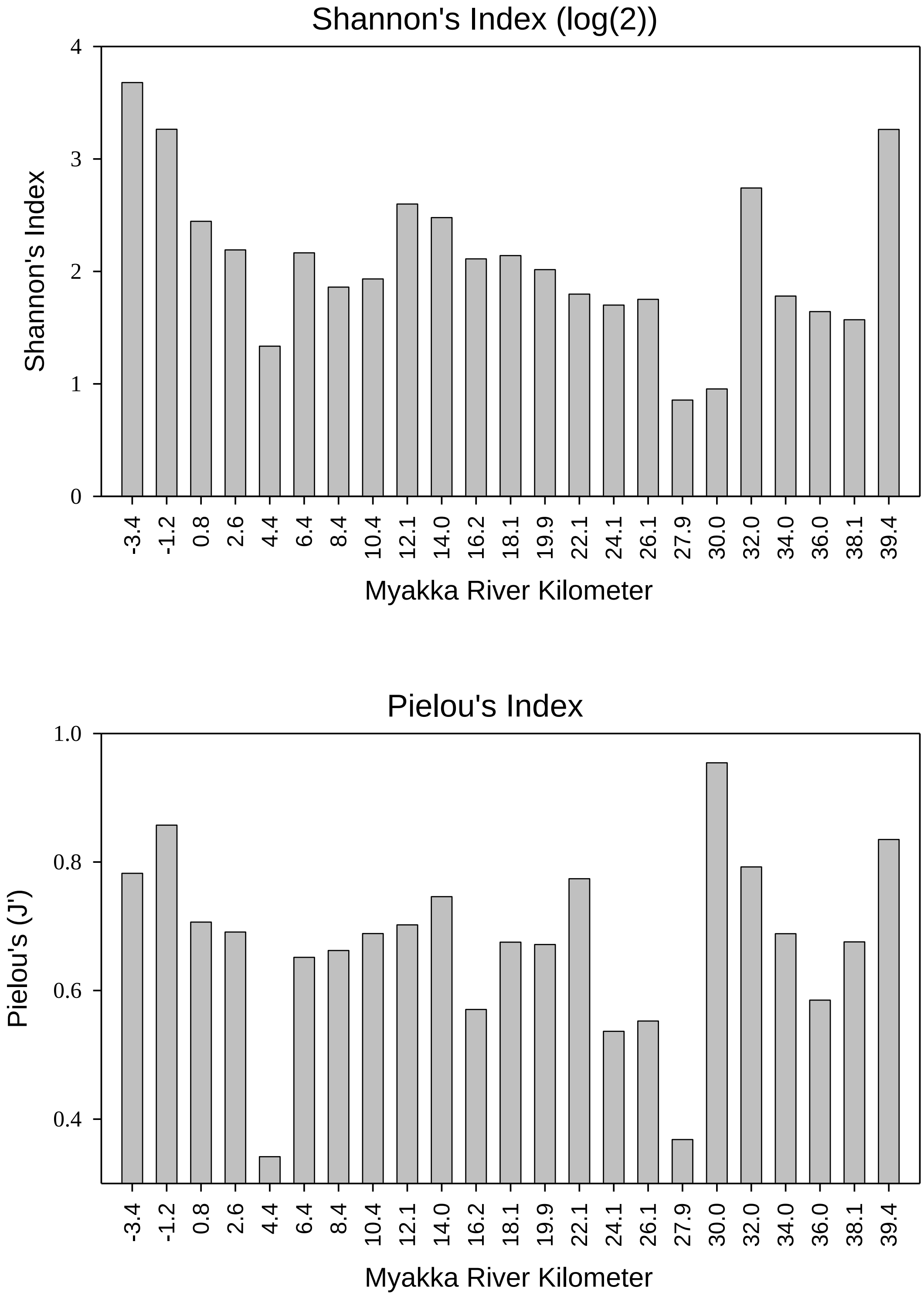


Figure 6-24. Myakka River benthic communities, June, 2004. Species diversity (top) and species eveness (bottom).

6.3.7 Dominant Taxa

Species that are relatively abundant and occur at a frequent number of stations are considered dominant for the purpose of this analysis. Of the 348 taxa identified from the Myakka River, thirty-three were regarded as dominant. A list of dominant taxa (from the subtidal cores) and their distribution within the river is presented in Table 6-9. The two most dominant species were the crustaceans *Corophium* sp. and *Grandidierella bonnieroides*, which were found in the intermediate reaches of the river (RK 12.1 – RK 28). The next dominant species, also a crustacean, was *Cyclaspis varians*, which was found towards the mouth of the river (RK -3 – RK 8). The bivalve *Corbicula fluminea* was the most dominant species in the freshwater section of the river. Other dominant species in the lower Myakka River were: *Mysella planulata, Rudilemboides naglei, Mulinia lateralis, Amygdalum papyrium,*(bivalves) and *Neanthes succinea, Pectinaria gouldii, Spiochaetopterus costarum (polychaetes)*. Additional species dominant in the middle portion of the river were: *Streblospio gynobranchiata, Laeonereis culveri* (polychaetes); Hydrobiid snails, *Polymesoda caroliniana* (bivalve), *Gitanopsis laguna* and *Mesanthura floridensis* (crustaceans). Finally, *Cryptochironomus* sp. *Cladotanytarsus* cf. *davies* (inscects), Oligochaeta spp., and *Gammarus* spp.(crustacean) were additional dominant species in the freshwater portion of the river.

These dominant taxa are responsible for shaping the unique faunal assemblages found in the different sections of the river. Dominant taxa are also the primary contributors to the high faunal abundance, which, in essence, makes up the bulk of available biomass for higher trophic lever predators. Consequently, any significant and prolonged alteration in salinity structure which shifts the peak of faunal abundance will impact available biomass.

Table 6-9 displays the spatial distribution of species in the Myakka River from all samples collected during June, 2004. Samples included cores and sweeps from intertidal and subtidal areas. The relative abundance of individuals is displayed in shades of grey since the sweep samples are not quantitative. These data complement and support the faunal distributions displayed in the previous figure.

The dispersion of individual mollusk species in the Myakka River from June 2004 are presented in Figure 6-25. Twenty-three mollusk species were collected. The data are sorted by first occurrence moving upstream (upper panel) and by first occurrence moving downstream (lower panel) (from Estevez 2005). The upstream endpoint for many estuarine species occurred between kilometers 6 and 12. More species occurred near the river mouth than upstream, especially up to near the county line (km 11.5). Species in the lower reaches included numerous forms common to upper Charlotte Harbor. Species normally found in oligohaline reaches extended down-river well into Charlotte County.

Species comprising ninety percent of the mollusk fauna included *Corbicula fluminea*, *Polymesoda caroliniana*, *Rangia cuneata*, *Tagelus plebeius*, *Littoraria irrorata*, *Guekensia demissa granossissima*, *Crassostrea virginica*, and *Ischadium recurvum*. The exotic Asian clam *Corbicula* occurred throughout the upper half of the study area and dominated the upper fourth. The dominance of this species in these upper reaches makes it important in terms of system structure and function. *Polymesoda* was abundant as multiple cohorts in the low intertidal zone and was also abundant as juveniles in the subtidal zones of the Myakka River. This bivalve, as well as the mussels that inhabit the edges of marshes and root zones of mangroves, are important as filter feeders and shoreline stabilizers, while also serving as a food source for predators. *Tagelus*, was aundant in shallow waters across a small area of the lower river. This species is highly valued as prey for benthic decapod crustaceans, elasmobranchs and teleosts, and there was evidence that predators had moved into portions of the river populated by *Tagelus* beds. In addition to the three dominant species, two intertidal gastropods, *Neritina usnea* and *Littorina* (*Littoraria*) *irrorata*, are common on mangroves and marshes fringing the river. These species are important intertidal consumers and prey items.

Table 6-9. Dominant Taxa in the Myakka River, June, 2004. Total Number of Individuals in Subtidal Cores. Species Arranged by First Appearance in River Moving Upstream.

Taxon/Species	**Total Num**	**Myakka River Kilometer**																						
		-3.4	**-1.2**	**0.8**	**2.6**	**4.4**	**6.4**	**8.4**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**39**
Spiochaetopterus costarum	**12**	8	3	1																				
Rudilemboides naglei	**30**	29			1																			
Mulinia lateralis	**34**	8	5	20		1																		
Nemertea sp. F	**4**	1		1		2																		
Paraprionospio pinnata	**4**	1			1	2																		
Glottidia pyramidata	**8**	7				1																		
Acteocina canaliculata	**9**	4	2	1			2																	
Mysella planulata	**52**	21	4	21		2	4																	
Neanthes succinea	**18**	3		1	1	1	2			10														
Cyclaspis varians	**194**	8		2	17	114	33	18			2													
Pectinaria gouldii	**73**	42	12	8	4		4	1		1		1												
Amygdalum papyrium	**33**	18		4		7	2	1				1												
Tellina sp.	**25**	8	2				6	3		3	2	1												
Edotea montosa	**7**	1									1		3	2										
Bivalvia spp.	**25**	10	1							1						2	1					2		8
Glycinde solitaria	**5**		2			1	1		1															
Oligochaeta spp.	**93**		1						1								3	3	5	12	20	24	11	13
Oxyurostylis smithi	**4**				1	3																		
Ampelisca spp.	**20**				2		1	5	12															
Streblospio gynobranchiata	**19**				2				3		1	4	9											
Hydrobiidae spp.	**68**												31	15	15		1	1		1		1	1	2
Mesanthura floridensis	**4**					1				1		1	1											

Table 6-9. (Continued).

Taxon/Species	**Total Num**	**Myakka River Kilometer**																						
		-3.4	**-1.2**	**0.8**	**2.6**	**4.4**	**6.4**	**8.4**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**39**
Polymesoda caroliniana	**75**					1				41	2	30		1										
Pseudochironomus sp.	**4**																			2	1	1		
Gammarus spp.	**26**																10	1		1	8	4		2
Cladotanytarsus cf. davies	**18**								1									2						15
Grandidierella bonnieroides	**234**								1	16	16	39	62	36	27	31	6							
Gitanopsis laguna	**6**									4		2												
Corophium sp.	**269**									4	2	1	24	14	34	86	62	42						
Xanthidae spp.	**15**									4	1	1	3		1	1	3			1				
Laeonereis culveri	**8**										3	2		3										
Cryptochironomus sp.	**6**													1		2					1		1	1
Corbicula fluminea	**46**													1	4	22	5		3	5	5		1	

Table 6-10. Species distribution in the Myakka River, June, 2004. Light grey (< 10 ind); medium grey (10 – 100 ind); dark grey (> 100 ind). Includes individuals from all samples (sweeps, cores, intertidal and subtidal samples).

	Myakka River Kilometer																						
Taxon/Species	**-3.4**	**-1.2**	**0.8**	**2.6**	**4.4**	**6.4**	**8.4**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**39**
Astyris lunata	▒	▒	░																				
Rudilemboides naglei	▒			░																			
Bittiolum varium	▓	░		░	░																		
Haminoea succinea	░	▒	▒	▒	░																		
Mysella planulata	▒	░	▒	░	░	▒	░																
Mulinia lateralis	▒	▒		░	▒	▒	░																
Bemlos sp.	▒	░	░	░			░																
Erichsonella filiformis	░	░	░	░		░	░																
Caprellidae spp.	░	░	░	▒			░	░															
Bowmaniella floridana	░	░	▒		░			░															
Acteocina canaliculata	▒	▒	▒	░	░	░	░	░															
Paraprionospio pinnata	░			░	░	░	░	░															
Cyclaspis varians	░	▒	▒	▒	▓	▒	▒	░	░														
Tagelus plebeius	░		▒	░	▒	▒	▒	▒	░	░													
Pectinaria gouldii	▒	▒	▒	▒	▒	▒	▒	░	░	░	░												

Table 6-10. (Continued).

	Myakka River Kilometer																					
Taxon/Species	**-3.4**	**-1.2**	**0.8**	**2.6**	**4.4**	**6.4**	**8.4**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**	**38**	**39**
Neanthes succinea	▒		░	░	░	▒	░	░	▒	░	░												
Amygdalum papyrium	▒	▒	▒	▒	▒	▒	▒	▒	░	░	░	░	░										
Mesanthura floridensis	░		░		░	░	░	░	░	░	░	░	░										
Tellina sp.	░	░	░	▒	█	█	▒	▒	░	░	░	░	░										
Oxyurostylis smithi	░	░	░	▒	░	░	▒	░	░					░									
Edotea montosa	░				░	░	▒		░	▒	░	░	░	▒									
Grandidierella bonnieroides	░				░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	░						
Oligochaeta spp.	░	░	░					░					░	░	░	▒	▒	▒	▒	▒	▒	▒	
Oedicerotidae		░	░	░		▒		░															
Capitella capitata		░	░		░	░	░	░															
Glycinde solitaria		░	░	░	░	▒	░	▒															
Mysidopsis almyra		░	░		░	░	▒	░	▒	░	▒	░				▒		▒					
Gammarus spp.		▒	░		░	░	░	░	░					░		▒	░	░	░	░		░	
Ampelisca spp.			░	▒	░	▒	▒	▒	░														
Streblospio gymnobranchiata			░	░	░	░	░	░	░	░	░	░											
Polymesoda caroliniana			░	░	░	▒	▒	▓	█	▒	▓	▒	░	░	░								

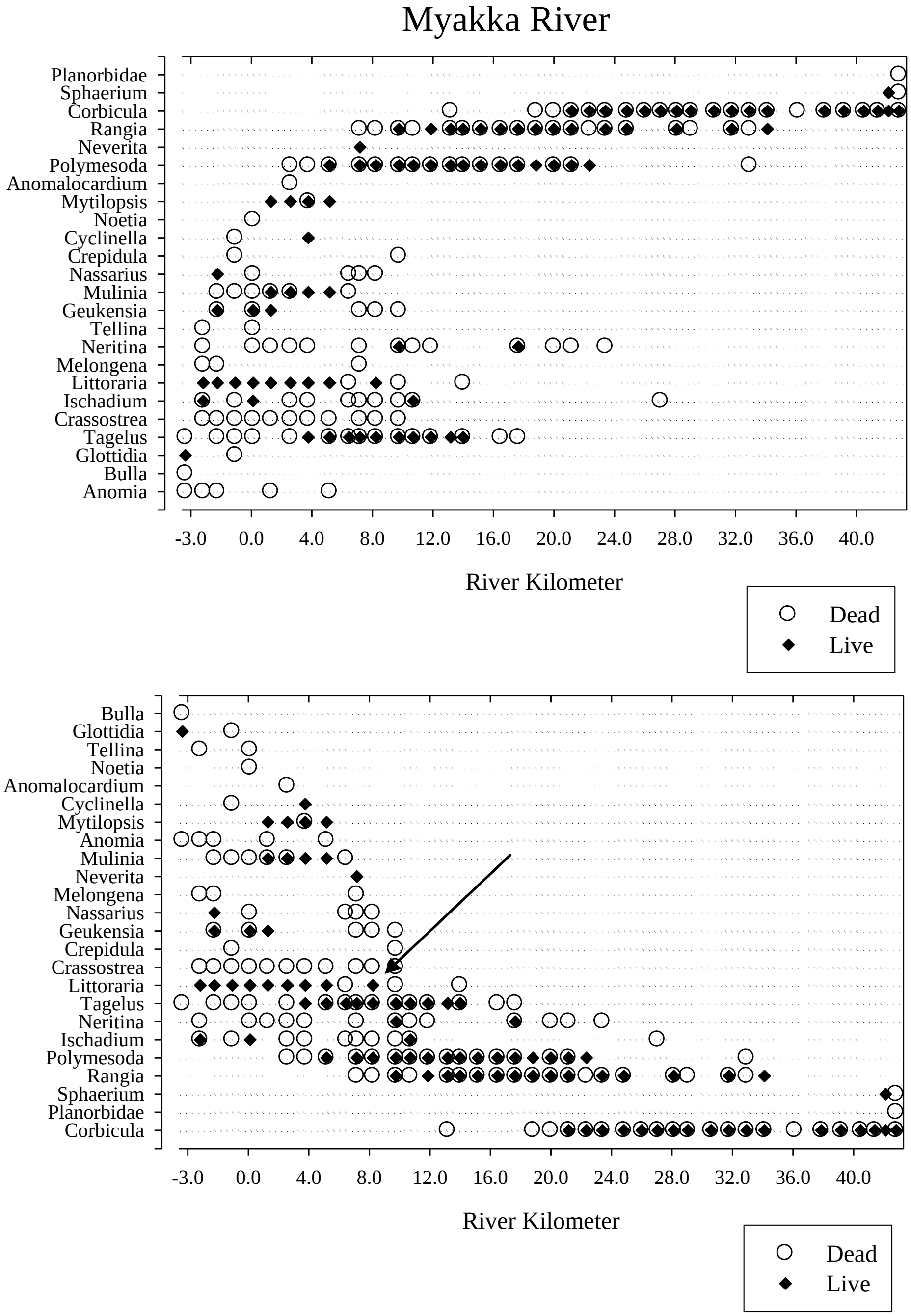


Figure 6-25. Dispersion of individual mollusk species in the Myakka River, June 2004, sorted by first occurrence moving upstream (upper panel) and by first occurrence moving downstream (lower panel). Reprinted from Estevez (2005). Arrow in lower panel added to denote upstream limit for many estuarine species.

6.3.8. Relationship of Myakka River Benthic Community Structure to Salinity

There are a variety of approaches that can be used to relate benthic fauna to the environment. Most techniques use salinity as a surrogate for freshwater flow. One approach is to look at relationships between abundance or frequency of occurrence and salinity. Another approach is to relate (by univariate or multivariate models) salinity with abundance, diversity, or community structure.

Bottom salinities per river kilometer for the Myakka River during the collection of benthic samples on June 4, 2004 are shown in Figure 6-26. With data collection in early June, this sampling effort was designed to collect benthic invertebrates at the height of the spring dry season when salinity values in the river were near their yearly maxima. This objective was achieved, as the flows in the Myakka River were very low prior to sampling. The flow at the Myakka River near Sarasota gage on June 4 was 2.1 cfs, while the preceding 30-day and 60-day mean flows were 13.5 and 14.3 cfs, respectively, which are also indicative of very low flows Plots of observed and modeled bottom salinity values at three continuous recorders operated by the USGS also show that salinity in the river was very high at that time (Figure 4-55).

Using the Venice estuarine classification system (Anonymous 1959), the benthic zones in the river on the sampling day could be classified as polyhaline (18 – 30 psu) from the river mouth to km 16, mesohaline (5 – 18 psu) between kms 16 and 29, oligohaline (0.5 – 5 psu) between kms 29 and 35), and limnetic (< 0.5 psu) above km 35. The location of these zones were near their maximum upstream penetration, as the much lower salinity values are observed in the river during other times of year (Figures 4-23 and 4-24), and locations of isohalines that can be used to classify salinity zones similar to the Venice system are typically located further downstream (Figure 4-33, 4-44, 4-45).

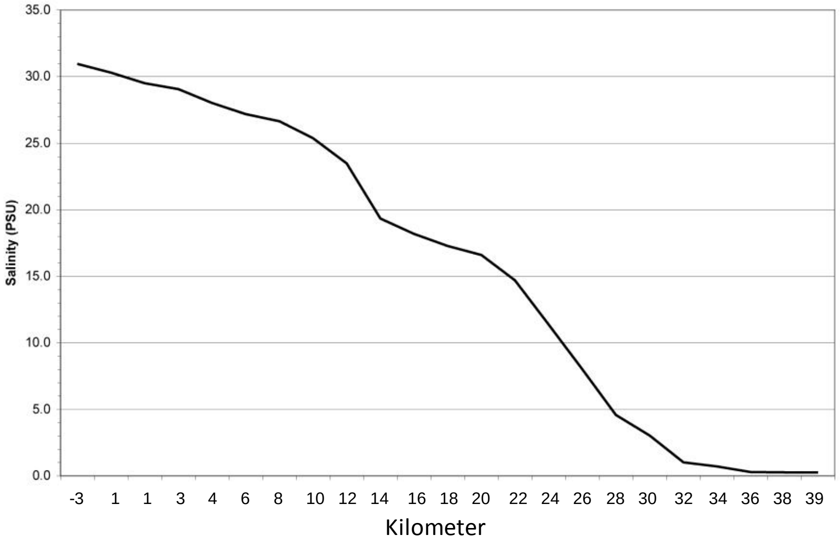


Figure 6-26. Smoothed line of bottom salinity values recorded at sub-tidal benthic sampling stations on June 4, 2004.

The distinct gradients observed in the faunal characteristics (Tables 6-9 and 6-10 and Figure 6-25) correspond to the horizontal salinity gradients in the river on the sampling day (Figure 6-26). The increase in a number of species downstream of a transition zone around kilometers 12 to14 reflected the transition to a higher salinity, polyhaline environment. Conversely, increased numbers of freshwater and low salinity species (e.g., oligochaetes and *Corbicula*) were observed upstream of a zone around kms 24 – 30. A transition zone was observed in the range of kms 14- 28, with high numbers of species that are known to proliferate in the mesohaline zones of estuaries, such as the amphipods *Grandidierella bonnieroides* and *Corophium* sp, and the mollusk *Polymesoda caroliniana* (Janicki Environmental 2007, Montagna et al. 2008).

The benthos sampling that was conducted in June 2004 was an informative, one-time snapshot of conditions in the estuary during one sampling event which represented near maximum salinity conditions. Seasonal changes in freshwater inflow and shifts in the salinity distributions would be expect to shift the distribution of most of the macroinvertebrate species.

Using much larger data bases that were combined from a number of rivers in the region, the District has funded studies to examine the relationships of salinity and sediment characteristics to benthic macroinvertebrate communities in the region. Janicki Environmental (2007) used a variety of statistical techniques to examine relationships of salinity and sediment characteristics to the abundance and distribution of benthic macroinvertebrate infauna. Montagna et al. (2008) combined data for mollusk surveys conducted on eleven creeks and rivers to examine similar relationships. Because these data bases include observations for many species that were collected from a variety of locations and hydrologic conditions, more powerful analytical tools become available because they incorporate a sample/species matrix that includes a wide range of environmental variables associated with each sample. The distribution of common taxa in the Myakka River during the very dry period of June, 2004 is a part of this more comprehensive data sets, so that the relationship between faunal distribution and salinity can be more fully analyzed.

Janicki Environmental (2007) used multidimensional scaling analysis to show that the Charlotte Harbor tidal rivers (Peace and Myakka Rivers and Shell Creek) form a geographically distinct group based upon “presence-absence” of the resident taxa. Collectively, four salinity classes were identified from Principal Components Analysis based on data from the Charlotte Harbor tidal rivers (Figure 6-27). The lowest range (< 11 psu) ranges from the tidal freshwater to the low mesohaline zone. The second range (11 – 17 psu) corresponds to the high mesohaline zone. The third range (17 – 28 psu) corresponds to the polyhaline zone and the fourth zone (> 28 psu) represents the euhaline zone of the Venice classification scheme. The benthic community structure within these different salinity classes for the Charlotte Harbor tidal rivers (from Janicki Environmental, 2007) are displayed in Tables 6-11 and 6-12. Each salinity zone is characterized by several dominant taxa, which in turn, may be present in one or more zones.

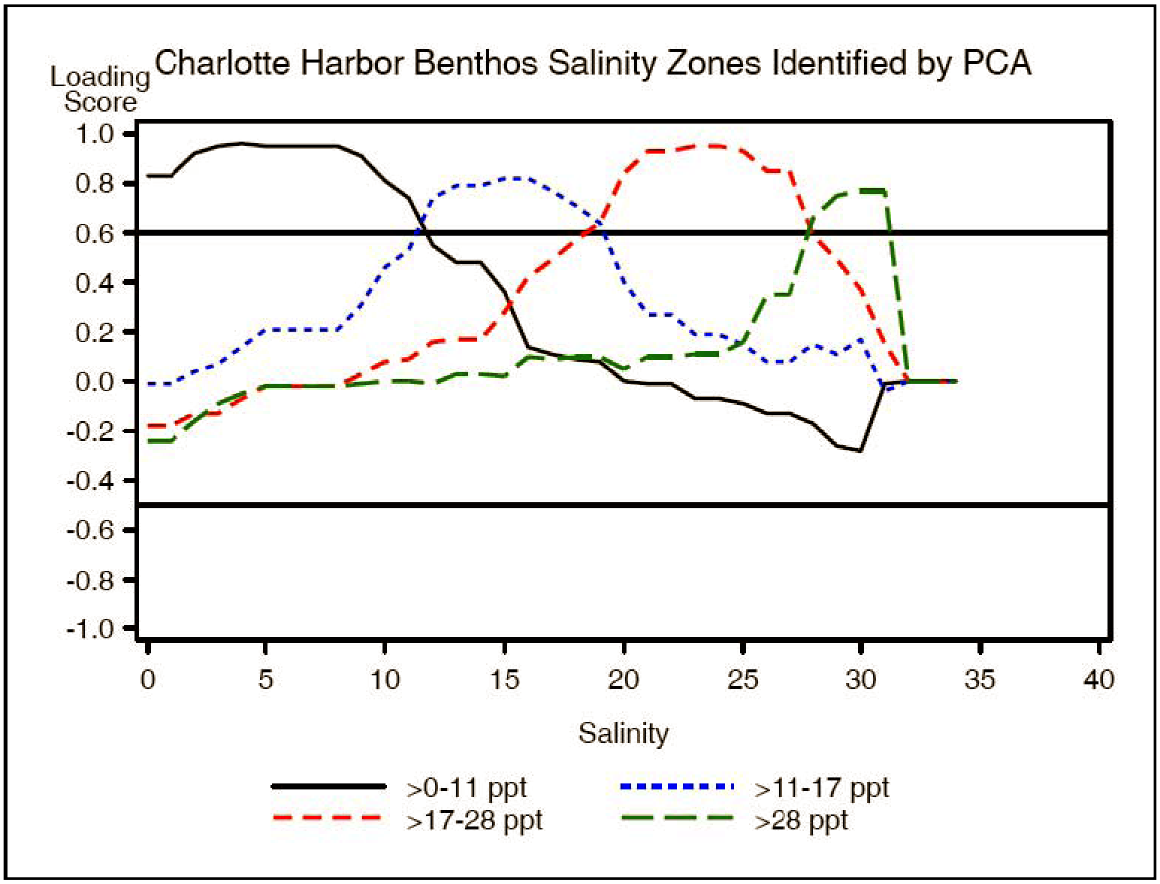


Figure 6-27. Salinity classes identified for the Charlotte Harbor group of tidal rivers based upon the distribution of the benthos (From Janicki Environmental 2007).

Table 6-11. Benthic species in the Charlotte Harbor tidal rivers that explain at least 50% of the within-class similarity (Bray Crutis similarity; presence-absence data) by salinity class. (From Janicki Environmental 2007). Species with an asterisk were present in the Myakka River.

Species	**<11 psu**	**11-17psu**	**17-28 psu**	**>28 psu**
**Amakusanthura magnifica*		0.41		
**Ampelisca abdita*			0.58	
**Amygdalum papyrium*			0.52	
**Corbicula fluminea*	0.33			
**Cyclaspis cf. varians*		0.49	0.60	0.83
**Edotea montosa*		0.44		
**Grandidierella bonnieroides*	0.39	0.39		
**Laeonereis culveri*	0.36	0.54		
**Mulinia lateralis*			0.45	0.63
**Mysella planulata*				0.80
**Pectinaria gouldii*				0.63
**Polypedilum scalaneum*	0.39			

Table 6-12. Forty most abundant benthic species in the Charlotte Harbor tidal rivers by salinity class. Abundance is 4th root transformed density. (From Janicki Environmental 2007). Species with an asterisk were present in the Myakka River.

Species	**<11 psu**	**11-17 psu**	**17-28 psu**	**>28 psu**
**Acteocina canaliculata*				0.83
**Almyracuma proximoculi*		0.67		
**Amakusanthura magnifica*	0.65	0.81	0.69	0.70
**Ampelisca abdita*	0.64	0.78	1.18	1.06
**Amygdalum papyrium*	0.69	0.92	1.00	1.00
**Apocorophium lacustre*	0.91	0.98		
**Apocorophium louisianum*	0.69	0.72		
**Asychis elongate*				0.68
**Bemlos* sp.				0.74
**Capitella capitata complex*		0.75	0.75	0.72
**Chironomus sp.*		.064		
**Coelotanypus sp.*		.066		
**Corbicula fluminea*		.088	.072	
**Cryptochironomus*		.067	.067	
**Cyclaspis cf. varians*	0.66	1.06	1.29	1.57

Species	**<11 psu**	**11-17 psu**	**17-28 psu**	**>28 psu**
**Edotea montosa*	0.67	0.91	0.69	
**Gammarus cf. Tigrinus*	0.79			
**Glottidia pyramidata*				1.08
**Glycinde solitaria*			0.67	0.71
**Grandidierella bonnieroides*	0.97	1.04	0.73	
Hobsonia florida	0.67	0.71	0.66	
**Laeonereis culveri*	0.82	1.03	0.74	
**Macoma tenta*				0.85
**Mulinia lateralis*	0.63	0.85	1.07	1.17
**Mysella planulata*			0.76	1.41
**Nemertea* sp. F				0.76
**Nereis succinea*		0.69	0.83	0.88
**Oxyurostylis smithi*		0.66	0.81	0.90
**Paramphinome* sp. B			0.65	0.68
**Paraprionospio pinnata*			0.64	0.73
**Pectinaria gouldii*			0.75	1.08
**Polydora ligni*		0.66	0.67	
**Polymesoda caroliniana*	0.77	0.82	0.72	
**Polypedilum halterale* Group	0.67			
**Polypedilum scalaneum* Group	0.85	0.75		
**Spiochaetopterus costarum*				0.80
**Streblospio gynobranchiata*	0.74	0.84	0.84	
**Tagelus plebeius*		0.66	0.72	

6.4 Zooplankton and Fish

The Lower Myakka River supports diverse and abundant fish and zooplankton communities and serves as a prime nursery area for several species that contribute to economically important sport and commercial fisheries in the Charlotte Harbor region. Economically important fish and shellfish species that utilize the lower river as nursery habitat include mullet, snook, red drum, tarpon, spotted seatrout, pink shrimp, and blue crab. The lower river also serves as productive habitat for many other important fishes and invertebrates that serve as prey for these species of economic importance and support the overall wildlife resources of the river (e.g. wading birds).

Fish populations, including early life stages comprising the ichthyoplankton, have been sampled in the Myakka River by two principal efforts – the first in the mid-1980s and the second nearly 20 years later. Mote Marine Laboratory conducted surveys of ichthyoplankton and fishes in the Myakka River during 1985-1987 (Phillips 1985, Phillips 1986, East et al.1987, Estevez et al. 1991). Bay anchovy (*Anchoa mitchilli*) larvae and juveniles were both the most abundant species and most frequently collected. Hogchoker (*Trinectes maculatus*) was the second most abundant species. Fish eggs were more abundant near the river's mouth and declined upriver. Eggs were most abundant during spring months although there was also a spike in abundance in the winter of 1987. Larval densities were also high during the spring, although there were other periods of high abundance during winter 1986 and fall 1987. Juveniles, on the other hand, were most abundant in the winter months.

In a more recent effort initiated as part of the minimum flows project for the Lower Myakka River, zooplankton and fishes were collected from the Lower Myakka River and Myakkahatchee Creek during 2003 and 2004. Zooplankton and early life stages of fishes were sampled by plankton nets by researchers from the University of South Florida, College of Marine Science (USF). The nekton (free-swimming larger fishes and invertebrates) invertebrates (blue crabs, larger shrimps) were sampled by seines and trawls by researchers from the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute (FWRI). The combined findings of the plankton and seine and trawl sampling are presented in a report by Peebles et al. (2006).

The USF/FWRI study during 2003-2004 occurred during what was an unusually wet period. In order to collect data during low flow conditions, plankton sampling by USF was resumed for five additional months during a prolonged dry period from February through June 2008. Using similar analytical techniques, these additional samples were used to update the analyses for key indicator plankton taxa (Peebles 2008).

The overall objectives of the USF/FWRI effort were to:

- provide a database characterizing the composition of the fishes, ichthyoplankton, and invertebrate zooplankton of the Myakka River and the Myakkahatchee Creek;
- develop information on the distribution and seasonality of specific life stages and taxa within these two systems;
- identify patterns of estuarine habitat use and organism abundance under variable freshwater inflow conditions
- develop quantitative, predictive tools to assess how changes in freshwater inflow affect the distribution and abundance of various fish and invertebrate species and change the composition of these biological communities.

The results generated by the USF/FWRI program comprised the primary information for zooplankton and fishes used in the District's minimum flows analysis of the Lower Myakka River. This approach was chosen because of the extensive spatial coverage of the USF/FWRI sampling effort, the taxonomic resolution of the invertebrate sampling, and the presentation of predictive tools that could be incorporated in the minimum flows analysis. As described in more detail in Chapter Seven, the District's assessment of freshwater inflows effects focused primarily of biological use of habitats in the channel of the Lower Myakka River. As such, the District did not evaluate the effects of freshwater inflow reductions on zooplankton and fish populations within Myakkahatchee Creek.

Some pertinent findings from the USF/FWRI program for the Lower Myakka River are summarized in the following sections. Statistical models presented in the two reports for this project (Peebles et al. 2006, Peebles 2008) are further described in Chapter 7 and applied in Chapter 8 to examine the effects of potential reductions in freshwater inflows on the abundance and distribution of fish and zooplankton indicator species in the Lower Myakka River.

6.4.1 Overview of Fish Communities and Estuary Nursery Function in Tidal River Estuaries

The District has sponsored studies of the zooplankton and fishes in a number of tidal river estuaries in the region, including unregulated rivers like the Myakka whose inflows are dominated by surface water runoff. This group of rivers has included the Peace River and Shell Creek (Peebles 2002, Greenwood et al. 2004) the Little Manatee River (Peebles and Flannery, 1992, Peebles 2007, MacDonald et al. 2007), the Alafia River (Peebles 2005a, Matheson et al. 2005) and the Anclote River (Greenwood et al. 2006). Some findings from these studies and the scientific literature are synthesized below regarding the characteristics of fish and zooplankton communities in the region's tidal rivers that are related the management of freshwater inflows.

Three groups of fishes species that inhabit tidal rivers can be categorized based on their autecology and life history strategies; freshwater, estuarine-resident, and estuarine-dependent species.

Freshwater fishes are typically associated with fresh non-tidal waterways, but they also have inhabit tidal freshwater zones which can be extensive in some rivers. Many freshwater fishes will also migrate into and feed in low salinity waters, since many of these species can tolerate some amount of salt for limited periods of time (Peterson and Meador 2002). Increases in freshwater inflow expand the amount of tidal freshwater and low salinity habitats in rivers, so that positive associations with inflow and the abundance of freshwater fishes are generally observed.

Estuarine residents are fish species that spend their entire life cycle in the tidal river, such as many species of the family Cypriodontidae (killifishes). These species often have broad salinity tolerances, but they do not migrate away from the tidal river for feeding or reproduction. Estuarine residents tend to be small species that do not contribute substantially to fishery yields, however, they serve as important forage for wading birds and piscivorous estuarine dependent fishes.

Estuarine dependent species typically spend a portion of their early life cycle in the estuary, typically with a later return to higher salinity coastal waters as they mature. The nursery function of estuaries with regard to coastal fisheries is well known, as it is estimated that over 70 to 80 percent of the sport and commercial fisheries catch associated with the Gulf of Mexico is comprised of species that are estuarine dependent (Comp and Seaman 1985, Day et al. 1989). The abundance or harvest of estuarine dependent species are often positively correlated with the rate of freshwater inflow (Longley 2004, Drinkwater 1986), and various studies from around the world have shown that significant reductions in the abundance of economically important fish and shellfish species have resulted where the timing and volume of freshwater inflow to estuaries have been dramatically altered (Aleem 1972, Moyle and Leidy 1992, Mann and Lazier 1996, Baisre and Arboleya 2006). Given such findings, potential impacts to estuarine dependent fisheries are often a critical element of freshwater inflow assessments.

Peebles (2005a) provides an overview of the life history strategies of estuarine dependent species and the ecological characteristics of tidal rivers that make them prime nursery habitats for these organisms. Estuarine dependent species spawn either at sea or in relatively high salinity estuarine waters (e.g., regions of Charlotte Harbor). The young typically begin migrating landward during the first few weeks of life, eventually congregating in estuarine nursery habitats. After spending a few months in these low salinity habitats, the older individuals gradually move seaward. For some species, the ingression of young animals into tidal rivers is detectable during the animals' larval stages, which are planktonic and may be captured by plankton tows. Other species invade the tidal rivers at larger juvenile stages and are usually first captured in seine or trawl catches.

Other ichthyoplankton and seine/trawl studies in the region have consistently shown a migration of many estuarine dependent fish species into low salinity habitats as they grow from larval to juvenile stages (Peebles and Flannery 1992, Peebles 2005a; Greenwood et al. 2004, Greenwood et. al. 2006, Matheson et al. 2005). Based on data from plankton net samples in the Little Manatee River, the decreasing salinity at capture with age is shown in Figure 6-28. This generally results in an upstream migration, with the maximum concentration of juveniles often well within the tidal river

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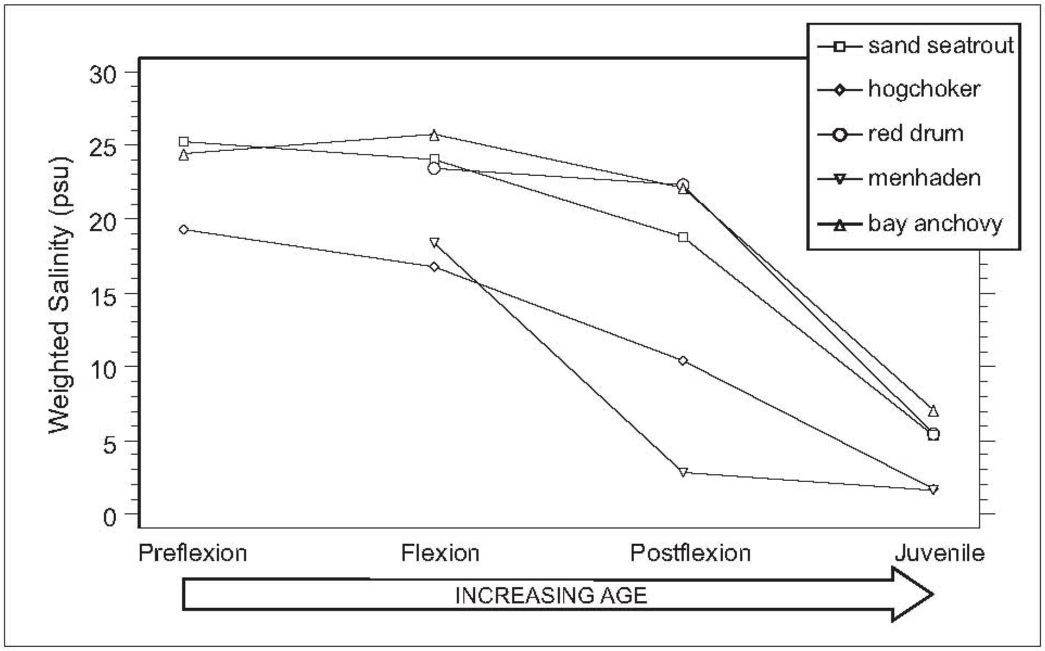


Figure 6-28. Example of declining mean salinity at capture with increasing age in plankton samples from the Little Manatee River. Preflexion, flexion and postflexion are successive larval stages (adapted from Peebles and Flannery 1992).

Such relationships were also found in the Lower Myakka River. For example, on the mean location of the bay anchovy population moved progressively upstream during development, starting at 0.5 km during the egg stage, to 2.0 to 2.4 km during various larval stages, and to 7.4 km during the juvenile stage (Peebles et al. 2006).

The diets of the young fishes change as they mature from larval to juvenile stages, generally switching from zooplankton prey (e.g., copepods) in higher salinity waters to larger benthic invertebrate prey (e.g., amphipods) in upstream, low salinity depositional areas. For some species, the landward migration coincides with their first use of structured habitats such as mangroves, marshes, seagrasses, macroalgae beds and oyster reefs, which can provide cover and some refuge from predation. Other species may aggregate over what is featureless bottom habitat in the upper reaches of estuaries, characterized by fine grained sediments that can support large numbers of benthic invertebrates.

Freshwater inflow can exert a strong effect on the productivity of nursery areas by delivering nutrients and organic matter and affecting zones of primary production, which in turn drives the production of invertebrates and fishes. Peebles (2005a) suggests that estuarine-dependent fishes and invertebrates often use depositional areas of estuaries as their prime nursery habitat, which can constitute comparatively small areas within tidal creeks and rivers. Because these semi-confined riverine locations are strongly influenced by watershed runoff, there is significant potential for human alterations to impact the nursery functions of these areas.

6.4.2 Sampling for Zooplankton and Early Life Stages of Fishes in the Lower Myakka River

USF scientists conducted monthly plankton tows in the Myakka River (May 2003 to December 2004) and Myakkahatchee Creek (May 2003 to July 2004) in order to capture the early life stages of fishes and invertebrate species that occur in the water column (Peebles et al. 2006). The sampling gear consisted of a 0.5-m diameter mouth conical plankton net of 500 µm mesh. Tows were made in a stepped oblique fashion of five minutes duration with the tow time equally divided equally among relative bottom, mid-water and surface depths. Tow speed was ~1.3 m sec^{-1}. The resulting tow lengths were ~400 meters with ~70-80 m^3 of water was filtered.

Plankton tows were made within seven sampling zones in the Myakka River and two zones within Myakkahatchee Creek (Figure 6-29). Two tows were made within each zone, so fourteen tows were made in the Myakka River and four tows in Myakkahatchee Creek on each sampling trip. The Myakka River sampling zones extended over more than 40 kilometers from near the mouth of the river almost to RKM 42 (see note below for conversion factor to SWFWMD centerline). Myakkahatchee Creek samples were collected in two zones extending almost 5 kilometers upstream of the confluence with the river. After the report for the 2002-2004 sampling was completed (Peebles et al. 2006), plankton sampling at the stations in the Lower Myakka River were resumed for five months between February through June 2008 (Peebles 2008).

Note: To avoid negative values in the population distribution assessments (which used Ln transformed data), USF/FWRI set a zero kilometer reference point 6. 5 kilometers downstream of the mouth of the river on the SWFWMD centerline. Results taken directly from Peebles et al. (2006) should be corrected by subtracting a value of -6.5 km to correspond to the SWFWMD centerline (Figure 3-1).

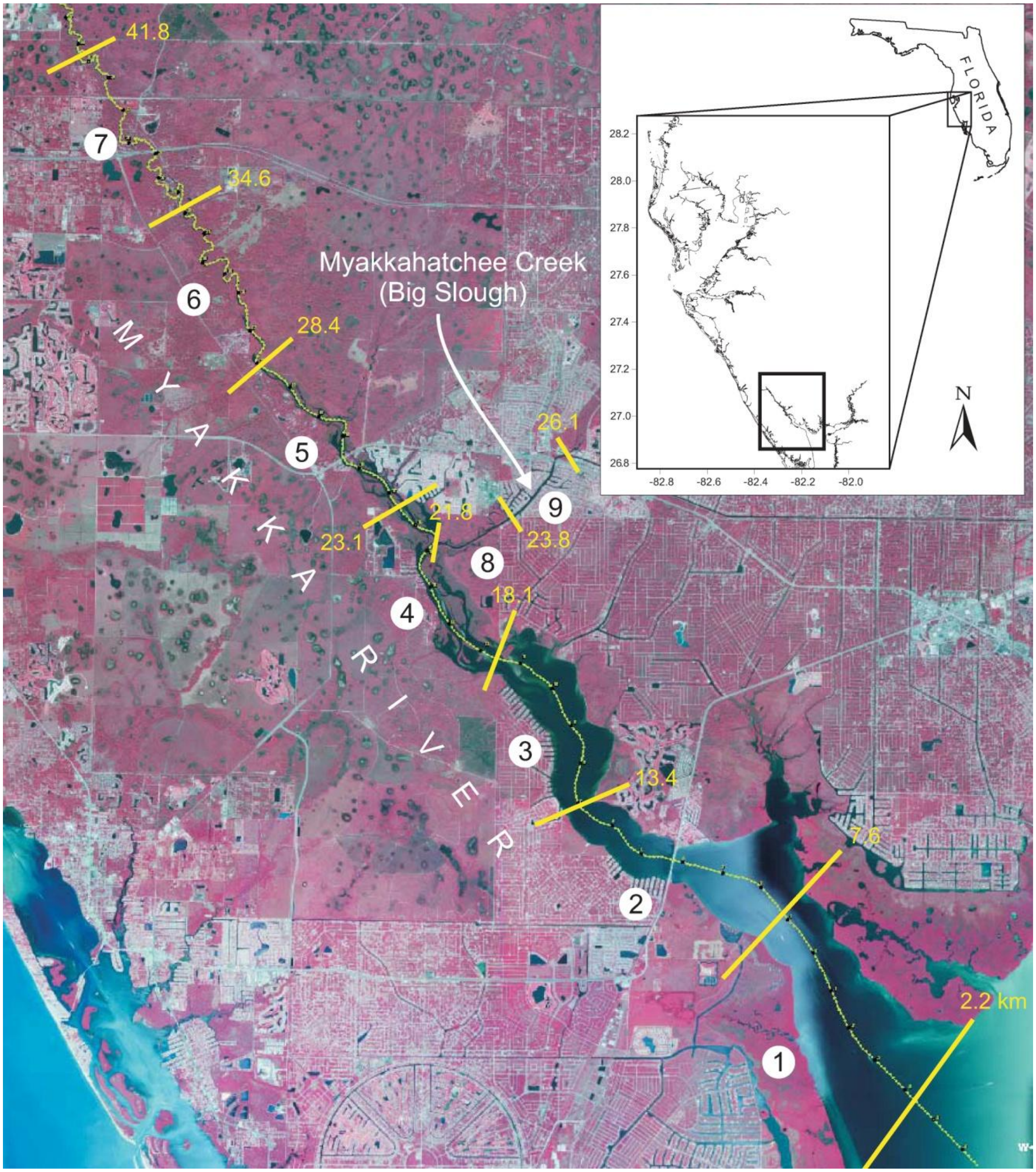


Figure 6-29. Map of USF/FFWCC sampling zones with kilometer distiches shown in yellow. A value of 6.5 km should be subtracted from the kilometer values shown on the map to correspond to the SWFWMD centerline scale for the river.

Peebles et al. (2006) addresses some of the biases of gear selection and deployment methods for zooplankton studies in general and how these may affect the data. The authors, however, emphasize that the methods selected do yield data that are both comparable and appropriate for evaluating the spatial and temporal distributions of the vertebrate and invertebrate zooplankton.

All aquatic taxa collected by the plankton net were identified and counted, except for those invertebrate eggs and organisms that were attached to debris. Most organisms collected by the plankton net fell within the size range of 0.5 to 50 mm, which spans three orders of magnitude and includes mesozooplankton (0.2 to 20 mm) and macrozooplankton/micronekton (> 20 mm). Zooplankton were also categorized into three groups based on how dependent they are on a planktonic existence:

- holoplankton are planktonic throughout their life cycle (e.g., calanoid copepods);
- meroplankton are planktonic during the early stages of their life cycle (e.g., larval decapods and ichthyoplankton); and
- demersal zooplankton are the animals that live in or just above the sediment-water interface and undergo diel vertical migrations into the water column (e.g., amphipod crustaceans) to facilitate feeding, reproduction or dispersal.

The fish fauna that was collected included planktonic eggs, ichthyoplankton, as well as the juveniles and adults of smaller fish species. Where possible and appropriate, fish specimens were categorized and enumerated into one of five developmental stages, which included eggs, three larval stages, and juveniles. More complete information on the field sampling, laboratory protocols, and the taxonomic and aging conventions employed can be found in Peebles et al. (2006).

6.4.3 Plankton Catch Composition

Detailed catch statistics (abundance, frequency of occurrence) are provided by Peebles et al. (2006) for all vertebrate and invertebrate taxa collected by the plankton surveys. The most abundant ichthyoplankton and nekton in plankton net samples included bay anchovies (*Anchoa mitchilli*) several species of gobies, and the soleid flatfish commonly known as hogchoker (*Trinectes maculatus)*. The bay anchovy (*Anchoa mitchilli*) was the most abundant fish in the plankton catch, a pattern which has been observed in all other rivers in the region by the aforementioned studies. The fourth most abundant juvenile in the Lower Myakka plankon samples were those of an exotic callichthyid (armored) catfish *Hoplosternum littorale*.

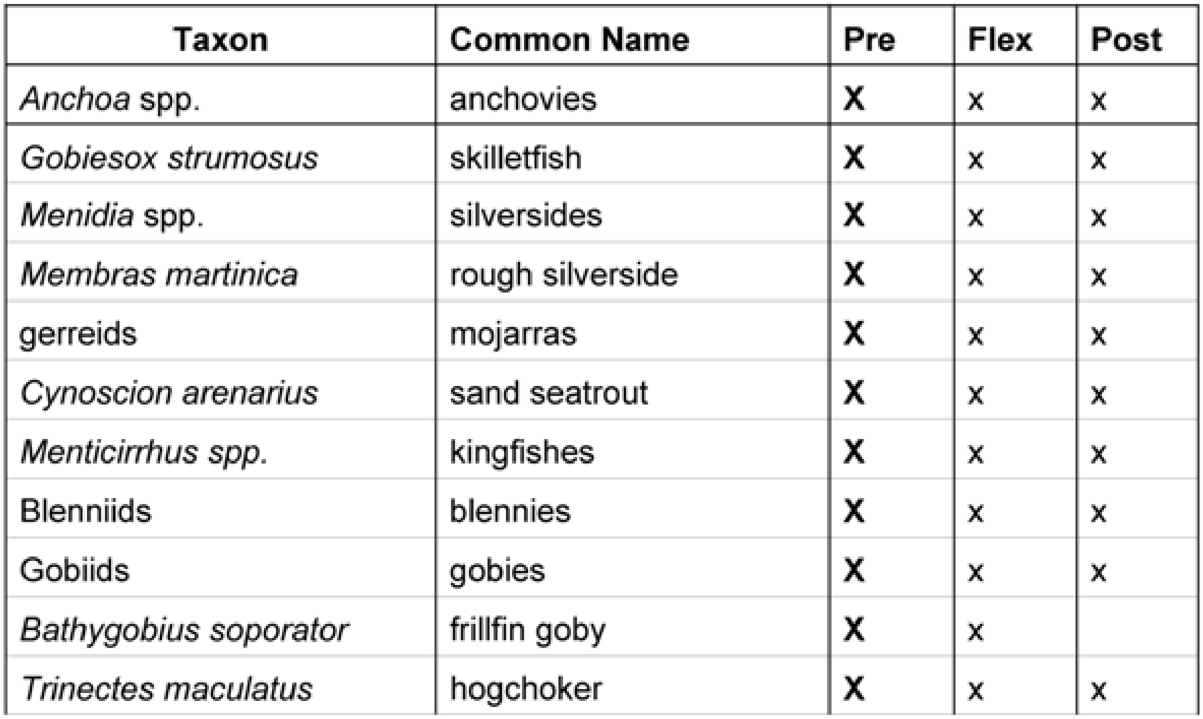
The most abundant groups of invertebrate plankton included meroplankton (decapod larvae) and demersal zooplankton (cumaceans and Gammaridea). Other abundant taxa included *Americamysis* spp. (Mysidacea), *Acartia tonsa* (Copepoda), and the larvacean *Oikoleura dioica* (Peebles et al. 2006).

6.4.4 Spawning Areas Indicated by the Plankton Catch

Fishes that spawn very near or within the lower river are indicated by the presence of eggs or early stage larvae in the plankton catch. Percomorph eggs, the most abundant of the fish life stages, had a center of abundance at RK 8.6 and a weighted mean salinity of 22.6. These are likely sciaenid eggs (Peebles et al. 2006) Several sciaenid species are known to spawn near the mouth of the Myakka River, either from hydroacoustic surveys or by the collection of early stage larvae (Peebles et al. 2006).

Engraulid eggs, representing *Anchoa mitchilli* and *Anchoa hepsetus,* were also abundant near the mouth of the Myakka River. The presence of other fishes likely to spawn near or within the lower Myakka River are summarized in Table 6-13. Several of these taxa (e.g., atherinids and gobies) produce demersal or adhesive eggs, and only the presence of pre-flexion larvae in plankton samples would indicate local spawning.

Table 6-13. Relative abundance of larval stages for non-freshwater fishes with a collection frequency > 10 for the larval stage aggregate, where Pre = preflexion (youngest larval stage), Flex = flexion (intermediate larval stage) and Post = postflexsion (oldest larval stage). X indentifies the most abundant stage and x indicates that the stage was present, reprinted from Peebles et al. (2006).



Taxon	Common Name	Pre	Flex	Post
Anchoa spp.	anchovies	**X**	x	x
Gobiesox strumosus	skilletfish	**X**	x	x
Menidia spp.	silversides	**X**	x	x
Membras martinica	rough silverside	**X**	x	x
gerreids	mojarras	**X**	x	x
Cynoscion arenarius	sand seatrout	**X**	x	x
Menticirrhus spp.	kingfishes	**X**	x	x
Blenniids	blennies	**X**	x	x
Gobiids	gobies	**X**	x	x
Bathygobius soporator	frillfin goby	**X**	x	
Trinectes maculatus	hogchoker	**X**	x	x

6.4.5 Seasonality in Plankton Species Richness

The numbers of taxa present in both the ichthyoplankton and the invertebrate zooplankton generally increased from a winter low to a spring maximum, followed by a decline through the late summer to the winter (Figure 6-30). Underlying this general seasonal pattern were species specific abundance cycles. For example, bay anchovies were present throughout the year and menhaden (*Brevoortia* spp.) and red drum *(Scienopd occellatus)* recruit to the river during fall and winter. The authors thus concluded that through the spring is a time of high species richness, there is no time of year when the recruitment of early life stages of some important species are not be affected by freshwater inflows

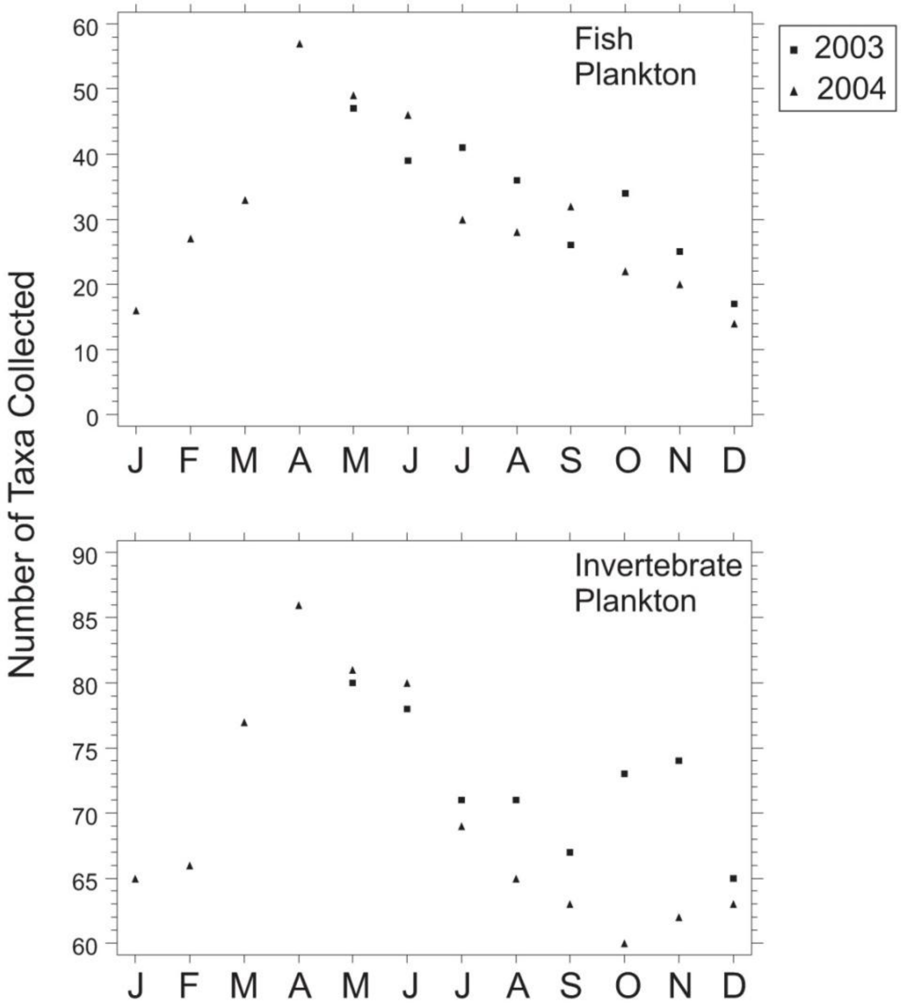


Figure 6-30. Number of fish and invertebrate taxa collected per month in plankton tows from the Myakka River and Myakkahatchee Creek (combined) during 2003-2004.

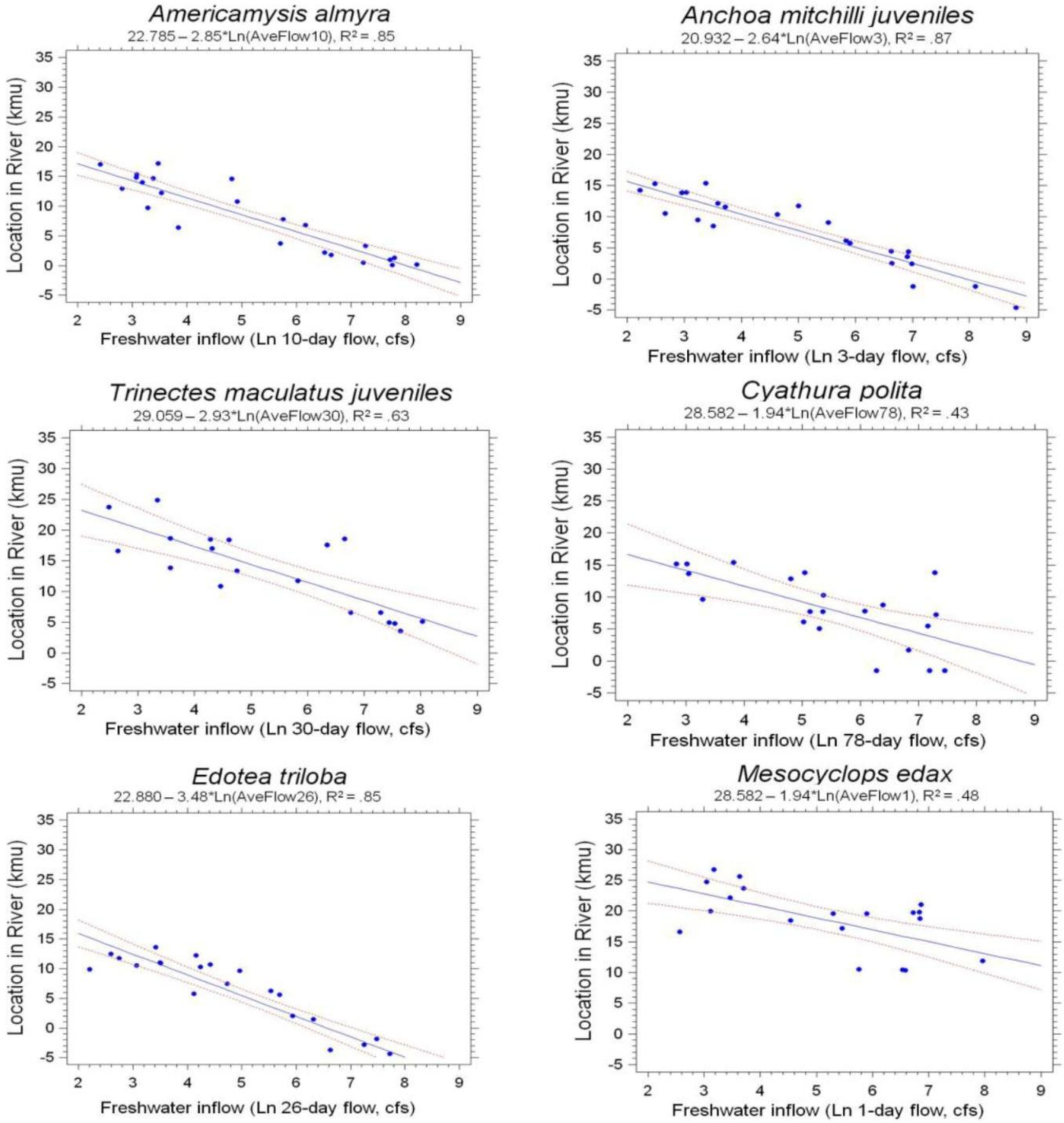
6.4.6 Distribution Responses to Inflow

In a report on the Alafia River, Peebles (2005a) summarized a review by Young (1995) that discusses dispersal and position control mechanisms used by small aquatic organisms. Many animals exhibit behaviors that allow them to regulate their position along the estuarine gradient, which allows them to optimize the combination of food availability, physiological costs, and predation risk. The holoplankton appears to be the least adept at controlling their position and are easily transported by prevailing water currents. Meroplankton and the demersal zooplankton may show migrational responses to variety of directional cues, such as light, gravity, water currents or salinity. Non-directional responses are also used, including response to changing pressure in response to water depth due to tides.

Estuarine organisms may use combinations of these signals to selectively occupy a tidal stream (incoming or outgoing) that will result in their rapid transport to a preferred habitat or food source (e.g., anchovy larvae; Schultz et al. 2000). Organisms that use selective tidal steam transport or two layered circulation are capable of repositioning themselves within the tidal river within hours or days. On the other hand, larger fishes and crustaceans may simply swim toward preferred habitats. The migrations to low salinity habitats as juvenile stages that are illustrated in Figure 6-28 likely result from these fishes gaining stronger swimming ability as they undergo ontogenetic changes from larval to juvenile stages.

Peebles et al. (2006) examined relationships between the distribution of fish and invertebrate species collected in plankton tows and freshwater inflow. Significant linear responses were found for 41 taxa of fishes and invertebrates. Distribution was quantified as Km_U, or the density weighted center of catch per unit effort, expressed in river kilometers. Regressions were then developed to predict Km_U as a function of freshwater inflow using data from the 20 plankton surveys. Forty of the 41 significant relationships in the Myakka River were negative (higher flow results in lower Km_U value closer to river mouth). Thus, as flows increased these organisms were displaced downstream. Conversely, when flows declined populations of these taxa migrated upstream through a variety of transport mechanisms.

As part of the additional plankton sampling of the lower river in 2008, regressions of Km_U were recalculated for nine key taxa related to the District's inflow assessment, including freshwater taxa and estuarine resident and estuarine dependent species (Peebles 2008). Regressions for six of these taxa are shown in Figure 6-31. As is described in Chapters 7 and 8, more emphasis was put on the Km_U results for the taxa captured by the plankton, due to the wider range of flows that were encountered with the additional sampling in 2008 and less confounding effects of habitat variability compared to seine and trawl samples.



Americamysis almyra

Anchoa mitchilli juveniles

Trinectes maculatus juveniles

Cyathura polita

Edotea triloba

Mesocyclops edax

Figure 6-31. Relationships of location of center of catch per unit effort (Km_U) vs. freshwater inflow for six fish and invertebrate taxa captured by plankton net in the Lower Myakka River. The gage in the flow term for *Mesocycops edax* is the Myakka River near Sarasota. The sum of flows at that gage and the Big Slough (Myakkahatchee Creek) at Tropicaire Blvd. is the flow term for the other taxa.

Shifts in Km_U resulting from reductions in freshwater inflow could result in a loss of recruitment or abundance if a population shifted away from what are most desirable habitats for that species. In most regions of the lower river, the area and volume of the segments of the river decrease progressively upstream (Figures 3-2 and 3-6). The upstream movement of a population due to large flow reductions could therefore compress that population into smaller regions of the tidal river with less habitat area and volume. As described in Chapters 7 and 8, shifts in Km_U were used as an ecological indicator in the determination of minimum flows for the Myakka River.

6.4.7 Abundance responses to inflow

Peebles also evaluated the response of the total abundance of species captured in the plankton catch to freshwater inflow. Using a spreadsheet that quantified the volume of the river in close-interval segments, the catch density in each plankton tow for a given species was extrapolated to the volume of river segment from which it was collected, adjusting the volume for tide stage and at the time of the catch. These values were then summed for the entire river to produce a total abundance estimate for the river on that sampling date. Because the plankton tows were conducted with such high spatial frequency along the longitudinal axis of the river, this method probably accounted well for changes in abundance along the length of the river. However, it did make the assumption that mid-channel catch densities were representative of areas closer to the river shore.

Total abundance numbers calculated for the sampling dates were then regressed against freshwater inflow terms of varying length. Both positive and negative responses to inflow were observed for various species. Peebles describes three types of mechanisms for positive inflow responses to inflow that can appear in time series data; catchability, recruitment, and stock response mechanisms. The first step in detecting the likely mechanism behind a positive response is identification of the time scale of the response, examples for which are illustrated in Figure 3.8.3 of Peebles (2005a). Catchability response involves the shortest time scales, as animals may redistribute themselves into the surveyed area from upstream areas or from marshes on the edge of the channel. Numbers simply increase because the animals' redistribution causes them to be more likely to be collected. Peebles suggests that catchability responses are not true abundance responses and are not of interest to resource managers, unless they involve the delivery of individuals to areas of critical habitat.

Recruitment responses take longer to become evident in the catch data. These responses can result from increased reproductive output by the parent generation and/or improved survival of the spawned progeny. The hallmark of a recruitment response is a time lag in the correlation with inflow that is similar to or within the age of the catch. The ages of animals in the plankton net catch for the Myakka River and Myakkahatchee Creek are highly variable, but the vast majority are less than four months old.

Stock response relates to the dynamics of the parent stock, as this has an obvious, but highly variable impact on recruitment. If the parent stock responds favorably to inflow, then an inflow response may result that is scaled to the age of the parent stock. The method of evaluating mean inflow effects by using progressively longer inflow periods will detect both reproductive and survival responses. However, there are many complicating factors in these relationships, which are discussed by Peebles (2005a). Peebles et al. (2006) examined a range of preceding time periods for the inflow terms used in the inflow analysis for each species, and the positive correlations observed in the Myakka River and Myakkahatchee Creek catch data appear to be genuine positive responses of animal abundance to freshwater inflow.

Peebles et al. (2006) produced linear relationships between the abundance of 51 plankton taxa and streamflow in which the relationships were statistically significant. Both freshwater inflow and species abundance were transformed to the natural logarithm (ln). Twenty-three of these responses were positive, meaning the abundance of the taxon increased with increased with freshwater inflow. Sixteen of these positive responses were freshwater taxa, while seven were estuarine resident or estuarine dependent species. Freshwater inflow tends to introduce freshwater animals into the tidal portion of the river from upstream areas, increasing their number in the tidal river and yielding positive slopes. These regressions typically had small intercepts, because the numbers of these freshwater species were small when inflows were low. Conversely, species that invade the river from the bay during low inflow periods have relatively large intercepts, as their numbers are maximum when flows are low. These organisms move away from the river during high inflow periods, giving them a negative correlation with flow.

The estuarine taxa that has positive response slopes in the plankton catch included bay anchovy adults, two stages of hogchoker, two stages of *Americamysis* mysid shrimp, juvenile silversides (Menidia), and an isopod (*Cyathura polita*). Peebles et al. (2006) suggested that the response time of *Menidia* and *Cyathura* in the plankton catch were too short to reflect a true population response, but the flow responses of the bay anchovy, hogchoker, and *Americamysis* were of durations that were commensurate with improved reproductive output or growth and survival.

The District requested that Peebles revisit the abundance regressions for nine key taxa by including the samples collected from the river during 2008. Since the initial 2003-2004 sampling period was unusually wet, the 2008 samples provided valuable data during low flows, which improved the regressions from what were presented in the original report. Reanalysis of the response for *Cyathura* and *Menidia* found that longer flow terms were significant, indicating a true population response. Also, regressions were developed for freshwater taxa using only the flow at the Myakka River near Sarasota gage as the independent variable, since populations of these taxa are usually centered above the confluence with Myakkahatchee Creek.

The abundance regressions for three estuarine taxa and one freshwater taxon captured in the plankton that were presented by Peebles (2008) are shown in Figure 6-32. The regressions for the estuarine taxa were among those utilized in the determination of minimum flows for the Lower Myakka River, and greater details on the statistical properties of the abundance-inflow regressions and their application to the minimum flow analysis are discussed in Chapters 7 and 8.

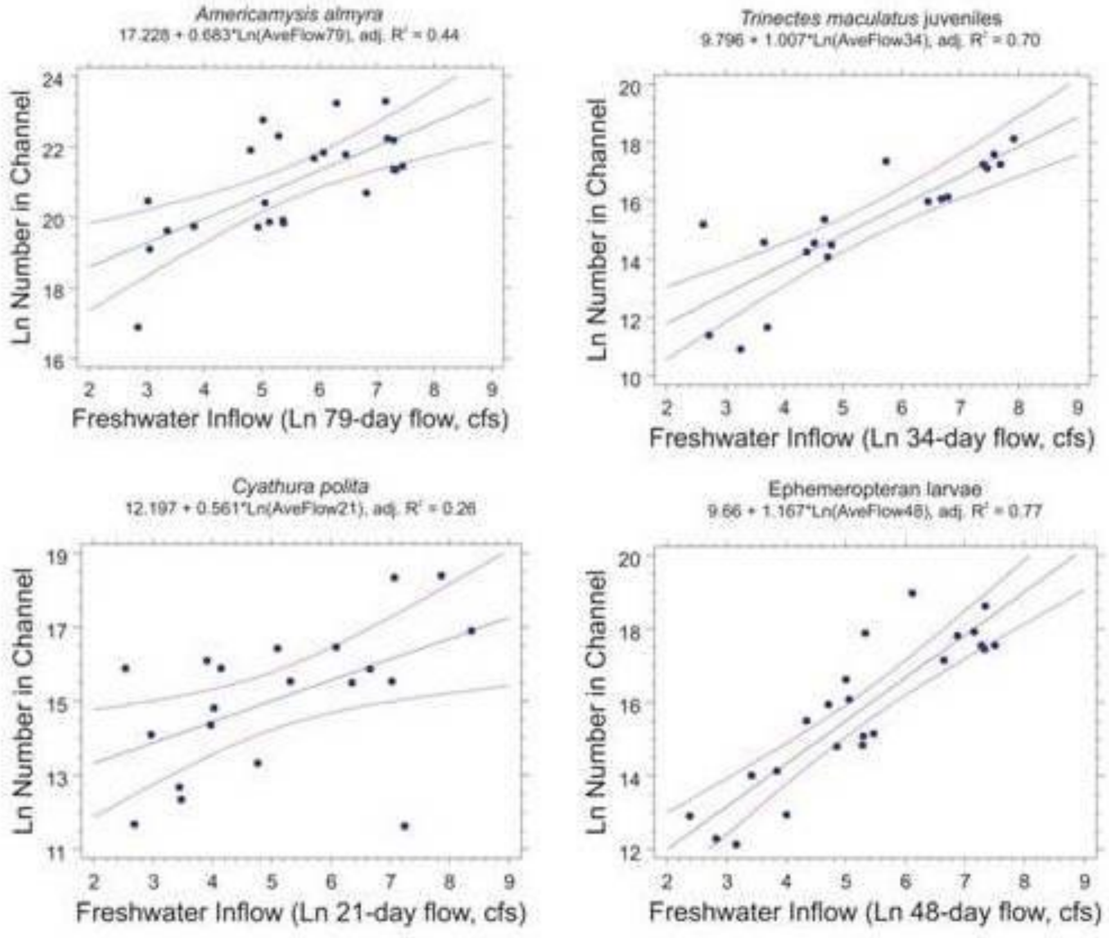


Figure 6-32. Relationships of total abundance vs. gaged freshwater inflow for four fish and invertebrate taxa captured by plankton net in the Lower Myakka River. The gage in the flow term for *Ephemeropteran* larvae is the Myakka River near Sarasota. The sum of flows at that gage and the Big Slough (Myakkahatchee Creek) at Tropicaire Blvd. is the flow term for the other taxa.

6.4.8 Fishes and Selected Macroinvertebrates in Seine and Trawl Surveys

The Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute (FWRI) was responsible for the collection of fishes and selected macroinvertebrates during this investigation of the Myakka River system (Peebles et al. 2006). The FWRI collected finfish and macroinvertebrates using both seines and trawls. The nekton collected by the seines is more indicative of shallow-water habitats and the trawls typically sampled a deeper water habitat near the middle of the river channel. The time periods and sampling zones for the seine and trawl program corresponded with the plankton sampling conducted during 2003 and 2004.

The beach seine that was utilized was 21.3 m with a center bag of 3.2-mm mesh netting and sampled ~68 square meters (m^2). The 6.1-m otter trawl was outfitted with a tickler chain to increase sampling efficiency for demersal species. The net was of 38-mm mesh with a 3.2 mm mesh liner. The trawl was towed for ~180 m at ~0.6 m sec^{-1}, thereby sampling ~720 m^2 (Peebles et al. 2006). Abundances are expressed as catch per unit effort (CPUE) in numbers per 100 m^2.

Both sampling gears tend to primarily collect small fish, either adults of small bodied species or juveniles of larger taxa. Trawls tend to catch larger fish than seines, and whether this is due to gear characteristics or preferred use of channel habitat by larger fish is uncertain. Greater details on field sampling and sample processing methods can be found in Matheson et al. (2005). The analysis by FWRI for the District had four objectives:

- to assess the composition of the nekton (finfish and selected macroinvertebrates) community in 2003-2004;
- to examine habitat use for selected species of economic or ecological importance;
- to analyze movement and relative abundance of nekton populations in relation to the quantity of preceding freshwater inflow; and
- to examine relation of freshwater inflow and physical-chemical gradients to fish community composition.

6.4.9 Composition of the Seine and Trawl Catch

The six most abundant fishes in the seine hauls accounted for >85% of the total catch:

- *Anchoa mitchilli*
- *Menidia spp.*
- *Gambusia holbrooki*
- *Leiostomus xanthurus*
- *Eucinostomus spp.*
- *Trinectes maculatus*

Five species of fishes made up almost 94% of the total trawl catch:

- *Anchoa mitchilli*
- *Trinectes maculatus*
- *Cynoscion arenarius*
- *Leiostomus xanthurus*
- *Menticirrhus americanus*

Two species of grass shrimp, *Palaemonetes pugio* and *Palaemonetes intermedius* comprised >85% of the invertebrates collected in the seines, with *P. pugio* being dominant. Pink shrimp (*Farfantepenaeus duorarum)* and blue crab (*Callinectes sapidus)* made up >98% of the trawl catch.

6.4.10 Distribution, Seasonality, and Habitat Relationships of Selected Species

Six species were selected for detailed analysis of their distribution in the Myakka River based on their high abundance in the river or recreational or commercial importance:

- *Farfantepenaeus duorarum*
- *Callinectes sapidus*
- *Anchoa mitchilli*
- *Cynoscion arenarius*
- *Cynoscion nebulosus*
- *Menticirrus americanus*

Information presented by Peebles et al. (2006) for each of these species pertained to their seasonality, size class frequency, and distribution by salinity range, river zone (kilometers) and shoreline habitats. Life history information was also presented for seventeen of these species. Example plots taken from seine catches for three important fish and invertebrate species in the river are reprinted from Peebles et al. (2006), which can be consulted for plots for other species.

Bay anchovy (*Anchoa mitchilli*) were more abundant during both spring and late fall and least abundant in January, August, and September (Figure 6-33). They were most abundant in Myakahatchee Creek and least abundant in the river above the confluence with the creek. Anchovies were most often collected in mesohaline salinities and were rare in limnetic habitats. More anchovies were collected along hardened shorelines than any other habitat. This may be an artifact since it may be easier to catch fish along hardened shorelines (cf. Matheson et al. 2005).

The hogchoker (*Trinectes maculatus*) is common estuaries and is among the most abundant species in the upper portions of tidal rivers (Peebles and Flannery 1992, Greenwood et al. 2004, Wagner and Austin 1990). Hogchokers were present year-round, with a distinct July maximum (Figure 6-34). Hogchokers in shoreline habitats captured by seines were most abundant in the Myakka River above the confluence with the creek, with CPUE increasing as salinity decreased. Daggerblade grass shrimp (*Palaemonetes pugio*) were most abundant in the lower river below the confluence with Myakkahatchee Creek in low mesohaline salinities and mangrove habitats.

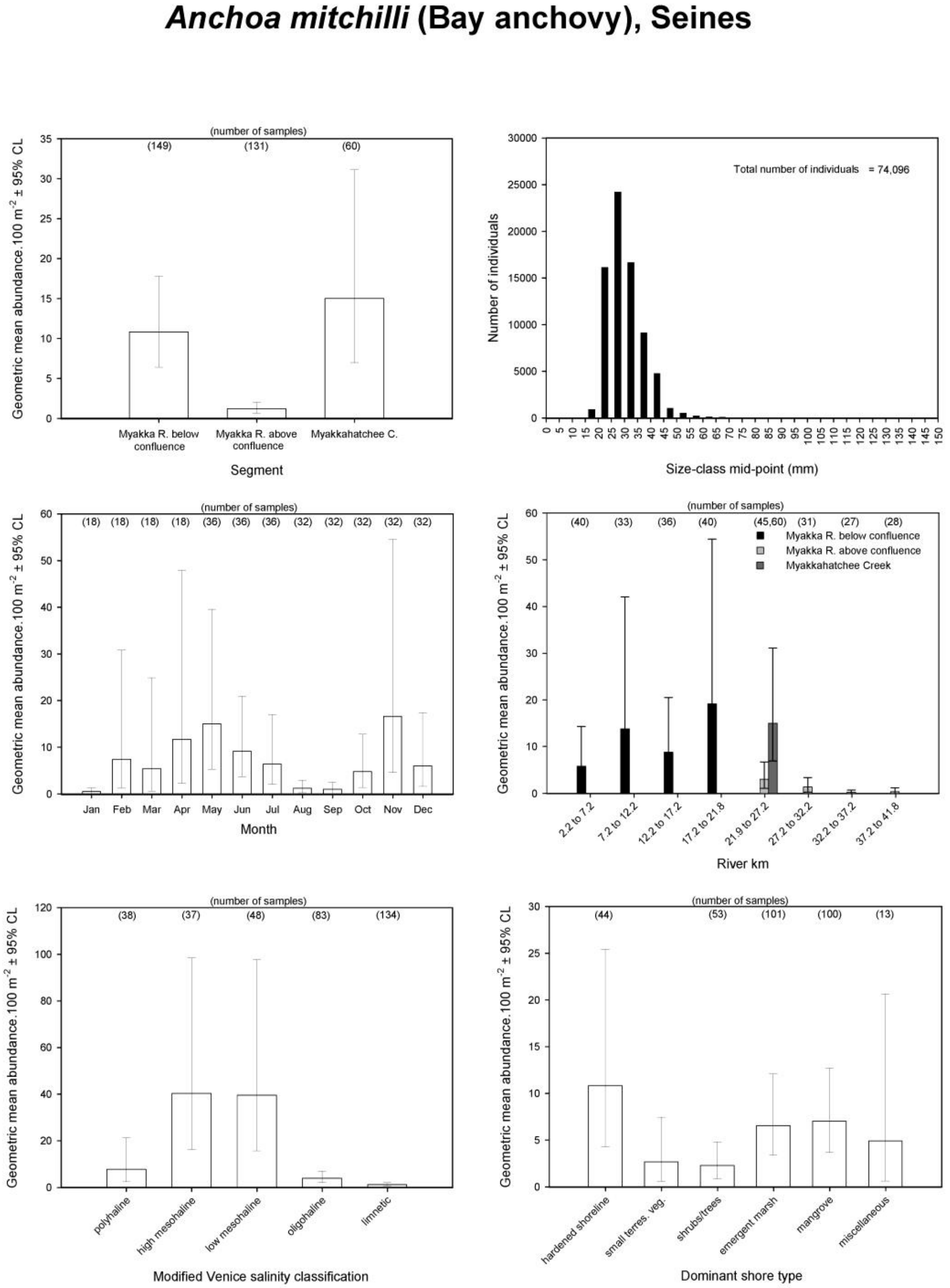


Figure 6-33. Abundance of bay anchovy, *Anchoa mitchilli*, in nearshore habitats (seine samples) by month, size class, river zone, salinity range, and shoreline habitat (reprinted from Peebles et al. 2006).

***Trinectes maculatus* (Hogchoker), Seines**

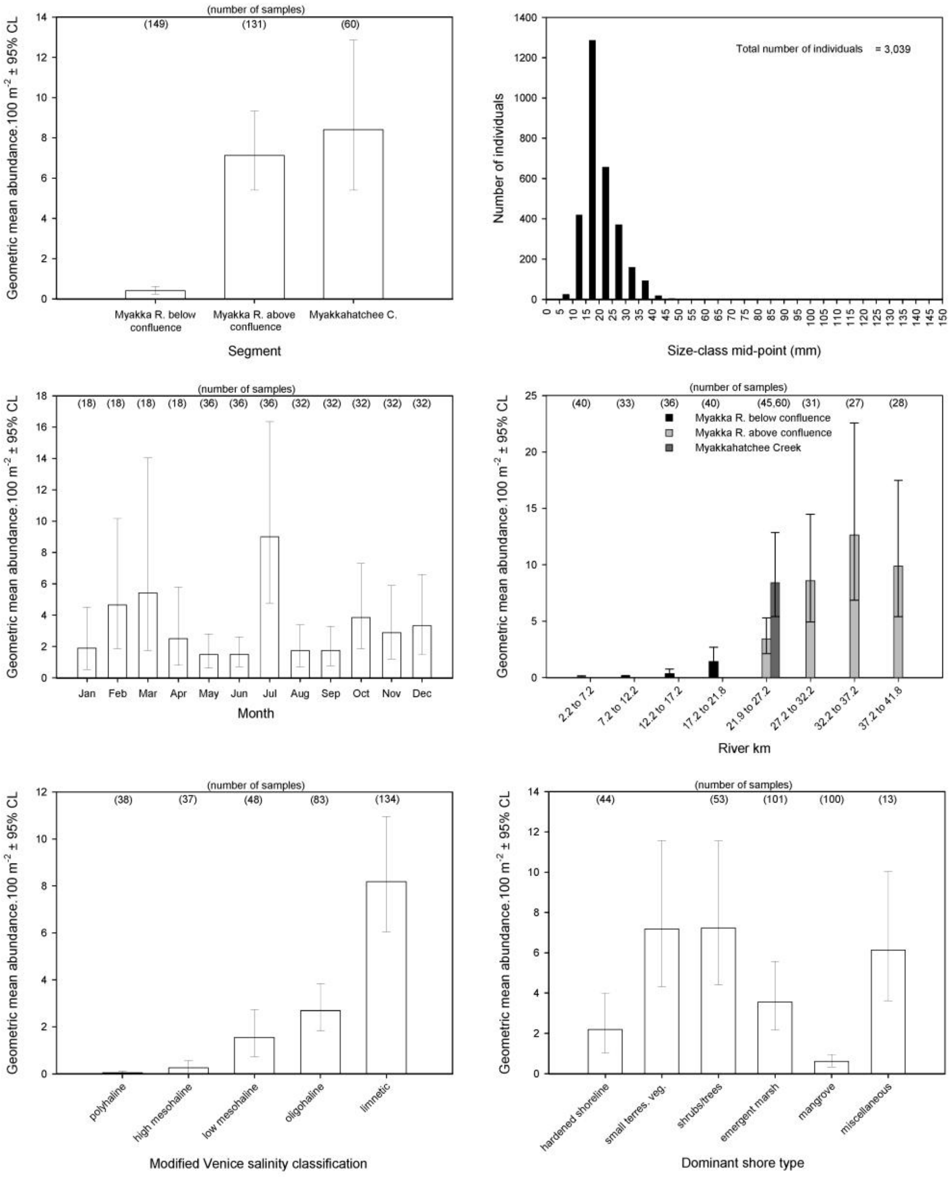
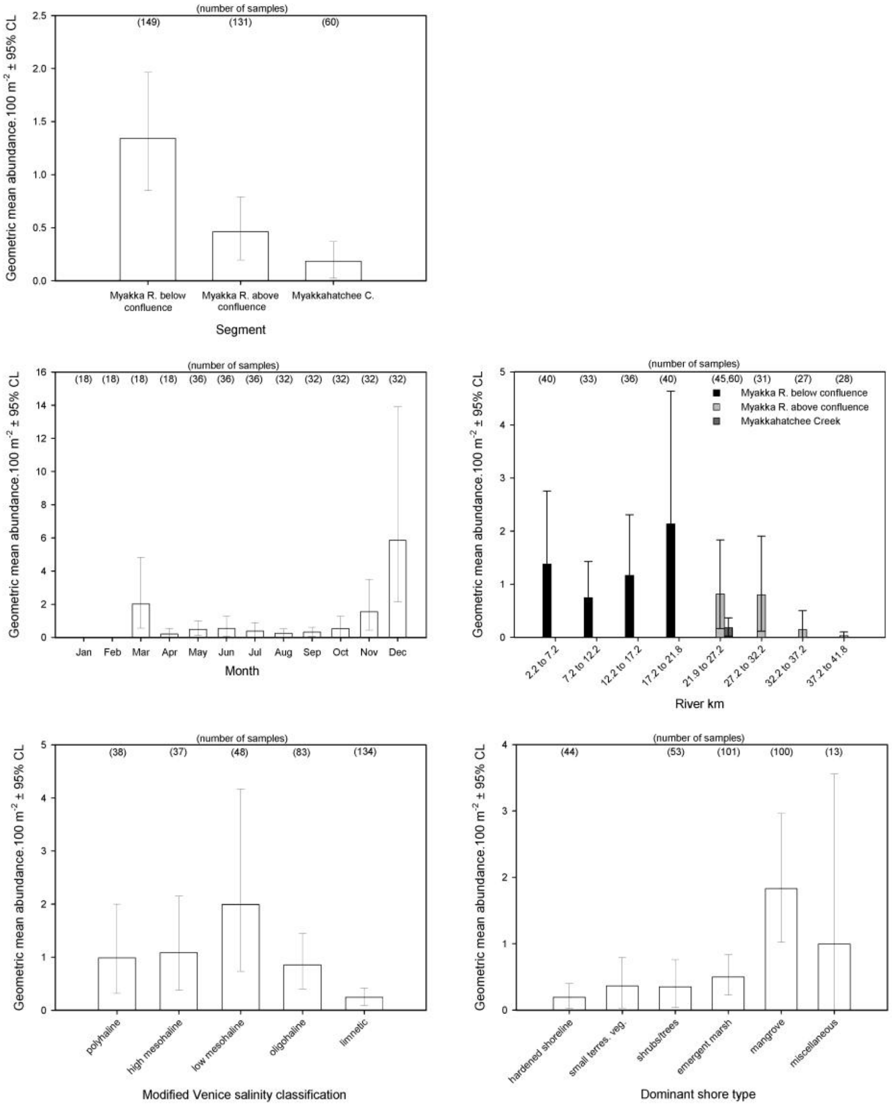


Figure 6-34. Abundance of hogchoker, *Trinectes maculatus*, in nearshore habitats (seine samples) by month, size class, river zone, salinity range, and shoreline habitat (reprinted from Peebles et al. 2006).



***Palaemonetes pugio* (Daggerblade grass shrimp), Seines**

Figure 6-35. Abundance of daggerblade grass shrimp, *Palaemonetes pugio*, in nearshore habitats (seine samples) by month, size class, river zone, salinity range, and shoreline habitat (reprinted from Peebles et al. 2006).

6.4.11 Regression Analyses of the Distribution of Species in the Seine and Trawl Catch

Peebles et al. (2006) examined the response of the spatial distribution of many species in the river to freshwater inflow. These relationships were examined separately for different age and size classes of some species to account for possible ontogenetic (growth related) changes in the response to inflow. The term pseudo-species was used by Peebles et al. (2006) to describe a specific size class for a given species captured by seine or trawl. Population distributions for pseudo-species were again estimated by calculating Km_U, which is a density weighted center of CPUE for each sampling trip. This parameter does not describe the variability of a population about the mean, but does provide useful information on what location in the river the population distributed about on a given day and set of inflow conditions.

Linear regression of Km_U against freshwater inflow were examined for the 82 pseudo-species captured by seine or trawl, of which over half exhibited significant distributional responses with freshwater inflow. Both the Km_U and inflow terms were ln-transformed in the models, and inflow terms of different preceding lengths were examined. The relatively short duration of the seine and trawl sampling (20 months in the river) limited the range of flow conditions. Due to cost constraints, seine and trawl sampling was not reinstated during the low flows during 2008, as was the plankton. Consequently, the predictive ability of these relationships for the seine and trawl samples is more limited.

Over 72% of the best-fitting significant responses were negative, indicating downstream movement in response to increasing freshwater inflow. FWRI suggested various reasons that some positive relationships were reported, and suggested that some of those relationships might be spurious or overly influenced by outlying data points. Using various inflow terms of different lengths, the best r^2 values for the different pseudo-species ranged from 22% to 92%. Pseudo-species with r^2 >50% were more typical of estuarine dependent and estuarine resident species. Examples of distributional response for four pseudo-species with freshwater inflow are shown in Figure 6-36.

The response of Km_U for seven pseudo-species to baseline flows and a series of potential freshwater flow reductions are presented in Chapter 8. Pseudo-species were selected for analysis based on their ecological importance and the presence of significant regressions with comparatively high r^2 values. It was concluded that among the taxa captured by seine or trawl, these pseudo-species would provide the most meaningful and reliable estimates of the effects of changes in freshwater inflows on the distribution of fish and invertebrates in the Lower Myakka River.

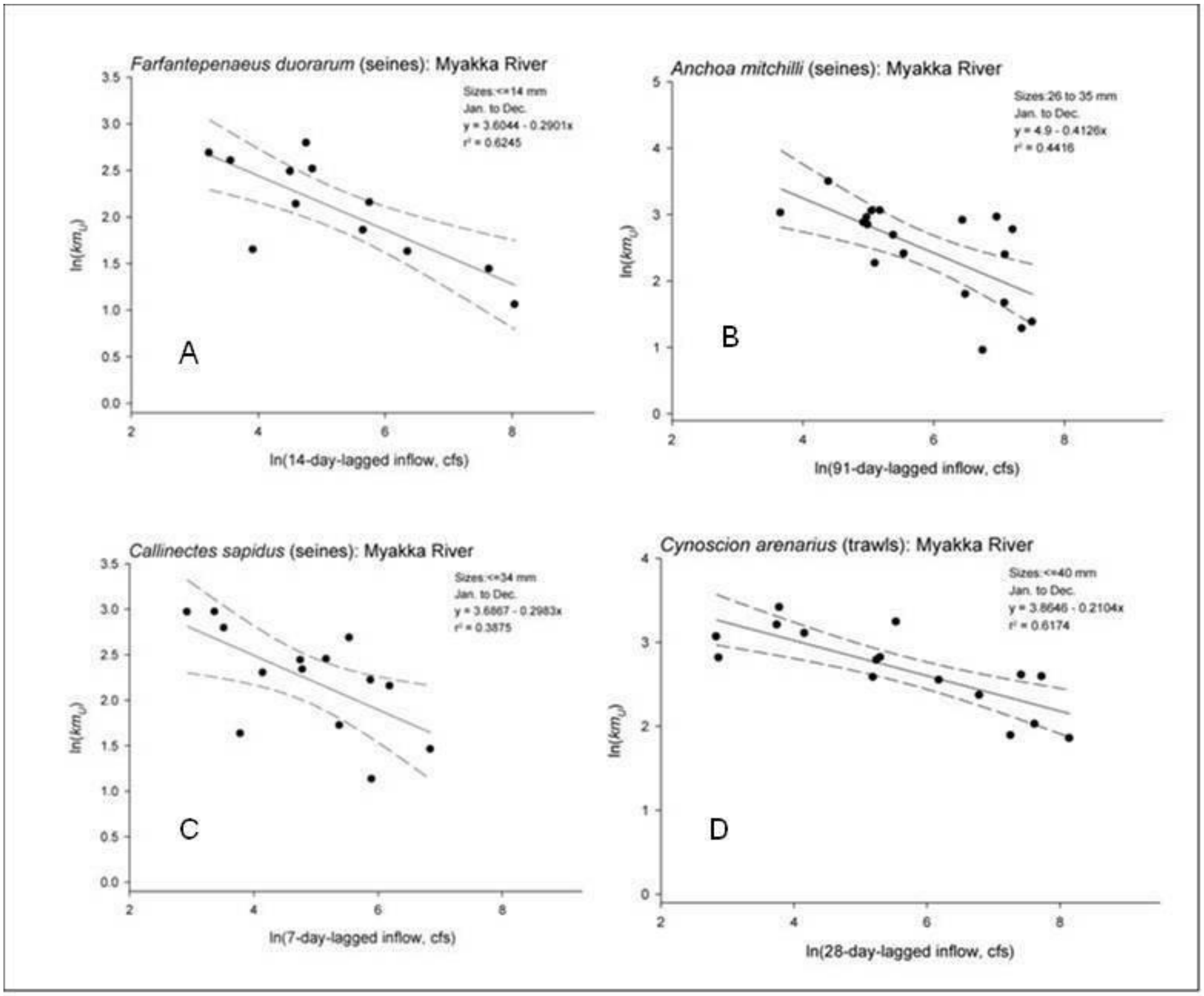


Figure 6-36. Relationship of the population distribution (as Km_U) of four pseudo-species to freshwater inflow in the Lower Myakka River (adapted from Peebles et al. 2006)

6.4.12 Regression Analyses of Abundance Response of Seine and Trawl Catch

FWRI also examined relations between relative abundance (number of animals as CPUE) and freshwater inflow. Regressions were developed for groups of months when each pseudo-species was abundant in the river, including zero abundance values within the corresponding time window. All biological and inflow data were natural log (ln) transformed for analysis. Both linear and nonlinear models were examined to determine the best fit. The non-linear models that produced the best results were quadratic formulae.

Sixty-six of 98 pseudo-species examined had significant relations between abundance and inflow. The best-fitting regression models were linear for 23 pseudo-species and quadratic for 42 pseudo-species. Of the 23 linear models, 61% were negative relationships with increasing abundance with decreasing flow, indicating these pseudo-species move into the lower river during low flows.

The proportion of abundance responses to inflow differ by life-history category: residents contrasted with estuarine and offshore spawners in having more positive responses than negative. The best fitting models tended to incorporate longer lag terms for all life-history categories. The strongest abundance-inflow relationships among resident species were for shoreline – associated species and probably indicated inflow-related changes in catchability. Several estuarine species had maximum abundance had maximum abundance at intermediate flow rates, a pattern that was also observed on the Lower Alafia River (Matheson et al. 2005). Positive linear relationships were reported for most of the freshwater pseudo-species, including *Ictalurus punctatus, Gambusia holbrooki*, and *Labidesthes sicculus*. For these taxa, increased abundance could have resulted from immigration into the study area from upstream freshwater areas upstream of the study boundary near km 36 on the SWFWMD centerline.

In general, the findings of the FWRI seine-trawl effort show important information concerning patterns for the size classes, spatial distributions, and numbers of organisms in the river. However, use of the regressions of abundance and distribution of flow have to be handled with caution due to the limited number of samples and the hydrologic conditions during the two years this program was conducted. In all likelihood, continued seine and trawl sampling in the lower river would strengthen some the relationships observed by FWRI, or in some cases, find that those patterns did not hold.

Some of the predictive relationships documented by FWRI were used in Chapter 8 for the evaluation of minimum flows for the lower river. However, the abundance relationships for some of the taxa collected in the plankton were more robust due to the additional number of samples taken over a wider range of flows. As will be described in Chapter 8, the determination of minimum flows for the Lower Myakka River relied more on the taxa captured in the plankton, than the pseudo-species that were collected by seine or trawl.

Chapter 7

Resources of Concern and Technical Approach for Determining Minimum Flows for the Lower Myakka River

7.1 Overview

The chapter describes the District's technical approach for determining minimum flows for the Lower Myakka River. More specific details on the application of the approach and the findings of the minimum flows analysis are presented in Chapter 8. As described in Chapter 1, minimum flows are defined in Florida Statutes as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." In essence, minimum flows represent the water that can be withdrawn from a river without causing significant harm to the ecological resources associated with that water body.

In determining minimum flows, it is critical to first define the geographic region in which potential impacts are to be evaluated, identify the ecological resources to be protected within that region, describe the analytical methods by which potential impacts to those resources are to be assessed, and identify the amounts of change to those resources that will be considered to be significant harm. How those steps were applied to the Lower Myakka River is described below.

7.2 Geographic Region for Analyses of the Effects of Reductions of Freshwater Inflow

The Lower Myakka River is connected to the larger Charlotte Harbor estuarine system and there are extensive and complex physical, chemical, and biological interactions between the harbor and the lower river. It has been well documented that flows from both the Peace and Myakka rivers can affect salinity, water quality, color, phytoplankton production, and the occurrence of summer hypoxia in the harbor (Montgomery et al. 1991, Stoker et al. 1992, McPherson et al. 1996, Coastal Environmental 1996, McPherson et al. 1996, Camp Dresser and McKee 1998, PBS&J 1999a, Turner et al. 2001, Tomasko et al. 2006). Also, many fish species that spawn in either the nearshore regions of the Gulf of Mexico or Charlotte Harbor migrate into these rivers as early life stages and use the Lower Myakka River as a nursery area (PBS&J 1999a, Peebles et al. 2006).

Withdrawals from the Myakka River could potentially have a significant effect on the freshwater inflow budget and ecology of Charlotte Harbor, particularly the upper harbor above Cape Haze. However, the approach taken for this report is that ecological resources and processes that occur within the river are much more susceptible to change and significant harm than are resources or processes that occur in the harbor. Over most of the river's flow regime, freshwater discharge from the Myakka River watershed exerts a much greater relative effect on the salinity and water quality of the lower river than the upper harbor. Though this may not entirely be the case during very high flows, it is unlikely that withdrawals will represent a high proportion of freshwater inflow during floods.

Similarly, there are distinct biological communities within the tidal river whose distribution, and in some cases abundance, are closely related to the rate of freshwater inflow in the Myakka. It is the District's position that there are sensitive and important ecological resources in the lower river that warrant protection, and in all likelihood, these resources would experience significant harm from freshwater withdrawals before the resources in the harbor. Minimum flows that are developed to protect the ecology of the river, should therefore, be protective of the ecology of Charlotte Harbor.

The analyses conducted for this report support this conclusion, and the geographic region for the resources of concern considered for this minimum flows analysis are within the Lower Myakka River. This approach was also taken for the proposed minimum flows for the Lower Alafia and Lower Peace rivers, which was endorsed by the peer review panel for those reports (Powell et al. 2008, Montagna et al. 2008).

7.2.1 Application of the study design to the minimum flow boundaries

As described in Chapters 4 and 5, data collection for the Lower Myakka minimum flows project generally extended from just below the mouth of the river to near the location of the maximum penetration of brackish water during the dry season. Sampling was thus intended to capture the complete salinity gradient that typically occurs within the lower river. Water quality sampling extended from about 6 kilometers downstream of the designated river mouth upstream to near river kilometer (RK) 34. Sampling for zooplankton and fishes was conducted in seven zones that extended from near RK -4 to RK 35. Benthic macroinvertebrate samples extended from RK -3.4 to RK 40. The bottom area and water volume values generated by the District's hydrodynamic model that were incorporated in the minimum flows analysis extended from the river mouth to RK 38.4.

For reasons of practicality and a reduced likelihood of significant harm, the upper limit of the study area did not extend to the upstream terminus of the lower river at the sill on Lower Myakka Lake, which is located near RK 51 (Figure 3-1). Navigability is very difficult above RK 46, making the collection of many data elements difficult. As described in Chapter 2, tidal water level fluctuations extend past Rocky Ford RK 41.6, but not above Downs Dam (RK 46). During very low flows, slightly brackish waters (1 psu) have been documented to penetrate above RK 30, but this is very infrequent (Figs. 4-34 and 4-36).

As a result, the findings of the minimum flows project are most applicable to the reach of the river from the river mouth to just upstream the confluence of the Blackburn Canal (RK 32). Though sections of the river upstream of this reach were not sampled extensively, it is likely that minimum flow recommendations developed for river between kilometers 0 and 32 will also be protective of the reaches further upstream (RK 32 to 51). Since the upstream reach remains almost entirely fresh, reductions of freshwater inflows will have little effect on salinity distributions there. Water levels and current velocities in the upstream reach could be affected by reductions of inflow, but as will be discussed in Chapter 8, the proposed minimum flows are very close to the flows the river received before the augmentation of streamflow in the upper river sub-basin began in the 1970s.

As described in Section 2.4.1.1, three new streamflow gages have been in operation in the lower river between the Blackburn Canal and the Lower Myakka Lake since 2007. Data collection at these streamflow gages will allow for the better assessment of the relationship of flows to water levels and velocities in the river above the Blackburn Canal. As discussed in Chapter 8, future analyses are recommended to examine the potential effects of proposed minimum flows on this reach of the river. However, as discussed in Chapter 8, it is reasonable to conclude at this time that the proposed minimum flows should provide a suitable level of protection for the entire lower river below Lower Myakka Lake.

7.3. Exclusion of Myakkahatchee Creek

Potential impacts to ecological resources within the tidal portion of Myakkahatchee Creek were not considered for the analysis of minimum flows for the Lower Myakka River and minimum flows specifically for Myakkahatchee Creek are not proposed in this report. As will be discussed in later Sections, the effects of City of North Port's withdrawals from Myakkahatchee Creek on the ecological resources of the Lower Myakka River (excluding the creek) were evaluated as part of the minimum flows determination for the lower river, and the effects of the City's maximum permitted withdrawals on the lower river are very small.

The tidal portion of Myakkahatchee Creek is 4.2 kilometers long and joins the Myakka River 15.1 kilometers above the river mouth. The area and volume of Myakkahatchee Creek are equal to 3.5% of the area and 3.1% of the volume of the Lower Myakka River (not including the creek), below a reference elevation of 0.48 meters NGVD. In contrast to the lower river, the tidal reach of Myakkahatchee Creek has been highly altered, as the stream channel was dredged and straightened and much of the creek's southern bank has been hardened by seawalls and suburban development. Water control structure 101 truncates the tidal portion of the creek, creating a barrier that acts to eliminate tidal freshwater, oligohaline and much of the mesohaline habitat in the creek in the dry season (PBS&J 2009). Because of the relatively small amount of habitat in the creek compared to the river and the altered condition of the creek habitat, the District concluded that the evaluation of significant harm and determination of minimum flows for the Lower Myakka River could exclude consideration of habitats and communities in the creek at this time.

There have been previous and ongoing data collection activities in the tidal reach of Myakkahatchee Creek. The report by Peebles et al. (2006) presented interpretative analyses of 15 months of sampling for zooplankton and fishes within Myakkahatchee Creek. Mote Marine collected benthic macroinvertebrates at four locations in the creek as part of the dry season 2004 data collection effort in the Myakka River. Some limited interpretive analyses of these data were presented in a report submitted by the City of North Port as part of the renewal of their water use permit in 2006 (PBS&J 2006a).

Data for salinity and water quality in the creek have been collected since July 2004 by the City of North Port as part of the conditions of their water use permit. The City recently submitted an interpretive report of the findings of this monitoring program from its inception through June 2009 (PBS&J 2009). This report characterizes the gaged flows and withdrawal from the creek,

water quality conditions in the creek including relationships to freshwater inflows, and empirical models to predict salinity at various locations in the creek as a function of freshwater inflow.
The 2009 monitoring report was the first interpretive analysis that incorporated flows from the new USGS gages at Myakkahatchee Creek (a.k.a. Big Slough Canal) at West Price Boulevard and the Cocoplum Waterway. However, the period over which these gages had been operating was fairly dry. As described in Section 2.4.1.1, continued data collection at these gages allow for much improved evaluation of flows to the tidal creek, largely because flows for Cocoplum Waterway are now available.

Utilizing data from these new streamflow gages and the continued data collection that is being conducted by the City of North Port, it is recommended that minimum flows for Myakkahatchee Creek be established within five years. This time frame will coincide with the schedule re-evaluation of minimum flows for the Lower Peace River. As discussed in Chapter 8, future minimum flows assessments of both the Lower Peace River and Myakkahatchee Creek can incorporate improvements to the District's hydrodynamic model of the Upper Charlotte Harbor – Lower Peace River – Lower Myakka River system. Also, new biological data collection in Myakkahatchee Creek and the Lower Myakka River should be included in the minimum flow study for Myakkahatchee Creek. At present, however, not having minimum flows established for Myakkahatchee Creek should not hinder the establishment of minimum flows for the Lower Myakka River in the year 2010.

7.4 The Determination of Baseline Conditions: Relevance of Structural Alterations and Changes to the Lower River's Flow Regime

The determination of minimum flows for the Lower Myakka River accounted for historic alterations to the river's flow regime. The most significant of these alterations fall into two categories. The first being physical re-routing of Cowpen Slough and the construction of the Blackburn Canal, both of which acted to reduce flows in the Lower Myakka River. The second alteration is the changes in land and water use in the upper river sub-basin which have acted to increase flows to the lower river.

As described in Chapter 1, Florida Statues specify that Florida's Water Management Districts are to consider changes and structural alterations to watersheds, surface waters, and aquifers when establishing minimum flows. The District took this approach by evaluating the effects of modifications to both Cowpen Slough and the Blackburn Canal. Though estimates of increased flows to Dona Bay were modeled as part of the determination of minimum flows for Shakett Creek (SFWMD 2009), the quantity of streamflow that was historically lost to the Myakka River by the modification of Cowpen Slough has not been simulated. It is known that amount of drainage area lost from the Myakka River was equal to about 10% of the river's current watershed area, thus reductions in flows at least during some times of year may have been significant. However, as evidenced by gaged sub-basins in the Myakka River watershed, discharge from the Cowpen Slough basin probably had very low rates of baseflow, with large differences between dry and wet season flows.

Data collection in the Blackburn Canal since 2004 has allowed for the quantification of the effects of that canal on the river's flow regime. These data have shown that although bi-directional flow in the canal sometimes occurs, the canal primarily acts to divert water away from the Myakka River. Based on streamflow data from the USGS and Sarasota County gages, which began in 2004 and 2005 respectively, average flows in the canal at these two gages have equaled 11.5 and 18.7 percent of the average flows for the Myakka River near Sarasota gage for the corresponding periods. However, the rate of diversion from the river by the canal is not linear, and appears to increase as flows at the Myakka River near Sarasota gage rise above about 400 to 500 cfs (Figure 2-13).

An opposite effect has been observed in the upper river sub-basin, where a number of studies have documented an increase in flows in the tributaries and channel of the upper river (Coastal Environmental 1998, PBS&J 1999b, SWFWMD 2005a, Interflow Engineering 2008b). Development of a detailed MIKE SHE integrated ground water/ surface water model has allowed for the estimation of excess water the lower river receives due to land use changes in the upper river sub-basin. The model was run for the period May 15, 1994 through April 30, 2006. Based on model output generated in late 2008, the total excess flows due to all land use changes was equal to 17% of the gaged flow at the Myakka River at Sarasota gage during this period. Monthly average values for excess flows ranged from 6% of the gaged flow during November to 43% of the gaged flow in May.

To some extent, the effects of the alterations to Cowpen Slough and the Blackburn Canal on reducing flows to the lower river have been counteracted by the increased flows the river receives due to land use changes in the upper river sub-basin. These two opposing hydrologic effects have resulted in the existing flow regime for the Lower Myakka River, which for practical purposes, has been in effect since the late 1970s.

Based on the factors described above, the District chose to use the existing flow regime of the Lower Myakka River as the baseline for assessing the effects of potential flow reductions on the natural resources of the lower river. The Lower Myakka River is considered to be one of the most highly valued natural resources in west-central Florida. As described on page 2-1, various reaches of the lower river are designated as a State of Florida Wild and Scenic River, an Outstanding Florida Waterway, and a State of Florida Aquatic Preserve.

Although the lower river has received increased flows resulting from agricultural land use in upper river sub-basin, data collected from the 1980s to current indicate the Lower Myakka River remains in a healthy ecological condition with generally good water quality. As described in Chapter 4, problems with low dissolved oxygen concentrations primarily occur in the downstream reaches of the lower river during high flows in the summer wet season. Although the increases in freshwater flow surely have increased nutrient loading to the lower river, chlorophyll *a* concentrations in the lower river are still comparatively low compared to other rivers in the region (see data for the Peace, Alafia and Little Manatee Rivers in SWFWMD 2008b). Chlorophyll *a* values in the Lower Myakka seldom exceed 20 µg/l, and the median value for the lower river (5 µg/l) is less than the median chlorophyll *a* value for estuaries in the state of Florida (8.5 µg/l) reported by Friedemann and Hand (1989).

The existing flow regime has had a strong influence on the distribution of biological communities in the lower river, and reductions in freshwater inflow from the existing flow regime would likely result in upstream shifts of many biological communities. As discussed in Section 6.2.6, the current distribution of oligohaline and tidal freshwater marshes in the lower river are related to the location of low salinity isohalines in the dry season. The distribution of these wetlands, which have comparatively high plant diversity and are excellent wildlife habitat, could shift or become more limited if freshwater flows are significantly reduced.

The distribution, and in some cases abundance, of many fish and invertebrate are also influenced by the existing flow regime of the lower river. Reductions in these inflows would cause the distributions of many populations to shift upstream. Based on the information presented by Peebles et al. (2006) and Peebles (2008), it is also reasonable to conclude that the excess flow the river has received after the 1970s has increased the abundance of a number of important species such as mysid shrimp (*Americamysis almyra*) and hogchokers (*Trinectes maculatus*). Reduction of freshwater inflow could reduce the abundance of some key species in the Lower Myakka River from their current population levels. Other studies have shown that the abundance or harvest of many estuarine dependent fishes and invertebrates are often positively correlated with freshwater inflow (Browder 1985, Drinkwater 1986, Wilber 1993, SWFWMD 2008b).

To reiterate, due to the counteracting effect of the hydrologic changes in the Myakka River watershed and the generally good ecological heath of the lower river in its current condition, the District chose the existing flow regime of the river as the baseline for assessing the effects of future withdrawals. For the purposes of the minimum flows project the current status of the Blackburn Canal or Cowpen Slough were not changed. The proposed minimum flows for Cowpen Slough have recommended removing fresh water from that system to improve the ecology of Dona Roberts Bay, but not specifically rerouting it to the Lower Myakka River (SWFWMD 2009). With regard to the Blackburn Canal, future analyses could be pursued to examine the effect of plugging or otherwise modifying the canal so that it does not divert flow from the Lower Myakka River. At this time, however, the District concluded it was appropriate to first determine the minimum flows for the Lower Myakka River using the existing flow regime as the point of reference.

7.5 Flow reduction scenarios in relation to baseline

The effects of removing water from the Lower Myakka River were evaluated by running a series of flow reduction scenarios. Response variables in the estuary were simulated first for the baseline condition, i.e. the lower river's existing flow regime. These response variables were simulated for each successive flow reduction scenario and changes from the baseline were evaluated to determine which flow scenarios did, or did not, constitute significant harm.

The first flow reduction scenario involved simulating the maximum permitted withdrawals from Myakkahatchee Creek that are allowed by the City of North Port's water use permit (see page 2-23). As described in Chapter 8, these relatively small withdrawals have had only minor effects on the resources within the Lower Myakka River.

The next withdrawal scenarios involved diverting the excess flows that were predicted by the MIKE SHE model. Since the excess flows have resulted in documented ecological damage in the upper river sub-basin, management strategies are being developed to remove or reduce these excess flows. Using the existing flow regime of the lower river as the baseline, the question then becomes - what would removal of these excess flows do to the ecology of the lower river? The removal of excess flows were evaluated alone, and in combination with flow reductions resulting from the City of North Port's permitted withdrawals.

The removal or reduction of excess flows could be achieved at a number of locations in the upper river sub-basin. However, for the purposes of determining minimum flows for the Lower river, all removal of all excess flows were applied to flows at the Myakka River near Sarasota gage to integrate the removal of the total excess flow quantities regardless of where they were applied in the upper river sub-basin.

As described in Chapter 8, two methods were used to calculate the excess flow values to be subtracted from the gaged flows of the river. The first was to subtract the modeled excess flows for each day that were taken directly from the MIKE SHE output. The second method was to express the modeled excess flows as a percent of the modeled existing flow on a daily basis, then reduce the daily gaged flows by these same percentages. The first method that used the actual modeled excess flow values proved to be more suitable and was used in the analysis of minimum flows.

The remaining flow reduction scenarios involved diverting different percentages (e.g., 10, 20, 30%) of the remaining streamflow, after removal of the total excess flows and the City of North Port's permitted withdrawals. These percentage diversions were applied to the remaining flows at the Myakka River near Sarasota gage. This approach was taken because it is unlikely that any new proposed withdrawals in the near future will be from the lower river sub-basin. The City of North Port's water use permit is expected to meet their needs through its renewal date in the year 2016. Aside from Myakkahatchee Creek, other tributaries in the lower river sub-basin are very small and are not projected for water supply use in the near future.

The approach of removing percentages of the remaining streamflow is in keeping with the District's percent-of-flow method, which allows water users to take a percentage of streamflow at the time of the withdrawal. The percent-of-flow method has been used for the regulation of water use permits since 1989, when it was first applied to withdrawals from the Lower Peace River. The percent-of-flow method is also used to regulate withdrawals by Florida Power and Light Corporation from the Little Manatee River and withdrawals from the Alafia River by Tampa Bay Water.

The District has also used the percent-of-flow method for minimum flow studies of both freshwater streams and tidal rivers in the region (SWFWMD 2005a, 2005b, 2008a, 2008b, 2009, 2010a, 2010b). The District's percent-of-flow method was first developed based on a program of District sponsored research on tidal river estuaries that has been conducted since the 1980s. A summary of how these findings were used to develop the percent-of-flow method is presented in a paper by Flannery et al (2002), and relevant findings are discussed in the report on minimum flows for the Lower Alafia River estuary (SWFWMD 2008b).

7.6 Identification of a Baseline Time Period

An important step in the determination of minimum flows is the selection of a baseline period over which diversions of various amounts of water are simulated. Optimally, the baseline period should reflect the long-term streamflow characteristics of the river, and not be over a period of years that are overly wet or dry. The Lower Myakka River presents an unusual situation because it is known that the flow regime of the river has changed due to anthropogenic effects. Trend analyses of streamflow data from the Myakka River near Sarasota presented clearly show that certain components of the river's flow regime have increased since the 1970s, with changes in land and water use as the causative factors (SWFWMD 2005a, Interflow 2008b).

Development of the MIKE SHE model has allowed estimates of excess flows that are occurring in the Upper Myakka River sub-basin. Because of the critical role these excess flows play in the flow regime of the Myakka River, it was concluded that the period covered by the MIKE SHE modeling effort be used as the baseline period for the determination of minimum flows for the lower river. The MIKE SHE study produced excess flow estimates for the period May 15, 1994-April 30, 2006. A ten year period of complete calendar years from 1995 to 2004 within this period was for the minimum flows analysis. Certain minimum flows analyses that were in progress when the modeling results were published had data that ended in 2004, thus results from 2005 and 2006 were not included.

The ten-year period from 1995-2004 covered a wide range of hydrologic conditions, including major droughts and very wet years. As described in Chapter 8, the flow duration characteristics of this period, with and without the excess flows, were compared to the different periods within the long-term streamflow records for the Myakka River near Sarasota and it was concluded this was a suitable representative period to perform the minimum flows analysis.

The empirical models to predict salinity distributions and the abundance and distribution of various fishes and invertebrates were run for this ten-year period. However, it was impractical to run the District's hydrodynamic model of Upper Charlotte Harbor for ten years to evaluate numerous flow scenarios because of the computer time it takes to run the model. As part of the evaluation of minimum flows for the Lower Peace River, which was based primarily on salinity simulations using the District's hydrodynamic model, the years from 1999 through 2002 were selected for analysis (SFWMD 2010b). Using the same boundary conditions that were used for the modeling for the Peace River minimum flows, this same four-year period was used to assess changes in the bottom area and volumes of salinity zones for the Lower Myakka River minimum flows project.

As described in Chapter 8, the 1999-2002 period was generally drier than the ten-year 1994-2004 period. In that way, it was treated as a conservative time period in which to assess potential impacts within the estuary. For comparison, deviations from baseline were statistically analyzed for both periods using the empirical salinity and biological models. These results found that deviations from baseline were greater for all variables when viewed within the 1999-2002 period, confirming that it was a conservative period for analysis.

7.7 Low-Flow Thresholds

The District has established low-flow thresholds on some rivers, below which no surface water withdrawals are allowed. Low-flow thresholds are currently in effect for the water use permits for withdrawals from the Peace, Alafia, and Little Manatee Rivers. Low-flow thresholds have also been established as part of minimum flow rules adopted for the freshwater reaches of the Myakka, Middle Peace, and Alafia Rivers, and minimum flows for the tidal reaches of the Lower Peace and Lower Alafia Rivers. The criteria used to justify these low-flow thresholds for these two tidal rivers has ranged from the relation of poor water quality to low flows on the Lower Alafia River, to the protection of the withdrawals by an existing legal user on the Lower Peace River, where withdrawals at low flows result in the upstream movement of brackish water to the intake for that water treatment plant.

A low-flow threshold is not recommended as part of the proposed minimum flows for the Lower Myakka River. In contrast to the Lower Alafia River, there are no water quality problems in the Lower Myakka that are exacerbated at low flows (apart from high salinity), and unlike the Lower Peace River there are no intakes for existing legal users on the river are potentially affected. Secondly, as described in Chapter 2, the flows from the upper river sub-basin at the Myakka River near Sarasota gage used to go to zero flow during most years prior to the late 1970s. Given these findings, the implementation of low flow threshold for the Lower Myakka River is not warranted.

7.8 Resources of Concern in the Lower Myakka River

The response of a large suite of physical, water quality and biological variables to changes in freshwater inflow were analyzed as part of the minimum flows analysis. Of particular concern were resources or ecosystem characteristics that would experience some form of undesirable change if freshwater inflows are reduced, such as a reduction in species abundance, a reduction in the distribution of a population or community, or a degradation of water quality. The geographic range over which a potentially affected species or community occurs was considered in the identification of the resources of concern.

Although the water quality characteristics of the lower river were assessed as part of the minimum flows analysis, salinity was the only physical-chemical parameter that was finally used to determine the minimum flows. While acknowledging that the water quality characteristics of the lower river are strongly influenced by freshwater inflow, significant relationships of inflow with salinity and a number of biological variables were more direct and sensitive indicators of potential undesirable changes that could occur if freshwater flows are reduced. The rationale for these conclusions are described below.

7.8.1 Emphasis on estuarine species and communities as resources of concern

The resources of concern for the determination of minimum flows for the Lower Myakka River were primarily estuarine species and biological communities that are occur in the reach of the lower river where salinity concentrations undergo seasonal variations. As previously discussed, this zone of the river lies primarily downstream of the confluence of the Blackburn Canal. The biological communities that were assessed for potential impacts from reduced freshwater inflows included benthic macroinvertebrates, zooplankton, larger nektonic macroinvertebrates (e.g. pink shrimp, blue crab), fishes, and oligohaline/tidal freshwater marshes. Empirical regressions were used to directly predict the effect of flow reductions on the distribution or abundance for some key species, while in other cases, reductions in the area, volume, or shoreline length of various salinity zones were used to assess potential changes to estuarine biological communities.

Although a large number of freshwater species were collected during the study, freshwater fish and macroinvertebrate communities were not considered as indicator organisms for the assessment of adverse impacts or significant harm. A freshwater zone of some extent occurs within the lower Myakka River during all times of year. During very dry periods the freshwater zone may be limited to 15 kilometers or so below the sill on Lower Myakka Lake, while during the wet season this zone may extend 40 kilometers or so to below the confluence with Myakkahatchee Creek. Not surprisingly, the fish and invertebrate sampling program found significant positive relationships between freshwater inflow and the abundance of many freshwater species in the lower river, as these species expanded their habitat into the study area (Peebles et al. 2006, Peebles 2008).

Reductions in the abundance of some indicator freshwater organisms are reported in Chapter 8. However, during dry periods these species can survive and reproduce in the uppermost region of the river above the Blackburn Canal, so they were not considered to be species which could experience significant harm from freshwater withdrawals. It is true their habitat will be smaller as the freshwater zone of the river becomes compressed. This effect is simulated in Chapter 8 by examining the reduction in the area and volume of the < 2 psu salinity zone during three seasonal blocks. As described in Chapter 8, reductions in all salinity zones during the winter and summer did not approach thresholds that would constitute significant harm. During the spring, simulated reductions in the area and volume of < 2 psu salinity zone were near District criteria for determining significant harm, but these values overestimated habitat reductions because waters less than 2 psu still occurred upstream of the area assessed by the model.

A different approach was taken for reduction in the shoreline lengths for oligohaline/tidal freshwater marshes. These wetlands, which are described in Section 6.2.5, include many freshwater plant species which differ in their salt tolerance. However, in addition to relationships with salinity, the distribution of marshes is closely related to the geomorphology of the river, particularly the slope of its banks. Unlike fishes and benthic invertebrates, intertidal marsh species may not be able to migrate upstream if salinity in the river becomes high because the upstream banks are not suitable for mash development. Therefore, salinity distributions in the region of the river where oligohaline/tidal freshwater marshes are abundant were used as a criterion for the assessment of significant harm. This zone lies between kilometers 22 and 29, where extensive data for salinity and a suite of biological variables were collected.

7.8.2. Emphasis on salinity as the physical-chemical indicator of resources of concern

Salinity is a primary variable in defining the zonation of biological communities that occur in estuaries and many physical chemical processes vary along salinity gradients. As will be described in Section 7.11, the District modeled changes in the area, water volume, and shoreline length of various salinity zones to evaluate potential impacts to the biological resources of the lower river. In addition, as part of the first phase of the minimum flows analysis, relationships were also examined between freshwater inflow and a number of water quality variables, including dissolved oxygen, water color, nutrients, and chlorophyll concentrations (Chapter 4). This follows District work on the nutrient enriched Lower Alafia River, where significant relationships between inflow and water quality variables were used to establish minimum flows because it was found reductions of inflow would contribute to increased hypoxia or large phytoplankton blooms in various parts of that river (SWFWMD 2008b).

In contrast, the minimum flows analysis of the Lower Myakka found that the river has generally good water quality, and potential problems due to inflow reductions were not apparent. Although hypoxia periodically occurs in some river reaches during summer months, there was no evidence that reduced flows would contribute to any increases in hypoxia. Similarly, chlorophyll concentrations in the Lower Myakka are comparatively low for other surface drainage tidal rivers in west Central Florida. Although there appear to be some general relationships with the location and magnitude of chlorophyll concentrations with salinity, inflow, and river location in the Lower Myakka, predictive relationships between chlorophyll and various forcing functions did not appear useful for the minimum flows analysis due to the large variability in these relationships relative to the chlorophyll concentrations in the river. Similarly, although nutrient concentrations are also generally affected by freshwater inflow, the modeling or other assessment of nutrient dynamics in the minimum flows determination of the Lower Myakka did not seem useful.

Instead, the direct relationship of freshwater inflow on salinity was emphasized for the minimum flows determination, along with significant relationships that were found between inflow and a number of biological variables. It was concluded these relationships provided more sensitive metrics for which changes in the estuary could be assessed.

7.9 Identifying Acceptable Levels of Change - Preventing Significant Harm

Once a set of quantifiable metrics have been identified for the resources of concern, decisions must be made on how much change can be allowed before significant harm occurs. In some cases, there may be obvious inflections in relationships between flows and available habitat or species abundance which can help resource managers make decisions on where significant harm occurs. In many cases, however, changes in habitat or abundance occur incrementally over the range of flows, often without a clear inflection (Montagna et al. 2002). In these cases, decisions must be made as to how much change along such a continuum can be allowed.

In determining minimum flows for freshwater streams, the District has taken an approach that a reduction of more than 15 percent of available habitat constitutes significant harm (SWFWMD

2005a, 2005b). This was partly based on a scientific review of the proposed minimum flows for the Upper Peace River, in which the reviewers stated "In general, instream flow analysts consider a loss of more than 15 percent habitat, as compared to undisturbed or current conditions, to be a significant impact on that population or assemblage" (Gore et al. 2002). The District, and subsequent peer reviews of freshwater minimum reports, acknowledged that allowable percentage changes used in other instream flow analyses have ranged from ten to thirty-three percent (SWFWMD 2005b). Nevertheless, the peer review panels for earlier freshwater minimum flows reports concluded that a 15 percent loss of habitat is a reasonable and prudent threshold for minimum flow analyses (Cichra et al. 2005, Shaw et al. 2005). They also mentioned that the fifteen percent threshold has been used by the District to assess both spatial and temporal reductions of habitats.

In a review of proposed minimum flows for the Upper Hillsborough River (SWFWMD 2007), that peer review panel stated that use of the specified percent habitat loss threshold was reasonable and pragmatic, but the specific value of 15 percent threshold is subjective and has only modest validation or support in the primary literature (Cichra et al. 2007). That panel suggested that additional literature review be conducted to determine that if higher or lower percentages were used in other situations, then examine what was the rationale for those decisions (e.g. lower percentage change for sensitive species vs. high percentages for more degraded systems). The panel also reiterated earlier recommendations that the District commit the necessary resources to evaluate the effectiveness of a 15 percent change in spatial or temporal habitat availability as a threshold for identifying significant harm, by conducting additional monitoring, natural experiments, or other analyses as part of a larger adaptive management program. The District is currently implementing a field experiment on a freshwater stream to investigate the effects of various rates of streamflow diversion and biological effects of habitat loss.

At this time, it is concluded the District's use of a fifteen percent change in habitat availability remains a reasonable and effective criterion to prevent significant harm to riverine systems. Although estuaries are fundamentally different than freshwater streams, a fifteen percent loss of a habitat criterion can be used to assess allowable environmental change in estuaries, as long as a linkage can be made between that habitat and the viability of a species or population. In keeping with the approach established for freshwater streams, the District has employed a fifteen percent threshold for evaluating changes in estuarine habitats that constitute significant harm (SWFWMD 2007, 2008b, 2009, 2010a, 2010b).

The question of habitat availability can be avoided if predictive relationships can be established between flow and the abundance that are resources of concern. In that manner, a 15 percent change in the abundance of one or more species can also be used to determine significant harm if that is the level of change the agency accepts. As described in Chapter 8, the District used regressions developed by the University of South Florida and the Florida Wildlife Research Institute (Peebles et al. 2006, Peebles 2008) to predict changes in the abundance for a number of life stages of fish and invertebrate species in the Lower Myakka River as a function of freshwater inflow. Four statistical methods were used to compare changes in predicted species abundance. Changes in the distribution of selected species were also examined over the flow regime of the river.

As will be described in Chapter 8, the District did not use a strict compliance with a 15 percent change when examining the effects of removing the excess flows from the Lower Myakka River. For some quantifiable resource indicators, removing these flows resulted in changes more than 15 percent in the spring dry season and even during the winter and summer during some dry years. This was considered acceptable since removing the excess flows returned the flows of the river to a more natural flow condition. Although the modifications to the Blackburn Canal and Cowpen Slough have affected flow regime of the river, the relative effect of these modification in the dry season is probably much smaller than the increases in flow due to land use changes in the upper river sub-basin. However, as described in Chapter 8, removing the excess flows will cause significant changes in the Lower Myakka River from its present condition, it is concluded that that withdrawing any water in addition to the excess flows should not be allowed until flows at the Myakka River near Sarasota gage exceed 400 cfs.

7.10 Assessment of significant harm within seasonal blocks

In many of its recent minimum flow reports, the District has taken a seasonal approach to assessing significant harm by examining changes to the resources of concern within three seasons of the year (SWFWMD 2005a, 2008a, 2009). These seasons have included the late spring dry season, the summer wet season, and an intermediate flow season that runs from the fall to the early spring. These seasonal breakdowns are based on the typical seasonal variation of flows in west central Florida streams that are dominated by surface runoff. The plot of the 10th, 50th, and 90th daily percentile values for the Myakka River near Sarasota shows this pattern (Figure 2-9).

The seasonal breakdowns that were used for establishing minimum flows for the Upper Myakka River were given block numbers to represent the typical progression from low to high flows: Block 1 (April 20 to June 20); Block 2 (October 26 to April 20) and Block 3 (June 20 to October 25). The seasonal breakdowns used for the determination of minimum flows for the Lower Myakka River were similar to these, but the beginning of Block 1 was moved to the beginning of March. This approach was taken because the abundance of a number of key species in the lower river are related to inflows over preceding time periods, and that if protection of these species in the late spring dry season is desired, then levels of flow reductions that affect the abundance of these species abundance should be assessed for sometime prior. Adjustment to the starting dates of the other blocks did not seem warranted.

7.11. Analytical methods to assess changes to the resources of concern

Within the context of a conceptual understanding of the interactions of freshwater inflow with estuarine ecology and production, the District examined relationships of streamflow to various ecological indicators that represent the resources of concern in the Lower Myakka River. The goal was to use identify statistically significant, predictive relationships between inflow and these ecological indicators so that the effect of potential reductions in inflow could be quantified. In addition to the District's linked hydrodynamic model of the lower river and upper harbor, predictive relationships were taken from the empirical isohaline modeling conducted by Mote Marine Laboratory (see Chapter 4) and the regressions of inflow with the abundance and distribution of selected fish and invertebrate species published by Peebles et al. (2006) and Peebles (2008).

The resource management goals for the minimum flows assessment of the Lower Myakka River are listed below along with a brief description of the analytical methods of how these goals were addressed. The analytical tools used for the minimum flow analysis, such as the District's hydrodynamic model and various regression models, were described in earlier chapters and their application to the assessment of potential flow reductions are discussed in Chapter 8.

7.11.1 Maintain River Bottom Areas Within Biologically Important Salinity Zones for the Protection of Benthic Macroinvertebrate Communities

Benthic macroinvertebrates comprise a critical biological community with regard to energy transfer in the estuary and maintenance of food webs that support the nursery function for estuarine dependent sport and commercial fisheries. As described in Chapter 6, many benthic invertebrate groups, such as amphipods, polychaetes and mysid shrimp, are important food sources for the early life stages of fish species that migrate into and use the tidal river as nursery habitat. Numerous studies, including the data from the Lower Myakka River, have shown that salinity gradients exert a strong influence on the distribution of macroinvertebrate communities (Culter 2004, Estevez 2005, Janicki Environmental 2007, Montagna et al. 2008). Furthermore, many invertebrate taxa that are known to be important prey items for fishes reach high population numbers in the oligohaline and mesohaline zones of tidal rivers (Peebles 2005b, Peebles et al. 2006, Janicki Environmental 2007).

Accordingly, the maintenance of areas of biologically relevant salinity ranges to support benthic macroinvertebrate production can be used as a goal for inflow management and the determination of minimum flows. Various salinity zone classifications have been used to evaluate the ecological characteristics of estuaries. Probably the best well known is the Venice salinity Classification system, which was based on a consensus of estuarine biologists in the 1950s (Anonymous 1959). That system established five salinity zones as limnetic (freshwater) at <0.5 psu, oligohaline at 0.5 to 5 psu, mesohaline at 5 to 18 psu, and polyhaline at 18 to 30 psu, and euhaline at > 30 psu. In another well known study, Bulger et. al (1993), used principal components 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.

As part of the District's program of minimum flows research, data for benthic macroinvertebrates have been collected in twelve tidal rivers within the District. In order to evaluate relationships between salinity and the presence and/or abundance of benthic macroinvertebrates, these data have been analyzed both within rivers and in multi-river analyses which combined data from various rivers. In a report that included data from nine rivers in the region, Janicki Environmental (2007) presented the results of logistic regression analyses that examined presence/absence across a broad salinity range for a large number of species. These results clearly showed that many of the dominant species in tidal rivers are most frequently collected from oligohaline and mesohaline zones.

Based on mollusk surveys were conducted by Mote Marine Laboratory in ten rivers in the region, Montagna et al. (2008) similarly found that the abundance of several common mollusks, such as *Polymesoda caroliniana*, *Rangia cuneata*, and *Tagelus plebius* were most frequently collected in low salinity waters. Both the report by Janicki Environmental (2007) and the article by Montagna et al. (2008) included macroinvertebrate data collected from the Lower Myakka River that were discussed in Chapter 6.

Using combined data from the nine study rivers, Janicki Environmental (2007) used 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. They also segregated the data into the rivers flowing to Charlotte Harbor, which included Shell Creek and the Peace and Myakka Rivers. That analysis showed breaks macroinvertebrate community structure along salinity zones of at < 11 psu and 11-17 psu. They reported, however, that species assemblages differed between these rivers, for example, *Grandidierella bonnieroides*, *Strebblospio gynobranchia* and *Pectinaria gouldi*i were more common in the Lower Myakka.

Although many macroinvertebrate species show broad salinity tolerances that do not conform to salinity zones identified by various statistical techniques, changes in the amounts of different salinity zones in estuaries can be used as a meaningful indicator to assess the effect of flow reductions on salinity distributions related to the distribution of benthic macroinvertebrate communities. The salinity zones that were selected to assess potential impacts to benthic macroinvertebrate communities in the Lower Myakka River were synthesized from the findings of various studies and are as follows:

< 2 psu,
< 5 psu
< 12 psu
< 17 psu
  2 to 12 psu
  11 to 17 psu

The < 12, < 17, and the 11 to 17 psu zones were taken from PCA analyses of data from the Charlotte Harbor rivers, with the slight adjustment of the <11 psu zone to < 12 psu. The < 5 psu zone corresponds to the upper limit of the oligohaline zone in the Venice system. It was used as an indicator salinity zone in the minimum flows assessment of the Lower Peace River, allowing comparisons of changes of that salinity zone for these two adjacent rivers. The < 2 psu zone was chosen for to assess the abundance of low salinity zones in the lower river that approach fresh water. The 2 to 12 psu zone was examined to see how the bottom areas within a low salinity range responded to changes in freshwater flow.

The District's hydrodynamic model of the lower Myakka and Peace Rivers and Upper Charlotte Harbor (see Chapter 5) was used to examine changes in the river bottom areas within these salinity zones that would result from potential flow reductions. Mote Marine Lab also developed empirical models for the prediction of surface and bottom isohalines, but the District model was used for the salinity zone analysis for it can simulate bottom areas in a very large number discrete layers and cells on a continuous basis for a series of years. It also was able to assess the effects of permitted withdrawals from Myakkahatchee Creek, whereas all but one the Mote isohaline models did not find flows from the creek to be a significant explanatory variable.

The District model was run was for four years from 1999 through 2002. Daily mean values of total bottom areas in 1 psu salinity increments were produced and the amounts of bottom area within the salinity ranges described above were derived. The model was run for all flow scenarios evaluated in the study. For each flow scenario, cumulative distribution functions (CDF) plots of the amounts of bottom area within the target salinity zones were generated. These curves were them compared to the CDF curve for the baseline flow condition and the net change in bottom area for each flow reduction scenario was calculated as the difference in the area underneath the cdf curve for the baseline flow and curve for the flow reduction. Greater details on this method are presented in Chapter 8 with the results of the bottom area analysis.

7.11.2 Maintain salinity zone volumes for the protection of nekton communities

Free swimming fishes and larger invertebrates (nekton) frequently show changes in community composition along salinity gradients in estuaries. As described above, Bulger used PCA to identify four overlapping salinity zones in mid-Atlantic estuaries that were related to fish community composition. In the study of minimum flows for the Peace River, PCA of seine catch data was also used to identify zones of 1 to 3 psu, 4 to 14 psu, and 15-23 psu (SWFWMD 2010b). Conversely, in an assessment of six years of data for the Lower Alafia River, Greenwood et al. (2007) found that a distinct community occurred in very low salinity waters below 1 to 2 psu, but there were no significant differences in fish community composition in the higher salinity ranges in the river.

As described in Section 6.4.1, the migration of the early life stages of estuarine dependent fish species into low salinity nursery areas is well documented, including studies of tidal rivers in the region. The reasons for this migration can be varied and not directly related to salinity, per sè. The avoidance of predators in low salinity waters may be a factor, but a possibly a more important driving function is the availability of abundant food sources for juvenile fishes in low salinity waters, which is driven the input of nutrients and organic matter from the watershed. Peebles et al. (2007) found that juvenile bay anchovies were concentrated in low salinity waters in twelve estuaries in the region, but the salinity at capture for this species varied among rivers. They suggested that the low salinity at capture in each river reflected that bay anchovies were migrating into regions that provided food rich habitats, which were related to the interaction of the geomorphology and each river with the volume of its freshwater inflows.

Regardless of the mechanisms by which nekton communities vary with salinity, the District concluded it was prudent to examine changes in salinity zone volumes in order to assess potential effects on fish populations. As with bottom area, the District's hydrodynamic model was used to generate daily values for volumes of water in various salinity zones in the lower river. The salinity zones chosen for analysis were:

< 2 psu,
< 5 psu,
< 14 psu,
3 to 14 psu,

The < 2 psu zone was selected to represent the very low salinity fauna, including tidal freshwater species, which were identified by Greenwood et al. (2007) in the Lower Alafia and by Janicki Environmental in the Lower Peace (SWFWMD 2010b). The < 5 psu zone corresponds to the upper limit of the Venice system oligohaline zone and is near the upper limit of the lowest salinity zone (< 4 psu) identified by Bulger et al. (1993). The < 14 psu and the 3 to 14 psu salinity zones were selected to correspond to the combined oligohaline to low mesohaline ranges important for fish community structure that were identified for fishes in the Lower Peace River (SWFWMD 2009).

It was concluded these salinity ranges would provide useful metrics to evaluate changes in salinity zones that could affect fish populations. Although the distribution and abundance of various species may not show relationships with these specific salinity zones, the amounts of similar salinity ranges are highly correlated. For example, a management decision based on the amount of the < 14 psu salinity zone would likely not different substantially from a decision based on the < 12 psu salinity zone. The District model provides a powerful tool to examine the amount of both bottom areas and water volumes within various salinity zones. Comparison of the results for multiple salinity zones that cover the range of values ensures that salinity zones that are important to protect the nursery function of the river are being assessed.

7.11.3 Maintain Surface Isohaline Locations within Ranges that Protect the Distribution of Low-Salinity Shoreline Vegetation Communities.

The distribution of tidal wetlands in the Lower Myakka River were described in Chapter 3. Based on as assessment of published information of salinity relations of tidal wetlands, Mote Marine Lab concluded that a zone of oligohaline and tidal freshwater (OTF) marshes between kilometers 22 and 29 were the plant communities that would be most vulnerable to changes due to salinity increases that could result from freshwater withdrawals. The District agreed with this conclusion and OTF marshes were the focus of the assessment of salinity changes important to tidal wetlands. Low-salinity wetlands provide valuable functions with regard to shoreline stability and wildlife habitat (Odum et al. 1984, Florida Fish & Wildlife Conservation Commission 2005), and were considered to be an important community for minimum flow management.

Many studies have shown that distribution of wetland communities along tidal rivers correspond to salinity gradients within the river (Latham et al. 2001, Perry and Atkinson 1997, Clewell et al. 1999, Clewell et al. 2002). Furthermore, changes in soil salinity within the wetlands can change the species composition and growth of tidal wetland communities (Pearlstine et al. 1993, Wetzel et al. 2004). Measurements of soil salinity within the wetlands adjacent to the river channel were not performed for this study. It can be reasonably inferred, however, especially for wetlands near the river channel, that maintaining salinity concentrations suitable for plant growth in the river adjacent to the wetlands is a useful strategy for protecting these wetlands from harm, since river waters flood into the wetlands on high tides, influencing soil salinity (Hackney and De La Cruz 1978, Hackney et al. 1996, Wang et al. 2007).

The District chose to use the surface isohaline models developed by Mote Marine Lab to assess changes in river salinity relevant to tidal wetlands. These models were generated from large salinity data base for the river and generally had very good r^2 values (see Section 4.2.4). As opposed to benthic macroinvertebrates, which occur over all depths within the river channel, tidal wetlands are inundated by the shallow waters of the river, thus the location of the surface isohalines can be a useful tool for assessing potential impacts to wetland communities from salinity increases that could result from freshwater withdrawals.

The results presented in Chapter 4 showed a close agreement between the median location of the 2 psu surface isohaline during the spring dry season and the downstream limit of the OTF marsh zone in the lower Myakka River (Figure 6.17B). During the other seasons the OTF marshes were typically exposed to fresh water which extended well past the downstream marsh boundary. It was therefore concluded that movement of the 2 psu isohaline during the spring dry season (Block 1) would be the best indicator for potential changes to the OTF marsh community.

This conclusion is supported by the findings of studies from other rivers. Both the South Florida and Suwannee River Water Management Districts have used the location of the 2 psu isohaline to evaluate the protection of tidal freshwater floodplain wetlands (South Florida WMD 2002, Water Research Associates et al. 2005). In a survey of seven rivers on the coast of west central Florida, Clewell et al. (2002) similarly found that sensitive freshwater plants were mainly located upstream of the median location of 2 psu salinity in the river channels. They also found that freshwater plants that are tolerant of low salinity, which are often dominant in brackish marshes (e.g. cattails, sawgrass, and bulrush), were most common where median surface salinity values were less than 4 psu. Scattered stands of these plants do occur downstream of the OTF zone in the Lower Myakka, but the OTF zone between kilometers 22 and 29 identified by Mote Marine Lab appears to the principal transition zone in the river, and movement of the 2 psu isohaline within this zone appears to be a sensitive indicator for management.

Daily values for the location of the 2 psu surface isohaline were calculated for all flow reduction scenarios assessed for the project for entire baseline period from 1995-2004. Using this output, the shoreline length and area of OTF marshes upstream of the 2 psu isohaline were calculated on a daily basis. CDF curves of these results were generated for the baseline flow condition and compared to CDF curves of shoreline length and area for the potential flow reduction scenarios. Shifts in the median positions of the 2 psu isohaline were also examined.

7.11.4 Protect the Nursery Function of the Lower Myakka River by Maintaining the Abundance and Distribution of Important Fish and Invertebrate Taxa

The Lower Myakka River serves as a nursery area for the early life stages of several species that comprise economically important sport and commercial fisheries in the Charlotte Harbor region, including snook, mullet, red drum, spotted seatrout, pink shrimp, spotted seatrout and blue crab. Many other ecologically important fish and invertebrate species and groups that serve as prey for these economically important species also use the lower river as habitat (e.g., bay anchovies, mojarras, killifishes, amphipods, opossum shrimp). Biological data collection in the lower river by the University of South Florida and the Florida Fish and Wildlife Research Institute found that the distribution and/or abundance of many of these economically and ecologically important species in the Lower Myakka River are affected by the rate of freshwater inflow (Peebles et al. 2006, Peebles 2008).

With regard to distribution of these taxa in the river, the typical response to inflow is characterized by the center of abundance for a population (as catch-per-unit-effort) moving upstream as inflows decline. Following the conceptual model of Browder and Moore (1981), this could potentially result in a loss of recruitment or abundance, as a population could shift away from what are most desirable habitats for that species. Desirable habitats could be comprised of shoreline habitats which provide cover or regions with high concentrations of invertebrate prey. It is known that the area and volume of the lower Myakka decreases upstream, with an inflection in this relationship near the confluence of Myakkahatchee Creek (Figures 3-5 and 3-8). As a result, the upstream movement of a population due to a large reduction of inflows could compress that population into smaller regions of the tidal river that have less habitat area and volume. Because of this morphological characteristic, it could be generally assumed that maintaining the distribution of a population near where it occurs under baseline flow conditions would help protect the viability of that population

Peebles et al. (2006) provided regressions to predict Km_U (center of catch-per-unit effort) of different life stages for various taxa as a function of freshwater inflow. These regressions were developed for taxa collected either by plankton nets, seines, or trawls. The Km_U regressions for some key taxa in the plankton were updated to include five samples that were collected during low flows in 2008 (Peebles 2008). Using these regressions in the assessment of minimum flows, the District simulated shifts in the distribution in the different life stages of a number of fish and invertebrate species.

Peebles et al. (2006) and Peebles (2008) also presented regressions to predict the abundance of different life stages various fish and invertebrates species in the river as a function of freshwater inflow. For taxa collected by plankton net, these regressions predicted the total number of animals in the river channel. For taxa collected by seines or trawls, the regressions predicted the change in catch-per-unit effort. The regressions differed considerably in their r^2 values, which identify the proportion of the variation in abundance or CPUE that is explained by freshwater inflow. Given the number of factors that can affect abundance, including predation, food availability, dissolved oxygen concentrations, the simple fact that significant regressions were found with freshwater inflow is meaningful. These regressions, however, appeared more promising for some taxa than others, based on the level of the r^2 values and fit of the regressions to the observed data. Based on measures of model performance, several regressions of abundance with flow were selected for use in the minimum flows analysis.

The series of successive percent flow reductions described in Section 7.5 were applied to these regressions to predict total abundance in the river (plankton) or catch-per-unit effort (seines and trawls). Changes in the reductions of various key species were evaluated. As would be expected, the amount of change differed between taxa for a given flow reduction scenario. The results for all the selected taxa were reviewed, but with emphasis placed on several species that are important for economic or ecological reasons and the regressions appeared robust. The regressions for the hogchoker (*Trinectes maculatus*) and the opossum shrimp (*Americamysis almyra*) were particularly useful. Opossum shrimp are a prey item widely used by juvenile fishes and a positive relationship of the abundance of this species with freshwater inflow has been observed in other rivers (SWFWMD 2008b, SWFWMD 2010a). *Trinectes* is one of the dominant fishes in the lower river, and it is often concentrated in oligohaline zones which can be particularly susceptible to freshwater inflow reductions. Changes in these indicator species, and the other metrics described above, are presented in Chapter 8.

Chapter 8

Results of the Minimum Flows Analysis

8.1 Introduction

Minimum flows for the Lower Myakka River were determined by evaluating the effects of a series of potential flow reductions on the existing flow regime of the river. Predictive models were used to evaluate the effects of these hydrologic changes on a group of key ecological indicators that represent the resources of concern in the lower river. The geographic range of the minimum flows assessment, the ecological indicators selected, and the methods used to assess changes in these resource-based indicators were described in Chapter 7. This chapter presents the results of the minimum flows analysis and the proposed minimum flow rule.

The District's approach for determining minimum flows considered the historic changes to the lower river's flow regime due to the construction of the Blackburn Canal and alteration of the Cowpen Slough drainage, along with excess flows the lower river has received due to land use changes in the upper river sub-basin. To address ecological problems these excess flows have caused to freshwater reaches of the Myakka River, management plans are being developed to reduce or remove the excess flows from the upper river sub-basin. Therefore, the initial flow reduction considered by the District in the determination of minimum flows for the Lower Myakka River was removal of the excess flows in the upper river sub-basin.

As described in Chapter 2, an integrated surface water / ground water model (MIKE SHE) was developed to quantify the excess flows the upper river has received due to changes in land and water use. After some adjustments of the modeled excess flow values, the District subtracted the excess flows from the daily gaged flow records at the Myakka River near Sarasota gage to create an adjusted flow record to simulate the effect of removal of the excess flows on freshwater inflows to the lower river. Additional flow reductions conducted for the minimum flows analysis involved reducing these adjusted flow values at the Myakka River near Sarasota gage by different percentage rates. Because of the critical role these excess flow values played in the minimum flows determination, the rationale and methods by which the excess flows were adjusted and then subtracted from the gaged flows are described first below.

The development and calibration of the MIKE SHE model are described in detail in a report by Interflow Engineering, LLC (2008a). The minimum flows analysis of the Lower Myakka River utilized predicted excess flow values at the location of the Myakka River near Sarasota gage that were generated by Interflow in the latter part of 2008 (Interflow 2009a). As discussed in Section 2.4.2.3, the MIKE SHE model has been updated and revised since the minimum flows analysis of the lower river was conducted. Because the revisions were limited primarily to localized land use changes and addition of local-scale detail, the excess flow values that were used for the minimum flows analysis are very similar to the predicted values at the long-term gage site generated by the revised MIKE SHE model. However, the plots and tables that relate the quantity of modeled excess flows to the observed flows at the Myakka River near Sarasota gage presented on the following pages should not be considered final, as the revised MIKE SHE model would produce slightly different results.

The emphasis of this report is how removal of the excess flows will affect the salinity characteristics and ecology of the Lower Myakka River. Considering all factors, the excess flows that were generated in 2008 and utilized in this report provide very good values to evaluate the downstream effects of the excess flows for the period of study and establish minimum flow regulations for the lower river. However, as will be discussed in Section 8.9, the actual removal of excess flows in future years, for which modeling estimates will not be available, will require hydrologic monitoring and adaptive management strategies to evaluate the effects of removing the targeted excess flow quantities on the flow regime of the upper and lower river.

8.2. Methods for adjusting the gaged flow record for the excess flows

The initial step in applying the excess flow values to the minimum flows analysis of the lower river was to examine how the modeled flows for both the existing watershed condition and the excess flows compared to the observed flows at the Myakka River near Sarasota gage. On a monthly basis, there was good agreement between the modeled existing watershed conditions flows and the gaged record for the period of the MIKE SHE study (Fig. 8-1).

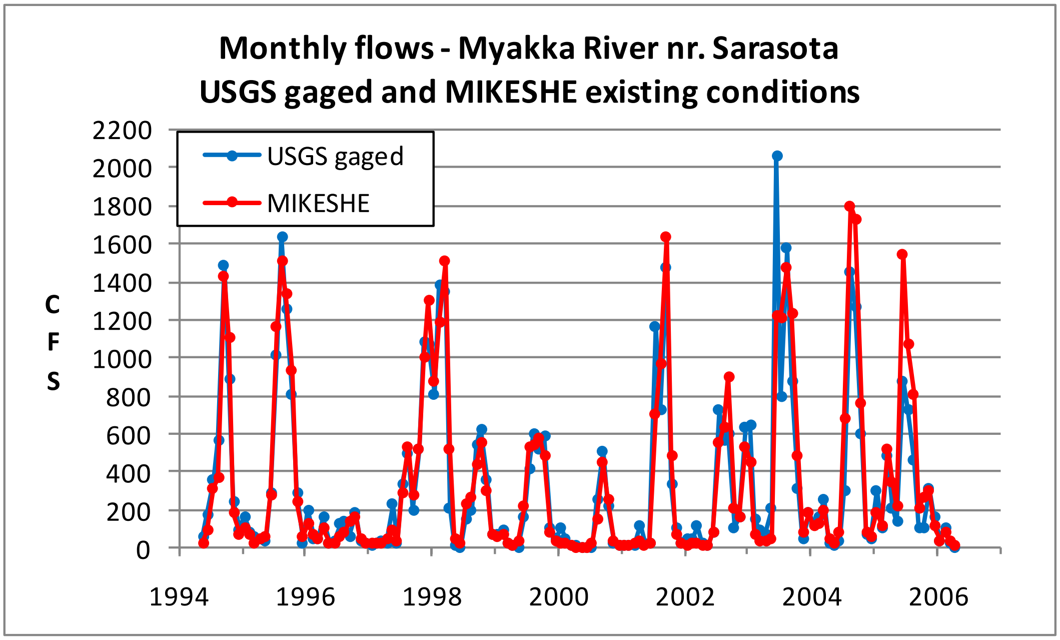


Figure 8-1. Monthly values for gaged flows at the Myakka River near Sarasota and flows for existing watershed conditions at that site predicted by MIKE SHE.

Hydrographs of daily USGS gaged flows and predicted existing conditions flows are plotted by year for all complete years (1995-2005) in Appendix 8A, with hydrographs for 1995 and 2002 shown in Figure 8-2. In general, the model did a good job of predicting mean daily flows at the USGS gage site. However, on some days, the modeled excess flows showed brief peaks not observed in the gaged record (Figure 8-2A), due possibly to differences in the timing of modeled flow peaks at this gage site vs. measured stage peaks that served as the downstream boundary condition. During other periods, such as the fall of 2002, the existing conditions scenario tended to be higher or lower for more prolonged periods of time (Figure 8-2B).

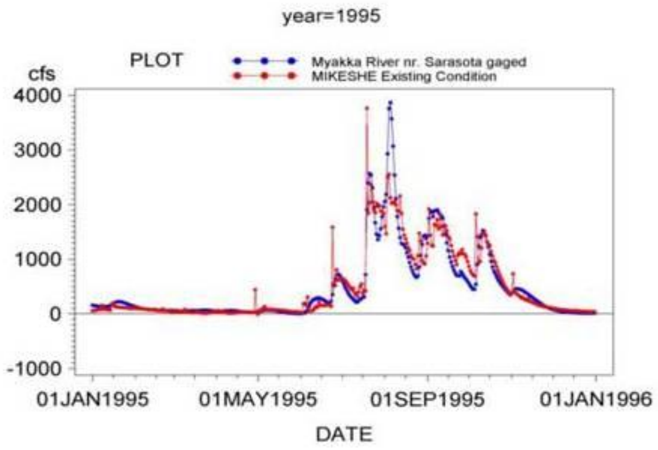


Figure 8-2. Daily gaged flows at the Myakka River near Sarasota gage and flows at that site predicted by MIKE SHE for existing watershed conditions for 1995 and 2002.

Predicted daily values of excess flows also showed brief peaks in flows not observed in the gaged record (years 1995 and 2002 in Figure 8-3; all years shown in Appendix 8B). Negative values for excess flow were recorded on 4% of the days during the 12-year modeling period, meaning that on those days the flow for the historical scenario was greater than the flow of the existing scenario. On some days the excess flows equaled or exceeded the gaged flows measured by the USGS. Such results occurred over due to time routing factors in the model that varied from what occurred in the gaged record for particular hydrologic conditions. The approach taken for the minimum flows analysis was to subtract the model generated excess flows from the gaged flow record to simulate the effect of removing the excess flows on the flow regime of the lower river. On days when the excess flows were greater than the gaged flows this resulted in negative flow values, which are not feasible, so the adjusted gaged values on those days were set to zero.

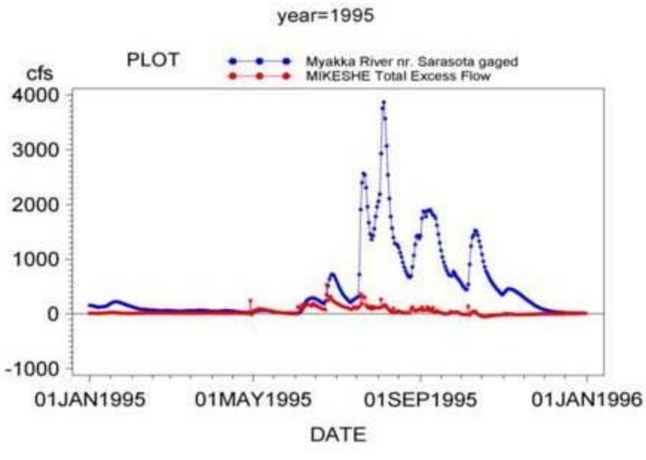


Figure 8-3. Daily gaged flows at the Myakka River near Sarasota gage and total excess flows predicted at that site by MIKE SHE for existing watershed conditions for 1995 and 2002.

8.2.1 Assignment of a maximum limit for excess flows for the minimum flows assessment

Based on review of the MIKE SHE model output, concern was expressed by District staff about subtracting some of the very high excess flows predicted by the model from the gaged record for the minimum flows analysis. During some isolated wet periods, this would result in negative flows (set to zero) for a week or more, which did not seem plausible. To address this problem, District staff investigated the effect of capping the excess flow values to be used for the minimum flows analysis. To a large extent, this would address those periods when very high excess flows were predicted by the model. It was also considered practical from a water management perspective, since it is unlikely that very high diversions (> 100 cfs) will be implemented from the upper river sub-basin.

To investigate a reasonable high-flow limit for the predicted excess flows, adjusted flow rates at the Myakka River near Sarasota gage were calculated by capping the excess flows at different limits and then subtracting these capped excess flows from the gaged record. Average flows for the May 1994 – April 2006 modeling period are listed in Table 8-1 for the following variables: USGS records at the Myakka River gage; modeled flows for existing watershed condition; modeled flows for the historical watershed condition; modeled total excess flows capped by different limits; and the resulting adjusted gaged flows if the capped excess flows are subtracted from the gaged record. Average values are listed for the entire modeling period and for three seasonal blocks.

The average flow rate for the USGS gage record for the modeling period was 329 cfs, equivalent to 19.5 inches per year. The average flow for the modeled existing watershed condition (346 cfs) was greater than the gaged average by about 5 percent (Group 1 in Table 8-1). The average excess flow not limited by any cap was 56 cfs, or about 17% of the gaged flow average and about 16% of the existing condition average. Subtracting the unadjusted excess flows from the gaged record produced an average flow rate of 276 cfs. Since this was lower than the average flow for the modeled historical watershed condition (290 cfs), subtracting the excess flows without a high flow cap seemed to underestimate what the gaged flows should be in the absence of excess flows. This does necessarily not mean the excess flows are unrealistically high, but may result from subtracting values that are computed as the difference between two modeling scenarios from recorded gaged values.

Average flows were also calculated after applying various caps to the excess flows with results for caps of 200, 150, and 130 cfs shown in Table 8-1. Subtracting excess flows capped at 130 cfs from the gaged record produced an average flow (290 cfs) that was the same as the modeled historical condition (Group 4). For the three seasonal blocks, this adjusted gaged record was 9% less than the historical condition average in Block 1, 13% greater than the historical average in Block 2, and 3% less than the historical average in Block 3. Given the similarity of these values, it was concluded that applying a 130 cfs cap to the excess flow values was a suitable method for limiting the high excess flows predicted by the model to produce reasonable adjusted flow estimates when the excess flows are subtracted from the gaged flows.

Table 8-1. Average streamflow (cfs) and runoff values (inches) for the Myakka River near Sarasota gage for: USGS gaged records, modeled values for existing and historical watershed conditions, modeled total excess flows with and without high flow caps, and resulting adjusted flows from subtracting the total excess flows from the USGS gaged records. All values are for May 15, 1994 through April 30, 2006. Seasonal blocks are: 1 - March 1 to June 20; 2 - June 21 to October 27; 3 - October 28 to February 28 or 29.

Group		all year		Block 1		Block 2		Block 3	
	Scenario	**cfs**	**in**	**cfs**	**in**	**cfs**	**in**	**cfs**	**in**
1 no cap to exess	**USGS**	329	19.5	122	2.2	211	4.3	620	13.0
	Existing	346	20.5	138	2.5	190	3.8	679	14.2
	Historical	290	17.2	105	1.9	173	3.5	563	11.8
	Total excess	56	3.3	30	0.5	17	0.3	116	2.4
	USGS - total excess	276	16.4	96	1.8	195	3.9	510	10.7

		all year		Block 1		Block 2		Block 3	
	Scenario	**cfs**	**in**	**cfs**	**in**	**cfs**	**in**	**cfs**	**in**
2 200 cfs cap to excess	**USGS**	329	19.5	122	2.2	211	4.3	620	13.0
	Existing	346	20.5	135	2.5	190	3.8	679	14.2
	Historical	290	17.2	105	1.9	173	3.5	563	11.8
	Total excess	47	2.8	29	0.5	17	0.3	92	1.9
	USGS - total excess	284	16.9	97	1.8	195	3.9	531	11.1

		all year		Block 1		Block 2		Block 3	
	Scenario	**cfs**	**in**	**cfs**	**in**	**cfs**	**in**	**cfs**	**in**
3 150 cfs cap to excess	**USGS**	329	19.5	122	2.2	211	4.3	620	13.0
	Existing	346	20.5	135	2.5	190	3.8	679	14.2
	Historical	290	17.2	105	1.9	173	3.5	563	11.8
	Total excess	43	2.6	28	0.5	17	0.3	81	1.7
	USGS - total excess	287	17.0	98	1.8	195	3.9	541	11.3

		all year		Block 1		Block 2		Block 3	
	Scenario	**cfs**	**in**	**cfs**	**in**	**cfs**	**in**	**cfs**	**in**
4 130 cfs cap to excess	**USGS**	329	19.5	122	2.2	211	4.3	620	13.0
	Existing	346	20.5	135	2.5	190	3.8	679	14.2
	Historical	290	17.2	105	1.9	173	3.5	563	11.8
	Total excess	41	2.4	27	0.5	17	0.3	76	1.6
	USGS - total excess	290	17.2	98	1.8	195	3.9	546	11.5

Another way to check the reasonableness of the adjusted gaged flows is to compare the values to gaged records at the Myakka River near Sarasota when alterations to the watershed were slight. As discussed in Section 2.4.2.2, increasing trends for a number of streamflow parameters began in the late 1970s. The period from 1937 to 1978 was selected as an early gaged period to reflect more natural flow conditions of the river. Differences in seasonal rainfall between the modeled and the early gaged periods can affect this comparison, but as an approximate tool, it provides a useful measure of how similar the adjusted flows are to flows the river experienced in earlier decades when alterations to the upper river sub-basin were minor.

The average flow for 1937-1978 (252 cfs) is less than average value for adjusted gaged record for the 1994-2006 modeling period. The average for the early gaged record for Block 3 (557 cfs) is close to the adjusted gaged record. Average flows for the early gaged record for Blocks 1 (80 cfs) and 2 (91 cfs) are less than the average adjusted flows for the corresponding blocks in the modeling period. Since the averages for the adjusted flows are greater than average flows for the early gaged period, it does not appear that unrealistically high excess flows are being subtracted from the gaged record.

Given these considerations, the District capped excess flows at 130 cfs for the minimum flows analysis of the Lower Myakka River. Yearly hydrographs of gaged flows at the Myakka River near Sarasota gage and total excess flows capped at 130 cfs are presented in Appendix 8C.

8.2.2 Selection of method to adjust for excess flows

The next step in adjusting the gaged records for the excess flows involved a decision on whether to use the actual excess values in cfs, or to use percentages of excess flow calculated from the model runs. Method 1 was to subtract the adjusted excess flow values predicted by the MIKE SHE model from the gaged record for each day. Method 2 was to calculate the percentage of modeled existing flow that was comprised of modeled excess flow for each day, and then multiply the daily USGS gaged records by those percentages to derive the proportion of the gaged flow that was excess flow. In either case, the final excess flows were capped at 130 cfs, and if the excess flow was greater than the USGS gaged flow, the resulting adjusted gaged flow was set to zero.

Yearly hydrographs of excess flows calculated by these two methods are plotted in Appendix 8D. During most years there was fairly good agreement between excess flow calculated by the two methods. However, during some periods, notably during the unusually dry year of 1996, the excess flows calculated by the two methods diverged during some wet periods.

The District did a number of analyses to compare the values calculated by the two methods. A box plot of excess flows calculated by the two methods is presented in Figure 8-4, along with the unedited total excess flows from MIKE SHE without the 130 cfs cap. Since the Method 1 used the predicted excess flow values, the inter-quartile ranges were the same for the unedited modeled flows and the adjusted excess flows except for July through September, when the 130 cfs cap had an effect on the upper quartile limit. Excess flows calculated by the Method 2, which transferred percentages from the model to model output the gaged record, differed to some degree. Most notable was the higher upper quartile and 90th percentile values for Method 2 compared to Method 1 during some months, especially January through May.

Inspection of the data indicated that on some days, the model was predicting low flows for the existing conditions scenario, but with a high percentage of excess flows. On some of those days the gaged flows were considerably higher, and extrapolating those percentages to the gaged flows resulted in high excess flow values for the minimum flows analysis. Although Method 2 was appealing because the percent of excess flow was applied from the model to the gaged record rather than the absolute excess flow amount, Method 2 appeared to overestimate excess flows in the gage record during some periods.

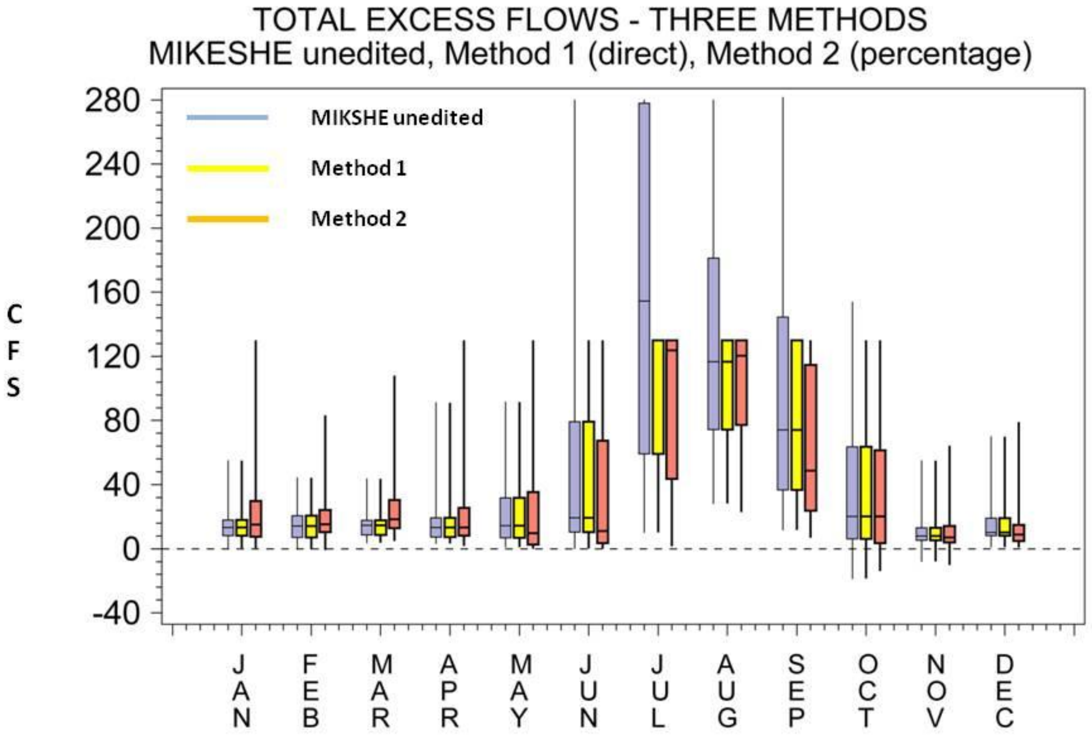


Figure 8-4. Box plot of monthly values of excess flows from MIKE SHE unedited (no high value cap) and by adjusted by Method 1 (direct values with 130 cfs cap) and Method 2 (percentages from model applied to gaged flows with 130 cfs cap). The y axis was limited 280 cfs for plotting purposes, some whiskers extend higher.

To be conservative with regard to the minimum flows analysis for the lower river (less flow reduction), Method 1 was used to determine the excess flows to be subtracted from the gaged record. Also, and equally important, the management plans that are being considered for the upper river sub-basin are being based on the predicted excess flows values taken directly from the MIKE SHE model. To be consistent with those efforts and ensure that management strategies for the upper and lower river sub-basins are being based on the same hydrologic variables, Method 1 was chosen to adjust the USGS gaged records to simulate removal of the excess flows from gaged inflows to the lower river.

As previously discussed, there were a number of days when the excess flows from the MIKE SHE model were greater than the gaged flows at the Myakka River near Sarasota gage. Subtracting these excess flows from the gaged flows would result in negative flows at the USGS gage, which cannot happen in nature. Therefore, whenever the excess flows exceeded the gaged flows, the excess flow values were set to the gaged flow value resulting in a zero adjusted flow at the Myakka River near Sarasota gage. Hydrographs of daily excess flows calculated by Method 1, with and without capping the excess flows to the gaged flows, are shown for two years in Figure 8-5 and for all complete model years in Appendix 8E.

The negative excess flow values in these plots (e.g., 1995 in Figure 8-5) represent days when the excess flows for the historic scenario were greater than the existing conditions scenario. Subtracting these negative excess flows from the gaged flows resulted in an increases in the adjusted gaged flows. This was considered acceptable for the minimum flows analysis, as it represented days when the historic watershed conditions would have resulted in greater flows than current watershed conditions. As previously discussed, this occurred on 4% of the days in the 12-year modeling period.

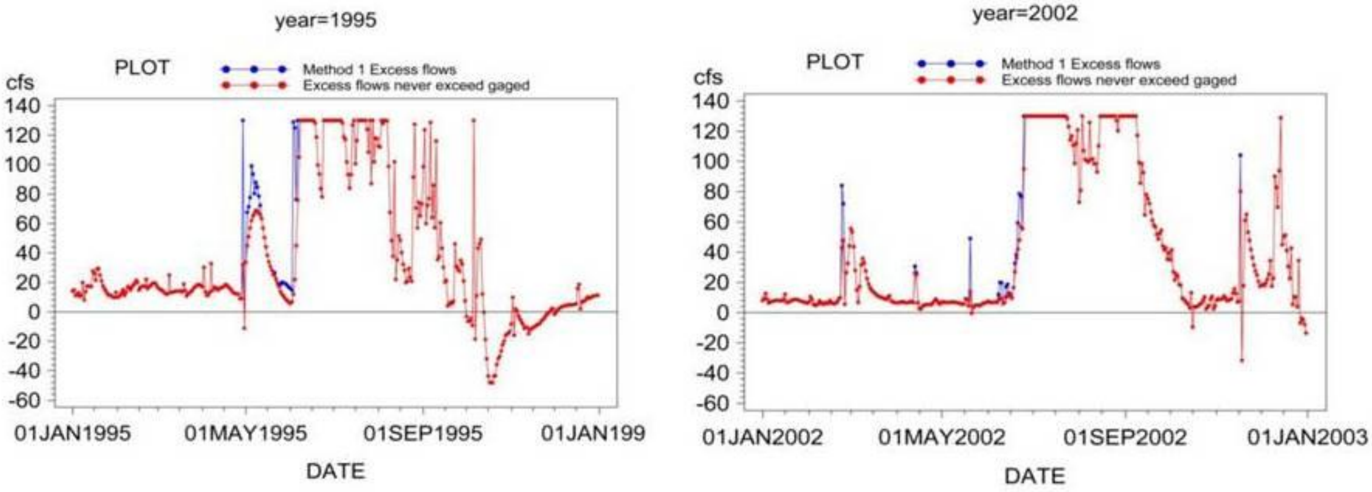


Figure 8-5. Total excess flows calculated by Method 1 and by limiting the Method 1 flows to the gaged flows on days when the excess flows were greater than the gaged flows during 1995 and 2002.

To summarize, an adjusted gaged flow record was created for the Myakka River near Sarasota gage to simulate removal the excess flows the river has received according the MIKE SHE model. To create this adjusted gage record, daily total excess flow values predicted by the MIKE SHE model were subtracted from the corresponding daily gaged flow records with the following limits: (1) all daily excess flow values that greater than 130 cfs were set to 130 cfs; and (2) any excess flow values that were greater than the gaged flow value for that day was set to the gaged flow values so that the resulting adjusted gaged flow was zero.

Table 8-2 lists summary statistics for the MIKE SHE modeling period for: (1) the excess flows used for the minimum flows analysis; (2) the Method 1 excess flows (with 130 cfs cap, but excess flows could exceed gaged flows); and (3) the unedited excess flow values from the MIKE SHE model. These same statistics are listed on a monthly basis in Table 8-3.

Table 8.2 Statistics for total excess flows calculated under three constraints: (1) for the minimum flows analysis (direct from MIKESHE with 130 cfs cap and no daily excess flows greater than the same-day gage flow); (2) Method 1 (from MIKESHE with 130 cfs cap only); and (3) unedited values from MIKESHE. All values calculated from the entire MIKESHE modeling period and expressed as cfs.

Excess flow method	**Mean**	**St. dev.**	**Minimum**	**Maximum**
Minimum Flow (Method 1 capped to gage)	38.7	44.1	-48.2	130
Method 1 (MIKE SHE 130 cfs cap only)	40.7	44.6		
MIKE SHE unedited	55.9	92.1		980

Table 8.3 Monthly statistics for total excess flows calculated under three constraints: (1) for the minimum flows analysis (direct from MIKESHE with 130 cfs cap and no daily excess flows greater than the same-day gage flow); (2) Method 1 (from MIKESHE with 130 cfs cap only); and (3) unedited values from MIKESHE. All values expressed as cfs.

Month	**Excess flow method**	**Mean**	**St. dev.**	**Minimum**	**Maximum**
	Minimum Flow (Method 1 capped to gage)	18.1	18.6	-24.8	130
Jan	Method 1 (MIKESHE 130 cfs cap only)	18.3	18.6		
	MIKKESHE unedited	18.3	18.7		136
Feb	Minimum Flow (Method 1 capped to gage)	17.4	18.5	-24.8	130
	Method 1 (MIKESHE 130 cfs cap only)	18.2	20.1		
	MIKKESHE unedited	19.1	27		283
Mar	Minimum Flow (Method 1 capped to gage)	20.6	24.4	-27.6	130
	Method 1 (MIKESHE 130 cfs cap only)	21	25.2		
	MIKKESHE unedited	22.9	35.9		324
Apr	Minimum Flow (Method 1 capped to gage)	19	23.1	-11.2	130
	Method 1 (MIKESHE 130 cfs cap only)	20.9	25.4		
	MIKKESHE unedited	22.1	32.4		
May	Minimum Flow (Method 1 capped to gage)	22	28.9	-7.2	130
	Method 1 (MIKESHE 130 cfs cap only)	26.5	30.3		
	MIKKESHE unedited	27.6	34.6		217
Jun	Minimum Flow (Method 1 capped to gage)	45.2	49.1	-15.9	130
	Method 1 (MIKESHE 130 cfs cap only)	52.3	49.5		
	MIKKESHE unedited	88.5	145.6		980
Jul	Minimum Flow (Method 1 capped to gage)	89.7	46.6	1	130
	Method 1 (MIKESHE 130 cfs cap only)	94.8	42.9		
	MIKKESHE unedited	174.2	153.7		719
Aug	Minimum Flow (Method 1 capped to gage)	94	38.3	4.7	130
	Method 1 (MIKESHE 130 cfs cap only)	94	38.2		
	MIKKESHE unedited	126.4	90.7		604
Sep	Minimum Flow (Method 1 capped to gage)	73.9	43.6	-26	130
	Method 1 (MIKESHE 130 cfs cap only)	75.7	43.4		
	MIKKESHE unedited	100.1	90.6		692
Oct	Minimum Flow (Method 1 capped to gage)	33	41.6	-48.2	130
	Method 1 (MIKESHE 130 cfs cap only)	33.4	42.1		
	MIKKESHE unedited	36.1	49.5		244
Nov	Minimum Flow (Method 1 capped to gage)	13.4	20.8	-31.7	130
	Method 1 (MIKESHE 130 cfs cap only)	13.5	21.1		
	MIKKESHE unedited	14.7	31.2		416
Dec	Minimum Flow (Method 1 capped to gage)	16.1	21.4	-25.5	130
	Method 1 (MIKESHE 130 cfs cap only)	16.7	22.1		
	MIKKESHE unedited	16.9	23.9		226

As expected, the unedited excess flows predicted by the MIKE SHE model had the highest mean values among the three groups, averaging 55.9 cfs for entire modeling period (Table 8-2). The mean excess flow for Method 1 (40.7 cfs) was 2 cfs greater than the mean excess flow for the minimum flows analysis (38.7 cfs). This largely resulted from differences in values calculated by these two conditions during the late spring and early summer (May through July in Table 8-3). Differences in monthly mean values for these two methods were fairly small during the other months, indicating the times when the model predicted daily excess flows were greater than the gaged flows occurred primarily during the late spring and early summer.

The next step was to examine what proportion of the gaged flows were comprised by the excess flows calculated for the minimum flows analysis. A monthly bar chart of average vales for monthly gaged and excess flows is shown in Figure 8-6. Monthly average total excess flows were the greatest in July and August (near 90 and 94 cfs) and least in November (13.4 cfs). Proportionately, excess flows comprised the higher proportion of gaged flows in May (34%) and least (6% to 10%) from October through March.

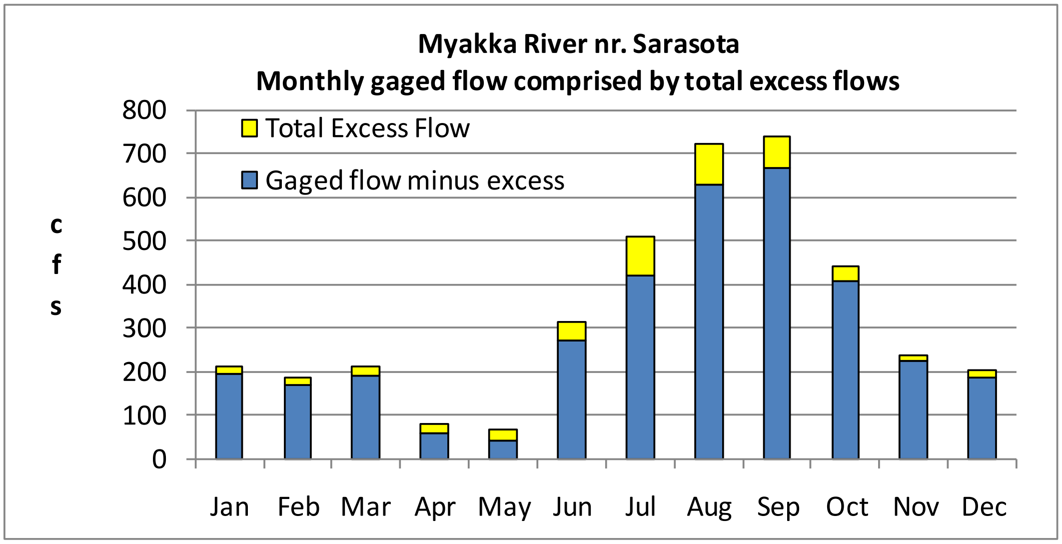


Figure 8-6. Average monthly values of for gaged flows at the Myakka River nr. Sarasota with proportion comprised by total excess flows used in the minimum flows analysis (sum of blue and yellow bars equals total gaged flow). Values calculated for the MIKE SHE modeling period.

Yearly hydrographs of daily gaged flows and adjusted gaged flows (minus total excess flows) are shown in Appendix 8F, with plots for 1995 and 2002 shown in Figure 8-7. For most part, the adjusted gaged flows looked very reasonable compared to the gaged flows, although some unusual values occurred in the fall of 1996 (Appendix 8F). However, this was very dry year and the difference between the gaged flows and the adjusted flows were not unusually large on an absolute basis. A box plot of monthly flows for gaged flows and adjusted gaged flows show a similar pattern, with lower values for adjusted flows due to subtraction of the excess flows (Figure 8-8).

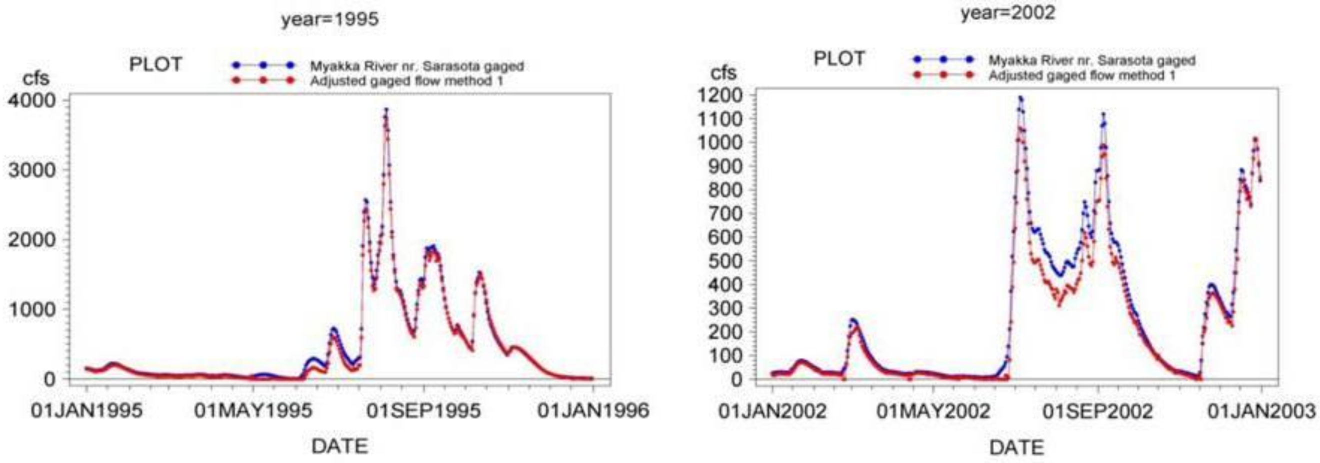


Figure 8-7. **Hydrographs of daily gaged flows and adjusted gaged flows at the Myakka River near Sarasota for 1995 and 2002.**

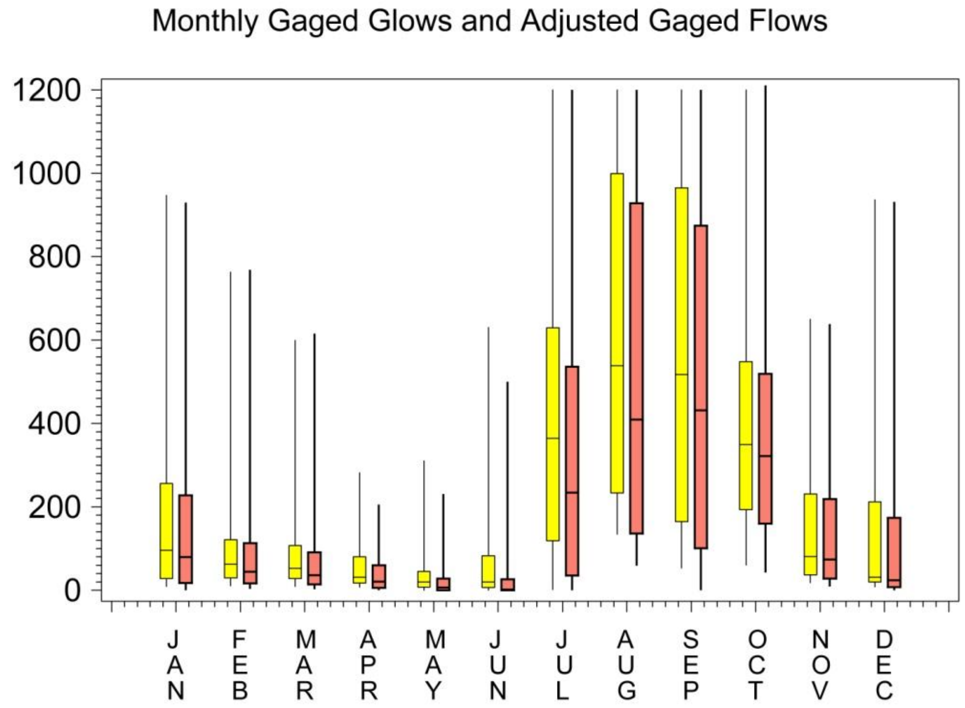


Figure 8-8. **Box plot of monthly values for gaged (yellow) and adjusted gaged flows at the Myakka River near Sarasota (orange). Top of whiskers (90th percentile) truncated at 1200 cfs.**

It is also informative to examine what proportion of the gaged flows were comprised by the adjusted excess flows used for the minimum flows analysis. Percentages of the daily gaged flows at the Myakka River near Sarasota comprised by the adjusted excess flows are plotted against the gaged flows in Figures 8-9 and 8-10. Excess flows frequently comprised over 10% of the gaged flows up to flows of about 700 cfs (Figure 8-9). The percent of gaged flows comprised by excess flows increased as gaged flows diminished (Figure 8-10). It was common for excess flows to comprise from 50% to 100% of the gaged flows at flows less than 20 cfs.

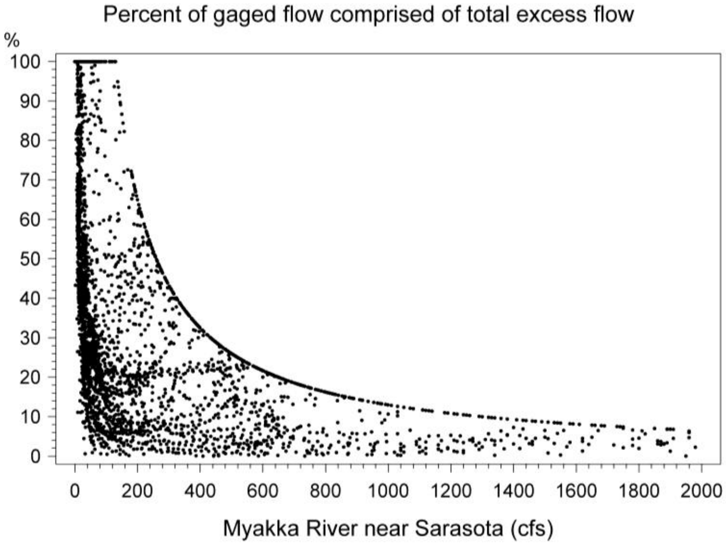


Figure 8-9. Percentages of daily flows at the Myakka River near Sarasota gage comprised by the adjusted total excess flows.

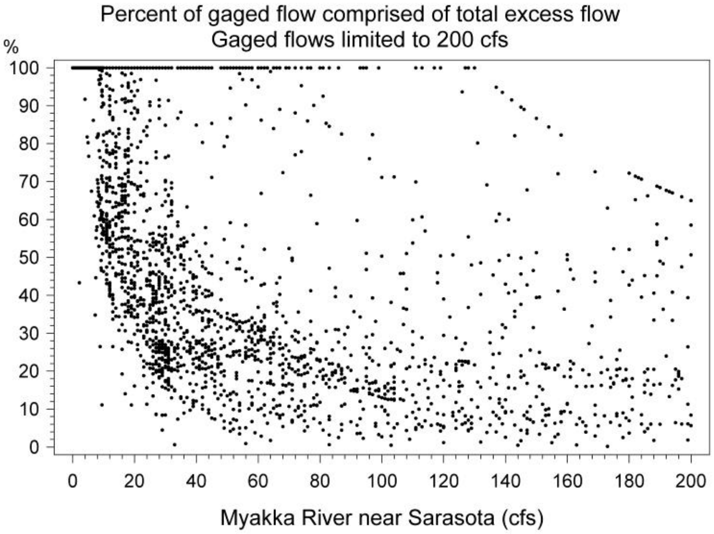


Figure 8-10. Percentages of daily flows at the Myakka River near Sarasota gage comprised by the adjusted total excess flows with the scale of the x axis limited to 200 cfs.

Although excess flows from the MIKE SHE model were available for May 1994 through April 2006, the District only used excess flow values from a ten-year period from 1995 – 2004 for the minimum flows analysis. The 1995 starting date was selected so that data only from complete years was included to keep the analyses seasonally balanced. The ending date of Dec. 31, 2004 was selected because a number of other minimum flows analyses that used data updated through 2004 were well underway when the MIKE SHE output became available. The ten-year period selected for analysis captured 83 percent of the entire MIKE SHE modeling period, and included very low flow years (1996, 2000, 2001) and high flow years (1995, 1998, 2003). Monthly bar graphs of mean and median values for adjusted excess flows for the 1995-2004 and complete MIKE SHE periods are shown in Figure 8-11. The monthly mean and median values were very similar, indicating the ten-year period was representative of the entire 12-year MIKE SHE modeling period.

All remaining comparisons of flows for the minimum flows study refer to the 1995-2004 study period. Monthly summary statistics for the excess flows for this period are listed in Table 8-4. Monthly mean excess flows ranged from 13.8 cfs in November to 100.2 cfs in August, while monthly median excess flows ranged from 7.9 cfs in November to 130 cfs in July. These statistics represent the final excess flows on which the analysis of minimum flows for the lower river was based, and are important when comparing the findings of this study to management plans are being developed for the upper river sub-basin.

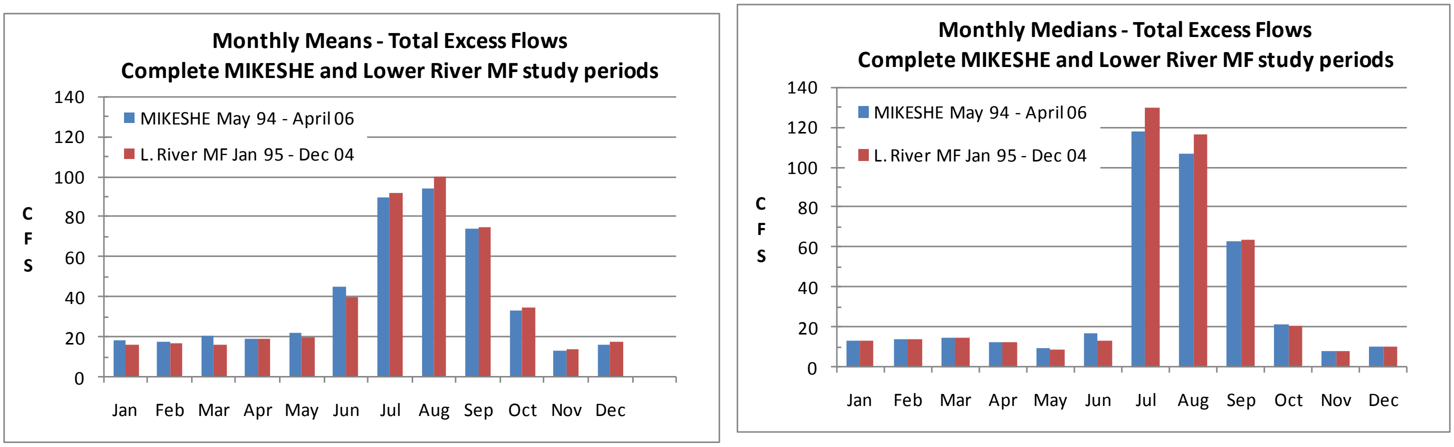


Figure 8-11. Monthly mean and median values for excess flows for the 1994-2004 minimum flow study period and the May 15, 1994 – April 30, 2006 MIKE SHE modeling period.

Table 8-4. Monthly summary statistics for adjusted excess flows for the minimum flow study (1995-2004). All values in cfs

					Percentiles				
Month	**Mean**	**Std.**	**Min**	**Max**	**5th**	**25th**	**50th**	**75th**	**95th**
Jan	16.0	15.6	-24.8	112.0	0.3	8.0	13.1	17.8	55.0
Feb	17.0	19.3	-24.8	130.0	-0.4	7.1	14.2	20.5	34.0
Mar	16.1	17.1	-27.6	130.0	3.6	8.4	14.6	17.8	39.3
Apr	19.4	24.0	-11.2	130.0	3.3	6.5	12.5	19.0	70.4
May	19.8	27.6	-0.8	130.0	0.0	3.8	8.5	24.6	69.0
June	40.0	47.6	-15.9	130.0	0.0	5.9	13.0	67.2	130.0
Jul	91.8	48.6	0.1	130.0	1.7	47.3	130.0	130.0	130.0
Aug	100.2	35.7	17.9	130.0	28.2	74.3	116.7	130.0	130.0
Sep	74.6	43.3	-26.0	130.0	11.8	36.6	63.7	130.0	130.0
Oct	34.9	43.6	-48.2	130.0	-18.5	6.2	20.2	59.1	130.0
Nov	13.8	21.7	-31.7	130.0	-7.9	5.2	7.9	13.1	54.9
Dec	17.5	23.0	-25.4	130.0	1.1	7.7	10.2	18.0	69.6

8.2.3. Comparison of adjusted flows to gaged flows for different periods

The adjusted gaged flows were compared to early streamflow records for the Myakka River as a check for the reasonableness of the adjusted flows. In other words, does subtracting the excess flows from the gaged records produce adjusted flows that are comparable to gaged flows for the early 1937-1978 period, when augmentation of the upper river's flows by agricultural land and water use was minor. The initial check involved determining if the adjusted gaged flows contained an inordinate number of zero flow days. Since very low flow rates near zero cfs are reported in the gaged record, the average number of days with flows < 1 cfs were compared between the adjusted flows from the minimum flow study period and gaged flows from 1937-1978 (figure 8-12). On a yearly basis the number of days were very similar between the two periods, at 55 days for the gaged flows during 1937-1978 and 50 days for the adjusted gaged flows for 1995-2004.

Viewed on a monthly basis, there were generally similar patterns between the two periods, but some seasonal deviations in the number of days with flows < 1 cfs (Figure 8-12). The 1937-1978 gaged period had more days <1 cfs than the adjusted records for the months February through May. Conversely, the adjusted flow records had more days < 1 cfs in June and especially July. The early gage record did not show any near-zero flow days during August through October, whereas the adjusted flows had very low average values (< 2 days per month). This may have resulted from routing timing issues for the modeling of storm peaks when the daily flow record for the model is compared to the gaged record (see Appendix 8A). Capping the excess flows at 130 cfs probably reduced the number of near-zero flow days from what would have occurred in the adjusted flows data set in the wet season had the cap not been applied.

In general, though, the number of days < 1 cfs was generally comparable for the early gaged record and the adjusted records for the recent period, supporting the validity of the excess flow estimates. However, as previously discussed, differences in rainfall between these two periods can affect the certainty of this analysis.

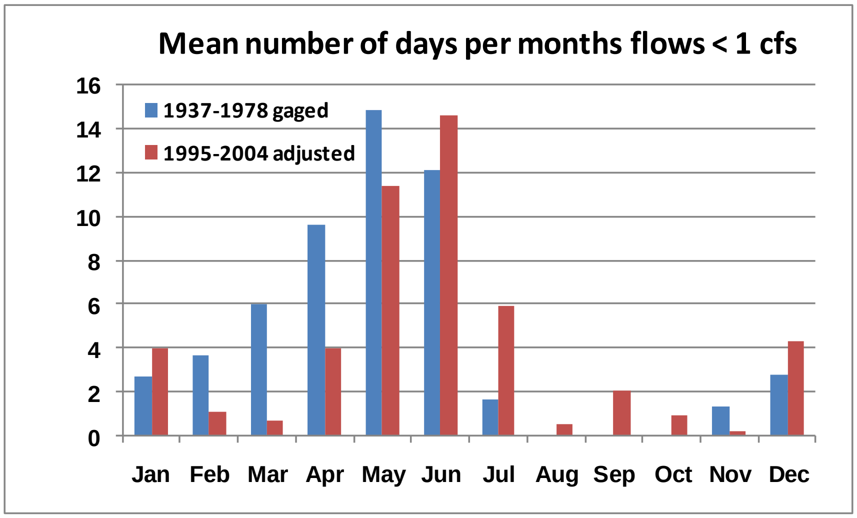


Figure 8-12. Mean number of days per month with flows <1 cfs at the Myakka River near Sarasota gage for 1937-2008 and adjusted flows at the gage site for 1995-2004.

Flow duration analysis was also conducted to examine how the adjusted flows for the minimum flows analysis compared to gaged flows from various time periods. As described in Chapter 2, a number of streamflow parameters have shown increasing trends at the Myakka River near Sarasota gage, with a pronounced increase in a number of parameters in the late 1970s due to increased agricultural land use and irrigation. Figure 8-13 shows flow duration curves for gaged flows for three time periods at the Myakka River near Sarasota gage: the early gaged period (1937-1978); the recent gaged period (1979-2007); and the period of the minimum flows analysis (1995-2004). A flow duration curve is also included for the adjusted flow data for 1995-2004. Data were limited to those years for which published records were available for complete years at the time of this analysis (1937-2007).

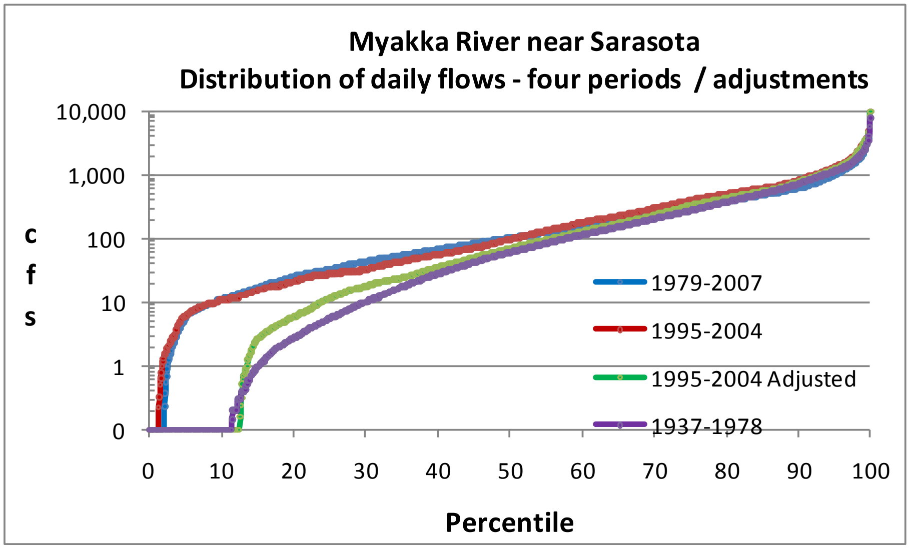


Figure 8-13. Flow duration curves for gaged flows at the Myakka River near Sarasota for three time periods (1937-1978, 1979-2007, and 1995-2004) and adjusted flows at the gaged site for 1995-2004.

Table 8-5. Percentile values for gaged flows at the Myakka River near Sarasota for four periods: period of record (1937-2007); early gaged period (1937-1978); recent gaged period (1979-2007); and minimum flows study period (1995-2004)

	period of record	early gaged	recent gaged	minimum flows unadjusted	minimum flows adjusted
Percentile	**1937 - 2007**	**1937-1978**	**1979-2007**	**1995-2004**	**1995-2004**
1	0	0	0	0	0
5	0	0	6	6	0
10	1	0	11	11	0
20	9	3	25	21	6
30	23	10	43	33	18
40	46	28	68	56	35
50	80	60	102	97	69
60	132	114	153	179	128
70	220	205	239	299	233
80	376	374	379	504	426
90	675	720	621	823	768
99	2250	2330	2120	3070	2940

Table 8-5 lists values for selected percentile values for the flow data that appear in Figure 8-13. The flow duration curves for the gaged records from the recent (1979-2007) and minimum flow study (1995-2004) periods include some of the highest flow values at each percentile, particularly at the lower flows. Tenth percentile flows are 0 cfs for the early gaged period, but 11 cfs for the recent and minimum flow study periods (Table 8-5). Similarly, the median flow for the early period (60 cfs) is considerably less than the medians for the recent and minimum flow study periods (102 and 97 cfs). The curves do not show as much relative divergence at high flows. Percentile values above the 70th percentile are very similar for the early and recent gaged periods. However, high flows were significantly higher in the unadjusted flow record for the minimum flow study period, as the upper percentile values for 1995-2004 were above the corresponding percentile values for other time periods.

Subtraction of the excess flows from the gaged record causes the adjusted gaged record for the minimum flow study to be similar to the flow duration characteristics of the early gaged period. To compare the similarity of the data, the percentile values for the adjusted flows are expressed as percentages of the corresponding percentile flows for the unadjusted gaged records for three periods in Table 8-6. The word “same” is inserted in the table for those percentile flows for which both the adjusted flows and the gaged were 0 cfs.

Table 8-6. Comparison of percentiles for the adjusted gaged record adjusted for 1995-2004 to unadjusted gaged records for the early gaged (1937-1978), recent gaged (1979-2007), and minimum flow study (1995-2004) periods.

Percentile	Adjusted flows (cfs)	Percent of unadjusted flows 1937-1978	Percent of unadjusted flows 1979-2007	Percent of unadjusted flows 1995-2004
1	0	same	same	same
5	0	same	0%	0%
10	0	same	0%	0%
20	6	215%	23%	28%
30	18	175%	41%	53%
40	35	126%	52%	63%
50	69	115%	68%	71%
60	128	112%	84%	71%
70	233	114%	98%	78%
80	426	114%	113%	85%
90	768	107%	124%	93%
99	2940	126%	139%	96%

Both the adjusted flows and the early gaged flows had 0 cfs for the tenth percentile and below. The adjusted flows were greater than the early gaged flows at the 20th and 30th percentiles by 215% and 175%, respectively, indicating that subtracting the excess flows had not caused unrealistic reductions in the low-flow characteristics of the river. If anything, the low-flow characteristics of the adjusted flows are a bit higher than the low flows during the early gaged period. This finding was not caused by unusually high low flows during the minimum flow study period, as the lower percentile flows for the unadjusted gaged flows for 1995-2004 were the same or lower than the corresponding unadjusted gaged flows for the longer (1979-2007) recent gaged period (Table 8-5).

For the 40th to the 99th percentiles, the adjusted gaged flows range between 107% and 126% of the corresponding percentile values for the early gaged period, again indicating that subtraction of the excess flows did not result in unrealistic values for the adjusted gaged record. However, as described above, the minimum flows study period had very high flows which may have influenced these results.

Although the comparison of flow duration curves suggests the adjusted flows are very plausible when compared to the early gaged record, the adjusted flows represent substantial flow reductions when compared to the unadjusted flows for the recent and minimum flow study periods. The 20th percentile flow for the adjusted record is 23% and 28% of the corresponding percentile flows for the recent unadjusted and minimum flow study periods, respectively. The median flow for the adjusted record is 68% and 71% of the median flows for the recent and minimum flow study period flows. The percentage differences diminish at high flows, as the upper quartile flows for the adjusted flows are actually greater than the unadjusted flows for the recent gaged period. Again, the high flows that occurred during 1995-2004 period likely influenced these results. Also, limiting the excess flows to 130 cfs reduced the effect of subtracting the modeled excess flows on the gaged flow record.

In sum, when examining the duration characteristics of flows collected throughout the year, the adjusted flow records appear very reasonable when compared to the early gaged record, which spans 42 years However, the adjusted flows represent substantial flow reductions from the recent gaged record, particularly at low flows. To examine how the adjusted flows compare to the early and recent gaged records on a monthly basis, a box plot of monthly flows for these three conditions is presented in Figure 8-14. Figure 8-15 presents the same information omitting the months of July through October and reducing the scale of the y axis so that more differentiation can be seen in the dry season months.

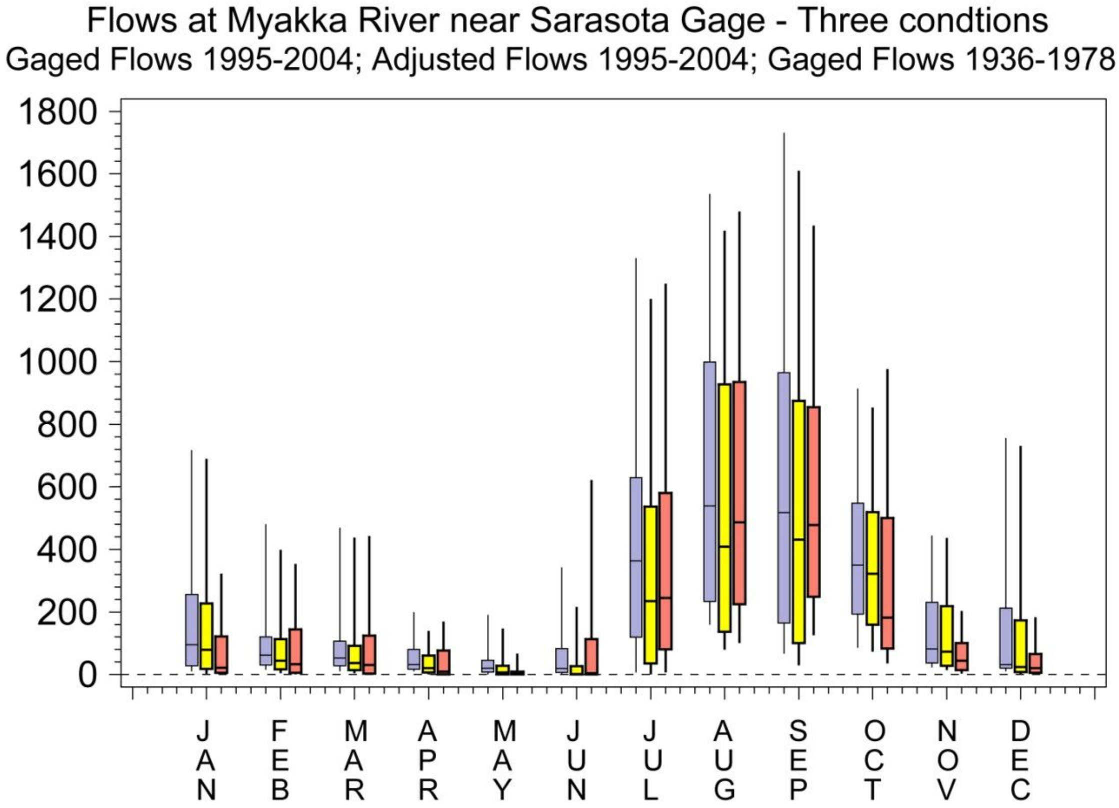


Figure 8-14. Box plot of monthly values of gaged flows for 1995-2004 (gray), adjusted gaged flows for 1995-2004 (yellow), and gaged flows for 1937-1978 for the Myakka River near Sarasota (orange).

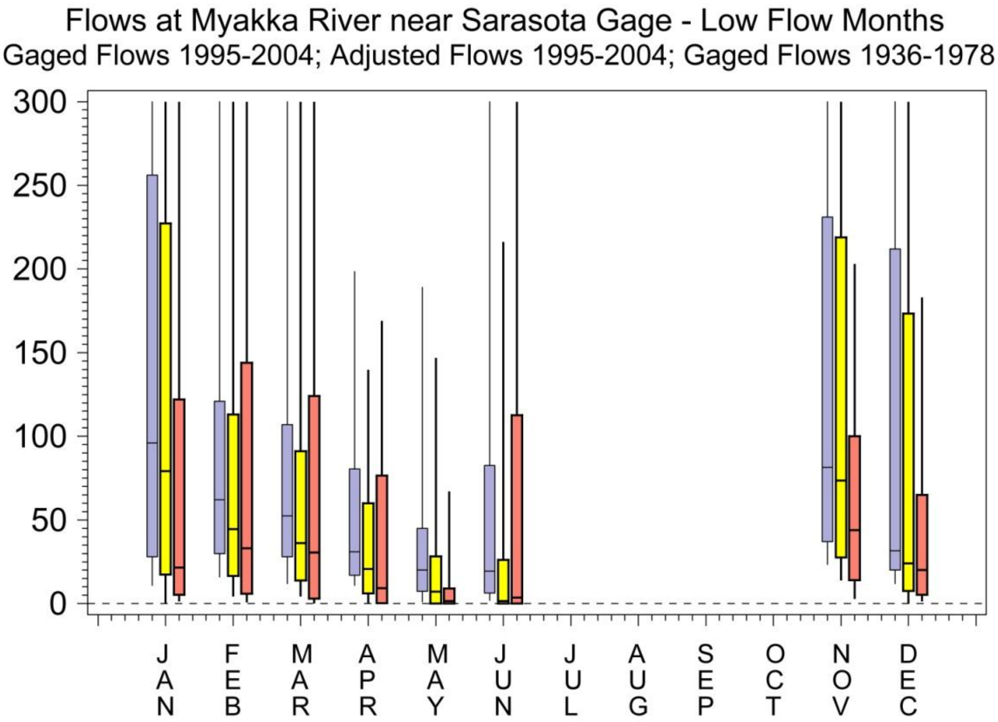


Figure 8-15. Box plot of monthly values for November through June for gaged flows for 1995-2004 (gray), adjusted gaged flows for 1995-2004 (yellow), and gaged flows for 1937-1978 for the Myakka River near Sarasota (orange). Vertical axis truncated at 300 cfs.

In all months except July through September, the medians for the unadjusted gaged flows are greater than the adjusted gaged flows, which are in turn greater than the medians for the early gaged flows (Figure 8-15). Lower quartile values also follow this pattern, except during May and June when the lower quartile values for the adjusted flows and the early gaged flows are zero. These results also confirm that the adjusted flows do not increase the occurrence of low flows within each month compared to the early gaged record. It is again emphasized, however, that differences in rainfall between the two periods can affect the certainty of this analysis.

The pattern for upper quartile flows is not so consistent. The upper quartile values for the adjusted flows are greater than the upper quartile values for the early gaged record for November through January, indicting the higher flows within those months tend to vary more in the 1995-2004 period than during the early gaged record. Conversely, upper quartile values for the gaged flow record are markedly higher in June, indicating the removal of excess flows is dampening the variation of flows in that month. This could be a cause for concern in the lower river, for June often represents the time when the first pulse of high flows is received by the estuary. Plots of modeled excess flows with gaged flows also indicates this is when the MIKE SHE model often predicts high excess flows relative to gaged flows at the beginning of the summer wet season (Appendix 8B). This finding probably accurately reflects changes in runoff characteristics in June, as excess irrigation water fill storages in wetlands, soils and the surficial aquifer, which would have absorbed early wet-season high runoff events in a less altered watershed. Other changes such as the construction of dikes and impoundments in the Tatum Sawgrass area also contribute to high excess flows in the beginning of the summer wet season.

For the months July through September, median values and lower quartile values for the adjusted flows are lower than the corresponding values for the early gaged flows (Figure 8-12). This could indicate that the subtraction of excess flows overestimates the effects of land changes in the wet season. However, this could result from higher wet season rainfall in the early part of the gaged record corresponding to the Atlantic multi-decadal oscillation (Kelly 2004). Regardless, caution should be used in development of management plans that divert high rates of excess flow, particularly at the beginning of the wet season.

8.3 Selection of flow reduction scenarios for the minimum flows analysis

The minimum flows analysis was conducted by applying a series of flow reduction scenarios to models that predict the response of key variables in the Lower Myakka River estuary to changes in freshwater flow. Comparison of these results in a sequential manner allows for the determination of what flow reductions will result in significant harm to the Lower Myakka River.

The initial flow reduction that was tested was comprised by the maximum withdrawals allowed by the City of North Port's water use permit for withdrawals from Myakkahatchee Creek. As described on pages 2-13 and 2-23, withdrawals by the City can range from 3.2 to 9.3 cfs depending on the rate of flow in the creek. This scenario was conducted to determine if existing permitted withdrawals from Myakkahatchee Creek by the City can result in significant harm to the lower river. As will be discussed in a subsequent section, this has not occurred because the effects of the City's withdrawals on the lower river are very small.

The second scenario involved subtracting the adjusted total excess flows from the river at the location of the Myakka River near Sarasota gage. This was done twice: (1) by itself with no other withdrawals; and (2), in combination with the maximum withdrawals permitted to the City of North Port. Simulations were also performed subtracting the adjusted excess flows that resulted from agriculture and these results are presented in a number of figures and tables. However, the final emphasis was placed on the total excess flows, since these are the flows that are being considered for removal or reduction in management plans for the upper river sub-basin

The next scenarios involved removing percentages of the daily flows at the Myakka River near Sarasota gage that remained after subtracting the total excess flows from the gaged flow records. Flow reductions of 10%, 20%, and 30% of these remaining flows were simulated. These percentage withdrawals from the main stem of the river were applied along with simulated withdrawal from Myakkahatchee Creek that are permitted to the City of North Port.

8.4. Hydrologic conditions during minimum flows modeling periods

The minimum flows for the Lower Myakka River were based on mechanistic and empirical modeling of salinity and ecological variables in the Lower Myakka River. As described above, a ten-year period from 1995-2004 was used as the baseline period for the modeling scenarios of the lower river in order to incorporate the period when excess flows from the upper river sub-basin were available for simulation. However, it was necessary to limit the simulations of salinity distributions in the lower river using the District's hydrodynamic model to a four-year period from 1999-2002.

As described in Chapter 5 and Appendix 5A, a mechanistic hydrodynamic model of the Upper Charlotte Harbor that included detailed grids in the Lower Peace and Myakka rivers was used to simulate changes in the water volumes and bottom areas of different salinity zones in the Lower Myakka. This model was also the primary tool for assessing minimum flows for the Lower Peace River (SWFWMD 2010b), which were evaluated simultaneously, but completed before the minimum flows for the Lower Myakka River.

Because of the long computing times required to run the hydrodynamic model and the need to run multiple flow scenarios, it was necessary to restrict the modeling scenarios to four-year periods. Analyses of seasonal flows for the Lower Peace River indicated that a four-year period from 1999-2002 was the most suitable period for representing the recent (1985-2004) flows that were assessed for that river. Because potential withdrawals from both the Peace and Myakka Rivers will affect freshwater inflows to Upper Charlotte Harbor, there was a desire to run the model for the Lower Myakka River for the same period so the effect of cumulative withdrawals in the study area could be simulated. Therefore, the 1999-2002 period was also selected for simulating the effects of freshwater withdrawals on salinity distributions in the Lower Myakka using the District's hydrodynamic model.

Because seasonal and inter-annual variations in the magnitude of freshwater inflows exert a strong influence on the modeling results, the variations in freshwater inflows during the 1995-2004 and 1999-2002 modeling periods are compared below. Comparisons are also shown for how the various withdrawal scenarios affected freshwater flow to the lower river within these two time periods. These results help put the findings of the estuarine modeling scenarios presented in subsequent sections into better context.

A hydrograph of daily flows at the Myakka River at Sarasota for the 1995-2004 is shown in Figure 8-16 with the hydrodynamic modeling period from 1999-2002 delineated. The 1999-2002 period was generally dry and included one of the most severe droughts on record during 2000 and 2001. High flows occurred during the summer of 2001, but a period of low flows resumed in the winter and spring of 2002. Flows at the Myakka River near Sarasota gage and the adjusted gaged flows are plotted by year from 1995-2004 to Appendix 8F.

A comparison of flow duration values for the 1999-2002 period to the recent gaged (1979-2007) and minimum flows baseline period (1995-2004) confirm the four-year hydrodynamic modeling period was generally dry (Table 8-7). This comparison was restricted to the Myakka River at Sarasota because this is where gaged flow values for these three time periods are available.

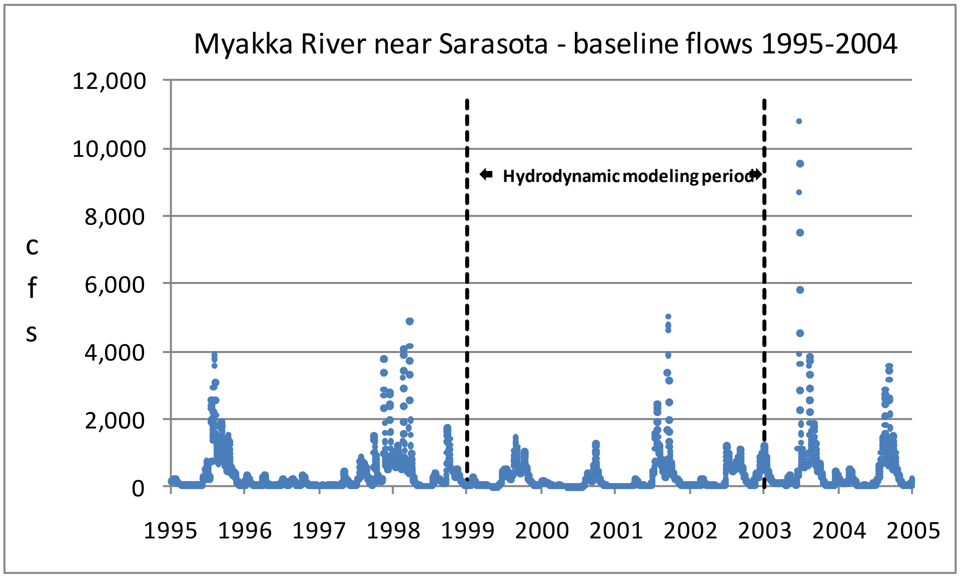


Figure 8-16. Baseline flows (no adjustments) at the Myakka River near Sarasota gage for 1995-2004 with the hydrodynamic modeling period from 1999-2002 delineated.

Percentile flow values below the 60th percentile were particularly low for the 1999-2002 period, never exceeding 68% of the corresponding percentile flows for the other two periods except for the first percentile flow which was zero in all cases. For the higher percentile flows the four-year period was very similar to the 29-year recent gaged record, but still less than the higher percentile flows for the 1995-2004 minimum flows baseline period. As previously discussed, the ten-year minimum flows baseline period had high values for the higher percentile flows due to high wet season flows that occurred during 1995, 2001, 2003 and 2004, plus unusually high winter-time flows that occurred in the El Nino years of 1997 and 1998 (Figure 8-16).

Table 8-7. Selected percentile flows (cfs) for the USGS Myakka River near Sarasota gage for the recent gaged (1979-2007), minimum flows baseline (1995-2002), and the hydrodynamic modeling (1999-2002) periods, with percentages of the percentile flows for the hydrodynamic period to the corresponding percentile flows for other two periods. All values based on unadjusted flows at the USGS gage.

Percentile	recent gaged 1979-2007	minimum flows baseline 1995-2004	hydrodynamic modeling 1999-2002	1999-2002 % of 1979-2007	1999-2002 % of 1995-2004
p1	0	0	0	same	same
p10	11	11	8	68%	68%
p20	25	21	12	48%	57%
p30	43	33	22	51%	67%
p40	68	56	31	46%	55%
p50	102	97	50	49%	52%
p60	153	179	103	67%	58%
p70	239	299	229	96%	77%
p80	379	504	410	108%	81%
p90	621	823	625	101%	76%
p99	2120	3070	1690	80%	55%

It is also useful to examine flow duration statistics within the three seasonal blocks that were used in the minimum flows analysis. Table 8-7A lists percentile values for flows at the Myakka River near Sarasota gage for the spring dry season (Block 1: March 1 – June 20), the fall – winter intermediate flows (Block 2: Oct. 28 – Feb. 28) and the summer wet season (Block 3: June 21 – Oct 27.)

Flows in the Block 1 were particularly low in the 1999-2002 period, with the percentiles during that four-year period never exceeding 63% of the corresponding percentiles for 1995-2004. Flow percentiles in Block 2 were similarly lower in the four-year period, but not quite to the same degree. The percentile flows were much more similar between the two periods in Block 3. Percentiles below the median in Block 3 were higher for the four-year period and between 76% and 93% if the ten-year values for the percentiles above the median. High flows during the summer of 2001 influenced these results (Figure 8-16). In sum, the hydrodynamic modeling period was considerably drier for blocks 1 and 2, but similar to the longer ten-year period for Block 3.

Table 8-7A. Percentile values of flow at the Myakka River near Sarasota gage within three seasonal blocks for the ten-year period from 1994-2004 and the four-year period from 1999-2002.

	Block 1 (March 1 - June 20)			**Block 2 (Oct. 28 - Feb. 28)**			**Block 3 (June 21 - Oct. 27))**		
Percentile	1995-2004 (cfs)	1999-2002 (cfs)	Percent 4 yr / 10 yr	1995-2004 (cfs)	1999-2002 (cfs)	Percent 4 yr / 10 yr	1995-2004 (cfs)	1999-2002 (cfs)	Percent 4 yr / 10 yr
1	0	0	same	7	6	86%	1	0	12%
10	5	0	10%	15	10	65%	53	54	103%
20	10	5	54%	24	14	58%	133	180	135%
30	15	9	63%	31	27	87%	208	264	127%
40	23	12	52%	45	31	69%	307	356	116%
50	29	14	48%	68	41	60%	442	441	100%
60	42	22	52%	101	51	50%	532	494	93%
70	61	27	44%	166	73	44%	636	577	91%
80	104	32	31%	282	119	42%	889	724	81%
90	230	77	33%	592	246	42%	1410	1070	76%
99	795	233	29%	2420	906	37%	3840	3140	82%

To better understand the results of the estuarine modeling, it is helpful to first examine the effects of the various flow reduction scenarios on inflows to the lower river. Withdrawals were simulated from both the Myakka River and Myakkahatchee Creek, with withdrawals from the creek limited to the maximum amounts allowed by the City of North Port's water use permit. Figure 8-17 shows hydrographs of unadjusted flows for both the Myakka River at Sarasota and Big Slough Canal (Myakkahatchee Creek at Tropicaire Blvd.) for the study period from 1995-2004. Flows for Myakkahatchee Creek prior to June 2001 were estimated by regression as described on page 2-20**.** Including both measured and predicted values, the mean flow for Myakkahatchee Creek at Tropicaire Blvd. (84 cfs) was 26 % of the mean flow for the Myakka River at Sarasota (326 cfs) for the ten-year minimum flows study period.

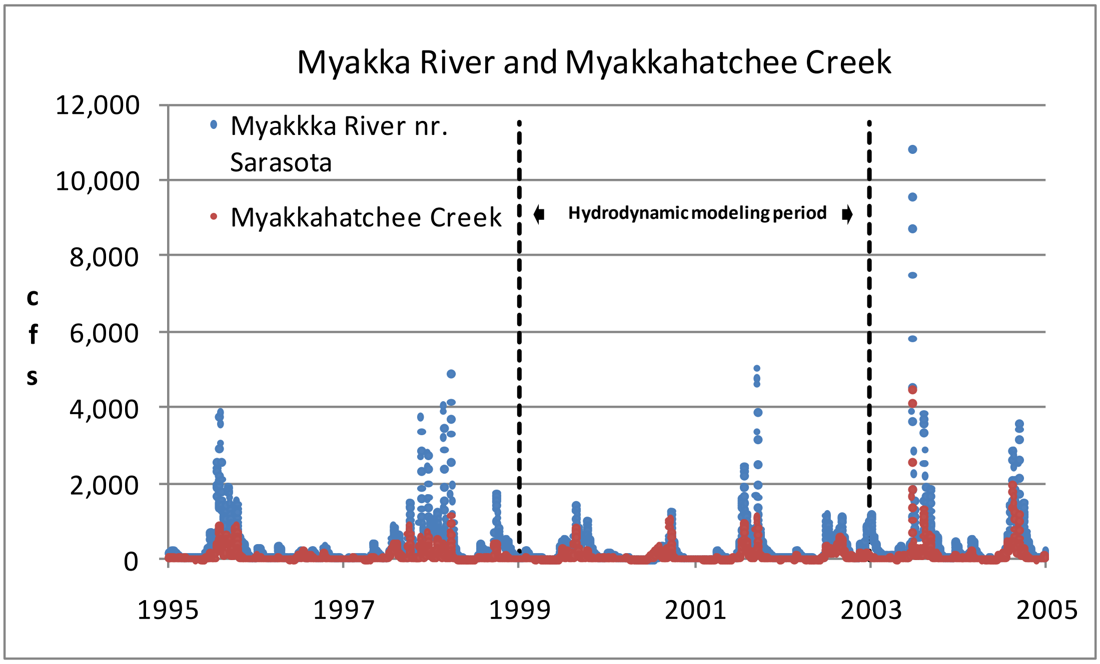


Figure 8-17. Daily flows for the Myakka River near Sarasota and Myakkahatchee Creek (Big Slough Canal) at Tropicaire Blvd. for 1995-2004 (flows for the creek prior to June 2001 were estimated by regression as described on page 2-22).

Figure 8-18 shows a hydrograph of the combined daily flows at the Myakka River near Sarasota and Myakkahatchee Creek at Tropicaire Blvd gages for the gaged baseline flows and the adjusted gaged flows in which the total excess flows are subtracted from the Myakka River gage. For visual clarity, a logarithmic scale is used on the y axis and only the total adjusted flow reduction scenario is shown, since this scenario plays such an important part in the minimum flows analysis. Combined baseline flows of less than 1 cfs occurred during six of the ten minimum flow study years.

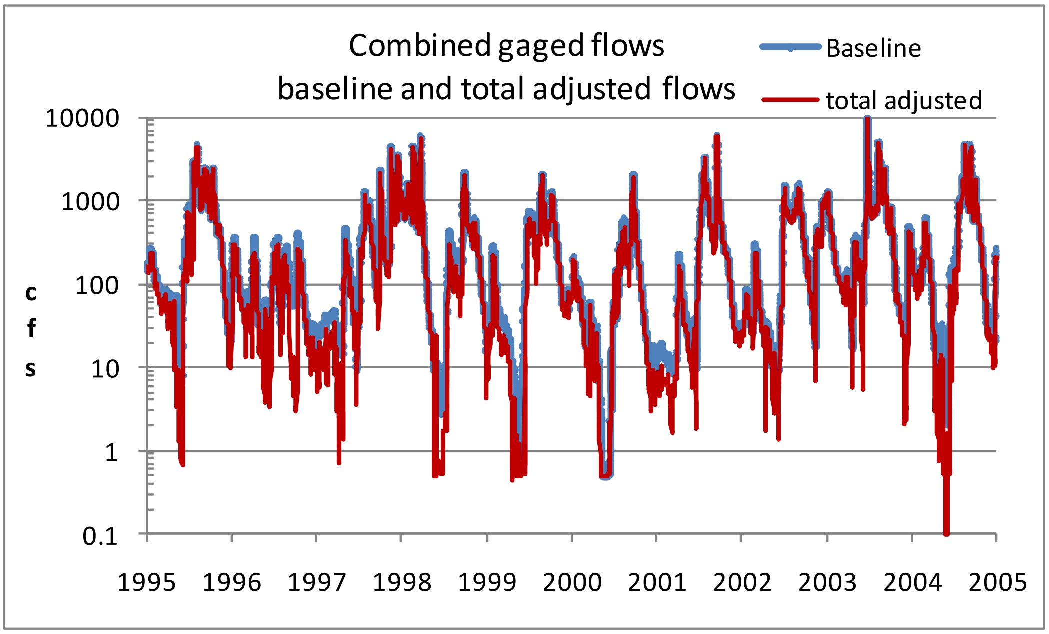


Figure 8-18. Daily combined flows for the Myakka River nr. Sarasota and Myakkahatchee Creek (Big Slough Canal) at Tropicaire Blvd. for baseline and total adjusted flows for 1995-2004. Flow rates of 0 cfs during 2004 were set to 0.1 cfs for plotting.

Flow duration values for the combined baseline flows and the flow reduction scenarios performed for the minimum flows analysis are listed in Tables 8-8 and 8-9 for the 1995-2004 and the 1999-2002 periods, respectively. Comparison of these tables again shows that the 1999-2002 hydrodynamic modeling period was comparatively dry. The median baseline flow for the 1999-2002 period (69 cfs) was 58 % of the median flow for the ten-year period (119 cfs) in which it was embedded.

The smallest flow reduction scenario that was simulated was the North Port permitted, which reduces the combined baseline flow by either 3.2 cfs, 6.2 cfs, or 9.3 cfs based on the rate of flow in Myakkahatchee Creek. The adjusted flow scenario, which reduces the flows at the Myakka River near Sarasota gage by the capped total excess flows reported by the MIKE SHE model, results in substantial reductions in baseline flows for both time periods, particularly at low flows. The 20th percentile values for the adjusted flows are half the corresponding values for baseline flows during both time periods, while the median values for the adjusted flows are near 80% of the median flows for baseline conditions for both time periods. The adjusted flows comprised higher percentages of the baseline flows at the higher flow percentiles, probably due in part to capping the excess flows in the minimum flows analysis to 130 cfs.

The magnitude of the flow reductions increase in both tables from left to right, as the North Port withdrawals from Myakkahatchee Creek and three percentage rates of withdrawal based on 10%, 20%, and 30% of the adjusted flows at the Myakka River near Sarasota gage are subtracted from the combined baseline flow along withdrawals that represent removal of the total excess flows from the upper river. These flow reductions represent the basic scenarios conducted for the estuarine modeling analyses presented in following sections.

Table 8-8. Selected percentile flows for the combined flows for the Myakka River near Sarasota and Myakkahatchee Creek (Big Slough Canal) at Tropicaire Blvd. for baseline conditions and six flow reduction scenarios. All values expressed as cfs for the minimum flows baseline period (1995-2004).

	Baseline	North Port Permitted	Adjusted Flow	Adjusted - North Port	Adjusted - North Port - 10%	Adjusted - North Port - 20%	Adjusted - North Port - 30%
p1	1	0	0	0	0	0	0
p10	14	12	6	3	3	3	3
p20	28	25	14	11	10	10	9
p30	43	39	27	23	21	20	18
p40	70	65	53	47	44	40	36
p50	119	113	94	89	82	74	67
p60	213	207	166	159	146	132	118
p70	350	341	285	278	254	231	209
p80	614	605	542	532	491	446	401
p90	1053	1044	990	981	898	815	742
p99	3799	3789	3670	3660	3382	3151	2859

Table 8-9. Selected percentile flows for the combined flows for the Myakka River near Sarasota and Myakkahatchee Creek (Big Slough Canal) at Tropicaire Blvd. for baseline conditions and six flow reduction scenarios. All values expressed as cfs for the hydrodynamic modeling period (1999-2002).

	Baseline	North Port Permitted	Adjusted Flow	Adjusted - North Port	Adjusted - North Port - 10%	Adjusted - North Port - 20%	Adjusted - North Port - 30%
p1	0	0	0	0	0	0	0
p10	11	9	4	2	2	2	2
p20	16	13	8	6	5	5	5
p30	29	27	18	16	15	13	12
p40	40	36	29	26	23	21	19
p50	69	65	56	50	47	43	39
p60	139	133	110	102	94	86	80
p70	282	274	230	222	204	185	165
p80	494	485	410	401	371	338	307
p90	833	824	716	707	657	608	560
p99	2305	2296	2213	2203	2016	1831	1681

8.5 Future management application of flow adjustments

Management plans are currently being evaluated by the District to either reduce (by agricultural BMPs) or remove (by surface water diversions) the excess flows from the upper river sub-basin. In recent reports, a series of management alternatives have been examined to remove the excess flows in the upper river sub-basin (Interflow 2009c, 2010a 2010b). These plans have focused on the excess flows to Flatford Swamp, since this is where the ecological impacts from the excess flows have been most apparent. The management plans that have been considered have investigated various infrastructure alternatives to divert the excess flows, including a reservoir to store excess flows so that reliable water supplies can be delivered to potential water users.

Plans have not yet been developed to remove, other otherwise remediate, excess flows that enter the river downstream of Flatford Swamp closer to the Myakka River near Sarasota gage. However, plans to address flow remediation in the more downstream reaches of the upper river sub-basin could be considered at a future date. To be conservative, the minimum flows analysis for the lower river assumed that all the excess flows in the upper river sub-basin would be withdrawn each day up to the daily limit of 130 cfs. This was done by simulating the removal of the adjusted excess flows at the location of the Myakka River near Sarasota gage for the 1995-2004 baseline period.

The quantities of water that have been considered for diversion in the upper river sub-basin at this time are generally similar to or less than the adjusted excess flow quantities used in the minimum flows analysis for the lower river. However, this is not the case at all times. Figure 8-19 shows hydrographs of monthly values for the adjusted excess flows used in the minimum flows analysis and the net excess flows to be removed by one possible option to construct a reservoir to store excess flows with a 20 cfs demand from the reservoir (Interflow 2010a, 2010b). This is shown only as an example, for a final plan to divert water from Flatford Swamp has not been established.

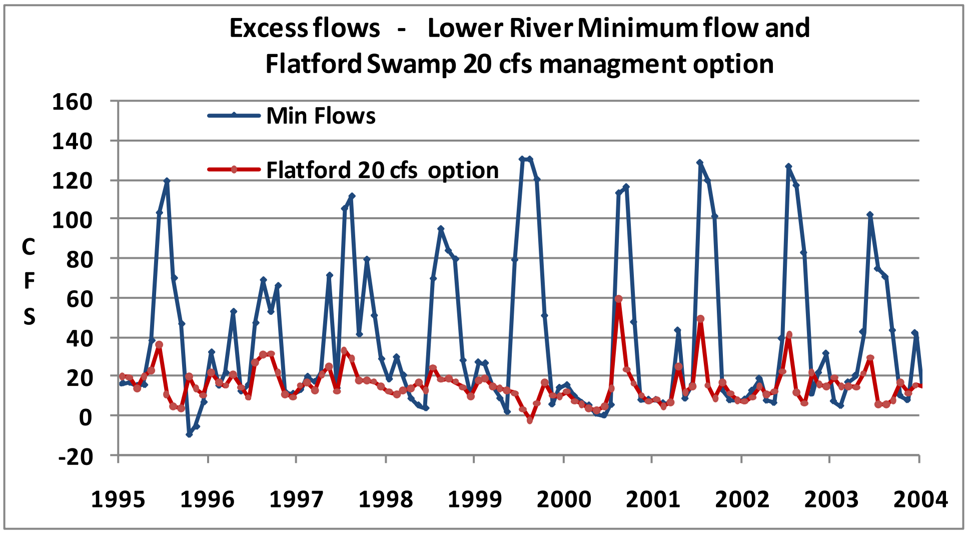


Figure 8-19. Monthly values of excess flows simulated in the minimum flows analysis for the lower river and the net excess flows that could be diverted with a reservoir and a 20 cfs demand as presented by Interflow (2010a).

The peak flows diverted by the management option are considerably less that the peak excess flows used in the minimum flows analysis, due to the limitations of the facilities in the management option to capture higher quantities of excess flow, and also because the management option would only remove the excess flows from the portion of the Upper Myakka River watershed that drains to Flatford Swamp (approximately 38% of the area above the Myakka River near Sarasota gage).

During some years (e.g., 1995, 1998, 1999, 2003), there are periods of 2 to 3 months when the excess flows to be removed as part of the management option are greater than the excess flows that were simulated for the minimum flows analysis. This occurs because some watershed alterations downstream of Flatford Swamp, particularly in the Tatum Sawgrass Area, can periodically act to reduce flows from the historic watershed condition, negating the excess flows that are entering the river upstream (John Loper, personal communication). This occurs during certain hydrologic conditions due to changes in the storage characteristics of the watershed. It appears that water storage in historic wetlands, which have since altered, tended to release water more slowly to the river than the current watershed condition. Therefore, historical flows were higher than existing flows in the river following some wet periods.

The excess flows for the management plan shown in Figure 8-19 were not simulated in the minimum flows analysis because the estuarine modeling was completed before these excess flow values were available. Also, it is emphasized the excess flows presented in Figure 8-19 are preliminary and are not for a final management plan for Flatford Swamp. The establishment of a funded hydrologic remediation plan for the Flatford Swamp and other areas of the upper river sub-basin has yet to be established, and could vary from the options heretofore examined.

It was beyond the scope of the minimum flows analysis for the Lower Myakka River to evaluate the effects of all possible flow remediation plans for the upper river sub-basin. Instead, the results presented in the following pages simulate the effects of the removal of the adjusted net excess flows at the location of the Myakka River near Sarasota gage as determined from model output made available in early 2009 (Interflow 2009c). If excess flow quantities being considered for diversion in the future are significantly greater than those analyzed in this minimum flows analysis, supplemental analyses may be necessary to quantify the effects of those diversions. The need for additional analyses and possible adaptive management strategies for the Lower Myakka River, in concert with management plans for the upper river sub-basin or other initiatives in the watershed, are discussed in Section 8-9.

8.6 Simulation of reductions in the bottom area and water volume of various salinity zones using the District's hydrodynamic model of the Lower Myakka River.

A fundamental component of the District' approach for establishing minimum flows for tidal river estuaries is determining reductions in the bottom area, water volume, and shoreline lengths within biologically important salinity zones that would result from freshwater withdrawals. Along with other tools, this approach has been applied in the determination of minimum flows for the Lower Hillsborough, Weeki Wachee, Lower Alafia, Anclote and Lower Peace rivers (SWFWMD 2006, SWFWMD 2008a, SWFWMD 2008b, SWFWMD 2010a, SWFWMD 2010b).

A hydrodynamic model of Upper Charlotte Harbor that includes spatially dense two-dimensional and three-dimensional grids in the Lower Peace and Myakka Rivers was used to determine reductions in the area and volume of selected salinity zones in the Lower Myakka River. A detailed description of the physical basis and calibration of this model is presented in Appendix 5A. An empirical model that predicts the locations of the 2 psu surface isohaline in the lower river that was developed by Mote Marine Laboratory (see Sections 4.5.4 and 4.5.5) was used to simulate reductions in shoreline lengths below that salinity value. The results of the hydrodynamic simulations of reductions in bottom area and water volume are presented first below.

8.6.1 Reductions in bottom area and water volume

As described in Sections 7.11.1 and 7.11.2, the District selected six salinity zones for the assessment of reductions in bottom area and four salinity zones for the assessment of reductions in water volume. These zones, which are listed in Table 8-10, were selected based on various studies that have documented relations between salinity and fish and invertebrate communities in southwest Florida estuaries. Although the selection of bottom area values was based primarily on relationships with benthic invertebrates and water volume was based primarily on relationships with fish, these zones have somewhat similar salinity groupings and can be applied across communities, since estuarine organisms do not comply with strict salinity ranges. Although the association of some estuarine communities with salinity gradients can be broad, a comparison of reductions in salinity zones can provide useful information on ecological changes the estuary may experience as a result of freshwater withdrawals.

Table 8-10. Salinity zones selected for the evaluation of changes in bottom area and water volume in the Lower Myakka River.

Bottom Area	Water Volume
< 2 psu	< 2 psu
< 5 psu	< 5 psu
< 12 psu	< 14 psu
< 17 psu	
2 to 12 psu	3 to 14 psu
11 to 17 psu	

8.6.2 Use of seasonal blocks

The District evaluated changes in salinity zones for the entire 1999-2002 hydrodynamic modeling period and for three seasonal blocks within the modeling period. The seasonal approach was conducted to determine if the sensitivity of ecological resources for significant harm was less or greater during various seasons than for the period as a whole. The seasonal blocks used for analysis were as follows:

Block 1 - March 1 – June 20

Block 2 - June 21 – October 27

Block 3 - October 28 – end of February

These seasonal blocks were primarily based on the general seasonal occurrence of low, high, and medium flows in the river (Figure 2-7). They are similar to the seasonal blocks used for the determination of minimum flows for the freshwater reach of the Myakka River (SWFWMD 2005a), but differ in that Block 1 for the lower river begins on March 1, whereas the Block 1 used for the upper river began on April 20. This earlier date for the lower river was based on the occurrence of lagged relationships in the tidal river, in which the response of ecological variables are related to the occurrence of flows over different preceding time periods. This applies not only to salinity, but also to biological variables such as the abundance of fish and invertebrate species, including a number of taxa documented for the Lower Myakka River (see Section 6.4 and Peebles et al. 2006). Since the springtime is a sensitive period with low inflows, increasing water temperatures, and an increase in the nursery use of the estuary, it was concluded that Block 1 should begin on March 1 to better protect inflows that could affect biological productivity in the spring.

It is important to note that the inclusion of flows from March and early April changes the flow duration characteristics of Block 1, generally increasing the quantity of flow at all percentiles. Since some estuarine variables are most sensitive to change at low flows, the broader Block 1 period might not be as sensitive a period for detecting change as the narrower Block 1 that is restricted to the very low flows in the late spring and early summer. However, considering all factors, it was concluded that beginning Block 1 on March 1 was the appropriate method to evaluate potential impacts to springtime conditions in the Lower Myakka River.

8.6.3 Water volume and bottom area for as a function of baseline flows

Before the effects of various flow reductions on salinity distributions are assessed, it is helpful to first examine how the selected salinity zones respond to freshwater inflow under the observed baseline conditions. Mean daily bottom area values less than 2, 5, 12, and 17 psu salinity are plotted versus 5-day preceding mean flows at the Myakka River near Sarasota gage in Figure 8-19, with the flow range limited to 2,000 cfs. Since salinity distributions are related to antecedent flow variability, tides, and meteorological conditions over various lengths of time, there is scatter in the relationship of bottom area with 5-day flows. However, as expected, the amounts of the bottom areas less than these four salinity values generally increase with the rate of freshwater inflow.

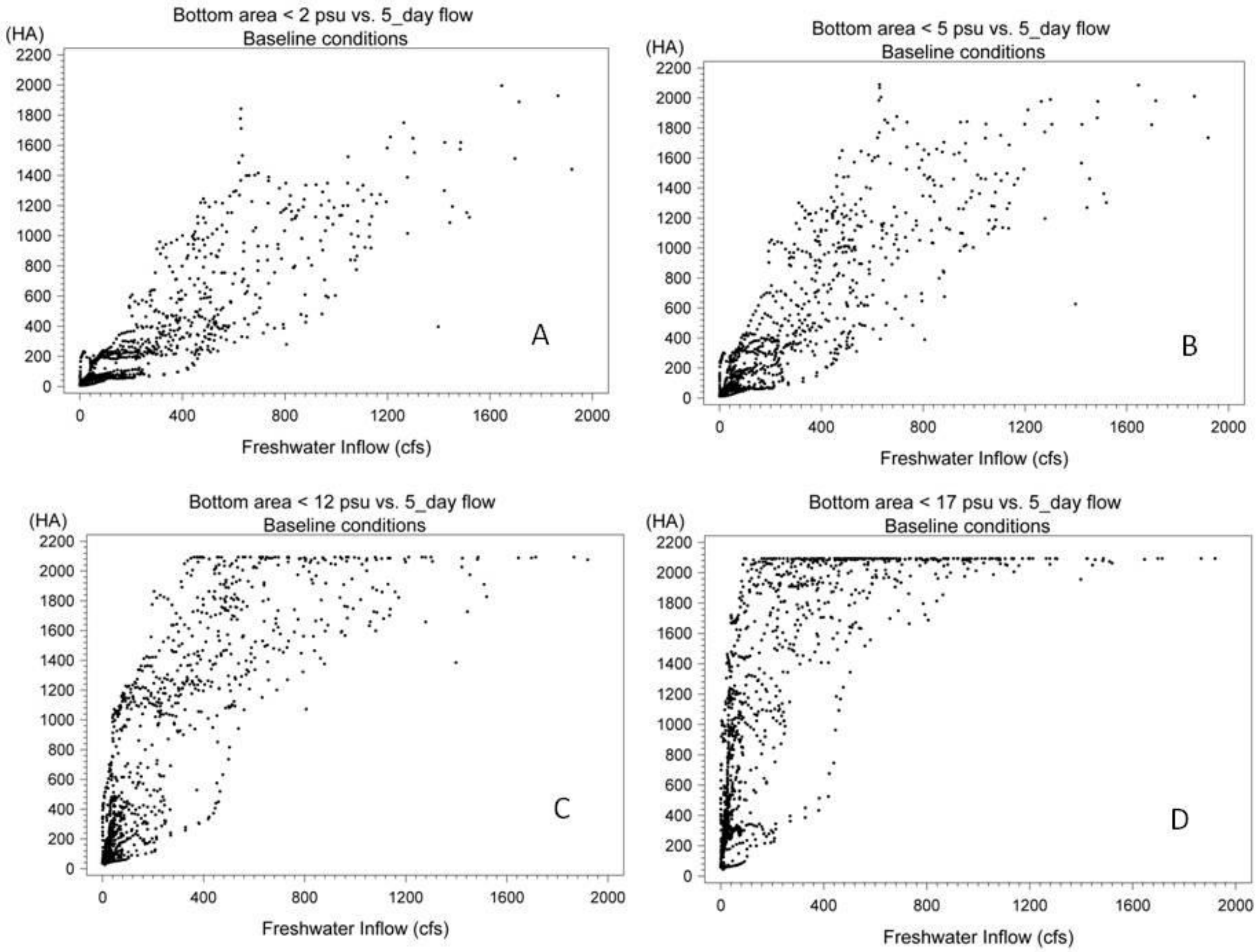


Figure 8-20. Daily mean values of bottom area less than 2 psu, 5 psu, 12 psu, and 17 psu versus 5-day preceding mean flows at the Myakka River near Sarasota gage. Flows limited to 2,000 cfs for plotting purposes.

The region of the river over which relationships of bottom area and water volume to flow were assessed extended from the river mouth to kilometer 38.4, near the upstream terminus of the model grid. The total bottom area in this region below and elevation of 0.13 meters NGVD is 2,130 hectares (21.3 square kilometers). The plots for the < 12 and < 17 psu zones in Figure 8-20 show many peak values near that amount, which represent days when all the bottom area within the study area was less than the specified salinity value. In essence, area values that plot near 2,130 ha represent days when freshwater inflow had pushed water less than the specified salinity value below the downstream limit of the study area, and all the water upstream of kilometer 0 below an elevation of 0.13 m was less than salinity value. This began to occur at flow rates near 300 cfs for the < 12 psu zone and at flow rates of 150 cfs for the < 17 psu zone. The results are very different for the two lowest salinity zones (< 2 and < 5 psu). Bottom areas < 2 psu never comprised all the study zone at flows at flows less than 2,000 cfs, while areas < 5 psu reached peak values on only three dates.

Means daily water volume values for these same salinity zones are plotted vs. 5-day flows at the Myakka River near Sarasota up to 2,000 cfs in Figure 8-21. The results are very similar to the results for bottom area, because the river is typically well mixed and there is close correlation between the amount of bottom area and water volume within the salinity zones on any given day.

The same salinity zones are plotted vs. flow separately for the three seasonal blocks in Appendices 8G (bottom area) and 8H (volume), with an example of the < 5 psu bottom area zone presented in Figure 8-22 (with one graph for the < 12 psu zone). In these graphics the flows are limited to the range that occurred within each seasonal block during the 1999-2002 modeling period.

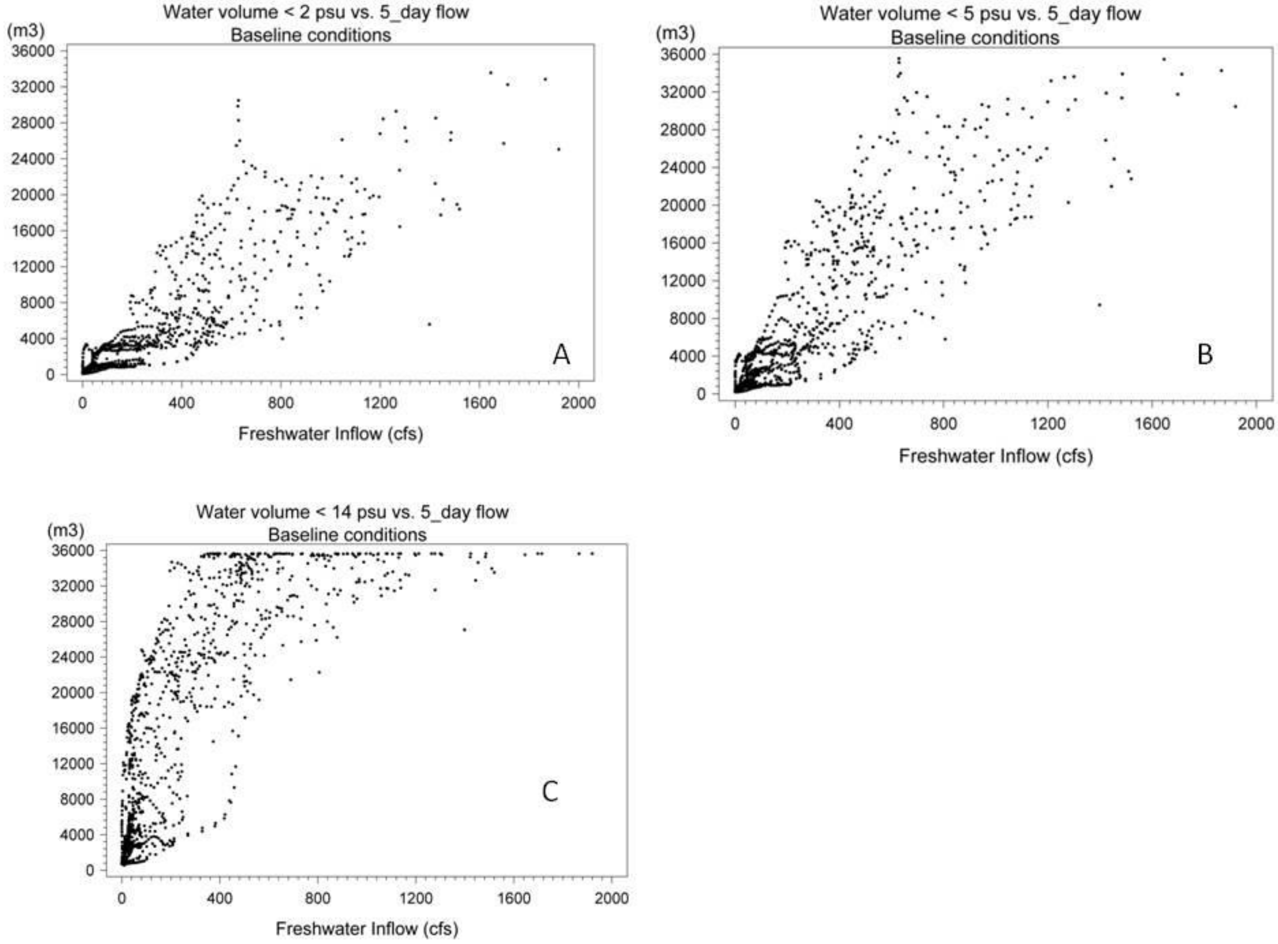


Figure 8-21. Daily mean values of bottom area less than 2 psu, 5 psu, 12 psu, and 17 psu versus 5-day preceding mean flows at the Myakka River near Sarasota gages. Flows limited to 2,000 cfs for plotting purposes.

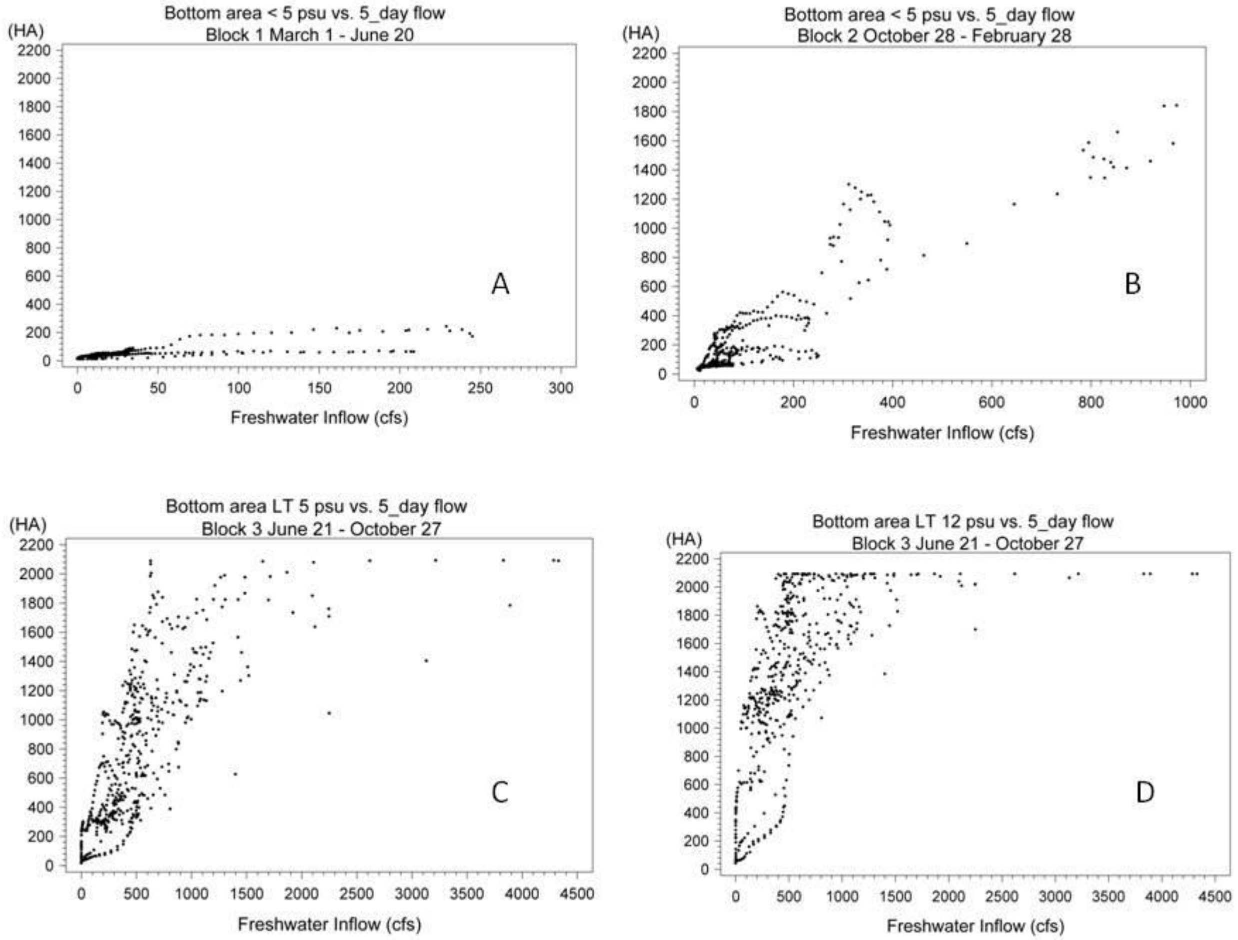


Figure 8-22. Daily mean values of bottom area less than < 5 psu versus 5-day preceding mean flows at the Myakka River near Sarasota gages for three seasonal blocks (A, B, and C) and bottom area less than < 12 psu vs. flow for Block 3.

The maximum same-day flows that occurred at the Myakka River near Sarasota gage were 252 cfs during Block 1 (spring), 1010 cfs during Block 2 (fall/winter), and 5030 cfs during Block 3 (summer). The maximum five-day moving average flows during this period that are used for plotting are 233 cfs during Block 1, 973 cfs during Block 1, and 4,330 cfs during Block 3.

These results are important for they show in what flow ranges the salinity zone was either completely (all depths) or largely (most depths) confined to the lower river above river kilometer 0. For example, the < 5 psu never approached the maximum area value in blocks 1 and 2, so it appears that salinity zone was likely confined to the lower river during those blocks (Figures 8-22A and B). In Block 3, the < 5 psu zone was also either completely or largely confined to the lower river except on several high flow days (Figure 8-22C). In contrast, during Block 3 the < 12 psu zone reached peak values frequently at flows greater than 400 cfs (Figure 8-22D).

These findings affect the statistical tests that can be used to assess changes in area and volume relative to baseline. When a salinity zone is primarily confined to the river under baseline conditions, statistical comparisons can be done for a flow reduction scenario relative to baseline for the entire seasonal block. However, if the salinity zone reaches peak values (fills up the lower river) within a seasonal block, a true baseline value cannot be obtained because some of the daily salinity zone values include bottom areas or water volumes that have moved beyond the study area. In those cases, the statistical comparison must be restricted to the range in which the salinity zone stays within the river.

8.6.4 Statistical analysis of changes in bottom area and water volume relative to baseline

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

The method used to compare alternative scenarios to the baseline condition using CDF plots is illustrated in Figure 8-23. The habitat available for a given scenario is estimated by calculating the area under the curve from the CDF plots. The blue-hatched area (area under the curve) in Figure 8-23A is the estimate of the habitat available for baseline flows (HA_B) for the entire modeling period. Figure 8-23B presents the habitat available under an alternative scenario, Scenario 1 (HA_{S1}), for the same period. To compare the two scenarios, the area between the two curves can be calculated (Figure 8-23C). This difference is the habitat loss from the baseline under that scenario.

Using this approach, the relative change from baseline can be calculated for a number of flow reduction scenarios. The normalized area under the curve (NAUC) representing the habitat loss was calculated for each flow reduction scenario relative to the baseline flows. The formula to calculate the NAUC for a scenario (e.g., Scenario 1) is:

$$NAUC = \frac{(HA)_{S1}}{(HA)_{B}}$$

The CDF plots for the various flow reduction scenarios can be overlain and the NAUC corresponding to these plots can be presented in summary tables or graphics. Then, relative changes from baseline that can be considered to constitute significant harm can be determined. This approach is termed the CDF/NAUC method in this report. The CDF/NAUC method can be performed on the population of habitat values for the various scenarios for the entire modeling period, or for populations of values restricted to various seasonal blocks. The results for the Lower Myakka River are presented first below for the entire 1999-2002 modeling period and then for the seasonal blocks previously described.

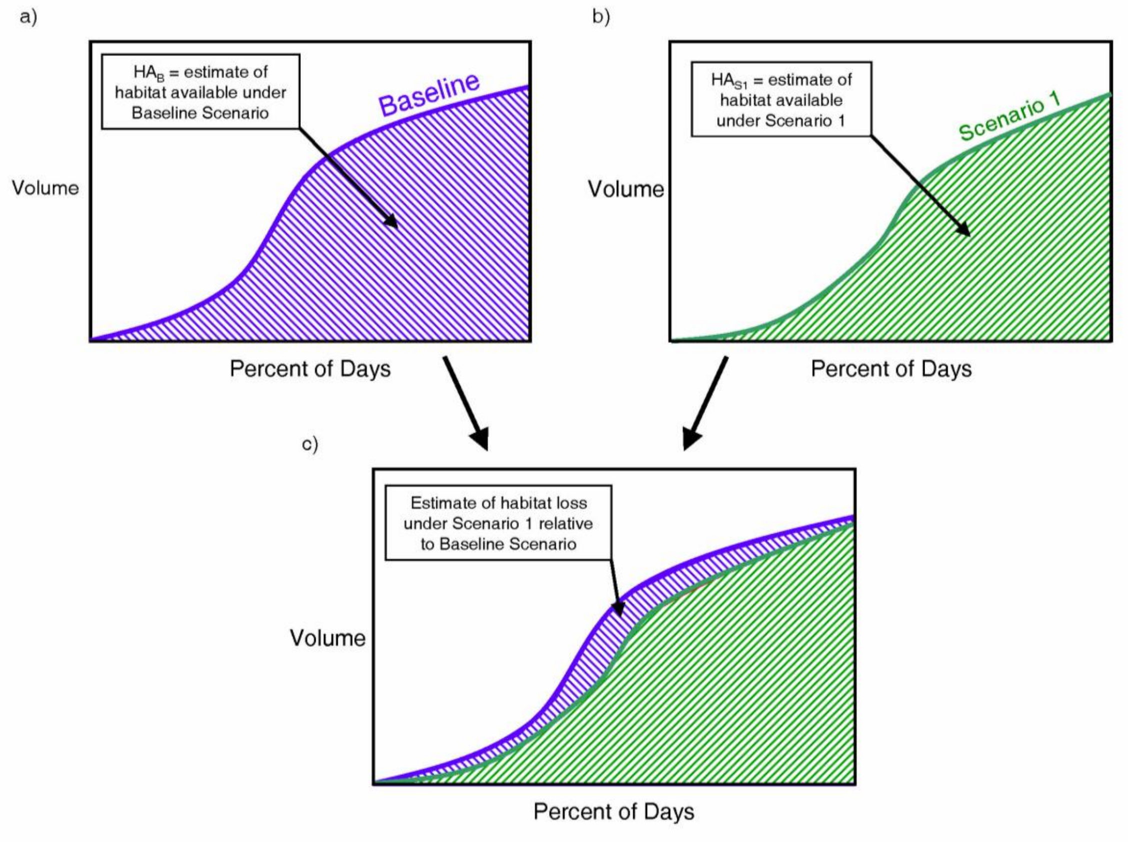


Figure 8-23. Example of area under curve calculated from a CDF plot: (a) represents the area under the curve for the Baseline condition; (b) represents the area under the curve for an alternative flow reduction Scenario 1; (c) represents the loss of habitat water for the flow reduction relative to baseline flows.

However, as previously described, valid statistical comparisons can be done only over the flow range in which the salinity zone was confined to the lower river. For that reason, percent changes are reported in tables for only those salinity zones and blocks in which the salinity zone was within the tidal river over all, or in some cases (< 5 psu during Block 3), nearly all flows.

8.6.5. Reductions in area and volume for the entire modeling period

The hydrodynamic model was run for baseline conditions and the flow reduction scenarios listed in Tables 8-8 and 8-9. Percent reductions were then calculated for the salinity zones listed in Table 8-10 (page 8-28). For the most part, percent reductions in bottom area and water volume were fairly similar for similar salinity zones. This occurs because the river is generally well mixed over most of its flow regime, causing the amounts of bottom area and water volume to track one another very closely. Because the results for bottom area and water volume are so similar, those two habitat metrics are described together for the entire modeling period below.

Overlain CDF plots of bottom areas for baseline flows and seven flow reduction are shown for the < 5 psu zone in Figure 8-24, with a bar chart of the corresponding reductions in percent bottom area calculated by the CDF/NAUC method shown in Figure 8-25. Similar paired CDF plots and bar charts for all the selected salinity zones (<2 psu, 5 psu, <12 psu, <17 psu, 2 to 12 psu, and 11 to 17 psu) are shown in Appendix 8I.

Overlain CDF plots of water volumes for baseline flows and eight flow reduction are shown for the < 2 psu zone in Figure 8-26, with a bar chart of the corresponding reductions in percent bottom area calculated by the CDF/NAUC method shown in Figure 8-27. Similar paired CDF plots and bar charts for the water volume in all the salinity zones (<2, <5, <14, and 3 to 14 psu) are shown in Appendix 8J.

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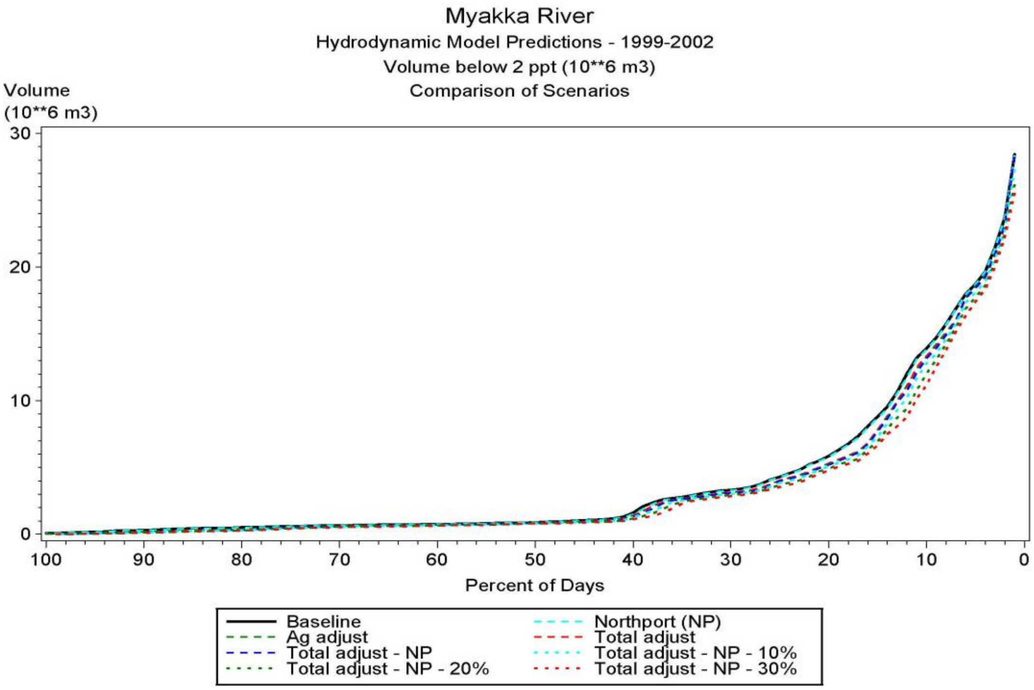

Figure 8-24. CDF lots of the percentage of days that bottom areas of less than 5 psu salinity were exceeded for baseline flows and seven flow reduction scenarios.

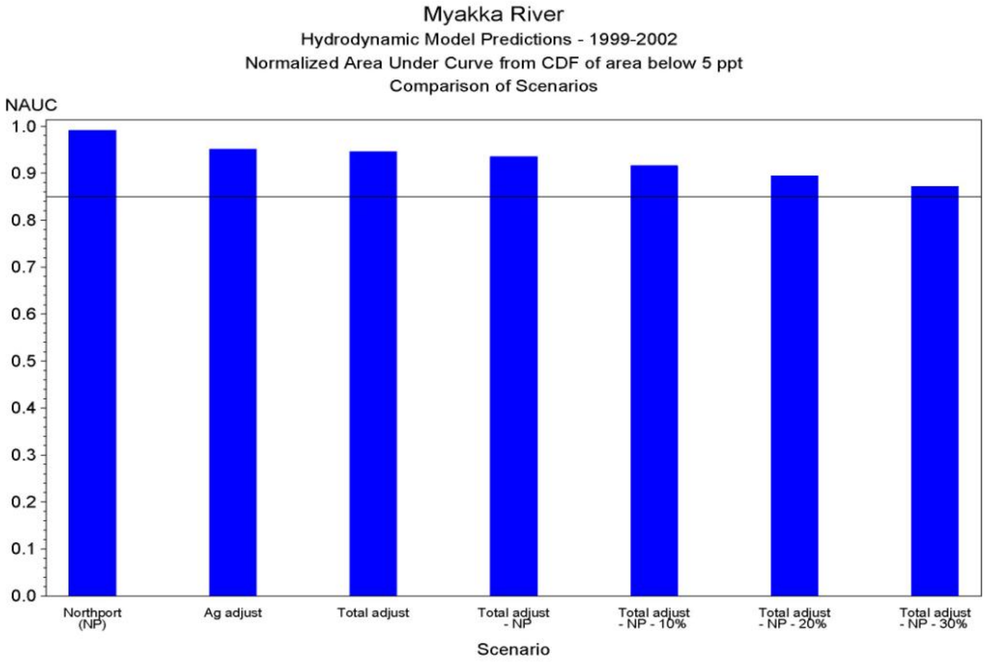

Figure 8-25. Bar chart of the percentages of bottom area less than 5 psu remaining from baseline conditions for the CDF curves and corresponding flow reductions shown in Figure 8-18. A reference line is shown at 15% reduction in bottom area.

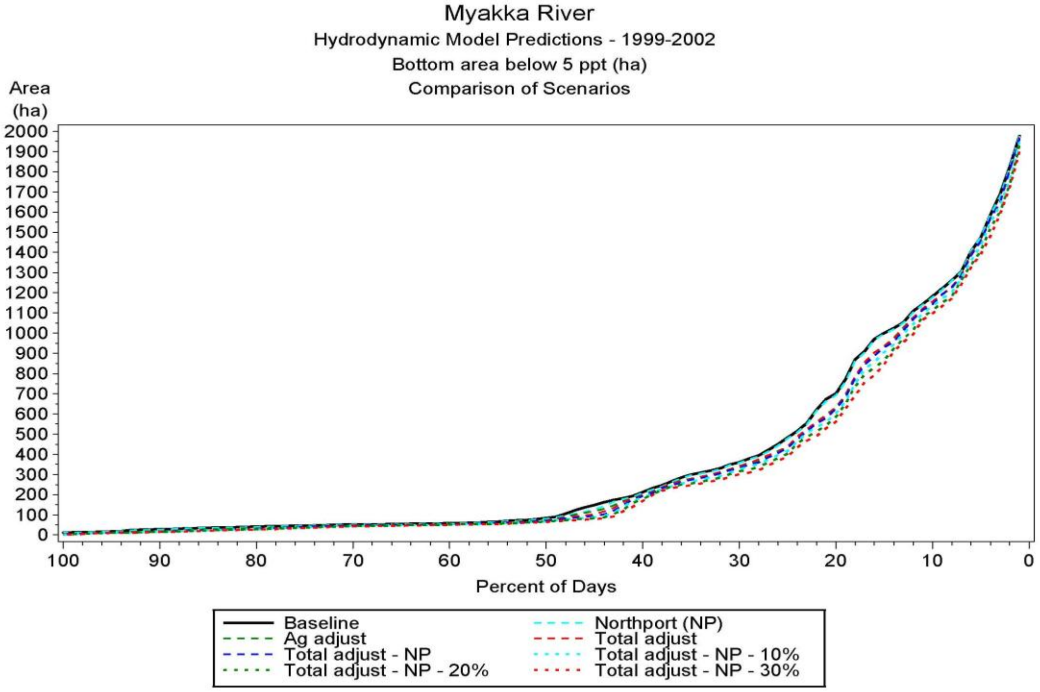

Figure 8-26. CDF lots of the percentage of days that water volume of less than 2 psu salinity were exceeded for baseline flows and seven flow reduction scenarios.

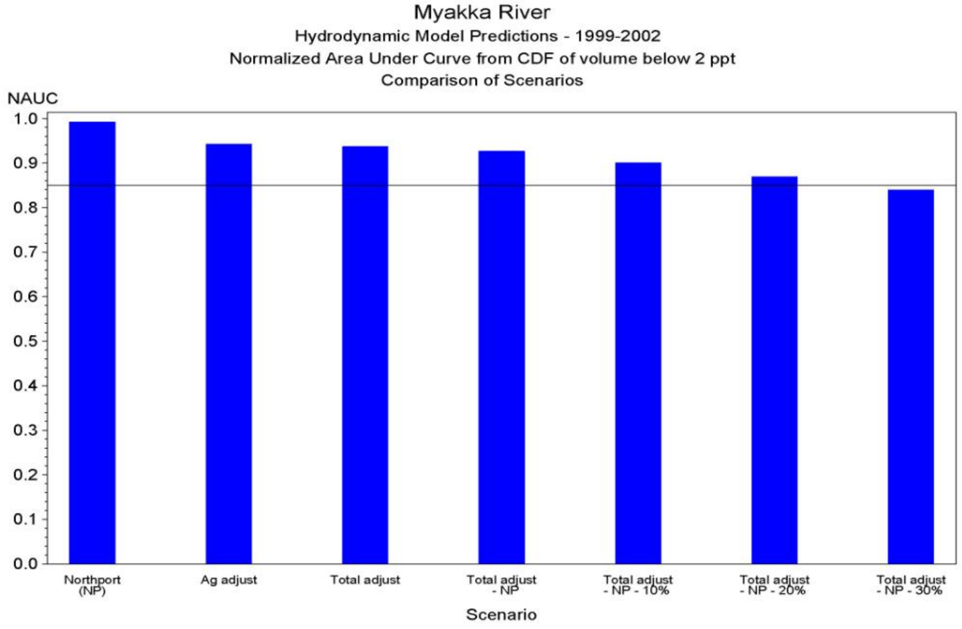

Figure 8-27. Bar chart of the percentages of water volume less than 2 psu remaining from baseline conditions for the CDF curves and corresponding flow reductions shown in Figure 8-20. A reference line is shown at 15% reduction in water volume.

A summary of the percent reductions in bottom area for the selected salinity zones for the seven flow reductions is listed in Table 8-11 for the 1999-2002 modeling period. Results are provided for only the < 2 values and < 5 psu salinity zones, as the other zones moved past the downstream study boundary for substantial amounts of time when the entire modeling period is considered. In contrast, none of the < 2 psu zone values and only 1% of the < 5 psu values reached peak area values. Results that represent a greater than 15 percent reduction in bottom area or volume of the < 2 and < 5 psu zones are highlighted in yellow. When viewed for the entire modeling period, the only flow reduction scenario that resulted in a 15% or greater reduction in bottom area was for the < 2 psu zone that involved removing the combined North Port withdrawals, the total excess flows, and 30% of the remaining flows at the Myakka River gage. Reductions in water volume produced very similar results, with only this same combined scenario causing greater than 15% change using the CDF/NAUC method.

Removal of the North Port withdrawals from Myakkahatchee Creek alone resulted in net reductions of about 1% in either the bottom area or water volume for all of the salinity zones. Combining the City's withdrawals with removing the total excess flows resulted in reductions of 6 or 7 percent of the area and volume of the < 2 and < 5 psu zones.

Table 8-11. Percent reductions in the bottom area and water volume of selected salinity zones in the Lower Myakka River for flow reduction scenarios relative to baseline flows for the years 1999-2002. Percent reductions greater than or equal to 15% are highlighted in yellow. All values rounded to nearest integer. NA is listed for zones that moved past the downstream end of the study area for substantial amounts of time.

Bottom Area	**Salinity Zone**					
	<2 psu	***< 5 psu***	***<12 psu***	***<17 psu***	***2 to 12 psu***	***11 to 17 psu***
North Port Permitted	1%	1%	NA	NA	NA	NA
Agricutural adjustment	6%	5%	NA	NA	NA	NA
Total adjustment	6%	5%	NA	NA	NA	NA
Total adjustment - North Port	7%	6%	NA	NA	NA	NA
Total adjustment - North Port - 10%	10%	8%	NA	NA	NA	NA
Total adjustment - North Port - 20%	12%	11%	NA	NA	NA	NA
Total adjustment - North Port - 30%	15%	13%	NA	NA	NA	NA

Water Volume	**Salinty Zone**			
	<2 psu	***< 5 psu***	***< 14 psu***	***3 to 14 psu***
North Port Permitted	1%	1%	NA	NA
Agricutural adjustment	6%	5%	NA	NA
Total adjustment	6%	6%	NA	NA
Total adjustment - North Port	7%	7%	NA	NA
Total adjustment - North Port - 10%	10%	9%	NA	NA
Total adjustment - North Port - 20%	13%	11%	NA	NA
Total adjustment - North Port - 30%	16%	13%	NA	NA

8.6.6. Reductions in area and volume for the seasonal blocks

Segregating the area and volume reductions into seasonal blocks produced markedly different results among blocks. Summary tables for reductions in bottom area and water volume for the seven scenarios are listed by block in Tables 8-12, 8-13, and 8-14. The complete set of CDF curves for bottom area for each block are grouped by salinity zone in Appendix 8K, with the corresponding bar charts of reductions in area are shown in Appendix 8L. The complete sets of CDF plots and bar charts for reductions in water volume are in Appendices 8M and 8N.

All the salinity zones remained within the study area during Block 1 (Table 8-12). The effect of the North Port withdrawals were small in Block 1, ranging from 2 to 5 percent for the various salinity zones. However, with one exception, removal of the agricultural excess flows and the total excess flows with no other flow reductions reduced the < 2 and < 5 psu zones by more than 15%. Taking water in addition to the excess flows (North Port and 10%, 20 and 30% withdrawals) caused greater reductions in the habitats which exceeded 15% for the other salinity zones. Scenarios that reduced salinity zones by 25% or more are highlighted in gray.

Table 8-12. Percent reductions in the bottom area and water volume of selected salinity zones in the Lower Myakka River for flow reduction scenarios relative to baseline flows for BLOCK 1 during the years 1999-2002. Percent reductions greater than or equal to 15% are highlighted in yellow; reductions greater than or equla to 25% are highlighted in gray. All values rounded to nearest integer.

Bottom Area **Block 1 (March 1 - June 20)**	**Salinity Zone**					
	<2 psu	*< 5 psu*	*<12 psu*	*<17 psu*	*2 to 12 psu*	*11 to 17 psu*
North Port Permitted	2%	2%	4%	3%	5%	2%
Agricutural adjustment	16%	16%	15%	10%	14%	8%
Total adjustment	21%	21%	20%	13%	19%	11%
Total adjustment - North Port	23%	23%	25%	17%	25%	15%
Total adjustment - North Port - 10%	27%	27%	28%	20%	28%	17%
Total adjustment - North Port - 20%	31%	31%	32%	23%	32%	20%
Total adjustment - North Port - 30%	35%	35%	37%	26%	37%	23%

Water Volume **Block 1 (March 1 - June 20)**	*<2 psu*	*< 5 psu*	*< 14 psu*	*3 to 14 psu*
North Port Permitted	2%	2%	4%	5%
Agricutural adjustment	16%	13%	15%	14%
Total adjustment	21%	17%	19%	19%
Total adjustment - North Port	22%	19%	24%	24%
Total adjustment - North Port - 10%	26%	22%	28%	28%
Total adjustment - North Port - 20%	30%	26%	33%	34%
Total adjustment - North Port - 30%	34%	31%	37%	38%

Results are presented for only the < 2 and < 5 psu salinity zones in Blocks 2 and 3 for the other salinity zones moved downstream of the study area for substantial amounts of time during each block. Compared to Block 1, percent reductions in the < 2 and < 5 psu salinity zones were considerably less during Block 2 (Table 8-13). The only scenario which caused a reduction in salinity zones in excess of 15% was the combined withdrawals of North Port, total excess flows, and 30% of the remaining flows at the Myakka River near Sarasota gage.

Reductions in the < 2 and < 5 psu zones were even less for Block 3 in the high flow season from late June through late October (Table 8-14). The maximum reductions found were 13% and 14% for the bottom area and volume of the < 2 psu zone for the combined withdrawals of North Port, total excess flows, and 30% of the remaining flows at the Myakka River near Sarasota gage. Reductions in area or volume did not exceed 7% when just the total excess flows and withdrawals by the City of North Port were included.

Table 8-13. Percent reductions in the bottom area and water volume of selected salinity zones in the Lower Myakka River for flow reduction scenarios relative to baseline flows for BLOCK 2 during the years 1999-2002. Percent reductions greater than or equal to 15% are highlighted in yellow. NA is listed for zones that moved past the downstream end of the study area for substantial amounts of time during Block 2.

Bottom Area Block 2 (Oct. 28 - Feb. 28)	**Salinity Zone**					
	<2 psu	***< 5 psu***	***<12 psu***	***<17 psu***	***2 to 12 psu***	***11 to 17 psu***
North Port Permitted	1%	1%	NA	NA	NA	NA
Agricutural adjustment	5%	5%	NA	NA	NA	NA
Total adjustment	5%	5%	NA	NA	NA	NA
Total adjustment - North Port	7%	7%	NA	NA	NA	NA
Total adjustment - North Port - 10%	11%	11%	NA	NA	NA	NA
Total adjustment - North Port - 20%	14%	14%	NA	NA	NA	NA
Total adjustment - North Port - 30%	18%	18%	NA	NA	NA	NA

Water Volume Block 2 (Oct. 28 - Feb. 28)	**Salinity Zone**			
	<2 psu	***< 5 psu***	***< 14 psu***	***3 to 14 psu***
North Port Permitted	1%	2%	NA	NA
Agricutural adjustment	6%	5%	NA	NA
Total adjustment	6%	6%	NA	NA
Total adjustment - North Port	7%	8%	NA	NA
Total adjustment - North Port - 10%	11%	10%	NA	NA
Total adjustment - North Port - 20%	15%	13%	NA	NA
Total adjustment - North Port - 30%	19%	16%	NA	NA

Table 8-14. Percent reductions in the bottom area and water volume of selected salinity zones in the Lower Myakka River for flow reduction scenarios relative to baseline flows for BLOCK 3 during the years 1999-2002. Percent reductions greater than or equal to 15% are highlighted in yellow. NA is listed for zones that moved past the downstream end of the study area for substantial amounts of time during Block 3.

Bottom Area Block 3 (June 21 - Oct. 27)	**Salinity Zone**					
	<2 psu	***< 5 psu***	***<12 psu***	***<17 psu***	***2 to 12 psu***	***11 to 17 psu***
North Port Permitted	1%	1%	NA	NA	NA	NA
Agricutural adjustment	5%	5%	NA	NA	NA	NA
Total adjustment	5%	5%	NA	NA	NA	NA
Total adjustment - North Port	6%	6%	NA	NA	NA	NA
Total adjustment - North Port - 10%	8%	8%	NA	NA	NA	NA
Total adjustment - North Port - 20%	11%	11%	NA	NA	NA	NA
Total adjustment - North Port - 30%	13%	13%	NA	NA	NA	NA

Water Volume Block 3 (June 21 - Oct 27)	***<2 psu***	***< 5 psu***	***< 14 psu***	***3 to 14 psu***
North Port Permitted	1%	1%	NA	NA
Agricutural adjustment	5%	5%	NA	NA
Total adjustment	6%	5%	NA	NA
Total adjustment - North Port	7%	6%	NA	NA
Total adjustment - North Port - 10%	9%	7%	NA	NA
Total adjustment - North Port - 20%	11%	9%	NA	NA
Total adjustment - North Port - 30%	14%	11%	NA	NA

Percent reductions in the various salinity zones were reported in Tables 8-11 through 8-14 were also examined by comparing mean values calculated for the baseline and the flow reduction scenarios. These results, which are listed in Appendix 8O, gave either identical or very similar values to the percent habitat reductions that were calculated using the CDF/NAUC method.

8.6.7 Reductions in area and volume as a function of freshwater inflow

It is also informative to the percent reductions in salinity zones as a function of the rate of freshwater inflow. Daily values of percent reductions in bottom area for four of the flow reduction scenarios are plotted vs. 5-day mean baseline flow at the Myakka River near Sarasota gage in Appendix 8P. As examples of these relationships, daily percent reductions in bottom area for the < 5 psu zone are plotted vs. baseline flow in Figure 8-28 for these same flow reduction scenarios. A smoothed line was fitted to the data using the SASGRAPH software (I=SM40 function) to show trends in the relationship between reduction in habitat and the rate of flow for each flow reduction scenario.

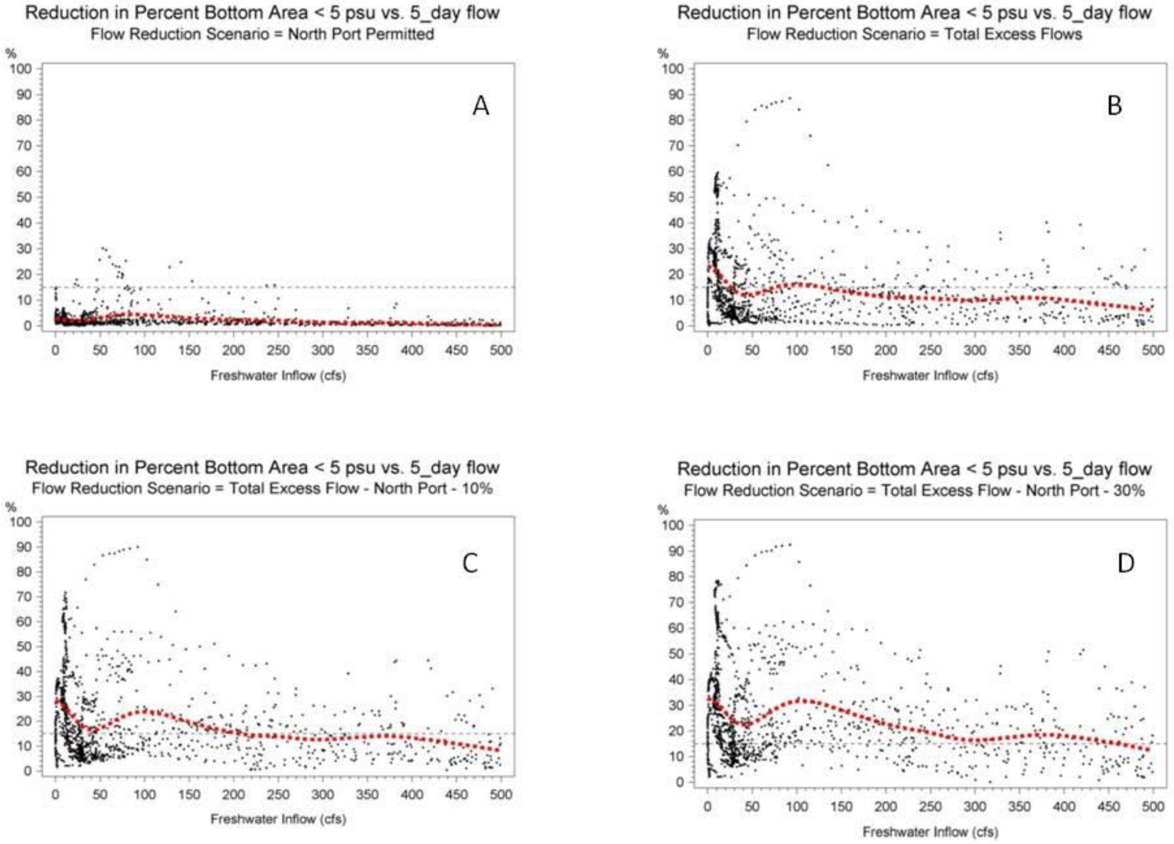

Figure 8-28. Percent reductions in daily values of bottom area < 5 psu vs. the preceding 5-day mean baseline flow at the Myakka River near Sarasota gage for four flow reduction scenarios: (A) North Port permitted; (B) total excess flows; (C) total excess flows – North Port permitted – 10% of remaining flow: (D) total excess flows – North Port permitted – 30% of remaining flow. A reference line is shown at 15% reduction in daily bottom area.

Withdrawal of the permitted quantities to the City of North Port results in very small reductions in bottom area (Figure 8-28A). For the other flow reduction scenarios, which all involved removing the total excess flows, the percentage reductions in bottom area were greatest at low flows. Habitat reductions in excess of 15% are common at low flows at flows less than 30 cfs when total excess flows alone are removed (Figure 8-28B). When percentages of the remaining flow at the Myakka River near Sarasota gage are removed along with the permitted withdrawals to the City of North Port, habitat reductions in excess of 15% are more common at higher flow values. The fitted line does not fall to 15% habitat loss until about 210 cfs when 10% of the remaining flows at the Myakka River at Sarasota gage is withdrawn, and not until about 430 cfs when 30% of the remaining flows is withdrawn.

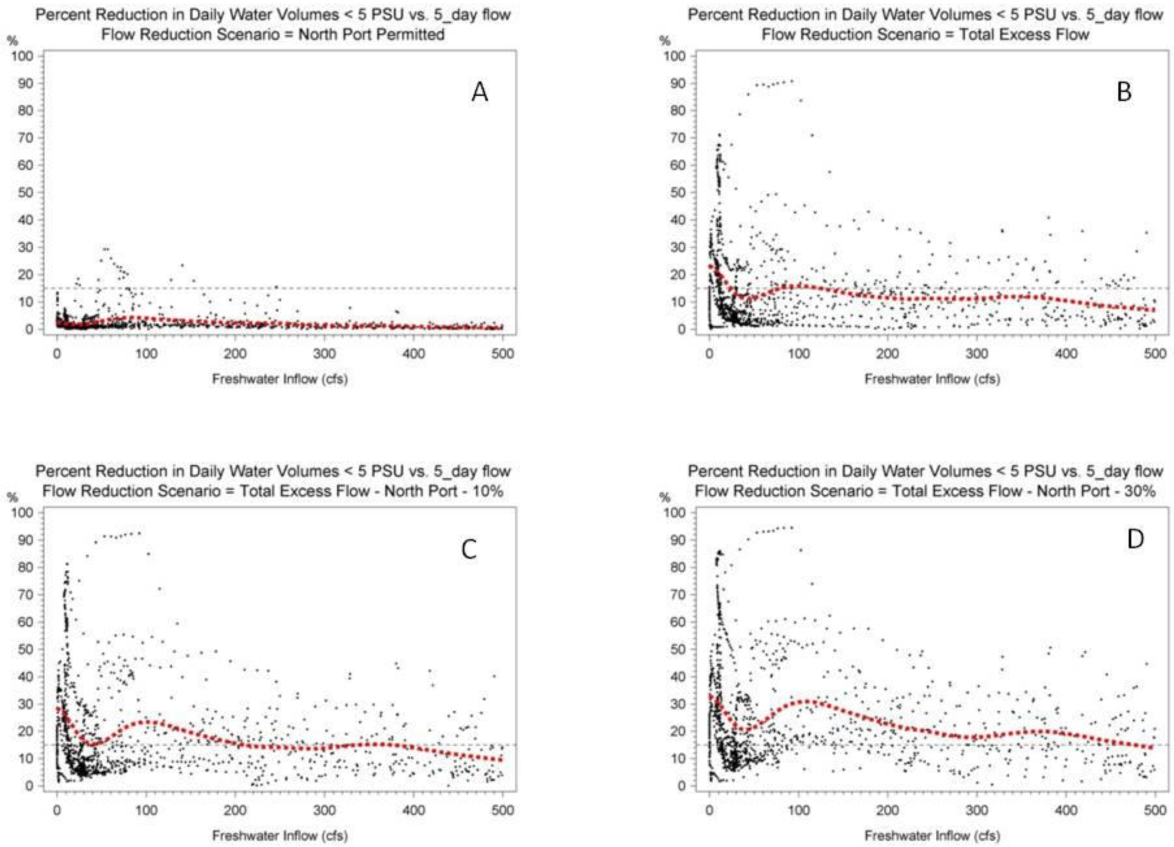

Figure 8-29. Percent reductions in daily values of water volume < 5 psu vs. the preceding 5-day mean baseline flow at the Myakka River near Sarasota gage for four flow reduction scenarios: (A) North Port permitted; (B) total excess flows; (C) total excess flows – North Port permitted – 10% of remaining flow: (D) total excess flows – North Port permitted – 30% of remaining flow. A reference line is shown at 15% reduction in water volume.

Percent reductions in water volume followed similar patterns to reductions in bottom area. Daily values of percent reductions in water volume for four of the flow reduction scenarios are plotted vs. 5-day mean baseline flow at the Myakka River near Sarasota gage in Appendix 8Q. Again as an example, reductions in water volumes less than 5 psu for four flow reduction scenarios are shown above in Figure 8-29. Because the river is typically well mixed, the scatter plots of percent reductions in volume < 5 psu volume track very closely the results for percent bottom area < 5 psu.

8.6.8 Time series plots of reductions in the area and volume of the salinity zones

Another informative way to view the reduction in salinity zones is as a time series. Graphics of daily percent reductions in the bottom area and water volume for all the salinity zones examined in the study are plotted date in Appendices 8R (bottom area) and 8S (water volume). As an example of these relationships, plots of the percent bottom area < 5 psu are shown in Figure 8-30 for the same four flow scenarios shown in Figures 8-28 and 8-29. As with relationships with flow, the reductions in habitat due to withdrawals to the City of North Port were very small, with daily reductions in bottom area < 5 psu in excess of 15% for only a brief period in 2000 and one day in 2002 (Figure 8-30A).

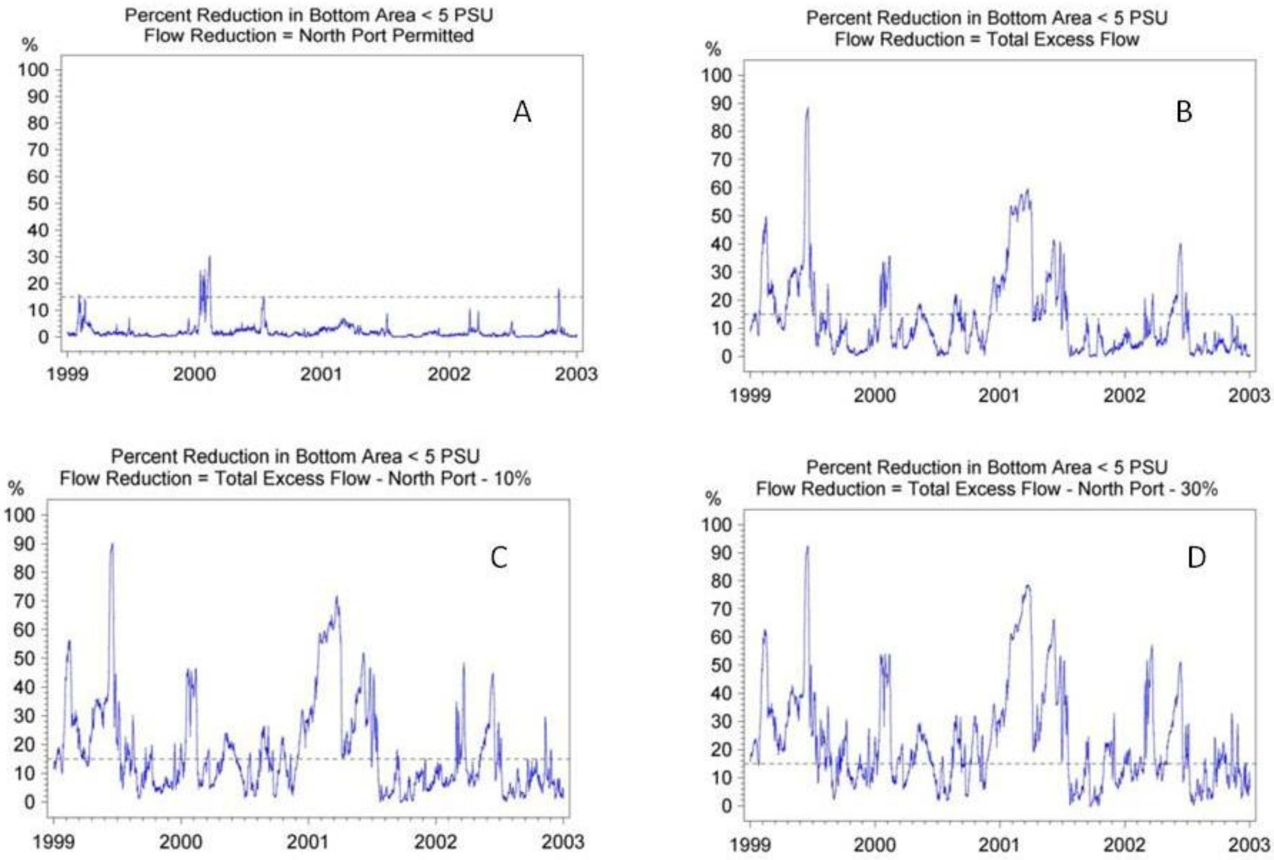

Figure 8-30. Percent reductions in daily values of water volume < 5 psu vs. time during 1999-2002 for four flow reduction scenarios: (A) North Port permitted; (B) total excess flows; (C) total excess flows – North Port permitted – 10% of remaining flow: (D) total excess flows – North Port permitted – 30% of remaining flow. A reference line is shown at 15% reduction in bottom area.

Percent reductions due to removal of total excess flows were greatest in 1999 and 2001, exceeding 15% for four to six months in those two years, including reductions in excess of forty to fifty percent during a two month period in 2001 (Figure 8-29B). Removal of ten and thirty percent of remaining water at the Myakka River near Sarasota gage (in combination with North Port withdrawals) extended the time that reductions in area less than 5 psu exceeded 15 percent (Figures 8-29C and D). Relationships with volume followed very similar patterns (Appendix 8S).

8.6.9 Relative and absolute changes in salinity zone habitats

The results presented above show that percent habitat reductions are greatest at low flows. This due in large part to the fact that total excess flows comprise larger percentages of the baseline flows at low flows (Figure 8-9). Below a flow rate of about 20 cfs at the Myakka River near Sarasota, total excess flows are commonly above 50 percent of the baseline flow (Figure 8-10). Similarly, plots of percent habitat reductions vs. time show that the greatest reductions are often in the spring dry season, when flows are typically at their lowest (see figure 2.8).

It should be noted that large percent reductions in habitat at low flows may represent fairly small reductions in area or volume. Plots of the area (as hectares) of the salinity zones evaluated in the study vs. flow for the baseline scenario were shown in Figure 8-19 and Appendix 8G. Similar plots for the volume of the salinity zones were shown in Figure 8-20 and Appendix 8H. These graphics show the amount area or volume are least at low flows. Therefore, a fairly small percent reduction in area of volume at high flows could represent as much habitat in a hectares or cubic meters as a large percent reduction in habitat at low flows. For example, for the total excess flow scenario, the average percent reduction in bottom area < 5 psu for baseline flows between 450 and 500 cfs was 7 percent, which corresponds to an average reduction of 855 hectares of habitat. Conversely, for this same scenario, the average percent reduction in bottom area < 5 psu for baseline flows between 0 to 50 cfs was 18 percent, corresponding to an average reduction of 51 hectares of habitat.

Given these relationships, management strategies could focus either on loss of absolute habitat (in hectares of cubic meters) or changes in percent of habitat. These changes could be potentially be assessed within flow ranges or seasons. For the Lower Myakka River the District is emphasizing changes in percent of habitat, for we suggest that as habitats become more scarce the loss of habitat becomes more critical. Secondly, all of the indicator salinity zones move upstream as flows decline, being less accessible to the early life stages of estuarine dependent fish and invertebrate species that migrate into the river from the Gulf or Charlotte Harbor (see Section 6.4). Since the percentage loss of habitat and the location of salinity zone habitats are both related to the rate of freshwater inflow, managing percentage losses of habitat as a function of flow incorporates factors of relative habitat quantity and its spatial availability. Using this approach, allowable percent reductions in habitat can be examined as a function of flow to ensure that excessive losses of habitat are not experienced over the river's flow regime. In that manner, the results of the salinity zone analysis described above are compared to other metrics evaluated for the river to determine the minimum flows for the Lower Myakka River estuary.

8.7. Changes in oligohaline and tidal wetlands exposure to surface water isohalines

The other salinity metrics assessed for the minimum flows analysis of the Lower Myakka River employed empirical isohaline models developed by Mote Marine Laboratory (See Sections 4.5.4 and 4.5.5). As described in Section 7.10.3, shifts in surface water isohalines were compared to the distribution of oligohaline and tidal freshwater (OTF) wetland communities that are distributed along the river channel between kilometers 22 and 29. It was concluded the OTF community represented a diverse vegetation transition zone that would be most susceptible to impacts from withdrawals. To give perspective on the seasonal salinity characteristics of the river, the general distribution of isohalines is briefly described first below, followed by simulations of the movements of isohalines important to the OTF wetland zone.

The distribution of predicted surface and bottom locations of six isohalines in the range of 1 to 16 psu are plotted as cumulative distribution functions in for the period 1995-2004 in Figure 8-31. The penetration of each isohaline above 22 kilometers is greatest for the lower isohalines (1 and 2 psu), with the 12 psu rarely extending above that location and the 16 psu isohaline location never extending upstream of km 22. There is generally close agreement between the locations of the surface and bottom locations of a given isohaline, as the Myakka is a shallow river that is usually well mixed over most of its flow regime. This is especially true at low flows, when brackish waters are near the OTF marshes, so the remaining discussion refers to the location of surface isohalines as they most closely correspond to the waters that inundate shoreline marshes.

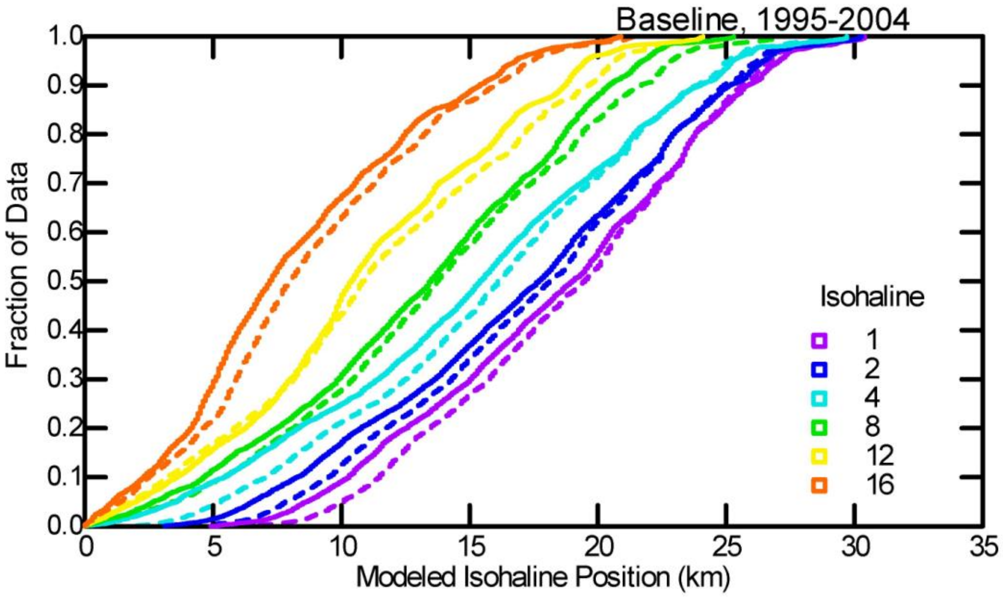

Figure 8-31. Cumulative distribution functions of predicted surface and bottom isohaline locations for six isohalines for the period 1995-2004.

The median values for the 1 to 12 psu surface isohalines are listed in Table 8-15 along with medians calculated for each seasonal block. Median values are also presented for the drier 1999-2002 hydrodynamic modeling period, along with the upstream shifts of the isohaline positions when the two periods are compared. In general, the upstream shifts for blocks 1 and 2 fell in the range of 3.1 to 3.6 kilometers, with a low value of 2.7 kilometers predicted for the 1 psu isohaline and an unusual shift of 4.9 kilometers reported for the 12 psu isohaline in Block 2. Shifts in all the isohalines were very slight in Block 3, as the 1999-2002 results were influenced by high flows in the summers of 2001 and 2002.

The median locations of all the isohalines are downstream of the OTF marsh zone when considered on a yearly basis (all blocks). However, as discussed in Chapter 6 (Figures 6-17), the median location of the 2 psu surface isohaline in Block 1 (21.7 km) corresponds to near the downstream extent of the OTF marsh zone for the ten-year 1995-2004 period (Table 8-15). Thus, as discussed in Section 7.10.3, the analysis of potential impacts to the OTF vegetation zones emphasized the movements of surface isohalines Block 1, when the isohalines are farthest upstream and the marsh plants are rapidly growing in the spring and early summer.

Because plant distributions could potentially be affected more long-term conditions or by conditions during low-flow years, the locations of isohalines were assessed for both the 1995-2004 and 1999-2002 periods. During the drier four-year period, the median location of both the 2 and 4 psu isohalines were well into the OTF marsh zone, with the with median position of the 8 psu isohaline located downstream.

Table 8-15. Median locations of five surface isohalines calculated for baseline flows during: (A)1995-2004; (B) 1999-2002; and (C) upstream shifts from 1995-2004 to 1999-2002. Results presented for whole years and separately for three seasonal blocks.

A	Median river kilometer locations 1995-2004				
	1 psu	2 psu	4 psu	8 psu	12 psu
All Blocks	18.4	17.0	14.9	12.2	9.7
Block 1 (March 1- June 20)	22.7	21.6	19.7	16.9	13.5
Block 2 (Oct 28 - Feb 28)	19.7	18.4	16.1	13.5	9.8
Block 3 (June 21 - Oct 27)	12.3	10.7	8.3	5.7	4.7

B	Median river kilometer locations 1999-2002				
	1 psu	2 psu	4 psu	8 psu	12 psu
All Blocks	21.1	20.1	18.3	15.6	13.3
Block 1 (March 1- June 20)	25.4	24.8	23.4	19.9	18.4
Block 2 (Oct 28 - Feb 28)	21.9	20.9	19.1	16.1	13.6
Block 3 (June 21 - Oct 27)	12.6	11.1	8.7	5.7	5.5

C	Upstream shifts in median locations 1999-2005 to 1999-2002				
	1 psu	2 psu	4 psu	8 psu	12 psu
All Blocks	2.7	3.1	3.4	3.4	3.6
Block 1 (March 1- June 20)	2.7	3.2	3.7	3.0	4.9
Block 2 (Oct 28 - Feb 28)	2.2	2.5	3.0	2.6	3.8
Block 3 (June 21 - Oct 27)	0.3	0.4	0.4	0.0	0.8

Shifts in isohaline positions were modeled for the same flow reduction scenarios simulated for the salinity zones analyses. As an example of these shifts, box plots of the location of the 2 psu isohaline for baseline flows and the withdrawal of the total excess flow and the total excess flow - 10% are shown in Figure 8-32. The results for all the flow reduction scenarios are also listed in Table 8-16. Since flow for Myakkahatchee Creek was not a significant term in the regressions for these isohalines, results for the North Port withdrawals are not included, but as with the salinity zone analysis, the impacts of the City's permitted withdrawals are expected to be very small.

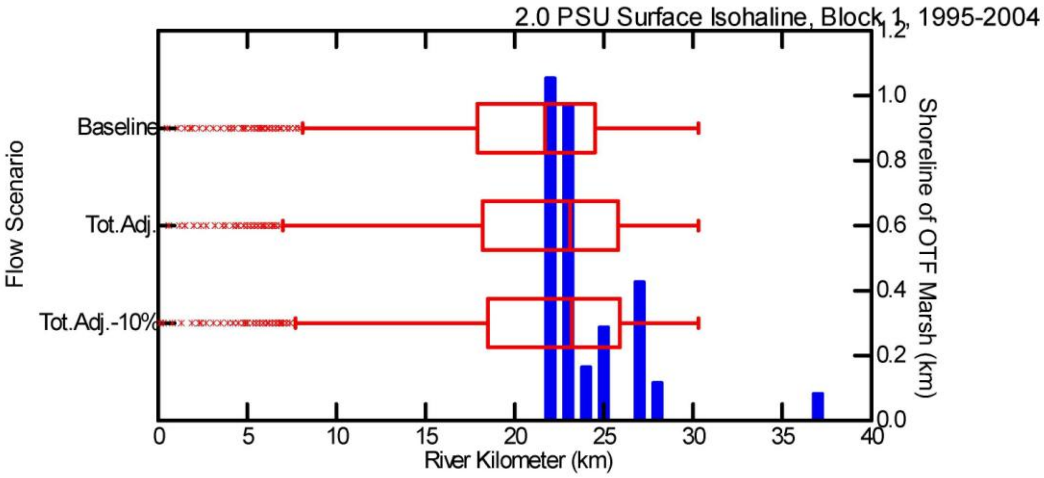

Figure 8-32. Box and whisker plot of the location of the 2 psu surface isohaline in Block 1 (March 1 – June 20) for baseline flows and flows reduced by withdrawals of the total excess flow and total excess flow minus 10 percent of the remaining flow at the Myakka River near Sarasota gage.

Table 8-16. Median kilometer locations of five surface isohalines for BLOCK 1 (March 1 - June 20) calculated for 1995-2004 and 1999-2002 for baseline flows and five flow reduction scenarios.

Isohaline	Median river kilometers of isohalines 1995-2004 - Block 1 (March 1 - June 20)					
	baseline flows	Ag adjusted	Total adjusted	Total adjusted - 10%	Total adjusted - 20%	Total adjusted - 30%
1 psu (km)	22.7	23.9	24.0	24.3	24.5	24.8
2 psu (km	21.6	22.9	23.0	23.2	23.5	23.7
4 psu (km)	19.7	21.0	21.2	21.4	21.6	21.7
8 psu (km)	16.9	18.0	18.1	18.2	18.4	18.6
12 psu (km)	13.5	14.1	14.3	14.5	14.6	14.7

Isohaline	Median river kilometers of isohalines 1999-2002 - Block 1 (March 1 - June 20)					
	baseline flows	Ag adjusted	Total adjusted	Total adjusted - 10%	Total adjusted - 20%	Total adjusted - 30%
1 psu (km)	25.4	25.9	26.2	26.4	26.7	26.9
2 psu (km	24.8	25.4	25.6	25.8	26.1	26.3
4 psu (km)	23.4	24.2	24.4	24.6	24.8	25.0
8 psu (km)	19.9	20.5	20.7	20.8	21.0	21.2
12 psu (km)	18.4	18.8	18.9	19.1	19.1	19.2

The greatest shifts resulted from the withdrawal of total adjusted flows, ranging from 1.3 to 1.5 kilometers for the 1, 2 and 4 psu isohalines during 1995-2004. The shifts were less during 1999-2002 when the isohalines had baseline locations farther upstream due to the extremely low dry season flows that occurred during that period. During both periods, most of the shifts due to removal of total excess flows was due to the agricultural adjustment, indicating that most of the excess flow was due to agricultural land use and irrigation in the spring and early summer. Shifts due to removal of 10 to 30 percent of the remaining flow at the Myakka River near Sarasota gage resulted in smaller shifts, generally in the range of 0.1 to 0.3 kilometers for each incremental 10% withdrawal.

These isohaline shifts were applied by Mote Marine Laboratory to the length and area of OTF shorelines upstream of each isohaline. These results were expressed two ways: (1) as the amount of shoreline length and area upstream of the median location of each isohaline in Block 1; and (2) by calculating the amount of OTF shoreline length and area upstream of each isohaline on a daily basis with comparison of the scenarios performed using cumulative distribution function analysis of the daily values. The lengths and areas of OTF wetlands upstream of the median positions of the isohalines are listed in Table 8-17 for both the 1995-2004 and 199-2002 periods, with the results listed in kilometers and hectares and as respective percentages of the baseline value. Reductions in shoreline lengths were substantial, ranging from 31% to 56% for the five flow reduction scenarios for the 1995-2004 period. Reductions were not as great for the 1999-2002, because the baseline values for shoreline length and area much lower, with the median location of the 2 psu isohaline upstream of the majority of the OTF marshes. The results for shoreline area were very similar to the results for shoreline length for 1995-2004, but differed somewhat for the 1999-2002 period as the marshes were did not extend laterally as far from the channel in the upstream reaches of the OTF marsh zone.

Table 8-17. Shoreline lengths and areas of oligohaline / tidal freshwater wetlands upstream of the median location of the 2 psu surface isohaline in Block 1 (March 1 - June 20) for 1995-2004 and 1999-2002. Values also expressed as percent reductions from baseline. Percent reductions greater than 15% are highlighrted in yellow, reductions greater than 25% are highlighted in gray

	Shoreline lengths of Oligohaline Tidal Freshwater Wetlands upstream of the median position of the 2 psu surface isohaline in Block 1			
	1995-2004		**1999-2002**	
Block 1 (March 1 - June 20)	***Kilometers of OTF Shoreline***	***Percent reduction from baseline***	***Kilometers of OTF Shoreline***	***Percent reduction from baseline***
Baseline	3.102	NA	0.952	NA
Agricutural adjustment	2.153	31%	0.796	16%
Total adjustment	2.048	34%	0.739	22%
Total adjustment + North Port - 10%	1.853	40%	0.681	28%
Total adjustment + North Port - 20%	1.562	50%	0.624	34%
Total adjustment + North Port - 30%	1.367	56%	0.624	34%

	Hectares of Oligohaline Tidal Freshwater Wetlands upstream of the median position of the 2 psu surface isohaline in Block 1			
	1995-2004		**1999-2002**	
Block 1 (March 1 - June 20)	***Hectares of OTF Wetlands***	***Percent reduction from baseline***	***Hectares of OTF Wetlands***	***Percent reduction from baseline***
Baseline	24.316	NA	7.075	NA
Agricutural adjustment	16.585	32%	6.546	7%
Total adjustment	15.725	35%	6.374	10%
Total adjustment + North Port - 10%	14.107	42%	6.203	12%
Total adjustment + North Port - 20%	11.680	52%	6.004	15%
Total adjustment + North Port - 30%	10.062	59%	5.950	16%

This analysis was repeated for the 4 psu isohaline to examine the shifts of a somewhat higher salinity concentration during the dry 1999-2002 period (Table 8-18). As discussed in Sections 6.2.6 and 7.10.3, some studies have suggested that exposure to salinity concentrations in the range of 4 to 5 psu can be important for vegetation zonation. There were no percent reductions in the 1995-2004 period as the 4 psu isohaline was downstream of the OTF marsh zone for all flow reduction scenarios. However, for the 1999-2002 period, the 4 psu isohaline was located within the OTF zone with substantial reductions in the amounts of shorelines and wetlands areas upstream of the isohaline relatives to baseline conditions.

Table 8-18. Shoreline lengths and areas of oligohaline / tidal freshwater wetlands upstream of the median location of the 4 psu surface isohaline in Block 1 (March 1 - June 20) for 1995-2004 and 1999-2002. Values also expressed as percent reductions from baseline. Percent reductions greater than 25% are highlighted in gray

	Shoreline lengths of Oligohaline Tidal Freshwater Wetlands upstream of the median position of the 2 psu surface isohaline in Block 1			
	1995-2004		**1999-2002**	
Block 1 (March 1 - June 20)	***Kilometers of OTF Shoreline***	***Percent reduction from baseline***	***Kilometers of OTF Shoreline***	***Percent reduction from baseline***
Baseline	3.1020	NA	1.6588	NA
Agricutural adjustment	3.1020	0%	1.0422	37%
Total adjustment	3.1020	0%	1.0094	39%
Total adjustment + North Port - 10%	3.1020	0%	0.9766	41%
Total adjustment + North Port - 20%	3.1020	0%	0.9438	43%
Total adjustment + North Port - 30%	3.1020	0%	0.9110	45%

	Hectares of Oligohaline Tidal Freshwater Wetlands upstream of the median position of the 2 psu surface isohaline in Block 1			
	1995-2004		**1999-2002**	
Block 1 (March 1 - June 20)	***Hectares of OTF Wetlands***	***Percent reduction from baseline***	***Hectares of OTF Wetlands***	***Percent reduction from baseline***
Baseline	24.3162	NA	12.4892	NA
Agricutural adjustment	24.3162	0%	7.4857	40%
Total adjustment	24.3162	0%	7.3364	41%
Total adjustment + North Port - 10%	24.3162	0%	7.1871	42%
Total adjustment + North Port - 20%	24.3162	0%	7.0378	44%
Total adjustment + North Port - 30%	24.3162	0%	6.8850	45%

Cumulative distribution plots of the daily amounts of shoreline upstream of the 2 psu isohaline are plotted in Figure 8-33 for the three seasonal blocks during 1995-2004 and 1999-2002. The curves reach a plateau at 3.1 kilometers, as this is the total amount of OTF shoreline at its downstream boundary near kilometer 22. As with the results based on median isohaline locations, the largest shifts in shoreline lengths are due to the removal of the total excess flows, with the agricultural adjustment comprising most of those quantities. Comparison of the results for 1995-2004 and 1999-2002 again show substantial reductions in the amount of shoreline length for Blocks 1 and 2. The CDF analysis was not performed for the 4 psu isohaline.

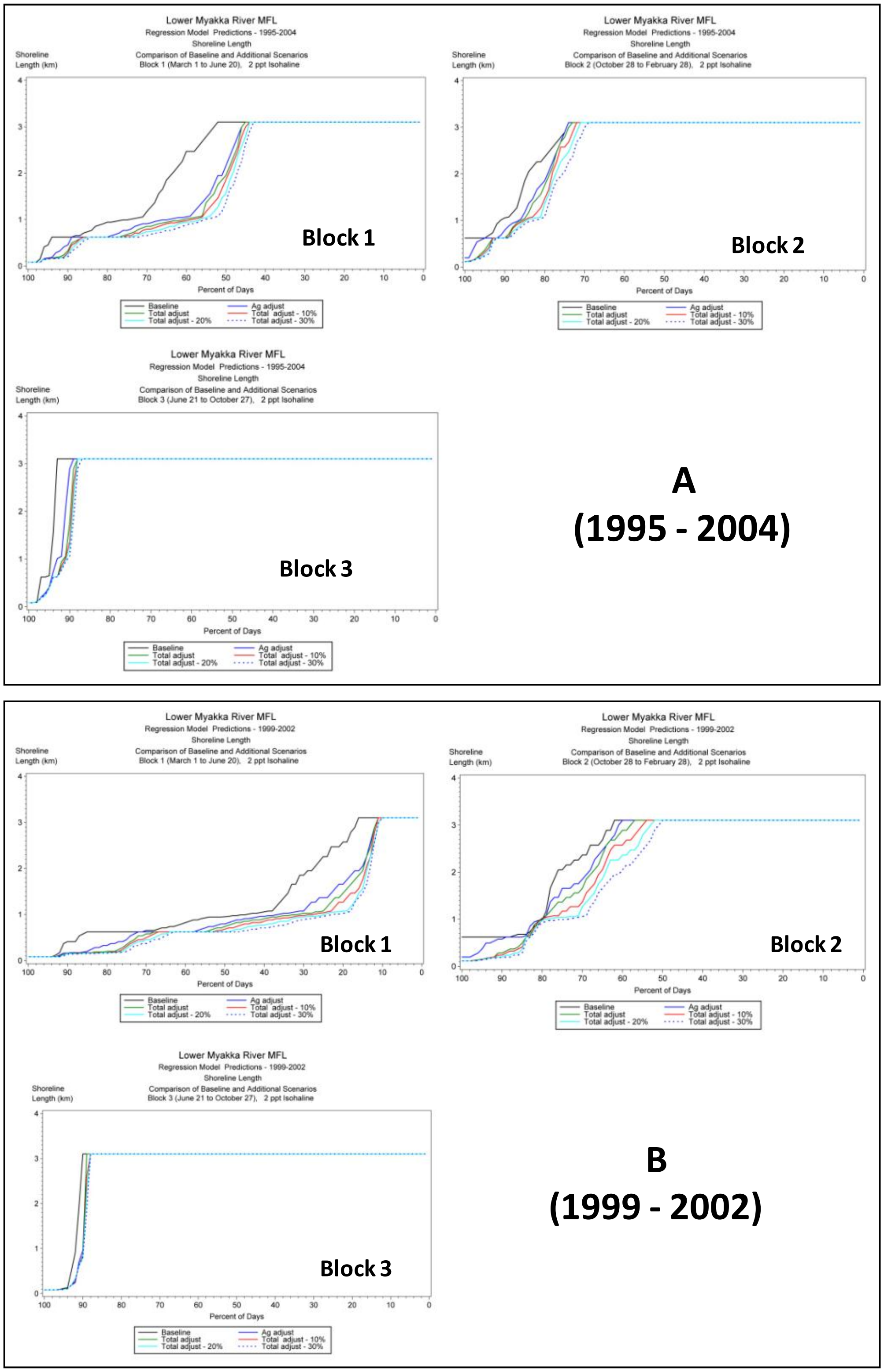

Figure 8-33. Cumulative distribution function plots of daily values of shoreline lengths of oligohaline / tidal freshwater marshes upstream of the 2 psu surface isohaline for Block 1 (March 1 – June 20) for the (A) 1995-2004 and (B) 1999-2002 periods.

By quantifying the normalized areas under the CDF curves (CDF/NAUC method), percent reductions in the amount of OTF marsh shoreline length and area were calculated for all seasonal blocks for both the 1995-2004 and 1999-2002 periods. Results for shoreline length confirm that changes in marsh exposure to the 2 psu isohaline are generally small during Blocks 2 and 3, except for the higher flow reduction scenarios during Block 2 in 1999-2002, when the 2 psu isohaline was usually far upstream due to the dry conditions. Still, reductions in shoreline lengths greater than 15% did not occur for any of the scenarios in blocks 2 and 3.

For Block 1, shoreline reductions calculated by the CDF/NAUC method were less than using the median location method for 1995-2004, because when the data are assessed on a cumulative daily basis, there were many days during Block 1 in 1995-2004 when there either no difference or very small differences between the scenarios (Figure 8-33A). For the drier 1999-2002 period, the results for block1 using the CDF/NAUC method and the median location methods were more similar, since there were fewer days when the amount of shoreline length < 2 psu for the flow scenarios did not differ (Figure 8-33B). In other words, there were fewer days in 1999-2002 when the location of the 2 psu isohaline for all flow scenarios was downstream of the OTF marsh zone. Given this condition during 1999-2002, the percent changes in the amount of shoreline upstream of the 2 psu isohaline were again substantial (26% to 35%).

Table 8-19. Percent reduction in the length of oligohaline / tidal freshwater shoreline upstream of the 2 psu surface isohaline for three seasonal blocks for the 1995-2004 and 1999-2002 time periods. Results calculated from the normalized areas under the curves for daily values for Block 1 shown in Figure 8-32. Reductions greater than 15% are highlighted in yellow and reductions greater than 25% are highlighted in gray.

	Percent reduction shoreline length upstream of the < 2 psu isohaline	
Block 1 March 1 - June 20	***1995 - 2004***	***1999-2002***
Agricutural adjustment	13%	21%
Total adjustment	15%	26%
Total adjustment + North Port - 10%	16%	29%
Total adjustment + North Port - 20%	18%	32%
Total adjustment + North Port - 30%	19%	35%
Block 2 October 28 - April 30	***1995-2004***	***1999-2002***
Agricutural adjustment	3%	4%
Total adjustment	4%	7%
Total adjustment + North Port - 10%	5%	9%
Total adjustment + North Port - 20%	6%	12%
Total adjustment + North Port - 30%	8%	14%
Block 3 June 21 - October 27	***1995-2004***	***1999-2002***
Agricutural adjustment	3%	2%
Total adjustment	4%	2%
Total adjustment + North Port - 10%	4%	2%
Total adjustment + North Port - 20%	4%	2%
Total adjustment + North Port - 30%	4%	2%

Table 8-20. Percent reduction in the areas of oligohaline / tidal freshwater marshes upstream of the 2 psu surface isohaline for three seasonal blocks for the 1995-2004 and 1999-2002 time periods. Results calculated from the normalized areas under the cymulative distributon function curves Reductions greater than 15% are highlighted in yellow and reductions greater than 25% are highlighted in gray

	Percent reduction in Wetland Area upstream of the 2 psu isohaline	
Block 1 March 1 - June 20	***1995 - 2004***	***1999-2002***
Agricutural adjustment	12%	19%
Total adjustment	14%	23%
Total adjustment + North Port - 10%	15%	26%
Total adjustment + North Port - 20%	16%	28%
Total adjustment + North Port - 30%	18%	30%
Block 2 October 28 - April 30	***1995-2004***	***1999-2002***
Agricutural adjustment	3%	4%
Total adjustment	4%	6%
Total adjustment + North Port - 10%	5%	9%
Total adjustment + North Port - 20%	6%	11%
Total adjustment + North Port - 30%	7%	14%
Block 3 June 21 - October 27	***1995-2004***	***1999-2002***
Agricutural adjustment	2%	2%
Total adjustment	3%	3%
Total adjustment + North Port - 10%	4%	4%
Total adjustment + North Port - 20%	4%	4%
Total adjustment + North Port - 30%	4%	4%

Although accompanying CDF plots are not shown, changes in the percent of area of OTF marshes were also assessed using the CDF/NAUC method (Table 8-20 above). Again, there were no changes greater than 15% for any of the flow scenarios in blocks 2 and 3. The percent changes in area in Block 1 were slightly less, but similar to, the percent changes in shoreline length using this same method.

8.7.1 Threshold rates of flow for exposure of oligohaline / tidal freshwater marshes to various surface isohalines

The seasonal block analyses presented above clearly indicates that the exposure of OTF marshes to brackish salinities primarily occurs at low flows. To examine the flow rates these marshes get exposed to different salinities, the lengths of OTF shorelines upstream of four different isohalines are plotted vs. 5-day mean flow at the Myakka River near Sarasota gage in Figure 8-34. Plots of marsh area vs. flow are not presented, since a given marsh area is only exposed to an isohaline if it's corresponding shorelines is exposed. Also, the plot of shoreline length exposed to 1 psu is very similar to the plot for 2 psu, so it is not shown.

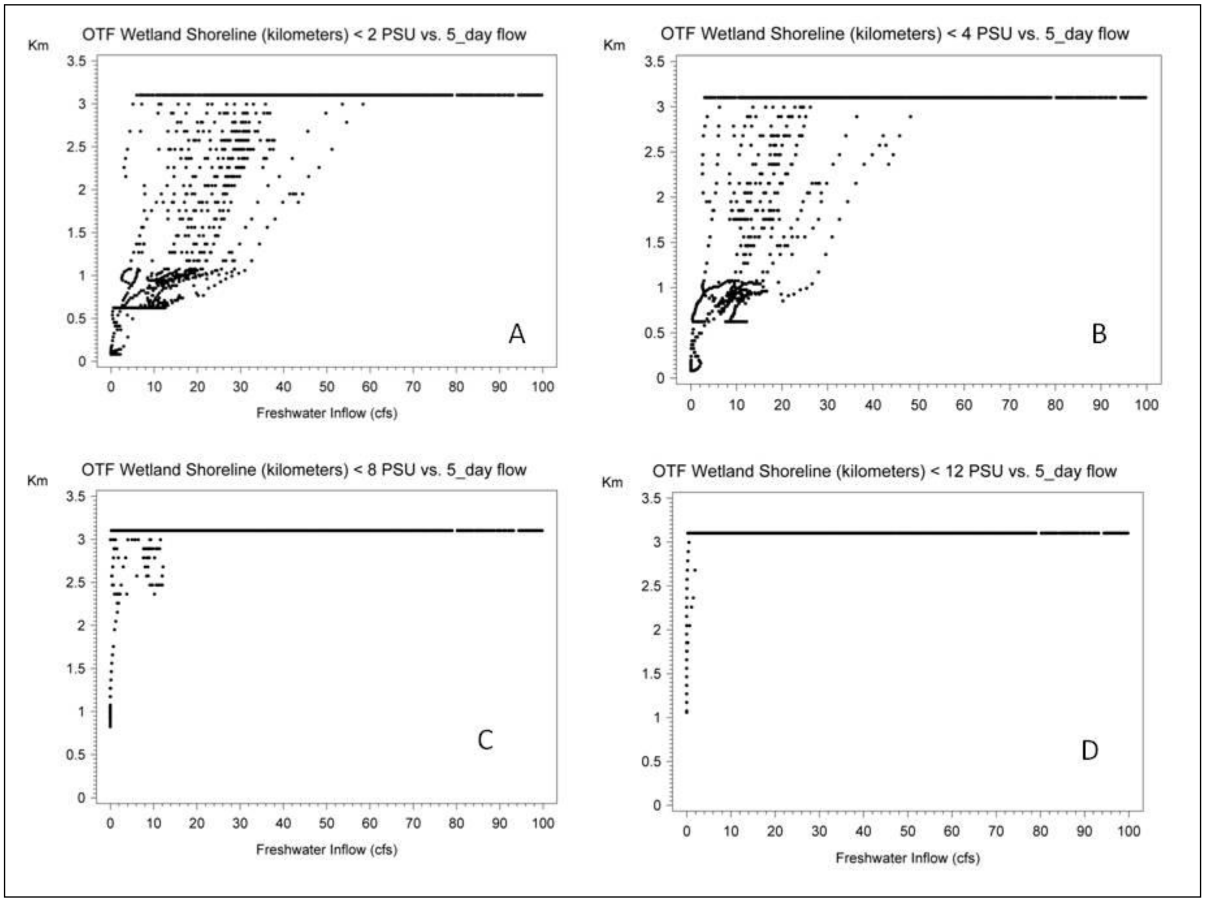

Figure 8-34. Shoreline lengths of oligohaline / tidal freshwater marsh upstream of the predicted locations of the 2 psu, 4 psu, 8 psu, and 12 psu surface isohalines vs. the preceding 5-day mean flow at the Myakka River near Sarasota gage.

OTF shorelines are typically exposed to salinities of 2 psu when flows are less than 35 cfs, although some infrequent exposures at flows up to 56 cfs were predicted for baseline conditions (Figure 8-34A). Marsh exposures to salinity of 4 psu are typically limited to flows of less than 24 cfs, although two exposures of flows up to about 48 cfs were predicted. Exposure of the OTF to salinity of 8 psu were limited to flows below about 14 cfs, while exposures of the marshes to salinities of 12 psu occurred very infrequently at zero and near zero flows.

As discussed in Section 8.2.2, the removal of excess flows will have the greatest effects on the low flow characteristics of the river (see Figures 8-9 and 8-10). It is likely that removal of the excess flows and potentially any remaining flow will result in some shifts in vegetation in the OTF marsh zone. It can be argued that changes resulting from removing the total excess flows will result in a more natural ecological condition, as the low flows of the river have clearly increased. However, removal of additional flows may result in additional changes to the OTF marsh zone, thus removal of additional flow (e.g. 10% or 20%) of the remaining flow at the long-term gage may not be justified at low flows. Removal of these percentages of the remaining flows may be justified at higher flows when even the 1 psu isohaline is downstream of the OTF marsh zone. In the final section of this report, findings from of the OTF marsh simulations are discussed in context of an allowable withdrawal schedule for the Lower Myakka River along with the findings for the other ecological indicators that were simulated for the minimum flows analysis.

8.8 Changes in the abundance of fish and invertebrate nekton and zooplankton species

As described in Section 7.10.4, regressions presented by Peebles et al. (2006) and supplemented by Peebles (2008) were used to predict changes in the abundance and distribution of a number of key fish and invertebrate species in the Lower Myakka River. Emphasis was placed on ecologically important taxa whose abundance would be reduced by reductions of freshwater inflow. In some cases, the regressions were specific to certain life stages or size classes of a particular taxon, which are referred to as pseudo-species by Peebles et al. (2006). Among these pseudo-species, the regressions selected for analysis were based on their coefficients of determination (r^2) and error of the predictions across the range of flows encountered during the study. In the following discussion, the terms taxa and pseudo-species are both used to denote the life stage/age class of the taxa selected for analysis.

As also described in Sections 6.4 and Section 7.10.4, the initial 23-month fish and invertebrate sampling effort occurred during a period of relatively high flows in 2003 and 2004. To supplement these data, the plankton component of the study was reinstituted with the same sampling design during a low flow period from February to June 2008 which provided an additional five sampling dates. Because of greater range of flows captured by these additional samples, the regressions for the plankton samples were more robust and were given greater emphasis in the minimum flows analysis than the predictions developed from the seine and trawl samples.

The pseudo-species utilized for regression analyses in the evaluation of minimum flows for the lower river are listed in Table 8-21, along with various statistical parameters of the regressions. The pseudo-species selected for analysis included four invertebrate and three fish taxa sampled by plankton net and two invertebrate and one fish taxa sampled by seines. These taxa included freshwater species which inhabit the upper reaches of the lower river and estuarine taxa which reside in the lower river throughout their life cycle or immigrate into the lower river as early life stages. Some of the most dramatic changes in abundance were observed for freshwater species, as increased freshwater flows expand the suitable habitat for these species into the study area (below kilometer 35). Although this information is useful as it describes changes in the biological structure of the lower river, changes in freshwater taxa were not used for the determination of significant harm as these species will retain suitable habitat upstream.

In contrast, the upstream distributions of estuarine taxa are largely confined to the brackish portion of the tidal river. As a result, predicted reductions in the abundance of these taxa better represent reductions of their total population within the tidal river. In particular, the opossum shrimp, *Americamysis almyra*, is an abundant species which is an important prey item for wide range of juvenile fishes (Peebles 2005, Peters and McMichael 1987, McMichael et al. 1989). Two regression models of different form were fitted to the abundance response for *Americamysis* from the plankton catch data. Because of the importance of this species and the relatively high r^2 values or the regressions (.44 and .52), the response of *Americamysis* was important to the minimum flows analysis. Similarly, *Trinectes maculatus* is a dominant fish in the lower river for which a good regression ($r^2 = .68$) was established for its juvenile stage, so changes in the abundance of *Trinectes* were given emphasis in the determination the minimum flows.

Table 8-21. Regressions between freshwater inflow and the estimated abundance (plankton) or relative abundance (seine and trawl) of taxon / age-size classes that were used in the minimum flow analysis. All regressions taken from Peebles et al. (2006) or Peebles (2008). The flow term is the preceding mean flow calculated as either the sum of flows from the Myakka River near Sarasota gage and Myakkahatchee Creek at Tropicaire Blvd. gage or the Myakka gage only. The number of days used to calculate the preceding mean flow is listed. Both abundance and flow data were natural log (ln) transformed with a value of 1 added to all flow and catch data in the seine and trawl regressions. DW denotes possible serial correlation based on p<0.05 for the Durbin-Watson statistic.

USF Plankton Sampling

Taxon	Common Name	Zone	Gear	age/size class	Months	Response	df	DW	r^2	Flow Term	Mean flow (days)
Invertebrates											
Americamysis almyra	mysid shrimp	Estuarine	plankton	adults	all	linear	23		0.44	Sum	79
Americamysis almyra (2) *	mysid shrimp	Estuarine	plankton	adults	all	d. r.*	23		0.52	Sum	79
Cyathura polita	isopod	Estuarine	plankton	all	all	linear	20		0.26	Sum	21
Ephemeropteran larvae **	mayflie larvae	Freshwater	plankton	larvae	all	linear	22		0.77	mrs **	48
Mesocyclops edax **	copepod	Freshwater	plankton	all	all	linear	20		0.63	mrs **	1
Fish											
Meinida spp.	silversides	Estuarine	plankton	juveniles	all	linear	14	x	0.36	Sum	10
Gambusia hobrooki **	mosquitofish	Freshwater	plankton	juveniles	all	linear	14		0.34	mrs **	12
Trinectes mactulatus	hogchoker	Estuarine	plankton	juveniles	all	linear	18	x	0.68	Sum	34
Trinectes mactulatus **	hogchoker	Estuarine	plankton	juveniles	all	linear	18	x	0.69	mrs **	34

* double recripocal model

** regression using Myakka River near Sarasota gage only

FFWCC Seine and Trawl Sampling

Taxon	Common Name		Gear	age/size class	Months	Response	df	DW	r^2	Flow Term	Mean flow (days)
Invertebrates											
Palaemonetes intermedius	brackish grass shrimp	Estuarine	seines	all	Mar. to Dec	quadratic	15	x	0.35	Sum	21
Palaemonetes pugio	daggerblade grass shrimp	Estuarine	seines	all	Mar. to Dec	quadratic	15	x	0.43	Sum	21
Fish											
Gambusia hobrooki	mosquitofish	Freshwater	seines	<= 25 mm	all	linear	18	x	0.41	Sum	168
Gambusia hobrooki	mosquitofish	Freshwater	seines	>= 26 mm	all	linear	18	x	0.26	Sum	168

The scatter plots of the regressions listed in Table 8-21 are presented in three separate figures. Figure 8-35 includes scatter plots for four taxa of estuarine fish or invertebrates sampled in the plankton, with separate plots for the two regressions shown for *Americamysis*. The explanatory flow variable for these regressions was the sum of flows from the Myakka River near Sarasota and Myakkahatchee Creek at Tropicaire Blvd. Figure 8-36 includes plots for four taxa that primarily inhabit the freshwater portion of the lower river. The explanatory variable for these regressions was gaged flow for the Myakka River near Sarasota, since the center of abundance of these species typically ranges above the confluence of Myakkahatchee Creek with the Myakka River. Scatter plots for the hogchoker, *Trinectes maculatus*, are included in both Figures 8-35 and 8-36 as regressions for this species were developed separately using the summed gaged flows and the Myakka River gage alone. The hogchoker is an estuarine resident species that typically reaches peak abundance in oligohaline waters in the upper reaches of tidal rivers, and this species was evaluated using both flow terms for comparison.

Figure 8-37 shows regressions for the seine catch of two closely related species of estuarine grass shrimp (*Palaemonetes intermedius* and *Palaemonetes pugio*), both of which that are also important prey items for fishes. *Palaemonetes pugio* was approximately five times more abundant in the river and usually located somewhat further upstream than *P. intermedius*. The form of the regressions for both species were quadratic, indicating that abundances were low at low freshwater inflows, maximum at intermediate inflows, and less again as inflows increased to high flow rates. This relationship was also observed for other taxa in the Lower Alafia River, indicating that increases in low flows increase populations in the river, while higher flows reduce numbers as the populations become centered downstream of the rivers in the receiving bay (SWFWMD 2008b).

Scatter plots for seine catch of two size classes of the eastern mosquitofish (*Gambusia holbrooki*) are also shown in Figure 8-37. Although *G. hobrooki* and be found periodically abundant in the upper reaches of tidal rivers, it is predominantly a freshwater species that is widely distributed in lakes and rivers in the Southeastern U.S. The mean salinity of capture for *G. holbrooki* in the Lower Myakka was 0.45 psu, and it's average center of distribution was at kilometer 25.3. Regressions of inflow and abundance for *G. holbrooki* were linear, indicating that the abundance of this species had a montonic positive relationship with freshwater flow, as increased flows greatly expand the suitable habitat for this predominantly freshwater species.

As previously discussed, the abundance of freshwater species such as *Gambusia holbrooki* was not considered as a criterion for determining significant harm, for these species have suitable habitat remaining upstream during periods of low freshwater inflow. Reductions of freshwater species in the study area (0 to 35 kilometers) could be important as they affect overall food web dynamics, such as providing prey for wading birds. However, it was assumed for this study that during periods of low inflow these species would be replaced by more estuarine species which provide similar ecological functions in those river reaches. Again, it was the reduction of estuarine species that was emphasized for the consideration of significant harm, as the habitats for these species are restricted to the brackish reaches of the tidal river, and reductions of freshwater flows could affect their total abundance within the Lower Myakka River.

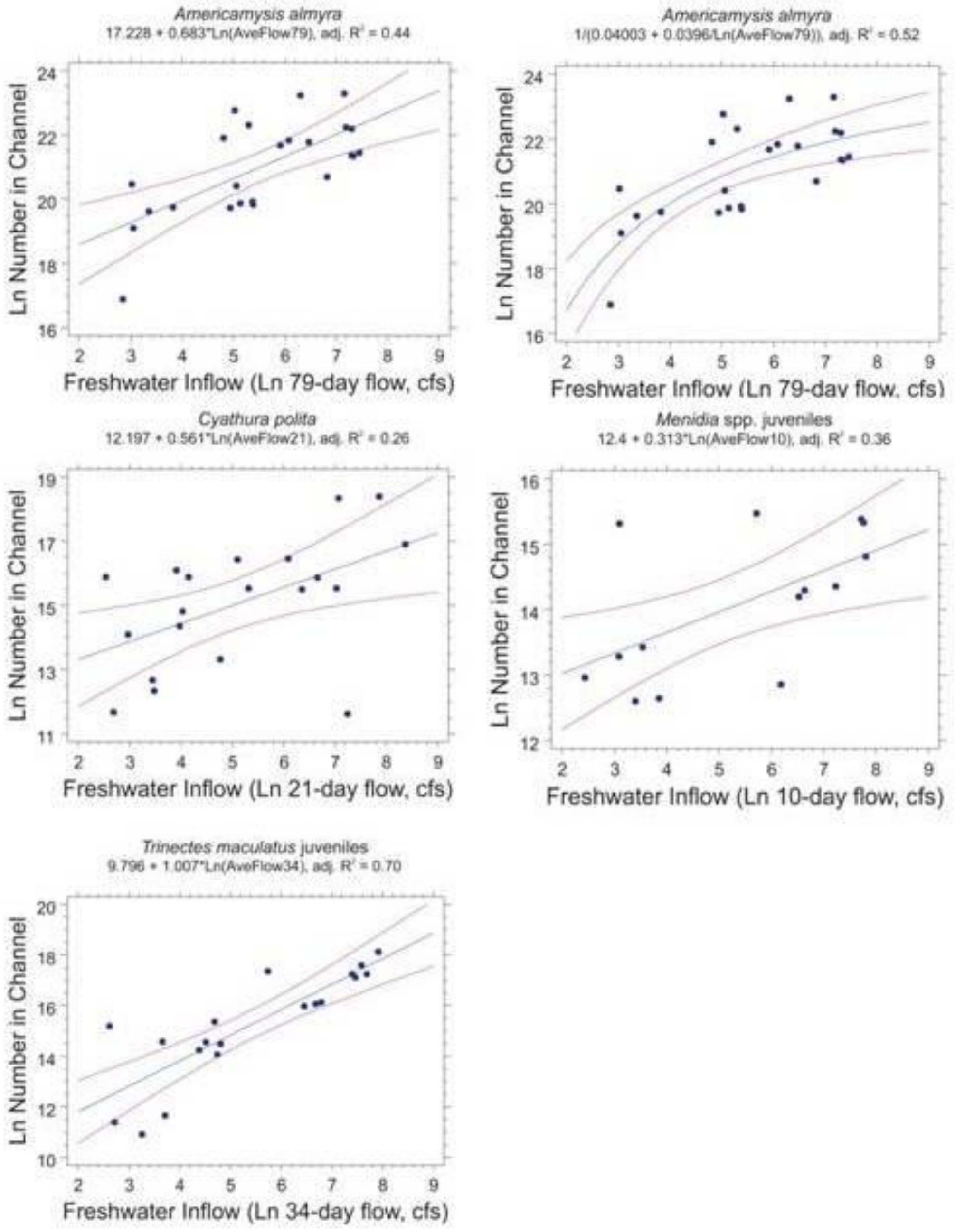

Figure 8-35 Regressions of the abundance of four pseudo-species collected by plankton net vs. freshwater inflow presented by Peebles (2008). Two regressions shown for *Americamysis almyra*. The flow term is the sum of flow from the Myakka River near Sarasota and Myakkahatchee Creek at Tropicaire Blvd.

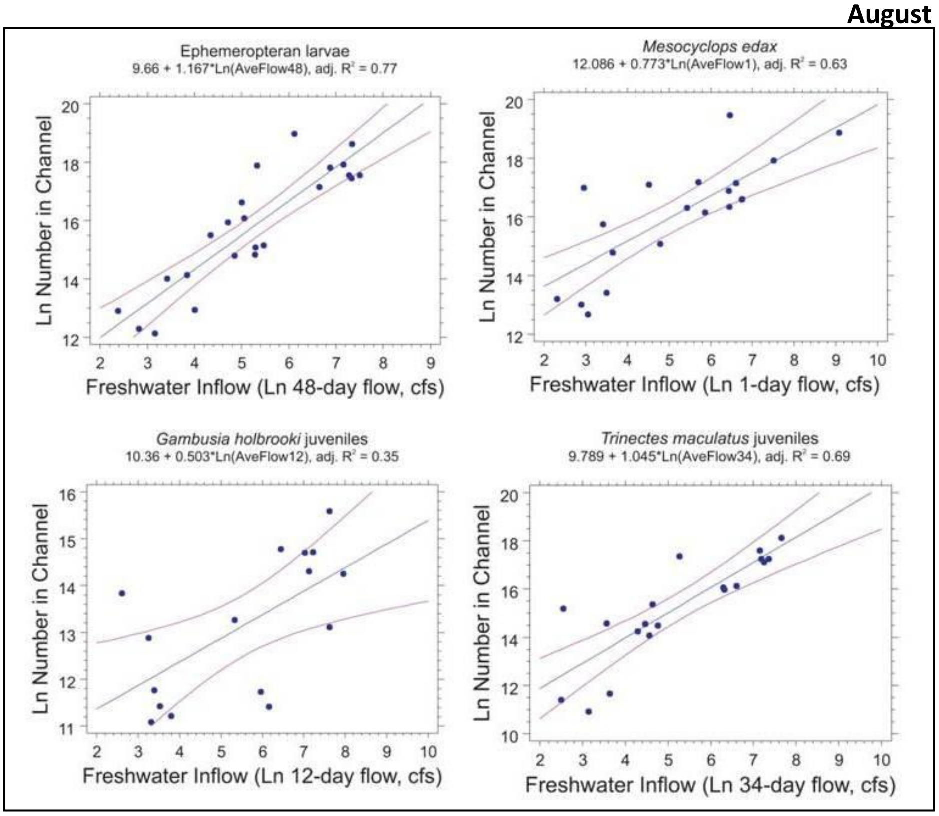

Figure 8-36 Regressions of the abundance of four pseudo-species collected by plankton net vs. freshwater inflow presented by Peebles (2008). The flow term is flow at the Myakka River near Sarasota gage.

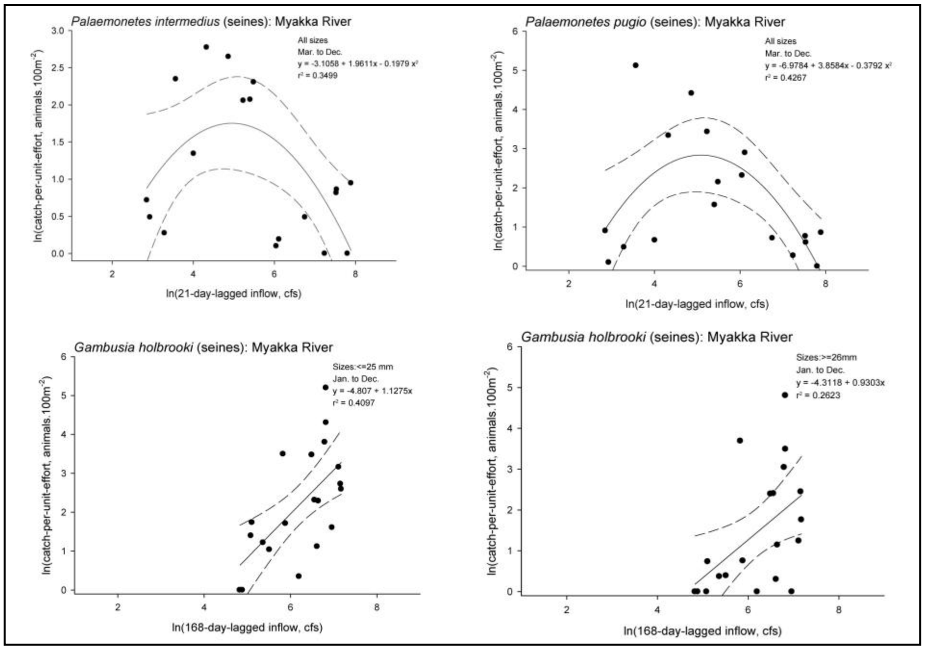

Figure 8-37 Regressions of the abundance of four pseudo-species collected by seine vs. inflow presented by Peebles et al. (2006). Regressions shown for two size classes of *Gambusia holbrooki.* The flow term is the sum of flow from the Myakka River near Sarasota and Myakkahatchee Creek at Tropicaire Blvd. gages.

It is the opinion of this report that the relationships listed in Table 8-21 and displayed in the associated figures are not spurious and freshwater inflow has a genuine causative relationship with the abundance of these taxa. The positive relationships with predominantly freshwater taxa are certainly plausible, and similar positive relationships with freshwater inflow were observed for the estuarine taxa *Americamysis almyra, Palaemonetes pugio*, and *Trinectes maculatus* in either or both the Lower Alafia and Anclote rivers (SWFWMD 2008b, SWFWMD 2010a). While accepting that these relationships are real, it is acknowledged that collection of more field samples or the application of other modeling tools that incorporate other explanatory variables could change or refine the prediction of species abundance for a given rate of freshwater inflow. However, it is suggested at this time that that these regressions, particularly the stronger ones for important estuarine taxa (*Americamysis almyra, Trinectes maculatus*), are useful tools that should be incorporated in the determination of minimum flows for the Lower Myakka River.

While accepting the use of the regressions, decisions had to be made on how changes in abundance were to be calculated. All the regressions allow for the prediction of abundance on a daily basis using preceding mean flow terms. However, while inflow does affect abundance, it is unlikely that the abundance of most of the species will change significantly on a daily basis in response to freshwater inflow. In that regard, a number of statistical comparisons were done on the predicted values to evaluate changes in population abundance resulting from the flow reduction scenarios. These statistical comparisons included evaluating changes in: the median values of daily percent changes in abundance; cumulative distribution functions of predicted abundance values; predicted mean abundance values; and median values of predicted daily abundance values. These comparisons were done on the three seasonal blocks to determine if the sensitivity of populations to change from baseline conditions varied during the year. Predicted abundance values for the flow scenarios were also plotted against the corresponding baseline flows to evaluate how the different flow reduction scenarios affect abundance over various ranges of freshwater inflow. Greater details on the methods and findings of these statistical comparisons are presented in following sections.

Another analytical consideration involved applying the regressions to the entire range of flows incorporated during the entire 1995-2004 modeling period. Based on the range of flows that were used to develop the regressions, flow domains were established that identified lower and upper flow limits for which the regressions would be applied. These upper and lower flow limits were established specific to the preceding day flow term in each regression based on the scatter plots presented by Peebles et al. (2006) and Peebles (2008). The flow terms and domains of each of the regressions that used the summed flows of the Myakka River and Myakkahatchee Creek gages are listed in Table 8-22. Table 8-23 lists the same information for regressions that used the Myakka River near Sarasota gage alone.

Tables 8-22 and 8-23 also list the percentage of the daily baseline flows that fell outside the regression domains for the 1995-2004 modeling period within each seasonal block. The percent of baseline flows that were outside the domain of the regressions were highest in Block 1. Since this is the driest time of year, this represents flows during the modeling period that were lower than the flows used to develop the regressions. This was particularly the case for the seine samples which were not supplemented by the additional five dry season samples in 2008. The number of flows that were outside the domain of the regression were much fewer in Block 2 (intermediate flows) and Block 3 (high flows), since low flows were not as frequent during those blocks.

Table 8-22. Lower and upper limits of flows that were within the domain of the regression for each taxon / age-size class and the percentage of predictions that were outside the flow domain of the regression for each scenario listed by seasonal block. Results are listed only for those taxa / age-size classses that were predicted using the sum of flows from the Myakka River near Sarasota and Myakkahatchee Creek at Tropicaire Blvd.

					Percentage of predictions outside flow domain of the regression by seasonal block for each scenario							
Taxon	**Common Name**	**Flow term (days)**	**Flow Lower bound (cfs)**	**Flow Upper Bound (cfs)**	**Seasonal Block**	**Baseline**	**North Port Permitted**	**Agricultural excess**	**Total excess**	**Total excess - NP - 10%**	**Total excess - NP - 15%**	**Total excess - NP - 20%**
Americamysis almyra	mysid shrimp	79.00	12	2,208	1	2%	5%	9%	10%	19%	20%	20%
					2	0%	2%	3%	3%	6%	7%	7%
					3	2%	2%	3%	4%	4%	5%	5%
Americamysis almyra *	mysid shrimp	79.00	15	1,998	1	6%	8%	11%	16%	21%	21%	22%
					2	2%	3%	3%	6%	7%	7%	7%
					3	4%	4%	5%	6%	7%	7%	7%
Cyathura polita	isopod	21.00	10	2,980	1	11%	12%	24%	26%	31%	32%	33%
					2	0%	1%	6%	8%	13%	13%	13%
					3	2%	3%	3%	4%	5%	5%	5%
Meinida spp.	silversides	10.00	10	2,980	1	0%	2%	0%	0%	9%	9%	9%
					2	0%	0%	0%	0%	0%	0%	0%
					3	0%	0%	0%	0%	1%	1%	1%
Trinectes mactulatus	hogchoker	34.00	11	3,294	1	9%	11%	21%	22%	26%	27%	28%
					2	0%	3%	6%	6%	11%	11%	11%
					3	3%	3%	3%	4%	4%	5%	5%
Palmonetes intermedius	brackish grass shrimp	21.00	15	2,980	1	18%	20%	32%	33%	41%	42%	44%
					2	4%	7%	9%	13%	18%	18%	18%
					3	4%	4%	6%	6%	7%	7%	7%
Palmonetes pugio	daggerblade grass shrimp	21.00	15	2,980	1	18%	20%	32%	33%	41%	42%	44%
					2	4%	7%	9%	13%	18%	18%	18%
					3	4%	4%	6%	6%	7%	7%	7%
Gambusia hobrooki <= 25 mm	mosquitofish	168.00	110	1,635	1	47%	48%	51%	51%	55%	56%	60%
					2	5%	5%	10%	10%	10%	10%	10%
					3	18%	20%	32%	33%	34%	35%	36%
Gambusia hobrooki >= 26 mm	mosquitofish	168.00	110	1,635	1	47%	48%	51%	51%	55%	56%	60%
					2	5%	5%	10%	10%	10%	10%	10%
					3	18%	20%	32%	33%	34%	35%	36%

* double recriprocal model

Table 8-23. Lower and upper limits of the domain of the regression for each taxon / age-size class and the percentage of predictions that were outside the flow domain of the regression for each scenario listed by seasonal block. Results are listed oly for those taxa / age-size classes collected by plankton net that were prediced using flows from the Myakka River near Sarasota gage only.

					Number of predictions outside flow domain of the regression by seasonal block for each scenario						
Taxon	**Common Name**	**Flow term (days)**	**Flow Lower bound (cfs)**	**Flow Upper Bound (cfs)**	**Seasonal Block**	**Baseline**	**Agricultural excess**	**Total excess**	**Total excess - 10%**	**Total excess - 15%**	**Total excess - 20%**
Ephemeropteran larvae	mayflie larvae	48	8	2,208	1	5%	15%	17%	19%	20%	21%
					2	0%	7%	10%	10%	10%	10%
					3	5%	8%	9%	9%	9%	9%
Mesocyclops edax	copepod	1	7	9,895	1	14%	34%	40%	41%	42%	42%
					2	1%	13%	17%	18%	18%	18%
					3	4%	10%	12%	12%	12%	12%
Trinectes mactulatus juveniles	hogchoker	34	10	2,980	1	10%	24%	28%	29%	30%	31%
					2	3%	10%	11%	12%	12%	12%
					3	5%	9%	10%	10%	10%	10%
Gambusia hobrooki juveniles	mosquitofish	12	10	3,640	1	16%	34%	38%	39%	40%	41%
					2	3%	13%	16%	18%	18%	19%
					3	6%	11%	13%	13%	13%	13%

The percentage of flows that were outside the domain of the regressions for the various flow reduction scenarios are also listed in Tables 8-22 and 8-23. The percentages outside the domain for the flow reduction scenarios increase relative to baseline, because the simulated withdrawals move more observations below the low flow bounds of the regressions. These increases were most pronounced in Block 1, since this is when the baseline flows were the lowest to begin with. For the scenario that represented the greatest flow reduction (total excess flows - North Port withdrawals - 20% of remaining flow at the Myakka River near Sarasota gage), the percentage of observations outside the flow domain were quite high, ranging as high as 60% for *Gambusia holbrooki* seine samples in Block 1 (Table 8-22).

The situation of having so many simulated flows below low flow bounds of the regressions was due to two factors. First, the fish and invertebrate sampling was during a predominantly wet period, which did not experience some of the prolonged low flows observed in drought years such as 1999, 2000, and 2001. In particular, the seine samples that were restricted to 2003 and 2004 were not well represented by low flows. The high percentage of flows outside the domain for *Gambusia holbrooki* because of the long preceding flow term used in the regression (168 days). Long mean flow terms during 2003-2004 did not nearly reach the low values observed over the longer 1995-2004 record. The range of shorter mean flow terms did not differ as greatly between the two periods, for even during 2003 and 2004 there were brief periods of low flows. The supplemental plankton sampling conducted during low flows in 2008 increased the range of flows used to develop those regressions.

Secondly, unlike minimum flows analyses for the Lower Alafia and Lower Peace Alafia Rivers, which involved low flow cutoffs for simulated withdrawals, the removal of total excess flows greatly reduced the low flow characteristics of the Myakka (see Figure 8.9). This caused the flow reduction scenarios to have much lower flows in the dry season than either the baseline flows or the range of flows on which the regressions were developed.

To examine the effect of the flow range issue, the statistical analyses of the predicted daily abundance values were run two ways. First, predictions were generated for only those flows that within the flow domain of each regression. Predictions that were outside the flow domains of each regression were set to missing values. Because it was desired that the flow reduction scenarios be evaluated equitably, if the flow for a given date was outside the domain of the regression for any of the flow reduction scenarios, the predicted abundance values for that species were set to missing for all the scenarios including baseline. In this manner, the effects of the flow reduction scenarios for that species would be compared using the same sets of days in the flow record.

The second method by which the predictions were statistically compared were to not limit the predictions to the flow domain of the regressions, so that predicted abundance values were generated for all the days in the record. Although this extended the predictions beyond the range of flow over which the models were developed, these predictions were considered valuable, for much information was lost in the first method when many of the predictions at low flows were set to missing, when much of the change in the river will be occurring due to removal of the excess flows. As described below, it was a comparison of the various statistical summaries of predicted values that were used to evaluate the results, rather than relying on single set of predictions or statistical comparison.

Comparisons between scenarios were done separately for 1999-2002 and 1995-2004 modeling periods to examine how the flow reduction scenarios would affect fish and invertebrate populations over a relatively dry four-year dry period compared to a longer more representative hydrologic period. Many tables and graphics were generated to summarize the findings of these statistical comparisons. Example tables and graphics for some of the comparisons are shown below as examples. Other tables and graphics are included as appendices to the report and referenced in the discussion below.

8.8.1 Changes in daily percentages of abundance relative baseline

The initial test conducted on the predicted abundance values was to compare median values of daily percentage abundance values calculated for the study period. These steps were to first calculate daily abundance values for baseline flow and the flow reduction scenarios. For each day the abundance for the flow reduction scenario was then divided by the baseline abundance, generating a population of daily percent reduction values. Box and whisker plots of these percent changes for six flow reduction scenarios for are shown for the plankton catch of *Americamysis almyra* (Figure 8-38) and *Trinectes maculatus* juveniles (Figure 8-39). These plots were generated using the results that were predicted for flows within the domain of the regressions for the period 1995-2004. A reference line for a 15% reduction in daily abundance is included in the plots. Plots for other taxa listed in Table 8-21 are included in Appendix 8T.

As with other metrics that were evaluated for the study, withdrawal of all water allowed by the City of North Port's permit from Myakkahatchee Creek caused very little change in the daily abundances of either species. As with other findings, the predicted changes from withdrawing the excess agricultural flows were similar to, but slightly less, than removing the total excess flows. The changes in abundance were greater for *Trinectes maculatus* than *Americamysis almyra,* due to the greater slope of that regression (Figures 8-35 A and E). The percent changes were greatest in Block 1 for both taxa, generally followed by Block 3 then Block 2.

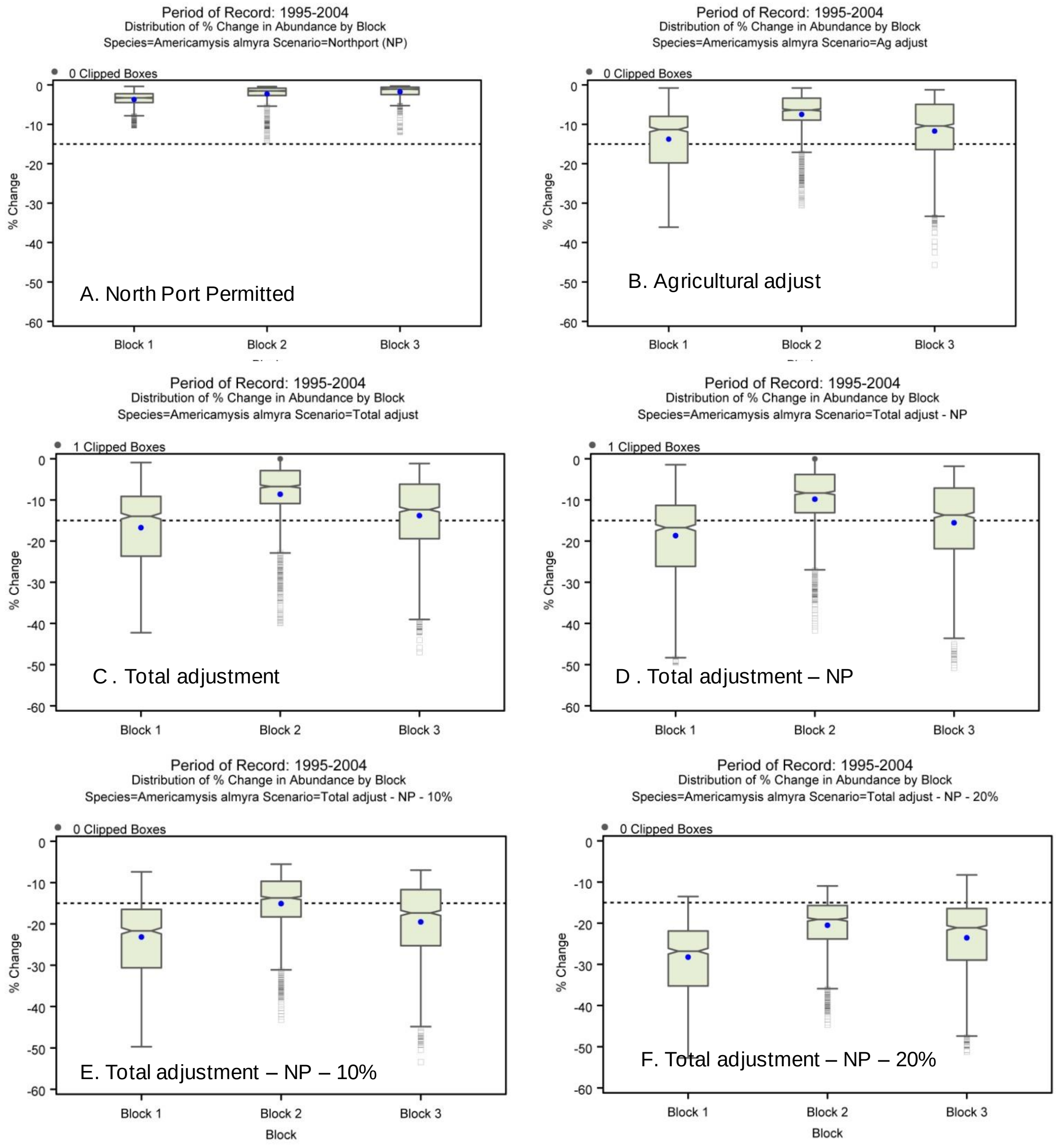

Figure 8-38. Box and whisker plots of predicted daily changes in abundance of *Americamysis almyra* from baseline for six flow reduction scenarios. Prediction limited to flows within the domain of the regression.

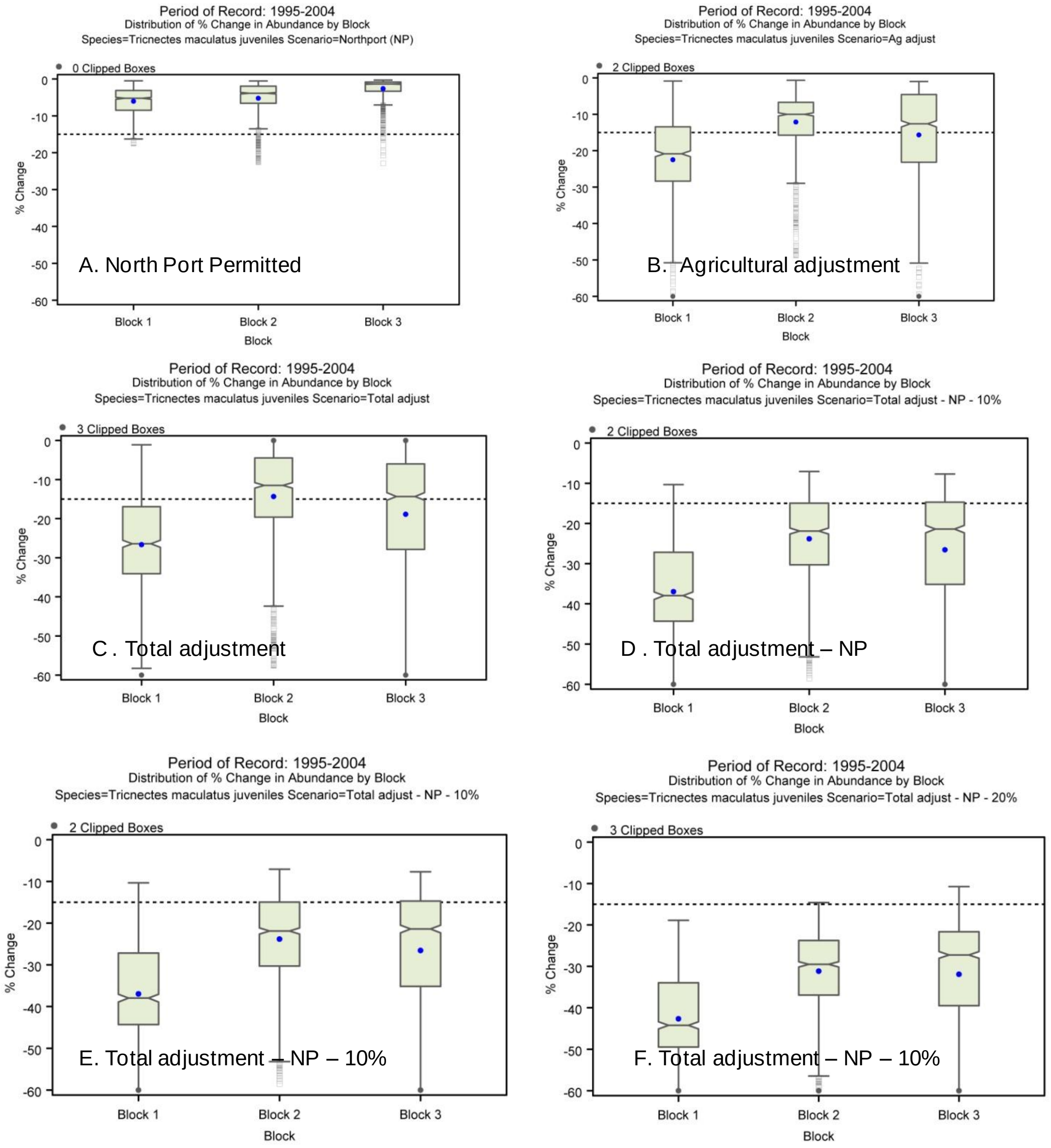

Figure 8-39. Box and whisker plots of predicted daily changes in abundance of *Trinectes maculatus* juveniles in the plankton catch from baseline for six flow reduction scenarios. Prediction limited to flows within the domain of the regression.

It was concluded that comparing medians of these percent reduction values best represented changes the central tendency in the data, so the median of each flow reduction scenario was divided by the median baseline value to determine percent change from baseline. These comparisons were done separately for each of the seasonal blocks, with the results of all the taxa tested for the study presented in Tables 8-24, 8-25, and 8-26. Changes in medians were generated just using the predicted values that were within the flow domain of the regressions, and also using all the flows during 1995-2004.

Results for the regression using the summed flows from two gages are listed in the top half of the table, and results listed for the regressions that used one gage are listed in the bottom half. Values in the table are rounded to one integer, with changes of 15% or greater for the all flows predictions highlighted in yellow and changes of 25% or greater are highlighted in gray.

The changes in medians were generally higher when all the flows were used, but the differences in the two methods varied between taxa, due to how many predictions were outside the regression domain for each taxon and how the form of the regression (linear vs. quadratic) affected changes in the medians. Because the comparisons are based on medians (which were always within the domain of the regressions) and the fact that so many predictions were outside the domains of regressions at low flows, the changes in medians using all the flows might be a more representative measure of population change. Therefore, the yellow and gray highlighting was based on the results for the predictions using all flows, but discussions of the data consider both values and percent changes over 15% are mentioned if either value exceeded that amount.

Table 8-24. Median values of daily percentage changes in the abundance of selected fish and invertebrate tax age/size classes for seven flow reduction scearnios **for BLOCK 1 during 1995-2004.** Results presented separately for regressions using the sum of the Myakka River and Myakkahatchee Creek gages and regressions that use the Myakka River gage alone. Results for each scenario are listed for predictions limited to the flow domains of the regression (left of -) and predictions using all flows (right of -). Predictions involving City of North Port withdrawals were not generated for the one gage regressions. Cells that include percent changes 15 % and greater are highlighted in yellow and changes 25% and greater are highlighted in gray.

Block 1 - Sum gaged*	Percentage reductions from baseline (predictions limited to regression domain and all flows)								
	Americamysis	***Americamysis***	***Cyathura***	***Palaemonetes***	***Palemonetes***	***Menidia***	***Trinectes***	***Gambusia***	***Gambusia***
	almyra	***almyra (2)***	***polita***	***intermedius***	***pugio***	***spp.***	***maculatus***	***holbrooki***	***holbrooki***
	plankton	plankton	plankton	seine	seine	plankton - juveniles	plankton - juveniles	seines <= 25 mm	seines >= 26 mm
North Port Permitted	3 - 3	4 - 4	3 - 4	2 - 3	5 - 5	2 - 2	5 - 6	4 - 3	4 - 1
Agricutural adjustment	11 - 12	14 - 17	13 - 15	7 - 13	14 - 20	10 - 9	21 - 24	9 - 8	10 - 4
Total adjustment	14 - 17	16 - 24	17 - 20	9 -17	17 - 28	12 - 12	26 - 30	9 - 6	10 - 3
Total adjustment - North Port	17 - 23	20 - 30	19 - 24	11 - 24	21 - 35	15 - 15	32 - 36	12 - 9	13 - 5
Total adjustment - North Port - 10%	22 - 28	26 - 36	24 - 28	12 - 30	23 - 43	18 - 18	38 - 42	22 - 20	23 - 13
Total adjustment - North Port - 15%	24 - 30	29 - 39	26 - 30	13 - 32	25 - 47	19 - 19	41 - 45	27 - 26	28 - 17
Total adjustment - North Port - 20%	27 - 32	33 -42	28 - 32	14 - 35	27 - 51	20 - 20	44 - 47	32 - 31	33 - 22

*** regression using sum of flow at Myakka River near Sarasota and Big Slough Canal at Tropicaire Blvd.**
**** regressions using Myakka River near Sarasota flow only, not applicable to North Port permitted withdrawals**

Block 1 - One gage **				
	Ephemeropteran	***Mesocyclops***	***Gambusia***	***Trinectes***
	larvae	***edax***	***holbrooki***	***maculatus***
	plankton	plankton	plankton - juveniles	plankton - juveniles
Agricutural adjustment	26 - 30	19 - 22	13 - 17	25 - 29
Total adjustment	34 - 37	22 - 28	16 - 21	30 - 35
Total adjustment - 10%	42 - 45	28 - 34	20 - 25	40 - 42
Total adjustment - 15%	45 - 48	31 - 36	22 - 27	40 - 45
Total adjustment - 20%	48 - 52	34 - 39	25 - 30	44 - 48

Table 8-25. Median values of daily percentage changes in the abundance of selected fish and invertebrate tax age/size classes for seven flow reduction scearnios **for BLOCK 2 during 1995-2004.** Results presented separately for regressions using the sum of the Myakka River and Myakkahatchee Creek gages and regressions that use the Myakka River gage alone. Results for each scenario are listed for predictions limited to the flow domains of the regression (left of -) and predictions using all flows (right of -). Predictions involving City of North Port withdrawals were not generated for the one gage regressions. Cells that include percent changes 15 % and greater are highlighted in yellow and changes 25% and greater are highlighted in gray.

Block 2 - Sum gaged*	Percentage reductions from baseline (predictions limited to regression domain and all flows)								
	Americamysis almyra	***Americamysis almyra (2)***	***Cyathura polita***	***Palaemonetes intermedius***	***Palemonetes pugio***	***Menidia spp.***	***Trinectes maculatus***	***Gambusia holbrooki***	***Gambusia holbrooki***
	plankton	plankton	plankton	seine	seine	plankton - juveniles	plankton - juveniles	seines <= 25 mm	seines >= 26 mm
North Port Permitted	2 - 2	1 - 1	3 - 3	0 - 1	1 - 1	2 - 2	4 - 4	2 - 2	2 - 2
Agricutural adjustment	6 - 6	5 - 5	6 - 6	1 - 1	2 - 3	4 - 4	10 - 11	8 - 11	8 - 8
Total adjustment	7 - 7	5 - 6	7 - 8	1 - 2	2 - 4	5 - 5	12 - 12	10 - 12	9 - 9
Total adjustment - North Port	8 - 9	7 - 7	10 - 11	0 - 3	1 - 6	7 - 7	14 - 17	11 - 14	10 - 11
Total adjustment - North Port - 10%	14 - 14	11 - 12	14 - 16	0 - 5	2 - 10	10 - 10	22 - 24	20 - 22	19 - 20
Total adjustment - North Port - 15%	16 - 17	14 - 14	16 - 18	0 - 6	3 - 13	11 - 11	26 - 28	25 - 26	24 - 24
Total adjustment - North Port - 20%	19 - 19	16 - 16	19 - 20	0 - 7	4 - 16	20 - 12	30 - 32	29 - 31	29 - 29

*** regression using sum of flow at Myakka River near Sarasota and Big Slough Canal at Tropicaire Blvd.**

**** regressions using Myakka River near Sarasota flow only, not applicable to North Port permitted withdrawals**

Block 2 - One gage **				
	Ephemeropteran larvae	***Mesocyclops edax***	***Gambusia holbrooki***	***Trinectes maculatus***
	plankton	plankton	plankton - juveniles	plankton - juveniles
Agricutural adjustment	13 - 14	10 - 11	6 - 7	11 - 13
Total adjustment	14 - 15	12 - 14	7 - 9	13 - 15
Total adjustment - 10%	24 - 25	18 - 21	12 - 14	22 - 24
Total adjustment - 15%	29 - 30	22 - 24	14 - 16	26 - 29
Total adjustment - 20%	33 - 34	25 - 28	16 - 19	31 - 33

Table 8-26. Median values of daily percentage changes in the abundance of selected fish and invertebrate tax age/size classes for seven flow reduction scenarios **for BLOCK 3 during 1995-2004.** Results presented separately for regressions using the sum of the Myakka River and Myakkahatchee Creek gages and regressions that use the Myakka River gage alone. Results for each scenario are listed for predictions limited to the flow domains of the regression (left of -) and predictions using all flows (right of -). Predictions involving City of North Port withdrawals were not generated for the one gage regressions. Cells that include percent changes 15 % and greater are highlighted in yellow and changes 25% and greater are highlighted in gray.

Block 3 - Sum gaged*	Percentage reductions from baseline (predictions limited to regression domain and all flows) + signs for *Palaemonetes* mean postive change								
	Americamysis almyra	***Americamysis almyra (2)***	***Cyathura polita***	***Palaemonetes intermedius***	***Palemonetes pugio***	***Menidia spp.***	***Trinectes maculatus***	***Gambusia holbrooki***	***Gambusia holbrooki***
	plankton	plankton	plankton	seine	seine	plankton - juveniles	plankton - juveniles	seines <= 25 mm	seines >= 26 mm
North Port Permitted	1 - 1	1 - 1	1 - 1	+ 1 + 7	+ 2 + 2	1 - 1	1 - 1	2 - 2	2 - 2
Agricutural adjustment	10 - 10	8 - 8	7 - 7	+ 9 + 1	+ 11 + 9	4 - 4	13 - 13	13 - 19	13 - 13
Total adjustment	12 - 12	9 - 9	8 - 8	+ 11 + 10	+ 15 + 12	5 - 5	14 - 14	16 - 22	15 - 16
Total adjustment - North Port	14 - 14	10 - 10	9 - 9	+ 21 + 11	+ 16 + 14	5 - 5	16 - 16	17 - 24	17 - 18
Total adjustment - North Port - 10%	17 - 17	13 - 13	13 - 13	+ 20 + 18	+ 28 + 26	8 - 8	21 - 22	25 - 31	24 - 26
Total adjustment - North Port - 15%	19 - 19	15 - 15	14 - 15	+ 23 + 21	+ 33 + 31	9 - 9	24 - 25	29 - 35	28 - 30
Total adjustment - North Port - 20%	21 - 21	16 - 16	16 - 17	+ 27 + 25	+ 40 + 38	10 - 10	27 - 28	32 - 39	32 - 34

*** regression using sum of flow at Myakka River near Sarasota and Big Slough Canal at Tropicaire Blvd.**

**** regressions using Myakka River near Sarasota flow only, not applicable to North Port permitted withdrawals**

Block 3 - One gage **				
	Ephemeropteran larvae	***Mesocyclops edax***	***Gambusia holbrooki***	***Trinectes maculatus***
	plankton	plankton	plankton - juveniles	plankton - juveniles
Agricutural adjustment	21 - 23	11 - 11	8 - 8	17 - 19
Total adjustment	24 -26	14 - 14	10 - 11	20 - 22
Total adjustment - 10%	32 - 34	20 - 20	14 - 15	28 - 30
Total adjustment - 15%	37 - 39	24 - 24	17 - 18	33 - 34
Total adjustment - 20%	41 - 43	27 - 27	19 - 20	37 - 38

As was shown graphically for *Americamysis* and *Trinectes*, the percent changes in medians were greatest for all taxa for Block 1 (Table 8-24). For the estuarine taxa, removal of total adjusted flows exceeded 15% reduction in medians for *Americamysis*, the isopod *Cyathura polita*, the grass shrimp *Palaemonetes pugio*, and *Trinectes*. Addition of the North Port withdrawals increased the percent changes in medians by 2 to 6% with the greatest increase for *Trinectes*. As expected, changes in median abundance values were larger for the freshwater invertebrates - ephemeropteran (caddisfly) larvae and the copepod *Mesocyclopx edax.* The plankton catch of juveniles of the brackish tolerant freshwater fish *Gambusia holbrooki* had reductions in medians similar to the estuarine taxa. Results for the seine catch of this species were unusual in that the changes in medians predicted for the all flows comparisons were greater than the predictions limited to the flow domains. As described earlier, the findings for this species are limited by a fairly narrow ranges of flows used for the regressions, although these regressions are reported, predicted changes in the seine catch of *Gambusia holbrooki* are not emphasized in the remainder of the report.

Reductions in the median values of all taxa were less in blocks 2 and 3 than in Block 1. Changes in median values did not exceed 15% for *Americamysis* until flow reductions had reached the total adjustment – North Port – 15% in Block 2 and the total adjustment – North Port – 10% scenario in Block 3. Reductions in *Trinectes* juveniles exceeded 15% at the total adjustment – NP scenario in Block 2 and the total adjustment – NP – 10% in Block 3. The results for *Trinectes* for Block 3 are interesting for the changes in medians using the single gage regression are greater than that using the sum of the two gages, likely due that the flow reductions comprise a higher proportion of the single gage flow.

Reduction in the two species grass shrimp (*Palaemonetes pugio* and *Palaemonetes intermedius*) were negligible or very small in Block 2 and showed positive changes from the flow reductions in Block 3. This response was due to the quadratic form of the inflow abundance relationship, and reductions of high flows could actually increase *Palaemonetes* abundance. Although this response may be real, the regression for these taxa were also limited by a fairly narrow range of flows used to develop the regressions. The more robust regressions for *Americamysis* and *Trinectes* indicate these taxa are more sensitive to change in Blocks 2 and 3 and be more limiting for determination of the minimum flows, so emphasis is put on those findings. While the results for *Palaemonetes* are interesting and informative, they are not given further emphasis in the report.

In order to compare how changes in fish and invertebrate abundance would change from baseline over a drier period, the changes in median test was performed for the 1999-2002 period. This also allows for a comparison of changes in these biological metrics to changes in salinity zone metrics that were calculated for the same period using the hydrodynamic model. To save space in this report, the tables for the 1999-2002 period are included as Appendix 8-U. The Appendices are bound separately and can be viewed side-by-side with this report for ease of interpretation.

Reductions in median values in Block 1 were greater for all taxa in 1999-2002 compared to the 1999-2004 period, due largely to the lower Block 1 flows in the four-year period (see Table 8-7A). Reductions in *Americamysis* using the two regressions for that taxon ranged from 20 to 34 percent for the total adjustment scenario for the four year period, compared to 14 to 24 percent during 1995-2004. Increasing the total adjustment by the North Port withdrawals again increased the percent reductions in median values by four to six percent. Reductions in median values for *Cyathura polita*, *Trinectes,* and the freshwater taxa went up as well for all flow reduction scenarios in 1999-2002, but not as greatly as for *Americamysis.*

Reductions in median values for *Americamysis* and *Cyathura* increased slightly in Block 1 for the shorter period, with the Total adjust – North Port – 10% causing 15% change in abundance for these taxa. Interestingly, differences between the regressions within the flow domains and regressions that used all flows were fairly small during Block 2 for both periods compared to Block 1. Reductions for both *Palaemonetes* species were greater in the four-year period due to the lower flows, which caused the *Palaemonetes* predictions to fall on the ascending part of the curve where the effects of reducing flows were most acute (Figure 8-37). Reductions in *Trinectes* went up as well, with a total adjusted flows now resulting in a 15% change in the median values. Changes in all taxa were much smaller in Block 3 between the two periods, largely because the flows between the 1999-2002 and the 1999-2002 were fairly similar during Block 3.

8.8.2. Changes in abundance using cumulative distribution functions

Changes in abundance were also evaluated using by the CDF/NAUC method. Abundance values were predicted for baseline and the flow reduction scenarios and cumulative distribution curves were overlain separately for the three seasonal blocks. Examples CDF curves for *Americamysis almyra* and *Trinectes maculatus* are shown in Figures 8-40 and 8-41, with CDF curves for remaining taxa shown in Appendix 8V. Results are reported on only for the regressions that used the sum of gaged flows from the Myakka River and Myakkahatchee Creek gages, with the predictions limited to the flow domain of the regressions.

Summary tables listing percent change in the CDF/NAUC curves for the same pseudo-species and flow reduction scenarios are listed by Block in Appendix 8-W. For most taxa, the percent reductions in abundance calculated using this method were similar to, but slightly less than, the percent changes calculated in the previous section using the medians of the percent daily changes. In Block 1 for 1995-2004, the linear equation for *Americamysis* resulted in a 17% reduction with the total adjustment – North Port – 10% flow scenario, whereas this scenario resulted in a 22% reduction using the previous method. The reduction in *Trinectes* for this same scenario was 22% using the CDF/NAUC method, compared to 38% using the previous method.

As before, reductions in abundance from baseline were less in Blocks 2 and 3. A fifteen percent reduction in *Americamysis* was not observed in Block 2 until with the total adjustment – North Port – 15% scenario was reached, and a reduction of 16% was observed for *Trinectes* at the total adjustment – North Port – 10% scenario (Table 8W-2). Results for Block 3 were very similar, but with slightly greater reductions for *Americamysis* and *Trinectes*.

This analysis was redone limiting the data to the 1999-2002 time period, and as before, greater reductions in abundance were observed for all taxa, with the increases substantial in some cases (Appendix Tables 8W-4, 5 and 6). For the total adjustment scenario in Block 1, the reduction in *Americamysis* rose from 9% for the ten-year period to 17% for the four-year period, while the reduction in abundance for *Trinectes* rose from 12% to 26% for this same period. Clearly, using the CDF/NAUC method, greater reductions were observed when the scenarios were evaluated for a series of years that represented drier conditions. Reduction in abundance for these taxa increased as well for Blocks 2 and 3, but not to the same extent as Block 1.

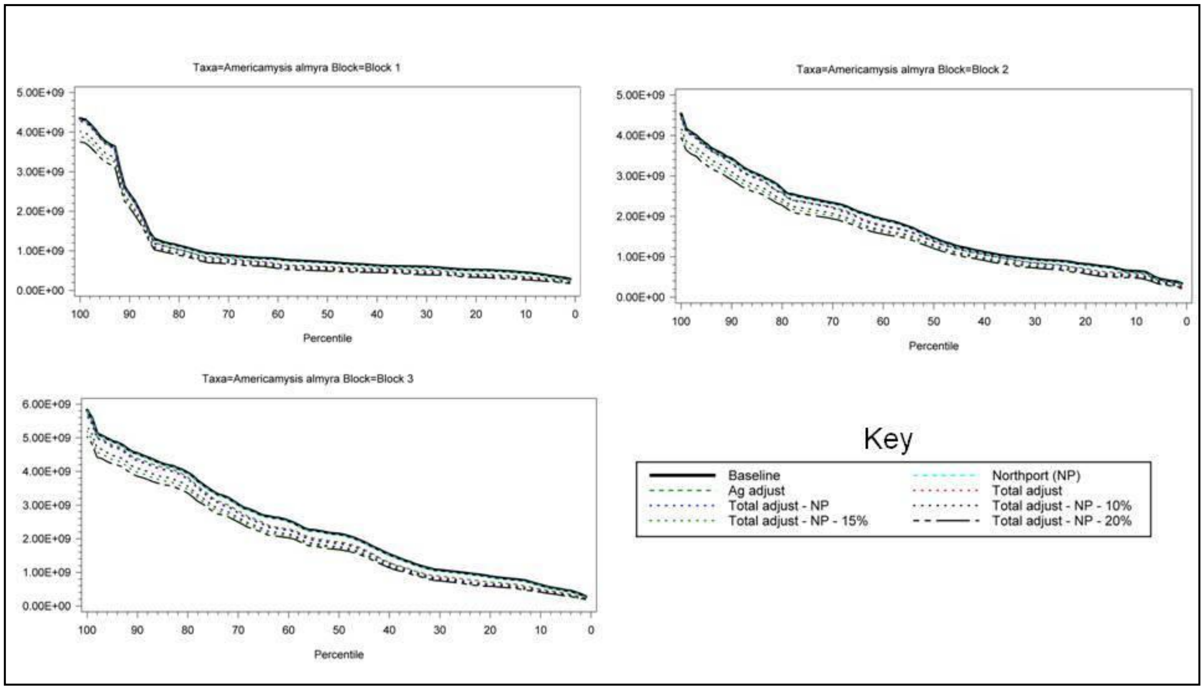

Figure 8-40. Cumulative distribution functions for the abundance of *Americamysis almyra* for three seasonal blocks for the period 1995-2004.

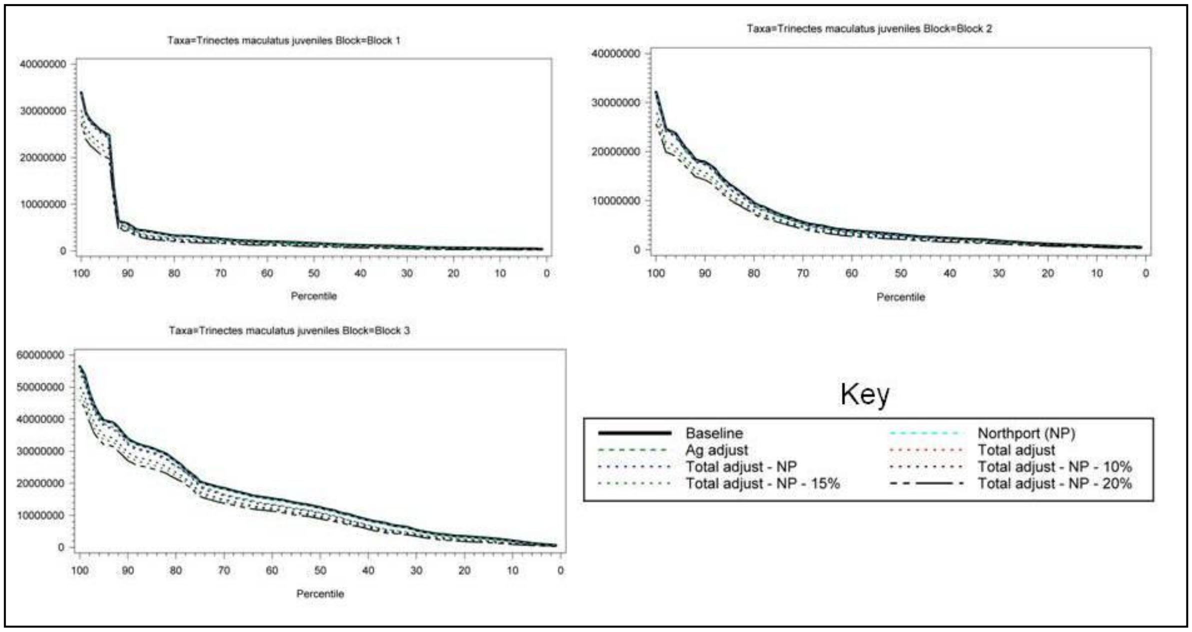

Figure 8-41. Cumulative distribution functions for the abundance of *Trinectes maculatus* for three seasonal blocks for the period 1995-2004.

8.8.3. Changes in mean abundance values

The effects of the flow reduction scenarios were also examined by comparing changes in mean abundance that were calculated from the predicted daily abundance values. This was performed two ways: (1) by limiting the predictions to the domain of the regressions; and (2), generating predictions for all flows during the modeling period. Means were calculated for all taxa and comparisons were done for the 1995-2004 and 1999-2002 periods. Tables for these results are presented in Appendix 8X.

For those taxa which were calculated using both methods, the percentage reductions in mean abundance values are very similar to the percent reductions calculated using the NAUC method (Appendix 8W), as the differences in the area under two cumulative distribution functions is mathematically similar to the difference in mean values. As discussed before, limiting the calculation of means to predictions within the flow domain of the regression is more statistically valid, but many observations are lost due to the flow reduction scenarios resulting in many low flow days being outside the regression domain. Including predictions outside the flow domain includes these low flow events, but the predictions are less certain. The percent changes in mean values that did, and did not, limit the predictions to the flow domains of the regressions did not differ greatly for some taxa. However, for two *Palaemonetes* species (which used quadratic regressions) the differences in the percent changes in the mean for these two methods was considerable, likely due to the large number of observations at low flows outside the flow domains of the regressions.

Similar to the CDF/NAUC method, reductions in mean *Americamysis* abundance were 15% and 20% for the total adjustment – North Port – 10% withdrawal scenario in Block 1 for the ten-year modeling period when the predictions were limited to the regression domains. Reductions in *Trinectes* were also virtually the same as the CDF/NAUC method, with a 22% reduction for Block 1 in this same scenario. Reductions in mean abundances in Blocks 2 and 3 were again less that Block 1. Rerunning these comparisons for the 1999-2002 period resulted in greater percent changes in the means, particularly in Block 1, with the values again very similar to the changes calculated using the CDF/NAUC technique.

Performing the analysis using predictions from all the flows in the modeling period did not substantially change the findings for *Americamysis* and *Trinectes*. The percent changes in mean abundances of *Americamysis* in Block 1 increased about 2 percent, while differences in *Trinectes* means were within 1 percent of the values limited to the regression domains. Differences in percent changes in means for the two analyses were especially small in Blocks 2 and 3, because less predictions were outside the flow domains of the regressions due to the higher flows in those blocks.

8.8.4. Changes in median abundance values

Changes in median abundance values were calculated for all taxa using values limited to the regression domains and predictions for all flows. As opposed to the analyses in section 8.8.1, which calculated medians of daily percentage population changes, medians were calculated for the data sets of predicted abundance values. Percent changes in median abundance values are reported in Appendix 8Y.

Percent changes in median abundances were often slightly greater than the corresponding changes in mean abundances, but this was not always the case. Changes in median abundances for *Americamysis* were greater than percent changes in mean abundances in Block 1, but fairly similar in Blocks 2 and 3. Percent changes in median abundance of *Trinectes* were similarly greatest in Block 1. As with the other statistical comparisons, reductions in median abundances were more pronounced when the analysis was restricted to 1999-2002, with the greatest changes observed in Block 1 and fairly small changes in the results between the two time periods in Blocks 2 and 3.

8.8.5. Summary of abundance analyses for key species

Using different statistical comparisons, the changes in predicted abundance for the selected fish and invertebrate taxa generally gave roughly similar results with regard to management application. Summary tables of percent changes in the abundance of two fish and two invertebrate taxa collected by plankton net are listed by Block in Tables 8-27, 8-28, and 8-29 for the four statistical comparisons that were performed. Again, results are presented for prediction limited to the domains of the regressions and for all flows for both the ten-year 1995-2004 period and the four-year 1999-2002 period.

As previously discussed, the plankton sampling covered a wider range of flows and generally provided more robust regressions than the seine and trawl sampling. Fairly good regressions were established for the plankton catch of mysid shrimp *Americamysis almyra* and the hogchoker *Trinectes maculatus*. *Americamysis* is an important prey species for juvenile fishes and *Trinectes* is a dominant fish in oligohaline areas; thus emphasis is put on the findings for those species. Accordingly, the results presented in the following three tables can be used to summarize the most reliable results for changes in the abundance of ecologically important fish and invertebrate species resulting from the modeled flow reductions.

Results are presented in the summary tables for percent population changes calculated over the ten-year (1995-2004) and four-year (1999-2002) periods. Results for the agricultural excess flow scenario are not listed in the summary tables, for those results are similar to the total excess flow scenario, and management plans for the upper river sub-basin are emphasizing removing the total excess flows. Also, results for scenarios removing more than ten percent of the flow remaining after removal of the excess flow and North Port withdrawals are not presented, as changes greater than 15% for *Americamysis almyra* and *Trinectes maculatus* were observed for at least some of the statistical comparisons in all blocks for the total excess – North Port – 10% scenario.

The withdrawal of water for the City of North Port's permitted withdrawals resulted in small percentage changes in species abundance. The largest changes due to removal of the North Port withdrawals were for *Trinectes maculatus*. Percent changes in mean *Trinectes* abundances (C columns in summary tables) in Block 1 ranged from 2 to 3 percent in the ten-year period and 5 to 6 percent in the four-year period (Table 8-27). Percent reductions in mean *Trinectes* abundances in Block 2 and 3 were considerably less, ranging from 2 to 4 percent in Block 2 to 1 to 2 percent in Block 3 when the two timer periods are viewed together (Tables 8-28 and 8-29). Percent changes were very similar using the CDF/NAUC method (B columns), which was run only for the within flow domain scenarios.

Table 8-27. Summary of results of percent changes in abundance metrics for **BLOCK 1** for four fish and invertebrate taxa from the plankton catch predicted with regressions presented by Peebles (2008) that use the sum of the Myakka River and Myakkahatchee Creek gages. Results listed as percent change from baseline for four flow reduction scenarios for two time periods (1995-2004 and 1999-2002). Results for each scenario are listed for predictions limited to the flow domains of the regression (left of -) and predictions using all flows (right of -). Cells that include percent changes of 15% and greater are highlighted in yellow and changes 25% and greater are highlighted in gray.

		1995-2004				1999-2002			
		A	B	C	D	A	B	C	D
Taxon	**Scenario**	median percent change	NAUC CDF curves	mean abundance	median abundance	median percent change	NAUC CDF curves	mean abundance	median abundance
Americamysis almyra	**NP**	3 - 3	2	2 - 2	3 - 3	4 - 4	4	4 - 4	3 - 4
	Total adjustment	14 - 17	9	10 - 11	17 - 14	20 - 21	17	18 - 20	23 - 22
	Total adjustment - NP	17 - 23	11	12 - 13	21 - 18	25 - 27	21	22 - 25	26 - 26
	Total adjustment - NP - 10%	22 - 28	17	17 - 19	26 - 23	29 - 31	26	26 - 29	27 - 31
***Americamysis almyra* (2) ***	**NP**	4 - 4	2	3 - 3	4 - 4	4 - 7	5	5 - 6	3 - 6
	Total adjustment	16 - 24	12	13 - 14	16 - 25	28 - 34	24	24 - 27	26 - 33
	Total adjustment - NP	20 - 30	15	15 - 17	19 - 26	33 - 38	29	29 - 33	26 - 39
	Total adjustment - NP - 10%	26 - 36	19	20 - 22	22 - 30	39 - 45	34	35 - 40	32 - 46
***Trinectes maculatus* juveniles**	**NP**	5 - 6	3	2 - 3	8 - 6	6 - 8	5	5 - 6	7 - 12
	Total adjustment	26 - 30	12	12 - 13	26 - 36	29 - 34	26	26 - 29	34 - 32
	Total adjustment - NP	32 - 36	14	14 - 15	31 - 39	34 - 42	31	31 - 33	39 - 41
	Total adjustment - NP - 10%	38 - 42	22	22 - 22	38 - 44	40 - 47	37	37 - 39	45 - 46
Cyathura polita	**NP**	3 - 4	2	2 - 3	4 - 4	4 - 5	3	4 - 2	3 - 4
	Total adjustment	17 - 20	12	12 - 13	16 - 25	18 - 22	17	18 - 22	19 - 24
	Total adjustment - NP	19 - 24	15	14 - 15	19 - 26	21 - 31	20	21 - 21	23 - 23
	Total adjustment - NP - 10%	24 - 28	19	22 - 22	22 - 30	25 - 34	24	25 - 25	27 - 27
***Menidia* spp.**	**NP**	2 - 2	2	2 - 1	3 - 1	3 - 3	2	3 - 0	3 - 1
	Total adjustment	12 - 12	9	13 - 13	15 - 15	14 - 14	11	15 - 15	14- 14
	Total adjustment - NP	15 - 15	11	16 - 11	17 - 14	19 - 19	13	19 - 12	19 - 13
	Total adjustment - NP - 10%	18 - 18	13	18 - 13	20 - 17	21 - 21	16	21 - 14	21 - 16

Table 8-28. Summary of results of percent changes in abundance metrics for **BLOCK 2** for four fish and invertebrate taxa from the plankton catch predicted with regressions presented by Peebles (2008) that use the sum of the Myakka River and Myakkahatchee Creek gages. Results listed as percent change from baseline for four flow reduction scenarios for two time periods (1995-2004 and 1999-2002). Results for each scenario are listed for predictions limited to the flow domains of the regression (left of -) and predictions using all flows (right of -). Cells that include percent changes of 15 % and greater and are highlighted in yellow and changes of 25% and greater are highlighted in gray.

		1995-2004				**1999-2002**			
		A	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Taxon	**Scenario**	**median percent change**	**NAUC CDF curves**	**mean abundance**	**median abundance**	**median percent change**	**NAUC/CDF curves**	**mean abundance**	**median abundance**
Americamysis almyra	**NP**	2 - 2	1	1 - 1	1 - 2	2 - 2	2	2 - 2	2 - 2
	Total adjustment	7 - 7	5	6 - 6	5 - 4	8 - 8	7	8 - 8	6 - 7
	Total adjustment - NP	8 - 9	7	7 - 7	6 - 6	10 - 10	9	9 - 10	8 - 9
	Total adjustment - NP - 10%	14 - 14	12	12 - 12	11 - 12	15 - 15	14	14 - 15	14 - 15
***Americamysis almyra* (2) ***	**NP**	1 - 1	1	1 - 1	1 - 1	2 - 2	2	2 - 2	2 - 2
	Total adjustment	5 - 6	5	5 - 5	4 - 4	7 - 8	7	7 - 7	7 - 6
	Total adjustment - NP	7 - 7	6	6 - 7	5 - 6	8 - 9	8	8 - 9	6 - 7
	Total adjustment - NP - 10%	11 - 12	10	11 - 11	10 - 11	13 - 14	13	13 - 14	8 - 8
***Trinectes maculatus* juveniles**	**NP**	4 - 4	2	2 - 2	4 - 4	6 - 6	3	4 - 4	6 - 7
	Total adjustment	12 - 12	6	5 - 5	11 - 14	15 - 16	11	11 - 12	13 - 14
	Total adjustment - NP	14 - 17	6	8 - 8	16 - 18	20 - 22	14	14 - 15	20 - 21
	Total adjustment - NP - 10%	22 - 24	8	10 - 10	24 - 26	28 - 29	22	22 - 23	25 - 27
Cyathura polita	**NP**	3 - 3	2	2 - 2	3 - 3	4 - 4	3	2 - 3	4 - 5
	Total adjustment	7 - 8	5	5 - 6	4 - 4	9 - 10	10	8 - 9	10 - 10
	Total adjustment - NP	10 - 11	7	7 - 8	5 - 6	13 - 15	15	11 - 13	13 - 14
	Total adjustment - NP - 10%	14 - 16	11	12 - 13	10 - 11	17 - 19	17	15 - 18	16 - 17
***Menidia* spp.**	**NP**	2-2	1	2 - 2	2 -2	2 - 2	2	2 -2	3 - 3
	Total adjustment	5-5	4	5 - 5	5 - 5	7 - 7	7	7 - 7	6 - 6
	Total adjustment - NP	7-- 7	5	8 - 8	7 - 7	10 - 10	10	11- 11	10 - 10
	Total adjustment - NP - 10%	10- 10	8	10 - 10	9 - 9	12- 12	11	13 - 13	12- 12

*** double reciprocal model**

Table 8-29. Summary of results of percent changes in abundance metrics for **BLOCK 3** for four fish and invertebrate taxa from the plankton catch predicted with regressions presented by Peebles (2008) that use the sum of the Myakka River and Myakkahatchee Creek gages. Results listed as percent change from baseline for four flow reduction scenarios for two time periods (1995-2004 and 1999-2002). Results for each scenario are listed for predictions limited to the flow domains of the regression (left of -) and predictions using all flows (right of -). Cells that include percent changes of 15 % and greater and are highlighted in yellow and changes of 25% and greater are highlighted in gray.

		1995-2004				**1999-2002**			
		A	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Taxon	**Scenario**	**median percent change**	**NAUC CDF curves**	**mean abundance**	**median abundance**	**median percent change**	**NAUC CDF curves**	**mean abundance**	**median abundance**
Americamysis almyra	**NP**	1 - 1	1	1 - 1	1 - 1	1 -1	1	1 - 1	1 - 1
	Total adjustment	12 - 12	9	9 - 9	12 - 12	13 - 12	10	10 - 11	13 - 12
	Total adjustment - NP	14 - 14	10	10 - 10	14 - 14	14 - 13	12	12- 12	14 - 13
	Total adjustment - NP - 10%	17 - 17	15	15 - 15	1 8 - 18	17 - 17	16	16 - 16	17 - 17
***Americamysis almyra* (2) ***	**NP**	1 - 1	1	1 - 1	1 - 1	1 - 1	0	1 - 1	1 - 1
	Total adjustment	9 - 9	8	9 -9	9 - 9	9 - 9	8	8 - 8	9 - 9
	Total adjustment - NP	10 - 10	9	10 - 10	9 - 10	10 - 10	8	9 - 9	10 - 10
	Total adjustment - NP - 10%	13 - 13	11	13 - 13	13 - 14	13 - 13	11	12 - 13	13 - 13
***Trinectes maculatus* juveniles**	**NP**	1 - 1	1	1 - 1	1 - 2	1 - 1	1	1 - 1	1 - 1
	Total adjustment	14 - 14	10	10 - 10	15 - 15	15 - 15	13	13 - 13	15 - 15
	Total adjustment - NP	16 - 16	11	11 - 11	15 - 17	16 - 17	14	14 - 14	16 - 17
	Total adjustment - NP - 10%	21 - 22	18	18 - 18	22 - 23	23 - 23	20	20 - 20	23 - 23
Cyathura Polita	**NP**	1 - 1	1	1 - 1	1 - 1	1 - 1	1	1 - 1	1 - 1
	Total adjustment	8 - 8	8	8 - 8	9 - 9	9 - 9	9	9 - 9	11 - 11
	Total adjustment - NP	9 - 9	8	8 - 8	9 - 10	10 - 10	10	10 - 10	12 - 12
	Total adjustment - NP - 10%	10 - 10	12	12 - 12	13 - 14	13 - 13	13	13 - 13	16 - 15
***Menidia* spp.**	**NP**	1 - 1	1	1 - 1	1 - 1	1 - 1	1	1 - 1	1 - 1
	Total adjustment	5 - 5	6	6 - 6	5 - 5	6 - 6	6	5 - 5	6 - 6
	Total adjustment - NP	5 - 5	6	7 - 6	6 - 6	6 - 6	6	6 - 6	7 - 7
	Total adjustment - NP - 10%	5 - 5	8	9 - 8	8 - 8	7 - 7	8	8 - 8	9 - 9

*** double reciprocal model**

Percent changes in *Trinectes* for the North Port withdrawals based on comparisons of median values, whether calculated from percent daily changes (A columns) or abundance values for the study periods (D columns), were greater for all blocks, with a maximum 12% change in Block 1 and a maximum 7% change in Block 2. The maximum percent change for North Port withdrawals during Block 3 was 2 percent.

Changes in abundance for the other flow scenarios were similarly most pronounced in Block 1, with considerably less percent changes in Blocks 2 and 3. Also, percent changes were greater when calculated over the drier four-year period than for the ten-year period. Using the linear model for *Americamysis almyra*, removal of the total excess flows in Block 1 resulted in percent reductions of 9 to 14 percent for the ten-year period and reductions of 17 to 23 percent for the four-year period, depending on the statistical test (Table 8-27). The double reciprocal model indicated greater changes in Block 1, ranging from 12 to 25 percent in the ten-year period and 24 to 33 percent in the four-year period.

Percent changes in the abundance of *Trinectes maculatus* juveniles in Block 1 were greater than for *Americamysis.* This is not surprising, for the distribution of *Trinectes* is centered further upstream in oligohaline and tidal freshwater zones, which are particularly sensitive to the effects of flow reductions. Changes in mean *Trinectes* abundance for the total excess flow scenario were 12 to 13 percent for the 1995-2004 time period and 26 to 29 percent for the 1999-2002 period (C columns in Table 8-27). The results of the CDF/NAUC test gave similar results (B columns). Percent changes were greater when median values were compared, either calculated from percent daily reductions (A columns) or as medians of study period abundance (column D), ranging from 26 to 36 percent among the two time periods.

Percent changes for two other two taxa, the isopod *Cyathura polita* and the fish of the genus *Menidia* (silversides), are also listed in the summary tables to indicate how other taxa may respond to flow reductions. Changes for *Cyathrua* in Block 1 are roughly similar to the changes predicted for *Americamysis* using the linear regression, while changes in *Menidia* are slighltly less.

In sum, for most of the statistical comparisons, percent reductions of *Americamysis almyra* and *Trinectes maculatus* juveniles resulting from removal the total excess flows in Block 1 exceeded the District's 15% standard for reductions in species abundance that constitute significant harm. As discussed in Section 7.4, the District used the existing flow regime of the Lower Myakka River as the baseline for assessing the effects of withdrawals. However, it can be argued that removing the excess flows simply returns the flow regime of the Myakka River to a more natural condition, albeit with the effects of flow reductions resulting from the Blackburn Canal and the modification of Cowpen Slough Drainage. Following this reasoning, it could be concluded that changes in resource metrics greater than 15% due to removal of the total excess flows should be allowed. However, if reductions in excess of 15% occur due to removal of the excess flows, no further flow reductions should be allowed. This topic will treated in more detail along with the effects of the permitted withdrawals for the City of North Port in Section 8.9.

Percent reductions in the abundance of *Americamysis* and *Trinectes* were much less in Block 2 (Table 8-28). Fifteen percent reductions in *Americamysis* were reached with the Total Adjust –

North Port – 10% scenario for three of the statistical comparisons during the 1999-2002 period. However, only the median change in daily percentages showed a reduction of over 12% for the 1995-2004 period (14%). Percent reductions were again higher for *Trinectes*, with reductions of 15 to 16 percent found for the median daily change comparison for 1999-2002, and several percent changes in the 16 – 22 percent range for the Total adjustment – North Port scenario over the two time periods. Reductions in *Cyathura* and *Menidia* were again comparable to changes observed for *Americamysis* in Block 2.

Percent reductions in Block 3 were generally similar to Block 2, with a couple of notable exceptions (Table 8-29). Using the linear regression for *Americamysis almyra*, percent reductions of 15% or greater were observed for the Total adjustment – NP – 10% scenario for all the statistical comparisons for both time periods. Similarly, this scenario also consistently exceeded 15% for *Trinectes* for all the comparisons in both time periods with percent reductions ranging from 18 to 23 percent. Statistical comparisons that used median values showed percent reductions in *Trinectes* of 15 to 17 percent in Block 3 for the total adjustment and the total adjustment – North Port scenarios. Reductions of 15% or greater for the other two taxa were limited to the total adjustment – North Port – 10% scenario for *Cyathura polita* for the 1999-2002 time period.

In sum, reductions of 15 percent or greater for *Americamysis* were predicted for the total adjustment – North Port – 10% scenario for all the statistical comparisons in Block 3 and some of the statistical comparisons in Block 2. Reductions of 15% or greater in *Trinectes* abundance in were observed for total adjustment – North Port scenario for most of the statistical comparisons in Blocks 2 and 3. For some of the statistical comparisons the total adjustment scenario resulted in a 15% change or greater in Trinectes. Reductions in *Trinectes* abundance in excess of 15% were common for the Total adjustment – NP – 10% scenario.

8.8.6. Abundance response for the flow reduction scenarios as a function of freshwater inflow

The above analyses show that the abundance of the key fish and invertebrate taxa to the flow reduction scenarios differed between the seasonal blocks, and were particularly sensitive to reductions in freshwater inflow in Block 1. These results were due to the differences in the flow characteristics of the seasonal blocks (Table 8-7A) and the fact that the excess flows comprised a much higher proportion of total inflow at low rates of flow (Figures 8-9 and 8-10). It is therefore illustrative to examine how predicted changes in daily abundance vary as a function of freshwater inflow.

Predicted reductions in daily abundance for the four taxa listed in Tables 8-27, 8-28, and 8-29 are plotted vs. baseline flow for the total excess flow scenario in Figure 8-42. In other words, each data point represents the daily percent reduction for the total excess flow scenario vs. the corresponding baseline flow on that day. The preceding mean summed flow term for the two gages for each regression is used for plotting (e.g. 34-day mean two gage flow for *Trinectes maculatus*). Predictions are limited to the flow domains of the regressions for all days in the 1995-2004 time period. Smoothed lines were fitted to the data using the I=SM40 function in SASgraph software, with a reference line shown at a 15% reduction in daily abundance.

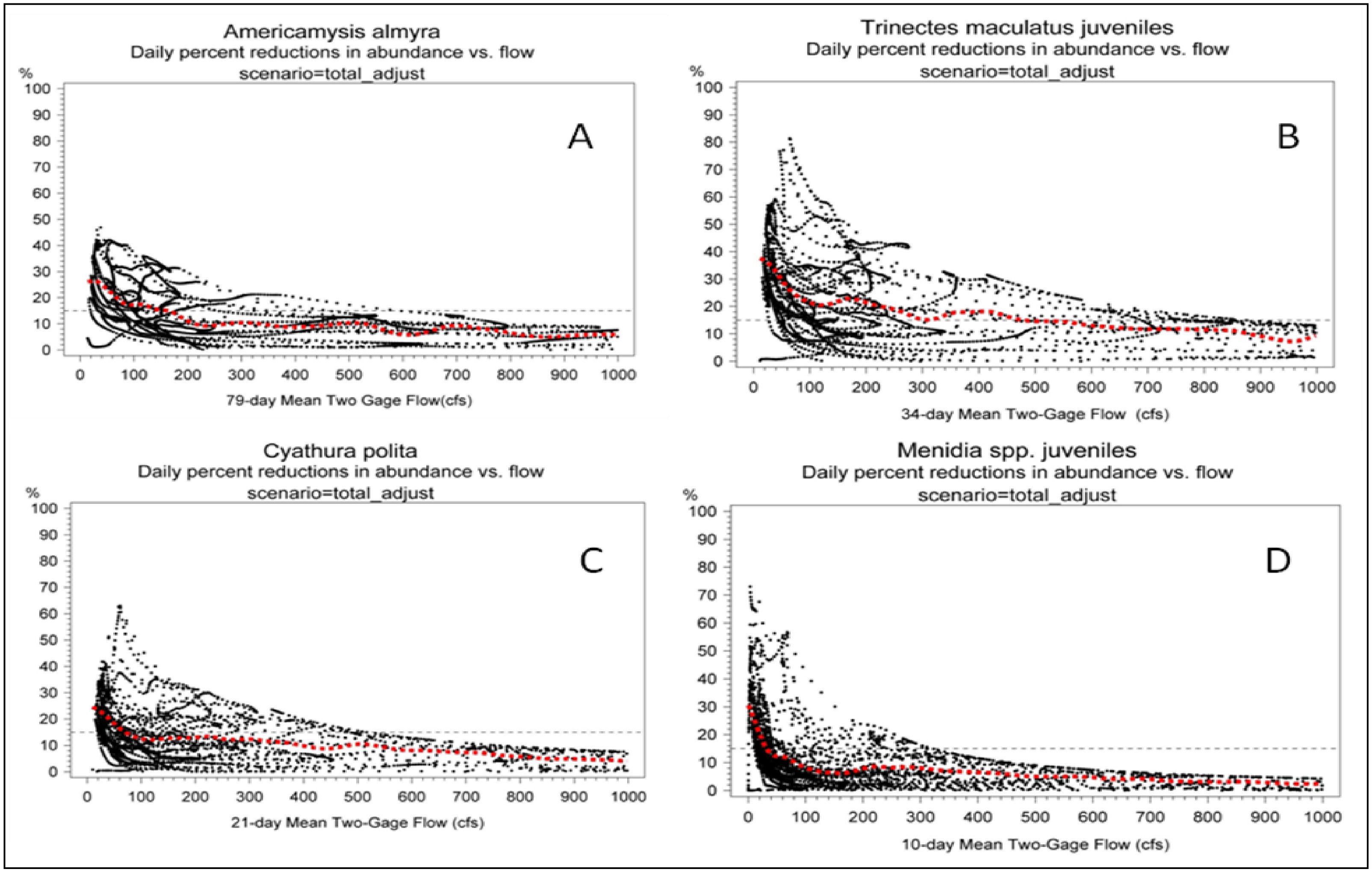

Figure 8-42. Predicted daily abundance values for four taxa vs. the corresponding preceding mean baseline flow term for the total excess flow scenario. Values taken from all days during 1995-2004 with predictions limited to the flow domains of the regressions (A=*Americamysis almyra*; B=*Trinectes maculatus* juveniles; C=*Cyathrua polita*; D=*Menidia* spp.) A reference line at 15% reduction in daily abundance is included.

All the plots show a general decrease in predicted daily abundance values as flows increase, for as previously described, total excess flows comprise a greater proportion of the total baseline flow at low flows. Also, although the regressions for these data were linear, they were done on natural log (Ln) transformed data so the relationship of abundance to non transformed flow may not be truly linear. As described by Flannery et al. (2002) for similar Ln transformed flow abundance relationships, the slope term indicates the degree that abundance changes at various rates of flow. Positive slope values closer to zero indicate a sensitive response to low flows while slope value closer to one indicate a more linear response. Values above one indicate a non-linear response with increasing sensitivity at high flows. The length of the preceding flow terms also affect the relationships, as longer flow terms tend to smooth variability in the preceding flow record and scatter in the plot of flow vs. abundance.

The plots of reduction in abundance vs. baseline flow are not smooth, because the total excess flow values can vary considerably from day to day and affect each daily prediction differently. Regardless, plots provide useful information on how reductions in daily abundance respond over various ranges of flow, and at what rates of flow is a 15% reduction in abundance is exceeded.

Using the smoothed fitted line as a guide, the total excess flow scenario tends to result in less than 15% reduction in the abundance of *Americamysis* when the preceding 79-day flow rate is above about 160 cfs (Figure 8-42A). Below that baseline flow rate, the total excess flow scenario results in more than a 15% loss in abundance. Similarly, the flow rates above which reductions in abundance are less than 15% are observed for *Trinectes* is near a 34-day flow rate of 500 cfs; a 21-day flow rate of 80 cfs for *Cyathura polita*; and a 10-day flow rate of 40 cfs for *Menidia* spp.

At will be discussed in Section 8.9, it makes sense at this time to base management strategies for the Lower Myakka River on the flows at the Myakka River near Sarasota gage, rather than on the summed flows for that gage with flows from Myakkahatchee Creek. Flows at the Myakka River gage are highly correlated with the two-gage flow, and the management strategies for the upper river sub-basin will affect the flows at the long term gage with no change in the flows from Myakkahatchee Creek. In that regard, it is useful to examine how reductions in abundance from the total excess flow scenario vary as a function of the corresponding baseline flow at the Myakka River near Sarasota gage.

The plot of reduction in abundance of *Americamysis* vs. two-gage baseline flow from Figure 8-42A is paired with a similar plot that uses the gaged flow at the Myakka River Sarasota gage in Figure 8-43. Because these flow terms are so highly correlated and the removal of excess flows are manifested solely at the Myakka gage, the plots are very similar, but the data have shifted somewhat to the left in the single gage plot as the baseline flow value will have a corresponding lower flow value using only one gage. For example, the smoothed line for *Americamysis* crosses the 15% population reduction reference line at about 130 cfs on the single gage plot, and at about 160 cfs on the two-gage plot. A paired graph for *Trinectes* juveniles shows a similar relationship, with the smoothed line crossing the 15% reduction reference line at about 400 cfs on the single gage plot, compared to 500 cfs on the two-gage plot (Figure 8-44).

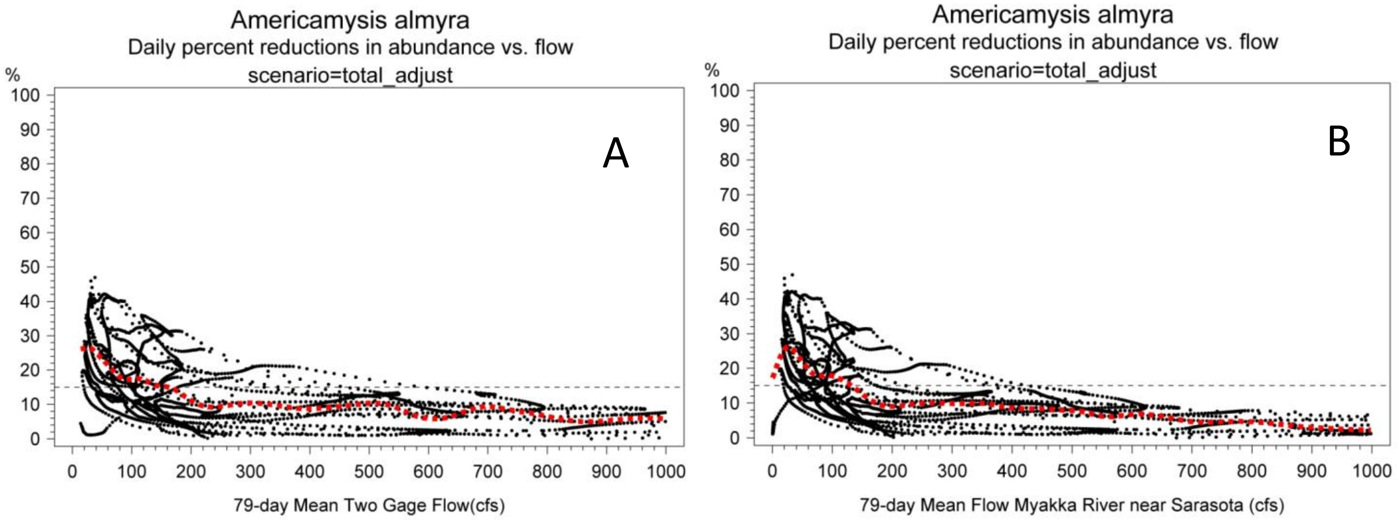

Figure 8-43. Predicted daily abundance values for *Americamysis almyra* vs. the corresponding preceding mean baseline flow terms for the total excess flow scenario for: A – summed daily flows for the Myakka River near Sarasota and Myakkahatchee Creek at Tropicaire Blvd. gages; and B – Myakka River near Sarasota gage alone.

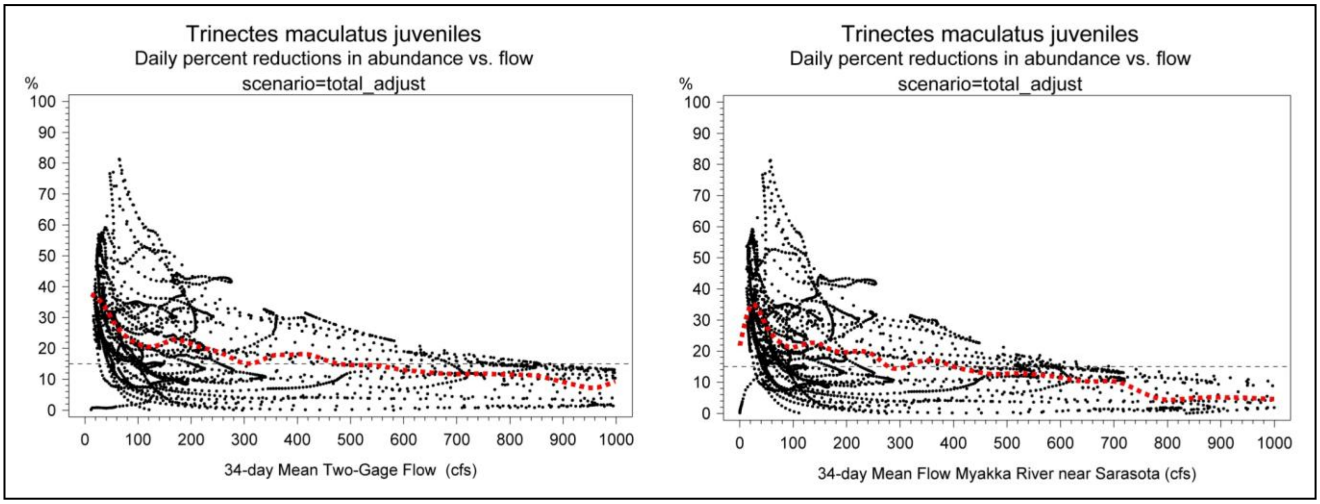

Figure 8-44. Predicted daily abundance values for *Trinectes maculatus* vs. the corresponding preceding mean baseline flow terms for the total excess flow scenario for: A – summed daily flows for the Myakka River near Sarasota and Myakkahatchee Creek at Tropicaire Blvd. gages; and B – Myakka River near Sarasota gage alone.

Given the similarity of the flow-abundance relationships using the single-gage and two-gage flows and the management importance of the single gage flows, a graphical comparison was conducted of the effects of the various flow reduction scenarios on species abundance using the baseline flow at the Myakka River near Sarasota gage. This assessment was restricted to *Americamysis almyra* and *Trinectes maculatus* as they are the two priority species in the river for which regressions with relatively high r^2 values were determined. An emphasis of the plots is to see at what rate of baseline flow at the Myakka River gage to reductions in abundance typically exceed 15% for the various flow reduction scenarios (Figures 8-45 and 8-46). The predictions are limited to the flow domain of the regressions, for it is transitions that are well within the flow domain of the regressions that are of interest for this analysis. Extending the predictions to include all flows would increase the number of high abundance reduction values that occur at low flows

The linear regression for *Americamysis* in Table 8-21 was used in the graphical analysis. Although not shown, the double reciprocal model exhibits a greater reduction in abundance at low flows and less reduction in abundance at high flows, but the rate of flow at which 15% reduction in abundance exceeds 15% is similar to the linear regression. Using the linear regression, the North Port permitted scenario never exceeded a 15% reduction in abundance, with reductions less that 5% observed at flows greater than about 60 cfs at the Myakka River gage (Figure 8-45A). The other plotted flow reduction scenarios, which all included removing the total excess flows, exceeded 15% reductions in abundance below some rate of flow. These flow rates were near: 140 cfs for the total adjustment scenario (Figure 8-45B); 150 cfs for the total adjustment - North Port scenario (Figure 8-45C); 180 cfs for the total adjustment - North Port – 10% scenario (Figure 8-45D); 380 cfs for the total adjustment – North Port – 15% scenario (Figure 8-45E); and 640 cfs for the total adjustment scenario – North Port – 20% scenario (Figure 8-45F).

Percent reductions in predicted daily abundance values were generally higher for *Trinectes maculatus*, including the threshold flows at which reductions in abundance exceeded 15%. A small number of percent reductions exceeded 15% for the North Port scenario at very low flows, but percent reductions were less than 5% when flows exceed about 100 cfs (Figure 8-46A). Flows at which the smoothed line went below 15% reductions were: 280 cfs for the total excess flows scenario (Figure 8-46B); 440 cfs for the total excess – North Port scenario (Figure 8-46C); and 740 cfs for the total excess flow – North Port – 10% scenario (Figure 8-46D). For the total excess – North Port – 15% and total excess – North Port – 20% scenarios, the smoothed lines did not go below at 15% reduction in daily abundance at the flow range plotted (1,000 cfs).

Using *Trinectes maculatus* as the most sensitive resource indicator, and accepting the rationale that the total excess flow scenario is allowable, then additional water could not be obtained at a rate of 10% plus withdrawals by North Port until 34-day flows at the Myakka River near Sarasota go above a flow rate of 740 cfs. Theoretically, withdrawals by the City of North Port could not be obtained in addition to the excess flows and stay within the 15% loss criterion until flows go above 440 cfs at the Myakka River near Sarasota gage. These and other considerations for an environmentally safe withdrawal schedule are discussed in Section 8-9.

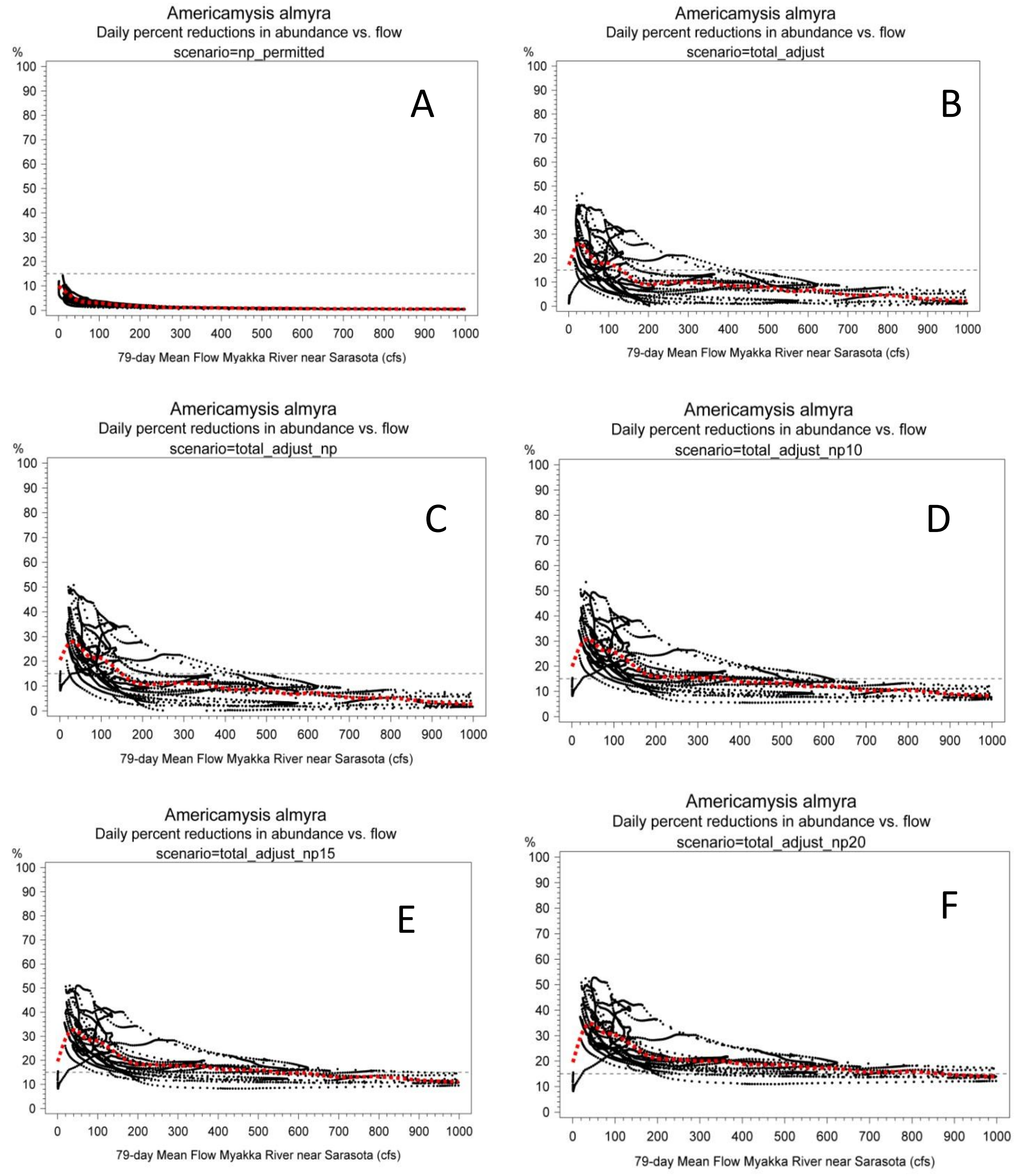

Figure 8-45. Percent reductions in the predicted daily abundance values of *Americamysis almyra* vs. baseline flow at the Myakka River near Sarasota gage for six flow reduction scenarios.

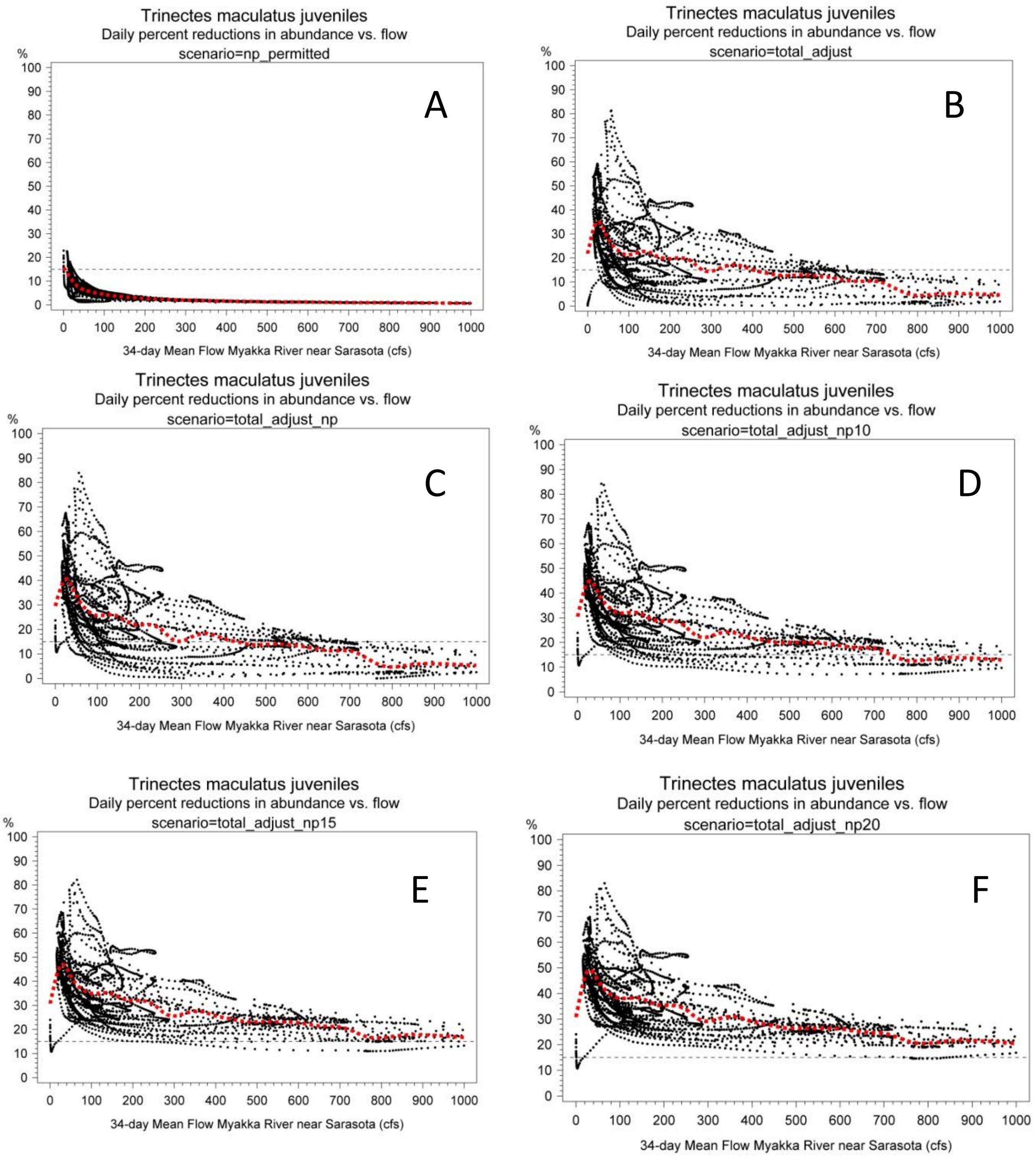

Figure 8-46. Percent reductions in the predicted daily abundance values of *Trinectes maculatus* vs. baseline flow at the Myakka River near Sarasota gage for six flow reduction scenarios.

8.8.7 Changes in the centers of distribution for fishes and invertebrates

Studies of the Lower Myakka and other tidal rivers within SWFWMD have documented shifts in the centers of population distributions of fish and invertebrates taxa as a function of freshwater inflow (Peebles 2002, Greenwood et al. 2004, Peebles 2005a. Matheson et al. 2005). As described in Section 6.4.6 and 6.4.11, significant regressions were developed between the center of distribution (Km_U) of various age and size classes of key fish and invertebrate species in the Lower Myakka and freshwater inflow by Peebles et al. (2006), with the regressions for the plankton catch taxa subsequently updated by Peebles (2008). As described in Section 7.11.4, these regressions were applied to the selected flow reduction scenarios to evaluate shifts in Km_U of key taxa that would result from implementation of the minimum flows. The Km_U analysis was conducted after the inflow abundance analysis, and those results were used to limit the flow reduction scenarios investigated for the Km_U analysis.

The taxa and age/size classes that were selected for analysis are listed in Table 8-30. Selection of the taxa was based on the strength of the regressions as indicated by r^2 and the presence of negative slopes in the regressions, which cause Km_U to move downstream with increasing freshwater inflow and upstream with decreasing freshwater inflow. Since the area, volume and shoreline of the lower river decreases upstream, reductions in freshwater inflow could cause populations of key species to become centered in regions of the estuary with reduced area, volume, and available shoreline habitat.

A total of fourteen fish and invertebrate pseudospecies are listed in Table 8-30; seven taxon age/size classes from the plankton catch that were updated by Peebles (2008) and seven taxon age/size classes sampled by seine or trawl (Peebles et al. 2006). Scatter plots of Km_U inflow regressions for six plankton taxa were shown in Figure 6.31, and plots for four taxa captured by seine and trawl were shown in Figure 6.36. Fairly high r^2 values (0.62 to 0.86) were observed for several taxa, indicating a close relationship between inflow and population distribution.

Km_U predictions were generated for the 1995-2004 period. As was discussed for the abundance analyses, more confidence and emphasis is put on the plankton data because additional samples were taken during a low flow period in 2008. Also, there is much less habitat variability for species and age/size classes that comprise the zooplankton and ichthyoplankton, compared to those age/size classes that are captured by seine or trawl. While strongly acknowledging that physical gradients in the river such as bottom type and currents could affect the distribution and abundance of the plankton, this differs from the distinct structural differences that exist in shoreline and bottom types that could affect seine and trawl catches in different parts of the river. Thus, it is suggested that habitat variability probably affects both CPUE and Km_U relationships more for seine and trawl collections than for the plankton.

Table 8-30. Regressions between freshwater inflow and the center of population distribution (KmU) for the species age/size classes (pseudo-species) that were used in the minimum flow analysis. Regressions for pseudo-species collected by seine or trawl taken from Peebles et al. (2006), while psedo-species collected by plankton net are taken from Peebles (2008). The mean flow term is the number of days used in the preceding mean flow term used in the regression, and the flow term (gages) indicates that either the sum of the Myakka River near Sarasota and Myakkahatchee Creek were used in the regression, or the Myakka River near Sarasota gage was used alone. DW denotes possible serial correlation based on p< 0.05 for the Durbin-Watson statistic.

USF Plankton Sampling

Taxon	Common Name	Gear	age/size class	Response	df	DW	r^2	Flow Term (gage)	Mean Flow Term (days)
Invertebrates									
Americamysis almyra	mysid shrimp	plankton	adults	linear	23		0.85	Sum	10
Cyathura polita	isopod	plankton	all	linear	20		0.43	Sum	78
Edotea tribola	isopod	plankton	all	linear	23		0.85	Sum	26
Mesocyclops edax*	copepod	plankton	all	linear	20		0.48	mrs**	1
Fish									
Anchoa mitchilli	bay anchovy	plankton	adults	linear	23		0.58	Sum	68
Anchoa mitchilli	bay anchovy	plankton	juveniles	linear	23	x	0.86	Sum	3
Trinectes mactulatus	hogchoker	plankton	juveniles	linear	18		0.63	Sum	30

FFWCC Seine and Trawl Sampling

Taxon	Common Name	Gear	age/size class	Response	df	DW	r^2	Flow Term	Flow Term (days)
Invertebrates									
Farfantepenaeus	pink shrimp	seines	<= 14 mm	linear	10		0.62	Sum	14
Callinectes sapidus	blue crab	seines	<= 34 mm	linear	12	x	0.39	Sum	7
Fish									
Anchoa mitchilli	mosquitofish	seines	26-35 mm	linear	17		0.44	Sum	91
Anchoa mitchilli	mosquitofish	seines	>= 36mm	linear	16	x	0.26	Sum	21
Cynoscion arenarius	sand seatrout	trawl	<= 40 mm	linear	14	x	0.62	Sum	28
Cynoscion arenarius	sand seatrout	trawl	>= 41 mm	linear	13		0.44	Sum	35
Menticirrhus americanus	southern kingfish	trawl	> = 36 mm	linear	13		0.5	Sum	112

Similar to the abundance analysis, the flows used to develop the Km_U regressions did not entirely cover the wide range of flows that occurred over the 1995-2004 modeling period. This was especially the case for the seine and trawl sampling that was limited to 2003 and 2004. The lower and upper flow rates of the corresponding mean flow terms that represent the flow domains of the regressions are listed in Table 8-31. Also listed are the percentages of days in that the resulting flows for the baseline and total adjustment scenarios were outside the flow domain of the regression. Again, there were more predictions outside the flow range of the regressions for the total adjustment scenario, as subtraction of the excess flows from baseline moved the flow for some days during low flow periods below the domain of the regression.

For some taxa (e.g, *Americamysis*, *Cyathura polita*, *Trinectes maculatus* and plankton catch of *Anchoa mitchilli* adults*)* the problem with the number of days outside the flow domains was not severe. However, for some other taxa (e.g. *Callinectes sapidus, Farfantepaneus durorarum*) there was a large number of days when flows were outside the flow domain of the regression, even for baseline conditions. Although the results for these taxa provide some useful information, the findings for these taxa should be viewed with caution and are not emphasized in the minimum flows analysis.

Table 8-31. Lower and upper limits of flows that were within the domain of the KmU regression for each taxon / age-size class (pseudo-species) and the percentage of predictions that were outside the flow domain of the regression for the baseline and total adjustment scenarios.

							Percentage of predctions outside flow domain	
Taxon	**Common Name**	**age/size class**	**Gear**	**Flow Term (days)**	**Flow Lower Bound (cfs)**	**Flow Upper Bound (cfs)**	**Baseline**	**Total adjustment**
Americamysis almyra	mysid shrimp	adults	plankton	10	12	4914	5%	15%
Cyathura polita	isopod	all	plankton	78	15	1998	4%	9%
Edotea tribola	isopod	all	plankton	26	8	4447	3%	10%
Mesocyclops edax	copepd	all	plankton	1	9	10838	13%	13%
Anchoa mitchilli	bay anchovy	adults	plankton	68	12	2440	2%	6%
Anchoa mitchilli	bay anchovy	juveniles	plankton	3	7	8103	6%	13%
Trinectes maculatus	hogchoker	juveniles	plankton	30	11	3640	4%	11%
Farfantepenaeus duorarum	pink shrimp	<= 14 mm	seines	14	20	4024	12%	22%
Callinectes sapidus	blue crab	<=34 mm	seines	7	20	992	24%	33%
Anchoa mitchilli	bay anchovy	26-35 mm	seines	91	33	1998	10%	13%
Anchoa mitchilli	bay anchovy	>= 36mm	seines	21	15	2980	7%	16%
Cynoscion arenarius	sand seatrout	<= 40 mm	trawls	28	16	3640	8%	15%
Cynoscion arenarius	sand seatrout	>= 41 mm	trawls	35	16	3640	7%	14%
Menticirrhus americanus	southern kingfish	> = 36 mm	trawls	112	67	2208	15%	26%

Given these limitations for some taxa, the Km_U relationships for all the collection gears provide important information on the distribution and potential habitat use of key species in the river. A box and whisker plot of the predicted KmU locations of seven key taxa in the river is presented in Figure 8-47 for baseline flow conditions. The predicted median locations of the seine catches of small pink shrimp (*Farfantepaneus duoarum*, <= 14 mm) and blue crab (*Callinectes sapidus* <= 34 mm) are centered near the mouth of the river. However, the true median locations of these pseudo-species are probably some further upstream due to the disproportionate number of low flows omitted from the regressions. Also, as pointed out by Peebles and Greenwood (2009), KmU values may not be as representative of true population distributions for speices for which substantial proportions of their populations extend past the mouth of the river, which could be the case for taxa with low median Km_U values.

Relying on the more robust regressions for the plankton tows, the predicted median locations of two abundant and ecologically important pseudo-species, (*Americaymysis almyra)* and juvenile bay anchovies (*Anchoa mitchilli*), were located in the broad portion of the tidal river near kilometers 7 and 8. *Trinectes maculatus*, which prefers lower salinity water, was located near kilometer 12.8, about 2 kilometers below the confluence of Myakkahatchee Creek. The predicted median location for the freshwater copepod *Mesocyclops edax* was located further upstream near kilometer 19.

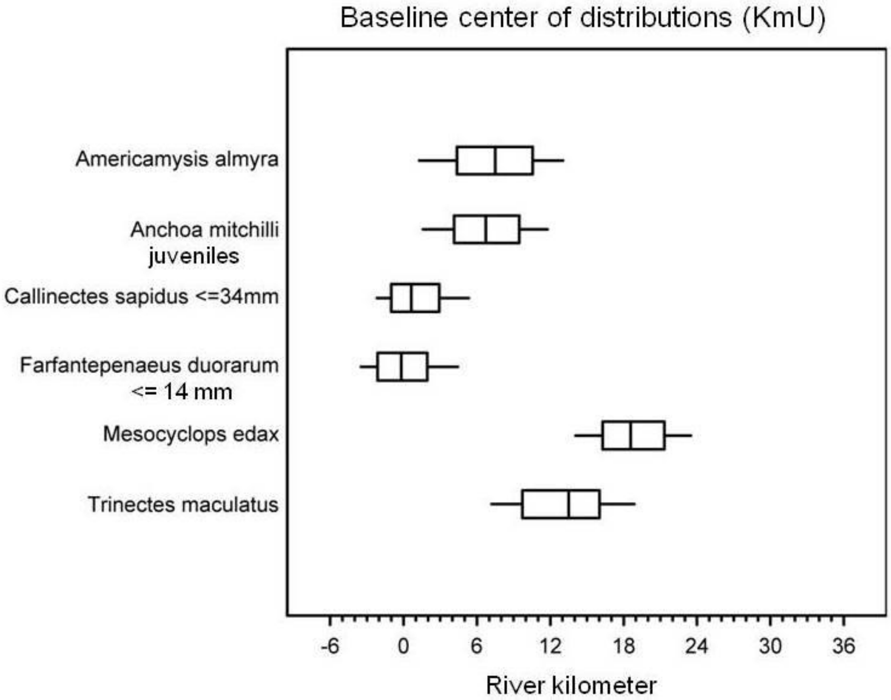

Figure 8-47. Box and whisker plot of the predicted daily centers of distribution (Km_U) for six pseudo-species in the Lower Myakka River for baseline flow conditions for 1995-2004. Whiskers extend to 5th and 95th percentiles of the predicted values.

Predicted percentile locations of Km_U for all the taxa examined in the minimum flows analysis are listed in Table 8-32 for baseline flow conditions, with the predictions limited to the flow domains of the regressions. The difference between the 10th and 90th percentiles, termed the inter-decile range, can be considered the distance over which Km_U varies eighty percent of the time. The inter-decile range for taxa collected by plankton tows ranged from 8.2 kilometers for the isopod *Cyathura polita* to 14.6 kilometers for adult bay anchovies (*Anchoa mitchilli*). The inter-decile ranges for two key species identified from the abundance analysis, *Americamysis almyra* and *Trinectes maculatus*, was 11.2 and 11.4 kilometers, respectively.

Using the seine and trawl data, the inter-decile range of two size classes of bay anchovies were also relatively high (14.1 km for the 26- 35 mm size class and 11 km for the >=36 km size class). Both the plankton and the seine results indicate that bay anchovies, which are by far the most numerous fish in the river, undergo large shifts in their distribution as a function of freshwater inflow. Fairly large shifts (12.6 and 13.5 km shifts) were also observed by two size classes of sand seatrout (*Cynoscion arenarius*) collected by trawls. Shifts were smaller for taxa collected near the mouth of the river (*Callinectes sapidus*, *Farfantepeneaus duorarum* and *Menticirrhus americanus*), but again these results should be viewed with caution, as the predicted percentile values may not reflect the true range of movement for these populations.

Table 8-32. Percentile values of predicted locations of KmU for fourteen fish and invertebrate taxa age/size classes for baseline flow conditions for 1995-2004. Predicted values were limited to the flow domains of the regressions.

USF Plankton Sampling				**Percentile values KmU Locations (kilometers)**					
Taxon	**Common Name**	**Gear**	**age/size class**	**99**	**90**	**75**	**50**	**25**	**10**
Invertebrates									
Americamysis almyra	mysid shrimp	plankton	adults	15.8	13.9	12.2	8.6	5.1	2.7
Cyathura polita	isopod	plankton	all	14.6	12.4	10.5	8.7	5.7	4.2
Edotea tribola	isopod	plankton	all	14.6	11.9	9.3	5.3	0.8	-1.9
Mesocyclops edax*	copepod	plankton	all	24.2	22.7	21.3	18.6	16.2	14.9
Fish									
Anchoa mitchilli	bay anchovy	plankton	adults	15.6	12.2	8.1	5.3	0.1	-2.6
Anchoa mitchilli	bay anchovy	plankton	juveniles	15.0	13.1	11.3	8.0	4.6	2.5
Trinectes mactulatus	hogchoker	plankton	juveniles	21.6	19.5	17.4	14.2	10.3	8.1
FFWCC Seine and Trawl Sampling				**Percentile values KmU Locations (kilometers)**					
Taxon	**Common Name**	**Gear**	**age/size class**	**99**	**90**	**75**	**50**	**25**	**10**
Invertebrates									
Farfantepenaeus	pink shrimp	seines	<= 14 mm	7.6	6.0	3.7	0.7	0.0	0.0
Callinectes sapidus	blue crab	seines	<=34 mm	8.6	7.0	5.0	1.9	0.0	0.0
Fish									
Anchoa mitchilli	mosquitofish	seines	26-35 mm	22.5	15.9	11.9	6.5	1.8	0.0
Anchoa mitchilli	mosquitofish	seines	>= 36mm	14.5	11.0	7.9	3.7	0.0	0.0
Cynoscion arenarius	sand seatrout	trawl	<= 40 mm	18.5	15.7	12.7	8.7	4.8	3.1
Cynoscion arenarius	sand seatrout	trawl	>= 41 mm	17.0	13.6	9.8	5.7	1.6	0.1
Menticirrhus americanus	southern kingfish	trawl	> = 36 mm	4.9	4.1	3.0	0.8	0.0	0.0

As previously discussed, upstream shifts in Km_U could potentially result in reductions in population abundance due to compression of the population into regions of the river with less available habitat. In a paper that analyzed data from several rivers including the Lower Myakka, Peebles and Greenwood (2009) suggested that KmU was a useful ecological metric for which relationships with inflow could be established with less data than needed to determine direct relationships of inflow with abundance. However, from a management perspective, shifts in Km_U are particularly relevant for species for which significant relationships between freshwater inflow and abundance are also documented. Conversely, if a significant relationship between inflow and abundance cannot be found, then shifts in Km_U would be given less weight in reaching management decisions. This does not suggest, however, that inter-relationships between freshwater inflow, Km_U, and abundance could potentially not be found for other important taxa, if there was additional data collection and possibly the application of other modeling techniques to examine relationships between inflow and abundance.

Given these considerations, the following discussion of shifts in Km_U emphasizes three key taxa that were collected as part of the plankton catch. *Americamysis almyra* and *Trinectes maculatus* as these are ecologically important species in the river for which both distribution and abundance are known to be sensitive to changes in freshwater inflow. The numerically dominant *Anchoa mitchilli* is very important to energy transfer in the river, and the distribution of juveniles of this species showed a close relationship with freshwater inflow (see Figure 6-31 on page 6-65).

As previously discussed, limiting the predictions to the domains of the regressions can have a major effect on the estimated effects of the modeled flow reduction scenarios. The Km_U regressions for all three taxa were linear, meaning that lower flows consistently result in higher Km_U values (moment upstream) and higher flows consistently result in lower Km_U values (movement downstream). Assuming that this relationship applies beyond the domain of the regressions, this allows for cumulative distribution statistics (medians and other percentiles) to be calculated on the entire population of days in the flow record, including those predictions that were outside the flow domain of the regression. For example, if high Km_U values are predicted for very low flows outside the domain of the regression, those values could still be included in the calculation of a median value that should be more representative of the true median than one that was calculated from a sub-set of all the days of record.

Percentile values of Km_U locations for the three indicator taxa predicted using 1995-2004 flow record are listed for baseline conditions and three flow reductions scenarios in Table 8-33. These flow reduction scenarios were selected based on the inflow-abundance analysis to capture the range of scenarios over which a 15% reduction in abundance occurs for *Americamysis* and *Trinectes* (total adjustment, total adjustment – North Port, and total adjustment – North Port – 10%).

Only 5% and 4% of the Km_U predictions for *Americamysis* and *Trinectes* respectively were outside the flow domain of those regressions for the baseline flow scenario (Table 8-31). Therefore, all percentile values listed in Table 8-33 are within the flow domains of the regressions except for the 99th percentile values. Six percent of the KmU predictions for *Anchoa mitchilli* were outside the flow domain for baseline flows, so predictions up to the 90th percentile value are valid as well.

Table 8-33. Percentile values of predicted locations of KmU for the plankton catch of *Americamysis almyra, Trinectes maculatus* juveniles, and *Anchoa mitchilli* juveniles for baseline flows and three flow reduction scenarios. Also listed are upstream shifts of the percentile values from baseline for each flow reduction scenario. Predictions were generated using flows from all days during 1995-2004.

Americamysis almyra

	KmU locations and upstream shifts from baseline						
Percentile	**Baseline (km)**	**Total adjust (km)**	**Shift (km)**	**Total adjust - NP (km)**	**Shift (km)**	**Total adjust - Np - 10% (km)**	**Shift (km)**
99	21.9	24.8	2.9	26.4	4.5	26.4	4.6
95	16.2	19.4	3.2	19.4	3.2	19.6	3.4
90	14.9	17.4	2.5	17.7	2.9	18	3.1
75	12.7	11.4	1.3	14	1.3	14.3	1.6
50	9	9.6	0.6	9.7	0.7	9.9	0.8
25	5.3	5.6	0.3	5.5	0.2	5.8	0.5
10	2.8	2.9	0.1	2.6	0.1	3.1	0.4

***Trinectes maculatus* juveniles**

	KmU locations and upstream shifts from baseline						
Percentile	**Baseline (km)**	**Total adjust (km)**	**Shift (km)**	**Total adjust - NP (km)**	**Shift (km)**	**Total adjust - Np - 10% (km)**	**Shift (km)**
99	26.6	29.9	3.3	32	5.4	32.3	5.7
95	21.6	24.2	2.6	25.4	3.8	25.6	4
90	20.3	22.4	2.1	23.1	2.8	23.3	3
75	17.9	19.2	1.3	19.4	1.5	19.7	1.8
50	14.4	15.2	0.8	15.3	0.9	15.5	1.1
25	10.5	10.9	0.4	10.9	0.4	11.2	0.7
10	8.1	8.2	0.1	8.2	0.1	8.5	0.4

***Anchoa mitchillii* juveniles**

	KmU locations and upstream shifts from baseline						
Percentile	**Baseline (km)**	**Total adjust (km)**	**Shift (km)**	**Total adjust - NP (km)**	**Shift (km)**	**Total adjust - 10% (km)**	**Shift (km)**
99	20.8	na	na	na	na	na	na
95	15.0	19.1	4.1	na	na	na	na
90	13.9	16.2	2.3	17.5	3.7	17.8	3.9
75	11.7	12.9	1.2	13.3	1.7	13.6	1.9
50	8.3	8.9	0.6	9.1	0.8	9.3	1.0
25	4.7	5.2	0.4	5.2	0.5	5.4	0.7
10	2.6	2.8	0.1	2.8	0.2	3.0	0.4

Using the entire flow record, the inter-decile range for all three species slightly larger than listed in Table 8-32, as the 90th percentile values moved further upstream (1 km for *Americamysis*, 0.8 km for Trinectes, and 0.8 km for *Anchoa*). Shifts in median values were smaller (0.2 to 0.4 km) and the 10th percentile values were nearly the same between the flow conditions.

Table 8-33 also lists the upstream shifts of the percentile values for each flow reduction scenario relative to baseline. Shifts in the median Km_U locations ranged from 0.6 to 1.1 kilometers for the set of flow reduction scenarios for the three selected taxa. Shifts for lower percentile values (more downstream Km_U locations), were less, ranging from 0.1 to 0.4 kilometers for the 10th and 25th percentile values.

The most important point of Table 8-33 is the fairly large shifts of the higher percentile values, which represent times when Km_U is located upstream during low flows. Shifts in the 90th percentile values for *Americamysis* ranged from 2.5 km to 3.1 km, with shifts of the 95th percentiles ranging from 3.2 to 3.4 km. Shifts in the 90th percentile values for *Trinectes* ranged from 2.1 to 8 km, with shifts of the 95th percentile values ranging from 2.1 to 4 km. Shifts in the 99th percentile values were larger – 2.9 km from 4.6 km for *Americamysis* and 3.3 to 5.7 km for *Trinectes*, but it is reiterated these predictions are outside the flow domains of the regressions. Shifts in 90th percentile values for *Anchoa mitchilli* juveniles ranged from 2.3 to 3.9 kilometers. Ninety-fifth and 99th percentile values were not generated for two of the flow reduction scenarios for *Anchoa*, as these resulted in zero flows, which was problematic for the Ln transformed flows and adding constants to the data was considered not appropriate.

These large shifts in the higher Km_U values are not surprising, for total excess flows comprise a large percentage of flows at low flows (Figures 8-9 and 8-10). Even the effects of adding the North Port withdrawals can comprise substantial quantities of flow when the total adjusted flows are very low.

In the analysis of minimum flows for the Lower Alafia River, shifts in predicted Km_U values were applied to volume data for the tidal river to determine the changes in volume between the 10th and 90th percentile Km_U locations for different flow scenarios (SWFWMD 2008b). On that river, which included a 120 cfs low flow threshold which prohibited withdrawals at low flows, there was a reduction in volume between the 10th and 90th percentile locations as flows were reduced. That approach was also applied to the Km_U shifts of the three indicator taxa in the Lower Myakka, but the resulting changes in volume were very small, or in some cases, increased as water was removed. This occurred because the locations of the lower percentile Km_U values in the wet season changed very little, but the dry season Km_U values moved considerably upstream as the low flows of the river were dramatically reduced by removal of the excess flows. This increased the distance between the 10th and 90th percentile Km_U locations, and at least for this metric, did not show a substantial effect of the simulated withdrawals.

Predicted changes in Km_U could possibly be applied to changes in volume in other ways, but changes in Km_U were not used directly in the analysis of minimum flows for the Lower Myakka River. However, the Km_U results are presented for they clearly demonstrate the effect of removing the excess flows and additional withdrawals over different flow ranges within the flow regime of the river. The pronounced shifts in Km_U at lower flows mimic similar large changes that were predicted for salinity zones and fish and invertebrate abundance, due primarily to the large proportion of baseline flow comprised by the excess flows in the dry season. These results are discussed in the following section in an overall synthesis of the minimum flow findings for the lower river and considerations of adaptive management strategies and further research.

8.9 Synthesis of findings and recommended minimum flows, including related management strategies that affect freshwater flow to the Lower Myakka River

The following section presents a synthesis of the findings for the minimum flows analysis and recommends proposed minimum flow rules for the Lower Myakka River. The implementation of the proposed minimum flows in relation to other resource management strategies that affect freshwater flow to the lower river is also discussed. The Myakka River watershed has experienced several physical alterations in both the upper river and lower river sub-basins that affect freshwater flow to the lower river. It is possible that some management strategies could be coordinated to restore the hydrology of the upper river sub-basin by reducing excess flows, while partially offsetting the associated flow reductions to the lower river. In that regard, it is suggested that minimum flows for the Lower Myakka River be viewed as part of an adaptive management strategy for the Myakka River in which the findings of ongoing efforts are used to update and implement other related management methods and plans.

The proposed minimum flows and these related considerations are discussed in the following sections, with summary points listed below:

- Excess flows, which have been estimated by a very detailed MIKE SHE modeling effort, need to be removed from the upper river sub-basin for purposes of restoration of the Flatford Swamp and other freshwater riverine wetlands.

- Using the existing flow regime of the Lower Myakka River as the baseline, flow reductions corresponding to minimum flows for the Lower Myakka River should not exceed quantities hydrologically equivalent to the adjusted excess flows evaluated in this report (including the 130 cfs cap), until flows at the Myakka River near Sarasota gage exceed 400 cfs. Above a flow rate of 400 cfs, 10% of the remaining flow above the excess flows at the Myakka River near Sarasota can be removed for withdrawal.

- In addition to above, withdrawals that are currently permitted to the City of North Port for withdrawals from Myakkahatchee Creek are in compliance within the proposed minimum flows for the lower river. However, minimum flow rules for Myakkahatchee Creek should be adopted within a five-year time frame, concurrent with the scheduled re-evaluation of minimum flows for the Lower Peace River. Coordination of these two efforts will allow for recalibration and refinement of the hydrodynamic salinity model of the Upper Charlotte Harbor – Lower Peace River – Lower Myakka River system. The model should then be used to reexamine the effects of minimum flows and other management options on the salinity characteristics of both the Lower Peace and Lower Myakka rivers. Data collection of other priority ecological indicators in the Lower Myakka River could be conducted and evaluated during this five-year period.

- The stream gaging network in the Lower River sub-basin should be improved to reinstitute the USGS gage on Deer Prairie Slough and begin periodic measurements of flow from Warm Mineral Springs. These data, plus continued data collection at the more recent (post-2007) stream gaging sites on the lower river, Myakkahatchee Creek, and the Cocoplum Waterway will allow for better assessment of total freshwater flow to the lower river.

- The removal of excess flows from the Upper Myakka River sub-basin will cause substantial changes in the low flow characteristics of the lower river, but the remaining flows will be similar to what the river experienced before the extensive augmentation of flows began in the late 1970s.

- Removing the excess flows will cause ecological shifts and changes in the salinity characteristics and some biological communities that currently exist in the Lower Myakka River. The effects of the flow reductions will be most pronounced in the spring dry season, which is an important time for fish nursery use and increasing biological productivity in the estuary. However, these resulting ecological changes are considered to be acceptable because they correspond to conditions in the river before the flow augmentation began.

- Management options for other hydrologic features that affect inflows to the lower river, such as modifications of the Blackburn Canal, Cowpen Slough, or Tatum Sawgrass marsh, could be investigated in order to partially offset reductions in low flows to the lower river that result from removal of excess flows in the upper river-sub-basin. However, the removal of the excess flows and compliance with the minimum flow rule for the lower river would not be contingent upon the implementation of such management plans.

8.9.1 Recommended minimum flows for the Lower Myakka River

It has been well documented that changes in land and water use have increased flows in the upper Myakka River sub-basin, resulting in tree die-off and other impacts to riverine wetlands. Management plans are now being developed to reduce these excess freshwater flows. These excess flows have also resulted in a significant supplementation of flows to the Lower Myakka River estuary. Accordingly, the first scenario conducted for the minimum flows analysis was simulating the effects of removing these excess flows on a series of ecological indicators in the lower river estuary. A series of sequential simulations were then performed that removed various percentages of the remaining flow at Myakka River near Sarasota gage, in addition the maximum possible withdrawals from Myakkahatchee Creek that are currently permitted to the City of North Port.

Based on the findings of these analyses, the recommended minimum flows for the Lower Myakka River are that flow reductions be limited to the flows that are hydrologically equivalent to the adjusted excess flows identified in this minimum flows report (including the 130 cfs cap), unless flows at the Myakka River near Sarasota gage are in excess of 400 cfs. The justification for the 400 cfs high flow threshold is discussed further in Section 8.9.2.

The recommended minimum flows were based on analysis of changes in a series of resource indicators in the lower river estuary that included; the bottom area and water volume of biologically important salinity zones, shifts in the 2 psu surface isohaline in relation to oligohaline/tidal freshwater marshes, and the abundance of two ecologically important fish and invertebrate species in the river (*Trinectes maculatus* and *Americamysis almyra*). Changes in these resource indicators were evaluated within three seasonal blocks and different flow ranges.

The lower river's existing (present) flow regime was considered the baseline for evaluating the effects of potential withdrawals, including removal of the excess flows from the upper river sub-basin. This approach was taken because of the present healthy condition of the Lower Myakka River, the role of freshwater flow in maintaining the ecological structure and productivity of the current ecosystem, and that freshwater flows to the lower river have been reduced by modifications to Cowpen Slough and construction of the Blackburn Canal. The Lower Myakka River is one of the most highly valued natural resources in the region, and various reaches of the lower river are designated as an Outstanding Florida Water, a Wild and Scenic River, and/or an Aquatic Preserve.

In minimum flow analyses for other rivers, the District has used a 15% reduction in habitats or other resource indicators to determine significant harm. Reductions in resource indicators in the Lower Myakka that result from removal of the excess flows will at times exceed the District's 15% reduction threshold, depending on the season and rate of flow. Reductions in resource indicators in excess of 15% occur at low flows due to removal of the excess flows, with the magnitude of these reductions increasing dramatically at very low flow rates (Figures 8-27, 8-28, 8-43, 8-44). This occurs because excess flows can at times comprise most or all of the low flows at the Myakka River near Sarasota gage (Figures 8-9, 8-10).

Reductions in resource indicators resulting from removal of the excess flows were most acute in the spring (Tables 8-12, 8-27), a time when flows are typically low and fish nursery use and biological use of the lower river is increasing. Reductions in resource indicators were typically less during the fall-winter and summer seasons (Tables 8-13, 8-14, 8-28, 8-29). However, a comparison of predicted ecological changes over a ten-year period (1995-2004) to a drier four-year period (1999-2002) found that reductions in resource indicators greater than 15% could occur during the winter and summer of dry years. As a result, the minimum flows for the Lower Myakka River incorporated a flow based component, rather than relying strictly on a seasonal approach.

It can be argued that reductions in resource indicators in excess of 15% are allowable because the flows of the Myakka River, particularly the low flows, have been artificially increased by changes in land and water use in the upper river sub-basin. Removal of these excess flows will return the flow regime of the river to conditions that were prevalent in the decades from the 1950s to the late 1970s. While modification of Cowpen Slough and construction of the Blackburn Canal have reduced flows, data indicate the flow reductions caused by these structural modifications are most prevalent in the wet season, and are relatively small compared to the excess flows the river receives in the dry season.

While the timing and magnitude of these changes in the river's watershed and flow regime are relevant, it is also important to recognize that removal of the excess flows, while benefiting the restoration of the Flatford Swamp, will cause reductions in habitats and other resource indicators in the lower river in the dry season. The flow reductions will reduce the availability of low salinity habitats during periods of high fish nursery use, and will likely cause a shift and reduction in the extent of the diverse oligohaline / tidal freshwater marsh zone that serves as excellent wildlife habitat. The flow reductions will also reduce the abundance of a key invertebrate prey species (opossum shrimp, *Americamysis almyra*) and a dominant fish (hogchoker, *Trinectes maculatus*) in the low salinity reaches of the lower river. The centers of distribution for both of these species will shift considerably upstream (3 or more kilometers) due to removal of the excess flows during periods of low flow.

As a result of these predicted ecological changes, the recommended minimum flows for the Lower Myakka River are that no water other than the excess flows (capped at 130 cfs) be removed from the Myakka River, until flows at the Myakka River at Sarasota reach a flow rate of 400 cfs. The permitted withdrawals to the City of North Port may also be removed along with the excess flows, for the City's withdrawals have a very small effect on the ecology of the river. However, as discussed further below in Section 8.9.3, minimum flows for Myakkahatchee Creek are recommended for establishment within five years, at which time the maximum flow reductions from Myakkahatchee Creek that can be allowed in combination with removal of the excess flows can be better determined.

8.9.2 Minimum flows at high flow rates at the Myakka River near Sarasota gage

Various analyses indicate that removal of the excess flows do not cause reductions in resource indicators greater than 15% when flows in the river are high. During such high flow periods, some reductions in flows in addition to removal of the excess flows could be allowed as part of the minimum flow rule. Key indicators that are used to support the diversions in addition to excess flows include relationships of freshwater flow with the area and volume of low salinity habitats (< 2 and < 5 psu) and the abundance of two key fish and invertebrate species.

Plots were examined of percent reductions in the area and volume of low salinity habitats that result from removing the excess flows. These results indicate that if flows at the Myakka River near Sarasota gage are sufficiently high, removal of the excess flows do not reduce the area and volume of the selected salinity zones by more than the District's 15% significant harm threshold. The flows at which 15% reductions were not exceeded were highest for the < 5 psu salinity zones, which corresponds to the upper limit of oligohaline water. Using the < 5 psu zones as conservative indicators, model simulations found that removing the excess flows resulted in a 15% reduction in habitats when existing flows at the Myakka River near Sarasota gage were in the flow range of about 50 to 150 cfs (Figures 8-27B, 8-28B). Reductions in habitats were less at higher flow rates.

The lowest rate of withdrawal of additional water that was simulated involved removing 10 percent of the remaining flow at the Myakka River near Sarasota gage after the excess flows were removed. The removal of permitted withdrawals to the City of North Port were also included in these simulations. These results indicated that reductions in habitat were about 15% in a flow range of about 200 to 400 cfs when these cumulative quantities of water were taken from the river, with lesser reductions at higher flow rates (Figures 8-27C, 8-28C). This indicates that 10% of remaining flow can be removed when the existing flows for the river are above 400 cfs without exceeding the District's 15% significant harm threshold.

Using biological indicators, reductions in *Americamysis almyra* abundance due to removal of the excess flows tended to be less than 15% when the existing flows were greater than about 150 cfs (Figure 8-43B). However, when the excess flows and 10% of the remaining flow and the City of North Port's permitted withdrawals are removed, reductions in abundance near 15% occur in a flow range of about 200 to 550 cfs, with lesser reductions at higher flow rates (Figure 8-43D). These results, however, are based on preceding 79-day mean flows. Predicted reductions in abundance for *Trinectes maculatus* due to removal of the excess flows were less than 15% when the existing flows were above 400 cfs using a 34-day mean flow term (Figure 8-44B). However, when the excess flows and 10% of the remaining flow with City of North Port's permitted withdrawals are removed, reductions in abundance do not go below 15% until flows reach about 740 cfs (Figure 8-44D). Statistical comparisons of predicted abundances for both *Americamysis* and *Trinectes* found that reductions in excess of 15% occurred within each of the seasonal blocks when 10 percent of the remaining flows were removed (Tables 8-27, 8-28, 8-29), so higher percentage diversion rates were not considered as feasible.

Though these simulations produce findings that are not entirely consistent, they provide useful results for the management of high flows. The findings of the < 5 psu salinity zones and the abundance of *Americamysis almyra* indicate that 10 percent of the remaining flow at the Myakka River near Sarasota gage could be removed when the total flows at that gage are above 400 to 550 cfs. The results for *Americamysis* however, are based on preceding mean flows over two and one-half months in duration. Compared flows computed over shorter time intervals, these mean flows will typically reach high values (e.g. >500 cfs) later in the summer and will persist later in the fall due to the influence of preceding flows in their calculation.

Because salinity is directly related to freshwater inflow and responds much quicker to changes in freshwater inflow than biological variables, 400 cfs was selected as the high flow threshold to allowing withdrawals that are in addition to removing the excess flows. Although the timing of the response of salinity and the biological variables is not the same, restricting the additional withdrawals to same-day flows over 400 cfs will largely protect the preceding mean flow terms upon which the biological variables respond. Although reductions in *Trinectes maculatus* will be somewhat greater than reductions of *Americamysis almyra* at flows in the range of 400 to 700 cfs, there will be abundant habitat at these flow rates for *Trinectes*, a species that is most abundant in low salinity waters.

At this time, the recommended 400 cfs high flow threshold is based solely on flows at the Myakka River near Sarasota gage, for this is where the removal of excess flows on the lower river will be expressed. It is important to also note that the high flow threshold expressed is based on the existing flows at this gage, which have the excess flows included. As described further below, the implementation of restoration plans for the upper river sub-basin will require that the quantities of water that are removed from the river be monitored. It is recommended at this time that the switch to the higher flow threshold be based on sum of the excess waters that are removed and the remaining flows at the Myakka River near Sarasota gage. Though this will require real time data collection, reporting and calculation, it will ensure that the total flows in the river are sufficiently high before additional waters above the excess flows can be removed.

8.9.3 Schedule the establishment of minimum flows for Myakkahatchee Creek

Myakkahatchee Creek is a major tributary to the Lower Myakka River, but until recently, much of the flow of that system had not been gaged. The USGS has operated two stream gages on the main stem of the creek with records going back to 1980 and 2001 (Table 2.2), but considerable water enters the creek downstream of these gages. The installation of two recent USGS gages in the Myakkahatchee Creek system in the summer of 2007 (Big Slough Canal at West Price Blvd. and the Cocoplum Waterway) has greatly improved the completeness of flow data for the Myakkahatchee Creek system. The development of rating curves for these index velocity sites by the USGS took some time, and approved flow data for these gages were made available after much of the minimum flows analysis for the Lower Myakka River had been completed. The District concluded, therefore, that any minimum flows for Myakkahatchee Creek be postponed until a longer period of flow records were available for these sites.

It is now recommended that minimum flows for Myakkahatchee Creek be scheduled for adoption within five years. The City of North Port has been monitoring salinity and water quality in the creek as part of their water use permit, and there will be a robust data set for the creek available for analysis within the five-year window. In the most recent report for City's monitoring project, it was recommended that additional analyses would be valuable when more flow data are available from the new streamflow gages in the basin (PBS&J 2009).

It is also relevant that the minimum flow rule that was recently adopted for the Lower Peace River specified that minimum flows for that system will be reevaluated within five years. A key component of the minimum flows for the Peace River was the District's hydrodynamic model of the Upper Charlotte Harbor – Lower Peace River – Lower Myakka River system. This is the same model that was used for the salinity analysis of the Lower Myakka River. It is expected that the hydrodynamic model will be refined as part of the reevaluation of the Lower Peace River minimum flows. A major component in that refinement will be inclusion of the gaged flows that are now available in the Myakka River basin, including the recent USGS gages on Myakkahatchee Creek, the Cocoplum Waterway, the Blackburn Canal, and the lower river near kilometer 45 below Lower Myakka Lake.

The new gaging and refinements to the District's salinity model will allow for much better assessment of the relative role of flows from Myakkahatchee Creek on salinity in the Lower Myakka River. As part of the determination of minimum flows for the Myakkahatchee Creek, the total quantity of water that can be removed from the creek in addition to withdrawals from the main stem of the river including the excess flows, can be better determined. In the mean time, the actual withdrawals from the Creek by the City of North Port have been very small, and it not expected that this water use will have any adverse impacts on the creek or river until the minimum flows for the creek are adopted.

8.9.4. Measure flows from Deer Prairie Slough and Warm Mineral Springs

The freshwater flow budget to the Lower Myakka River would also be improved by reinstating the former USGS gaging station at Deer Prairie Slough at Power Line near North Port. This gage measured flow from 83 km^2 of drainage area that flows directly to the lower river near river kilometer 19. At a minimum, periodic flow measurements should also be instituted from Warm Mineral Springs. The springs contribute dry season flow to the river below kilometer 17, which has not been well documented in the past.

8.9.5 Develop an adaptive management strategy for the removal of excess flows and compliance with minimum flows for the Lower Myakka River

The implementation of minimum flows for the Lower Myakka River will require the implementation of new water management strategies and regulatory methods by the District. For example, adopted minimum flows that are currently used to regulate water use on the Lower Peace and Lower Alafia rivers establish allowable withdrawal rates as percentages of the preceding day flow at one or more USGS gages. In contrast, allowable minimum flow withdrawals on the Lower Myakka River will be largely based on estimates of excess flows that the river receives. The estimates, based on monitoring and modeling, should be updated periodically to consider changes in land use and current rainfall patterns.

The hydrologic restoration strategies for the upper river sub-basin and the minimum flows for the lower river are both based on estimates of excess flows the river received for 1994-2006 and 1995-2004 time periods that were generated by a MIKE SHE integrated model of the upper river sub-basin. Using these model predictions, the effects of removal of excess flows from the river were simulated and assessed. However, the implementation of restoration plans for the upper-river sub-basin and minimum flows for the lower river in the future will have to be done on real time basis and will not rely on precise modeled values. The quantities of water than can be withdrawn or retained in the upper river sub-basin will be based on operations plans for the various facilities in order to capture what are expected to be the excess flows. The quantities of excess flow that can be diverted or retained will vary on a daily basis, depending on changes in rainfall and streamflow in the river and its tributaries.

A series of management alternatives are already being considered to remove water from the upper river sub-basin (Interflow 2009c, 2010a, 2010b), and it is likely that other management alternatives may be considered in the future. If the effects of these facilities on the Myakka River are to be managed, it will be necessary to monitor the quantities of excess flows that are removed from the river and its tributaries. These records can then be compared to flows at stream gaging sites in the basin to assess proportion of river flow is being diverted or retained. The combination of these diversion and streamflow records can in turn be used to determine how much additional water can be withdrawn at other locations in the watershed and still be in compliance with the minimum flows for the lower river.

The alternatives that have been evaluated by the District to date have not been designed to remove all the excess flow from the upper river sub-basin. During some months, the estimated excess flows that the river receives are considerable, with the adjusted average monthly values that were used in this minimum flows report ranging between 75 and 100 cfs for the months July through September (Table 8-4). However, current analyses indicate there may be times during low flows when the removal of excess flows in the upper reaches of the upper river sub-basin will equal, or possibly for short periods of time, appear to exceed the excess flows in the Myakka River at Sarasota that were considered in the minimum flows analysis presented in this report (Figure 8-19). The degree that restoration plans for the upper river sub-basin comply with the guidelines of the lower river minimum flows will require hydrologic monitoring of both diversions and streamflow. The degree of compliance should also take into account the spatial variations of excess flows within the upper river sub-basin, and any timing differences associated with the storage and routing of flow pulses through the upper river system.

It is difficult at this time to establish the exact method by which withdrawals of estimated excess flows from the upper river sub-basin will be checked against the minimum flow requirements of the lower river. The quantities of excess flows in the future will vary with hydrologic conditions. It is also expected that the excess flow estimates will be revisited in the future to account for changes in land and water use in the upper river sub-basin. The facilities and operations plans to divert excess flows will therefore rely on real time data to capture what are expected to be the excess flows for varying rainfall and streamflow conditions for a given set of watershed characteristics.

Although the future excess flows in the river cannot be predicted at this time, minimum flows for the Lower Myakka River can be adopted using the adjusted excess flow values presented in this report. However, given the uncertainty of the future management plans for the river, the simultaneous application of restoration strategies for the upper river sub-basin and compliance with minimum flows for the lower river should be viewed in terms of adaptive management, in which the findings of ongoing management methods are used to develop improved management techniques as experience is gained through time. Using the findings of this minimum flow study as a benchmark in such an adaptive management approach, the removal of excess flows from the river can be managed to comply with the minimum flows for the lower river.

8.9.6 Management options to maintain low flows to the lower river

As previously described, the removal of excess flows will benefit the restoration of Flatford Swamp, but will cause changes in the low flow characteristics of the Lower Myakka River that will likely result in shifts in some ecological communities and reductions in the abundance of some key fish and invertebrates species in the lower river. While the proposed minimum flows for the river are acceptable because the flows of the river have been augmented, future management options could be pursued to partially replace the lost excess flows to the lower river during periods of low flow (< 20 cfs). The purpose of these options would be to partially reduce the ecological changes in the lower river will experience as a result of removing the excess flows. It is expected these changes will be most pronounced in the spring dry season, which is a time of high fish nursery use and increasing biological productivity in the lower river. The purpose of such management options would be to partially maintain the ecological structure and productivity the lower river estuary now has during times of low flow.

Options that could be possibly be pursued to partially offset the loss of low flow include diverting and storing wet season flows from Cowpen Slough or the Blackburn Canal and releasing them to the Lower Myakka River in the dry season. Another option could be restoration of Tatum Sawgrass marsh, which lies above the Myakka River near Sarasota gage. Some preliminary management alternatives for Tatum Sawgrass marsh to reduce peak flows have been evaluated (Interflow 2009e). Alternatives for Tatum Sawgrass could be further examined to store some water which could be released to the river in the dry season. Of particular importance would be providing some baseflow to the lower river in the spring.

While these management options are not recommended for adoption as part of the minimum flow rule, they could be considered as part of an adaptive management strategy for the Lower Myakka River. The development of such a strategy, including the monitoring and coordination of restoration plans for the upper river and compliance with lower river minimum flows, could be a District project that periodically reviews the status of freshwater flows to the lower river. Plans to reduce the excess flows in the upper river sub-basin will be implemented in incremental steps, and it is unlikely that all the excess flows to the lower river will be removed in near term. Similarly, the recommended establishment of minimum flows for Myakkahatchee Creek will involve some reanalysis of relationships of flow with salinity and other variables in the Lower Myakka River using expanded stream gaging data for the river. During this period, the cost, practicality, and hydrologic effect of various management options to maintain low flows to the lower river could be investigated. However, the removal of the excess flows and compliance with the minimum flow rule would not be contingent upon such management plans.

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