Southwest Florida Water Management District

The Determination of Minimum Flows for the Lower Alafia River Estuary

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AMO	Atlantic Multidecadal Oscillation
cdf	cumulative distribution function
cfs	cubic feet per second
CPUE	Catch-per-unit-effort
District	Southwest Florida Water Management District
DO	Dissolved Oxygen
EPCHC	Environmental Protection Agency of Hillsborough County
ERT	Estuarine Residence Time
F.S.	Florida Statutes
FFWCC	Florida Fish and Wildlife Conservation Commission
FWRI	Florida Fish and Wildlife Reseach Institute
HBMP	Hydrobiological Monitoring Program
HSPF	Hydrologic Simulaion Program for FORTRAN
JEI	Janicki Environmental Inc.
km	kilometer
Km_U	Center of catch-per-unit-effort
LAMFE	Laterally Averaged Model for Estuaries
m	meter(s)
MFLs	Minimum Flows and Levels
mgd	milllion gallons per day
NOAA	National Oceanic and Atmospheric Administration
PCA	Principal Components Analysis
PRT	Pulse Residence Time
psu	practical salinity units
SWFWMD	Southwest Florida Water Management District
USF	University of South Florida
USGS	United States Geological Survey
WCRWSA	West Coast Regional Water supply Authority

EXECUTIVE SUMMARY

The Determination of Minimum Flows for the Lower Alafia River Estuary

The Southwest Florida Water Management District is directed by the Florida Legislature to establish minimum flows and levels for streams and rivers within its jurisdiction. Minimum flows are defined in Florida Statures (373.042) as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area". Minimum flows are based on technical evaluations that use the best available information to determine the amount of water that can be withdrawn from a stream or watercourse without causing unacceptable ecological impacts. Minimum flows play a critical role in the water use regulation and resource planning programs of the Southwest Florida Water Management District.

Minimum flows were determined for the Lower Alafia River, which extends 11.3 miles (18.2 kilometers) from the river mouth on Tampa Bay upstream to Bell Shoals Road. The lower river is a brackish estuarine system over most of its length. The determination of minimum flows for the lower river, therefore, involved evaluating the effects of freshwater inflow on the water quality and estuarine resources of the river, including its plankton, fish, macroinvertebrate, and tidal wetland communities. Many studies have shown that adverse impacts and losses of biological productivity can result from excessive reductions of freshwater inflow to estuaries.

The District used the percent-of-flow method for determining minimum flows for the Lower Alafia River. The percent-of-flow method determines what percentage of the daily flow of a river can be removed without causing significant harm to the river's ecology or biological productivity. The method is designed to protect the natural flow regime of a river to which the ecosystem has become adapted. The allowable withdrawal percentage can vary between seasons or ranges of flows, or be combined with a low-flow threshold, below which no withdrawals may occur. Based on trend analyses of long-term flow records for the Alafia River, it was concluded that the period from 1987 to 2003 represented a suitable baseline for evaluating the effects of a series of potential flow reductions in order to determine minimum flows for the Lower Alafia River.

The proposed minimum flows for the Lower Alafia River are a nineteen percent (19%) reduction of daily flows to the upper estuary, assuming an unlimited maximum diversion capacity for withdrawals from the river. Flows to the upper estuary are calculated as the sum of the daily flows at Bell Shoals Road and Buckhorn Springs. A low-flow threshold of 120 cfs, which requires that cumulative withdrawals not be allowed to reduce flows below that rate of flow, is also part of the proposed rule. The 120 cfs low-flow threshold will be in effect about 18% of the time on average during the year, with more frequent application in the spring dry season. This low-flow threshold is very similar to a low-flow threshold of 124 cfs that is currently applied in the water use permit issued to Tampa Bay Water, though they are calculated slightly differently. The other water user on the river, Mosaic Fertilizer Inc., currently makes withdrawals from Lithia or Buckhorn Springs without the restrictions of a low-flow threshold. Adoption of the minimum flow with the low-flow threshold will require that Mosaic Fertilizer will have to cease withdrawals, provide replacement flows, or otherwise offset impacts to the lower river when flows are below 120 cfs.

The recommended minimum flows and low-flow threshold were based on analyses of extensive hydrobiological data that were collected in the Lower Alafia River. Many of these analyses show that the water quality and biological resources of the lower river are particularly sensitive to the effects of flow reductions during periods of low flow. The Lower Alafia River is highly nutrient enriched and has associated problems with large phytoplankton blooms. Hydrodynamic residence time simulations and other analyses indicate these problems are most pronounced at low flows, when flow reductions could act to exacerbate these conditions. The comb-jelly, *Mnemiopsis mccradyi*, is also most abundant in the river during low flows. *Mnemiopsis* is a predator of zooplankton and larval fish, and flow reductions during low flows could act to increase the abundance of this non-desirable species.

The abundance of different life stages and size classes of a number of desirable fish and invertebrate species in the river were positively correlated with freshwater inflow. Regression models were used to predict changes in abundance of these species that would occur for a series of potential flow reductions. These analyses indicated that recommended 19% minimum flow, combined with the 120 cfs low-flow threshold, would not reduce the median abundance of juvenile red drum by more than fifteen percent. Red drum are a highly valued gamefish on the Florida gulf coast, and this change was considered the threshold for determining significant harm. Predicted changes in abundance were also calculated for other fish and invertebrate species to ensure that unacceptable reductions in their abundance would not occur.

The District also evaluated the effects of the same potential flow reductions on other resource characteristics of the river. Hydrodynamic modeling was conducted to quantify changes in the bottom areas of salinity zones that are important to the distribution of benthic macroinvertebrate communities. Regression models were used to simulate shifts in the locations of surface isohalines and compare these shifts to the amount of total and wetland shorelines along the river. Regression models were also used to predict shifts in the geographic centers of abundance for key fish and invertebrate species, which were compared to corresponding changes in the area and volume of available habitat. These combined results indicated that the minimum flows that were based on the abundance of key fish and invertebrate species would also prevent significant harm to these other valued resource characteristics.

Logistic regression analyses were performed to predict the increased probability of low dissolved oxygen and high chlorophyll *a* concentrations that could result from flow reductions. These analyses also indicated that the recommended minimum flows would not result in significant harm to the lower river, due to the very small changes that would occur in the probability of these occurrences.

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 boundaries. The purpose of minimum flows and levels (MFLs) is to create hydrologic and ecological standards against which permitting or planning decisions can be made concerning withdrawals from either surface or ground waters.

The Alafia River is one of the four major rivers that drain to Tampa Bay and is a highly valued natural resource in the region. The river is approximately fifty miles long and has both freshwater and estuarine reaches. Minimum flows and levels have been adopted for the freshwater portion of the Alafia River (SWFWMD 2005b). Minimum flows for the Lower Alafia River, or the tidal portion of the river that lies below Bell Shoals Road, are proposed in this report. In determining these minimum flows, the District evaluated to what extent flows from the river and contributing springs can be reduced without causing significant harm to the downstream ecosystem. The determination of minimum flows for the Lower Alafia 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 Alafia 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 Alafia 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 estuarine Lower Alafia River involved only a flow component, and the term minimum flows is used in this report with specific reference to Lower Alafia.

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."

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 these reasons, it is District practice for the technical report upon which a proposed minimum flow is based to be reviewed through an independent scientific peer review process. This process commences upon the publication a draft technical report by District staff that provides the technical justification for the proposed MFLs. Pending the findings of this peer review, the Governing Board may choose to adopt the proposed minimum flows or pursue further analyses and possible revision of the proposed minimum flows. The report of the scientific review panel is included as Appendix 1A. Responses by the District to questions raised by the panel are included as Appendix 1B.

1.3 General Technical Approach for Determining Minimum Flows for the Lower Alafia 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 2002, SWFWMD 2005a, SWFWMD 2005b). As described in the MFL report for the freshwater reach of the Alafia River, 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. If necessary, these percentages can vary by season or flow ranges to reflect changes in the sensitivity of the stream to flow reductions. MFLs determined for the freshwater reaches of the Middle Peace, Myakka, Alafia and Upper Hillsborough River that used the percent-of-flow method have all received independent scientific peer review, which generally supported this technical approach. MFL rules for three of these rivers (Alafia, Myakka, Middle Peace) have been adopted by the District Governing Board, while proposed rules for the Upper Hillsborough River are awaiting Board action.

In coastal areas such as Florida the management of streamflow must also take into account the health of the downstream estuaries, which are tidal brackish ecosystems that support abundant fish and wildlife resources. 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 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, including the Alafia. In keeping with these regulatory precedents and the approach used to determine minimum flows for freshwater streams, the percent-of-flow method was used to determine minimum flows for the Lower Alafia River based on the freshwater flow requirements of the natural resources associated with the tidal estuarine portion of the river downstream of Bell Shoals Road.

The steps that are critical to the determination of minimum flows are described in the following chapters of this report. Long-term climatic and streamflow records were examined to determine if the flow regime of the river has been significantly affected by human activities. Based on this assessment, a baseline period was selected for analysis in order to evaluate the effect of range of potential withdrawals on the ecology of the lower river. Biological resources of concern in the lower river were identified and analytical methods were developed to evaluate how these resources would change if freshwater inflows are reduced. Modeling scenarios that correspond to a range of percentage flow reductions were performed to determine the maximum rate of withdrawal that would not cause significant harm to the resources of concern. The amount of change that constitutes significant harm is defined in the report, though the final determination of significant harm and the adoption of the final minimum flow rule rests with the Governing Board of the Southwest Florida Water Management District, who may choose to adopt the minimum flows proposed in the report or request further analyses and revisions.

1.4 Application of the Minimum Flow Rules

After adoption, minimum flows for the Lower Alafia River and the freshwater reaches of the Alafia River will be used in combination so that water users will not be allowed to cause significant harm to either the freshwater or estuarine resources of the river. The Alafia River is presently used as a potable water supply source by Tampa Bay Water, a Regional Water Supply Authority. Mosaic Fertilizer, Inc. also makes withdrawals for industrial water supplies from Lithia and Buckhorn Springs, which contribute flow to the Alafia. These existing water users are not grandfathered, as the assessment of baseline conditions assumed no surface withdrawals from the river. If either of these permitted uses are in violation of the minimum rules to be adopted, a recovery plan must be adopted which will bring the permits into compliance with the minimum flow rules over a specified time frame. New requests to withdraw water from the river must comply with the minimum flow rules.

1.5 Content of Remaining Chapters

The organization of the following chapters is as follows. Chapter Two describes the physical and hydrologic characteristics of the Lower Alafia River watershed; assesses historical changes in flows; and recommends a baseline period for the minimum flows analyses. Chapter Three describes the physical characteristics of the Lower Alafia River estuary, while Chapter Four describes the relationships of tides and freshwater inflow to water levels and residence times in the lower river. Chapter Five describes how salinity and water quality in the lower river are related to freshwater inflow, 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 percentage flow reductions and presents the proposed minimum flows for the Lower Alafia River. The report concludes with the Literature Cited. Appendices 1A and 1B are included with this minimum flows report, while the remaining appendices are bound separately and provided electronically as a separate pdf file.

Chapter 2

Physical and Hydrologic Characteristics Of The Lower Alafia River Watershed

2.1 Major Physical Features

The following chapter presents an overview of the physical and hydrologic characteristics of the Alafia River watershed with emphasis on those features that are closely related to flows to the Lower Alafia River, or the tidal portion of the river that extends below Bell Shoals Road. A more extensive description of the physiography, hydrogeology, land use, streamflow and water quality characteristics of the entire river watershed is presented in the District's minimum flows report for the freshwater segment of the Alafia River (SWFWMD 2005b). That report can be consulted for additional information on topics such as surface-water/ground-water relationships and historical land use changes in the Alafia River watershed.

The Alafia River is a tributary to Tampa Bay on the gulf coast of west-central Florida (Figure 2-1). The river's watershed is located predominantly in Hillsborough County, with headwater regions extending into Polk County. With a watershed area of 422 square miles the Alafia represents the second largest river watershed that contributes flow to Tampa Bay, comprising about 19 percent of the total watershed area of the bay.

The river generally flows in a westerly direction, originating from eastern headwater creeks that form the north and south prongs of the river (Figure 2-2). These two prongs join near Alderman's Ford to form the main stem of the river. The most downstream streamflow gaging station on the river is the Alafia River at Lithia, located 16 miles (26 kilometers) upstream of the river mouth. About two miles (3.2 km) downstream of this gage the river receives groundwater discharge from Lithia Springs, a second magnitude spring that flows into the river along its south bank via a short spring run.

Approximately three miles (4.8 km) downstream of Lithia Springs the river passes under Bell Shoals Road, where large limestone shoals extend up from the riverbed. The elevation of the thalweg of the riverbed is near the mean high tide level between Bell Shoals and Lithia Springs, but the shoals in the river reduce tidal water level fluctuations upstream of Bell Shoals Road. As described further in the next chapter, tidal water level fluctuations increase rapidly below Bell Shoals and brackish water can penetrate to within a mile of Bell Shoals during droughts. Because of this tidal brackish influence, the portion of the Alafia River below Bell Shoals Road is designated as the Lower Alafia River for this minimum flows assessment.

Figure 2-1. Location of the Alafia River Basin in the Tampa Bay Watershed.

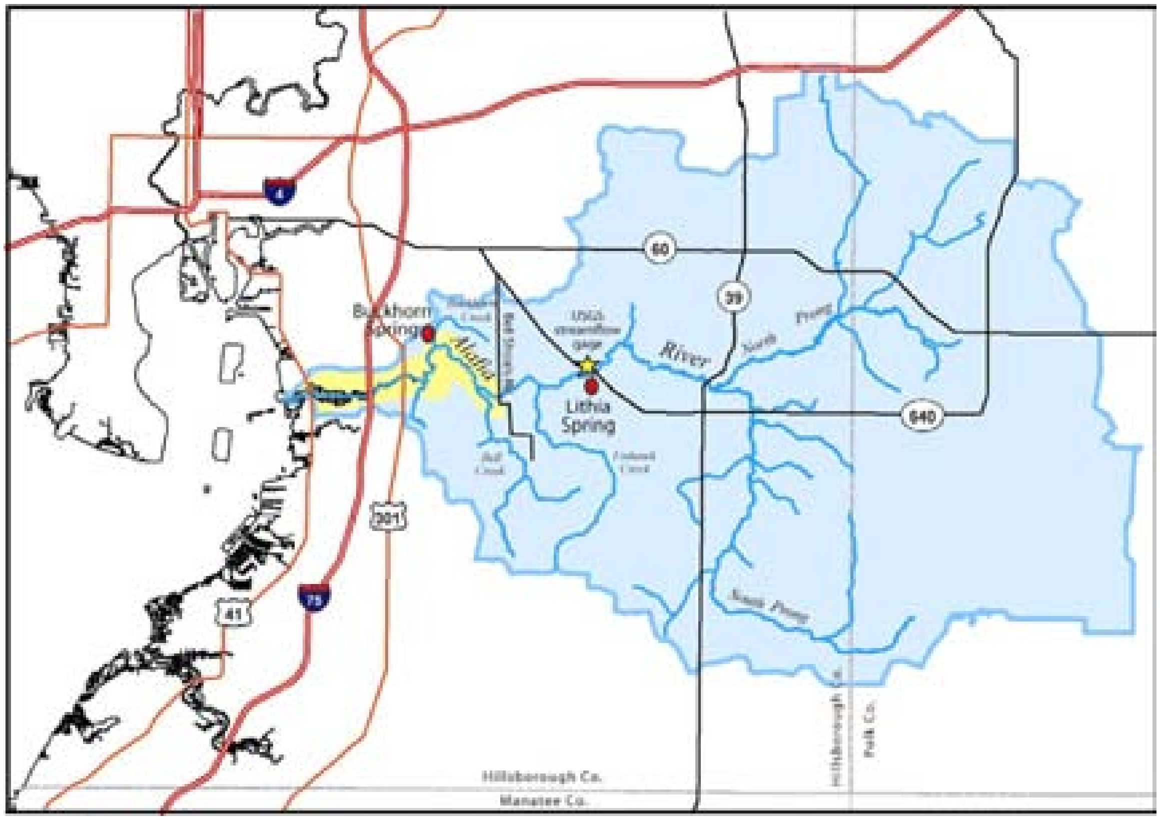


Figure 2-2. Alafia River watershed with the Lower Alafia River highlighted in yellow. Also shown are the locations of major tributaries, Lithia and Buckhorn Springs, and the USGS long-term streamflow gaging station on the Alafia River at Lithia.

Downstream of Bell Shoals the river watershed narrows dramatically (Figure 2-2). Land use in this portion of the watershed becomes increasingly urbanized, with the unincorporated towns of Gibsonton and Riverview lying along the river shore (Figure 2-3). Stormwater runoff from these urban areas contribute flow to the lower river, along with flow from three creeks that enter the river below the USGS streamflow gage (Buckhorn, Bell, and Fishhawk Creeks). Baseflow in Buckhorn Creek is supplemented by groundwater discharge from Buckhorn Springs. Although smaller than Lithia Springs, Buckhorn Spring provides significant flow to the lower river in the dry season. Greater detail regarding quantities of flow the lower river receives from these various sources are presented in a following section.

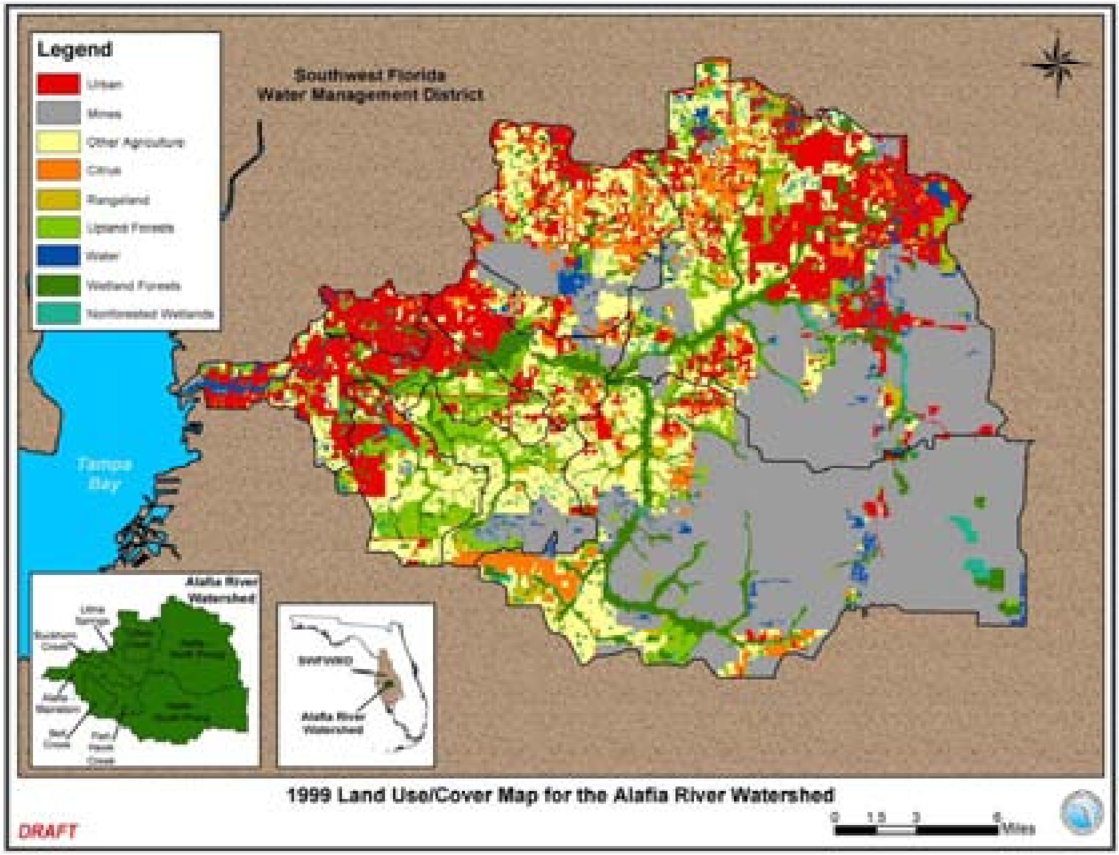


Figure 2-3. Land use/cover map of the Alafia River watershed for 1999.

2.2 Climate

The climate of the Tampa Bay region is described as subtropical marine. The mean annual air temperature is near 72.5^{o}F (22.5^{o}C), with average daily temperatures ranging from near 62^{o} F (16.7^{o}C) in January to near 82^{o}F (27.8^{o}C) degrees in the August (Wolfe and Drew 1990). The average yearly rainfall for a number of stations in the region is about 52 to 53 inches, with an average yearly total value of 52.3 inches reported for the Alafia River watershed (SWFWMD 2001b).

Rainfall is highly seasonal with a pronounced four-month summer wet season between June and September, when on average about 60 percent of the total yearly rainfall occurs (Figure 2-4). Low rainfall typically occurs in the late fall/early winter (November/December) and the spring (April/May). Evapotranspiration rates in the region average approximately 39 inches per year (SWFWMD 2001b). Potential evapotranspiration rates increase dramatically in the spring (Bidlake and Boetcher 1997, Lee and Swancar 1997), which often results in very low surface water levels and low rates of streamflow in the spring dry season.

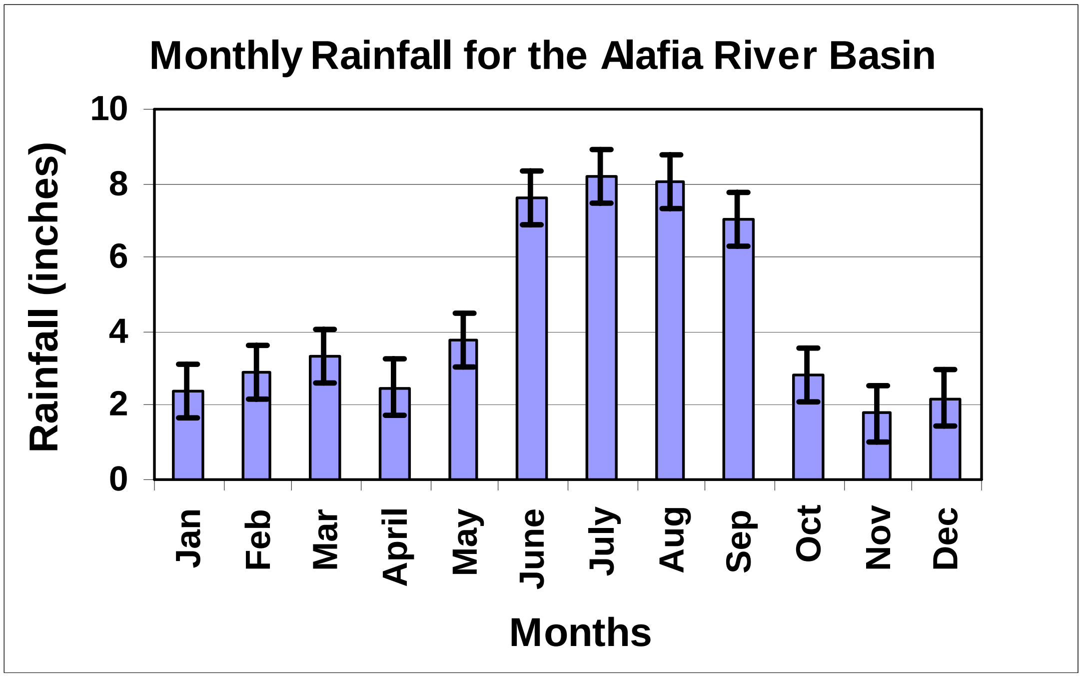


Figure 2-4. Mean monthly rainfall totals for the Alafia River basin with standard errors about the monthly means (source: SWFWMD Comprehensive Watershed Management Data Base).

2.3 Freshwater Inflow to the Lower River

Of particular importance for the establishment of minimum flows for both freshwater streams and estuarine systems is quantifying the timing and volume of streamflow. Streamflow and other freshwater inputs (e.g., overland sheetflow) to estuarine systems are referred to as freshwater inflow. The sources, timing, and volume of freshwater inflow to the Lower Alafia River are characterized in the following section, including the effects of currently permitted surface water withdrawals on inflows to the lower river. Trend analyses are performed to assess any historical changes in various aspects of the Alafia River's flow regime. Lastly, a combination of factors are evaluated to determine a suitable baseline period on which to simulate the effects of potential future withdrawals for the minimum flows analysis of the lower river.

Freshwater inflow to the Lower Alafia River is comprised of three main components: streamflow measured at the long-term USGS streamflow gage on the river; estimated flows from ungaged areas downstream of the USGS gage; and measured springflow from Lithia and Buckhorn Springs. Flow measurements and estimated flows from these three sources can be combined to characterize the timing and volume of total freshwater inflow to the Lower Alafia River. Although the lower river also receives direct rainfall to its water surface, this freshwater input is very small in relation to freshwater inflow from the sources listed above and inputs of rainfall directly to the lower river are not quantified in this report.

As described in Chapter 1, data for all sources of freshwater inflow to the lower river and physicochemical and biological variables within the estuary were compiled for periods that end in 2003. For that reason, most of the analyses presented in this report end with calendar year 2003. In some cases, however, hydrologic data have been updated for more recent years in order to demonstrate long-term trends in streamflow or water use from the Alafia River.

2.3.1 Long-term Streamflow Records at the Alafia River at Lithia Gage

The most useful data for characterizing inflow to the lower river are daily streamflow values reported for the long-term USGS streamflow gage on the main stem of the river which is called the Alafia River at Lithia, FL (#01201500). Daily streamflow records at this site began in October 1932, with continuous daily records extending to the present. This gage measures flow from approximately 335 square miles, or 79 percent of the entire Alafia River watershed. Assuming that rates of flow from the ungaged downstream areas vary in synchrony with this gage in response to temporal changes in regional rainfall, this gage provides a useful measure of seasonal and long-term patterns of freshwater inflow to the Lower Alafia River.

The long-term average flow for the Alafia River at Lithia for the complete years between 1933 and 2004 is 340 cfs. This average streamflow rate is equal to an areal runoff rate of 1.0 cfs per square mile, or 13.8 inches of runoff distributed over the drainage basin. A flow duration curve for this station is presented in Figure 2-5 with selected percentile values also listed in Table 2-1. The median flow for the river is 175 cfs, which is 51 percent of the mean value, reflecting that the mean is heavily influenced by large flow events in the wet season. For approximately three-fourths of the year the river flows below its mean value. Five percent of the time the gaged river flow has been below 36 cfs, with a minimum value of 4.1 cfs recorded in early June of the year 2000 drought. Ten percent of the time the river flow has been above 731 cfs, with a maximum flow rate of 40,800 cfs recorded in September of 1933. This maximum rate was very unusual, as the next highest period of high flows occurred in September of 1960, when flows ranged as high as 16,500 cfs.

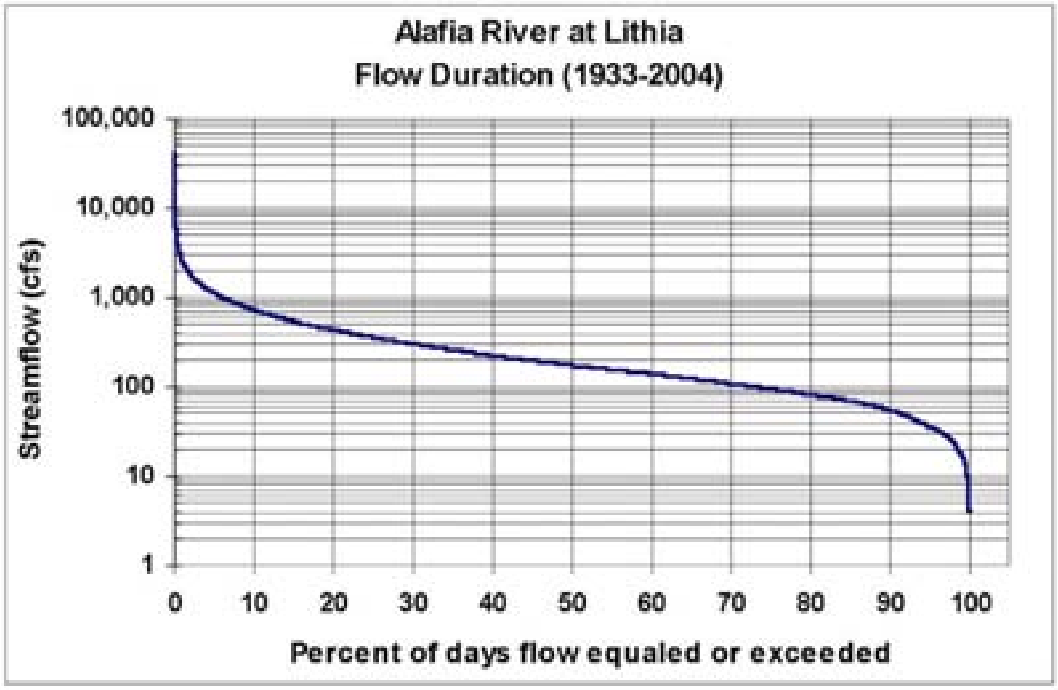


Figure 2-5. Flow duration curve for the USGS streamflow gage Alafia River at Lithia (# 01201500) for the period 1933-2004.

Table 2-1. Selected percentiles values for average daily flows for the Alafia River at Lithia for the period 1933 – 2004.

Percentile	Minimum	10%	25%	50% (Median)	75%	90%	Maximum
Flow (cfs)	4.1	55	95	175	362	731	40,800

Like other rivers in southwest Florida, streamflow in the Alafia River is highly seasonal, characterized by a summer wet season with the highest average monthly flows occurring from July through September (Figure 2-6). On average, about 47 percent of the total yearly streamflow occurs during this three-month period. This summer high-flow period reflects a delayed response to the onset of the summer rainy season that extends from June through September (Figure 2-4). The average percentages of total yearly rainfall and streamflow that occur each month are plotted in Figure 2-7. In the early summer months of June and July, the percentages of yearly rainfall exceed the percentages of yearly streamflow, but in September and October the percentages of yearly streamflow exceed the percentages of yearly rainfall. This pattern reflects that the amount of streamflow that is generated per unit rainfall is much higher in the late summer when soils are more saturated, water tables are high, and water levels in surface features such as ponds and wetlands are relatively full. In the dry season, particularly the late spring, the generation of streamflow per unit rainfall is much less.

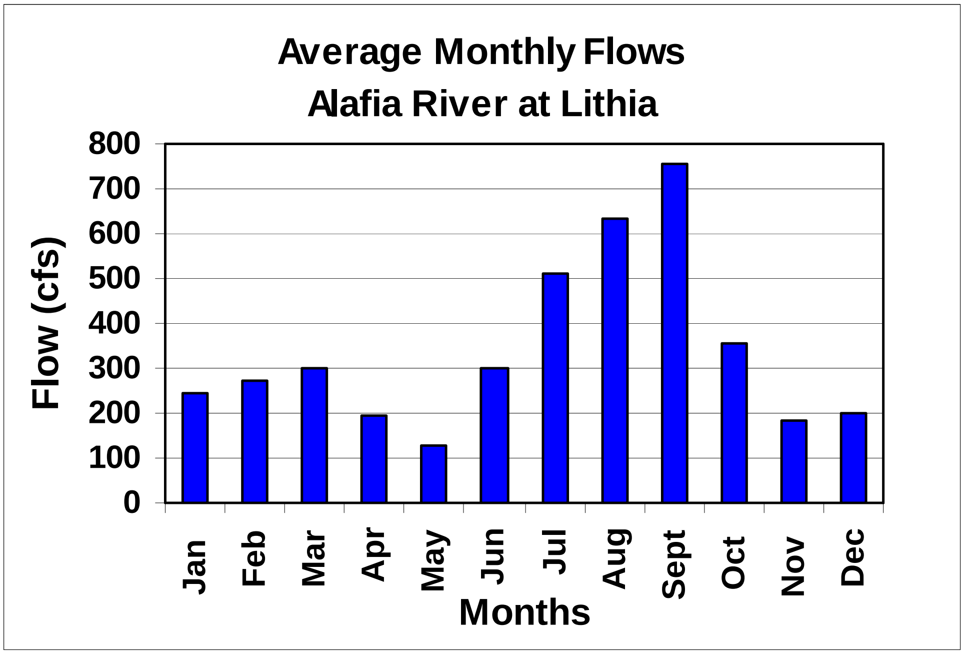


Figure 2-6. Average monthly flows for the Alafia River at Lithia for 1933 – 2004.

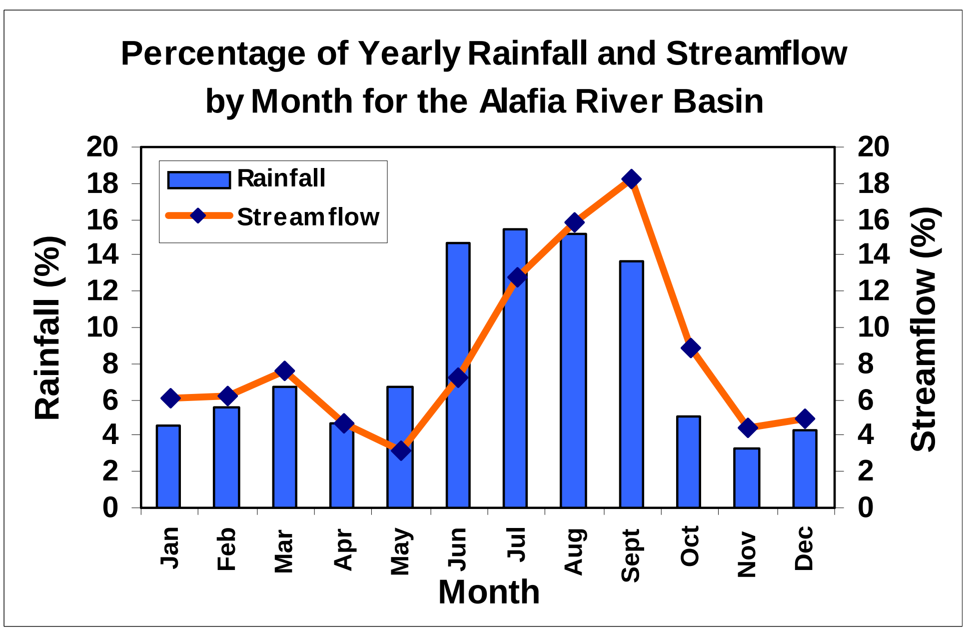


Figure 2-7. Percent of total yearly rainfall and streamflow for the Alafia River basin. Streamflow data taken from the Alafia River at Lithia gage and rainfall data from the Alafia River basin average values in the District's Water Management data base.

Low flows in the river generally occur between November through May, but can extend into early June if the onset of the summer rains is late during a given year. A minor wet period occurs in January through March, when winter cold fronts bring rains which result in pulses in streamflow in the late winter and early spring. This minor wet pulse is typically followed by low flows in the springtime, with flows generally dropping through April to the lowest values of the year in May. Although average monthly rainfall in May is higher than several months of the year, the late spring represents a period when air temperatures and potential evapotranspiration rates are increasing. Ground-water levels are also at their lowest at the end of the dry season, causing baseflow contributions to the river to be at or near their yearly minimal rates for the year during the spring.

The seasonal variability of flow in the Alafia River is shown on a daily basis in Figure 2-8, where the 10th, 50th, and 90th percentile flows are plotted for each day of the calendar year. These data, which are based on 71 years of daily streamflow record, show the typically pattern of flow variability throughout the year. The likelihood of high flow events, as evidenced by the daily 90th percentile flows, is greatest from mid-June through the end of September. The magnitude of high flow events drops dramatically during two periods - the spring and the fall.

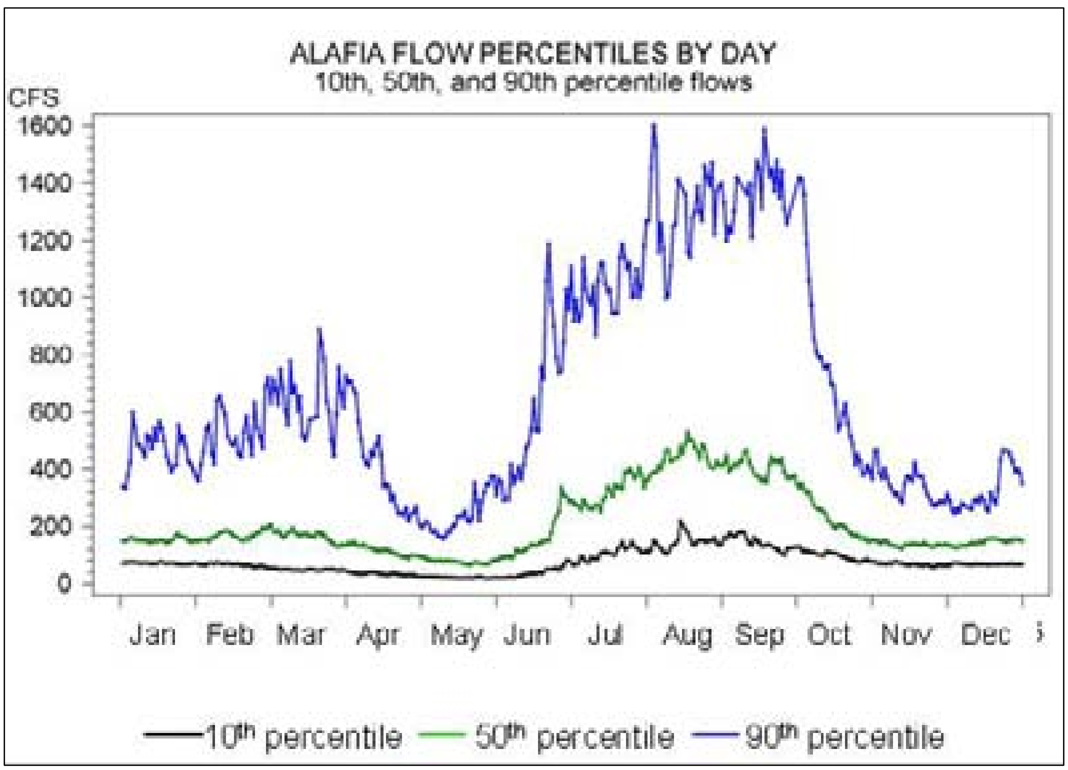


Figure 2-8. The 10th, 50th, and 90th percentile flow values for each day of the year for the Alafia River at Lithia gage.

2.3.2 Freshwater Inflows and Withdrawals from Lithia and Buckhorn Springs

The Alafia River receives flow from Lithia and Buckhorn Springs, which are artesian springs that discharge water to the river from groundwater aquifers. Both springs are located downstream of the long-term USGS gage on the river, so that their flow contributions are not reflected in that record. Lithia Springs is located about 15.5 miles (25 km) upstream of the river mouth on the south side of the river. Spring discharge largely comes from two main vents and pools, each having a short run that flows to the river. The larger vent is referred to as Lithia Springs major and the other as Lithia Springs minor (Rosenau et al. 1977). Recent data indicate the that Lithia minor discharges about 14 percent of the total flow of the springs, while Rosenau et al. (1977) indicated this percentage was about 20 percent. During times of high flows in the Alafia River, water from the river backs into the both pools at Lithia Springs, making estimates of spring discharge difficult.

Flows from Lithia and Buckhorn Springs are both affected by direct permitted withdrawals from the springs by Mosaic Fertilizer, Inc. for industrial water use at their fertilizer processing plant located near the mouth of the river. This has been a longstanding water supply use by companies who owned the plant prior to Mosaic, with withdrawal records going back to 1977. Withdrawals from Lithia springs have largely occurred on a regular daily basis, averaging 4.5 million gallons per day (equal to 6.9 cfs) in the five years between 1998-2003. Withdrawals from Buckhorn Springs are much more intermittent, as this spring is now used only as a back-up supply source when there are problems with the Lithia Springs withdrawal.

Flow records for both springs are not as extensive as those for the long-term USGS gage on the river. The USGS has periodic flow records for Lithia Springs dating back to 1934, but there are only 18 measurements between 1934 and 1966. Beginning in the late 1960s, the USGS began measurements on roughly a bi-monthly basis. Tampa Bay Water, a regional water supply authority formerly known as West Coast Regional Water Supply Authority, began measuring flow from Lithia Springs in 1984 to collect background data in support of water use permits for groundwater withdrawals in the region. Although the frequency of flow measurements has varied, a total of 1555 measurements of flow from Lithia Springs were recorded by Tampa Bay Water in the 20 years from 1984 – 2003 .

A hydrograph of flows from Lithia Springs recorded by both the USGS and Tampa Bay Water is presented in Figure 2-9. These flows are uncorrected for withdrawals from the spring by the Mosaic Fertilizer. The USGS recorded comparatively high flows from the Lithia Springs in the late 1950s and late 1960s. Flows from the spring declined during the 1970s, but have not shown evidence of any declining trend since that time, although very low flows were recorded during the extreme droughts of 2000 and 2001. Because the frequency of springflow measurements was uneven between years, average flows presented in this report were calculated by first computing yearly means for those years that had at least 4 flow measurements (which began in 1956), then taking an average of the yearly means. Using this method the average flow for Lithia Springs for the period from 1956 to 2003 was 33.5 cfs, while the mean for the 26-year period from 1978 – 2003 was 29.8 cfs, uncorrected for withdrawals. Correcting this latter value for withdrawals by Mosaic Fertilizer gives an average flow of 36.5 cfs for Lithia Springs for the 1978-2003 period.

Flow records for Buckhorn Springs are restricted to data collected by Tampa Bay Water, which began measurements in 1987 (Figure 2-10). A break in the records occurred between January 1997 and August 2000, but flow measurements on a bi-weekly basis have resumed since that time. Flows recorded since the year 2000 are roughly in the mid-range of flow records prior to that time. The average flow for Buckhorn Springs is 12.0 cfs for the period from 1987 to 2003, or 12.7 cfs corrected for withdrawals.

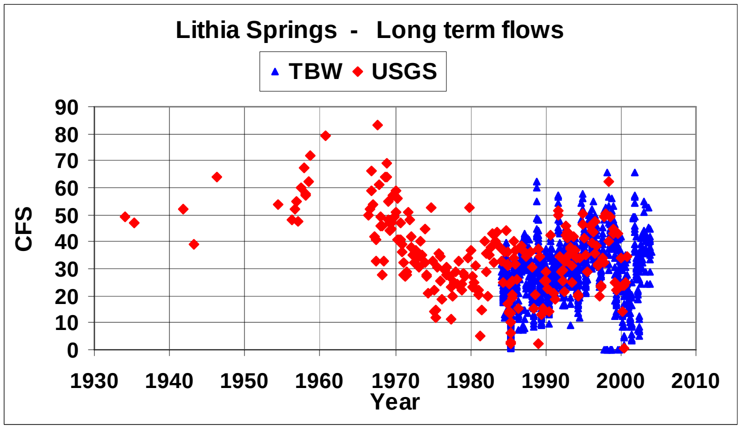


Figure 2-9. Period of record hydrograph of measured flows for Lithia Springs recorded by the USGS and Tampa Bay Water ending in 2003.

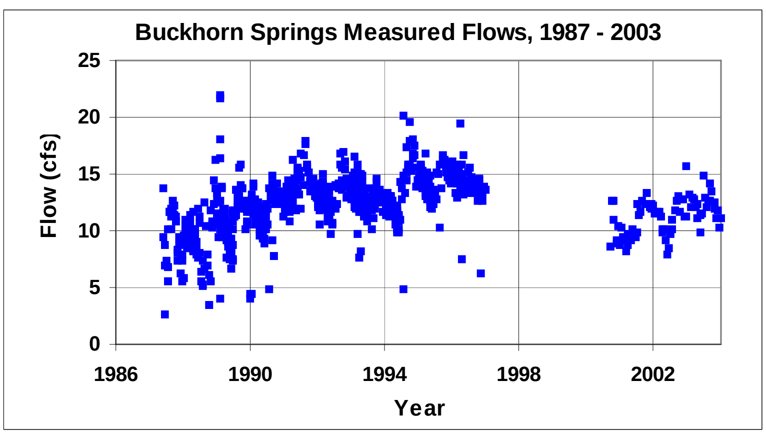


Figure 2-10. Period of record hydrograph of measured flows for Buckhorn Springs recorded by Tampa Bay Water ending in 2003.

Seasonal variations in average monthly flows from Lithia and Buckhorn Springs for the period are shown in Figures 2-11A and 2-11B. The period from 1987 – 2003 is shown in both graphs for consistency as this corresponds to the beginning of flow records for Buckhorn Springs. Included in these graphs are the average monthly quantities diverted from the spring for industrial water supply. Correcting for withdrawals, monthly flows from Lithia Springs range from a minimum value of 23.6 cfs in June to a maximum value of 49.6 cfs in October. Monthly variations in flows from Buckhorn Springs are much more subdued, ranging from a minimum of 11.8 cfs in June to 14.5 cfs in September.

On a yearly basis, withdrawals from Lithia Springs for the period 1987-2003 have averaged 6.7 cfs or 17.8 percent of the total springflow. Withdrawals from Buckhorn Spring for this same period have averaged 0.7 cfs, but have averaged only 0.1 cfs since 1994 because withdrawals from the spring have been more intermittent in recent years.

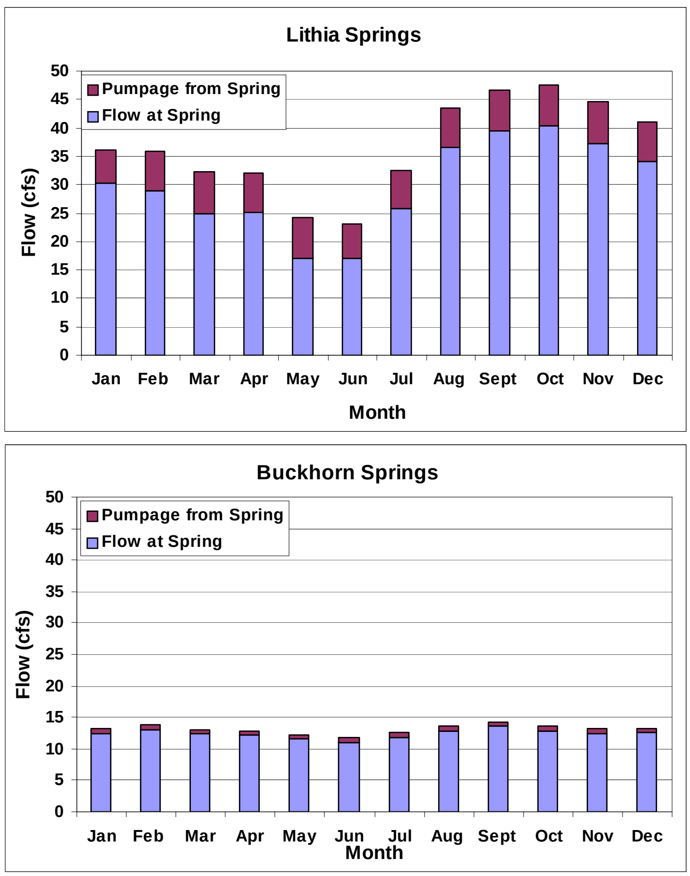
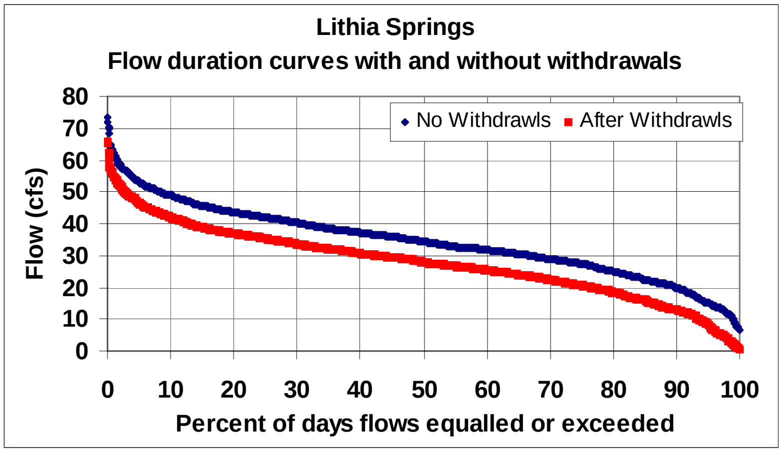


Figure 2-11. Upper Panel (A) - Average monthly withdrawals and flow after withdrawals for Lithia Springs for the period 1977 – 2003. Lower Panel (B) - Average monthly withdrawals and flow after withdrawals for Buckhorn Springs for the period 1987-2003.

Flow duration curves of flows for Lithia and Buckhorn Springs are shown in Figures 2-12A and 2-12B for total corrected flows and flow after withdrawals. The median flow for Lithia Springs is 34.4 cfs for total springflow and 27.8 cfs for flow after withdrawal. The median flow for Buckhorn Springs is 13.3 cfs for total springflow and 12.5 cfs for flow after withdrawal.



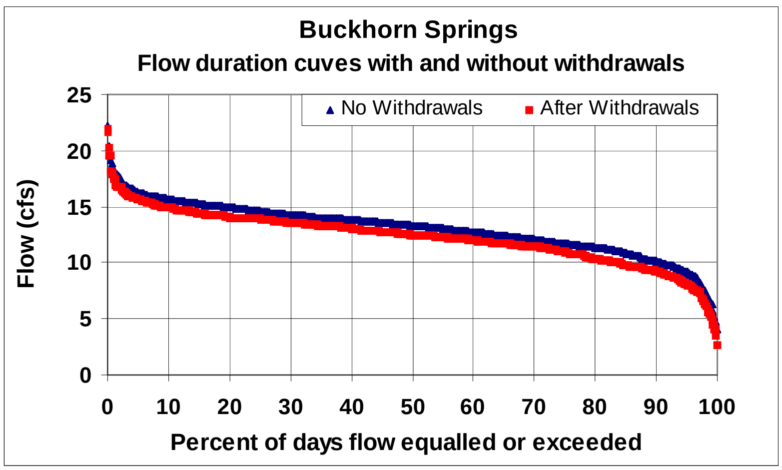


Figure 2-12. Upper Panel (A) - Flow duration curve for Lithia Springs with and without withdrawals for 1977 – 2003 based on days with measured spring flow. Lower Panel (B) - Flow duration curve for Buckhorn Springs with and without withdrawals for 1987 – 2003 based on days with measured spring flow.

Because flow daily records are not available for Lithia and Buckhorn Springs and springflow typically changes in a subdued manner with regard to changes in rainfall, linear interpolation of periodic measured records from Lithia and Buckhorn Springs were used to develop composite daily flow records that included both measured and interpolated values. Daily flow estimates for the period of missing data from Buckhorn Springs (1997-2000) were produced by a regression developed by Janicki Environmental, Inc. that predicted daily flows at Buckhorn Springs from flows measured at Lithia Springs and flows at the long-term streamflow gage on the river (Appendix 2-A). Because short-term and seasonal variations in springflow are small, the composite flow records created for the springs provide a reasonable data set of daily flows for inclusion in analyses of long-term inflows to the lower river.

During periods of low streamflow in the Alafia, combined flows from Lithia and Buckhorn Springs can comprise substantial proportions of the total measured flow to the lower river (sum of springflow and flow at the river gage). Using the composite daily flow records for the springs, a cumulative distribution function of the proportion of total measured flow represented by the springs is shown in Figure 2-13. The median value is 27 percent, meaning that for at least 50 percent of the time the springs comprise greater than 27 percent of the measured flow to the lower river. During the driest quarter of the year (75^{th} percentile), the springs comprise at least 40 percent of the measured inflow, and can comprise between 54 percent and 80 percent during the driest four percent of the year. Although these results do not include estimated runoff from the 21 percent of the watershed that is not gaged, they do indicate that management of flows from Lithia and Buckhorn Springs can be important to the overall management of freshwater inflows to the Lower Alafia River during much of the year.

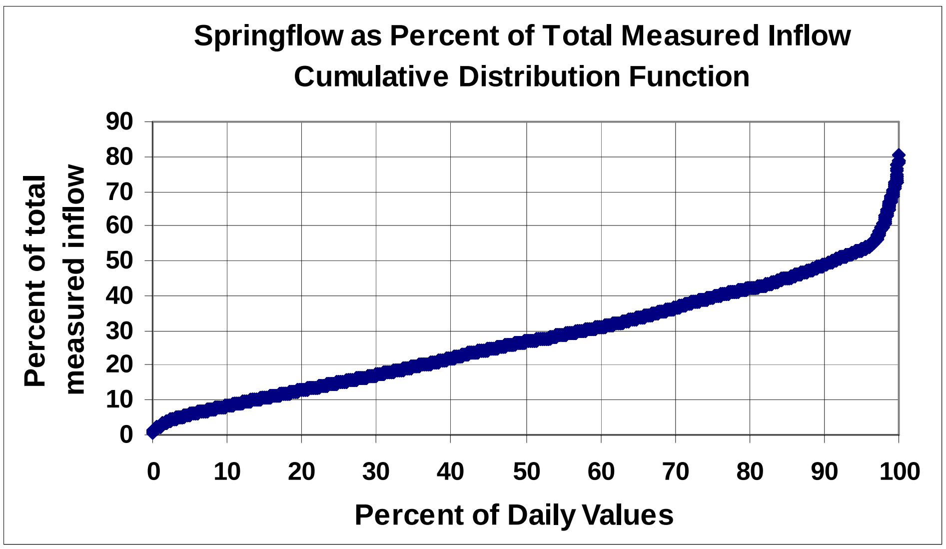


Figure 2-13. Cumulative distribution plot of the combined flow of Lithia and Buckhorn Springs as a percentage of the total measured inflow to the Upper Alafia River estuary (Alafia River at Lithia gage plus combined springflow). Values are based on daily flow records for the Alafia River at Lithia gage and recorded, interpolated, and modeled daily flow records for Lithia Springs and Buckhorn Springs for the period 1987-2003. Springflow rates are corrected for withdrawals.

2.3.3 Permitted Withdrawals from the River by Tampa Bay Water

Tampa Bay Water has been issued a Water Use Permit (WUP) by the District for potable water supply withdrawals from the Alafia River (WUP #20011794). The intake site is located approximately 65 yards upstream of Bell Shoals Road. An intake and pumping facility is located on the south bank of the river. A pipeline leads from the Alafia River pump station to a 1,000 acre offstream reservoir located approximately 5.9 miles southeast of the intake facility (Figures 2-14A and 2-14B). This offstream reservoir, called the C.W. Bill Young Reservoir, was

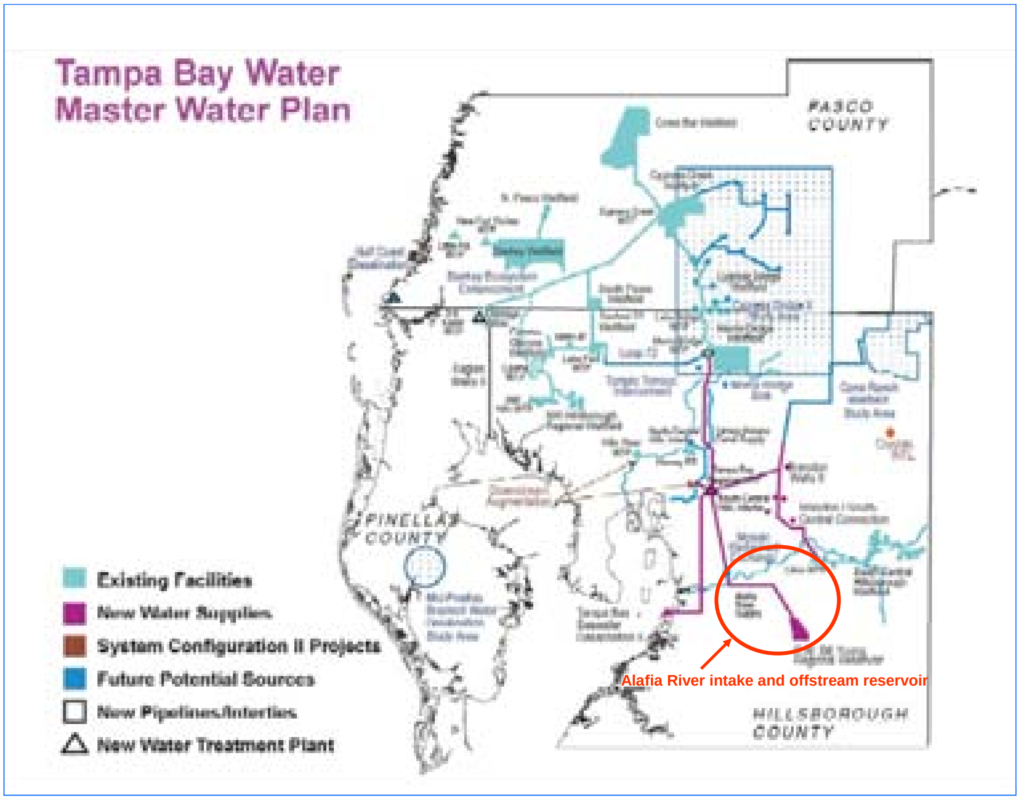


Figure 2-14. Upper Panel (A) - Location of facilities associated with the Master Water Supply Plan of Tampa Bay Water. The diversion facility at the Alafia River and the C.W. Bill Young regional reservoir are shown within the orange circle (adapted from material provided by Tampa Bay Water). Lower Panel (B) - Aerial view of the C.W. Bill Young regional water supply reservoir.

completed in 2005 and receives water from not only the Alafia River but also diversions from the Hillsborough River and the Tampa Bypass Canal, which are regulated by a separate WUP (#20011796). The reservoir is connected to regional water treatment plant near the Tampa Bypass Canal. Water diverted from the Alafia River can be sent directly to the reservoir or directly to the regional surface water treatment plant for treatment and distribution.

Withdrawals from the river by Tampa Bay Water are regulated by a withdrawal schedule contained within the WUP. Diversions are limited to 10 percent of the previous day's average flow at the Bell Shoals Road. Flow rates at the Tampa Bay Water intake at this location are estimated by multiplying the mean daily flows at the Alafia at Lithia streamflow gage by a factor of 1.117 and adding the daily flow from Lithia Springs. The flows from Lithia Springs in this formula are uncorrected for withdrawals by Mosaic Fertilizer (i.e., remaining springflow after Mosaic withdrawals). The multiplication factor applied to the gaged flow is based on a ratio of the drainage area at Bell Shoals Road to the drainage area at the USGS gage (374.2 mi^2 / 335 mi^2). This factor is applied to provide an estimate of ungaged flow between the two sites. Withdrawals from the river must cease when the estimated flows at Bell Shoals Road are below 124 cfs. Also, the maximum capacity of the intake structure is 80 cfs, equivalent to 52 million gallons per day.

As a result of this minimum flow schedule, Tampa Bay Water can take a full ten percent of flow at the Bell Shoals site when flows are between 124 and 800 cfs. Based on the period between 1987 and 2003, flows were below 124 cfs 28.2 percent of the time and above 80 cfs 8.5 percent of the time, resulting in 63.3 percent of the time when a full ten percent of flow could have been taken had the WUP been in effect. A hydrograph of daily flows in the river showing the potential effects of these two regulatory limits is shown in figure 2-15. Flow in the river fell below the 124 cfs low-flow cutoff during most years, and remained below the cutoff for prolonged periods during the 2000-2001 drought.

It is reiterated the results shown in Figure 2-15 are hypothetical, as actual withdrawals at the Alafia River facility by Tampa Bay Water began in February 2003. Before the offstream reservoir was completed in 2005, withdrawals from the river went directly to the regional water treatment plant. At present, however, withdrawals are diverted to either location. A hydrograph of monthly flows to the upper estuary with and without actual withdrawals by Tampa Bay Water for the period 2003 – 2006 is shown in Figure 2-16.

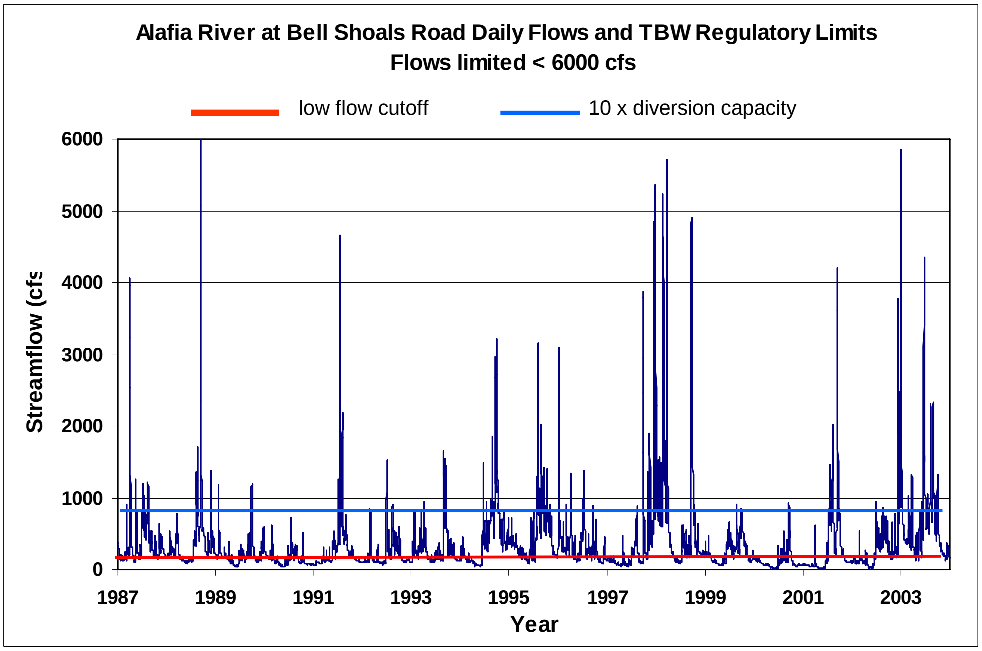


Figure 2-15. Daily flows at the Bell Shoals intake facility for 1987-2003 with reference lines for the 124 cfs low-flow cutoff and 800 cfs, which represents 10 x the diversion capacity for the intake structure. Tampa Bay Water can take a full 10% of flows at this site when the daily flows are between 124 and 800 cfs.

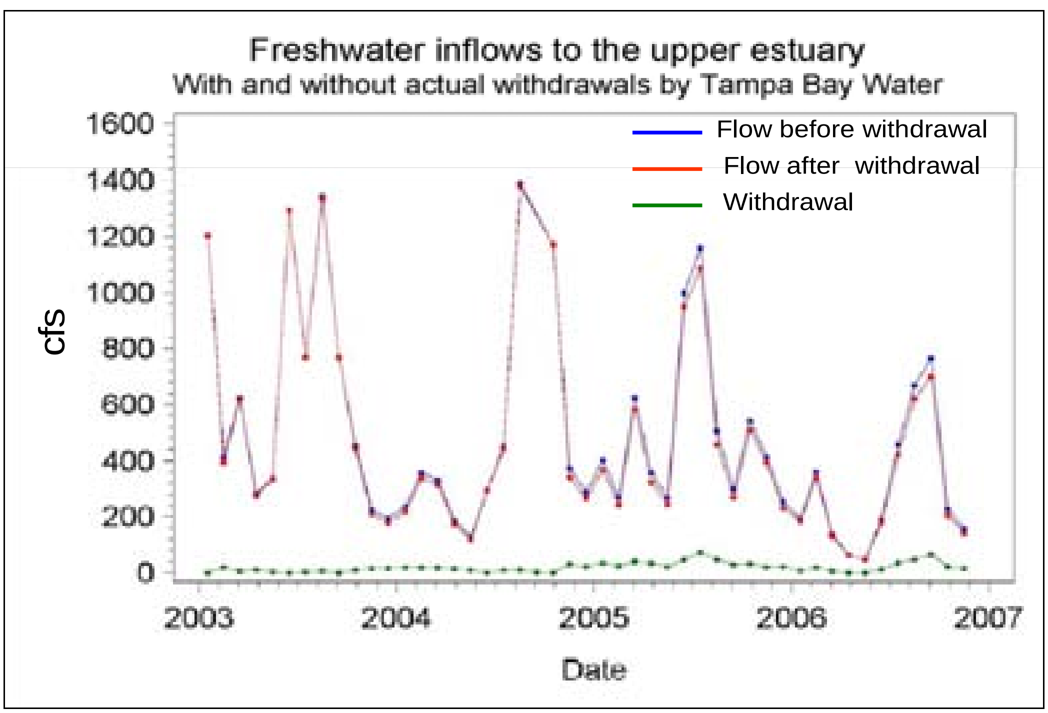


Figure 2-16. Hydrograph of monthly inflows to the upper estuary with and without actual monthly withdrawals by Tampa Bay Water for the period February 2003 through November 2006.

2.3.4 Maximum Possible Withdrawals from the River and Springs in Relation to Freshwater Inflows to the Upper Estuary

Downstream of the Tampa Bay Water intake site the only remaining measured flows to the river are from Buckhorn Springs. As discussed below, the sum of the flows at the Bell Shoals facility and Buckhorn Springs is a practical and accurate hydrologic term that is measured on a regular basis. For purposes of this report this hydrologic term is referred to as "inflows to the upper estuary." Many of the analyses in this report use this term, because uncertainties associated with ungaged runoff are avoided and the term can be update regularly with new data. This term is also useful for it includes all the water sources that are currently used for water supply (Alafia River main stem, Lithia and Buckhorn Springs).

The period from 1987 through 2003 is used for many analyses in this report, in part because 1987 is when flow records for Buckhorn Springs began. Given this consideration, a record of daily inflows to the upper estuary for 1987-2003 was constructed in order to examine the effects of existing permitted water use and potential new withdrawals on inflows to Lower Alafia River. However, flows were not recorded from Buckhorn Springs forty-five month period between 1997 to 2000. As describe earlier, regression analysis was used to estimate flows for Buckhorn Springs for this period (Appendix 2-A).

During periods when flows were recorded from Lithia and Buckhorn Springs, daily flows were estimated by interpolation from the periodic measured records. Using these combined springflow records (measured, interpolated, modeled) daily flow records for Lithia and Buckhorn Springs were computed. These flows were then added to streamflow values at Bell Shoals Road computed by the formula in the water use permit for Tampa Bay water (gageflow * 1.117) to produce a daily record of inflows to the upper estuary. In this report, comparisons of existing and potential water use from the river and both springs are compared to this daily record of flows to the upper estuary.

The combined existing permitted withdrawals from the river and the springs usually comprise a small percentage of the inflows to the upper estuary, but this percentage can go up substantially in the dry season. Average monthly values for maximum possible permitted withdrawals by both Mosaic Fertilizer and Tampa Bay Water are plotted with average monthly values for inflows to the upper estuary for the river for the period 1987-2003 (Figure 2-17). Since they are linked to the rate of river flow, maximum possible withdrawals for Tampa Bay Water are the highest in August and September, while permitted withdrawals from the springs are relatively constant year round. Combined, these withdrawals comprise the highest percentage of inflow during the dry season, averaging 12.7 percent of inflow in November, 15.0 percent of inflow in April, and 23.8 percent of inflow in May. In the summer wet season the withdrawals represent a much smaller percentage of inflow, averaging between 4.8 percent of inflow in September and 7.5 percent of inflow in July.

A hydrograph of monthly inflows to the upper estuary for 1999-2003 is presented in Figure 2-18, without any withdrawals (baseline flows) and the resulting flows if all maximum possible withdrawals were taken. This figure shows the high natural seasonal variability of flow in the Alafia River, and that the largest withdrawals occur in wet months. This is because withdrawals by the largest water user on the river, Tampa Bay Water, are based on a flow-based withdrawal schedule in which the rate of withdrawal is linked to the rate of flow

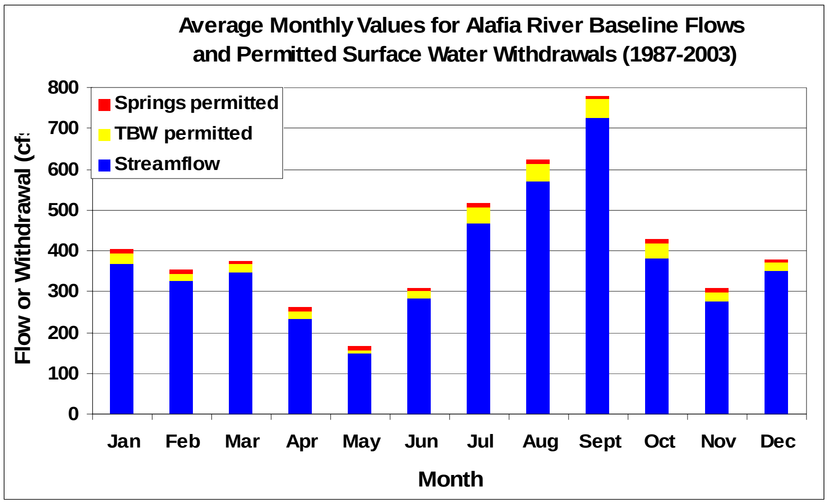


Figure 2-17. Average monthly values for baseline inflow to the upper estuary and maximum possible permitted withdrawals from the river by Tampa Bay Water and from Lithia and Buckhorn Springs by Mosaic Fertilizer for the period 1987-2003.

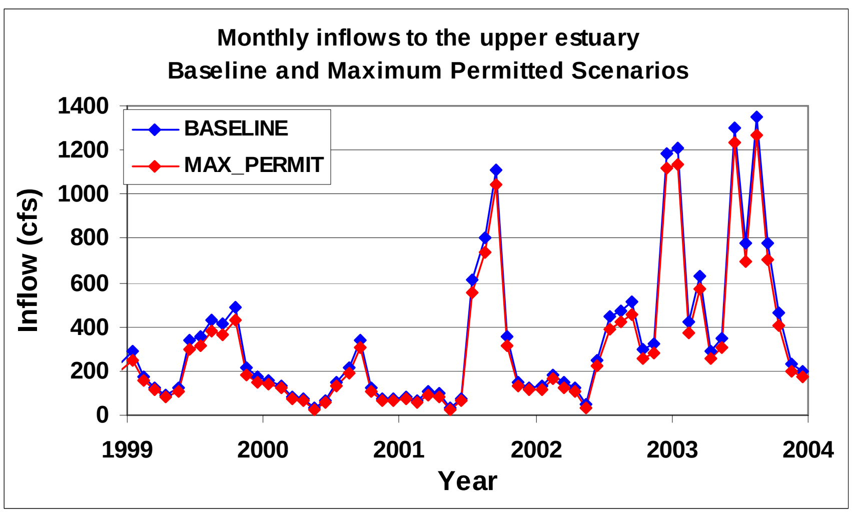


Figure 2-18. Hydrograph of monthly flows to the upper estuary for baseline flows and flows reduced by total maximum permitted withdrawals to Tampa Bay Water and Mosaic Fertilizer for the period 1999 – 2003.

It is informative to examine the potential effects of maximum possible permitted withdrawals on inflows to the river using daily flow duration statistics. Figure 2-19 shows a cumulative distribution function of the percent of inflow to the upper estuary represented by the combined maximum possible withdrawals. Ninety percent of the time these permitted withdrawals comprise less than 15 percent of the daily inflow to the upper estuary, with a median value of 12.4 percent. However, during rare, extremely dry periods, permitted withdrawals could potentially comprise between 20 and 47 percent of the inflow to the upper estuary. Since Tampa Bay Water is not allowed to withdraw water during these periods, these higher withdrawal percentages are due to the effects of Mosaic Fertilizer, whose withdrawals are not linked to the rates of river or spring flow.

Also shown in Figure 2-19 is the cumulative distribution function of percent of inflows if maximum possible pumpage from Lithia Springs is included with withdrawals by Tampa Bay Water. This is probably the most likely scenario, as pumpage from Buckhorn Springs does not now occur unless there is a problem with the Lithia springs withdrawal facility. The shape of this curve is similar, but the values are slightly lower; the median percent of inflows is 11.7 percent, while the highest percent of daily inflows is 38 percent. Again, it is reiterated these are maximum possible permitted withdrawals from the river and not historic water use, since withdrawals from the Alafia River by Tampa Bay Water began in 2003.

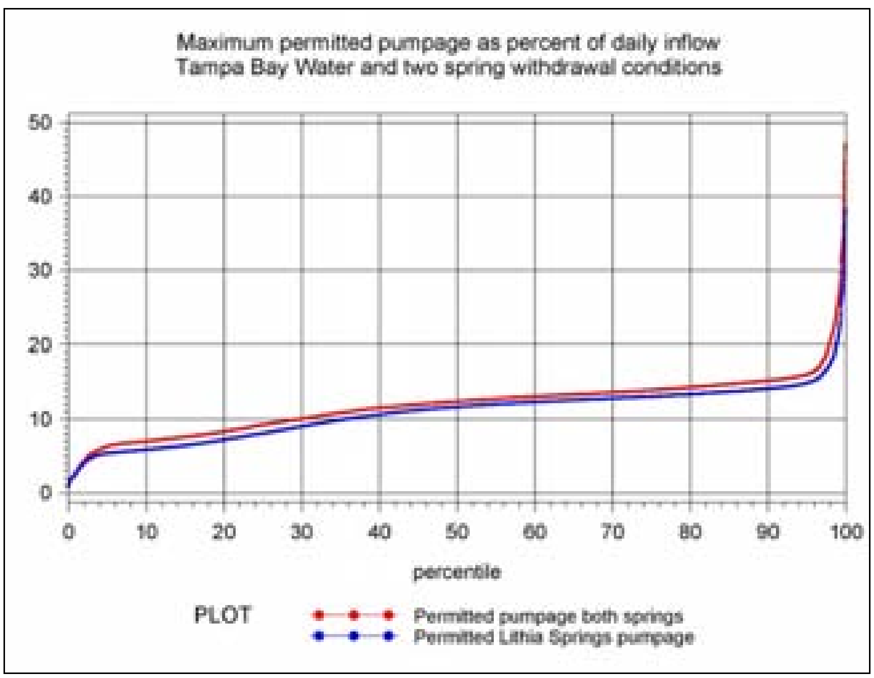


Figure 2-19. Cumulative distribution curve for percent of inflow to the upper estuary represented by maximum possible combined permitted withdrawals by Tampa Bay Water and Mosaic Fertilizer for the period 1987-2003

2.3.5 Estimated Ungaged Inflows to the Lower Alafia River

Downstream of the USGS Alafia River at Lithia streamflow gage there is approximately 87 square miles of ungaged drainage area that contributes freshwater inflow to the Lower Alafia River. This ungaged area represents about 21 percent of the watershed of the Alafia River (Figure 2-20). The effects of tides on water levels and currents complicate the measurement of total streamflow in the river downstream of Bell Shoals. In recent years, the development of acoustic Doppler current profile (ADCP) instruments has allowed assessments of flows in tidal water bodies. The USGS used ACDP and conventional current meter measurements to estimate tidal flow near the mouth of the Alafia River during 1991 and 1992 (Stoker et al. 1996). Due to the large cross-sectional area and strong physical forces (winds, tides, stratification) that affect water movement near the river mouth, these flow measurements in the tidal reach were much more complex than the flow measurements at the upstream Alafia River at Lithia gage, where physical setting of the river is much simpler and all flows are unidirectional.

Using ACDP technology, the USGS reinstituted flow measurements in the tidal reach of the Alafia River in October 2002. This site, the Alafia River near Gibsonton (#02301719), is located 4.4 kilometers upstream from the river mouth (see Figure 4-1). Daily residual flows at this site show much greater variability than daily flows at the upstream freshwater gage, due to the effects of winds and tides in the lower river. Also, discharge records for this tidal gage include many days of missing values, due to complications in estimating flows. This gage provides valuable data, which was used in the calibration of the District' hydrodynamic model of the lower river. However, for a number of reasons, the District concluded that additional methods would have to be pursued to estimate total flows in the lower river.

For purposes of the minimum flows analysis, inflows from the ungaged portion of the Alafia River watershed were estimated by a modeling study of the Lower Alafia River watershed conducted by the University of South Florida Center for Modeling Hydrologic and Aquatic Systems (Tara et al. 2001). These workers used an HSPF (Hydrologic Simulation Program – Fortran) model to simulate streamflow from the ungaged areas. Based on detailed basin delineation work that was conducted for Hillsborough County by Parsons Engineering, Tara et al. (2001) created 16 aggregated sub-basins in the ungaged area of the lower river. Simulated flows from these sub-basins where then summed within ten ungaged basins for use in the District's minimum flows analysis of the lower river (Figure 2-21).

The model developed for this study was built from existing model parameters that were developed for the Southern District model application (Geurink et al. 2001). Measured flows and land use data from three gaged basins in the Alafia River watershed (Alafia River at Lithia, North Prong, and South Prong) were used to calibrate the HSPF model. Land use data was taken from 1995 land coverage provided by the District. Agricultural irrigation water use data were provided by the District and evaporation data was taken from the Lake Alfred station. Rainfall data were taken from the District, USGS, and NOAA data bases. Greater details regarding the development of the HSPF model can be found in Tara et al. (2001).

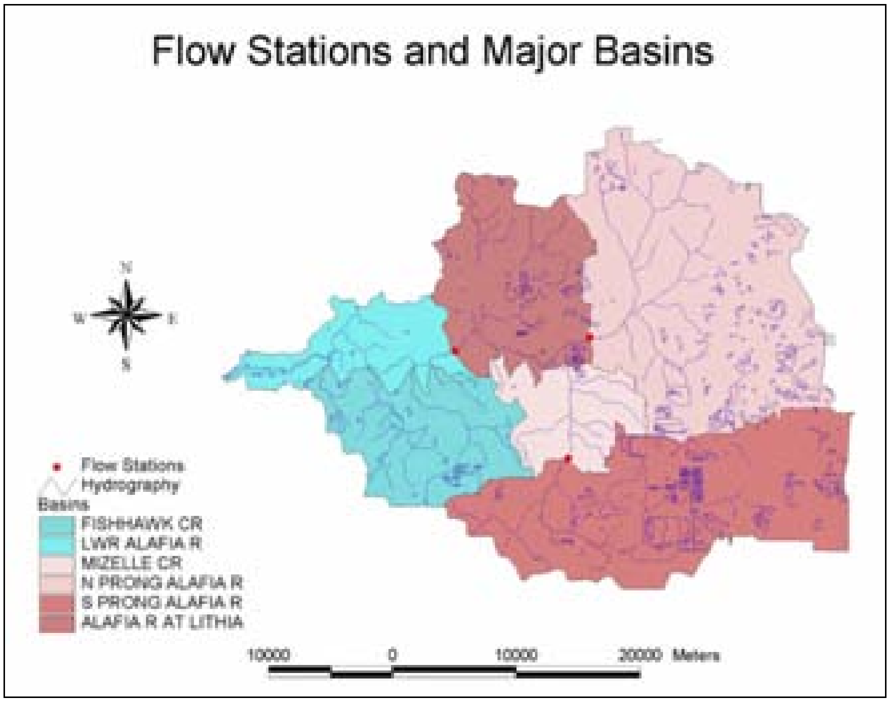


Figure 2-20. Map of Alafia River watershed showing major drainage basins. Ungaged basins from which flows are not monitored are shown in bluish tints in the western part of the watershed (reprinted from Tara et al. 2001).

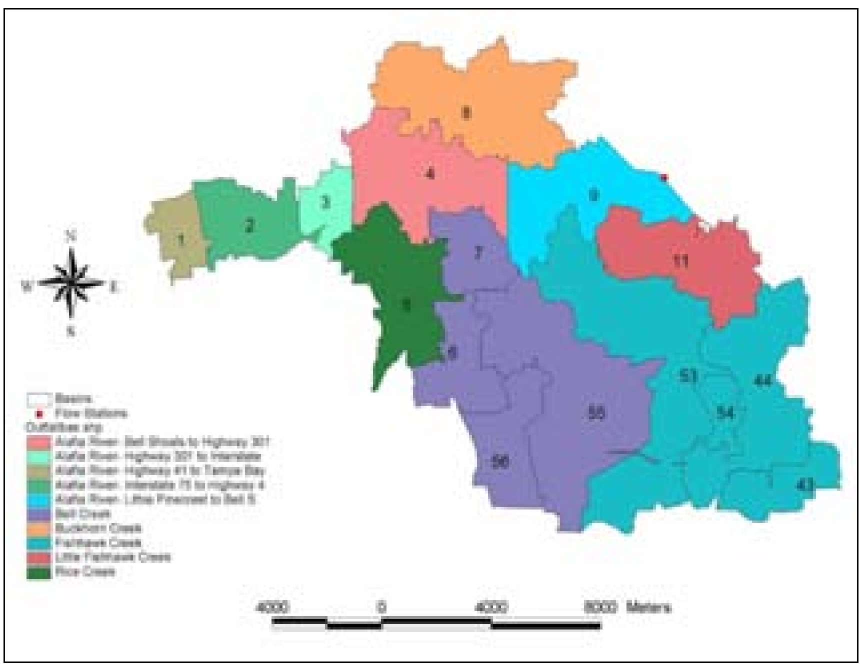


Figure 2-21. Ten ungaged basins in the ungaged portion of the Alafia River watershed for which ungaged flow estimates were provided to the District. Sixteen sub-basins for which flows were simulated and summed are numbered within each of the ten colored basins (reprinted from Tara et al. 2001).

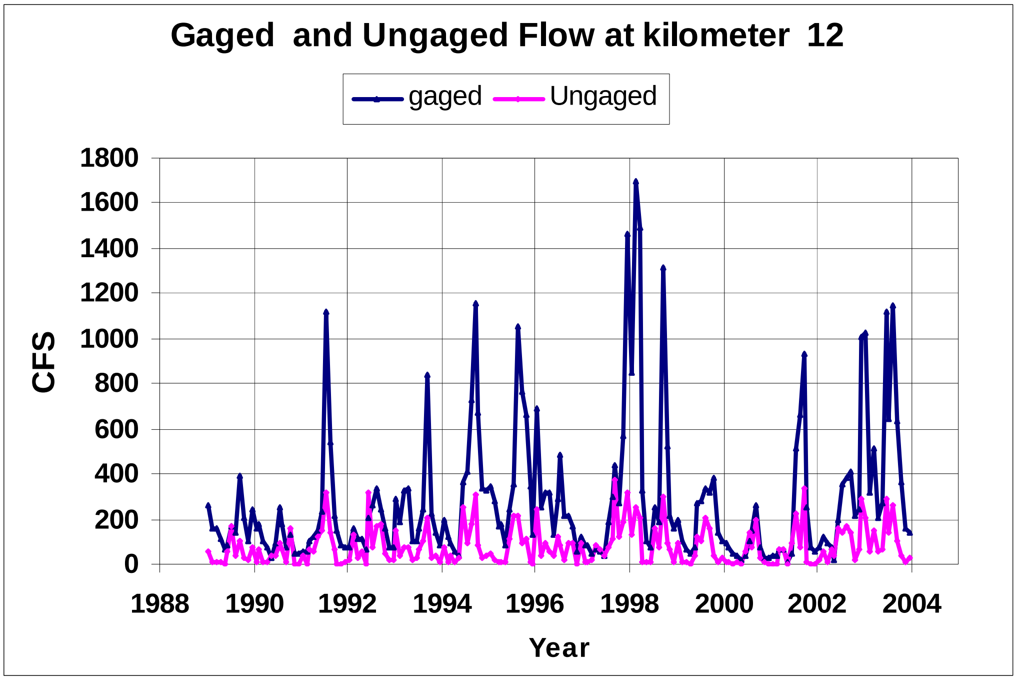
The HSPF model was used to generate surface water flow estimates for the 10 ungaged drainage basins for the period 1989 – 2001. Although the model ran on 15-minute time steps, average daily flow estimates were provided to the District. The model did not include estimates of flows from Lithia and Buckhorn Springs, as these inputs are measured separately within the ungaged area and the model was not designed to simulate these groundwater discharges.

As described later in this report, the ungaged flows were used primarily for calibration and development of the District's hydrodynamic model of the Lower Alafia River. As the minimum flow project progressed, it was desired to run the hydrodynamic model the years 2002 and 2003, in addition to existing model runs performed for the period 1999 through 2001. Because of the time delays required to access the necessary rainfall and irrigation data, regression analyses were used to predict ungaged flows for 2002 and 2003. The regressions were based on relationships between modeled ungaged flows and measured hydrologic data from 1989-2001 (Appendix 2B). The regressions were then used to predict flows from four groups of ungaged basins during 2002 and 2003 as a function of gaged streamflow and short-term (1-3 days) and longer term antecedent rainfall.

Hydrographs of monthly values for ungaged flows and flows measured by the USGS at the Alafia River Lithia gage are shown in Figures 2-22A and 2-22B. Figure 2-22A plots the ungaged flows that enter the river above river kilometer 12 (12 kilometers above the river mouth), while Figure 2-22B plots the total ungaged flows that enter the lower river. In both cases, temporal variations in ungaged flows mimic the records for the gaged flows, indicating the modeled ungaged flows are responding similarly to seasonal changes in rainfall that influence the gaged flow on the river. Mean values for gaged flows at the Alafia at Lithia River streamflow gage and predicted ungaged flows are listed in Table 2-2, along with the percent of the mean gaged flow represented by the mean ungaged flow. The ungaged mean for the 1989-2001 period was derived solely from the HSPF output, while the ungaged mean for 2002-2003 was derived from daily values predicted by regression. The combined mean for 1989-2003 was derived from daily values from these two data sets.

Table 2-2. Mean values for gaged flows at the Alafia River at Lithia and ungaged flows to the Lower Alafia River for three time periods between 1989 and 2003.

Period	Method	Gaged flow	Ungaged flow	Ungaged % of Gaged
1989 - 2003	Combined	279	102	36.6 %
1989 - 2001	HSPF	259	96	37.1 %
2002-2003	Regression	406	136	33.5 %



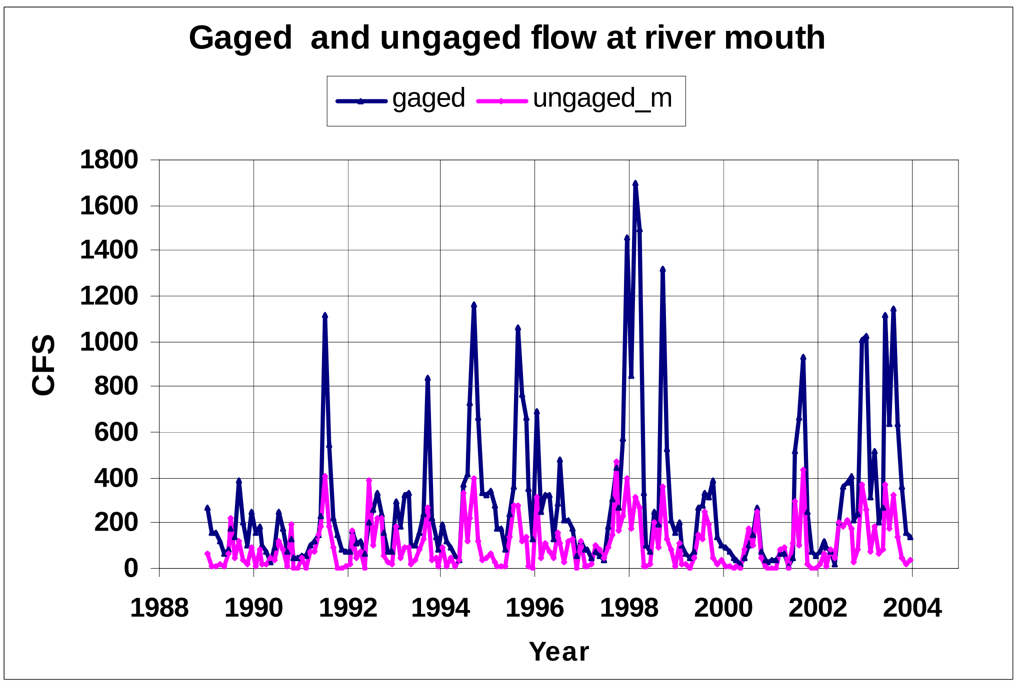


Figure 2-22. Upper Panel (A) - Hydrograph of monthly flows for the Alafia River at Lithia (gaged flows) and modeled ungaged flows above river kilometer 12 for the period 1989 – 2003. Lower Panel (B) - Hydrograph of monthly flows for the Alafia River at Lithia (gaged flows) and modeled ungaged flows above the river mouth for the period 1989 – 2003.

In general, the values predicted by the HSPF model and the regression models gave similar results, with the HSPF values representing 37.1 percent of the total flow to the lower river and the regression results representing 33.5 percent. A high degree of agreement between these two methods is expected since the regressions were developed from empirical hydrologic data and the HSPF results from 1989-2001. Since the ungaged area (87 mi^2) is about 26 percent of the area represented by the Alafia at Lithia gage (335 mi$^{2)}$, the ungaged flows predicted by both methods represent a greater rate of runoff than the gaged flows. For the combined 1989-2003 period, the inches of runoff for the gaged area was 11.3 inches, while the inches of runoff for the ungaged area was 15.9 inches. The ungaged area contains a higher proportion of urban land cover than the gaged area, so that higher runoff rates might well be expected.

It is reiterated that the ungaged flow estimates contain a fairly high degree of uncertainty and are not as accurate as either the gaged flows at the USGS gage or the flow measurements reported for Lithia and Buckhorn Springs by Tampa Bay Water. Tara et al. (2001) acknowledged these sources of uncertainty and make a series of recommendations to improve the modeling of ungaged flows, including increasing the spatial and temporal resolution of the rainfall network, refining the hydrographic features of the lower river basin in the model, using an integrated surface/groundwater model, and adding streamflow sites in the lower river basin for use in model calibration. Despite the limitations of the current model, the ungaged flow estimates provide important information for estimating total freshwater inflows to the Lower Alafia River estuary and served as input for hydrodynamic salinity transport simulations of the lower river presented later in this report.

2.3.6 Total Freshwater Inflow to the Lower Alafia River

The total freshwater inflow to the Lower Alafia River can be calculated as the sum of the gaged flows at the Alafia at Lithia gage, measured flows from Lithia and Buckhorn Springs, and the ungaged flow estimates. Mean values for gaged flow, springflow, and ungaged flow are listed in Table 2-3 for the 15 year period from 1987-2003. These results are for baseline conditions as the withdrawals from Lithia and Buckhorn Springs are added back into the springflow records. Correction for withdrawals by Tampa Bay Water, which began in 2003, are not necessary as these withdrawals occur downstream of the USGS gage and do not affect any streamflow records. The average rainfall for the 1987-2003 period was 50.8 inches compared to a long-term mean of 52.3 inches for the Alafia basin, indicating the mean flow values in Table 2-3 might be slightly lower than values for a longer-period if sufficient flow data had been available.

The average value of total freshwater inflow to the Alafia River is 433 cfs. Of this amount, 23 percent of the average inflow is estimated ungaged flow while 77 percent of the flow is measured flow from the long-term USGS streamflow gage and Lithia and Buckhorn Springs. In short, about three-fourths of the freshwater

Table 2-3. Mean flows for sources of freshwater inflow to the Lower Alafia River for the period 1989 – 2003.		
Source	**Mean flow (cfs)**	**Percent of Total flow**
Gaged flow	279	64.4%
Lithia Springs	40	9.2%
Buckhorn Springs	13	3.0%
Ungaged Flow	102	23.6%
Total inflow	433	100.0%
Existing permitted quantities to Tampa Bay Water and Mosaic Fertilizer	34.6	7.8%

Inflow to the Lower Alafia River is monitored on a frequent basis, while approximately one-fourth of the inflow is from ungaged flow for which modeling or other extrapolations must be performed. The maximum possible withdrawals allowed by the combined water use permits to Mosaic Fertilizer and Tampa Bay Water equal 34.6 cfs, or 7.8% of the total estimated flow of the river for 1989 to 2003.

Average monthly values for total freshwater inflows for the 1987-2003 period range from a low of 157 cfs in May to a high value of 832 cfs in September (Figure 2-23). Total freshwater inflows can show a high degree of seasonal and inter-annual variability. A time series of monthly freshwater inflows are plotted for the period 1989-2003 in Figure 2-24. High flow periods occurred during 1994-1995 and 1997-1998, while low flow periods occurred during 1989-1990 and 2000-2001. The highest average yearly flow value (790 cfs) occurred in 1998, while the lowest average yearly flow value (177 cfs) occurred in 2000. These data demonstrate that freshwater inflow to the Lower Alafia River is highly variable. In subsequent sections of this report, the physicochemical and biological characteristics of the lower river are related to this variation in flows and the effects of potential flow reductions during various ranges of flows are examined.

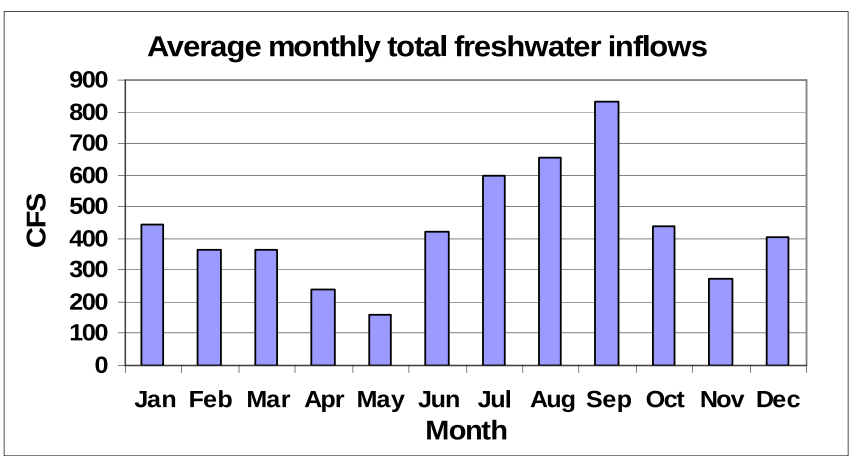


Figure 2-23. Average monthly total freshwater inflows to the Lower Alafia River for the period 1989-2003.

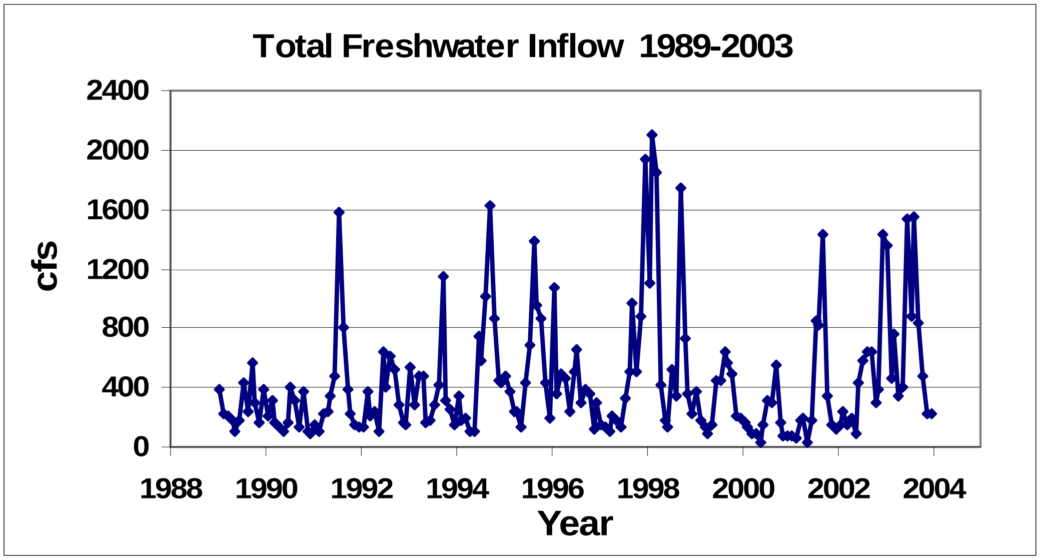


Figure 2-24. Time series of monthly total freshwater inflows to the Lower Alafia River for the period 1989-2003.

2.3.7 Trend Analyses of River and Spring Flow

As described in Chapter 1, the District used the percent of flow approach to determine minimum flows for the Lower Alafia River. A critical part of this method is to first examine trends in the flow regime of the river being considered for minimum flows to determine if any components of the river's flow regime have changed over time (Flannery et al. 2002). If the evidence indicates any changes are due to anthropogenic (human) causes rather than natural climatic variation, the impacts of any such anthropogenic changes on flow could be factored into the minimum flows assessment. Such anthropogenic effects could involve either increases or decreases in a specific component of a river's flow regime (e.g., rising vs. decreasing baseflow due to groundwater use).

The percent of flow method can be considered a "top-down" approach, in that the ecological requirements of the river and estuary are first evaluated under baseline flow conditions without any withdrawals. To construct the baseline flows any existing withdrawals are added back into the flow record. If present, other anthropogenic effects on flow can be accounted for in the baseline flow regime if they are related to the question of water use. Simulations are then performed in which various percentages of flow are taken away from the baseline flows and the response of physicochemical and biological metrics in the estuary are examined. Minimum flows are established as a percentage of flow that will not cause unacceptable changes in the targeted metrics, or not cause significant harm.

The baseline flows are usually assessed over a benchmark period, which is generally a series of continuous years over which potential percent reductions in flow reductions can be evaluated (Beecher 1990, SWFWMD 2005a, 2005b). For consistency, the benchmark period is called the baseline period in this report. Optimally, the baseline period should represent a wide range of flows and be representative of the long-term characteristics of the river's flow regime. However, the selection of the baseline period is often affected by data availability. In selecting the baseline period for freshwater inflows to an estuary, it is desirable to have measured data or good estimates of all major components to the estuaries inflow regime. For example, if an estuary receives flows from two rivers, one should select a period for which records were available for both rivers.

In the following section, a series of trend analyses are examined for the Alafia River at Lithia, since this is the largest source of freshwater inflow to the lower river and the only source for which long-term records are available. More limited trend analyses are also presented for Lithia Springs. Based on trends in the gaged flows and the availability of flow records for Lithia and Buckhorn Springs, a baseline period for evaluation of minimum flows to the Lower Alafia River is recommended.

2.3.7.1 Trends in Lithia Springs Flow

As described in Section 2.3.2, flow records for Lithia Springs are limited to periodic measurements made by the USGS Geological Survey and Tampa Bay Water, with the frequency of the flow records increasing beginning in 1984 (Figure 2-9). Periodic measurements made by the USGS indicate that comparatively high springflow values were recorded in the 1950s and 1960s, with flow values declining from the mid-1960s to the mid-1970s. Since the mid-1970s, however, there has been no apparent decline in flows, although very low flows were recorded during the 2000-2001 drought. As discussed further in a subsequent section, much of this apparent long-term pattern in flows is likely due to climatic trends, as studies from other streams in southwest Florida have observed flows declining from the 1960s to the mid-1970s, with no declining trends thereafter (Flannery and Barcelo 1998, Hickey 1998, Kelly 2004).

For purposes of statistical trend analyses, a seasonal Kendall test was run on measured flow data from Lithia Springs major between 1985 and 2003. Although there are useful periodic values for springflow that go back further, the assessment of longer term trends is hampered by a scarcity of historic data that were collected at frequent or regular intervals. Nineteen eighty-five was selected as the beginning year for the test as it was the first year to have flow records for Lithia Springs during each month. This test indicated a significant increasing trend from 1985 to 2003 (Table 2.4). Data after 2003 were not included in the test, but average yearly flows for 2004 and 2005 were relatively high (39 and 37 cfs, respectively). The average flow for the first 11 moths of 2006 was 24 cfs, but

2006 was a very dry year, averaging 44 inches of rainfall in the Alafia River watershed (SWFWMD water management data base). Collectively, these results indicate that flows from Lithia Springs have not declined over the last 25 - 30 years.

Flow trends were not measured for Buckhorn Springs due to the break in the period of record during 1997 – 2000. However, as described on page 2-11, flows since the year 2000 are within the mid-range of flows recorded during the ten year period from 1987-1996. Average annual flows for Buckhorn Springs in recent years (2004 -2006) have averaged between 13.7 and 18.2 cfs, further indicating that flows in the spring have not declined since the mid-1980s.

Table 2-4 Results of seasonal Kendall Tau tests for trends in streamflow for Lithia Springs for 1985-2003.

Site	Period	Tau statistic	P value	Slope
Lithia Springs	1985 – 2003	0.247	.000003	0.662

2.3.7.2 Alafia at Lithia Streamflow Gage

Streamflow trends were evaluated for the period 1933 – 2004 for the Alafia River at Lithia streamflow gage, as 1933 was the first year to have complete daily records. Trends were evaluated for the complete daily records, for individual months, for various yearly percentile flows, and for yearly values of mean, minimum, and maximum flows averaged over various time periods within each year.

Factors affecting streamflow trends at the Alafia River at Lithia gage were discussed at length in the District's minimum flows report for the freshwater segment of the Alafia River (SWFWMD 2005b). That report discussed the findings of other studies that evaluated flow trends in the Alafia River (Stoker et al. 1996, Hickey 1998, SDI 2003, and Kelly 2004). Key findings of these studies are summarized very briefly below in relation to the trend analyses presented in this report and the determination of a baseline period for the Lower Alafia River. SWFWMD (2005b) should be consulted for further discussion of possible causative factors affecting streamflow trends in the Alafia River.

A time series plot of yearly mean gaged flows is presented in Figure 2-25, including a smoothed trend fitted with SAS software. A seasonal Kendall test of flows for the entire period of record did not show a statistically significant (a=0.05) trend in flow, although a negative slope was reported with a probability of P=0.148 (Table 2-5) High yearly mean flows (>500 cfs) were fairly frequent in the 1940s and 1950s, with peak yearly values recorded in 1959 and 1960. There was tendency for flows to decline from the mid-1960s to the mid-1980s, but flows have rebounded some from the late 1990s forward with the exception of a very dry year in 2000.

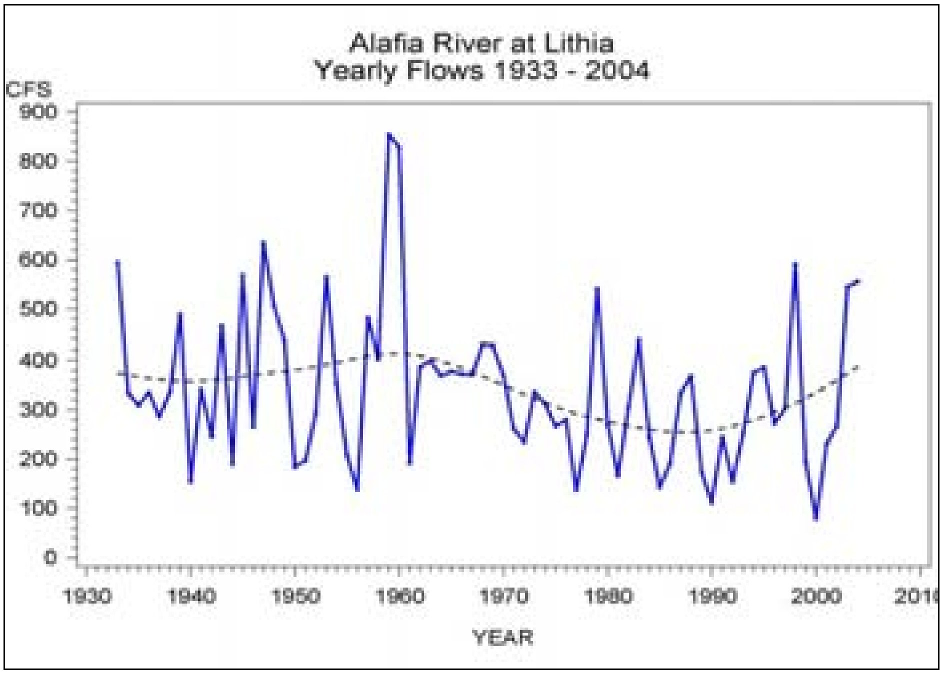


Figure 2-25. Mean annual flows for the Alafia River at Lithia for 1933 – 2004 with a smoothed trend line fitted to the data with SAS software.

Table 2-5 Results of seasonal Kendall Tau tests for trends in streamflow for Lithia Springs for 1985-2004 and the Alafia River at Lithia for 1933-2004 and 1979-2004.

Site	Period	Tau statistic	P value	Slope
Alafia River at Lithia	1933 – 2004	-0.034	0.148	-0.313
	1979 - 2004	-0.025	0.541	-0.774

Running the trend test for the period 1979-2004 again showed no significant trend, with a much higher P value (0.541). The year 1979 was chosen as the starting point for an assessment of recent trends, as it is within what is considered the beginning of the cool, dry AMO period (Kelly 2004, SWFWMD 2005b). However, since 1979 was a wet year (Figure 2-25), inclusion of this year at the beginning of a trend test tends to bias the test toward finding any possible declining trends. This was done intentionally, to see if there is any evidence of continued declining trends in the Alafia River by performing the test in a conservative manner.

The general temporal pattern for the long-term gaged flows in Figure 2-25 is largely related to temporal multi-year changes in rainfall patterns in west-central Florida. Kelly (2004) and SWFWMD (2005b) discussed the apparent effect of a multi-decadal oscillation in the water temperature of the North Atlantic Ocean (Enfield et al. 2001) on rainfall patterns in the United States and peninsular Florida. The Atlantic multi-decadal oscillation (AMO) suggests that periodic cooling and warming of the North Atlantic Oceans surface waters affect precipitation patterns in the United States, with a regional effect specific to peninsular Florida. While periods of warmer ocean temperatures generally result in less rainfall over most of the United States, rainfall tends to increase of peninsular Florida.

Basso and Shultz (2003) and Kelly (2004) suggested that rivers in peninsular Florida were in a period of higher flows during 1940-1969 due to a warm period in the AMO, with a period of lower flows during 1970-1999 during a cool period of the AMO. The assessment of flow trends presented in the minimum flows report for the freshwater segment of the Alafia River supported this causal mechanism (SWFWMD 2005b), and there is some evidence that recent wet years (2003, 2004 and 2005) may indicate a return to a wet cycle.

It should be noted the AMO affects general multi-year trends and very wet or dry years can occur within a AMO period. For example, a very dry year (1956) occurred within what was predominantly a wet AMO period in Florida during 1940 -1969. However, the AMO effect on general temporal rainfall patterns does result in some similarity in long-term trends in flows for rivers within the west-central Florida region. Flannery and Barcelo (1998) reported a long-term shift in flows for the Peace River at Arcadia, with declining flows in the 1970s with a rise in flows in subsequent years, similar to the smoothed trend line for the Alafia shown in Figure 2-25. Hickey (1998) similarly reported a change in flows in the Alafia River in the 1970s, which he attributed to a sharp break in rainfall.

Time series plots of yearly rainfall at the Plant City station are shown in Figure 2-26. This station is shown because of its proximity to the Alafia River basin and because consistent records are available at this station for the entire period of streamflow measurements on the Alafia. The effect of periodic high rainfall years on the moving three-year average rainfall total during the period from 1947-1960 is evident. Conversely, a period of frequent years with below average rainfall in the 1970s on the three-year average is clear, along with the effect of three wet years after 2001.

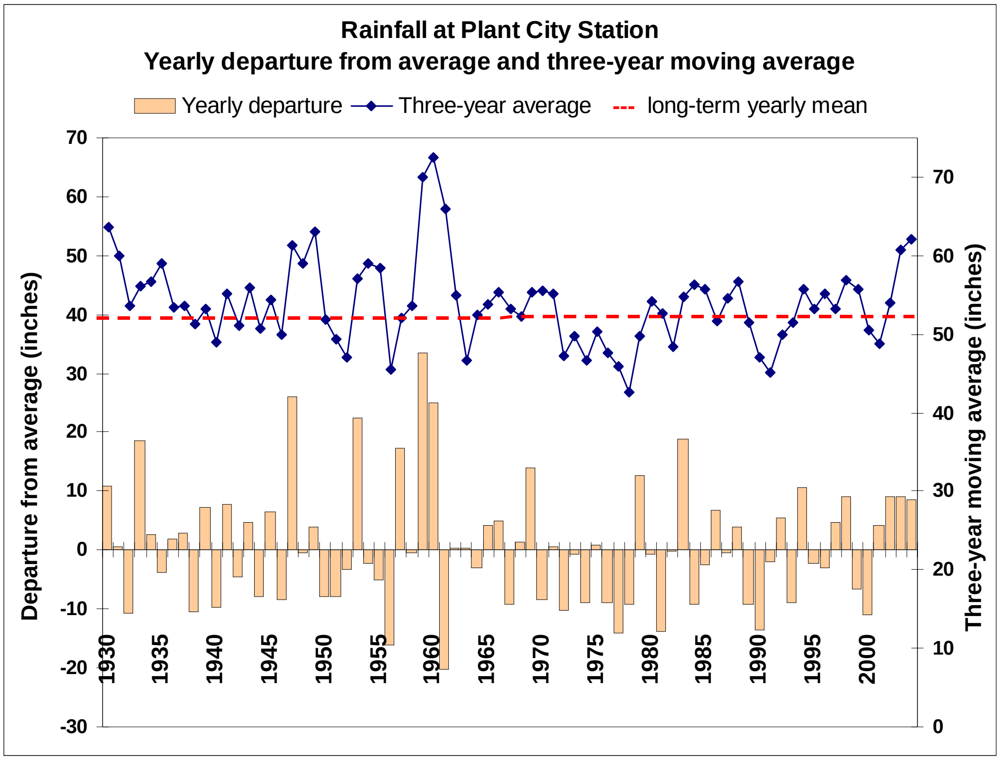
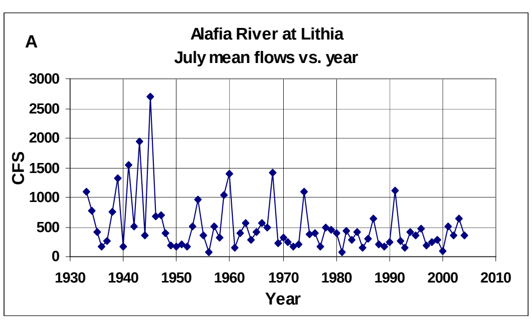


Figure 2-26. Yearly departure from average and three-year moving average for yearly rainfall totals at the Plant City station for the period 1930-2004.

In order to discern if seasonal components of the Alafia River's flow regime have changed over time, trends were tested on flows for each month (Table 2-6). Time series plots of average flows for each month are included in Appendix 2C, with plots for May and July shown in Figure 2-27. The only significant trend in monthly flows for the period of record (1933-2004) was a declining trend in July. However, the time series plot indicates this was largely driven by high flows that occurred in the 1940-1960 AMO period (Figure 2-27A), and flows for July since 1979 have shown no declining trend (Table 2-6).



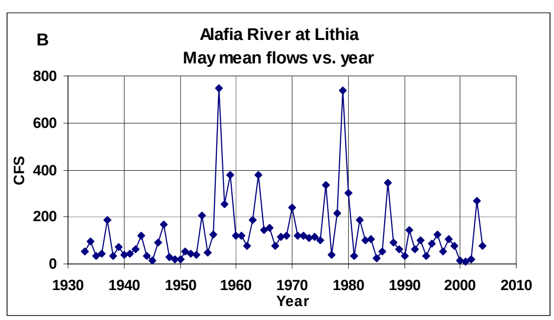


Figure 2-27. Monthly mean flows for July (A) and May (B) vs. year for the Alafia River at Lithia for 1933 – 2004.

Table 2-6. Results of Kendall Tau tests for trends in monthly streamflow for the Alafia River at Lithia for 1933 – 2004 and 1979-2004.				
Period	**Month**	**Tau statistic**	**P value**	**Slope**
1933 – 2004	January	0.095	0.237	0.937
	February	0.030	0.715	0.255
	March	-0.005	0.957	-0.048
	April	-0.023	0.774	-0.164
	May	0.029	0.722	0.119
	June	-0.108	0.183	-1.359
	July	-0.175	0.030	-3.273
	August	-0.121	0.133	-2.752
	September	-0.056	0.493	-1.423
	October	-0.103	0.201	-1.413
	November	0.021	0.797	0.144
	December	0.0125	0.880	0.604
1979 – 2004	January	0.215	0.895	0.882
	February	-0.156	0.270	-3.977
	March	-0.182	0.201	-4.649
	April	-0.074	0.612	-1.721
	May	-0.261	0.064	-3.748
	June	-0.083	0.567	-1.783
	July	0.058	0.692	2.186
	August	0.046	0.757	2.524
	September	0.065	0.659	3.861
	October	0.225	0.112	5.908
	November	0.040	0.791	0.500
	December	0.003	1.000	0.302

A comparison of trends for the other months did not indicate there were any other declining trends of potential concern. However, the results for May were unusual for there was no significant trend over the period of record, but there was some indication of a declining trend ($p < 0.06$) from 1979 to 2004. The time series plot for May shows that flows generally peaked in the middle part of the record, with higher flows generally recorded during the period from the mid-1950s to the mid-1980s. The declining trend after 1979 is likely influenced by high values for May during 1979 and 1980, and low values recorded during the very dry springs of 2000 – 2002. However, the monthly flow values during the recent period are generally not lower than the monthly values recorded for May prior to the early 1950s.

Streamflow and water quality data presented by SWFWMD (2005b) indicate the rise in May flows during the middle part of the streamflow record was due to largely to discharges by the phosphate industry. Prior to the 1980s, the phosphate industry used larger quantities of ground water for the mining of the phosphate ore than at present, with much of that water finding its way to the Alafia River. In the 1980s the phosphate industry began a series of measures to greatly improve their water use efficiency that included greater recycling of water in the mining process and less groundwater use. As a result, less water was discharged to the Alafia River. Since May typically experiences some of the lowest flows of the year, these changes in industrial water use are most apparent in the May flow record, because it reflects the baseflow characteristics of the river.

The effects of climate and changes in water use are also apparent in trends tests and plots of yearly percent exceedance flows. These are flows that are exceeded a certain percentage of the time within each year. For example, the flows that are exceeded 10 percent of the time each year (high flows), 50 percent of the time each year (yearly median flows), or 90 percent of the time each year (low flows). The only significant trend for the period of record was a declining trend for the 10 percent exceedance flows (Table 2-7), which showed high values during the warm AMO period in the 1940s and 1950s (Figure 2-28A). However, there has been no indication of a decreasing trend since 1979.

Table 2-7. Results of Kendall Tau test for trends in yearly percent exceedance flows for the Alafia River at Lithia for 1933 – 2004 and 1979 – 2004.

Period	Yearly percent Exceedance flow	Tau statistic	P value	Slope
1933 – 2004	10% exceedance (high flows)	-0.204	0.012	-4.414
	25% exceedance	-0.079	0.329	-1.043
	50% exceedance (median flows)	0.043	0.599	0.264
	75% exceedance	0.037	0.651	0.131
	90% exceedance (low flows)	0.078	0.336	0.25
1979 – 2004	10% exceedance (high flows)	0.166	0.243	10.3
	25% exceedance	0.040	0.791	1.500
	50% exceedance (median flows)	-0.095	0.508	-1.950
	75% exceedance	-0.164	0.252	-1.500
	90% exceedance (low flows)	-0.250	0.078	-2.000

Plots for the yearly 90 percent and 75 percent exceedance flows show a pattern similar to the monthly plots for May, in that values peaked in the middle part of the period of record (Figure 2-28 D and E). Although these flows have declined since the 1960s and 1970s, the recent values for the 75 percent and 90 percent exceedance flows are generally as high or higher than the corresponding values recorded prior to the 1950s. Similar to the results for May, these results reflect changes in industrial water use in the basin, and indicate that low flows in the river have not experienced any true flow declines.

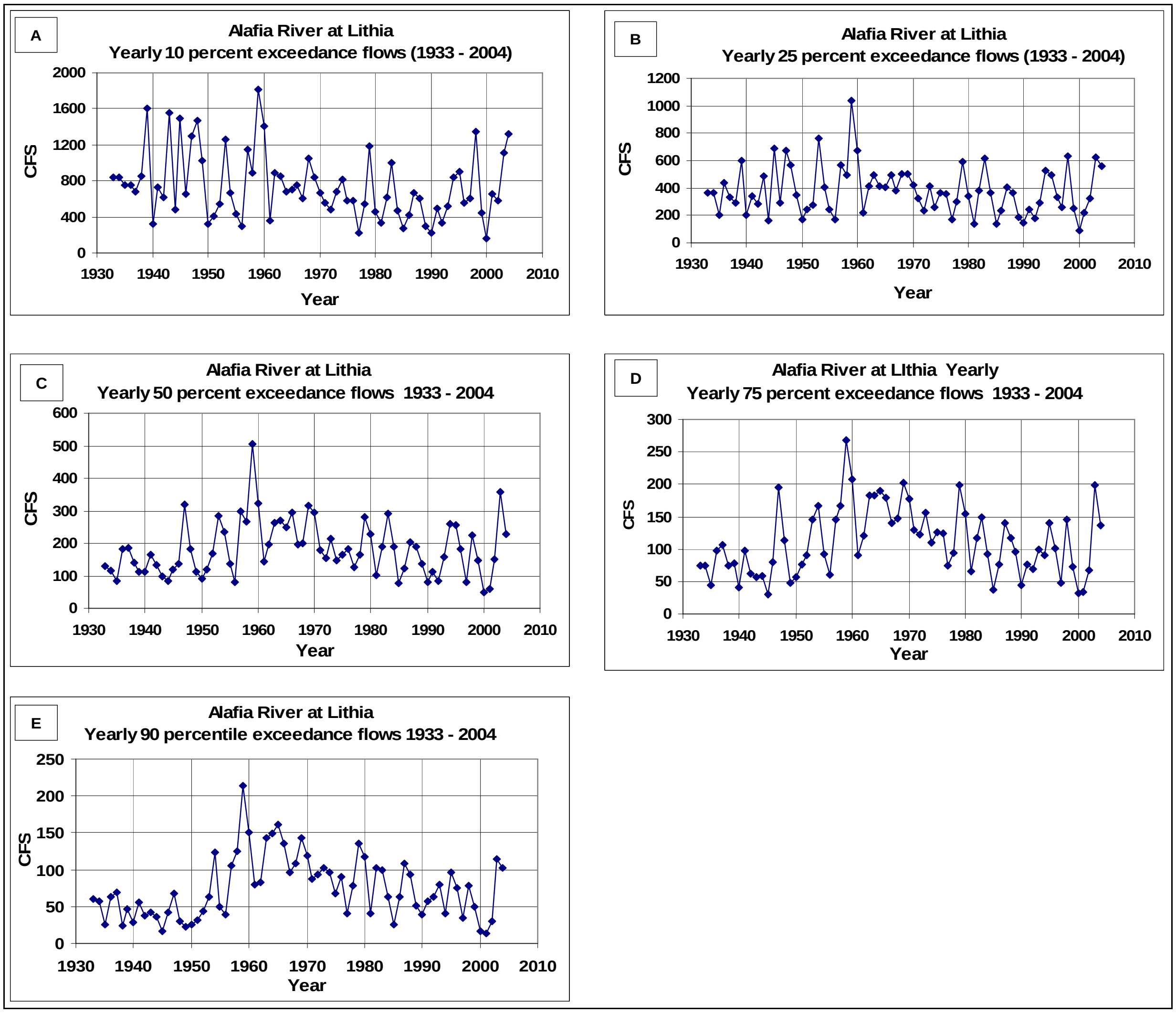


Figure 2-28. Hydrographs of five yearly percent exceedance flows or the Alafia River at Lithia (A = 10% exceedance; B = 25% exceedance; C = 50% exceedance; D = 75% exceedance E = 90% exceedance).

The final flow parameters for which trends were tested were flows which were averaged over moving periods ending within each year. Trends were tested for the mean, minimum maximum values for flow averaged over periods of 3, 10, 30, 60, 90, and 120 days (Table 2-8). As described in Chapter 6, there is evidence that various biological variables in the estuary respond to flows over preceding time periods of various lengths. These trend tests were therefore conducted to determine if flow characteristics of the river averaged for different lengths of time have changed over the period of record.

Plots of the moving average flow terms listed in Table 2-8 are presented in Appendix 2D, with example plots presented in Figure 2-29. Declining trends were found for all of the yearly mean values for the period of record, except for 60-day flows.

Table 2-8. 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 Alafia River at Lithia for 1933-2004 and 1979 – 2004.

Mean Values	Tau statistic	P value	Slope
1933 – 2004			
Mean 3-day average flow	-0.160	0.049	-1.659
Mean 10-day average flow	-0.172	0.033	-1.669
Mean 30-day average flow	-0.185	0.021	-1.709
Mean 60-day average flow	-0.191	0.179	-1.930
Mean 90-day average flow	-0.186	0.021	-1.966
Mean 120-day average flow	-0.195	0.016	-1.997
1979 – 2004			
Mean 3-day average flow	0.095	0.508	2.610
Mean 10-day average flow	0.077	0.597	1.749
Mean 30-day average flow	0.021	0.895	0.568
Mean 60-day average flow	0.028	0.860	0.675
Mean 90-day average flow	0.028	0.860	0.641
Mean 120-day average flow	0.009	0.965	0.448

Maximum Values	Tau statistic	P value	Slope
1933 – 2004			
Maximum 3-day average flow	-0.181	0.025	-23.731
Maximum 10-day average flow	-0.194	0.016	-15.688
Maximum 30-day average flow	-0.197	0.014	-8.826
Maximum 60-day average flow	-0.200	0.130	-6.438
Maximum 90-day average flow	-0.196	0.015	-5.059
Maximum 120-day average flow	-0.185	0.022	-4.150
1979 – 2004			
Maximum 3-day average flow	0.175	0.217	55.490
Maximum 10-day average flow	0.175	0.217	31.456
Maximum 30-day average flow	0.163	0.252	19.861
Maximum 60-day average flow	0.144	0.311	11.125
Maximum 90-day average flow	0.163	0.251	10.739
Maximum 120-day average flow	0.120	0.402	8.682

Minimum Values	Tau statistic	P value	Slope
1939 – 2004			
Minimum 3-day average flow	0.093	0.249	0.202
Minimum 10-day average flow	0.075	0.353	0.160
Minimum 30-day average flow	0.073	0.371	0.178
Minimum 60-day average flow	0.055	0.493	0.147
Minimum 90-day average flow	0.085	0.294	0.255
Minimum 120-day average flow	0.053	0.511	0.235
1979 – 2004			
Minimum 3-day average flow	-0.311	0.027	-1.867
Minimum 10-day average flow	-0.286	0.043	-1.918
Minimum 30-day average flow	-0.280	0.047	-2.018
Minimum 60-day average flow	-0.194	0.172	-1.570
Minimum 90-day average flow	-0.126	0.378	-1.187
Minimum 120-day average flow	-0.083	0.567	-1.375

Plots of the 30-day and 120-day values show that these results were likely influence by high values recorded during the wet AMO period from 1940-1960 (Figure 2-29A and 2-29B). Since 1979, however, there has been no indication of a decline in any of the mean flow parameters (Table 2-8). The results for yearly maximum values was similar, with high values in the 1940-1960 period resulting in significant declines over the period of record, but no declines over the last 26 years (Table 2-8, Figures 2-30).

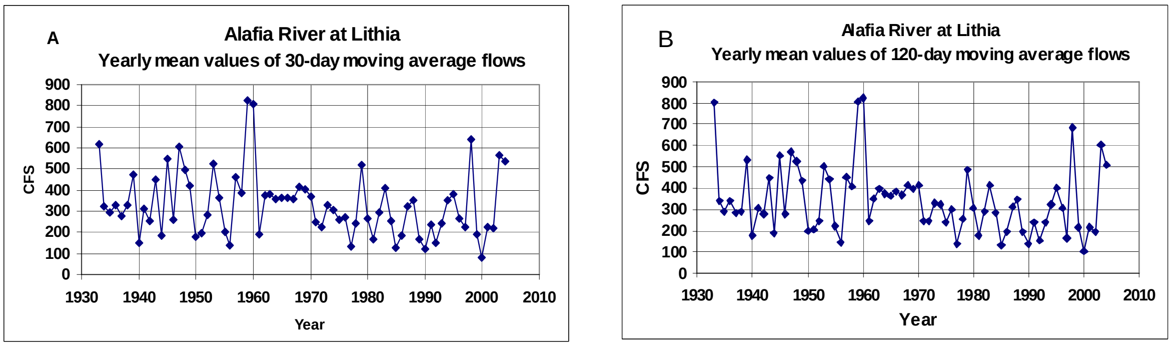


Figure 2-29. Hydrograph of yearly mean values for 30-day moving average flows (Left Panel - A) and 120-day moving average flows (Right Panel - B) for the Alafia River at Lithia for 1933-2004.

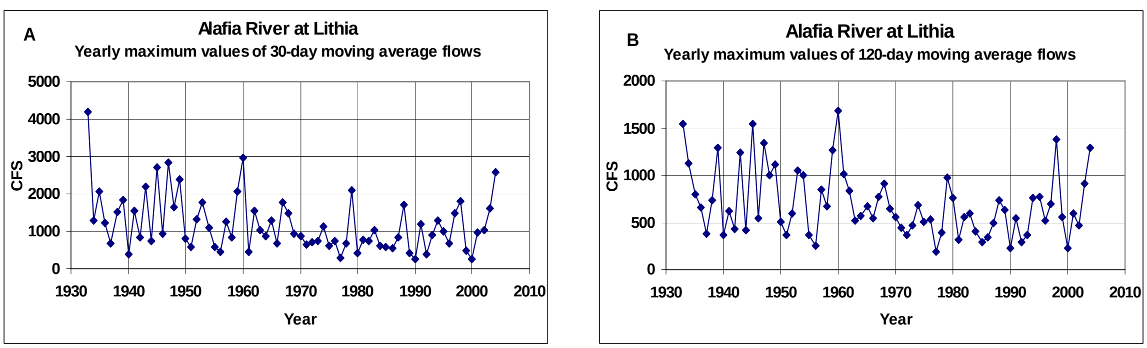


Figure 2-30. Hydrograph of yearly maximum values for 30-day moving average flows (Left Panel - A) and 10-day moving average flows (Right Panel - B) for the Alafia River at Lithia.

Similar to the results for May and the percent exceedance values for low flows, minimum values peaked during the mid-1950s to the late 1970s, reflecting the baseflow augmentation of the river by industrial water use. No significant declines trends were detected for the period of record. Although declining trends were observed for the 3, 10, and 30 day minimum flows during the recent period, these appeared largely driven by the very low flows in the 2000 – 2002 drought, combined with the decline from previous period of elevated baseflow. Yearly minimum flows for most years during the recent period are as high or higher than the values recorded prior to 1950 (Figure 2-31).

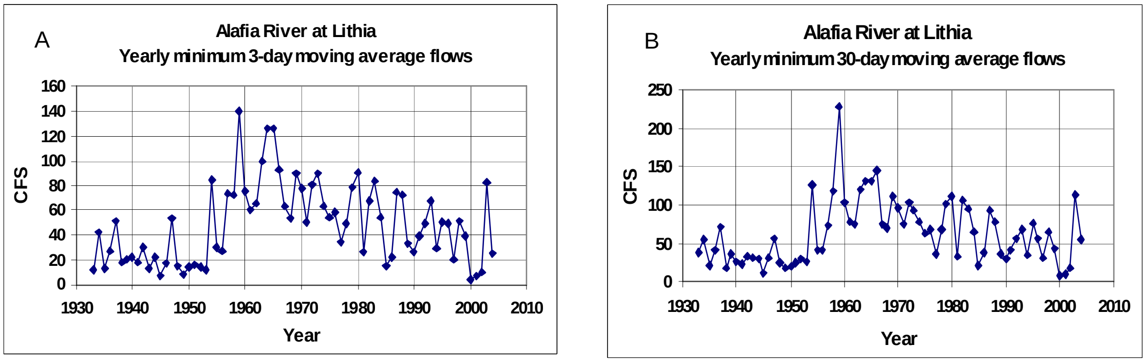


Figure 2-31. Hydrograph of yearly minimum values for 3-day moving average flows (Left Panel - A) and (Right Panel - B) 30-day moving average flows for the Alafia River at Lithia for 1933-2004.

2.4 Determination of Baseline Period for the Assessment of Minimum Flows to the Lower Alafia River

Based on the collective findings presented above, the District concluded the period from 1987 through 2003 would be a suitable baseline period to evaluate minimum flows for the Lower Alafia River. One principal reason for this is the availability of flow records for Buckhorn Springs. Buckhorn Springs provide freshwater flow directly to the lower river estuary near river kilometer 12.3. As such, it likely affects physicochemical conditions and possibly biological variables in the upper part of the estuary during dry conditions when inflows from the river are low. The combined flow from Lithia and Buckhorn Springs comprise about 12 percent of the estimated total freshwater inflow and 16 percent of the measured inflow on an average annual basis. However, during dry periods the proportion of inflow comprised by the springs can be much higher (Figure 2-13). Given these considerations, it was desirable to not extend the baseline period back further than when records for both springs were available.

Trend tests indicate there have been no long-term (1933-2004) or recent trends (1979-2004) that would complicate using the 1987-2003 as a baseline period. In other words, the flow regime of the river does not appear to changing due to continued anthropogenic factors. Baseflow in the river was elevated by flow from excess industrial water use during the mid-1950s to the early 1980s, so the baseline period misses this alteration to the river's flow regime. Since the flow regime of the river appears to have stabilized and recovered from previous alterations, assessments of the effects of future withdrawals on the river based on the flow records from 1987-2003 appear sound at this time.

The 1987-2003 period largely agrees with other management strategies applied to the river. As part of their water use permit for withdrawals from the Alafia River, Tampa Bay Water conducts an extensive monitoring program of the lower river (PBS&J 1999, 2003, 2006). It was concluded by the District in the approval of that monitoring program that a baseline period for assessing the effect of their withdrawals would begin in 1975 to avoid the period of baseflow supplementation of the river. Results presented by SWFWMD (2005b) and in this report indicate the baseflow supplementation may have extended longer, but starting the baseline for the minimum flow analysis in 1983 misses this effect, regardless.

In the minimum flows report for the freshwater segment of the Alafia River, SWFWMD (2005b) discussed two benchmark periods for the assessment of minimum flows. One for the wet AMO period (1940 – 1969) and one for the dry AMO period (1970-1999). They point out, however, that the period from 1980-1999 should be used to assess minimum flows during low flow conditions. As previously discussed, extending the baseline back for the inflows to the lower river past 1987 was not considered due to a lack of flow records for Buckhorn Springs. Thus, much of the baseline period for the lower river occurs within what is considered the dry AMO period.

The baseline for the lower river assessment was extended through 2003 to capture as many years as possible for the minimum flows assessment. The period was ended in 2003, as this is when work on the project began and it was decided not to further update files for hydrologic data, ungaged flows, and the extensive water quality and biological information that had been collected in the estuary. It was important to include the years 1999-2003 in the baseline period as this is when most of the salinity, water quality, and biological data in the estuary had been collected. This period included a severe drought during 2000-2001, and the District wanted to assess minimum flows over this period when the ecological response of the estuary to very low freshwater inflow had been documented with extensive water quality and biological data collection.

Based on records from the Alafia River at Lithia gage, the 1987-2003 baseline period was somewhat drier than the long-term (1933-2004) flow characteristics of the Alafia River. A cdf curve of flows at the Alafia River at Lithia gage are plotted in Figure 2-32. Percentile values from these curves are listed in Table 2-9 and expressed as percentages of the corresponding values for the long-term record in Table 2-10.

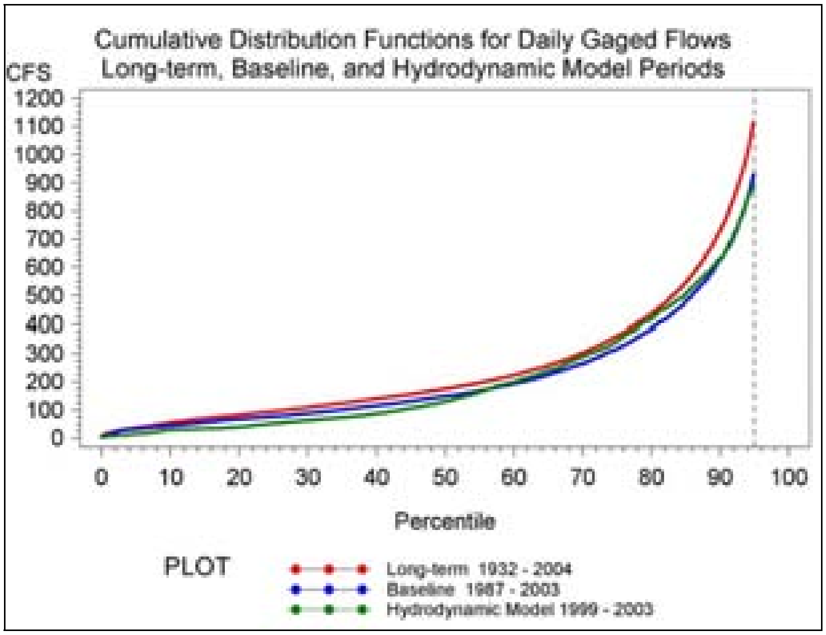


Figure 2-32. Cumulative distribution functions for gaged flows for the Alafia River at Lithia for three time periods: long-term (1933-2004); baseline (1987-2003); and the hydrodynamic modeling period (May 1, 1999 – Dec 12, 2003). Upper limits of flow values are the 95th percentile flows.

With the exception of extremely low flows (e.g., first percentile), percentile flows for the baseline period ranged between 80 and 95 percent of the corresponding percentiles for the long-term period (Table 2-10). Since evidence indicates the flows of the river were supplemented during the mid-1950s to the mid-1980s, flow durations for the baseline period were also tested against the 21-year period from 1933-1953 for comparison. Rainfall during this early period was slightly above normal, averaging 55 inches at the Plant City gage compared to a long-term mean of 52.3 inches at that site. With the exception of very low (first percentile) and high flows (80th percentile and above), percentile flows during this early period represented lesser percentages of the long-term flows than did the corresponding baseline flows. As previously discussed, there is evidence that high flows in the river have declined over the period of record. However, comparison of flow duration characteristics of the recent baseline flows to the early period indicate that much of the river's flow regime has not experienced any flow reductions from what were likely more natural flow conditions.

Table 2-9. Selected percentile flows for the Alafia River at Lithia gage for four time periods: long-term (1933-2004); baseline (1987-2003); early (1933-1953), and hydrodynamic modeling (May 10, 1999 - Dec 12, 2003). All values expressed as cfs.					
Percentile		**1933-2004**	**1987-2003**	**1933 - 1953**	**1999-2003**
1		18	11	15	7.3
5		36	33	25	14
10		55	44	35	29
20		82	68	61	39
30		109	88	81	63
40		140	115	104	87
50		175	148	134	130
60		224	193	182	199
70		303	265	257	288
80		437	384	424	416
90		731	625	837	631
99		2530	2400	3290	2180

Table 2-10. Selected percentile flows for the Alafia River at Lithia gage for four time periods expressed as percent of the long-term value: long-term (1933-2004); baseline (1987-2003); early (1933-1953), and hydrodynamic modeling (May 10, 1999 - Dec 12, 2003).					
Percentile		**1933-2004**	**1987-2003**	**1933 - 1953**	**1999-2003**
1		100%	61%	83%	41%
5		100%	92%	69%	39%
10		100%	80%	64%	53%
20		100%	83%	74%	48%
30		100%	81%	74%	58%
40		100%	82%	74%	62%
50		100%	85%	77%	74%
60		100%	86%	81%	89%
70		100%	87%	85%	95%
80		100%	88%	97%	95%
90		100%	85%	115%	86%
99		100%	95%	130%	86%

As will be discussed later in this report, the District developed a hydrodynamic model of the Lower Alafia River to evaluate salinity distributions and residence times in the tidal river. Boundary conditions to run the model, which included continuous tide and salinity data at the mouth of the river, were available for a four and one-half year period that extended from May 10, 1999 to December 12, 2003. Flow duration values for this modeling period plotted in Figure 2-32 and listed in Tables 2-9 and 2-10. The middle and low flow characteristics of the river were markedly lower during the modeling period than the long-term record, largely due to the inclusion of the 2000-2001 drought in the modeling period. This phenomenon is discussed later in the evaluation of the hydrodynamic simulations relative to the other simulations performed for the minimum flows analysis.

Chapter 3

Physical Characteristics of the Lower Alafia River Estuary

3.1 Major Physical Features

The Lower Alafia River extends 18.2 kilometers from Bell Shoals Road to the river mouth at Tampa Bay (Figure 3-1). The lower river flows in a westerly direction with a broad bend to the north between kilometers 5 and 18. The lower river is narrow (< 40 meters wide) above kilometer 12, widens to approximately 110 meters at US 301 (km 8), and generally ranges between 200 and 600 meters wide between I-75 and the mouth of the river.

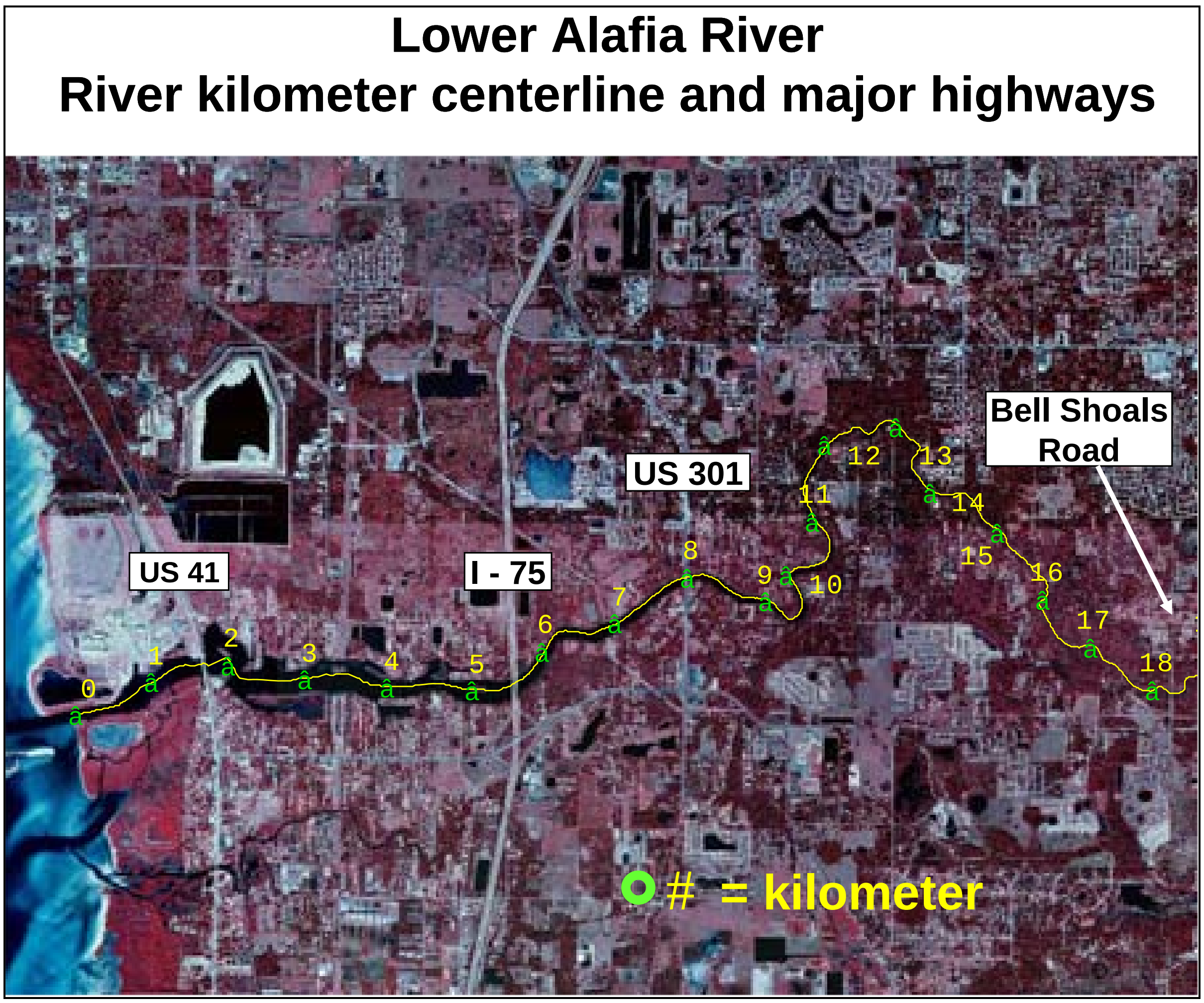


Figure 3-1. Map of the Lower Alafia River showing kilometers along the river centerline and location of major highways.

The mouth of the Alafia River was modified extensively by dredge and fill activities that were completed by the 1930s (Fehring 1985). A deep-water channel was dredged from the main ship channel in Tampa Bay through uplands north of the river mouth to intersect the river channel some distance upstream (Stoker et al. 1996). This channel was dredged to provide access to the fertilizer-processing plant that is located within one kilometer of the river mouth. This facility is still active and a major docking site for the shipping of fertilizer. The former river mouth to the south was partially filled with the excavated material as part of the construction of the barge channel and its turning basin. Over the years, sediment from a spoil area has accumulated in the historic river mouth, reducing the former river mouth to a small tidal creek with little or no connection to the river.

Much of the riparian zone of the Alafia River downstream of kilometer 13 has been highly modified for residential development (Figures 2-3 and 3-1). This development occurs within two small, unincorporated areas known as Gibsonton and Riverview, which lie along the banks of the river. Commercial development in this section of the river is largely limited to a marina located just upstream of US 41.

Much of the river shoreline in Gibsonton and Riverview has been modified by seawalls, rip-rap, or other structures and residential docks are common. Small sets of finger canals extend from the river near kilometers 2.3 and 3.3 and from a bayou connected to the river near kilometer 4 (Figure 3-1). A small side channel to a county park and boat ramp has been cut near kilometer 8, and small side cuts are attached to the river near kilometers 10 and 12.

There are areas of mangroves, marshes, and limited floodplain forests on the lower river, but tidal wetlands along the Alafia are generally not as abundant as on other more natural tidal rivers in the region. The distribution of wetlands and other habitat features along the shoreline of the Lower Alafia River is discussed in more detail in Section 3.5.

3.2 Bathymetry

A series of bathymetric maps of the lower river prepared by Mote Marine Laboratory (2003) are presented in Figure 3-2. The excavated channel and turning basin are confined to the first kilometer of the river. Bottom depths in the middle of the channel and turning basin range are over 10 meters (m) deep. Upstream of US Highway 41 (kilometer 1.5), the river is considerably shallower, with mid-channel bottom depths more typical of a natural Florida tidal River (2 to 4 m). A marked channel for recreational boats runs through the middle of the river, but it is not dredged and is less than 3 meters deep in many places at mean tide.

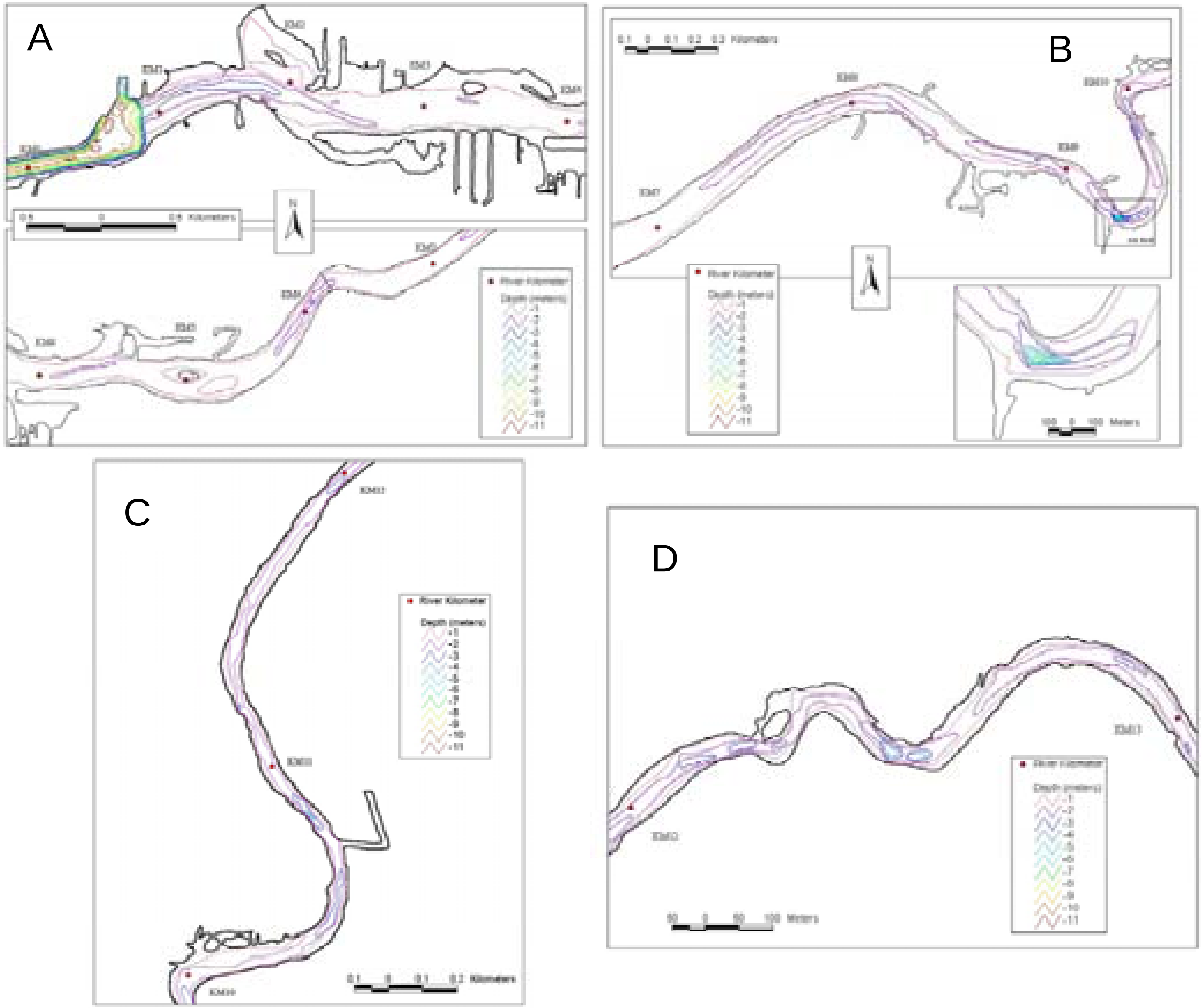


Figure 3-2. Bathymetric maps of lower river reprinted from Mote Marine Laboratory (2003) - continued on next page.

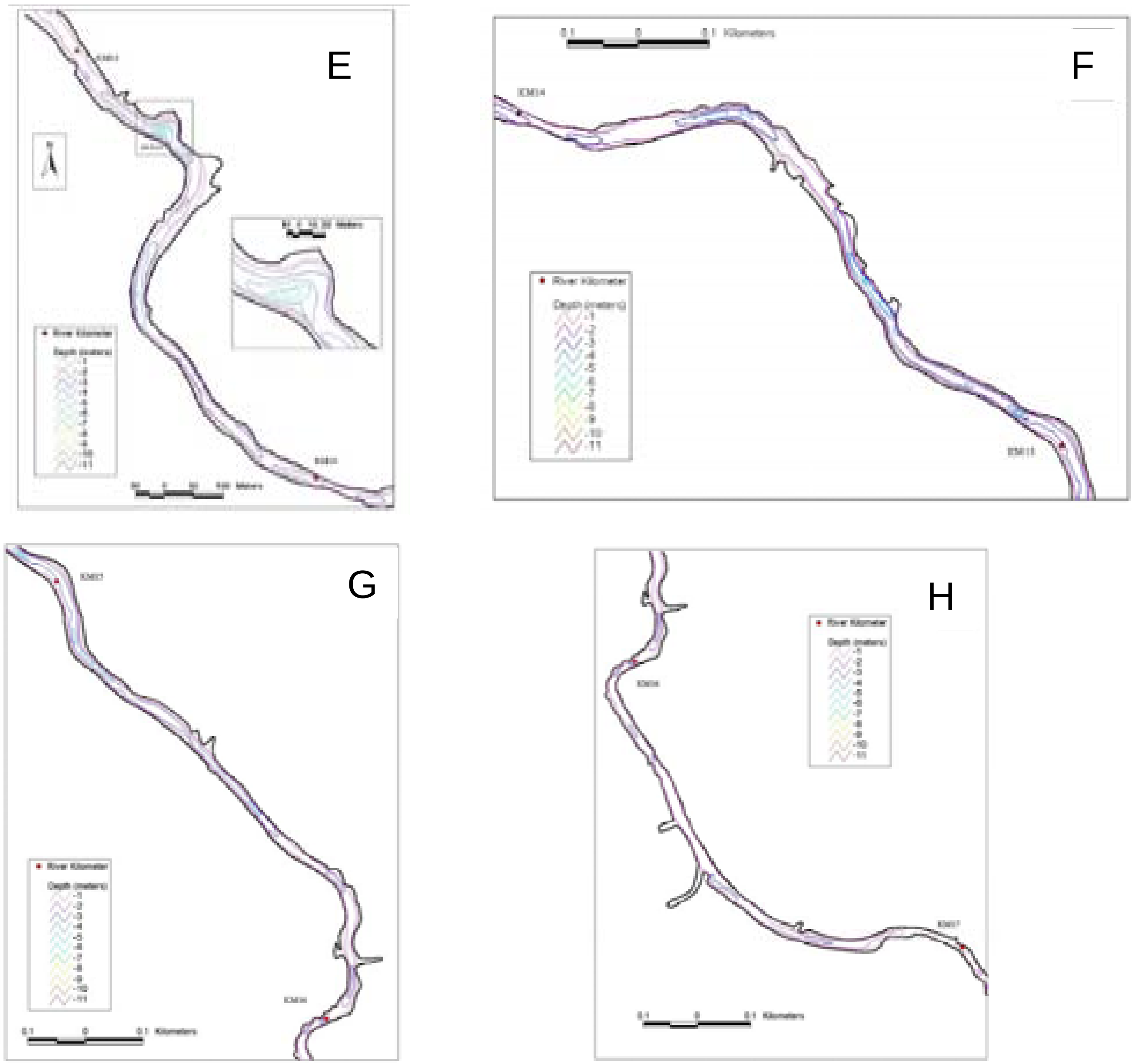


Figure 3-2. continued

Maximum depths in the river channel from recording fathometer data recorded by Mote Marine Laboratory (2003) are presented in Figure 3-3. Depths in the barge channel range from 10 to 11 meters. Depths range from 4 meters to less than 2 meters from just upstream of the barge channel to near kilometer 9, with the shallowest areas between kilometers 2 and 7. The river gradually deepens between kilometers 8 and 15, with deep holes at kilometers 9.7, 12.5, and 13.2 (Figures 3-2 and 3-3). Upstream of kilometer 15 the river again begins to shallow with a shallow shoal near kilometer 16.

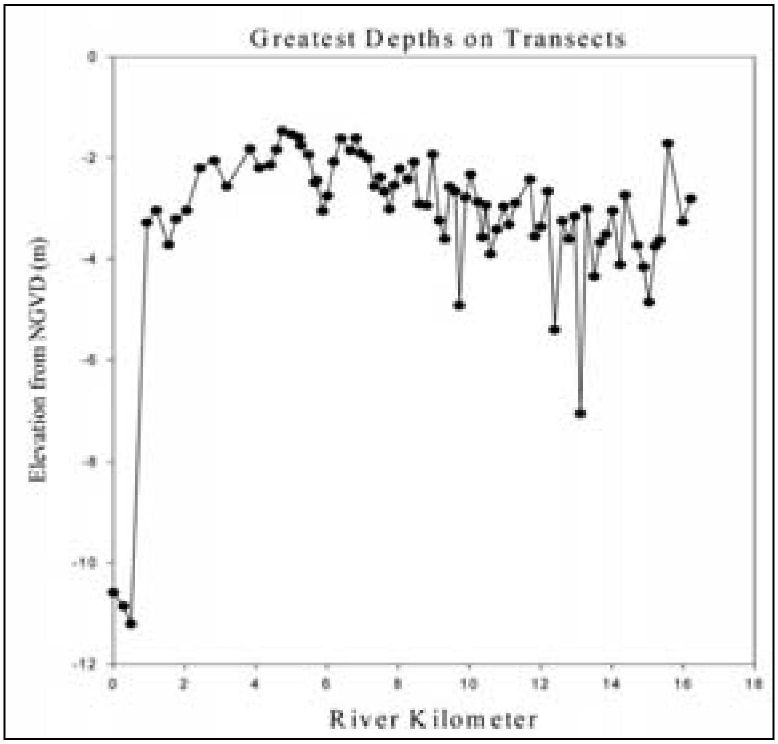


Figure 3-3. Maximum depths recorded on fathometer transects recorded by Mote Marine Laboratory (2003).

Mean cross sectional depths relative to mean water level at the river mouth (0.17 meters) is shown for 178 segments in the lower river in Figure 3-4. Upstream of kilometer 16 the river bed begins a gradual increase in elevation in the transitional area from tidal portion of the river to the upstream non-tidal portion. Three sets of shallow, limestone shoals occur in the river bed between kilometer 17 and Bell Shoals. The bottom of the river bed intersects mean high tide level near kilometer 23, but brackish waters typically do not extend upstream of the limestone shoals near kilometer 17.

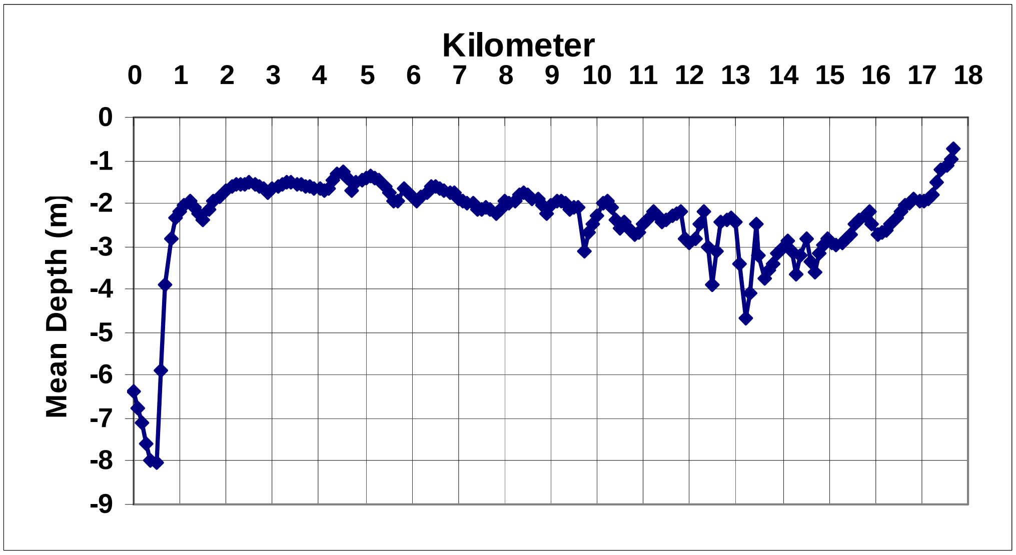


Figure 3-4. Mean cross-sectional depths calculated for 178 segments in the Lower Alafia River relative to mean water levels at the mouth of the river (0.17 meters above NGVD, 1929).

3.3 River Area and Volume

The area and volume of the lower river between the mouth and kilometer 17.8 was quantified within 178 longitudinal segments based on the bathymetry presented in Figure 3-5. The volume of the entire lower river is approximately 72 million cubic meters. Area and volume totals are divided into 1 kilometer segments in several figures, with the segments labeled zero running only from kilometer 0.0 to 0.5. The volumes of the individual segments generally increase downstream as the river broadens near its mouth (Figure 3-6).

A hypsographic curve of volume for the lower river shows that most of the river volume occurs at elevations above -2 meters NGVD, with only about 12 percent of the river volume occurring below that depth (Figure 3-7). A hypsographic curve of surface area vs. depth shows similar characteristics, with 75 percent of the area above an elevation of -2 m, and only 4 percent of the area below a depth of 4 m (Figure 3-7). Viewing surface area in 1 km segments shows that segments with greatest surface areas at elevations near mean (0.18 m) tide and at -1 m are between kilometers 1 and 6 (Figure 3-8A and 3-8B). However, regions of the river with the most surface area below an elevation of -2 m are downstream of kilometer 2 and between kilometers 8 and14, where the river is deeper (Figure 3-8C).

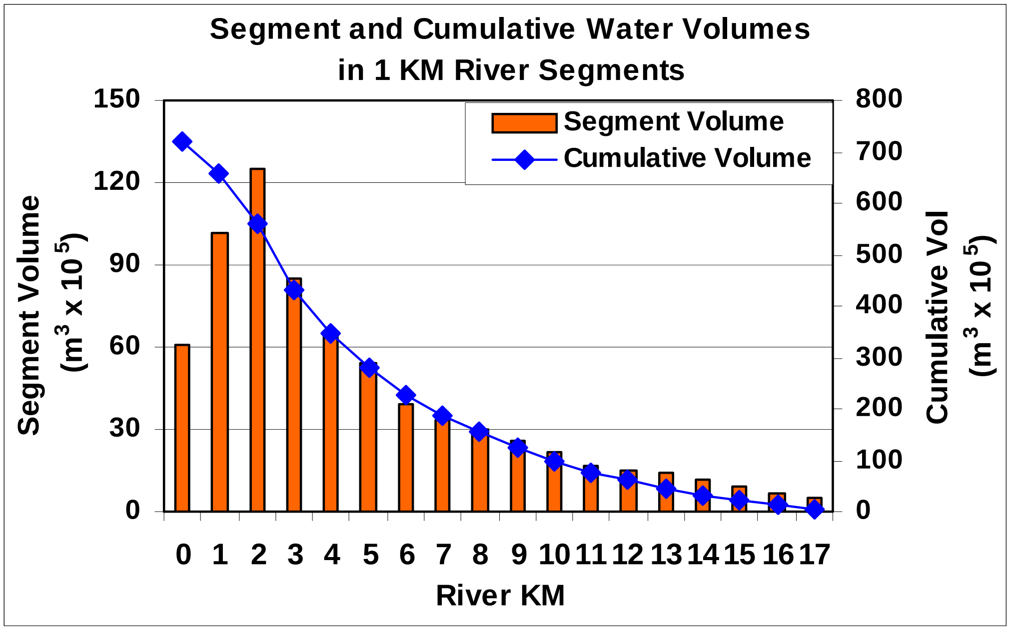


Figure 3-5. Water volumes in 1 km segments and cumulative volume progressing downstream in the Lower Alafia River (segment 0 extends for ½ km between river km 0 and 0.5).

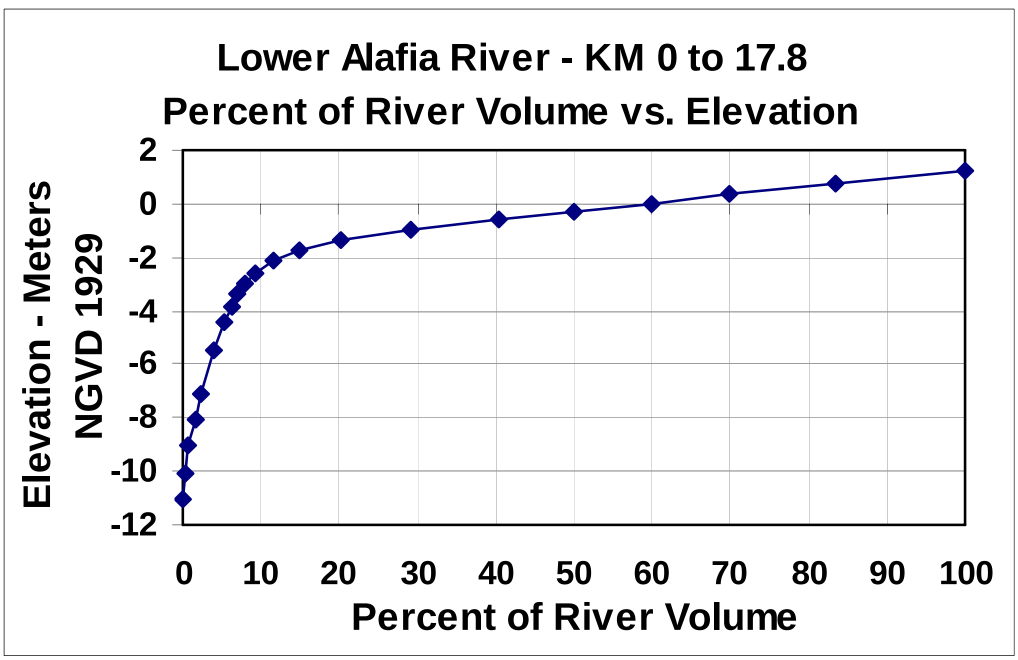


Figure 3-6. Hypsographic curve of percent of channel volume vs. elevation (NGVD 1929) for the Lower Alafia River between kilometers 0 and 17.8.

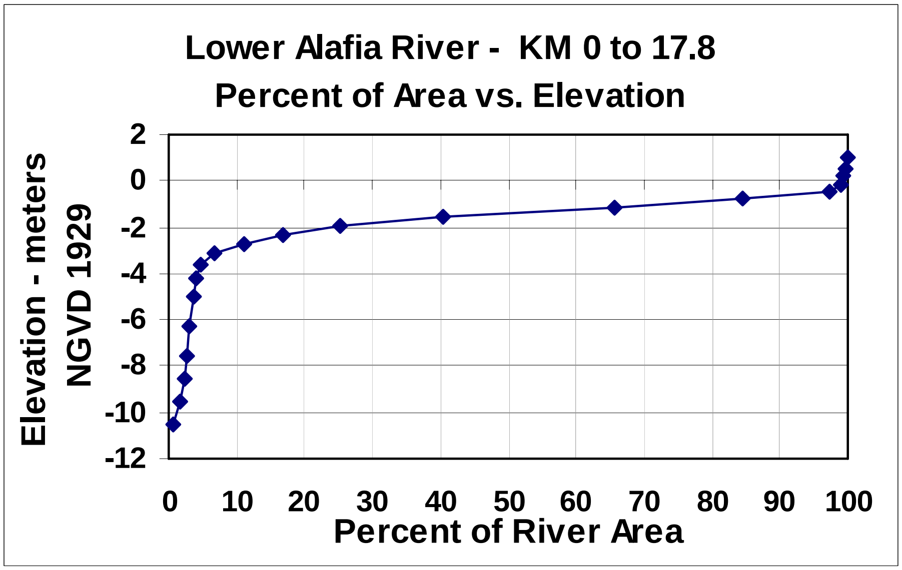


Figure 3-7. Hypsographic curve of percent of river bottom area vs. elevation (NGVD 1929) for the Lower Alafia River between river kilometers 0 and 17.8

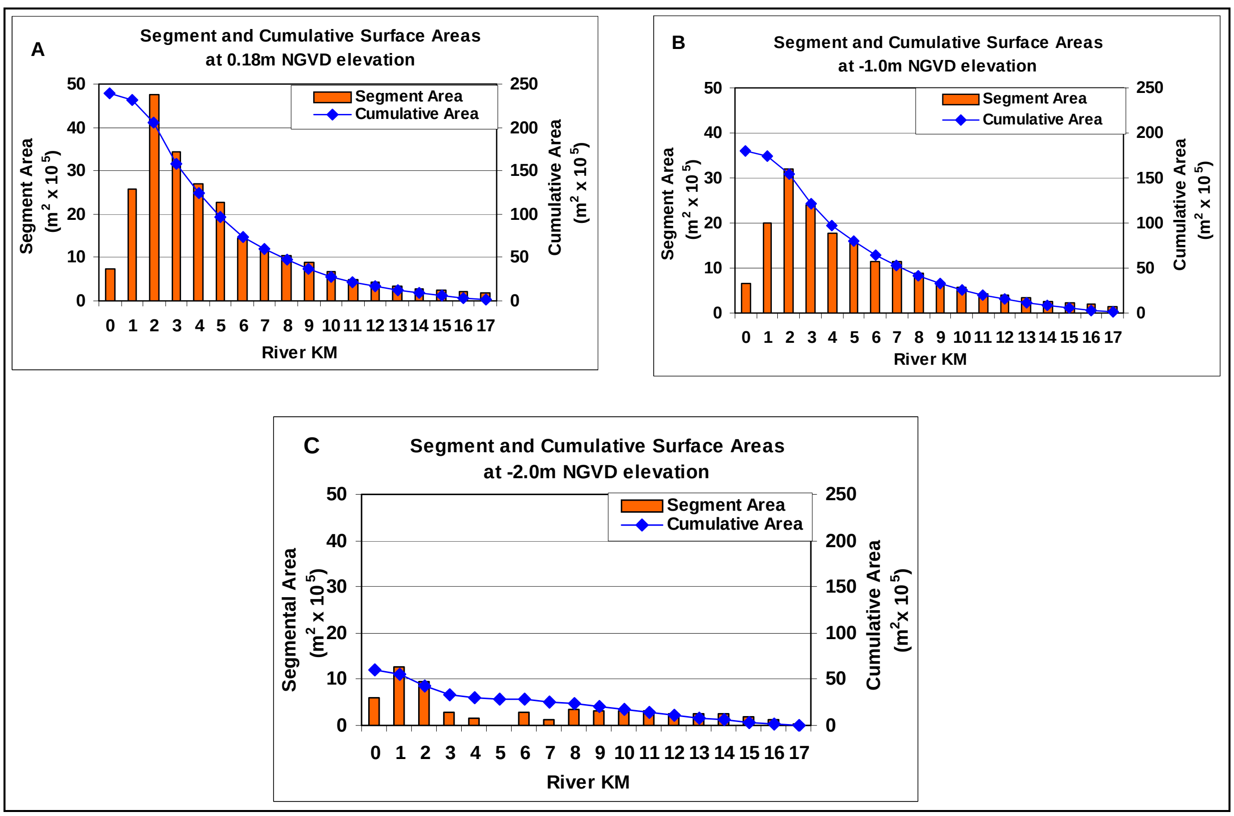


Figure 3-8. Cross sectional channel area in 1 km segments and cumulative area progressing downstream in the Lower Alafia River (segment 0 extends for ½ km between river km 0 and 0.5). Plots shown for cross sectional area at elevations of (A) 0.18 meters, (B) -1 meter, and (C) -2 meters relative to NGVD (1929).

3.4 Sediments and Bottom Habitats

The sediment characteristics of the Lower Alafia River have been documented by two data collection efforts. In a study of the benthic invertebrates of the lower river, Mote Marine Laboratory measured sediment grain size and percent organic matter and mapped major benthic habitats. Sediment data collection has also been performed for the Hydrobiological Monitoring Program (HBMP) conducted by Tampa Bay Water (PBS&J 2003, 2006). This extensive monitoring program, which includes the collection of various water quality and biological parameters, is conducted to support Tampa Bay Water's water user permit for withdrawals from the river near Bell Shoals Road. Various data from the HBMP are analyzed in this minimum flows document.

Sediments measured by the HBMP were sampled using a probabalistic design in which samples were randomly distributed within six strata that extended along the length of the river. Dividing the sediment data into the same one kilometer segments as area and volume shows that organic matter and silt/clay (combined) are highest between segments 3 and 7 (Figure 3-9). As will be described later in this report, this may be due to the position of phytoplankton blooms in the river, combined with the river's physical and hydrodynamic characteristics. Sediment and silt/clay are relatively low above kilometer 13 where the substrate is more coarse.

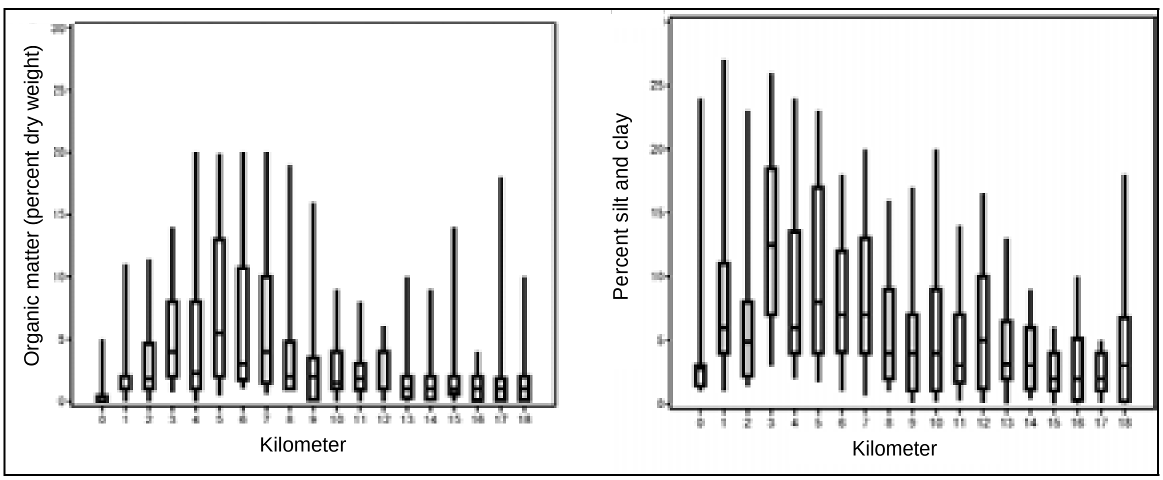


Figure 3-9. Box-and-whisker plots of percent sediment organic matter and silt/clay in one kilometer segments in the Lower Alafia River (source: Tampa Bay, 2003).

Sediment sampling by Mote Marine Laboratory (2003) was done in transects distributed in one kilometer intervals with samples systematically distributed between the two banks of the rivers. The results for this sampling are slightly different than the HBMP in that the transect at kilometer 1 had high silt/clay, but also similar in that typically high values were found in the middle portion of the

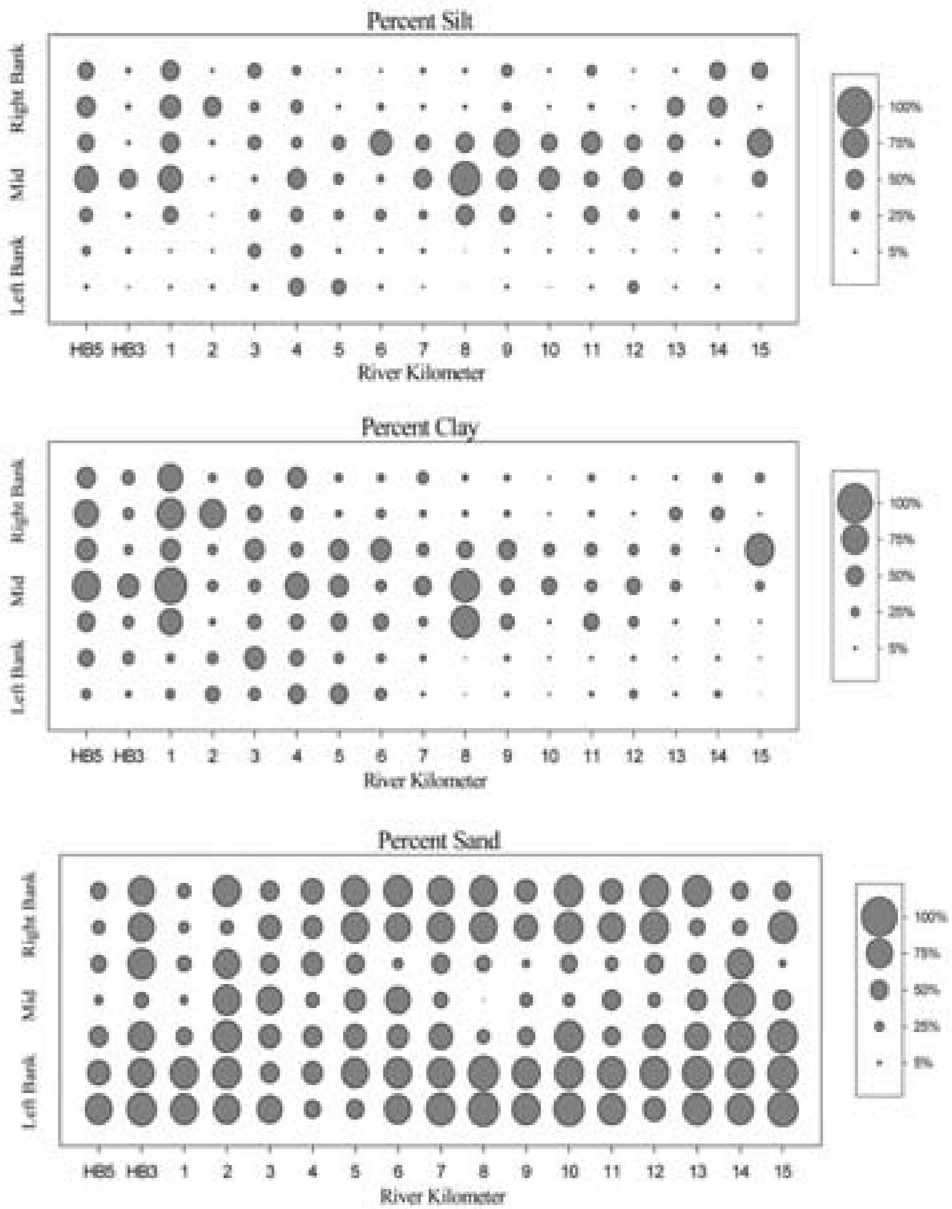


Figure 3-10. Percent silt, clay, and sand in samples from left, right, and mid-channel areas sampled by Mote Marine Laboratory (right bank = north bank).

river (Figure 3-10). The results by Mote Marine show that fine grained sediments were typically found toward the middle of the channel while sands were higher toward the shallower banks of the river. Natural organic compounds (e.g., proteins, lipids, lignin phenols, fatty acids) in sediments in the Lower Alafia were measured by Hall et al. (2006) and compared to a similar sampling regime for the Little Manatee River. They found that Alafia sediments were higher in lignin phenols while fatty acids were higher in the Little Manatee, suggesting that the Alafia sediments were relatively more influenced by allocthonous material, though the Alafia sediments were higher in total organic matter.

3.5 River Shorelines and Riparian Habitats

An infra-red aerial photo highlighting the shorelines associated with the Lower Alafia River is shown in Figure 3-11. The modification of the river below US 41 is conspicuous, showing the change in the location of the river mouth and re-orientation of the river shorelines. Only those shorelines adjacent to the river near its mouth were delineated and quantified for this report, because of the spoil that separates the river channel from the areas to the south.

A graph of total shoreline length in one kilometer segments and the cumulative shoreline length is shown in Figure 3-12. The region of the river with the most shoreline per unit length is between US 41 and the I-75 bridges (kilometers 2- 5). A small secondary rise in shoreline length occurs between kilometers 8 and 11 due largely to small recreational side channels cut into the river. Compared to volume and area, the curve of cumulative shoreline is more linear, due partly to the fairly linear, non-dissected shoreline downstream of US 41 where the barge channel and turning basin lie. Given the lack of islands and relatively non-sinuous shoreline of the Alafia, the amount of shoreline per unit length is less than other more natural rivers in southwest Florida such as the Peace, the Myakka, and the Little Manatee.

Figure 3-11. Outline of shorelines associated with the Lower Alafia River.

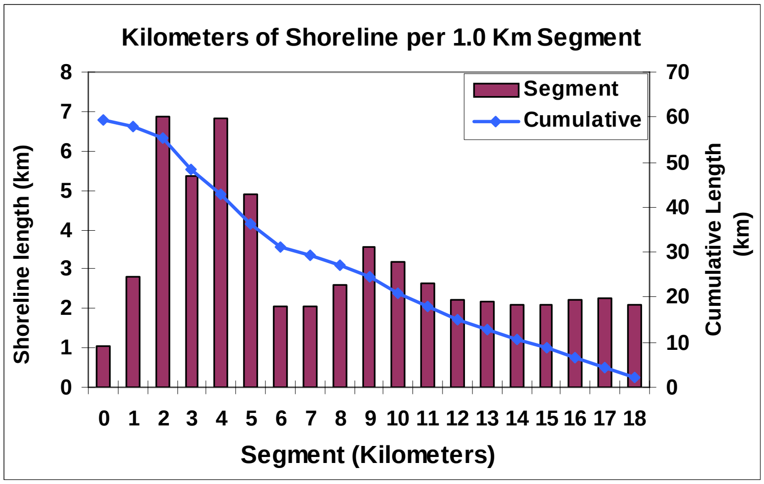


Figure 3-12. Kilometers of shoreline per 1 km segments in the Lower Alafia River with the cumulative shoreline totaled toward the mouth of the river. The segment labeled 0 is a ½ kilometer segment between the river mouth and kilometer 0.5

As part of Tampa Bay Water's application (formerly WCRWSA) to use the Alafia River for water supply, the entire shoreline of the lower river was delineated and quantified into different shoreline types (West Coast Regional Water Supply Authority 1998). As expected, modified shorelines are most numerous below kilometer 13 in the area of Riverview and Gibsonton (Figure 3-13). Much of the shoreline between US 41 and I-75 (kilometers 2 to 6) are seawalls, while rip-rap is most common in the industrial zone downstream of US 41. A concentration of seawalls also occurs around kilometers 9 and 10, but the amount of modified shoreline is generally less above kilometer 11 as natural land covers become more prevalent on the river bank. The distribution of different vegetated shoreline types is discussed below with other vegetation mapping efforts.

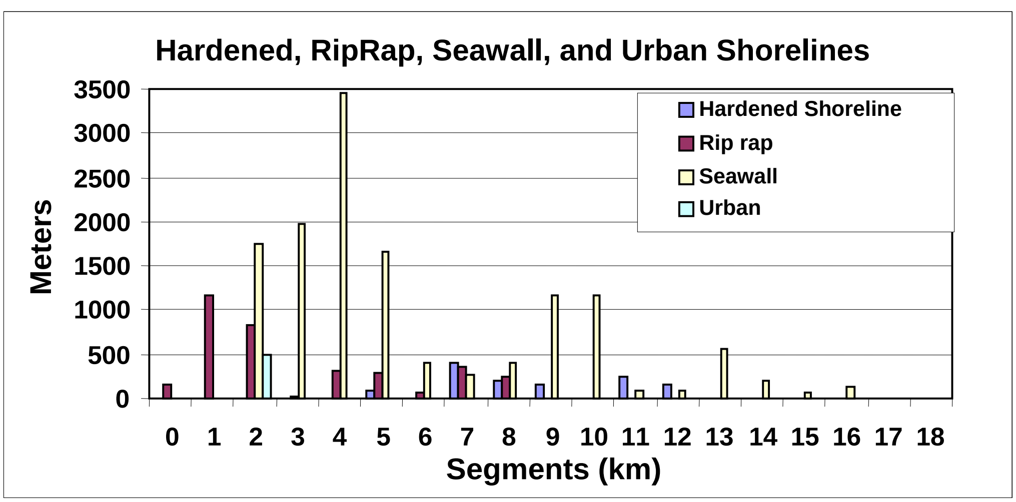


Figure 3-13. Length of major modified shoreline types per one kilometer segment in the Lower Alafia River estuary (segment 0 extends ½ km from km 0 to km 0.5

3.6 Tidal Wetlands

The distribution of tidal wetlands in the Lower River has been mapped by three efforts. Agra-Baymont, Inc. (2002) used aerial imagery and ground-truthing to map tidal wetlands in the lower river for the District (Figure 3-14). The effect of the excavation of the barge channel on the lack of mangroves contiguous to the lower river downstream of kilometer 1 is obvious. Saltmarshes dominated by the black needlerush (*Juncus romerianus)* occur between US 41 and just upstream of the I-75 bridge (near kilometer 6). Small stands of mangroves are associated with these saltmarshes, which also contain leatherfern (*Acrostichum danaefolium*), particularly near the water edge. Small, isolated stands of bottomland hardwoord forests begin to appear kilometer 6.5, with a larger stand located near the confluence of Buckhorn Creek (kilometer 12). A more continuous stand of bottomland hardwoods extends upstream from kilometer 14 to Bell Shoals.

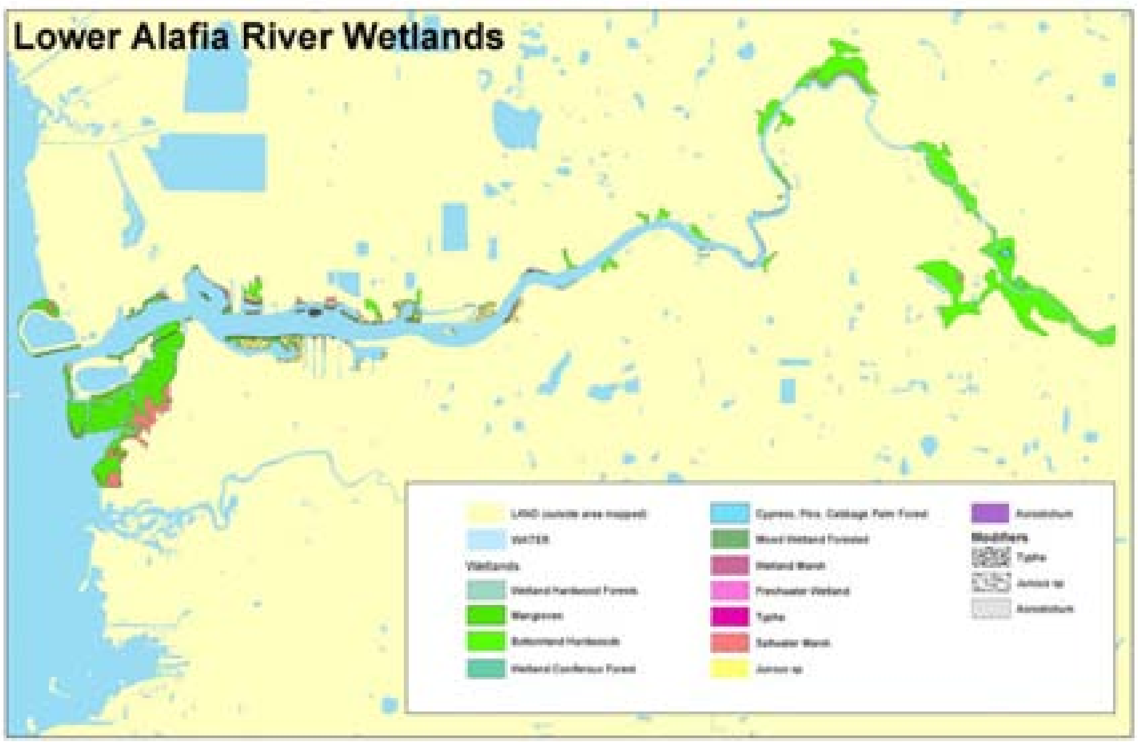


Figure 3-14. Distribution of major wetland communities along the Lower Alafia River mapped by Agra-Baymont, inc. for the District.

Another mapping effort of the wetlands in the Alafia has been conducted for the HBMP (PBS&J 2003, 2006). The spatial coverage and area of major vegetation communities in the Lower Alafia are determined from photo-interpretation and digitizing. Shoreline surveys are also conducted annually to estimate the first and last occurrence of vegetation populations of indicator species (e.g., *Juncus* *roemerianus*). Species composition is also measured in randomly placed quadrats in what are determined to be marine/brackish and brackish/fresh transition areas based on the upstream and downstream occurrence of *Juncus roemerianus*.

The HBMP reported 40.2 hectares of total wetland vegetation located along the Lower Alafia River (Table 3-1). Saltmarshes and mangroves are by far the two most abundant plant communities, followed by mixed herbaceous wetlands, the exotic tree brazilian pepper (*Schinus terebinthifolius*), and wetland hardwood forests. Brackish marsh plants such as cattails, sawgrass, and common reed, which are normally abundant in low salinity areas in other rivers, are not abundant on the Lower Alafia due to the morphology of the modified shoreline of the Lower Alafia rather than lack of an appropriate salinity regime.

Table 3-1 Area of major emergent plant communities along the shoreline of the Alafia River as measured by the Tampa Bay Water HBMP (Tampa Bay Water 2003).

Species or Group	Dominant Plants	Area (hectares)	Percent of Total
Black needlerush	*Juncus roemerianus*	18.86	47%
Mangroves	*Rhizophora mangle*	15.10	38%
Mixed herbaceous wetland	Includes needlerush, cattail, leatherfern, sawgrass, other	1.98	5%
Brazilian Pepper		1.55	4%
Wetland hardwood forest		1.55	4%
Cattail	*Typha dominguensis*	0.70	2%
Wetland coniferous Forest		0.23	1%
Common reed		0.10	0.3%
Cordgrass	*Spartina alterniflora*	0.10	0.2%
Sawgrass	*Cladium jamaicense*	0.05	0.2%
Leatherfern	*Acrostichum daneifolium*	0.002	0.0%
Total		40.2	100%

Bar graphs of the distribution of total wetland vegetation and five major wetland groups along the lower river are presented in Figures 3-15 a-f. Total wetland vegetation is most abundant below kilometer 6.5 due to the distribution of saltmarshes and mangroves. Mangroves are primarily found below kilometer 4, while saltmarshes largely occur between kilometers 2.2 and 6.5. The zonation of the mangrove forests downstream of saltmarshes is the typical plant zonation pattern for rivers in this part of Florida (Clewell et al. 2002). Brackish water communities, such as stands of cattails and mixed herbaceous marshes with mixtures of cattail, needlerush and leatherfern, extend primarily between kilometers 6 and 11. These plants extend as narrow fringing bands along the river shoreline in this reach of the river.

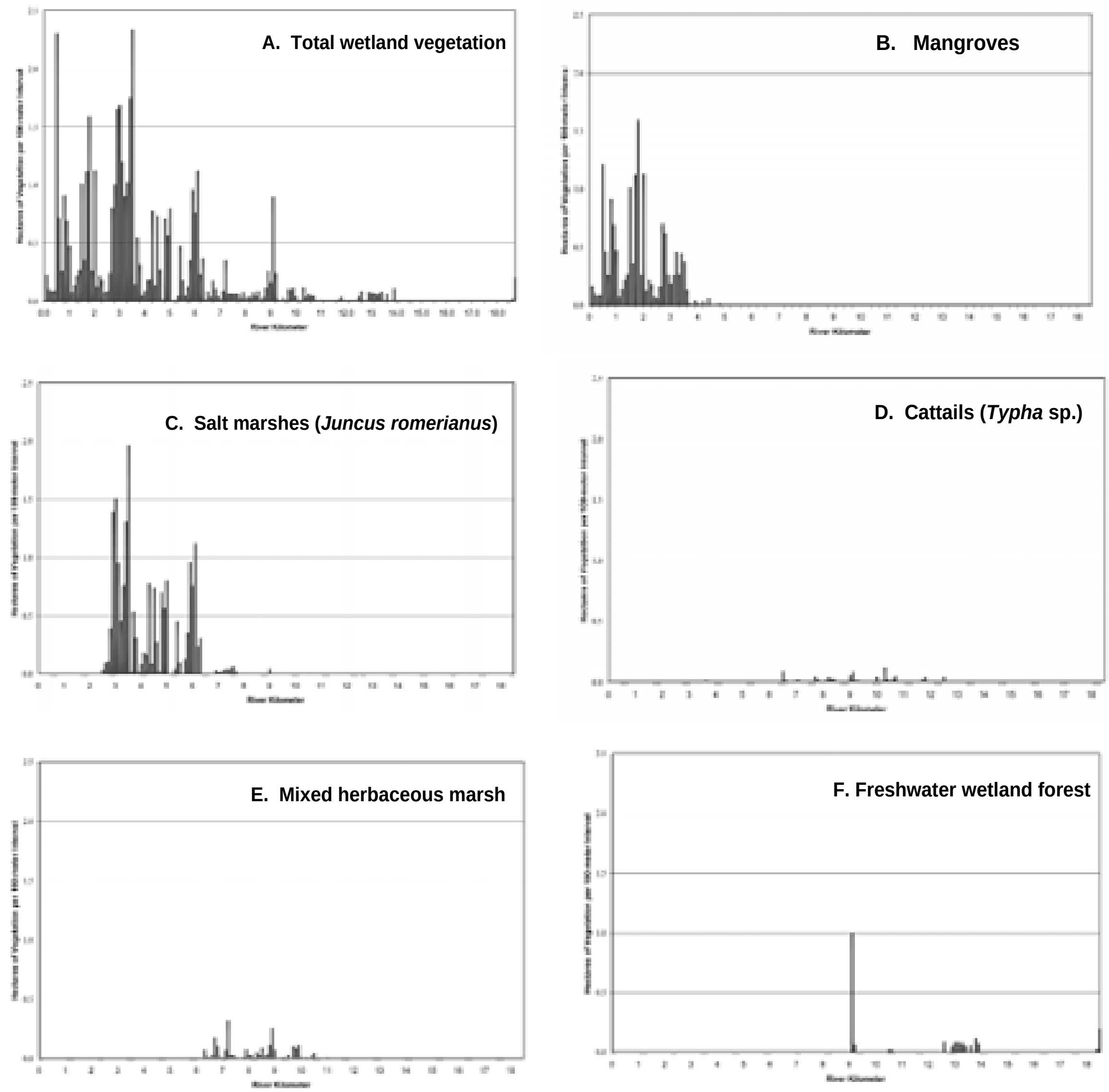


Figure 3-15. Area (hectares) of total wetland vegetation and five major vegetation groups in 100 meter segments along the Lower Alafia River.

Upstream of kilometer 13 the banks of the river are comparatively steep, and where not in residential development, are in forested communities. The delineation and classification of forests in this region differ significantly between the Agra-Baymont and HBMP studies. Agra-Baymont mapped fairly abundant bottomland hardwoods near the confluence of Buckhorn Creek (kilometer 12) and upstream of kilometer 14 (Figure 3-14). By contrast, freshwater wetland forest identified by the HBMP were largely restricted to near kilometer 9 and near km 13, with stands near Buckhorn Creek. Where the two studies differ is above kilometer 14, where Agra-Baymont identified forested wetlands but the HBMP did not. This section of the river is dominated by hardwood forests on the river bank, but these studies differed on their classification due to different interpretation of the species that are there. In general, this is a steep banked portion of the river, and flooding of these forests only occurs at very high flows.

The shoreline inventory prepared for Tampa Bay Water permit 1998 application is also valuable for characterizing vegetation communities along the lower river and provides information on the amount of the shoreline habitat that can be used by fishes and other aquatic organisms. Although the shoreline results are based on length as opposed to area, they generally show the same distribution patterns in vegetation communities as the aerial map (Figure 3-14) and the bar graphs shown in Figure 3-15.

Major vegetative shoreline classes were summed in one kilometer intervals for presentation in this report. Total wetland shoreline is most abundant in the mangrove-saltmarsh zone between segments 2 and 4 (Figure 3-16). Similar to the results for the HBMP areal mapping, the shoreline survey shows very little wetland existing between kilometers 11 and 17. These results were generated by different workers several years apart, and confirm that the forested zone in this part of the river would not be considered wetlands, although it may get partially inundated during very high flows.

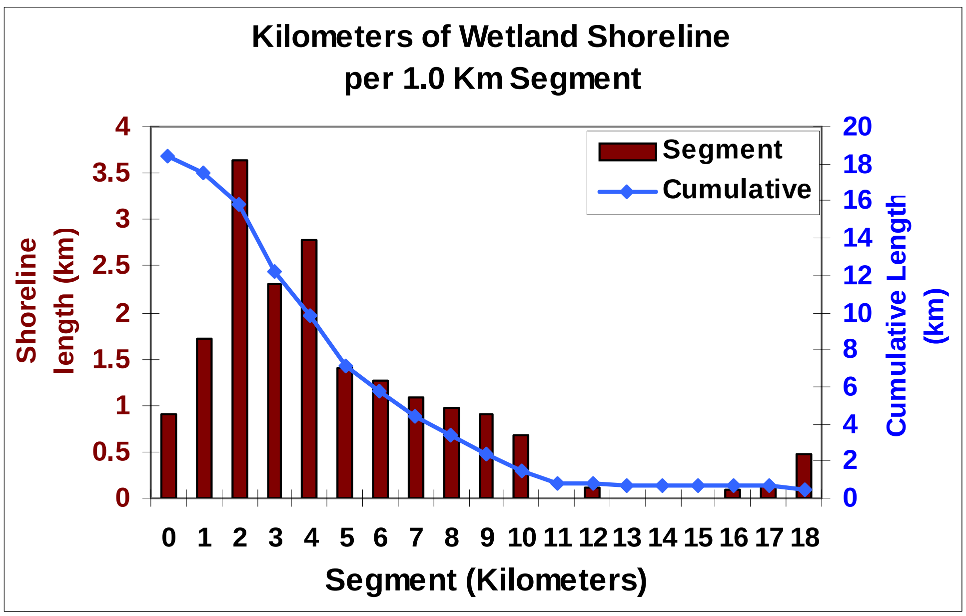


Figure 3-16. Kilometers of wetland shorelines in one kilometer segments along the Lower Alafia River and the total wetland shoreline accumulated toward the mouth of the river.

Shoreline mangrove habitat is most abundant in segments 1 and 2, while needlerush is most abundant in segments 2 though 6 (Figures 3-17a,b). Brackish transitional marshes comprised of cattails, sawgrass, leatherfern, and mixed marshes are most prevalent in the zone between kilometers 5 and 10 (Figures 3-17b,c).

The shoreline survey identified three forest types that could be considered freshwater forested wetlands; bottomland hardwoods, mixed forested wetlands, and wetland hardwood forests. Similar to the HBMP effort, the shoreline survey found relatively little freshwater floodplain forests in the lower river, with small stands of wetland forests found near kilometers 9 to10, 12, and 16 to 17. Upland forested shoreline is abundant upstream of kilometer 11, reflecting the general steep bank that occurs along much of the upper part of the lower river. Though not wetlands, these natural land covers provide buffers to improve water quality, habitat for wildlife in the riparian zone, and in many areas significant shading of the shallow river bottom.

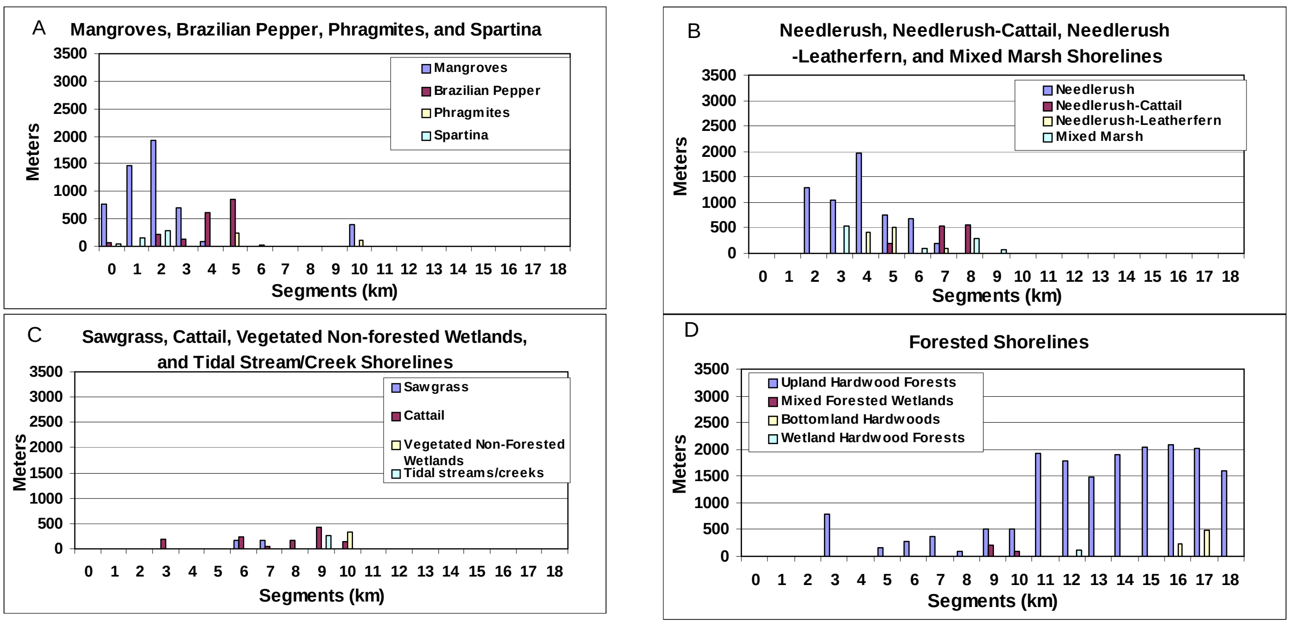


Figure 3-17. Total lengths of major plant groups in one kilometer segments in the Lower Alafia River estuary (segment 0 extends ½ km from km 0 to km 0.5). A = Mangrove, Brazilian Pepper, Phragmites, and Spartina. B = Needlerush, needlerush-cattail, needlerush-leatherfern, and mixed marsh. C= sawgrass, cattail, vegetated non-forested, and tidal stream/creek shorelines D = upland hardwoods, mixed forested wetlands, and bottomland hardwoods.

Chapter 4

Relationships of Tides and Freshwater Inflow with Water Levels and Residence Time in the Lower Alafia River

4.1 Introduction

The relationships of tides and freshwater inflows with water levels in the Lower Alafia River are described below. Also, a hydrodynamic model of the Lower Alafia River was used to simulate the residence times in the estuary that result from the combined effects of tidal flushing and freshwater inflow. The response of residence time in the lower river to the rate of freshwater inflow is described in this chapter of the report.

4.2 Tides

Tides in Tampa Bay and the Lower Alafia River are typically mixed, semi-diurnal tides in which two high waters and two low waters of unequal height occur within one tidal day. Water levels in the lower river have been recorded in recent years at four continuous recorders (gages) operated by the USGS (Figure 4-1). The gage at Gibsonton is located 1.5 kilometers above the river mouth, the gage at Riverview is located in the middle of the lower river (km 8.7), and the gage near Bell Shoals is near the upper end of the lower river (km 17.8). A fourth, submersed recorder that uses a pressure transducer to record water levels is located at kilometer 4.4 (near Gibsonton). Water level measurements recorded every 15-minutes at these gages provide data on the effects of tides on water levels in the lower river.

Tidal forces are the principal factor affecting water levels throughout the tidal river during times of low freshwater inflow. Time series of water levels at three of these gages over two tidal cycles illustrate the typical occurrence of two low and two high tides each tidal day. On three days when inflows to the upper estuary ranged between 117 to 120 cfs, water levels at Gibsonton and Riverview closely tracked each other throughout the tidal cycle, but low tide levels at the Bell Shoals gage were approximately 0.3 meters above low tide levels at the other gages (Figure 4-2A). This is largely due to the presence of limestone shoals downstream of the Bell Shoals gage, which acts to maintain low water levels in the river above kilometer 17. During times of high freshwater inflow (880 to 1015 cfs), water levels rise much higher at the Bell Shoals gage, due to the narrow cross-section of the river channel relative to the downstream gages where the river is much wider and cross sectional areas are greater (Figure 4-2B).

Lower Alafia River
Centerline and USGS gages

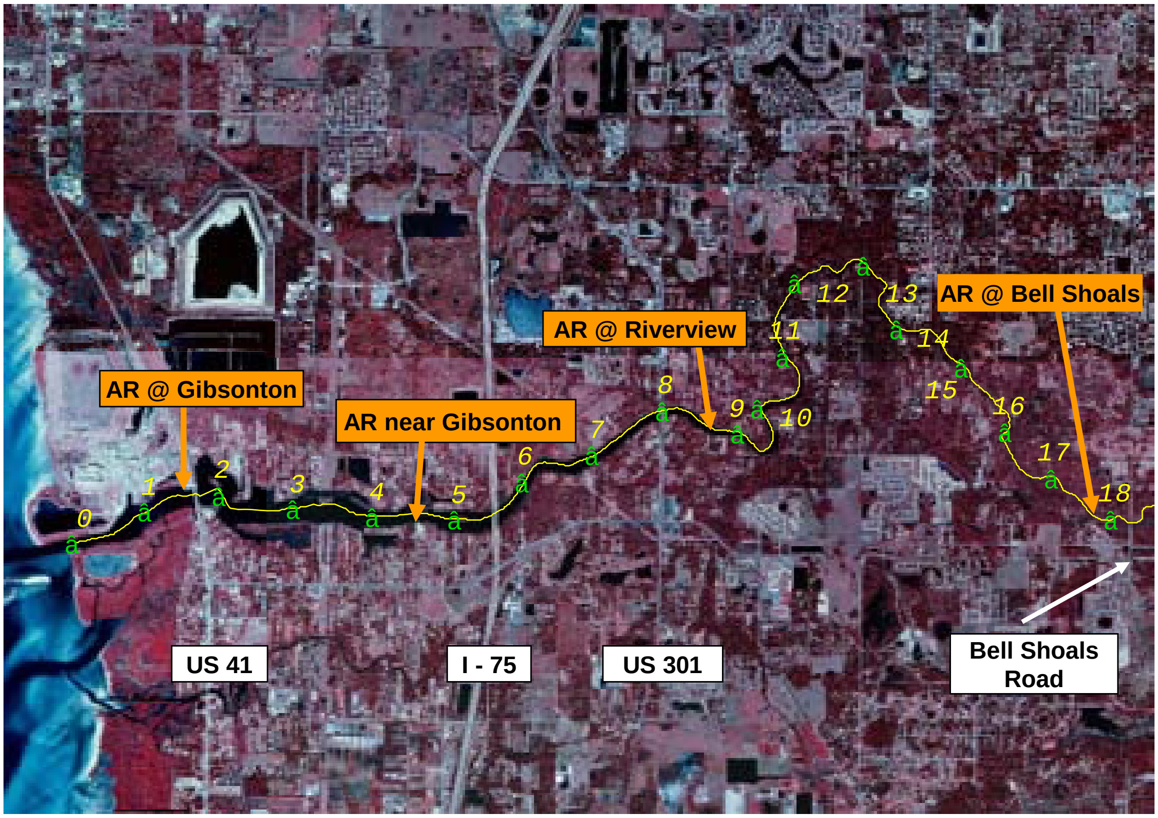


Figure 4-1. Map of the Lower Alafia River showing the locations of three continuous recorders operated by the U.S. Geological Survey. These gages measure water level, temperature, and specific conductance on a 15-minute basis.

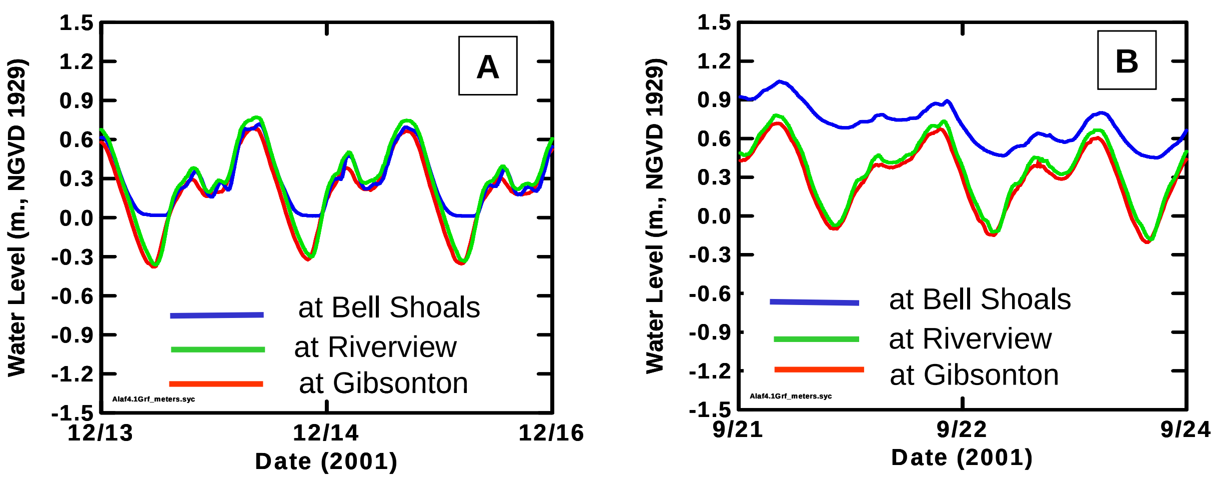


Figure 4-2. Continuous water level values at the three water level recorders in the lower river during two periods in 2001 with low freshwater inflows (A = 117 to 120 cfs) or high freshwater inflows to the upper estuary (B = 879 to 1015 cfs).

Diurnal tidal amplitudes at Gibsonton average about 0.8 meters, with spring tide amplitudes averaging about 1 meter and neap tide amplitudes averaging about 0.6 meters on a diurnal basis (lowest tide to highest tide). Tidal amplitudes are slightly greater (0.05 m increase) at Riverview due to tidal forces acting on a smaller cross sectional area. Diurnal tidal amplitudes at Bell Shoals are less, averaging about 0.6 meters, due to the higher low tide levels at that site.

Boxplots of water levels at these same three gages for the years 2000-2003 are shown in Figure 4-3. There is a gradual increase in median water levels progressing upstream, from a value of 0.20 m at Gibsonton to 0.38 m at Bell Shoals. Ninety-fifth percentile levels show a bigger proportional increase upstream of Riverview, due to the effects of high freshwater inflows on water levels at Bell Shoals. Box plots of monthly water levels at Gibsonton and Bell Shoals are shown in Figure 4-4. Due to seasonal changes in astronomical forces, tides are slightly lower in the winter at Gibsonton where tidal forces predominate. The high values that occurred in July 2001 and December 2002 appear related to the effects of easterly winds. Monthly water levels at Bell Shoals show greater variation in response to seasonal changes in freshwater inflow. Water levels above 3 meters NGVD occurred during high flows during September 2001 and December 2002, the latter events occurring during the wet El Nino winter of 2002-2003. These results show that the effect of freshwater inflows on water levels are most pronounced in the upper part of the lower river.

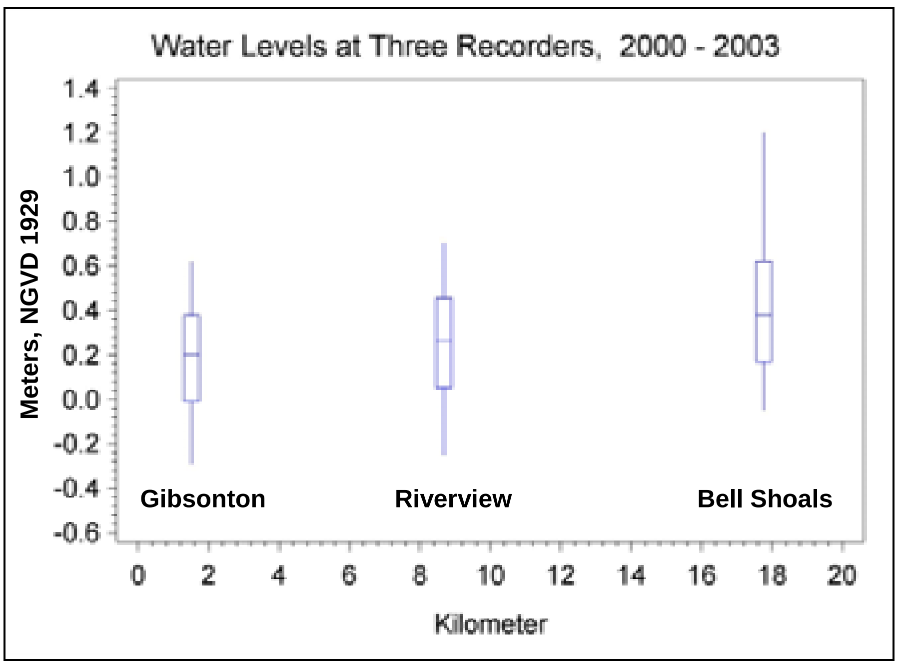


Figure 4-3. Boxplots of 15-minute water levels at three recorders in the Lower Alafia River for the period 2000 – 2003. The ends of the whiskers represent the 5th and 95th percentiles.

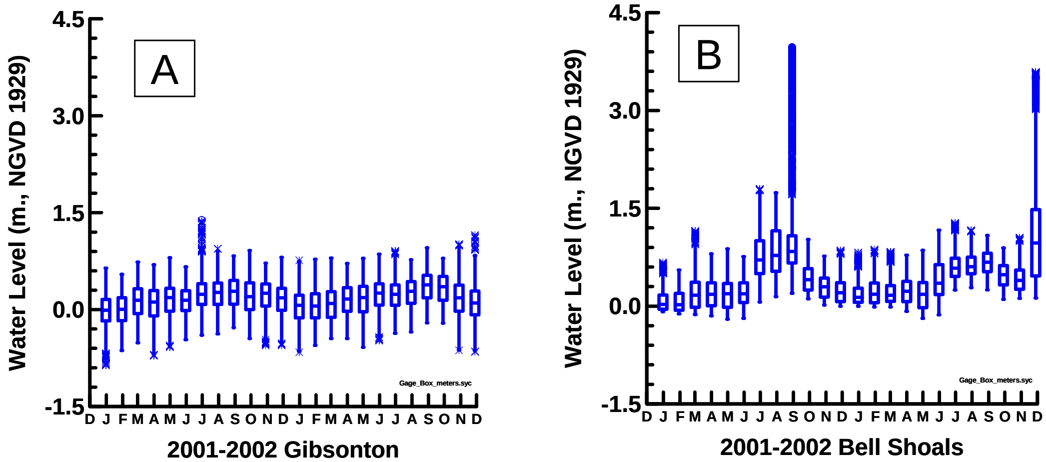


Figure 4-4. Box and whisker plot of mean daily water levels at the Alafia River at (A) Gibsonton and (B) Bell Shoals for 2001- 2002.

4.3 Relationship of Residence Times in the Lower Alafia River to Freshwater Inflow

The mixing time of water in estuaries is often expressed in terms of flushing or residence times. The exact meaning of these terms has varied in previous papers and reports and a variety of methods have been used to estimate either flushing or residence time. A paper by Sheldon and Alber (2002) provides a useful summary of various uses of the terms flushing and residence time, and describes how these represent two different mixing parameters. Flushing time is the time required for the freshwater inflow to equal the amount of fresh water originally present in an estuary. It is specific to fresh water or materials dissolved in it and represents the transit time through the entire estuary. Residence time is the average time it takes particles to escape the estuary. It can be calculated for any type of material and will vary depending on the starting location of the material. Stated another way, it is the remaining time that a particle will spend in a defined region after first arriving at some starting location (Zimmerman, 1976)

We chose to express residence time for the Lower Alafia River using the terms and concepts developed by Miller and McPherson (1991) based on their work on Charlotte Harbor. Using a box modeling approach, they expressed Estuarine Residence Time (ERT) as the time to flush a given fraction of water (or a conservative constituent) from the estuary if it is initially evenly distributed throughout the estuary. Pulse Residence Time (PRT) is the time to flush a given fraction of the constituent from the estuary if is introduced at one location as an instantaneous pulse. As described below, hydrodynamic simulations of the Lower Alafia River were run to determine both ERT and PRT in the lower river as a function of freshwater inflow.

4.3.1 Application of a Laterally Averaged Model for the Lower River

Residence times and salinity distributions in the Lower Alafia River were simulated using a two-dimensional hydrodynamic model for the Lower River developed by Dr. Xinjian Chen of District staff. The hydrodynamic model applied to the Lower Alafia River is a laterally averaged hydrodynamic model called LAMFE (Laterally Averaged Model for Estuaries). The LAMFE model is suitable for narrow rivers and estuaries, and has been previously applied to Hillsborough River, another narrow, tidal river estuary in the region (Chen and Flannery 1998; Chen et al. 2000). Application of the LAMFE model to the Lower Alafia River is described in Chen (2003, 2004, 2007) and Appendices 4A and 4B.

The USGS Alafia River Lithia streamflow gage (kilometer 24.8) was chosen as the upstream boundary and the USGS Alafia River at Gibsonton gage (kilometer 1.5) was chosen as the downstream boundary for the LAMFE model of the Lower Alafia River. Measured freshwater inflows at Lithia were used as the upstream boundary condition, while measured water elevations and salinity profiles at Gibsonton were used as downstream boundary condition. The total length of the simulation domain is about 23.3 km, and was discretized using a mesh with 84 grids distributed along the longitudinal axis of the river and 22 vertical layers.

Freshwater flows from the ungaged areas downstream of the Lithia gage were input to the model at their corresponding grids along the river, using flows predicted by HSPF model simulations (Hydrologic Simulation System – FORTRAN) performed by the University of South Florida (Tara et al. 2001). As described in Chapter 2, ungaged flows were estimated for the years 2002 and 2003 using a regression approach that was based on the relation of the HSPF model generated flows with independent measured hydrologic variables. Flows from Lithia and Buckhorn Springs were input to the model as measured flows from those sources.

The model was calibrated and verified to measured real-time data at USGS stations at Bell Shoals, Riverview, and near Gibsonton. The model was calibrated using data from May 10, 1999 to October 25, 2001, and verified against data from October 26, 2001 to December 14, 2003. Greater details on the LAMFE model and its calibration and verification can be found in Appendix 4A. After calibration and verification, the LAMFE model was used to conduct a series of flow scenario runs to investigate the effects of reductions of freshwater inflow on residence times and salinity distributions in the Alafia River.

The trajectory module in the LAMFE model was used to calculate estuarine residence times (ERT) and pulse residence times (PRT) in the lower river (Chen 2007, Appendix 4B). In the trajectory simulation, the model keeps track of particle movements at each time step. A random walk method was used to simulate the diffusive movements of the particles. Both ERT and PRT were calculated for a series of model runs using different freshwater inflow rates, each of which was kept at a constant flow rate during that simulation. To calculate ERT, particles were evenly distributed throughout the entire model domain at the beginning of the simulation. Because locations of all particles were tracked in the simulation, the percentage of particles being flushed out of the estuary can be calculated for each time step.

Both the ERT and PRT simulations were run for 18 rates of freshwater inflow (Table 4-1) that were selected to represent the flow range of the river based on a duration analysis of daily flows at the Alafia River near Lithia gage. However, total flows to the lower river are used to run the LAMFE model. Therefore, a total freshwater inflow rate had to be assigned to each rate of gaged flow to run the residence time simulations. This was accomplished by evaluating the daily record of combined gaged and total flows to the lower river described in Section 2.3.6. Using this flow record, spring flows and ungaged flows downstream of the USGS streamflow gage were averaged for each corresponding rate of gaged flow to produce eighteen total freshwater inflow rates for the residence time simulations (Table 4-1). In an actual time series, the ratio of total flow to gaged flow will vary temporally depending on localized rainfall and other factors. However, it was concluded this method would give a reasonable estimate of the typical total flow rate that occurs for each rate of gaged flow in order to run the model to evaluate residence time as a function of freshwater inflow.

4.3.2 Estuarine Residence Time (ERT)

The ERT simulations were run for 50 percent and 95 percent removal of particles that were evenly distributed throughout the model domain at the beginning of the simulations. The values for 50 percent removal ranged from 4 days at the lowest rate of inflow (14 cfs total inflow) to 0.4 days for the highest rate of inflow (1826 cfs). The values for 95 percent removal ranged from 19.9 days at the lowest rate of inflow to 1 day for the highest rate of inflow. This value for the lowest rate of inflow was extrapolated from other model output because the model runs were stopped at 14 days. The rate of change in residence time between the two next lowest rates of inflow (39 and 66 cfs total flow) was extrapolated to the produce an ERT value for a flow of 14 cfs. This extrapolation is applied only to rare events, as flows less than 16 cfs (39 cfs total) occurred only 1.6 percent of the time during the 1987-2003 baseline period.

The modeled rates of ERT were used to construct curves of ERT vs. freshwater inflow (Figure 4-5). Linear interpolation was used to estimate ERT values between pairs of modeled values. Since the relationship of ERT to inflow is curvilinear, this resulted in some error in the interpolated values, but given the close intervals of the flows that were simulated it was concluded these errors were very small, as well as errors associated with extrapolating values below a gaged flow rate of 16 cfs.

Table 4-1. Rates of Inflow and Estuarine Residence Time (days) for the Lower Alafia River for 18 rates of freshwater inflow. Inflows expressed as gaged flow at the Alafia River at Lithia gage and the corresponding rate of total flow to the estuary. The second value for 95% removal at 4 cfs gaged flow was extrapolated as described in the text.			
Flow at USGS gage	**Total Inflow**	**50% removal**	**95% removal**
CFS		**Days**	
4	14	4.0	13.9 - 19.9
16	39	2.3	10.4
36	66	2.1	7.8
50	85	2.0	7.0
68	111	1.8	6.3
73	118	1.8	6.1
95	144	1.7	5.4
105	161	1.6	5.1
120	176	1.5	4.7
151	213	1.4	3.9
192	281	1.3	3.5
235	341	1.2	3.1
258	381	1.2	2.9
368	515	0.9	2.4
413	582	1.0	2.2
575	784	0.9	1.9
837	1104	0.7	1.5
1100	1402	0.5	1.2
1400	1826	0.4	1.0

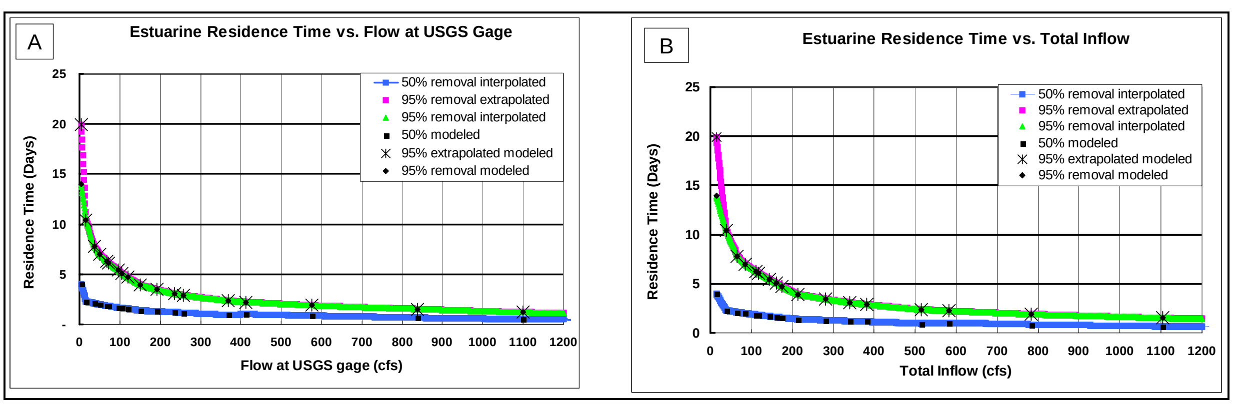


Figure 4-5. Simulated values of Estuarine Residence Time in the Lower Alafia River for 50% and 95% removal of particles evenly distributed in the river as a function of (A) gaged flow at the Alafia River near streamflow gage (B) and total inflow to the lower river.

These figures show the relationship of ERT to freshwater inflow is most responsive at low rates of inflow. This nonlinear relationship is due to the physical mixing characteristics of estuaries, and has been documented in other studies (Miller and McPherson 1991, Huang and Spaulding 2002, Huang and Liu 2007). This has important implications for the freshwater inflow management, for a given flow reduction (e.g., 100 cfs) will have much more effect on residence time if it occurs during low flows. In the Lower Alafia, a change of 100 cfs total inflow results in a change of ERT of 0.4 days if flows are reduced from 500 to 400 cfs, but results in a change of 4.0 days if flows are reduced from 150 to 50 cfs (Figure 4-5B). It is reiterated that ERT is the time to flush particles from the entire lower river if they are evenly distributed throughout the river at the beginning of the simulation. Although the reach from the upstream model boundary at the Alafia at Lithia gage and Bell Shoals is not part of the brackish estuary, there are tidal water level fluctuations in this reach. However, water moves through this portion of the river quickly, so its inclusion had very little effect on the simulated ERT values and also the PRT values discussed below.

4.3.3 Pulse Residence Time (PRT)

PRT was calculated by releasing particles at the head of the estuary and tracking how long it took for 50 percent of the particles to move past twenty-four locations in the lower river separated into one-kilometer intervals. In this way, PRT represents the age of water at each of these locations for a given rate of inflow. Figure 4-6 shows simulated particle distributions in the estuary that were released on three successive days for thee different flow conditions. The figures show locations of the particles on the third day of each simulation, to illustrate how the particles are distributed further downstream at higher rates of freshwater inflow. At a rate of 400 cfs gaged flow, the particles released on the first day have exited past the mouth of the river.

Figure 4-7 illustrates the time it took for 50 percent of the particles to move past different locations in the estuary. For example, for a flow rate of 151 cfs at the USGS gage, it took 0.6 days to move 50 percent of the particles past a point 10 kilometers downstream from the Alafia at Lithia gage, 1.0 days to move the particles past a point 12 kilometers downstream, and 1.5 days to move the particles past a point 14 kilometers downstream. For the MFL analysis, these results were converted to distances using the river centerline, in which distances increase from the mouth moving upstream.

The results for PRT for five segments in the lower river are listed in Table 4-2 for the same 18 rates of flow used for the ERT analysis. For a given rate of flow, the PRT values increase downstream as it takes longer times for 50 percent of the particles to move past those locations. For the lowest rate of inflow, the PRT at km 18 near Bell Shoals was 1.6 days and the PRT at kilometer 2 (just upstream from the US 41 bridge) is 11.1 days. For the highest rate of inflow the PRT was 0.1 days at Bell Shoals and one 1.0 days at kilometer 2.

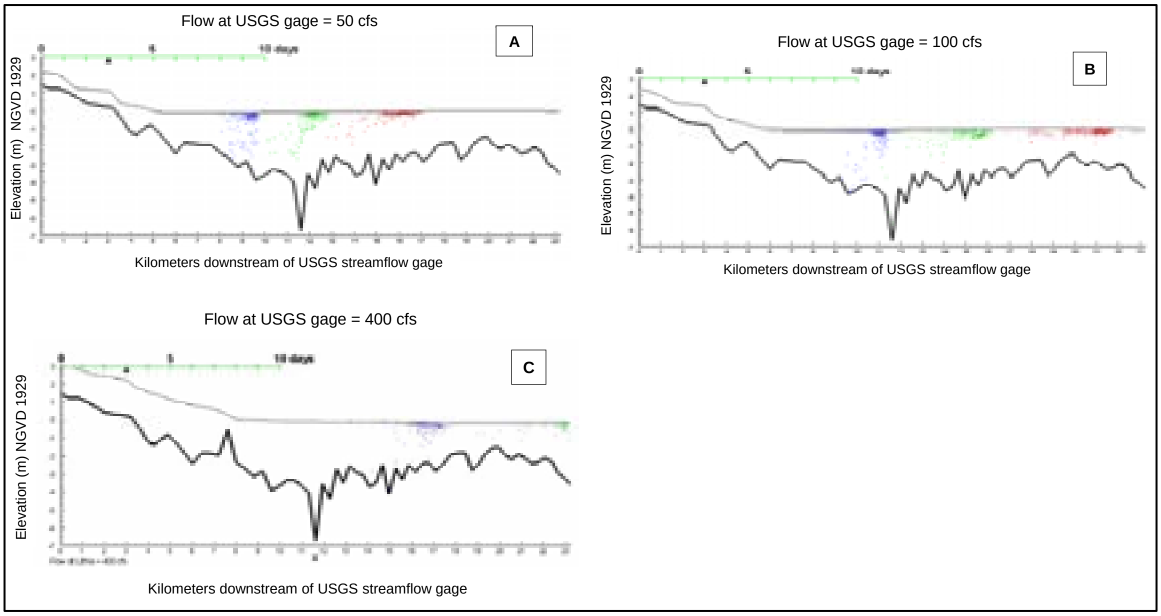


Figure 4-6. Simulated particle distributions in the Lower River resulting from instantaneous particle releases at the USGS streamflow gage at Lithia on three successive days (day 1 = red, day 2 = green, day 3 = blue). Distributions shown for three rates of flow at the gage: A = 50 cfs; B = 100 cfs; and C = 400 cfs. Graphics show distributions at the end of the third day after the first release.

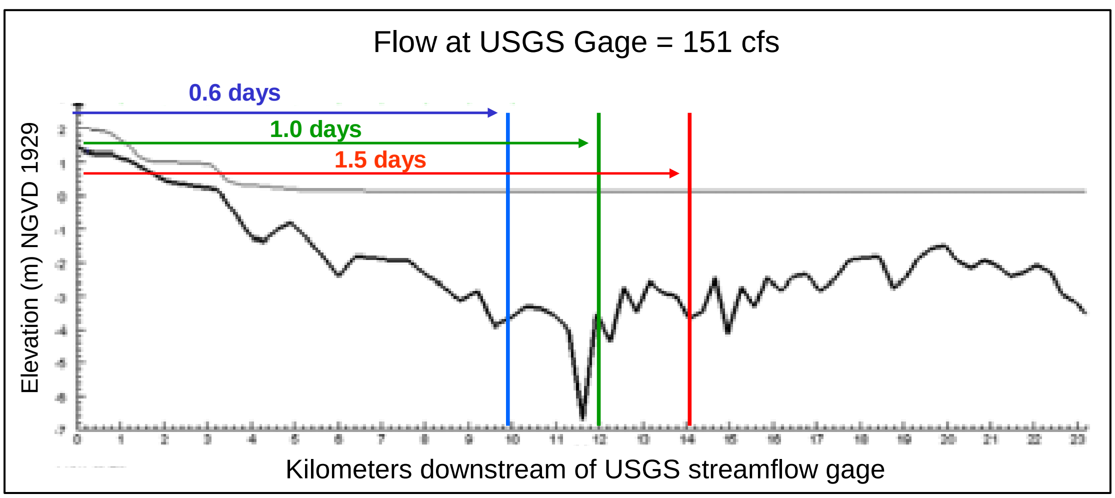


Figure 4-7. Illustration of method for calculating the time for particles to pass different locations in the estuary for a given rate of flow. The pulse residence time for a given location was when 50% of the particles passed that location.

Table 4-2. Simulated Pulse Residence Times in days for 50% or particles released at the USGS Alafia River at Lithia gage to pass various locations above the river mouth. Values expressed for flows (cfs) at the USGS gage and corresponding total flow to the lower river.

		Kilometer				
Gage Flow	**Total Flow**	**18**	**14**	**10**	**6**	**2**
4	14	1.6	3.4	5.0	6.8	11.1
16	39	1.2	2.4	3.4	4.5	6.9
36	66	0.6	1.8	2.9	4.2	6.0
50	85	0.5	1.6	2.7	3.6	5.2
68	111	0.5	1.2	2.0	2.9	4.6
73	118	0.4	1.2	2.0	2.9	4.2
95	144	0.3	1.0	1.9	2.7	3.6
105	161	0.3	0.9	1.9	2.7	3.8
120	176	0.3	0.9	1.6	2.4	3.5
151	213	0.3	0.8	1.7	2.4	3.4
192	281	0.3	0.7	1.4	2.0	2.9
235	341	0.2	0.5	1.2	1.9	2.7
258	381	0.2	0.5	1.1	1.8	2.6
368	515	0.2	0.4	0.7	1.3	2.1
413	582	0.2	0.4	0.7	1.3	1.9
575	784	0.2	0.3	0.6	1.1	1.7
837	1104	0.1	0.3	0.5	0.9	1.4
1100	1402	0.1	0.3	0.4	0.7	1.1
1400	1826	0.1	0.2	0.4	0.6	1.0

As with ERT, PRT values in 1 cfs increments were interpolated between the modeled values. Plots of both modeled and interpolated values are shown for three locations in the estuary in Figure 4-8. As with ERT, the relationship of PRT with inflow is highly nonlinear and most responsive to changes on inflow at low rates of inflow, a pattern which also has been observed in other estuaries (Sheldon and Alber 2002, Shen and Haas 2004, Huang and Liu 2007).

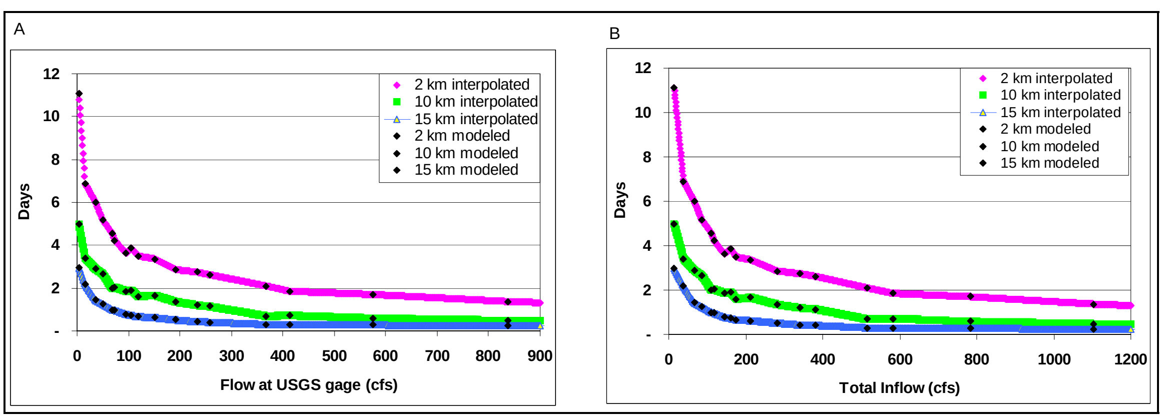


Figure 4-8. Curves of modeled and interpolated pulse residence times for three locations in the estuary vs. flow at (A) the Alafia River at Lithia streamflow gage and (B) total inflows to the lower river.

In order to evaluate the response of phytoplankton (as chlorophyll *a*) in the lower river to freshwater inflow, PRT values were assigned to water samples collected from the river during the minimum flows study. Depending on where they were collected, water samples were assigned to one of the seventeen one-kilometer segments in the lower river below Bell Shoals Road. For each of these segments, data sets of the combined modeled and interpolated PRT values were used to assign PRT values to samples collected within that segment. The PRT value that was assigned to a sample was based on the average flow rate during the time preceding when the sample was taken. Preceding flows were averaged over anywhere from 1 to 11 days so that the flow term used to assign the PRT value corresponded to the PRT time in that segment during the flow range over which the sample was taken. The results of the merging of the PRT values with data from the water quality samples are discussed in Chapter 5.

Chapter 5

Salinity and Water Quality Characteristics of the Lower Alafia River Estuary and Relationships with Freshwater Inflow

5.1 Introduction

The salinity and water quality characteristics of the Lower Alafia River and their relationships with freshwater inflow are discussed in this chapter. The thermal characteristics of the lower river are described first, as water temperature affects both the water quality and biological characteristics of the river. The salinity characteristics of the river and its response to freshwater inflow are then described, as seasonal salinity distributions exert a strong influence on the distribution of biota in the river. Both empirical data analyses and outputs from the District's LAMFE model are evaluated with regard to the effects of freshwater inflows on salinity distributions in the lower river.

The evaluation of water quality relationships focuses on dissolved oxygen, nutrients, and chlorophyll *a.* Both dissolved oxygen and chlorophyll *a* concentrations show relationships with freshwater inflow that are related to the effects of inflows on the salinity regime, density stratification, nutrient loading, and residence time in the lower river.

5.2 Data Sources

Salinity and water quality data analyzed in this report come from two principal sources. The first source is the USGS continuous recorders (gages) in the river that were described in Chapter 4. These gages record water level, temperature and specific conductance at 15 minute intervals at four sites in the lower river (Figure 4-1). Salinity values at these sites were computed from the 15 minute data for specific conductance by the District using the formulae of Cox et al. (1967). Data from these sites analyzed in this report were collected between the spring of 1999 through 2003, providing over four years of data. The high frequency of data collection at these sites captures the temporal variability of salinity on a tidal, daily, and seasonal basis and is valuable for examining relationships with freshwater inflows.

The other sources of data are an extensive series of grab samples taken by three agencies working on the lower river (Figure 5-1). The Environmental Protection Commission of Hillsborough County (EPCHC) has taken monthly grab samples at three fixed-location sites for vertical profiles and water chemistry analysis. Figure 5-1 shows the locations of these EPCHC sites: Station 74 at the US-41 bridge (km 1.6); Station 153 at the US-301 bridge (km 8.0) and Station 114 at Bell Shoals Road (km 18.2). These three stations are located near the

Figure 5-1. Location of SWFWMD (yellow triangles) and EPCHC (orange circles) vertical profile and water quality stations and six HBMP sampling strata (green AR series) in the Lower Alafia River.

mouth, the mid-point, and at the upstream end of the lower river. The station at Bell Shoals Road is located in the tidal freshwater zone of the river, where it provides valuable data for the quality of fresh water that discharges to the tidal river estuary from about 79 percent of the Alafia River watershed.

Sampling at these EPCHC sites consists of *in situ* measurements of specific conductance, salinity, temperature, and dissolved oxygen concentrations using portable meters and the collection of water samples that are returned to the laboratory for analyses of nutrients, chlorophyll, and other parameters. Meter measurements are taken from depths near the water surface, mid-depth, and near bottom. Water chemistry samples are collected at mid-depth. Sampling began in 1974 at the US-41 and Bell Shoals Road sites and in 1999 at US-301. In 1999, the EPCHC also began collecting vertical profile measurements taken from a boat at approximately one-kilometer intervals in the lower river. Those data through December 2003 were also included for analysis in this report.

Vertical profiles of specific conductance, salinity, temperature and dissolved oxygen were also taken at nineteen, fixed-location sites in the lower river by the SWFWMD between 1999 and December 2002 (Figure 5-1). Sampling was on roughly a monthly basis. Samples for water chemistry analysis were collected at six of these stations, and at four moving location stations that were based on the locations of the 0.5, 6, 12 and 18 psu isohalines in the lower river on each sampling day.

The final sampling program for the lower river is from the Hydrobiological Monitoring Program (HBMP) that is conducted by Tampa Bay Water. The Tampa office of the firm PBS&J Inc. coordinates the HBMP, conducts much of the field sampling, and prepares most of the interpretive analyses, although some data collection and analytical tasks are sub-contracted out to other agencies, academic institutions, or firms (PBS&J 2003, PBS&J 2006). The rationale, design, sampling protocols, and analytical strategies for the HBMP are described in PBS&J (1999). Vertical profile and water quality sampling in the Lower Alafia River by the HBMP is implemented using a probabilistic design in which sampling is randomized within seven strata that are oriented along the longitudinal axis of the lower river (Figure 5-1). Two vertical profile stations and water are collected within each stratum on a monthly basis, with grab samples for water chemistry analysis also collected at these sites.

The HBMP sampling began in the spring of the year 2000 and continues to the present. Data presented in this report are limited to that collected between 2000 and the end of 2003. In addition to water quality sampling, biological sampling is performed in the Lower Alafia River for benthic invertebrates, fish collections using seines and trawls, and ichthyoplankton collections using plankton nets. Sampling is on a monthly basis for all parameters, with the number of samples varying between biological collections (PBS&J 1999). Vertical profile measurements are made along with each of these biological collections, greatly expanding the data base for temperature, salinity, and dissolved oxygen in the lower river.

Combined data sets for vertical profiles and water chemistry data were created by merging data from the EPCHC, SWFWMD, and the HBMP data collection programs. Quality control checks were run on the data and variables were expressed in consistent units where possible. A total of 3032 vertical profiles with at least one meter maximum depth were included in the combined data base for 1999-2003. Data prior to 1999 were also available at two EPCHC water quality sites (US 41 and Bell Shoals Road). With a few exceptions, only those EPCHC data collected after 1998 were analyzed with the combined data base for the lower river for the sake of consistency and a desire to characterize the recent water quality characteristics of the lower river.

The distribution of vertical profile measurements within one-kilometer segments in the lower river is shown in Figure 5-2. The segment labeled 0 is a half-kilometer segment that extends from the mouth of the river to kilometer 0.5. Vertical profile data are distributed well across the river. All segments from kilometer 1 to 13 have at least 150 observations, with fewer collections made upstream, where salinity is normally fresh except during prolonged dry periods. The number of samples collected within these segments by the different agencies is shown in Figure 5-3. The HBMP clearly provides the most vertical profile measurements in nearly all segments, except for segments 2 and 18 where the EPCHC has fixed location water quality stations.

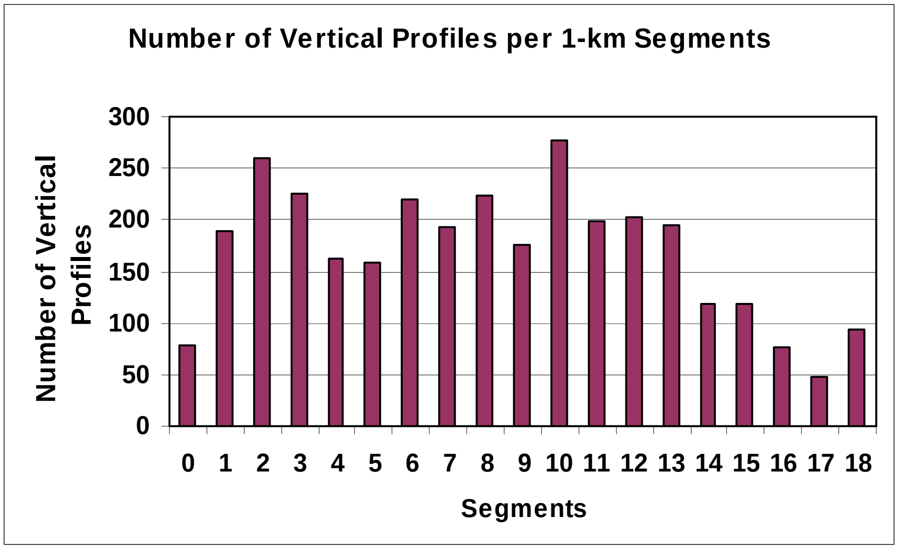


Figure 5-2. Number of vertical meter profiles (water temperature, salinity, dissolved oxygen) taken in one-kilometer segments during 1999-2003. Segment 0 is a one-half kilometer segment from the mouth of the river to kilometer 0.5.

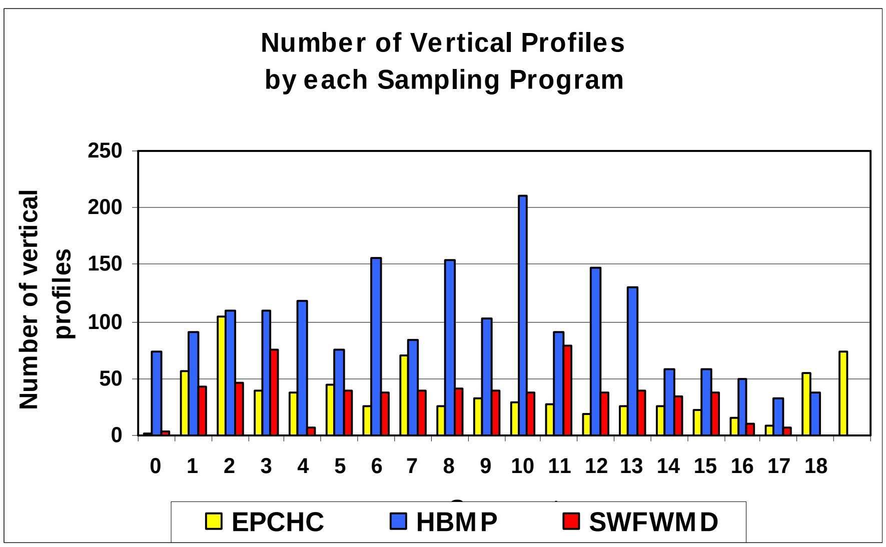


Figure 5-3. Number of vertical meter profiles taken by the three agencies collecting data on the lower river: Environmental Protection Commission of Hillsborough County (EPCHC); the Tampa Bay Hydrobiological Monitoring Program (HBMP) and the Southwest Florida Water Management District (SWFWMD).

Data for water temperature, salinity, and dissolved oxygen are discussed initially below using the combined vertical profile data base. The number and distribution of samples for chlorophyll *a*, nutrients and other water quality parameters are discussed later in this chapter with analyses and interpretation of those data.

5.3 Water Temperature

Water temperature affects a number of important physical, chemical and biological processes, including density of the water masses, the solubility of dissolved oxygen, and metabolic processes such as respiration and phytoplankton growth rates. Water temperature in the Lower Alafia River is in turn controlled by a number of physical factors, including the morphology of the tidal river, exposure to sunlight, water color, residence time, and the temperature of waters from both Tampa Bay and inflow from the river watershed.

Median water temperatures show a slight decrease from downstream to upstream in the river, ranging from about 27^0 C near the mouth of the river to about 25^0 C in the upper regions between kilometer 13 and Bell Shoals Road (Figure 5-4). Viewed on a monthly basis, water temperatures in the lower and upper reaches are similar in the cool months from November through January, but the upper reaches are cooler by about 2-3 degrees in the summer (Figure 5-5). A comparison of water temperatures between the USGS at Gibsonton (km 1.5) and Bell Shoals gages (km 17.8) support this spatial pattern (Figure 5-6). Warmer water temperatures in the lower portion of the river are likely due to the broad morphology of this region of the river, with longer residence times and greater exposure to sunlight. The upper reaches are more shaded and influenced by freshwater inflow, which is relatively cooler in the summer due to the rapid transport of runoff from rainwater through the riverine system.

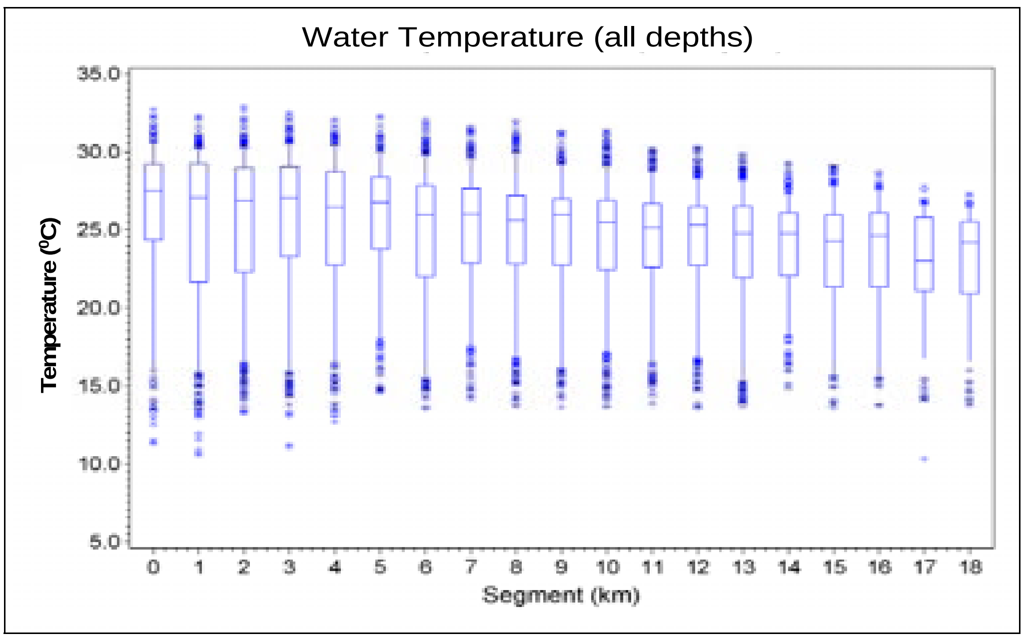


Figure 5-4. Boxplot of water temperatures for the 1999-2003 in one kilometer segments in the Lower Alafia River.

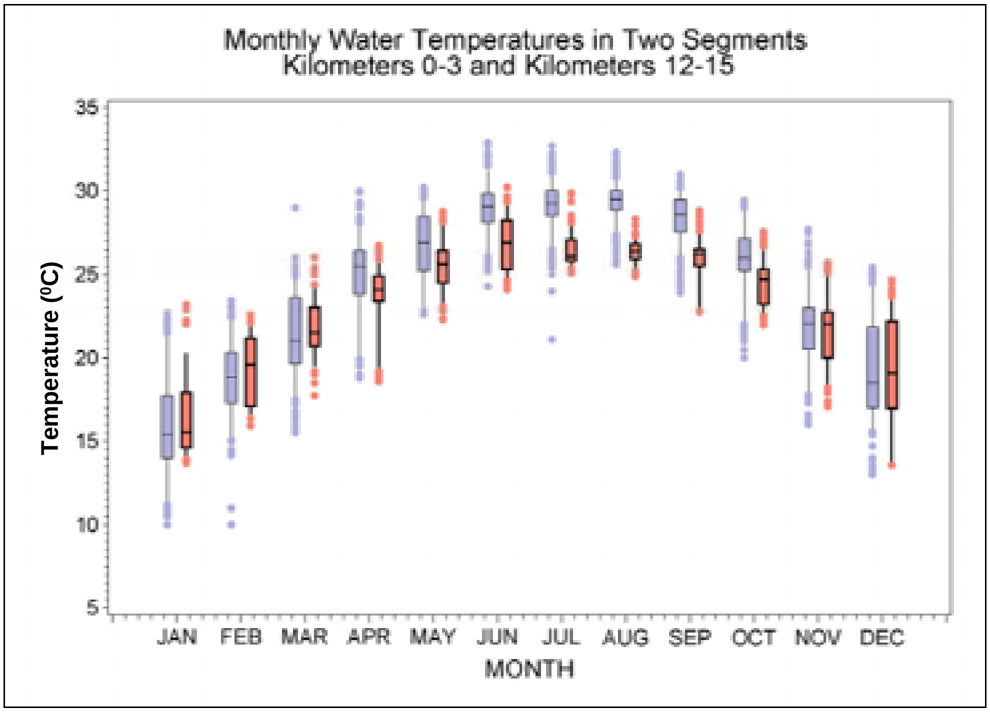


Figure 5-5. Boxplots of monthly water temperatures (all depths) for two three-kilometer segments from the vertical profile data base. Blue = kilometer 0-3; Orange = kilometer 12-15.

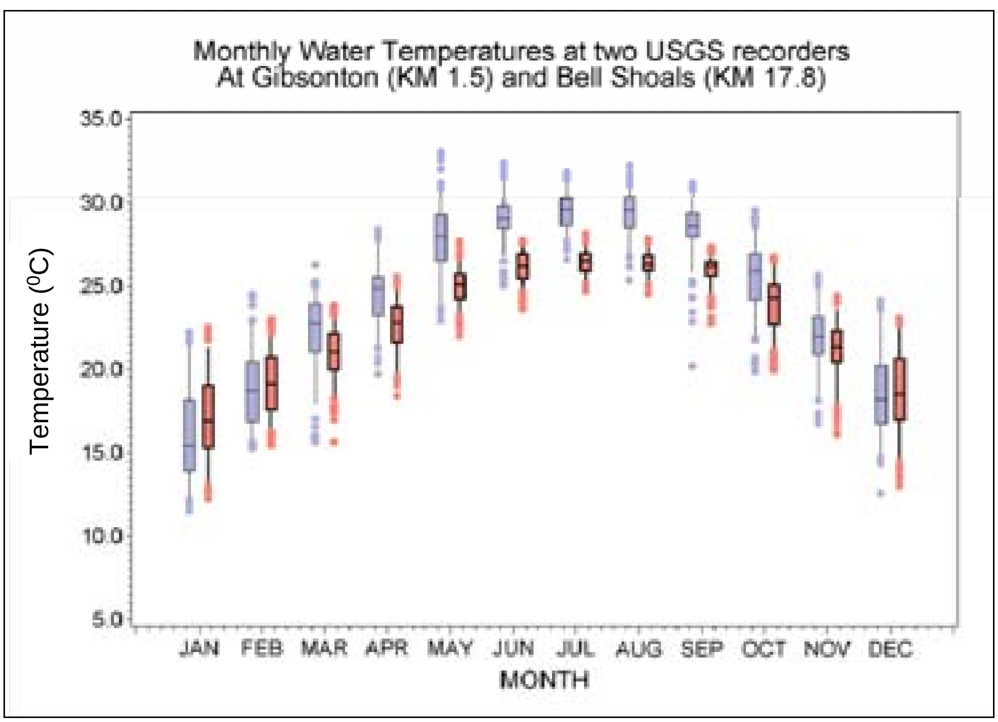


Figure 5-6. Monthly boxplots for surface water temperatures for two USGS gages at Gibsonton and Bell Shoals. Blue = at Gibsonton; Orange = at Bell Shoals.

Flows from Lithia and Buckhorn Springs also exert an effect on temperature in the upper river, both during cold and warm periods. Like other artesian springs in Florida, waters from Buckhorn and Lithia springs remain fairly isothermal year-round, averaging about 25^0C (Rouseneau et al. 1977). During the coldest winter months these spring-flows act to warm the river, which could provide benefits to cold intolerant species such as manatee and snook. During the warmer months spring flows tend to cool the river. This may be particularly important in the estuary's upper reaches during the spring low-flow season, when water temperatures are rising and groundwater discharge can provide a substantial proportion of total flow to the lower river. A cooling effect in warm months could help maintain adequate dissolved oxygen concentrations in this part of the river, since the solubility of dissolved oxygen declines with increasing water temperature. Although the thermal effects of flows from Lithia and Buckhorn Springs were not explicitly analyzed or modeled in this report, it can be concluded the spring discharges provide thermal benefits to the upper regions of the lower river during substantial portions of the year.

The daily variation of water temperature in surface and bottom waters is shown for the USGS gage at Riverview, which is located near the middle of the lower river (Figure 5-7). In general, there are only small differences between surface and bottom temperatures at all the USGS recorders and in the vertical profile measurements.

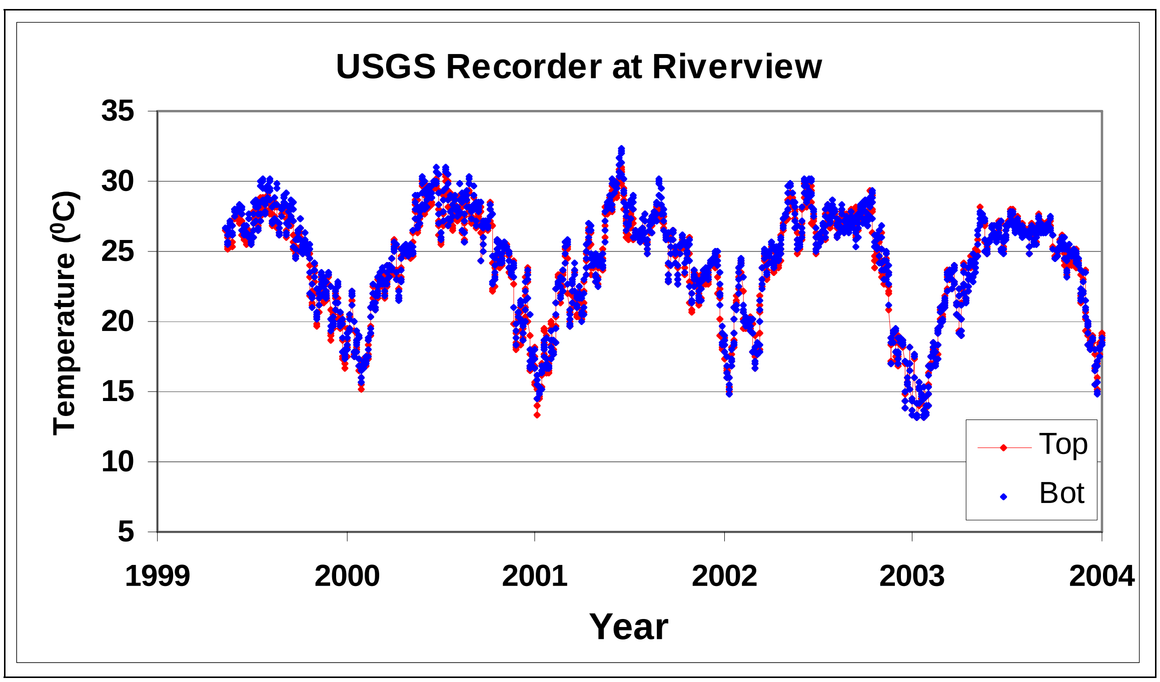


Figure 5-7. Mean daily water temperatures in the top and bottom recorders at the USGS Alafia at Riverview gage for 1999-2003.

5.4 Salinity

Both surface and bottom waters in the Lower Alafia River display strong horizontal salinity gradients that extend from the river mouth to the freshwater reaches, with the form of these gradients strongly influenced by the rate of freshwater inflow. As will be discussed in more detail, the Lower Alafia is unusual in that vertical salinity gradients are much more pronounced than in other unimpounded rivers in the region.

5.4.1 Horizontal salinity gradients

A boxplot of salinity in the top meter of water along the river's longitudinal axis shows that median salinity values were near 22 psu near the river mouth and near fresh water at kilometers 11 and above (Figure 5-8). However, there is wide variation in salinity in the river, with inter-quartile ranges (difference between the 25th and 75th percentiles) increasing toward the mouth of the river where the influence of Tampa Bay is the greatest. Maximum salinity values exceeded 30 psu in the most downstream three kilometers, and reached 8 psu as far upstream as km 13. Fresh water can extend to the river mouth in this top layer during high flows.

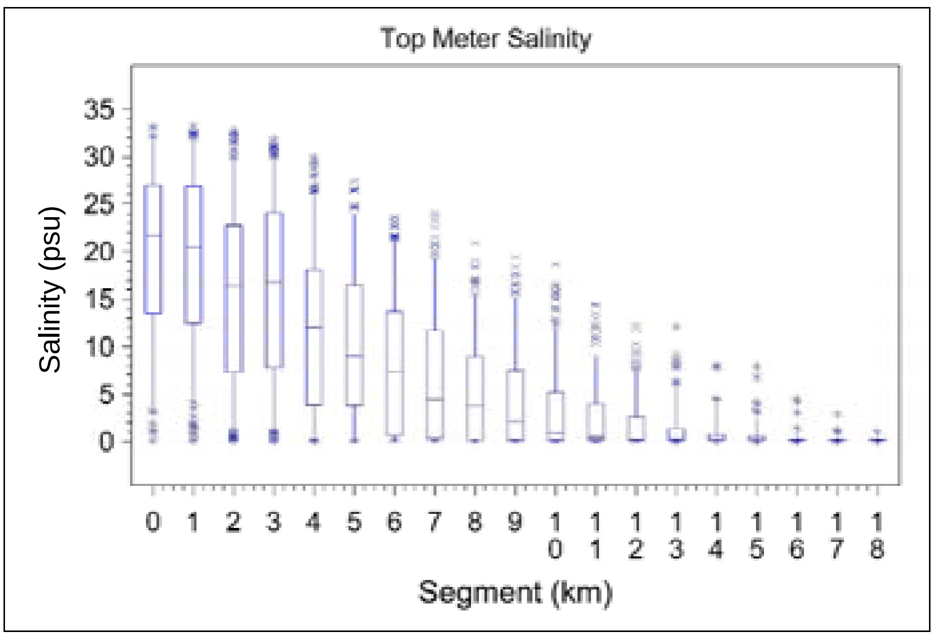


Figure 5-8. Boxplot of salinity in the top meter of the water column in one kilometer segments in the Lower Alafia River for 1999-2003 from the combined vertical profile data set.

Boxplots of salinity at two meters depth show higher values, with median values above 20 psu as far upstream as km 6 (Figure 5-9). Interquartile ranges are greatest between kilometers 6 and 10, partly because deep waters in this portion

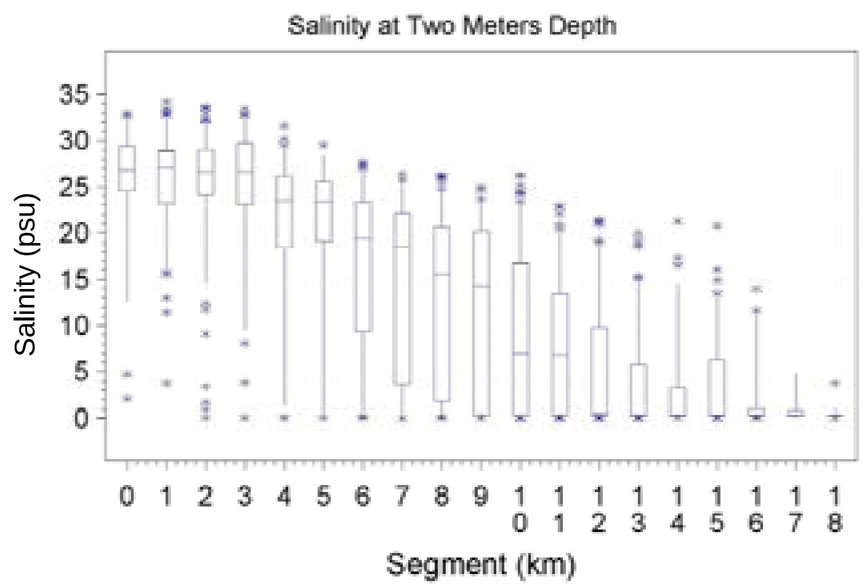


Figure 5-9. Boxplot of salinity at two meters depth in one-kilometer segments in the Lower Alafia River for 1999-2003 from the combined vertical profile data set.

of the river experience both high salinity in the dry season and low salinities in the wet season. Further downstream, salinity values tend to stay higher in the wet season. Maximum salinity values show much higher values in the upper river reaches compared to top meter values, with maximum values above 10 psu extending as high as kilometer 16.

Salinity gradients were also examined by performing empirical and hydrodynamic salinity modeling of the lower River. As described in Appendix 5A, 5B, and 5C, the firm of Janicki Environmental, Inc. developed empirical salinity models of the lower river from stream and springflow data and the combined vertical profile data base for the river. Three types of empirical salinity models were developed: a whole-river model to predict salinity at any location in the river based on its kilometer position and depth (Appendix 5A); models to predict the location of specific isohalines in the river (Appendix 5B); and models to predict salinity at a series of fixed location stations (Appendix 5C). Along with the LAMFE mechanistic model for the lower river, these empirical models were used to simulate the salinity characteristics of the lower river and evaluate the effect of reducing freshwater inflows on the river's salinity regime.

A boxplot of average top-meter salinity along the longitudinal axis predicted by the whole-river salinity model is presented in Figure 5-10. These values were generated for the 1987-2003 baseline period using freshwater inflow to the upper estuary as an independent hydrologic variable. These results show very similar patterns to the empirical data from the combined data base measured during 1999-2003 (Figure 5-8). Median salinity near the river mouth was near 22 psu,

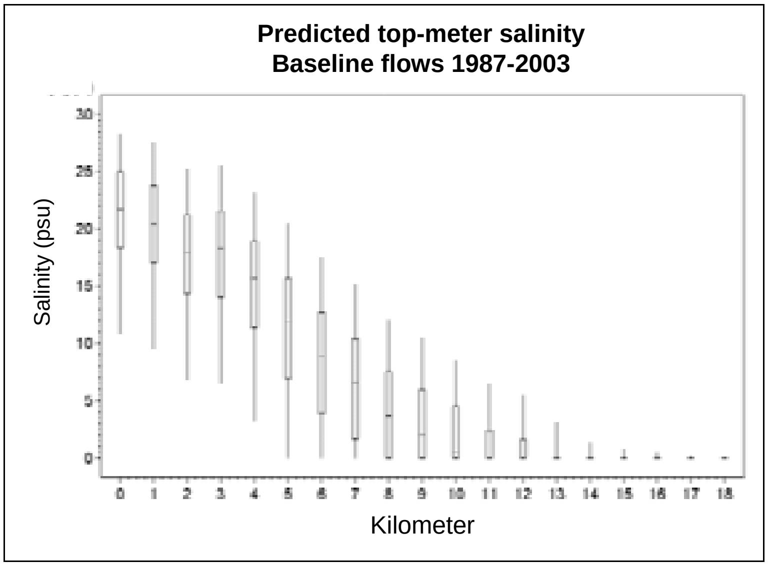


Figure 5-10. Boxplot of predicted top meter salinity in one-kilometer segments in the Lower Alafia River for the 1987-2003 baseline period.

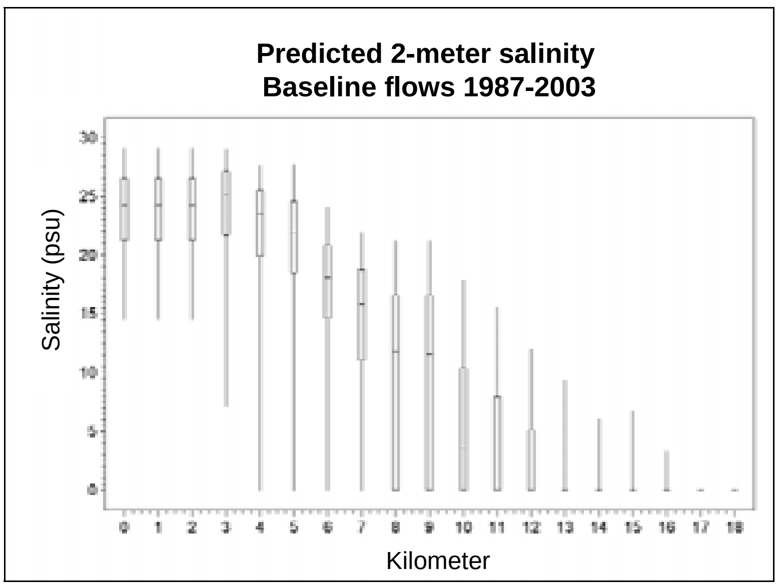


Figure 5-11. Boxplot of predicted salinity at two meters depth in one-kilometer segments in the Lower Alafia River for the 1987-2003 baseline period.

while median salinity values were near fresh from kilometer 11 upstream. Modeled values for two meters depth for the baseline period (Figure 5-11) also show similar patters to the data for the more recent period, except that the recent data showed higher upper quartile values upstream of kilometer 13. This is likely due to the influence of the very dry, saline conditions during the 2000-2001 drought, which influenced the recent data set. Very dry conditions also persisted during the spring of 2002, thus allowing this minimum flow study to document the estuary under prolonged low flow conditions.

5.4.2 Vertical salinity gradients

A very distinctive characteristic of the Alafia River is the high degree of vertical salinity stratification that occurs over much of the river channel during most flow conditions. Vertical density stratification, in which less dense fresher water tends to layer over more dense saline water, is common in riverine estuaries where large volumes of fresh water mix with salt water from the receiving bay or ocean. As will be discussed in this chapter, the relationship of vertical stratification to freshwater inflow has important implications to dissolved oxygen concentrations in the Lower Alafia, which in turn, makes it an important factor for the evaluation of minimum flows.

For some purposes in this report, stratification was calculated as the difference between surface salinity and salinity at 2 meters depth in order to keep this metric consistent between river segments to allow better comparison of stratification-inflow relationships throughout the lower river. Actual stratification, or the difference between the lowest and highest salinity in the water column, will be related to the maximum water depth at a particular site. However, examination of vertical profiles from the Lower Alafia indicate that the pycnocline, or region of greatest vertical salinity change in the water column, is usually shallower than two meters in most reaches of the lower river. Density stratification is also dependent on water temperature, but the focus of this study was to examine the effects of inflows on vertical salinity gradients.

A boxplot of salinity stratification in two kilometer segments in the river is presented in Figure 5-12. Stratification is typically highest in the lower and middle sections of the river, as this is where much mixing of fresh and saline water occurs. Median stratification is about 12 psu near segment 4 (3-5 km), and between about 5 to 10 psu between segments 2 and 10 (kilometers 1 – 11). Stratification was lower in the one kilometer segment labeled zero, as this is generally where higher salinity waters are found from top to bottom. Median stratification values near 0 are found at segments 12 to 18, as these segments are typically fresh from top to bottom during medium to high freshwater inflows.

The relationship of stratification to freshwater inflow is shown for four river segments in Figure 5-13. In segment 2 (kilometers 1-3) stratification is low during very low freshwater inflows (< 100 cfs), as there is not sufficient freshwater inflow to push a low salinity surface layer to this part of the river. Stratification, however, increases at higher freshwater flows. A similar response is observed at segment 6 (kilometers 5-7), but stratification is low at very high flows as this station becomes fresh. The two upper segments show a similar relationship in that stratification is highest in these zones at low flows, which allow the salt wedge to move into this part of the river. High flows eliminate stratification at these sites as they become fresh and are mixed from top to bottom.

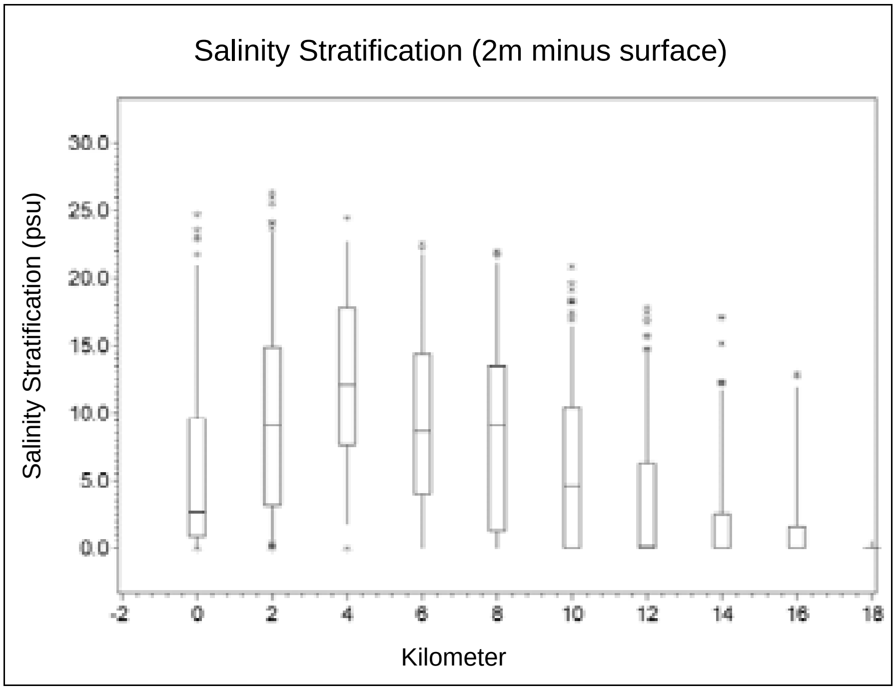


Figure 5-12. Boxplot of salinity stratification (2 meters – surface) in two-kilometer segments in the Alafia River taken from the combined vertical profile data base.

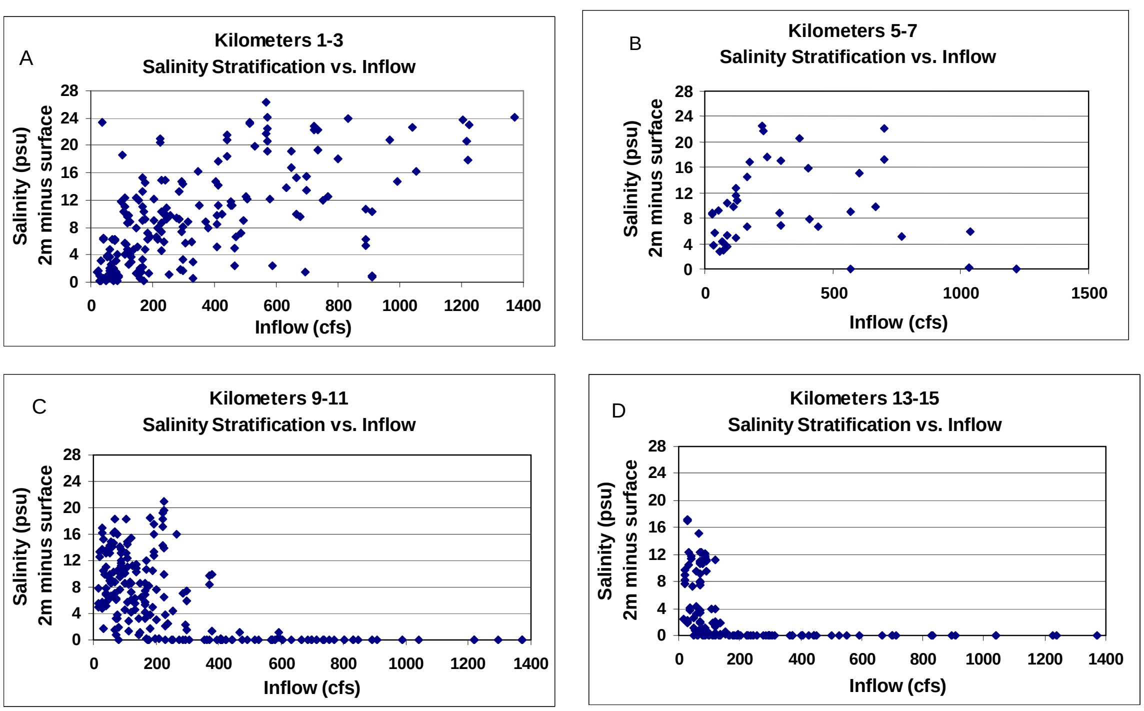


Figure 5-13. Relation between freshwater inflow and salinity stratification (two meters value minus surface) for samples in two meter intervals in the Lower Alafia River taken from the combined vertical profile data base.

Temporal variations in stratification are also apparent at the USGS continuous gages. Time series plots of 14-day moving average values for top and bottom salinity at Gibsonton and Riverview gages are shown in Figure 5-14. Stratification was very small at Gibsonton during the very low flows and high salinity conditions in the spring of 2000 and 2001, but increased dramatically when surface salinity dropped during periods of freshwater inflow (Figure 5-14A). At Riverview, salinity stratification was minimal in the summer wet seasons and much of 2003, when both top and bottom waters were fresh (Figure 5-14B).

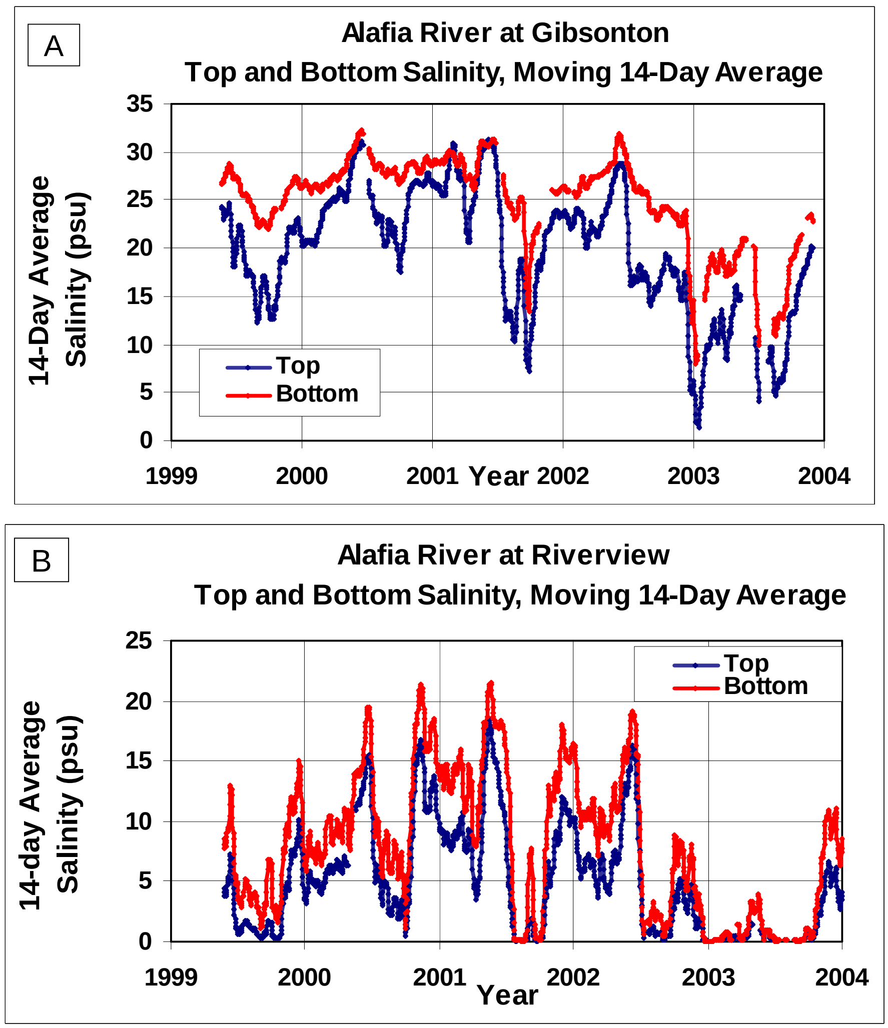


Figure 5-14. Fourteen-day moving average salinity for the top and bottom recorders at the USGS gages at Gibsonton and at Riverview.

It is important to note that salinity stratification is much more pronounced in the Lower Alafia than other free-flowing rivers in the region such as the Peace, Little Manatee, Myakka, and Anclote. Stratification in the Alafia tends to be highest when in areas of the river where mean water column salinity is in the range of about 7 to 25 psu (Figure 5-15), as this corresponds to the principal mixing zone of the river. For comparison, a similar plot of salinity stratification vs. mean salinity is presented for the Little Manatee River in Figure 5-16. The Little Manatee River is located about 9 miles south of the Alafia and also flows westward to Tampa Bay. Its watershed is only about 54 percent of the area of the Alafia, but the length of its estuarine reach is very similar (Estevez et al. 1991a). It is clear that stratification in the Little Manatee is much less, averaging 1.3 psu with only 8 values exceeding a vertical stratification value of 10 psu.

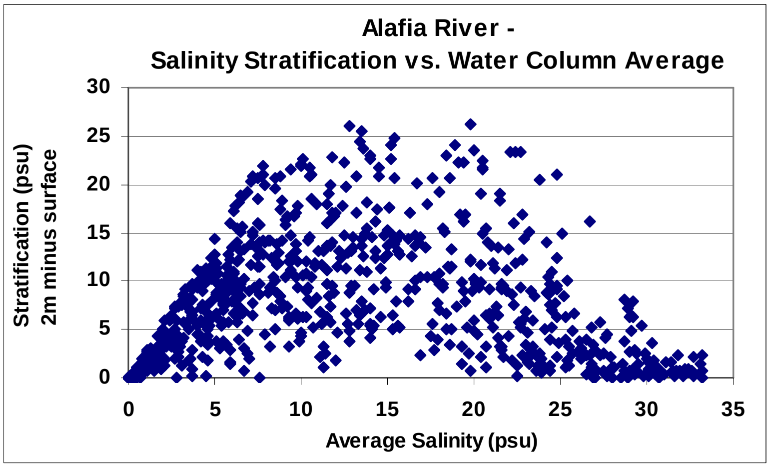


Figure 5-15. Relation of average water column salinity and salinity stratification (two meters – top) in the Lower Alafia River taken from the combined vertical profile data base.

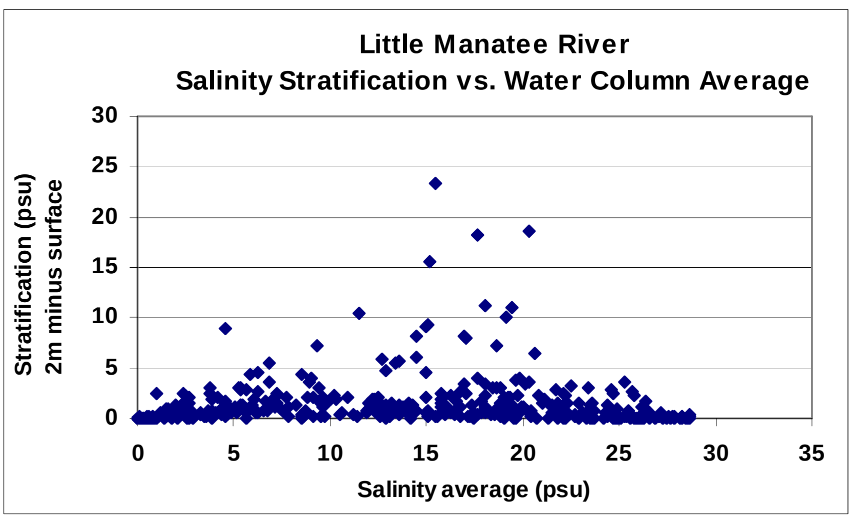


Figure 5-16. Relation of average water column salinity and salinity stratification (two meters – top) in the Little Manatee River taken from unpublished data by SWFWMD.

In addition to the ratio of freshwater inflow to the volume of the estuary, the high degree of stratification in the Lower Alafia is related to the morphology of the river. Probably the most important factor is the presence of the barge turning basin below kilometer 1.5 (Figures 3-2A and 3-3). This deep, dredged channel allows a large volume of high salinity water from Tampa Bay to extend approximately 1.5 kilometers upstream of the river mouth and influence the salinity of the tidal prism. Also, compared to other rivers, the Alafia is a fairly linear river with relatively few islands, which can cause sheer and increase mixing between deep and shallow waters. The Lower Alafia is also a fairly incised, deep river in its upper reaches (Figure 3-3), which allows salt water to move relatively far upstream and result in pronounced salinity stratification in the upper reaches during low flows.

5.4.3 Temporal salinity variations: relations to seasonal freshwater inflows

Like other rivers in the region, salinity in the Lower Alafia River is highly variable due to seasonal and short-term variations in freshwater inflow. The temporal variation in top-meter salinity in the river is shown for four one-kilometer segments in Figure 5-17. Taken from vertical profile measurements during 1999-2003, these plots demonstrate the large seasonal and inter-annual fluctuations of salinity that occur in the river. The drought years 2000 and 2001 and the dry spring of 2002 resulted in comparatively high salinity values at all sites, with much lower values occurring after the summer of 2002. The onset of the rainy season in July 2002 brought high flows to the river and rainfall in 2003 was also slightly above average. Salinity values in segment 2 exceeded 30 psu during 2000 and 2001, but only one value exceeded 20 psu during 2003, with values less than 10 psu being much more common in that year. Salinity at upriver segments (10 and 13) experienced mesohaline (5 – 18 psu) salinities during 2000 and 2001, but were almost entirely fresh during the second half of 2002 and all of 2003.

Given the large variation in hydrologic conditions that occurred during the recent data collection period, modeled salinity values for the baseline period are valuable for characterizing typical seasonal patterns of salinity in the lower river. Boxplots of top meter salinity by month are presented in Figure 5-18 for the same four segments in the estuary. The temporal pattern of monthly salinity is the inverse of the pattern of monthly streamflow, in that high salinity values occur during periods of low inflow and low salinity values occur during months with high inflow. The highest salinity values during the year occur during May and June at all sites. As described in Chapter 2, these months occur at the end of the dry season when streamflow is declining due to low rainfall, high evapotranspiration, and groundwater levels near their yearly minima. The rainy season typically begins in mid-June, but the occurrence of low flows in early June and the time it takes for the estuary to respond to increased flows causes June to typically be a high salinity month. Salinity values drop in July reaching their seasonal lows in August or September.

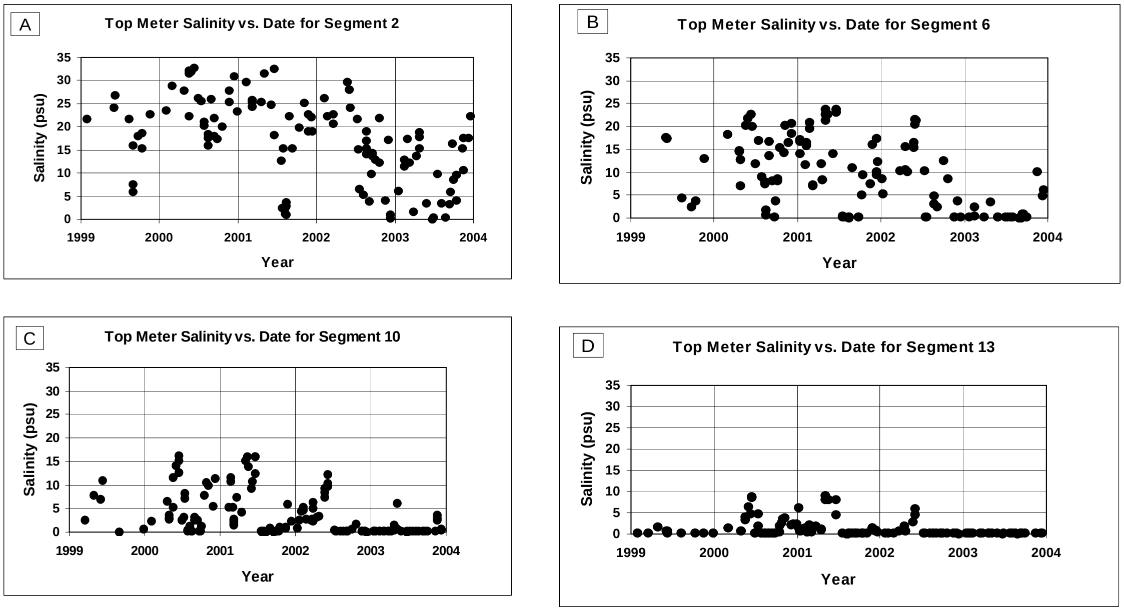


Figure 5-17. Plots of average top meter salinity vs. date for 1999-2003 for four one-kilometer segments in the Lower Alafia River taken from the combined vertical profile data base.

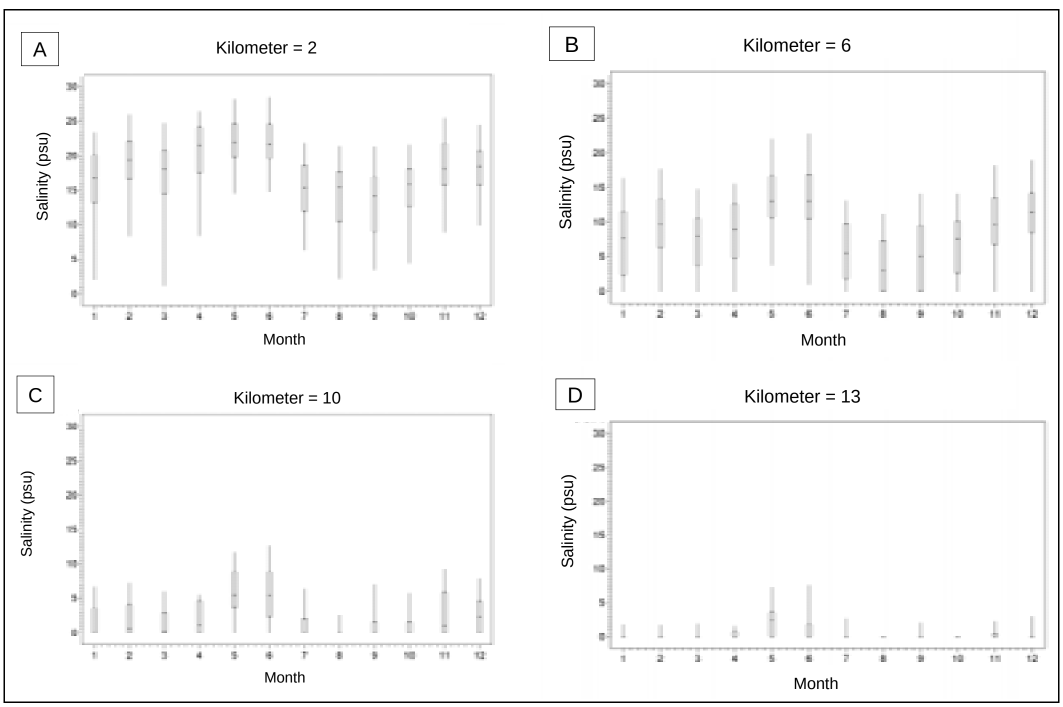


Figure 5-18. Boxplots of monthly top-meter salinity values in four one-kilometer intervals predicted by the empirical salinity model of the Lower Alafia River developed by Janicki Environmental (Appendix 5A).

The seasonal progression of salinity is also shown by the continuous data at the USGS gages in the lower river (Figure 5-19). Time series plots of mean daily values from all gages show the steady rise in salinity as the dry season progresses, followed by a dramatic decline in salinity in the summer as the rainy season begins. The plot from Bell Shoals shows that this station is almost always fresh, as the only time the station was not fresh was during a period of very low flows at the height of the year 2000 drought when some very low salinity values (<2 psu) were observed.

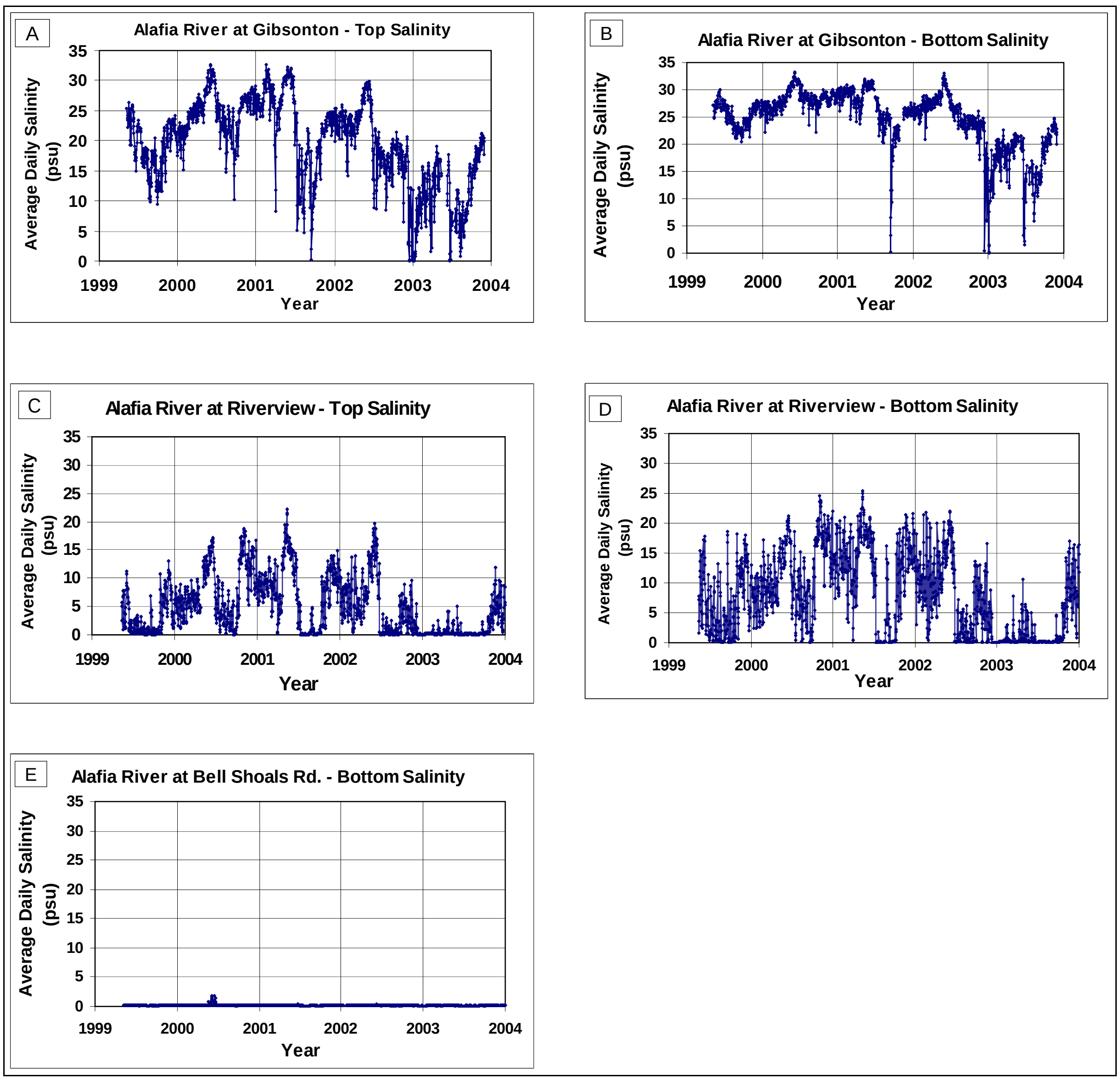


Figure 5-19. Time series of mean daily values for top and bottom salinity for the top and bottom recorders at the USGS gages at Gibsonton (kilometer 1.5), at Riverview (kilometer 8.7), and Bell Shoals (km 17.8, bottom only) for 1999 - 2003.

5.4.4 Salinity variations due to tides

The graphics presented in the preceding section were for instantaneous grab samples or daily mean values, so they do not portray the large variability in salinity in the river due to tides. The most informative data for analyzing tidal variations are the 15 minute values from the USGS gages. To portray these data in a manageable way, the daily ranges in salinity at the Gibsonton and Riverview gages are plotted against the mean daily salinity at these sites in Figure 5-20.

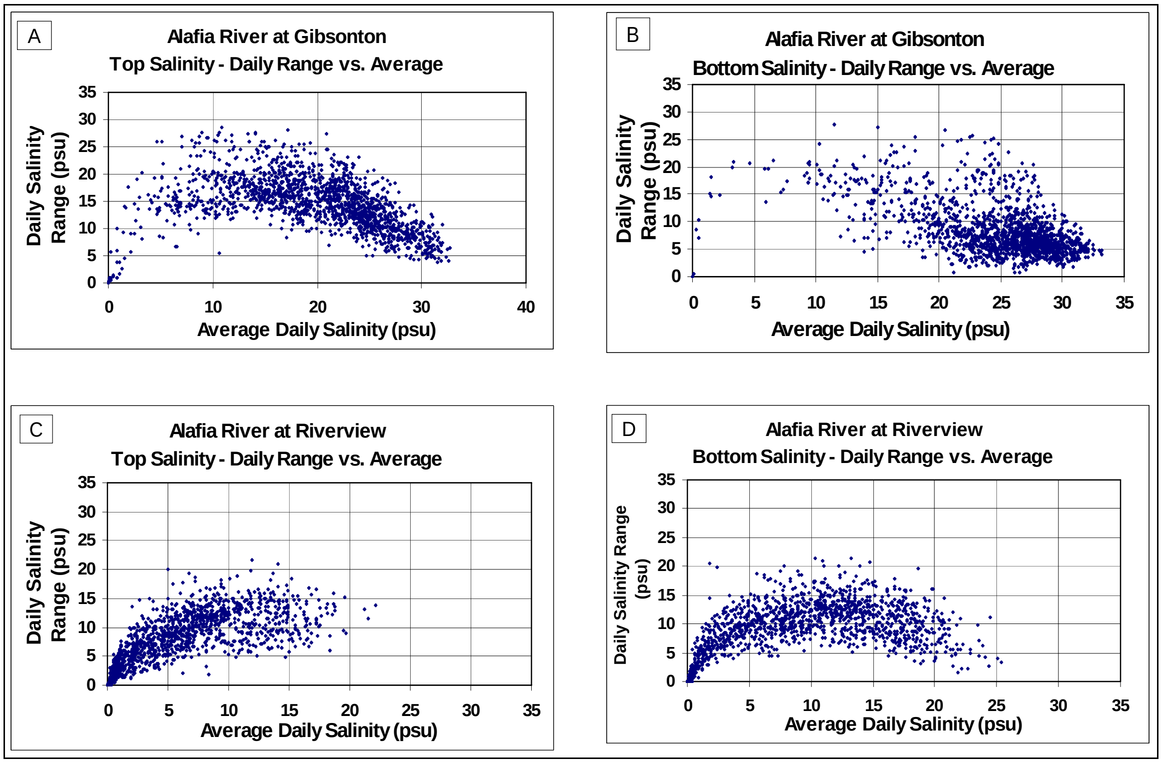


Figure 5-20. Relation between mean daily salinity and daily range of salinity (maximum minus minimum) for the top and bottom recorders at the USGS gages at Gibsonton (kilometer 1.5) an at Riverview (kilometer 8.7).

Large swings in salinity over the diurnal tidal cycle are seen at both sites. Similar to vertical stratification, the largest diurnal variations in salinity are frequently when average daily salinity is in the middle range, as this is when the principal mixing zone of the river is moving back and forth with tide in the vicinity of that gage. For the entire period of data collection between 1999 and 2003, average diurnal ranges in salinity were 14.7 and 7.7 psu for the top and bottom recorders at Gibsonton, respectively, and 7.5 and 9.0 psu for the top and bottom recorders at Riverview. Although there is large variation with tide in the lower river, large net shifts in the salinity distributions also occur in response to freshwater inflows, which are discussed in the following section.

5.4.5 Response of Salinity Distributions to Freshwater Inflows: Simulations with the LAMFE Model

The LAMFE model described in Section 4.3.2 and Appendix 4A was used to simulate salinity distributions in the lower river for the period May 9, 1999 through December 14, 2003. This period was simulated because there was available data for all hydrologic inputs and boundary conditions, including water levels and salinity at the Alafia River at Gibsonton gage which serves as the model's downstream boundary. The LAMFE model is an effective tool to examine the response of salinity distributions in the lower river to freshwater inflows. In order to graphically illustrate the effect on inflows on salinity, two-dimensional salinity distributions predicted by the LAMFE model are plotted in Figure 5-21 for six rates of freshwater inflow.

The graphics are for a mean tide condition. The inflow listed for each graphic is the observed five-day average freshwater inflow that preceded that day. The percent of time that five-day flow was exceeded during the 1987-2003 baseline period is also shown. Flows that are exceeded often (e.g. 92 percent exceedance) are low flows, while high flows are exceeded a low percentage of the time.

Isohalines, or lines of equal salinity, are plotted in Figure 5-21 to portray both horizontal and vertical salinity gradients. These graphics illustrate the pronounced salinity stratification in the river that was described in Section 5.4.2. Stratification is particularly strong in the lower portion of the river at medium to high flows (Figures 5-21 D through F), as freshwater inflows push the mixing zone into this portion of the river. The graphics also demonstrate how the isohalines move horizontally up and down the river with changes in freshwater inflow. At the lowest flow simulated, the 1 psu isohaline extends to kilometer 15 on the bottom of the river, but is pushed to between kilometers 6 and 7 at the highest rate of inflow illustrated. The increasing size of the freshwater zone of the river shows dramatic increases with freshwater inflow.

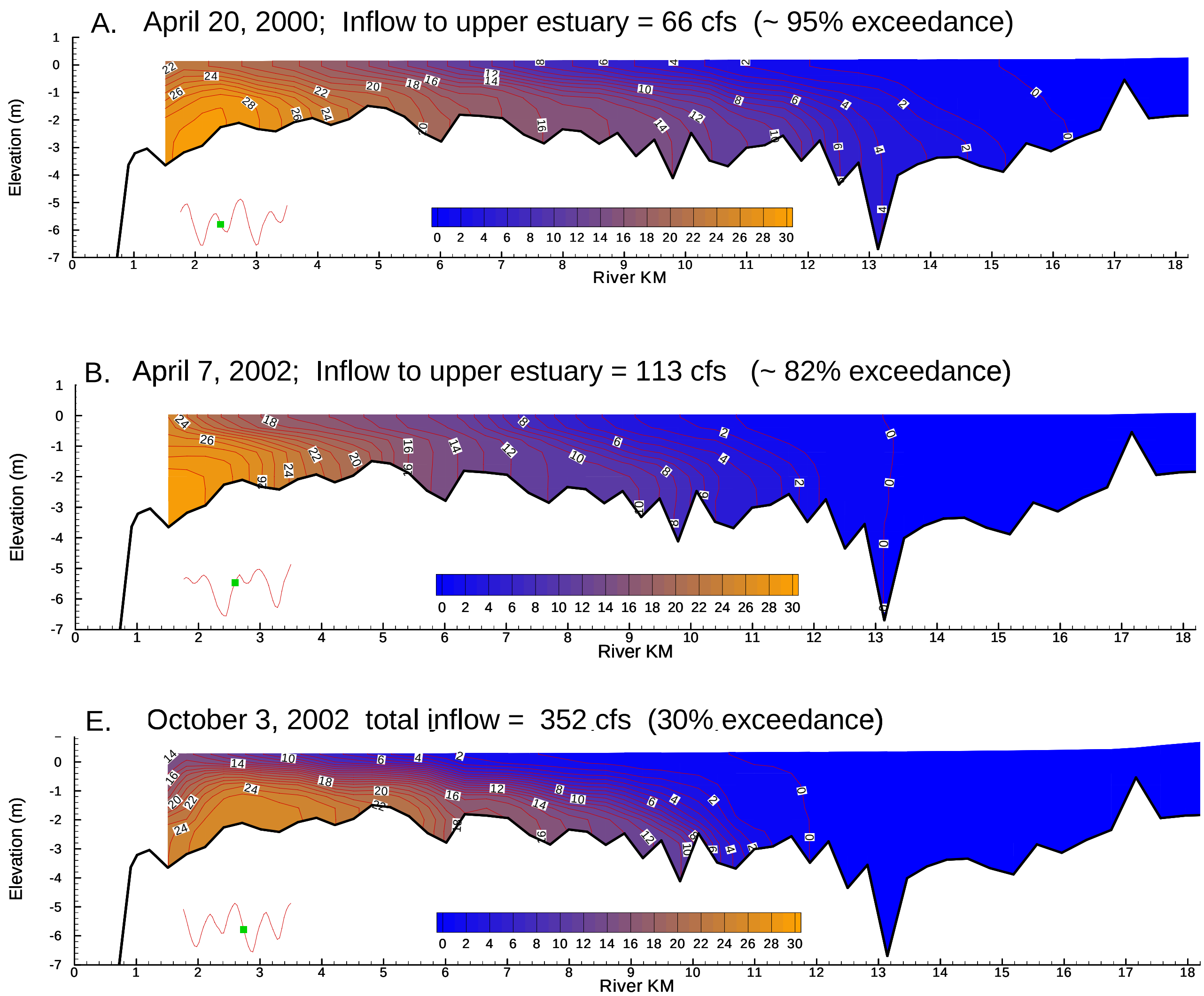


Figure 5-21. Two dimensional plots of salinity distributions in the Lower Alafia River near mean tide for six rates of freshwater inflow as predicted by the LAMFE model. Inflow rates are for the preceding six-day period. Exceedance values represent how often those six-day flows were exceeded during the 1987-2003 baseline period.

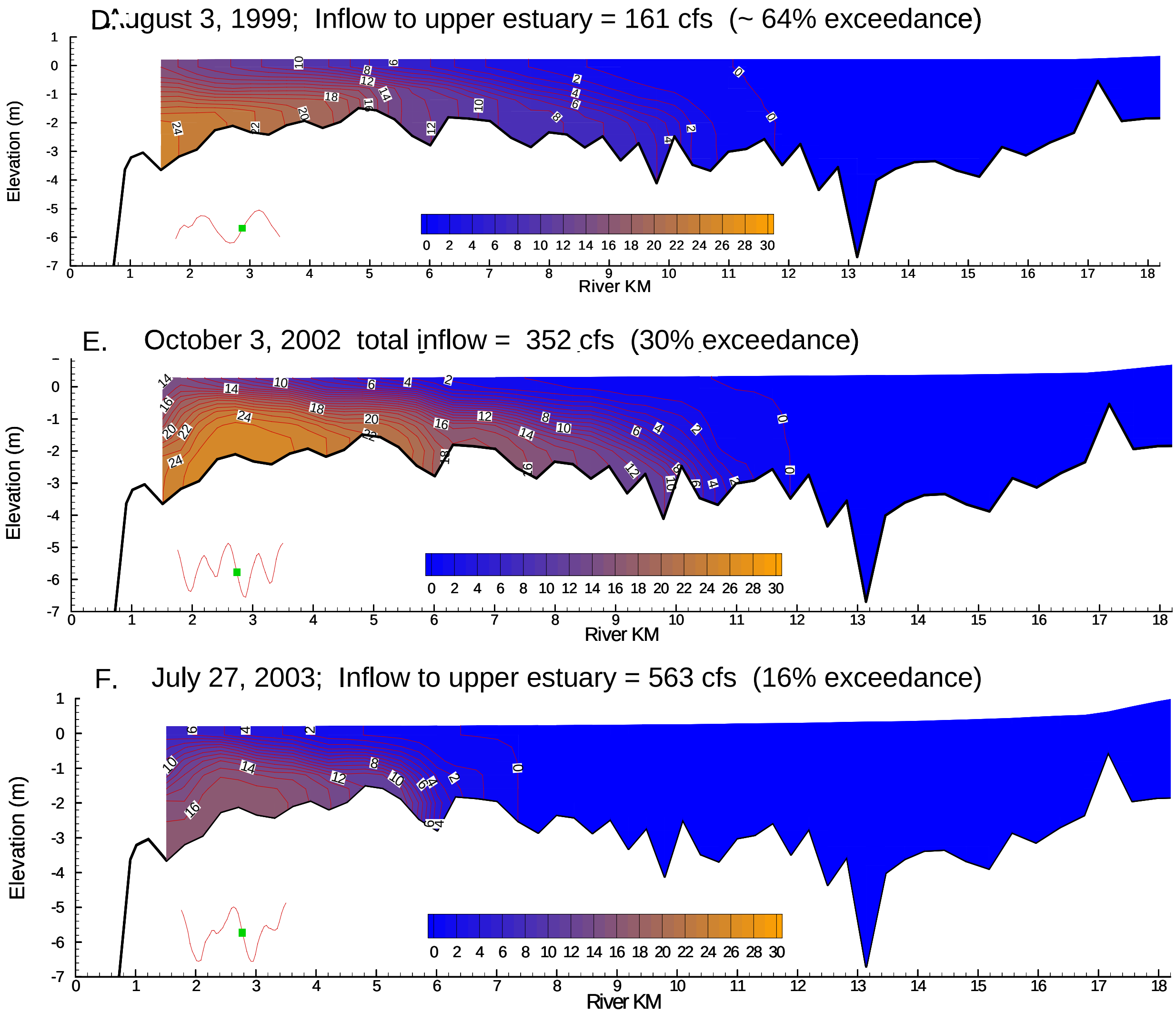


Figure 5-21 (continued).

The close interval horizontal and vertical discretization of the LAMFE model grid allows for the simulation of the area and volume of the lower river that is within various salinity zones for given rates of inflow. The mean daily volumes of water less than 1 psu, 6 psu, 12 psu, and 15 psu salinity in the river are plotted against preceding three-day mean freshwater inflow in Figure 5-22. A smoothed trend line was fitted to these results with SAS software to portray the general shape of the relation between inflow and water volume. Although there is variability in this relationship, due largely to differences in flow history and salinity at the downstream model boundary, there is a consistent relationship that more inflow results in more water volume less than a specified salinity value.

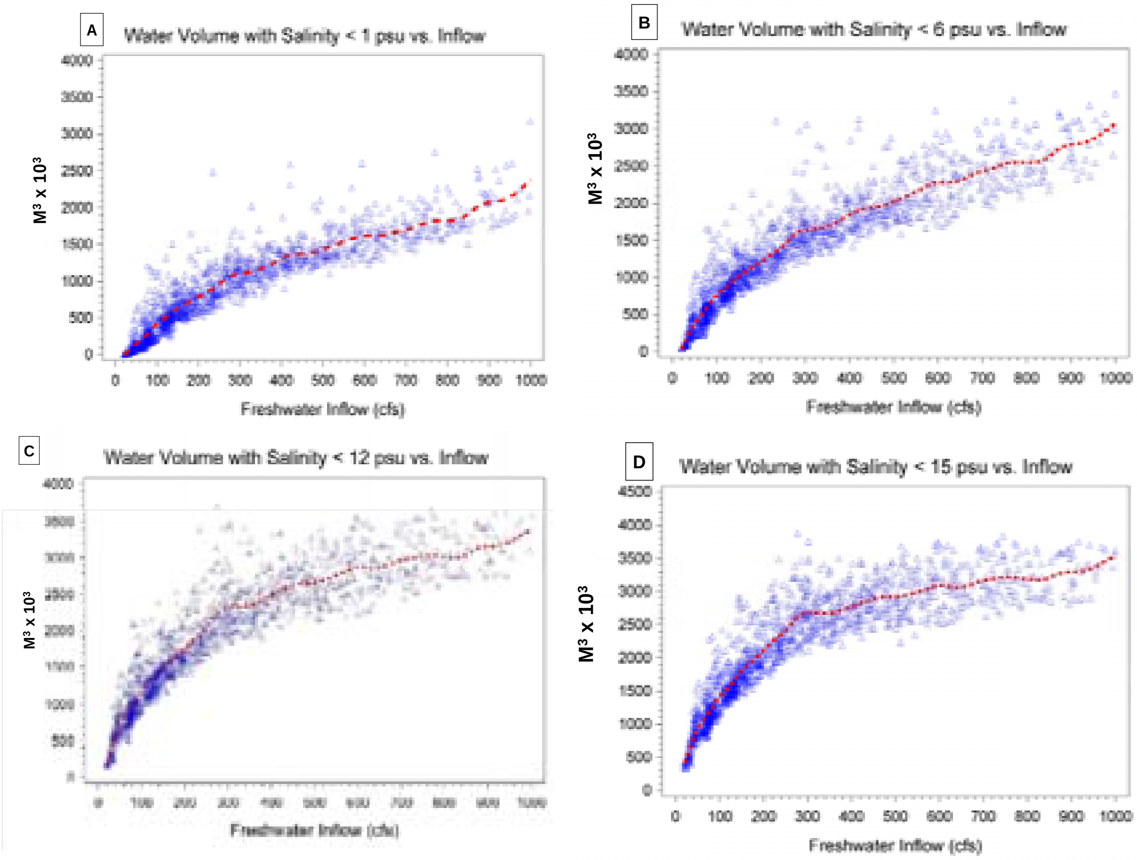


Figure 5-22. Relation between volume of the Lower Alafia River upstream of kilometer 1.5 with water less than 1 psu (A), 6 psu (B) 12 psu (C), or 15 psu (D) salinity and freshwater inflow to the upper estuary.

An interesting characteristic of these plots is that the response of water volume to inflow is nonlinear, with this nonlinearity increasing with the level of salinity zone simulated (<15 psu is more nonlinear than <1 psu). Using the < 12 psu zone as an example, the increase in water volume appears particularly steep below about 80 cfs, and has a major inflection abound 280 cfs. However, caution should be used in interpreting these graphs because some of the volume of a high salinity zone may actually be pushed past the downstream model boundary at high flows (see Figure 5-21 E and F). Thus, the values plotted for high flows may not be the actual total volumes for those high salinity zones. However, the general nonlinear relationship between inflow and water volumes in different salinity zones appears real and is consistent at least with nonlinear relationships of isohaline movements with freshwater inflow reported for other estuaries (Uncles and Stevens 1993, Sklar and Browder 1998, Flannery et al. 2002).

Plots of bottom area within these same salinity zones show similar relationships, with slightly different variations (Figure 5-23). The relationships of freshwater inflow to the area and volume of different salinity zones have important implications for maintaining the biological structure and productivity of the estuary. These relationships are evaluated as minimum flow criteria in Chapter 8, where the LAMFE model is used to evaluate how a series of flow reduction scenarios affect the area and volume of various salinity zones in the lower river.

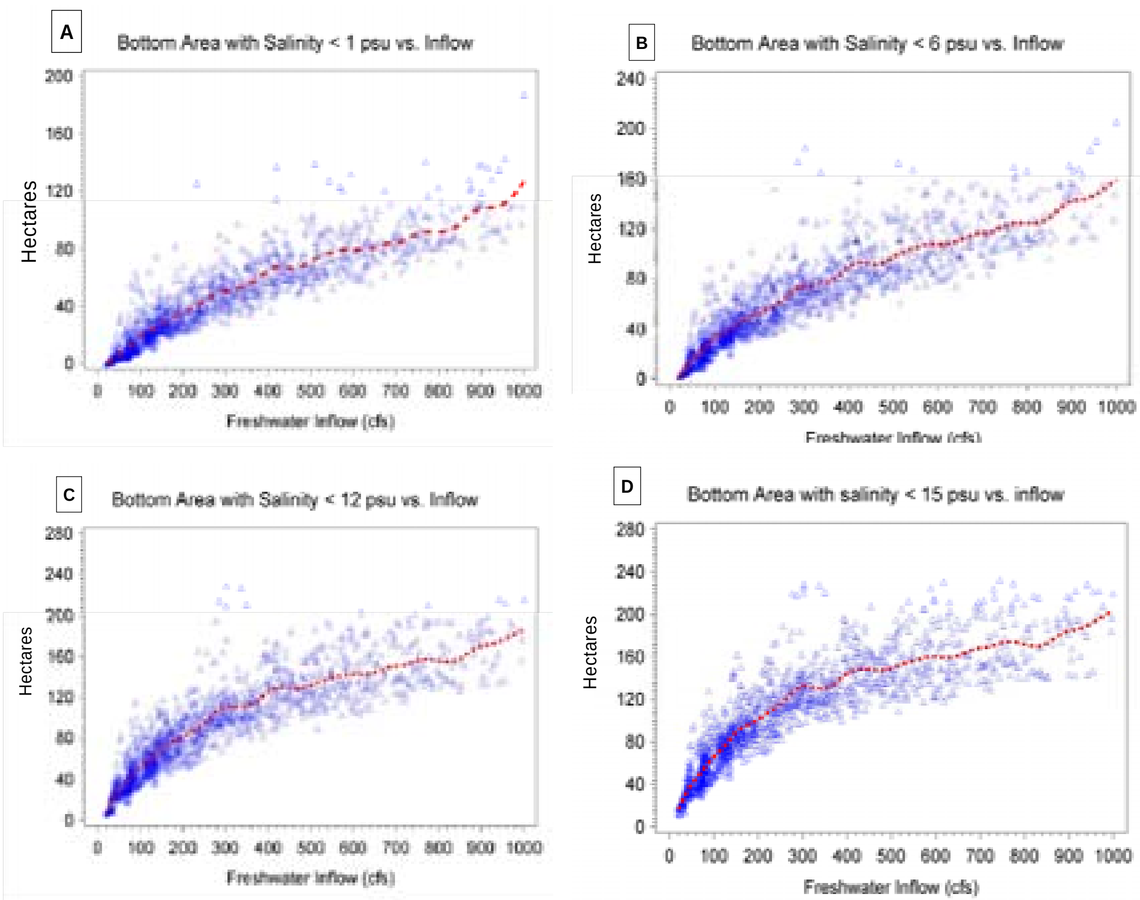


Figure 5-23. Relation between bottom area of the Lower Alafia River upstream of kilometer 1.5 with water less than 1 psu (A), 6 psu (B) 12 psu (C), or 15 psu (D) salinity and freshwater inflow to the upper estuary.

5.4.6 Empirical Modeling of Isohaline Locations

The response of salinity distributions in the Lower Alafia River were also investigated using a series of empirical models, which were based on regression analyses of salinity measurements collected in the estuary, tides, freshwater inflows and seasonal factors. The models serve as additional tools and checks to evaluate the potential effects of reductions in freshwater inflows on the salinity regime of the lower river. An advantage of the empirical models is that they can be applied to longer periods of record, provided data are available for all independent variables.

Janicki Environmental Inc. developed a series of empirical models to predict salinity for the lower river (Appendix 5B). One of these efforts was to predict the locations of four isohalines in the lower river. As described for the graphics of the LAMFE output, isohalines are basically lines of equal salinity that can be expressed vertically or horizontally. In the empirical modeling for this project, isohaline locations were modeled one-dimensionally along the longitudinal axis of the river channel. The isohalines that were modeled were the 0.5 psu, 2 psu, 4 psu, 11 psu, and 18 psu isohalines in top waters and at 2 meters depth.

Daily Isohaline positions were calculated from the vertical profile data base by interpolating values between profiles at known kilometer locations in the estuary. The top water isohalines were calculated by first averaging all salinity measurements in each vertical profile that were less than or equal to 1 meter in depth (usually a surface and 1 meter reading). This was done to give a better representation of the upper layer of the water column, as a narrow lens of low salinity water can sometimes extend in a very shallow surface (<0.5 meters depth) layer. The 2 meter isohaline calculations were restricted to salinity measurements at 2 meters, which were routinely recorded if the water column was that deep. Because the river is < 2 meters deep in many areas, the spatial intensity of 2 meter measurements was less than for the top meter, and these regressions have fewer numbers of observations. Suitable regressions for isohalines at 2 meters depth were developed for this project, but the minimum flows analysis focused on the top meter isohalines for comparison to shoreline features. Although the two-meter isohalines show expected responses to freshwater inflow, the LAMFE model outputs were used for the assessment of salinity distributions over the depths of the water column. Therefore, only the top meter isohalines are presented below.

The relationships between freshwater inflow and the location of four isohalines (2 psu, 4 psu, 11 psu, and 18 psu) are shown in Figure 5-24. Predicted location lines are fitted to these data using regressions that incorporated independent variables for inflows, tides, and seasonal factors. Because these were multivariate regressions, the fitted lines are not a smooth function of freshwater inflow. Nevertheless, the plots all show that isohaline locations tend to move downstream with increased freshwater inflow. Furthermore, all of the isohalines generally respond in a nonlinear manner, in that isohaline movements are most responsive to inflow at low flows. This pattern is related to the morphology of the river, as the cross sectional area of the river generally becomes smaller as it extends upstream. At low flows, the isohalines migrate upriver and are located in narrower parts of the river, where smaller changes in flow can result in a greater change in longitudinal position expressed as river kilometer.

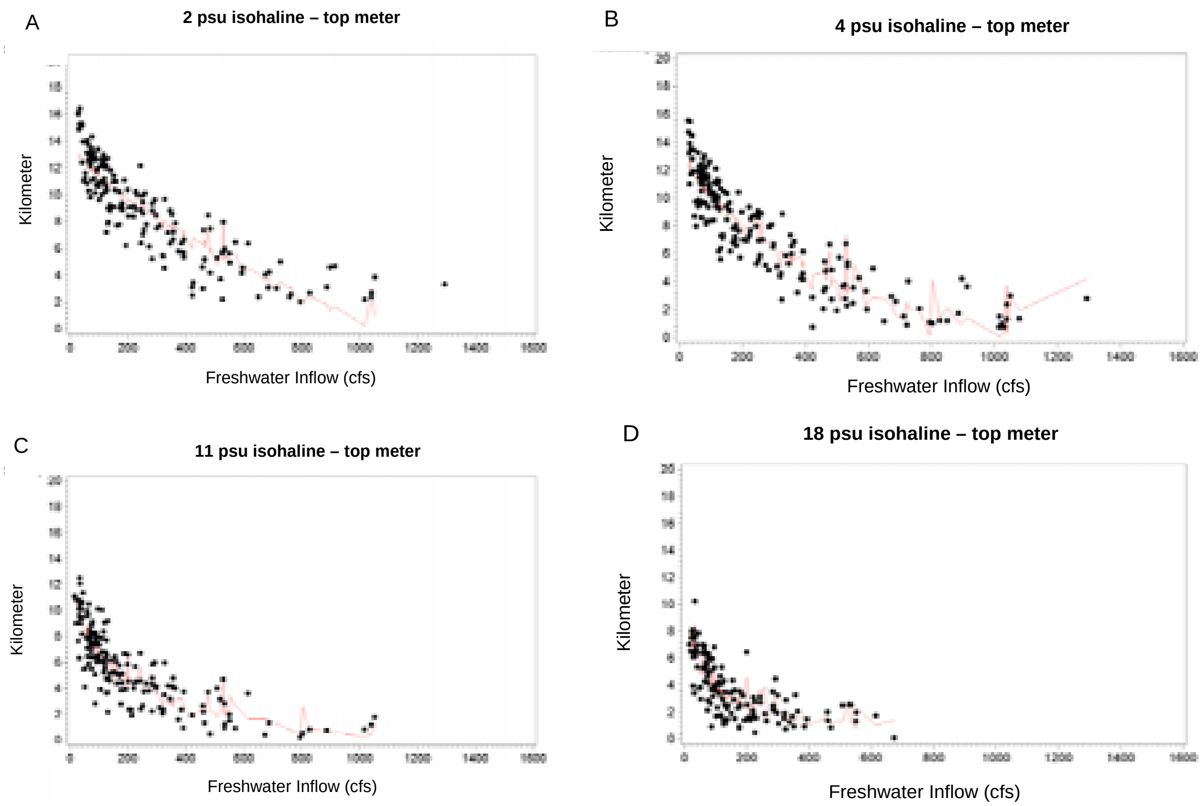


Figure 5-24. Relation of the 2 psu (A), 4 psu (B), 11 psu (C), and 18 psu (D) isohalines in the top meter of the water column to freshwater inflow to the upper estuary. Predicted lines plotted using the multivariate isohaline regressions developed by Janicki Environmental (Appendix 5B).

At higher flows, the response of isohaline position to inflow becomes flatter as the isohaline is now located in a broader section of the estuary. Where this flattening occurs is related to the typical position of the isohaline. For example, the predicted curve for the 18 psu isohaline tends to flatten out around 200 cfs, while the location of the 2 psu isohaline tends to flatten out around 600 cfs, as it takes more inflow to push it into the broad region of the estuary. Although the isohalines move less longitudinal distance at high flows, they are moving in an area of the river where the area or volume of the river increases more rapidly per unit distance due to the estuary's greater width.

A boxplot of the predicted locations of the five, top-meter isohalines is shown in Figure 5-25 for flows during the baseline period. The median location of the 18 psu isohaline is between kilometers 2 and 3, while the median position of the 0.5 psu isohaline is between kilometers 10 and 11.

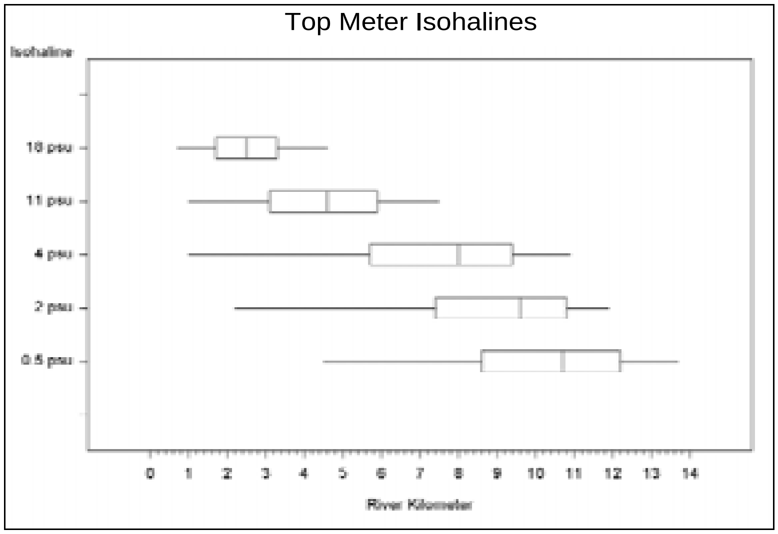


Figure 5-25. Boxplot of the locations of the top meter isohalines in the Lower Alafia River for observed flows during the baseline period.

Isohaline regression models were also fit for data collected near slack high tide conditions (maximum high tide). Since the variation due to tides is much less in these models, tide stage was not included in these models and the response to freshwater inflow is a smooth function of freshwater inflow, again demonstrating the nonlinearity of these relationships (Figure 5-26). Overall, empirical isohaline-inflow models are a useful tool for evaluating the effects of inflow reductions on the salinity regime and biological structure of estuaries and their use in the minimum flows analysis of the Lower Alafia is described in Chapters 7 and 8.

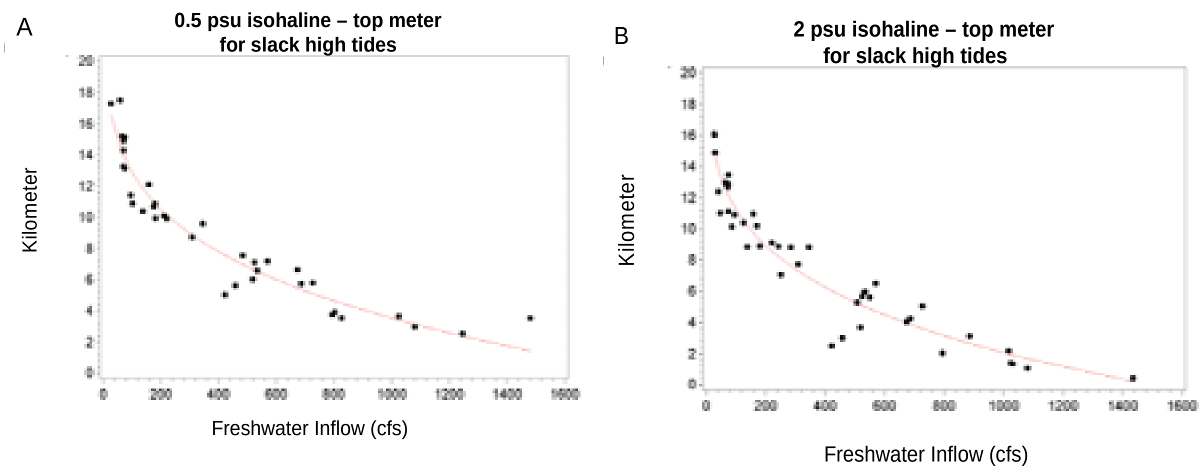


Figure 5-26. Relation between the 0.5 psu (A) and 2 psu isohalines (B) in the top meter of the water column and freshwater inflow to the upper estuary for slack high tide conditions. Predicted line fitted by regressions developed by Janicki Environmental (Appendix 5B).

5.4.7 Empirical Fixed Location Station Models

A series of empirical models were also developed by Janicki Environmental to predict salinity at a series of fixed location stations in the estuary as a function of freshwater inflow (Appendix 5C). These models are informative for showing at what rates of inflow different sections of the estuary fluctuate within different salinity ranges (e.g. mesohaline, oligohaline, fresh). As described in Chapter 7, the minimum flows analysis primarily used outputs from the LAMFE model and the isohaline regressions to determine the minimum flows. However, the fixed station regressions were used as a check to evaluate the effect of the proposed minimum flows at different locations in the estuary.

Plots of salinity vs. freshwater inflow at a series of fixed location stations in the estuary are presented in Figures 5-27 through 5-29 with fitted regression lines. Since these all were multivariate regressions, the shape of the fitted regression lines in relation to freshwater inflow is not smooth, but they all show the prevailing relationship of reduced salinity with increased freshwater inflows. Regressions fitted to average daily salinity in the top and bottom recorders at the Gibsonton and Riverview gages show that the response of salinity at these fixed locations is also nonlinear, in that salinity is most responsive to changes in flow at low flows (Figure 5-27). Salinity at the top recorder at Gibsonton can range above 30 psu at low flows, and approaches 10 psu at inflows near 1000 cfs. In contrast, salinity in bottom waters at this location does not go below 20 psu at flow up to 1000 cfs, demonstrating the highly stratified nature of the river at this location over most of the flow range. Plots from the gage near Riverview show that salinity at this location can become fresh at flows above 400 cfs for the top recorder and 600 cfs for the bottom recorder (Figure 5-27 C and D).

Though based on fewer observations than the USGS recorders, plots and regression lines fitted to the SWFWMD and EPCHC fixed location sites in the estuary show similar responses to freshwater inflow, which are dependent on their locations in the estuary. Plots of surface salinity vs. inflow for four SWFWMD stations show that freshwater conditions are reached at lesser rates of flow at upstream locations (Figure 5-28). Similarly, plots of salinity vs. inflow at the two EPCHC sites near US-41 and the US-301 bridge (Figure 5-29), show relationships that are similar to data from the USGS recorders near those locations. However, they generally show lower salinity values at high flows. This is due to the fact that the EPCHC data are measured from the water surface down, so the actual elevation of the sample can vary between sampling events, while the USGS data are recorded at the same elevation each time, which tends to be deeper than the EPCHC data. For example, the top recorder at each USGS site is placed deep enough to where it stays submerged at low tides. Regardless, these data collectively illustrate the response of salinity to freshwater inflow throughout the estuary, with the slope of the salinity response to inflow being generally greater for surface waters than bottom waters, and greater at upper rivers stations compared to lower river stations.

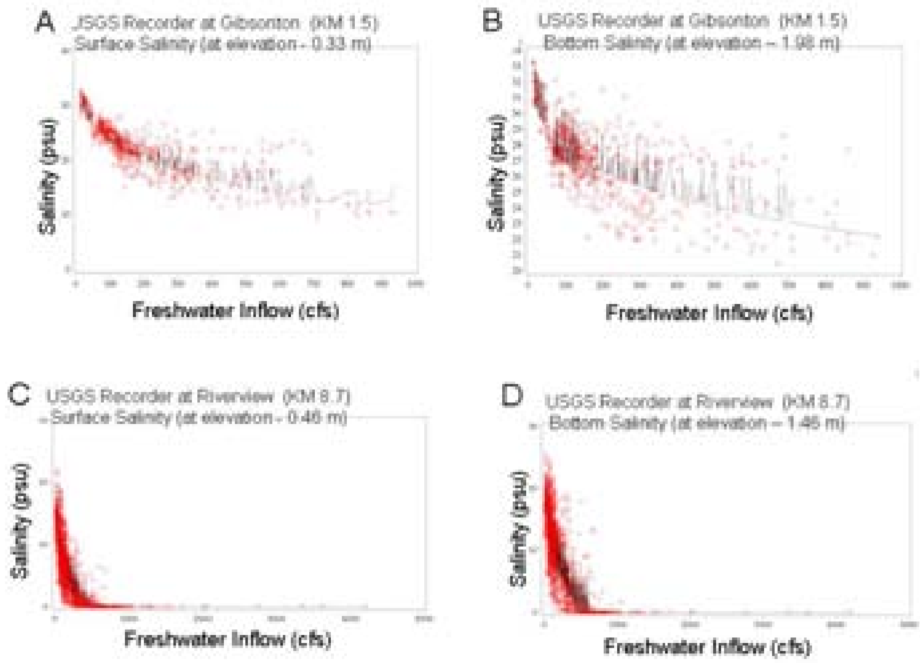


Figure 5-27. Four examples of the relation of top and bottom salinity to freshwater inflow to the upper estuary at the USGS gages at Gibsonton and near Riverview.

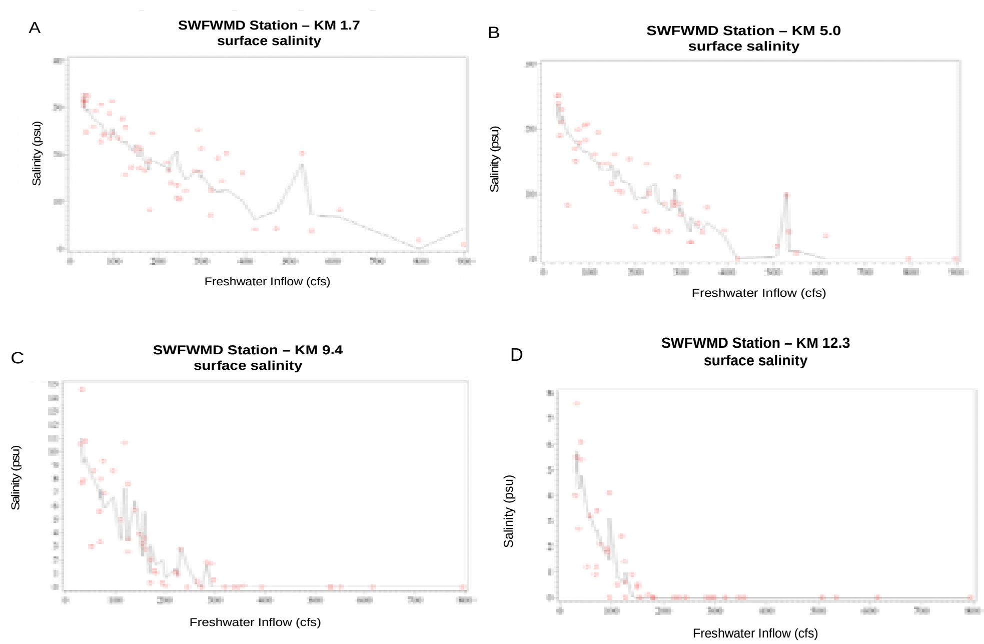


Figure 5-28. Relation of surface salinity to freshwater inflow to the upper estuary for four fixed-location stations sampled by SWFWMD between 1999 and 2003.

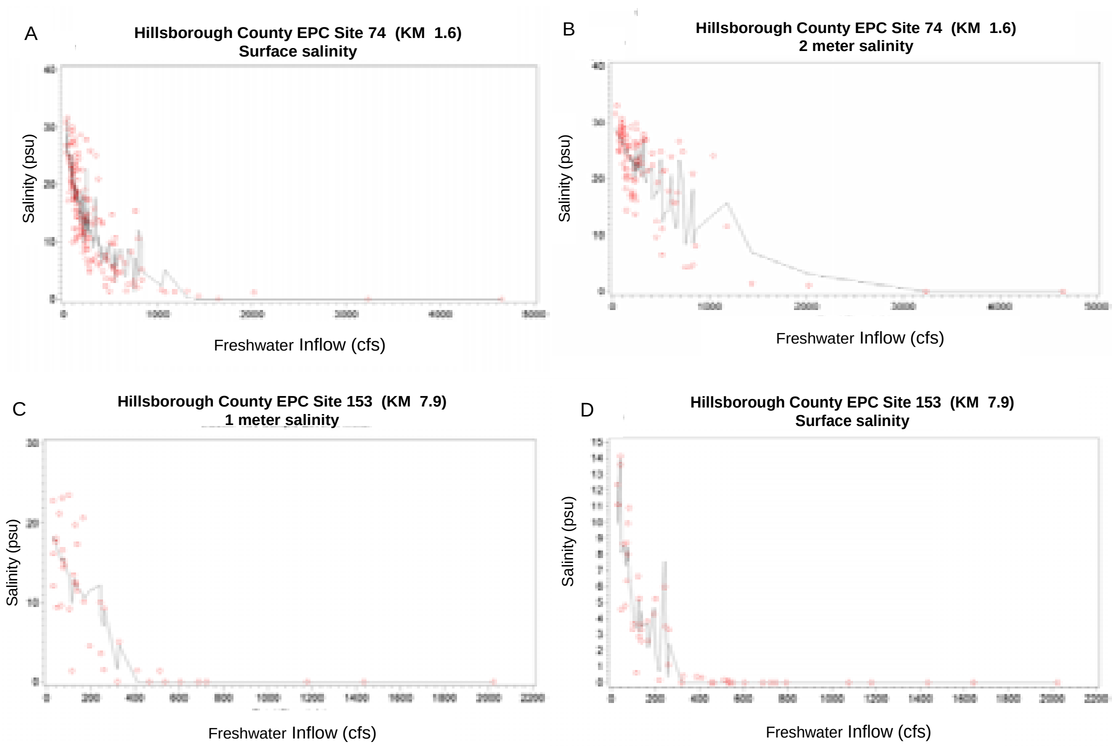


Figure 5-29. Relation of surface and mid-depth salinity to freshwater inflow at the two EPCHC fixed location water quality stations at US 41(site 74, km 1.6) and US 301 (site 153, km 7.9). Predicted lines fitted with multivariate regressions for the EPCHC stations developed by Janicki Environmental (Appendix 5C).

5.5 Dissolved Oxygen

5.5.1 Introduction

Dissolved oxygen is essential for the survival of aerobic aquatic organisms and is a critical parameter that should be evaluated in assessments of resource management strategies for natural water bodies. When dissolved oxygen concentrations go below critical thresholds for prolonged periods of time, dramatic reductions in the abundance, productivity, and diversity of aquatic biological communities can occur (Officer et al. 1984, Diaz and Rosenberg 1995, Wannamaker and Rice 2000, Brietburg 2002). Dissolved oxygen concentrations in rivers and estuaries are affected by a number of physical, chemical, and biological processes, which in turn can be affected by the freshwater inflow (Somville and Depauw 1982, Keister et al. 2000, Diaz 2001).

The dissolved oxygen (DO) characteristics of the Lower Alafia River and the relations of DO concentrations to inflow are described in the following section. The data base for analysis of DO relationships is the same as the vertical profile data base previously described for salinity (Figures 5-2 and 5-3), as all vertical profiles collected in the field included measurements of DO. The Lower Alafia River has frequent problems with low DO concentrations, which vary between the upper and lower reaches of the river dependent on the rate of freshwater inflow.

DO concentrations in segments of the river are compared to water quality standards that are used to assess the health of natural water bodies. The State of Florida Department of Environmental Protection (FDEP) has established water quality criteria for water bodies that include standards for DO concentrations. The Lower Alafia River is classified as a Class-III water body, meaning its waters must be suitable for swimming, recreation, and the support of fish and wildlife. The DO standards for Class-III water bodies are 5.0 mg/l for a 24 hour average, and 4.0 mg/l for instantaneous readings. It is assumed that maintenance of dissolved oxygen concentrations above these standards will provide for health of aquatic biological communities.

The occurrence of low dissolved oxygen concentrations in water bodies is termed hypoxia. In the technical literature, DO concentrations of less than 2 mg/l, or sometimes 3 mg/l, are frequently used to identify hypoxia (Ecological Society of America 2006, USGS 2006). These thresholds are based on studies that have shown aquatic biological communities can be impacted when DO concentrations go below these values for prolonged periods of time (USEPA 2000, Miller et al. 2002, Goodman and Campbell, 2007). Recent data from trawl samples in the nearby Lower Hillsborough River show that the abundance and species richness of fish communities are clearly negatively impacted when DO concentrations fall below 2.0 to 2.5 mg/l (McDonald et al. 2006). In the following discussion, comparisons are made to the proportion of DO values in the Lower Alafia River that are below 2 mg/l and 4 mg/l. The emphasis, however, is on the lower of these two thresholds, since the Lower Alafia River has frequent problems with hypoxia. Relationships of hypoxia to freshwater inflow are an important concern with regard to the establishment of minimum flows for the lower river.

5.5.2 Longitudinal and Vertical Gradients of DO in the Lower River

Boxplots of surface and bottom DO are plotted for one-kilometer river segments in Figure 5-30, with a reference line shown at 2 mg/l. Problems with low DO concentrations are infrequent in surface waters. Median and lower quartile concentrations are above 4 mg/l in all segments, and only a handful of individual measurements are below 2 mg/l. Bottom DO measurements were considerably lower. Bottom DO values in Figure 5-30B were taken from vertical profiles that were at least one meter deep. Median bottom DO concentrations below 4 mg/l occurred between segments 1 through 5 and segment 7. Median bottom concentrations were generally higher in the upper portions of the lower river, especially segments 12 and above. Lower quartile concentrations were below 2 mg/l for 11 of the 18 segments, showing that hypoxia in bottom waters in the lower river is not uncommon. Minimum bottom DO values near zero occurred in all segments except segment 18.

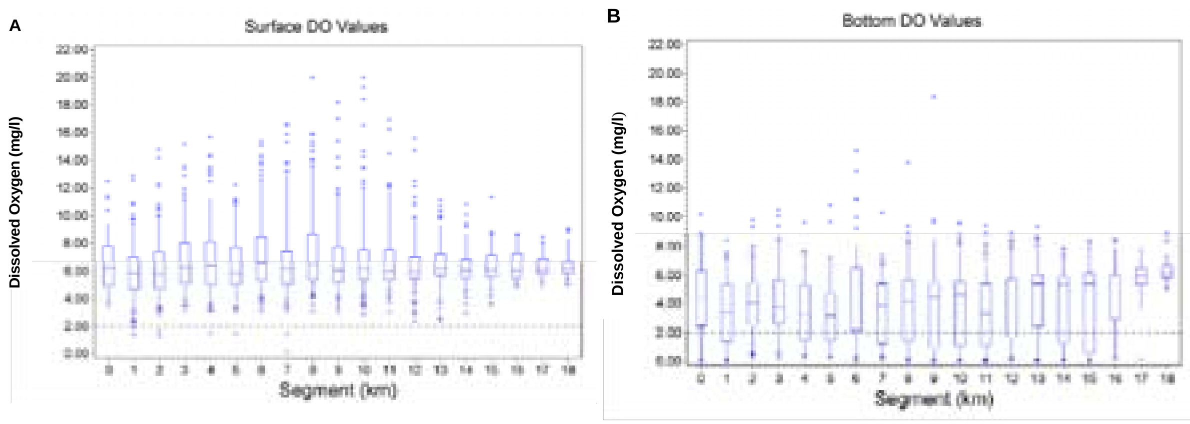


Figure 5-30. Boxplots of surface (A) and bottom (B) DO concentrations in the Lower Alafia River for one-kilometer intervals.

DO concentrations in the lower river are closely related to sample depth. Viewing data from the entire lower river, lower quartile values for bottom DO were above 2 mg/l for samples depths of 2 m or greater, but were less than 2 mg/l for all sample depths greater than 2 m (Figure 5-31). As will be discussed later in this section, very high DO values (> 10 mg/l) sometimes occur at shallow depths, due to photosynthesis by large phytoplankton blooms in this highly eutrophic (nutrient enriched) river.

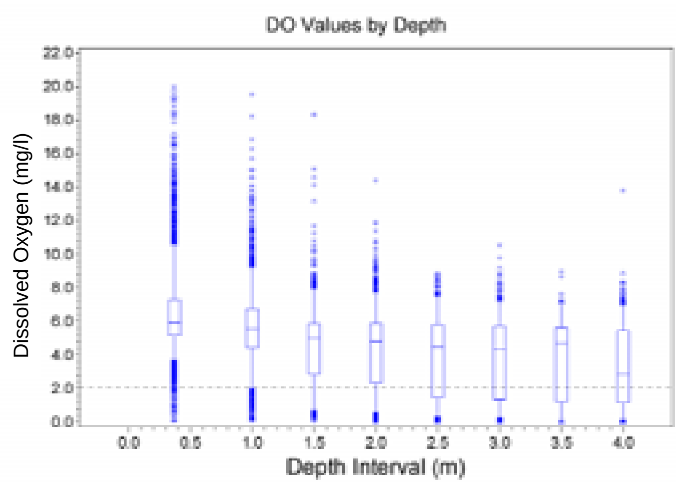


Figure 5-31. Boxplot of DO concentrations for the entire lower river in vertical one-half meter intervals.

The frequency of low DO in bottom waters in the lower river is shown for segments grouped in three-kilometer intervals in Figure 5-32. Values below 4 mg/l are very common, exceeding 35 percent to 57 percent of bottom DO values for segments between kilometers 0 and 15, which covers all of what is normally the brackish part of the lower river. Bottom values below 2 mg/l exceeded 25 percent to 35 percent of all values in these same segments. Lower dissolved

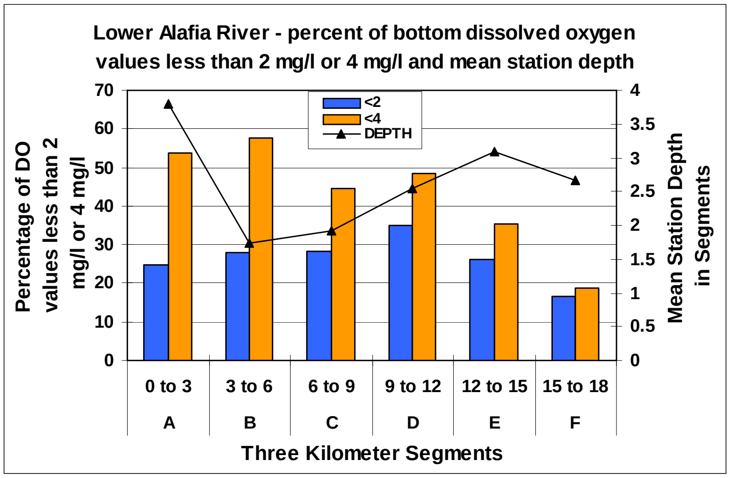


Figure 5-32. Percentage of bottom DO measurements below 2 mg/l or 4 mg/ in three-kilometer segments in the lower river, along with mean station depths.

oxygen concentrations are less frequent in segment 15 to 18 km, which is usually fresh except during very dry periods.

Before interactions with freshwater inflow are examined, it is helpful to point that hypoxia in the Lower Alafia River is much more common than in other unimpounded rivers in the region. Boxplots of bottom DO in profiles at a series of fixed location sites in the Peace and Little Manatee Rivers are shown in Figure 5-33. These rivers have very few hypoxic bottom DO observations at these sites, although bottom hypoxia can occur further downstream in the Peace River during periods of very high freshwater inflow in the summer. As will be described, the frequent occurrence of low DO in the Alafia is largely due to the much greater degree of vertical salinity stratification in this river (Figures 5-15 and 5-16) and also due to the highly eutrophic character of this river.

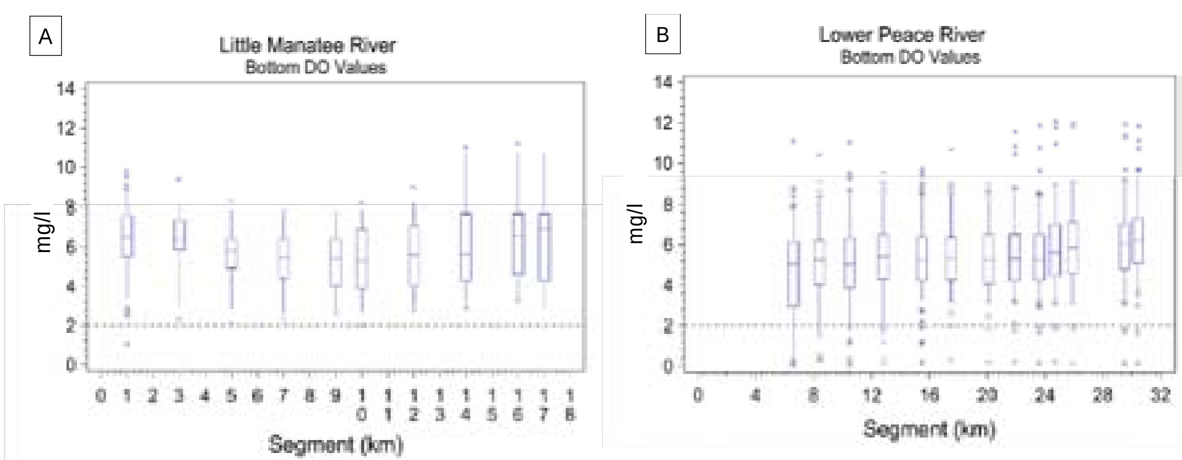


Figure 5-33. Bottom DO values from a series of fixed location stations in the Little Manatee (A) and Lower Peace Rivers (B), with a reference line drawn at 2 mg/l.

5.5.3 Seasonal DO Variations

DO concentrations shown distinct seasonal patterns in the lower river, which differ between river segments. Monthly boxplots for surface DO values are shown for four of the six three-kilometer segments in the lower river in Figure 5-34. Surface DO values at all segments are highest in the dry season months, with slightly lower values in the wet season that are accompanied by lower variability as evidenced by smaller inter-quartile ranges. In the mid to upper river segments (kilometers 6-9 and 9-12), large inter-quartile variations and very high maximum DO values occurred in April and May, when phytoplankton blooms occur in this part of the river. Factors affecting phytoplankton blooms in the lower river are discussed in a subsequent section of this report.

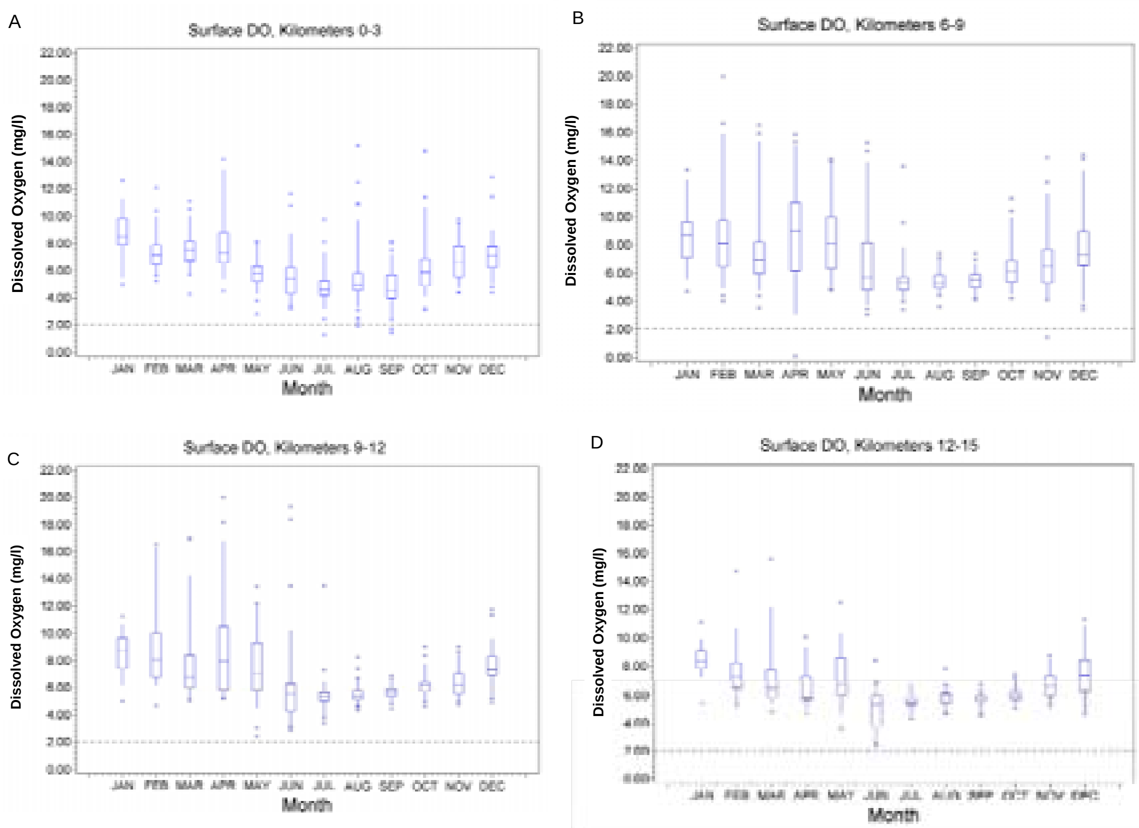


Figure 5-34. Boxplots for monthly surface DO values for four three-kilometer segments in the Lower Alafia River.

Monthly values of bottom DO show a very different seasonal pattern between the lower and upper parts of the tidal river (Figure 5-35). Near the mouth of the river (kilometer 0 - 3), DO values are lowest during the summer wet season, when median values are less than 2 mg/l. In the upper parts of the tidal river, bottom DO values are high in the late summer when this part of the river is flushed with fresh water, which allows vertical mixing over the water column. During the dry

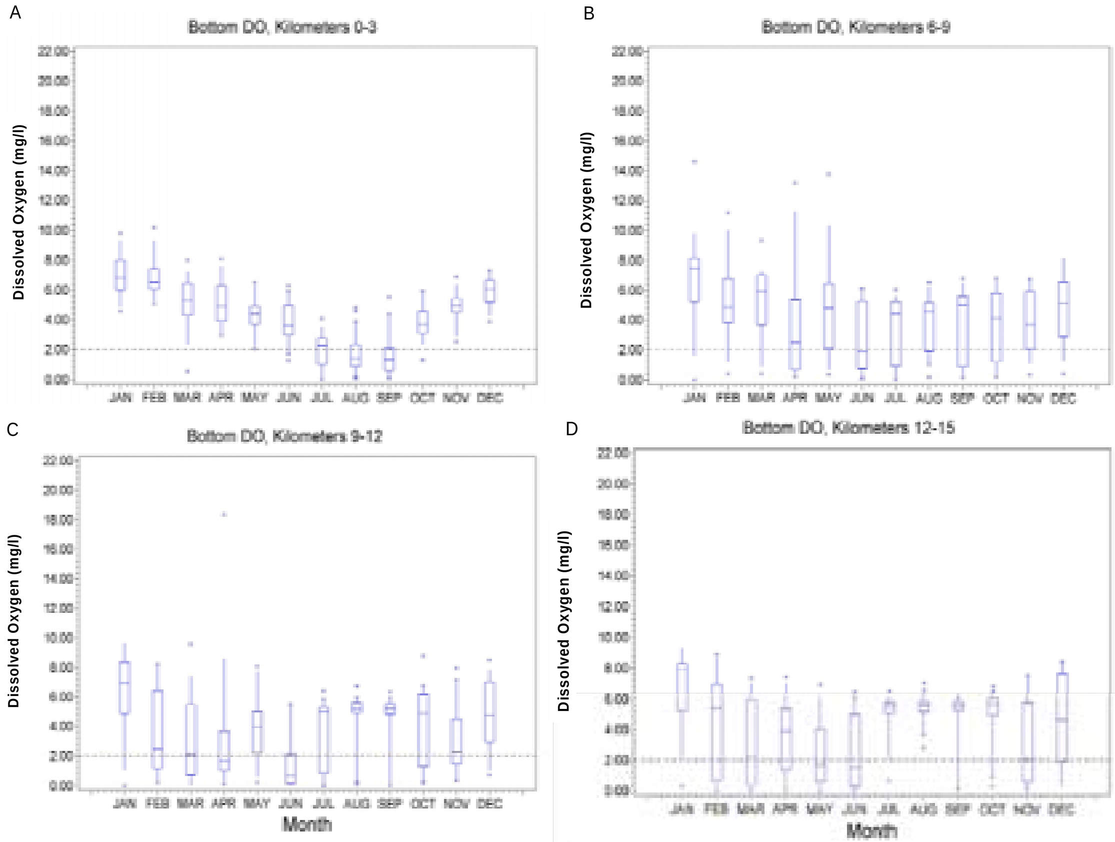


Figure 5-35. Boxplots for monthly bottom DO values for four three-kilometer segments in the Lower Alafia River.

season bottom DO values are low, due largely to the salt wedge occurring in this part of the river, which results in steep density stratification and limited aeration of bottom waters.

The solubility of dissolved oxygen is inversely related to temperature, as cool water will hold more DO that warm water if all other factors are equal (Head 1985, Kennish 1986). For example, the 100 percent saturation of DO in fresh water is 10.1 mg/l at a temperature of 15^{0} C, while the 100 percent saturation of DO in the same water is 7.5 mg/l at 30^{0}C. The solubility of DO is also related to salinity, as DO is less soluble in sea water compared to fresh water. In order to view seasonal DO variations while controlling for temperature and salinity effects, monthly percent saturation values of bottom DO from the vertical profiles are plotted in Figure 5-36. These plots show similar seasonal patterns to actual DO concentrations in mg/l, supporting the conclusion that variations in inflow rates have an opposite effect on DO in the upper and lower parts of the tidal river.

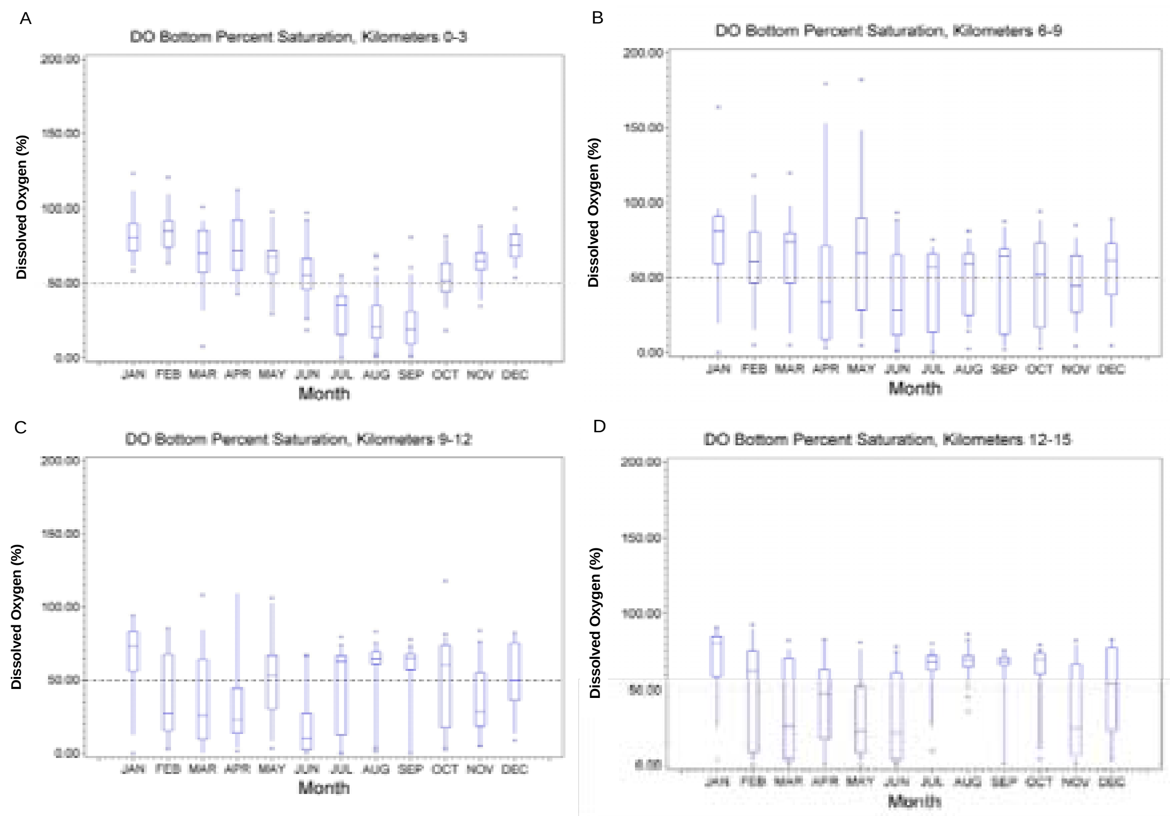


Figure 5-36. Boxplots for monthly bottom DO percent saturation values in four three-kilometer segments in the Lower Alafia River.

This does not suggest, however, that temperature is not an important factor controlling DO concentrations in the river. In addition to the direct effects on the solubility of DO, respiration and sediment oxygen demand generally go up with rising water temperature, and hypoxia is often most common during summer months. Bottom DO was significantly correlated ($p<0.05$) with water temperature at all segments of the estuary. Bottom DO values are plotted vs. bottom water temperature for all six river segments in Figure 5-37. In all segments there is a general negative relationship between water temperature and DO. However, the temperature at which bottom DO is less than 2 mg/l differs between segments. Near the mouth of the river, DO values below 2 mg/l are not common in the river until water temperatures are above 27-28^0 C. Further upstream, low DO values occur at lower water temperatures (18 – 25^0 C).

These apparent differences in temperature relationships are due to inflow effects. Near the mouth of the river, water temperatures above 27 degrees generally do not occur until the summer, when freshwater inflows are high. Further upstream, low DO occurs at lower water temperatures, because the salt wedge is located in this portion of the river during the spring when water temperatures are in the range of 18 – 24 ^{0}C (Figure 5-5).

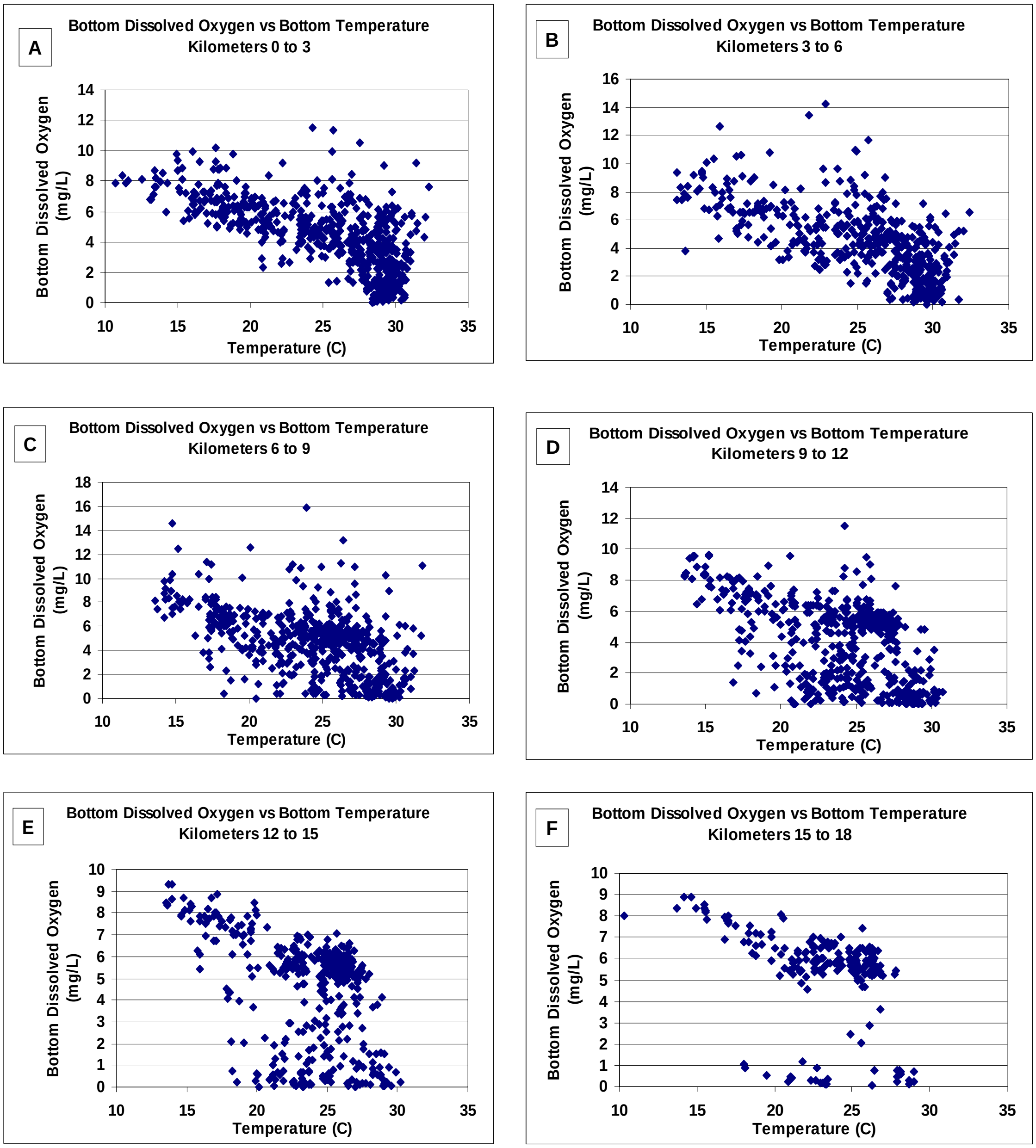


Figure 5-37. Bottom dissolved oxygen vs. water temperature for six three kilometer segments in the Lower Alafia River.

5.5.4 Relationships of DO with Inflow and Stratification

Surface and bottom DO concentrations are plotted vs. freshwater inflow in Figures 5-38 and 5-39. As was described on a seasonal basis, plots of surface DO vs. inflow show very few instances of hypoxia in surface waters. Some values below 4 mg/l were observed, but not were not common (Figure 5-38). More apparent are the very high DO values (> 10 mg/l) in surface waters, which typically occurred at low flows. The relationship of high DO values in the river to freshwater inflow are discussed in a later section of this report.

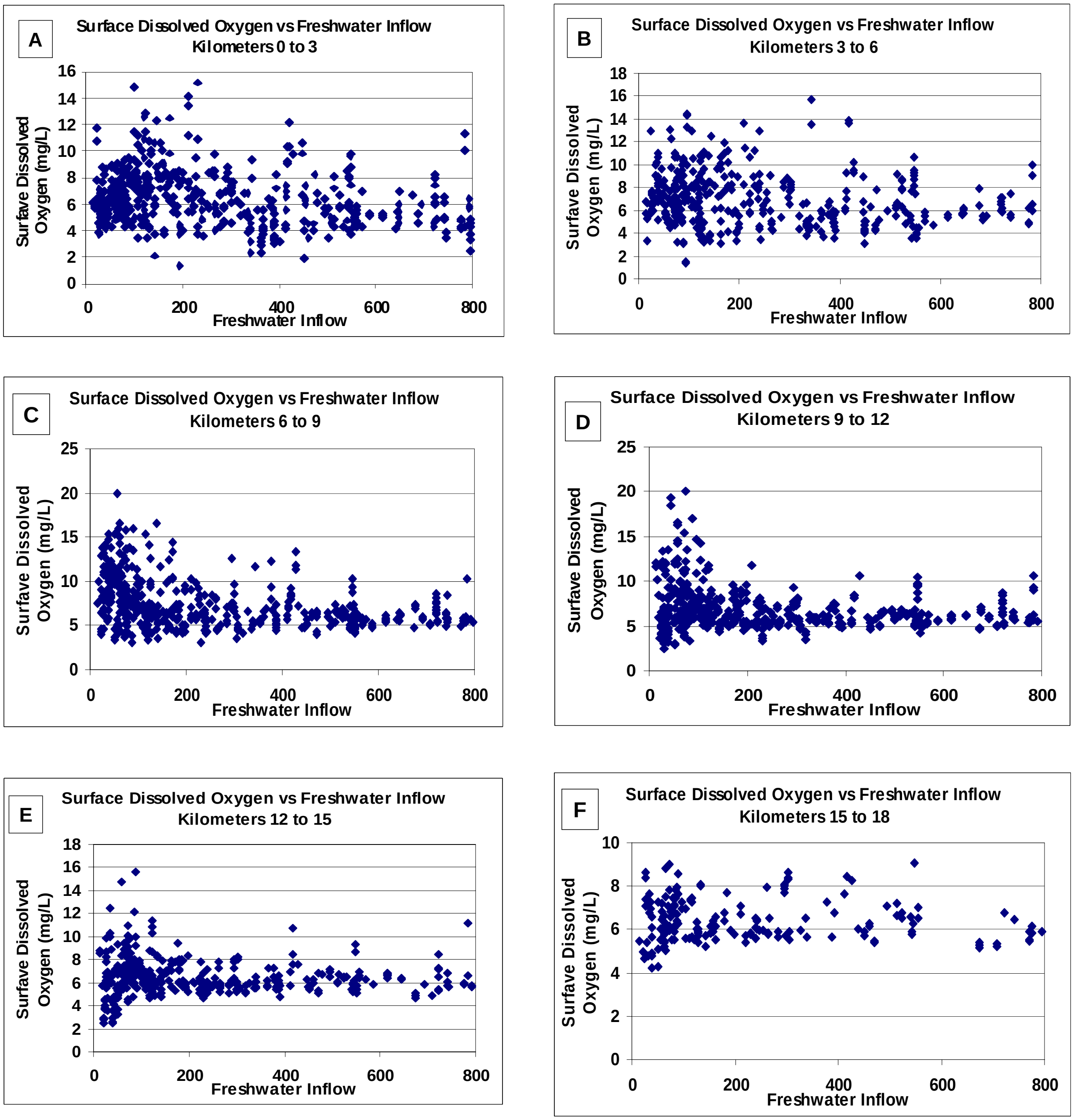


Figure 5-38. Surface dissolved oxygen vs. freshwater inflow for six three-kilometer segments in the Lower Alafia River.

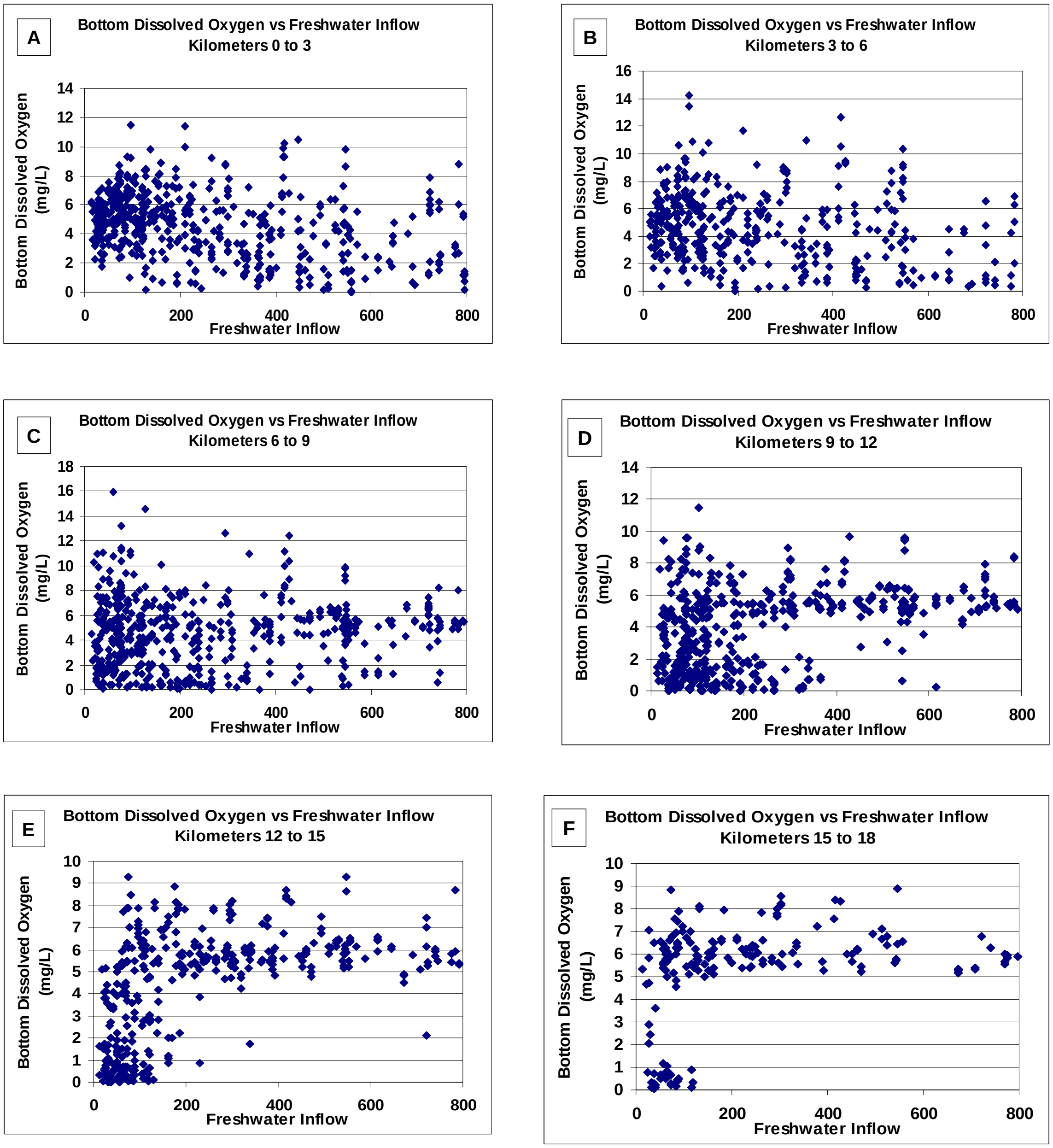


Figure 5-39. Bottom dissolved oxygen vs. freshwater inflow for six three-kilometer segments in the Lower Alafia River.

Plots of bottom DO vs. inflow show frequent hypoxia, with the relationship with flow differing between the lower, mid, and upper parts of the lower river. Near the mouth, hypoxia was nearly absent at flows less than 100 cfs and the occurrence of hypoxia generally increased with flow. A similar relationship was found at kilometers 3-6. In the mid-portion of the river, hypoxia occurred across the entire flow range shown, but seemed particularly frequent at flows less than 300 cfs. In the upper portions of the lower river, there was a distinct relationship with freshwater inflow as hypoxia was most frequent at low flows, with DO values above 4 being common above apparent critical thresholds. These critical flow thresholds become lower progressing upstream, ranging from about 400 cfs at kilometers 9-12, 200 cfs at kilometers 12-15, and 130 cfs at kilometers 15-18. These flow thresholds represent when these zones of the river become fresh, pushing the salt wedge out of these portions of the estuary which allows vertical mixing and the aeration of bottom waters.

The relationship of salinity stratification to DO concentrations in different segments in the river is shown in Figure 5-40. In all segments, there is a clear negative relationship between DO concentration and stratification; as stratification increases DO concentrations decline. In general, hypoxia is fairly infrequent when salinity stratification is less than 5 psu. The issue then becomes under what flow conditions does stratification occur. Plots of salinity stratification vs. inflow in Figure 5-13 shows that near the mouth of the river, stratification is low at flows less than 100 cfs, then generally increases with flow as the mixing zone of the river is pushed near the mouth of the river. A similar relationship is shown in the middle portion of the river, but very high flows reduce stratification as freshwater is pushed down to these locations (see 2-D salinity distribution in Figure 5-21). In the upper river segments there are clear relationships between flow, stratification, and DO, as high stratification and low DO are most common at low flows. These conditions are alleviated at high flows as these stations become fresh and the water column is well mixed.

5.5.5 Regression Models for the Prediction of Bottom DO Concentrations as a Function of Freshwater Inflow and Water Temperature

Regression modeling was used to investigate relationships of dissolved oxygen concentrations with the rate of freshwater inflow and water temperature. Multiple linear regressions were developed to predict the concentration of DO in deep bottom waters (> 2 meters deep), while logistic regressions were developed to predict the probability of hypoxia (< 2 mg/l DO) in these same bottom waters. Logistic regressions were also developed for the Tampa Bay Water HBMP to predict the probability of low DO (< 2.5 mg/l) in bottom waters at all depths measured in the lower river.

Multiple linear regressions to predict bottom water DO were developed for five of the six three-kilometer segments in the lower river (0-3, 3-6, 6-9, 9-12 and 12-15 kilometers). Regression models with water temperature and a single transformed flow term as the independent variables were used for the three most downstream segments (0-3, 3-6, and 6-9 kilometers). Although the solubility of DO can also be affected by salinity, salinity was not included as an independent variable because a separate model would be needed to predict salinity to perform withdrawal scenario runs, thus compounding model error. The regression coefficients, coefficients of determination (r-square), and the

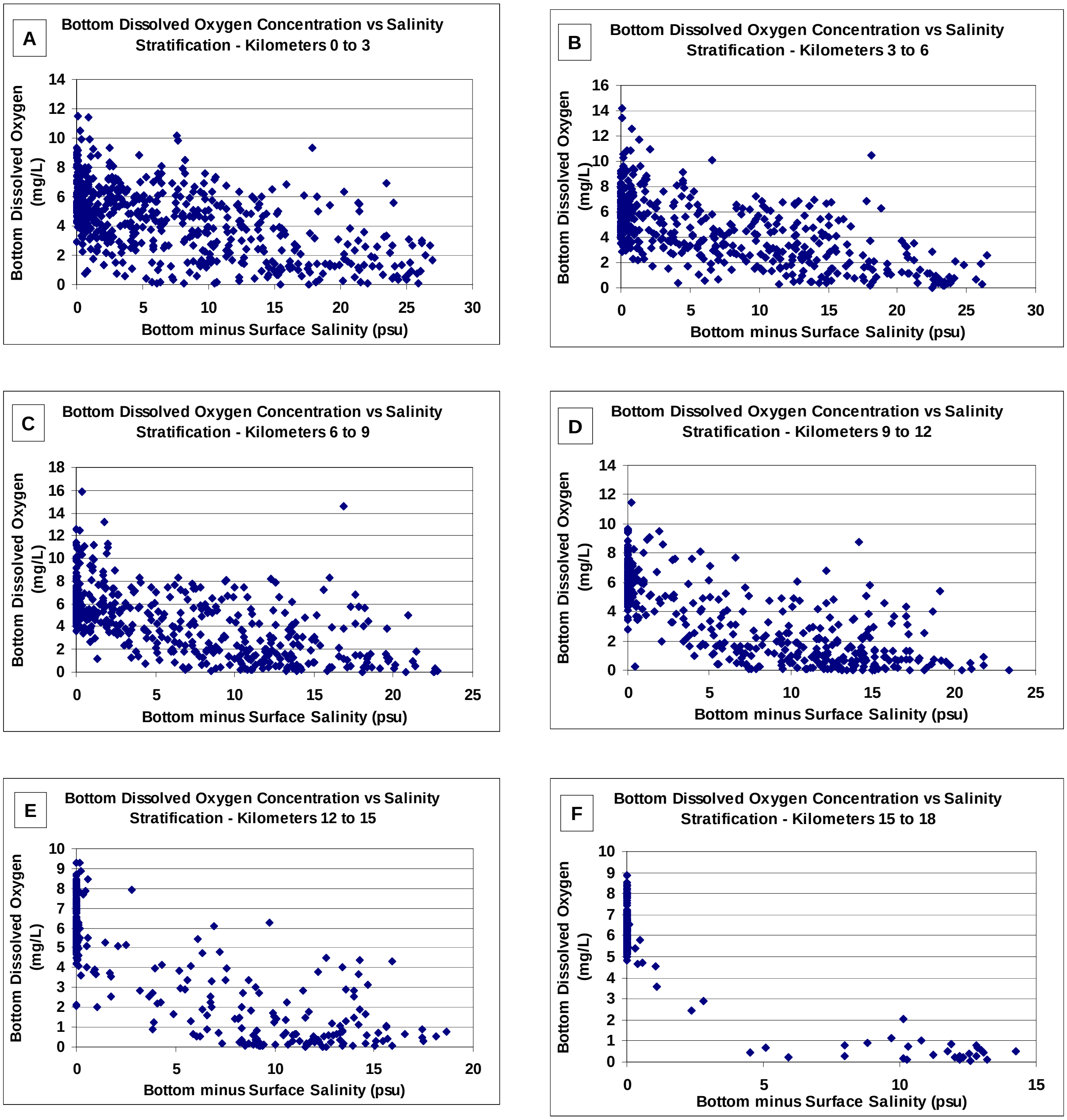


Figure 5-40. Bottom dissolved oxygen vs. salinity stratification for six three-kilometer segments in the Lower Alafia River.

transformations of the flow variables that were used in the regressions for these three segments are listed in Table 5-1. All regressions and regression parameters were significant at p<05. Plots of observed and predicted values are shown in Figure 5-41, with plots of the distribution and normality of the residuals presented in Appendix 5D. The flow term used in the regressions is the preceding three-day mean freshwater inflow to the estuary. The domain of the flow range for the regressions was 30 to 2000 cfs.

Table 5-1 Regression statistics to predict dissolved oxygen concentrations in bottom waters in three segments in the Lower Alafia River. Regressions are in the form of y = b + m_1 (temperature) + m_2 (inflow).					
Segment (kilometers)	**Intercept (b)**	**Slope temp (m_1)**	**Slope inflow (m_2)**	**Flow transformation**	**r^2**
0-3	13.68	-0.32	-0.28	Inflow $^{0.333}$	0.72
3-6	14.72	-0.38	-0.35	Ln(inflow)	0.62
6-9	10.85	-0.33	$2.83 * 10^{-6}$	Inflow^2	0.48

Since these are multivariate regressions that include flow and temperature as independent variables, plots of predicted values vs. flow in Figure 5-41 do not from smooth curves, as the temperature varied between observations. Nonetheless, some patterns do emerge. There is general negative relationship between DO and flow in the most downstream segment (0-3 km). However, the plot of estimated versus observed values shown in Appendix 5D shows that the model does not accurately predict DO values less than 2 mg/l. A similar negative relationship is found for segment 3-6 km, in that as flow increases DO generally declines. The equation for the middle river segment (6-9) has a very slight, positive slope for the flow term, which is the square of the freshwater inflow. This relationship shows a general positive relationship with flow at inflow rates above 200 cfs.

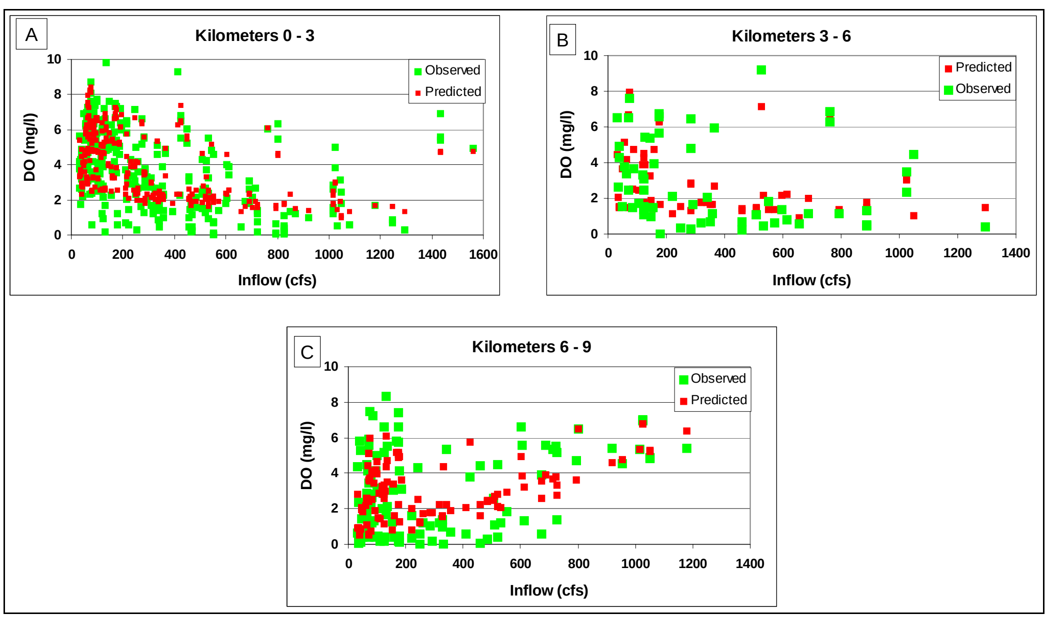


Figure 5-41. Observed and predicted values for bottom dissolved oxygen at depths greater than 2 meters using the regressions listed in Table 5-1 for three segments in the Lower Peace River between kilometers 0 and 9.

Piecewise regressions were developed for the segments between kilometers 9-12 and 12-15. In each piecewise regression, an inflection point was found in the relationship of DO with flow and different slope terms were applied to flow above and below the inflection point (termed knot1). Both water temperature and untransformed flow were significant independent variables in the regressions. The form of the piecewise regressions for predicting bottom DO were:

DO = b+ m1(temp) +m2(inflow) for inflows < knot 1
DO = b + m1(temp) + m2(inflow) + m3(inflow – knot1) for inflows > knot1

The regression coefficients and r-square values for the piecewise regressions for the two segments are listed in Table 5-2, and scatter plots of the observed and predicted values are shown in Figure 5-42. All regressions and regression parameters were significant at $p<0.05$. Residual plots from these regressions are shown in Appendix 5E. The analyses suggested inflections (knots) at 555 cfs for segment 9-12, and 226 cfs for segment 12-15. Scatter plots of the data, r-square values, and the distribution of residuals show that the piecewise regression for segment 12-15 had the best capability for predicting DO as a function of flow and temperature, partly because it appeared to accurately capture the inflection for this segment around 226 cfs.

Table 5-2. Regression coefficients for piecewise regressions to predict dissolved oxygen concentrations in bottom waters in two segments in the Lower Alafia River.

Segment	Intercept	Slope temp (m1)	Slope Flow one (m2)	Slope Flow two (m3)	Knot cfs	R-square
9-12 km	7.99	-0.27	0.007	-0.007	555	0.53
12-15 km	6.26	-0.25	0.024	0.024	226	0.63

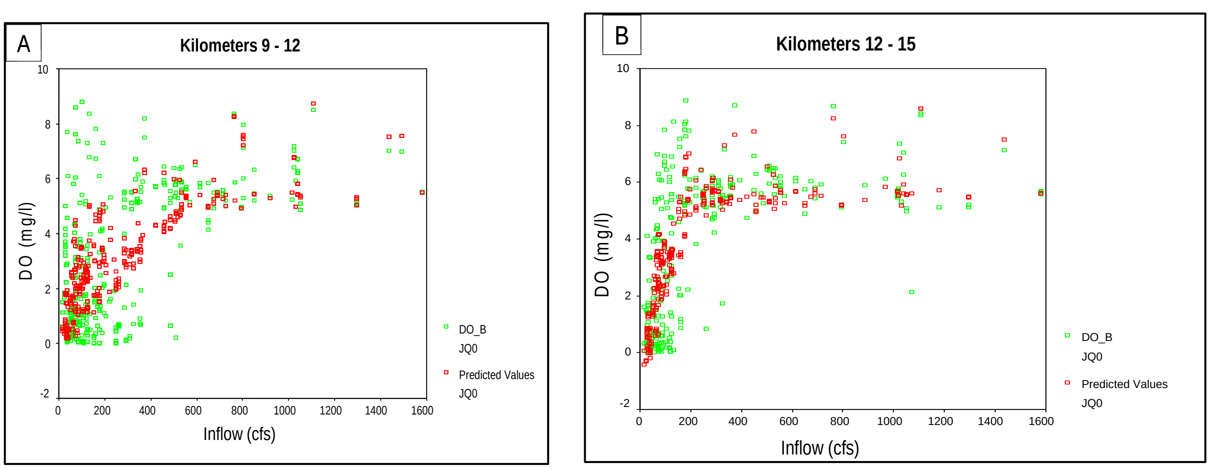


Figure 5-42. Observed and predicted values for bottom dissolved oxygen at depths greater than 2 meters using the piecewise regressions listed in Table 5-2 for two segments in the Lower Peace River between kilometers 9 and 12.

Logistic regressions were also developed to predict the probability of hypoxia in the river as a function of inflow and temperature. Logistic regressions determine the probability that a value of a response variable, in this case DO concentration, is either above or below a certain threshold value as a function one or more independent variables. In this analysis, the probability of DO being below 2.0 mg/l in waters greater than or equal to two meters deep was predicted as a function of freshwater inflow and water temperature. The fit of logistic regressions can be expressed as McFadden's Rho^2 values and as the percent of total observations that were correctly predicted as above or below the specified threshold. McFadden's Rho^2 values are lower than r^2 values from least squares regression, with values in the range of 0.2 to 0.4 considered satisfactory (Hensher and Johnson 1981). The regression coefficients, Rho^2 values, and correct prediction percentages for the logistic regressions to predict low DO in the six three-kilometer segments in the lower river are listed in Table 5-3. Concordance tables that list the percent correct predictions above and below the binary threshold of 2 mg/l DO are listed in Appendix 5F.

Table 5-3. Regression coefficients for logistic regressions to predict DO concentrations of less than < 2 mg/l for bottom waters greater than or equal to 2 meters deep in the Lower Alafia River.

Segment (km)	Intercept	Slope Temp	Slope Inflow	Rho^2	Inflow Transformation	Overall correct prediction percentage
0-3	-26.50	0.775	0.527	0.49	$Inflow^{0.333}$	80%
3-6	-20.35	0.565	0.885	0.41	Ln(Inflow)	74%
6-9	-7.58	0.301	0.000	0.25	$Inflow^2$	66%
9-12	-5.51	0.284	-0.008	0.36	Inflow	71%
12-15	-3.25	0.237	-0.024	0.50	Inflow	80%
15-18	8.5	0.000	-2.101	0.40	Ln(Inflow)	82%

The predicted curves for hypoxia in each of the lower river segments as a function of flow are plotted in Figure 5-43. The median yearly temperature in each segment was assigned to the regressions for this graphic so that the response to inflow could be better illustrated. As with predictions of bottom DO, hypoxia increases with rising flow in the two most downstream segments of the lower river (kilometers 0-3 and 3-6). The response of hypoxia to inflow is negative (less hypoxia with more flow), but fairly flat in the middle section of the river (kilometers 6 to 9), with a similar but steeper relationship in kilometer 9 to 12. The probability of hypoxia declines more rapidly with rising flow in the two upper river segments. Conversely, depending on the segment, as flows decline below about 100 or 200 cfs the probability of hypoxia in the upper river segments rapidly increases. As the previous data plots suggest, the logistic regression of the probability of hypoxia supports the conclusion that when the salt wedge moves into the upstream reaches of the tidal river during low flows, hypoxic conditions in bottom waters can result.

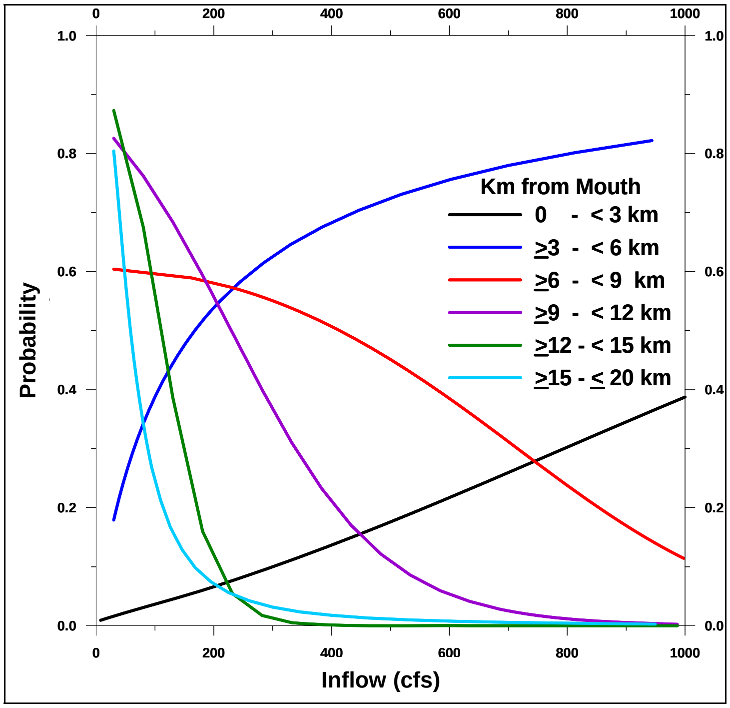


Figure 5-43. Logistic regression curves to predict the probability of bottom DO values less than 2 mg/l as a function of inflow for six three-kilometer segments in the Lower Alafia River.

Logistic regressions were also developed for the Year 6 Interpretive Report for the Tampa Bay Water HBMP by the firm of Janicki Environmental (PBS&J 2006). That analysis developed separate logistic regressions for the six sampling strata for the HBMP (Figure 5-1). To a large extent, these six strata largely overlie the six three-kilometer segments analyzed for the minimum flows report. The HBMP effort differed from the minimum flows analysis in that all bottom DO measurements in the river were used, and the threshold for identifying low DO was 2.5 mg/l. Also, the HBMP regression analysis only used data with flows above 112 cfs at Bell Shoals, as this represents the remaining flow after Tampa Bay Water has taken water at the lowest flow rate allowed by their permit (124 cfs). Graphs showing the logistic regressions from the HBMP report are shown in Figure 5-44 for six spatial strata in the lower river (see Figure 5-1). Although it used a different flow range and a slightly different threshold for identifying low DO, the HBMP analysis showed very similar results to the minimum flows analysis, in that the probability of low DO increased with rising flow in the lower two river strata and decreased with rising flow in the upper four river strata.

The regressions to predict DO concentrations and the probability of hypoxia in different segments in the lower river were used in the minimum flows analysis to determine the effect of potential flow reductions on DO concentrations in the lower river. Those results are presented in Chapter 8.

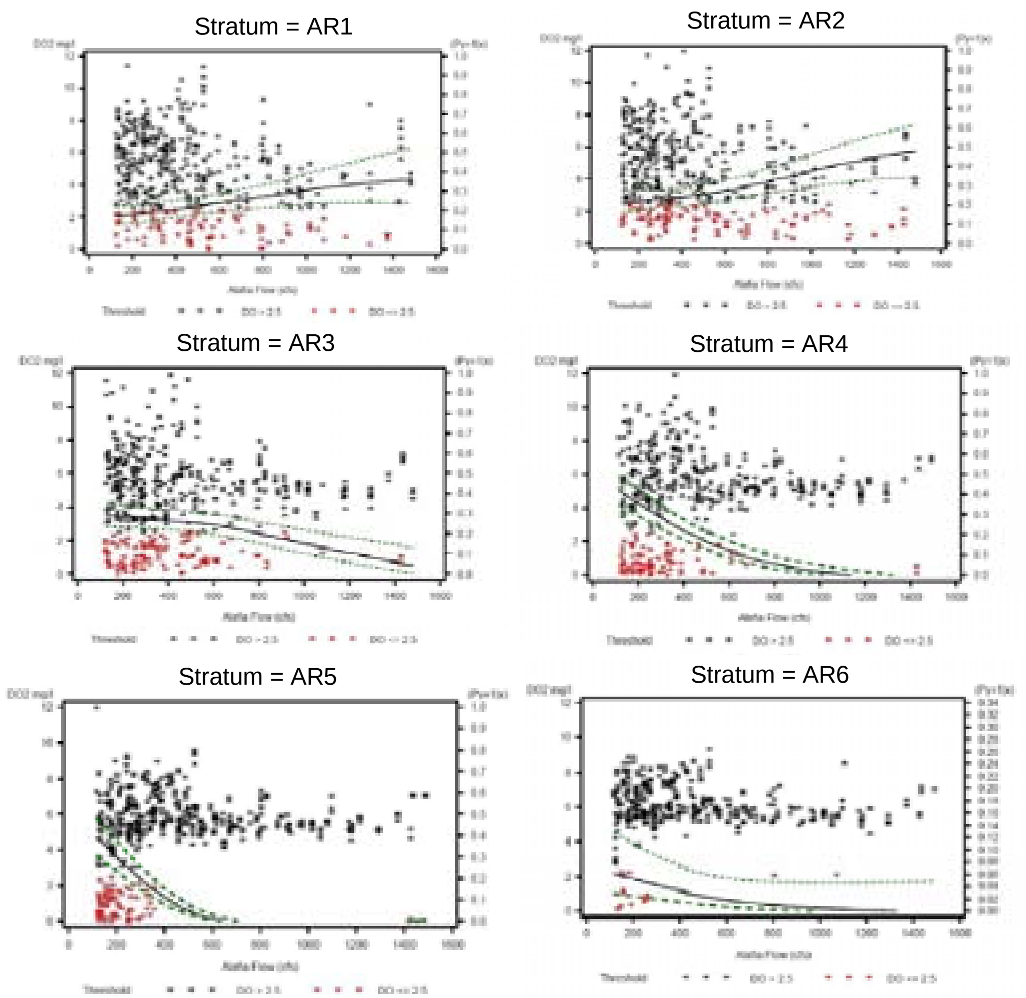


Figure 5-44. Bottom dissolved oxygen values and logistic regression curves to predict the probability of DO values less than 2.5 mg/l in six strata in the HBMP sampling program between flows of 112 and 1500 cfs. Upper and lower 95 percent confidence limits around the predicted exceedance probabilities also shown (adapted from PBS&J 2006).

5.5.6 Relation of DO Supersaturation in Surface Waters to Freshwater Inflow

As previously discussed, very high DO concentrations are sometimes observed in surface waters in the Lower Alafia River. When the concentration of dissolved oxygen exceeds 100 percent, or full saturation, this condition is referred to as supersaturation. Supersaturation can result from intense photosynthesis from phytoplankton or submersed aquatic plants. As submersed aquatic macrophytes are absent from the Lower Alafia River, it appears that the occurrence of supersaturation is largely the result of photosynthesis by phytoplankton blooms in the lower river.

A plot of percent saturation vs. inflow for all sites in the lower river shows there is a general negative relationship between supersaturation and the rate of inflow, as percent saturation values greater than 100 percent are most common below flow rates of 200 cfs, and values greater than 200 percent largely restricted to flows less than 100 cfs (Figure 5-45). Plotting these data for the six segments separately shows that the relationship of supersaturation to flow becomes more acute further upstream, as the rate of inflow needed to reduce DO saturation to below 100 percent generally becomes less (Figure 5-46). The occurrence of supersaturation at low flows is likely related to increased residence times in the river, which allows phytoplankton blooms to occur in the upper river segments during low flows. The relationship of phytoplankton blooms and high chlorophyll *a* concentrations in the river are discussed in the next section of this report.

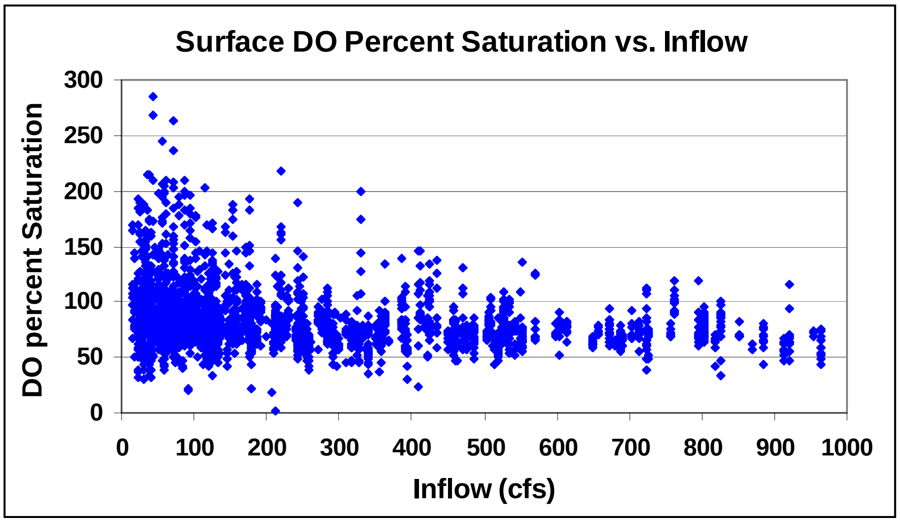


Figure 5-45. Relation of surface DO concentrations vs. freshwater inflow for samples throughout the lower river.

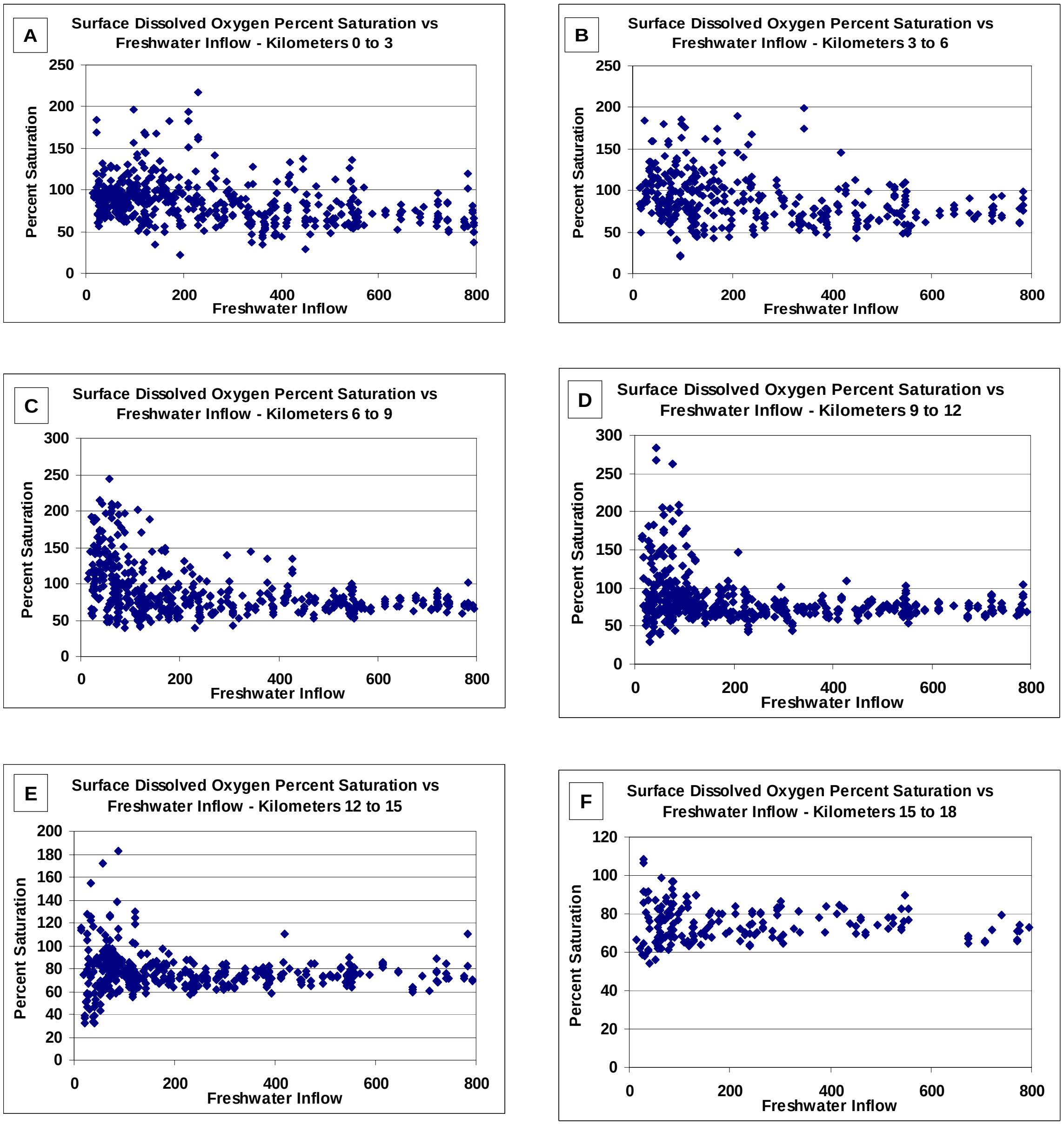


Figure 5-46. Surface dissolved oxygen percent saturation vs. freshwater inflow for six three-kilometer segments in the Lower Alafia River.

There is also a relationship between supersaturation and water temperature. Although there is considerable scatter in the relationship, values above 150 percent saturation were largely restricted to periods when temperatures were above 21^{0}C (Figure 5-47). Since DO is actually more soluble in cold water, the high saturation values must be related to other processes that are occurring in the warm water. Again, it appears that large phytoplankton blooms in warm waters are a contributing factor to the occurrence of DO supersaturation in the lower river.

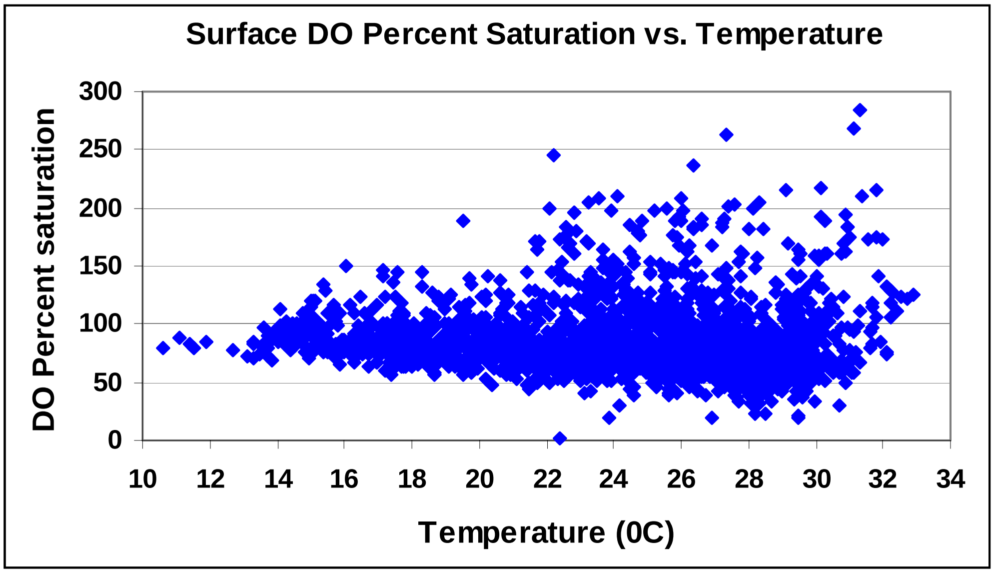


Figure 5-47. Surface DO concentrations vs. surface water temperature for sites throughout the lower river.

Logistic regression analyses were conducted to determine if the probability of supersaturation in the lower river could be predicted by physical factors. To be conservative, supersaturation was defined as DO percent saturation values greater than 120 percent. The analysis found that freshwater inflow was the sole significant explanatory variables for predicting the probability of supersaturation in all but one river segment (0-3 km), where temperature was also significant. Regression coefficients, McFadden's Rho^2 values, and the percent of correct predictions for the logistic regressions are listed in Table 5-4. Concordance tables that list the percent correct predictions above and below the threshold of 120 percent saturation are listed in Appendix 5F.

Table 5-4. Regression coefficients for logistic regressions to predict DO percent saturation values of greater than 120% in the Lower Alafia River.

Segment (km)	Intercept	Slope Temp	Slope Inflow	Rho^2	Inflow Transformation	Overall correct prediction percentage
0-3	-26.50	0.10	-0.466	0.05	Ln(Inflow)	88%
3-6	-20.35	n/s	-0.829	0.11	Ln(Inflow)	81%
6-9	-7.58	n/s	-1.536	0.27	Ln(Inflow)	82%
9-12	-5.51	n/s	-1.550	0.25	Ln(Inflow)	87%
12-15	-3.25	n/s	-1.197	0.13	Ln(Inflow)	95%

The Rho^2 values for three of the logistic regressions were very low (0.13 or less), but all the regressions were significant at $p<0.05$. The Rho^2 values and percent correct over the DO saturation threshold of 120 percent were the highest in the middle reaches of the river (kilometers 6 to 12), where high DO concentrations are most common (Figure 5-30). For all the regressions, the slope of the flow term is negative, meaning that the probability of supersaturation goes down as flows go up. The shape of the predicted curves for four segments are shown in Figure 5-48 (weak relationship for km 0-3 not shown). These curves show the segments that reach the highest probability of having supersaturation extend from kilometer 3 to kilometer 12. In all these segments, the predicted curves all take an upturn below 200 cfs, and are especially steep below 100 cfs. These results further indicate that supersaturation in the river is closely linked to the rate of freshwater inflow.

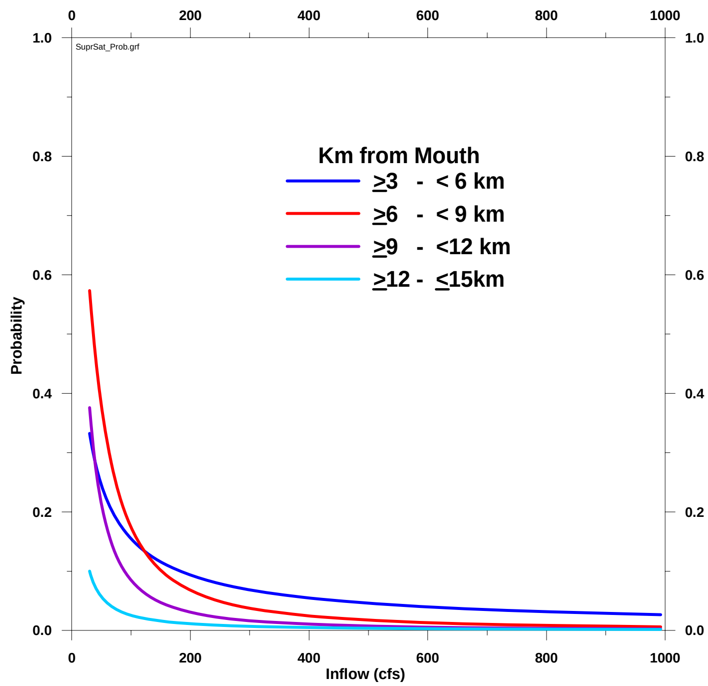


Figure 5-48. Logistic regression curves to predict the probability of surface dissolved oxygen percent saturation values > 120% for four three-kilometer segments in the Lower Alafia River.

5.6 Nutrients and Chlorophyll *a* in the Lower River - Relationships with Freshwater Inflow

Estuaries ecosystems are characterized by high rates of both primary and secondary productivity, which are linked to the delivery of nutrients to the estuary from its associated watershed (Correll 1978, Longley 1994). In cases where the impoundment of rivers and large reductions in freshwater inflows have occurred, decclines in fisheries production have been attributed in part due to reductions in nutrient delivery (Aleem 1972, Drinkwater and Frank 1994, Baisre and Arboleya 2006). In contrast, excessive nutrient delivery can lead to over-enrichment of estuaries, with resulting problems with hypoxia and harmful algal blooms (Paerl et al. 1998, Rabalais and Turner 2001, Anderson et al. 2002, National Science and Technology Council 2003). The rate of freshwater inflow strongly influences both the nutrient budget and the mixing characteristics of a receiving estuary. The concentration of nutrients in the freshwater inflow also exerts a strong influence on nutrient loading and the response of an estuary to changes in the volume of inflow.

The Alafia River is one of the most nutrient enriched rivers in southwest Florida. A long-history of phosphate mining and processing, industrial fertilizer production, and agriculture have resulted in very high nutrient concentrations in both the freshwater and estuarine reaches of the river (FDEP 1996, 2002). As a result of this nutrient enrichment, the Lower Alafia River often experiences very large phytoplankton blooms, which result in some of the highest chlorophyll *a* concentrations found in Florida. Given this enriched condition, freshwater inflow exert a very strong influence on the abundance of phytoplankton in the river, due to the effect on inflow on nutrient loading, water clarity, and residence time.

The distribution of nutrients and chlorophyll *a* in the Lower Alafia River are described in the following section, with emphasis on how these water quality parameters respond to freshwater inflow. Similar to hypoxia, the response of chlorophyll *a* to inflow differs markedly between the upper and lower sections of the lower river, so a segmented approach is taken below.

5.6.1 Water Quality of Freshwater Inflow at Bell Shoals Road

The EPCHC has collected monthly water quality data at a station on the Alafia River at Bell Shoals Road since 1974. The Bell Shoals site is a good location to characterize the water quality of inflow to the lower river, since most of the nutrient load to the lower river is delivered at this site. Summary statistics for selected water quality parameters at Bell Shoals are listed in Table 5.5 for the period 1999-2003. This period was chosen to represent the recent water quality characteristics of the river, and to coincide with the period of water quality data collection in the lower river estuary incorporated in the minimum flows analysis.

The Alafia River at the Bell Shoals site is highly nutrient enriched. Both ortho-phosphorus and total phosphorus concentrations exceed 1 mg/l, due partly to high background phosphorus concentrations in the river, but also influenced by the long-standing phosphate mining that has occurred in the basin. Phosphorus concentrations are actually much lower than during previous decades, due to improvements in mining and beneficiation practices by the phosphate industry (SWFWMD 2005b). The river is also highly enriched with inorganic nitrogen. Mean nitrate-nitrate nitrogen is 1.2 mg/l, which is considerably greater than the concentrations found in less polluted streams in the Tampa Bay region (Dooris and Dooris 1985, Flannery 1989, Boler 2001).

Neither chlorophyll *a* nor biochemical oxygen demand values at the Bell Shoals station are particularly high, as the mean chlorophyll *a* value was 3.0 µg/l with a maximum value of 9.8 µg/l. The relatively low mean chlorophyll value reflects that Bell Shoals is within the freshwater reaches of the river, where there are strong downstream currents, a largely shaded canopy, and quick transport times of flow from the river watershed to that location. As will be discussed in a later section, chlorophyll *a* values reach very high values in the estuary downstream of Bell Shoals, where the river widens and water residence times are longer.

Table 5-5. Statistics for selected water quality parameters at EPCHC station 114 on the Alafia River at Bell Shoals Road for the period 1999-2003.

	Units	Mean	Std. Dev.	Min.	Max.
Salinity	Psu	0.2	0.0	0.1	0.2
Temperature	^{0}C	22.3	3.2	13.8	26.5
pH	pH	7.5	0.3	6.8	8
Dissolved Oxygen	mg/l	6.4	0.7	5.4	8.8
Color	Cpu	51	41	10	221
Secchi Depth	meters	1.0	0.5	0.3	2.1
Biochemical Oxygen Demand	mg/l	1.1	0.4	0.3	2.3
Chlorophyll a	ug/l	3.0	2.3	0.5	9.8
Ortho-phosphorus	mg/l P	1.16	0.34	0.53	2.04
Total Phosphorus	mg/l P	1.39	0.49	0.50	2.95
Nitrate + Nitrite Nitrogen	mg/l N	1.22	0.58	0.24	2.28
Ammonium	mg/l N	0.03	0.02	0.01	0.08
Organic Nitrogen	mg/l N	0.52	0.31	0.03	1.32
Total Nitrogen	mg/l N	1.86	0.36	1.24	2.56

Color, ortho-phosphorus and four nitrogen parameters are plotted vs. flow at Bell Shoals in Figure 5-49. Ortho phosphorus and color concentrations are both positively correlated with flow ($r = 0.30$, $p<.001$ for ortho-P; $r = 0.66$, $p < .001$ for color). The positive response of color to flow results from increased surface drainage which transports dissolved organic matter from soils and vegetation in the watershed. The mechanism for increased phosphorus concentrations may be related to runoff from the large of amount of altered lands in the basin.

Nitrate-nitrite nitrogen is negatively correlated with flow ($r = -0.52$, $p < .0001$), with steep declines with flow below about 300 cfs, then some leveling of the flow response above 300 cfs (Figure 5-49C). The very high values at low flows are likely due to the enrichment of local groundwater with nitrate. Increasing trends in nitrate concentrations have been documented for Lithia Springs, with concentration from the springs averaging near 3 mg/l nitrate nitrogen during the 1990's (SWFWMD 2001a). Spring discharges and groundwater seepage provide most of the flow of the river during low flows, resulting in nitrate-nitrate concentrations mostly between 1 and 2 mg/l at flows less than 200 cfs. Though not as high as low flow conditions, nitrate-nitrate concentrations at higher flows still reflect considerable enrichment, largely remaining above 0.5 mg/l at flows up to 800 cfs.

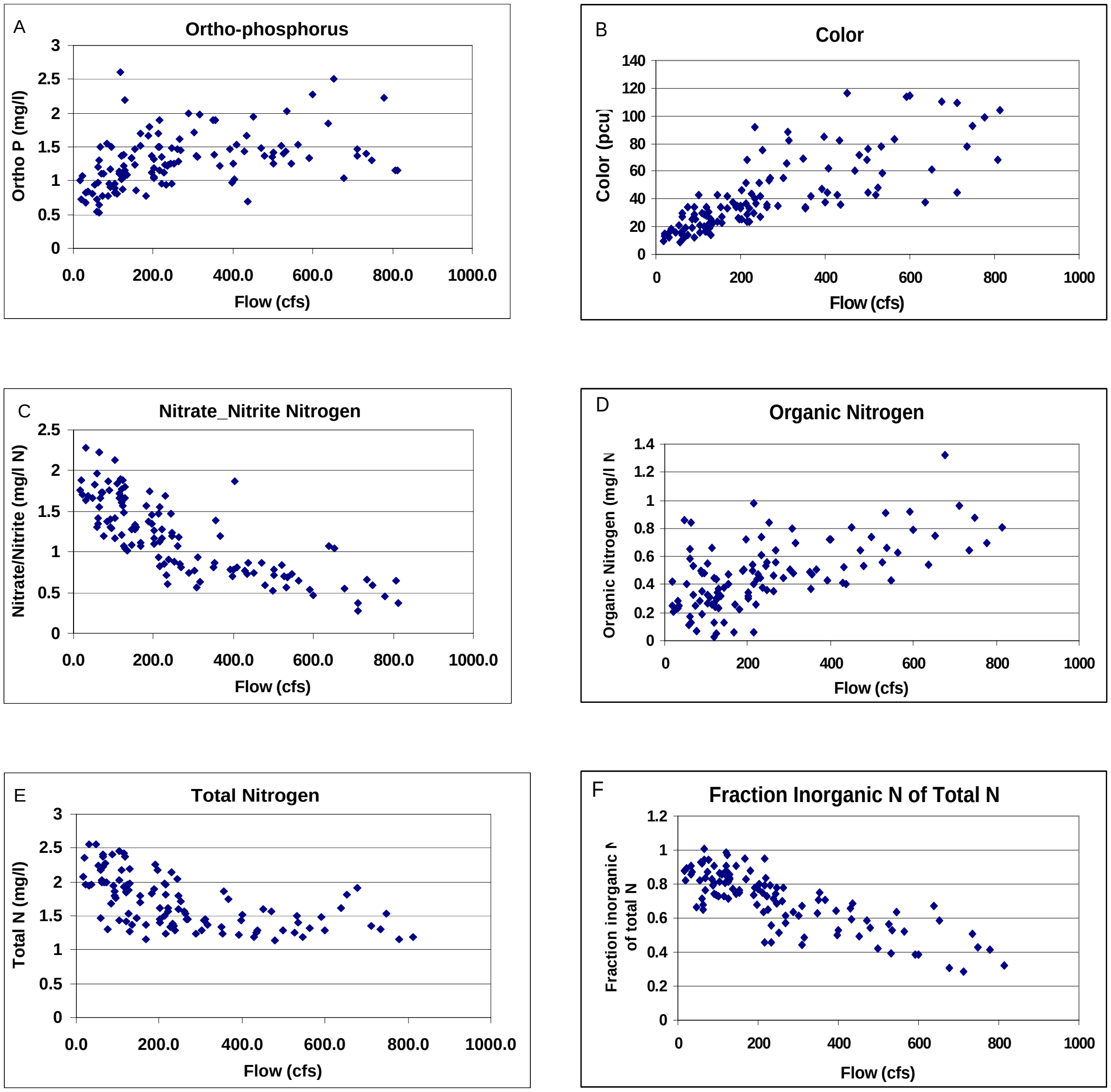


Figure 5-49. Plots of the concentrations of ortho-phosphorus (A), color (B), nitrate-nitrite nitrogen (C), organic nitrogen (D), total nitrogen (E), and fraction of total N comprised of inorganic N (F) vs. streamflow at the Bell Shoals Road. All water quality values from the EPCHC data base for 1999 – 2003.

In contrast to inorganic nitrogen, organic nitrogen is positively correlated with flow ($r = 0.52$, $p < .001$), due to organic matter being transported to the river by increased surface drainage during high flows. Total nitrogen shows a negative relationship with flow at flows below 300 cfs, but largely a flat response at high flows, as decreases in inorganic nitrogen are offset by increases in organic nitrogen. Thus, total nitrogen concentrations were not correlated with flow, but the fraction of total nitrogen comprised of inorganic nitrogen clearly decreases with flow (Figure 5-49F).

5.6.2 Water Quality Characteristics of Lithia and Buckhorn Springs

Water quality in the Lower Alafia River is strongly influenced by discharge from Lithia and Buckhorn Springs. Lithia Springs flows to the Alafia River approximately 7 kilometers above Bell Shoals Road, so the results described in the preceding section include the effects of these spring inputs. Buckhorn Springs flows into the Lower Alafia about 6 kilometers below Bell Shoals Road. As will be discussed in Section 5.6.5, flows from Buckhorn Springs influence water quality in that region of the river. The water quality characteristics of Lithia and Buckhorn Springs are discussed below. Nutrient loading rates are reported both for the springs and the river at Bell Shoals Road, so that the relative contribution of nutrient loading to the lower river from the springs can be evaluated.

Water quality data for Lithia and Buckhorn Springs are available from District sampling programs which are conducted on a roughly a bi-monthly basis. Summary statistics for both springs for the period 1991-2003 are listed in Table 5-6. Though more recent data are available, this time period was selected to better coincide with the baseline data collection for the lower river presented in this report.

Table 5-6. Water Quality Statistics for Litha and Buckhorn Springs during 1991-2003. Also listed are values for springflow in cubic feet per second and DIN loading in kilograms per day.

Lithia Springs						
Variable	**Units**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Springflow	cfs	78	33.9	11.9	11.2	64.5
Water Temperature	^{0}C	94	25.1	0.7	23.8	29.1
PH	pH	94	7.4	0.1	7.0	7.8
Specifc Conductance	µs/cm	98	487	38	400	563
Nitrate N	mg/l	77	2.96	0.50	1.70	4.36
Ammonia N	mg/l	93	0.01	0.01	0.01	0.10
Dissovled Inorganic N	mg/l	75	3.00	0.48	1.80	4.37
Ortho Phosphorus	mg/l	91	0.06	0.01	0.03	0.13
Total Phosphorus	mg/l	88	0.09	0.12	0.04	0.80
DIN Load	Kg/Day	69	251	97	59	492
Buckhorn Springs						
Variable	**Units**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Springflow	cfs	78	12.8	1.9	9.3	18.0
Water Temperature	^{0}C	85	24.7	1.0	22.5	29.7
PH	pH	85	7.5	0.1	7.3	7.6
Specifc Conductance	µs/cm	89	468	23	365	527
Nitrate N	mg/l	78	2.03	0.38	1.11	3.73
Ammonia N	mg/l	86	0.02	0.03	0.01	0.12
Dissovled Inorganic N	mg/l	76	2.06	0.38	1.21	3.74
Ortho Phosphorus	mg/l	83	0.05	0.04	0.02	0.35
Total Phosphorus	mg/l	81	0.08	0.13	0.03	1.11
DIN Load	Kg/Day	70	65	16	31	104

Both springs discharge fresh water, with mean specific conductance values of 487 and 469 µmhos/cm, respectively, for Lithia and Buckhorn Springs with fairly low standard deviation values. Both springs are highly enriched with inorganic nitrogen, with nearly all of this comprised by nitrate. Nitrate nitrogen values averaged 2.96 mg/l for Lithia Springs and 2.03 mg/l for Buckhorn Springs. These mean values are greater than the mean nitrate nitrogen values for the river at Bell Shoals (1.2 mg/l, Table 5-5) and the upstream USGS gage at Lithia (0.70 mg/l, unpublished District data). Nitrate moves readily through groundwater aquifers, and the high nitrate concentrations in these springs are reportedly due inorganic fertilizer use and in the region (SWFWMD 2001a).

In contrast, both springs are not nearly as phosphorus enriched as the river. The mean total phosphorus concentrations are 0.09 and 0.08 mg/l for Lithia and Buckhorn Springs, compared to a mean total P concentrations of 1.39 mg/l for the river at Bell Shoals and 2.02 mg/l at the Alafia at Lithia gage. In sum, the springs act to increase inorganic nitrogen concentrations and dilute phosphorus concentrations in the lower river.

5.6.3 Role of Lithia and Buckhorn Springs in Nutrient Loading to the Lower River

At the request of the technical panel that reviewed the original draft minimum flows report, the importance of the springs in seasonal nutrient loading rates to the Lower Alafia River was examined. Since nitrogen is the macronutrient that typically limits phytoplankton in Tampa Bay and its tributaries (Fanning and Bell 1985, Vargo et. al. 1991, Janicki and Wade 1996, Wang et al. 1999), the emphasis of this analysis was on dissolved inorganic nitrogen, which is readily available for algal uptake.

A record of estimated daily nutrient loadings of DIN in kilograms per day for the river was calculated by developing a regression between DIN concentrations and flow at Bell Shoals for the 1999 - 2003 period, then multiplying those predicted concentrations by daily flow record to yield daily loads. The relationship of DIN with flow at Bell Shoals Road is shown in Figure 5-50. Based on a tendency for the regression to overpredict DIN concentrations at low flows, a DIN concentration of 2.0 mg/l was assigned to all flows below 35 cfs (ln transformed value of 3.6), a flow rate that has been exceeded 98 percent of the time during the baseline period. Also, the regression was not used to predict DIN concentrations above a flow rate of 2440 cfs (ln transformed value of 7.8), above which a DIN concentration of 0.2 mg/l was assigned.

The average rate of DIN loading at Bell Shoals Road is 686 kilograms per day. This corresponds to an areal flux rate of about 2.6 kg per hectare per day from the watershed upstream of this location. A plot of the average monthly values for percent of total yearly DIN load at Bell Shoals Road is presented in Figure 5-51, with similar values included for monthly streamflow.

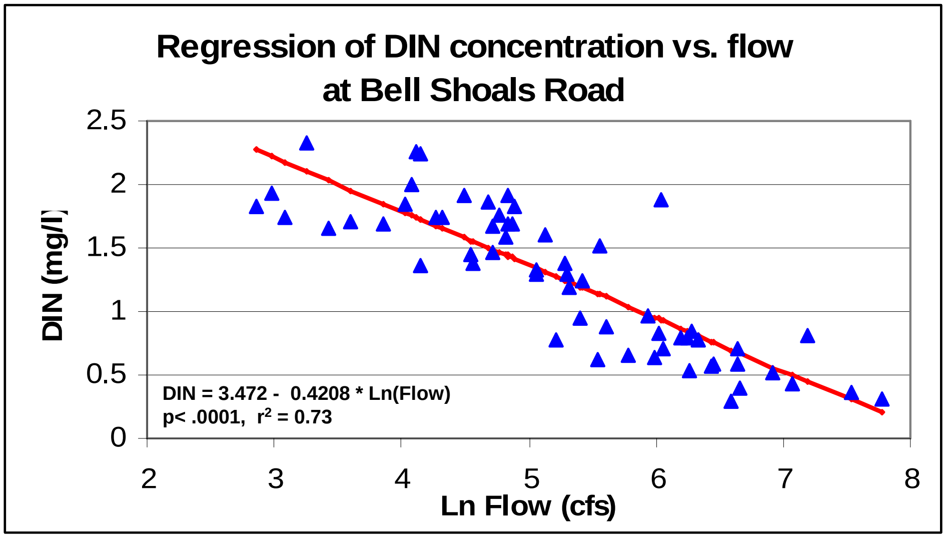


Figure 5-50 Relationship of DIN and streamflow at Bell Shoals Road with fitted regression.

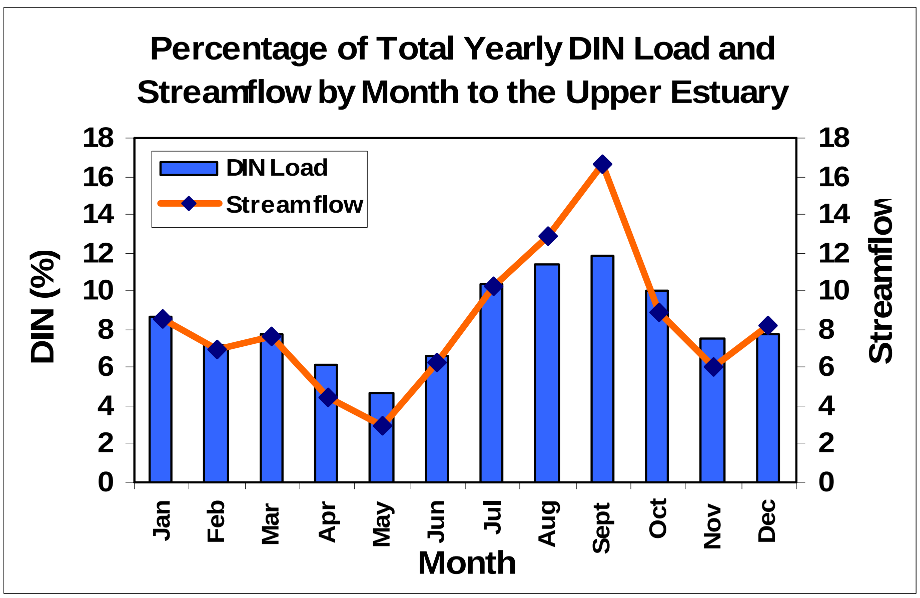


Figure 5-51. Proportion of total yearly DIN loading and total yearly streamflow by month, based on average monthly loading and streamflow rates

As expected, the monthly pattern of DIN loading follows the pattern of monthly streamflow. Since streamflow varies much more than nutrient concentrations, large variations in streamflow are the dominant factor controlling nutrient loading to the lower river. However, since DIN concentrations in the river are highest at low flows, the proportion of yearly DIN loading is higher than the proportion of yearly streamflow in the spring dry season. In the late summer there is a higher proportion of flow relative to load due to nitrate concentrations being lower in the river during high flows.

Daily DIN loadings were also calculated for Lithia and Buckhorn Springs. Mean values for DIN loading were presented in Table 5-6. The average DIN loading rate for Lithia Springs is 251 kg/day, while the average DIN loading rate for Buckhorn Springs is 65 kg/day. Since water quality monitoring form the springs is largely bi-monthly, there was no attempt to estimate daily records of nutrient loadings from the springs. Instead, average DIN loads in kg/day were calculated for individual months during the 1991 – 2003 period, assuming the flow and concentration on the sampling day was characteristic of that month. Loads were not calculated for a number of months between 1992 and 1994 when no nutrient data were recorded.

Plots of average monthly DIN loads in the river at Bell Shoals Road are overlain with loadings from Lithia Springs Figures 5-52 Since loads from Lithia Springs are included in the loads at Bell Shoals, this graphic illustrates the proportion of load at Bell Shoals comprised by Lithia Springs on those months when loads from Lithia Springs were calculated. Due in part to the high nitrate concentrations in Lithia Springs, loading from the springs comprises a high proportion of the DIN at Bell Shoals during low flows.

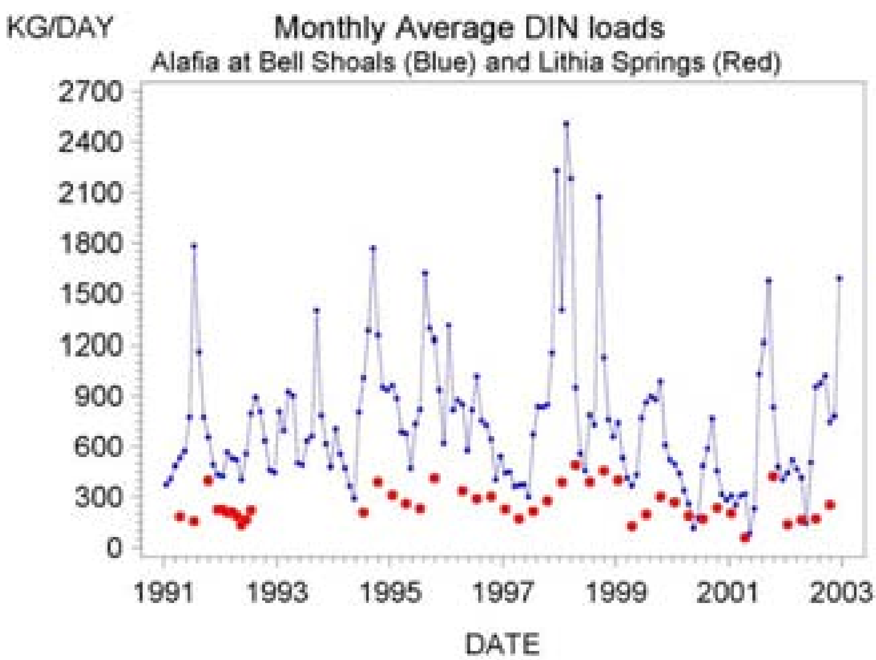


Figure 5-52. Monthly nutrient loading at Bell Shoals Road (blue) and from Lithia Springs (red) for 1991-2003.

This relationship is also shown below in Figure 5-53 where the percent of average monthly DIN loads at Bell Shoals comprised by the DIN loads from Lithia Spring are plotted separately vs. monthly loads and flows at Bell Shoals Road. The percent load at Bell Shoals comprised by Lithia Springs is frequently in the range of 30 to 60 percent when flows at Bell Shoals are less than 400 cfs, and can range to over 70 percent during very low flows.

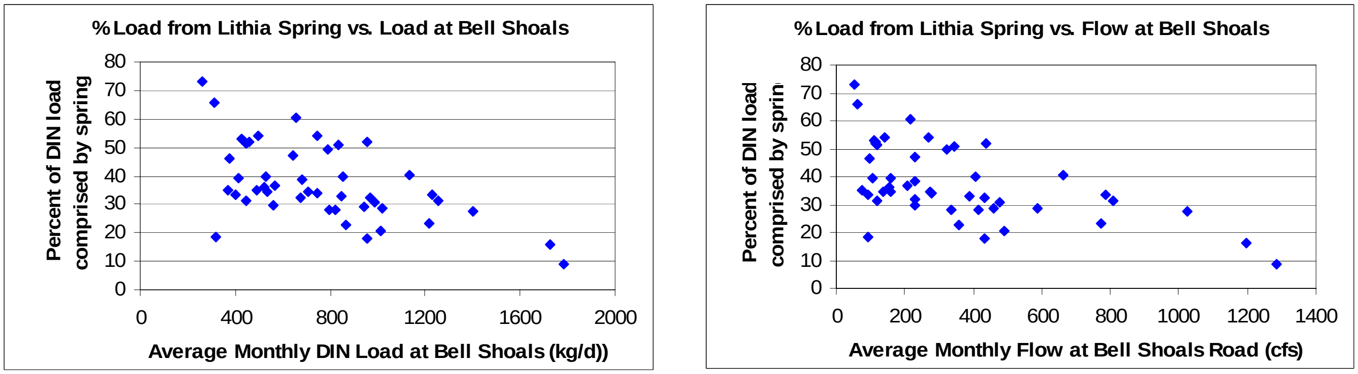


Figure 5-53. Percent of average monthly DIN loads at Bell Shoals comprised of DIN loads provided by Lithia Springs vs. average monthly DIN loads and flows at Bell Shoals.

Dissolved inorganic nitrogen loads from Buckhorn Springs are additive, in that they are not included in the load at Bell Shoals. A plot of average monthly loads at Bell Shoals is overlain with monthly loads from Buckhorn Springs in Figure 5-54. Because of its lower rate of flow and lower DIN concentrations, loads from Buckhorn Springs comprise much smaller fractions of loads to the river than do loads from Lithia Springs.

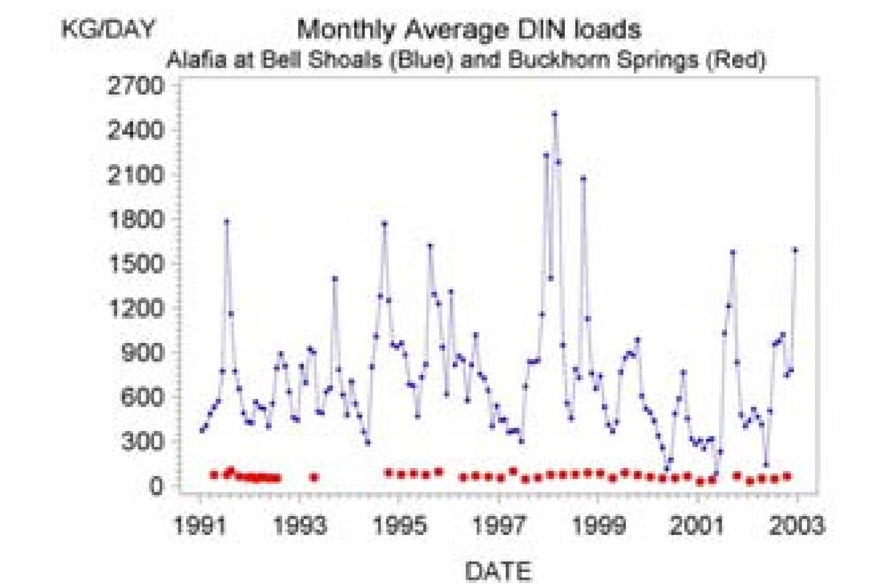


Figure 5-54. Monthly nutrient loads at Bell Shoals Road (blue) and from Buckhorn Springs (red) for 1991-2003.

The percent of average monthly DIN loads at Bell Shoals represented by the DIN loads from Buckhorn Springs are plotted separately vs. average monthly loads and flows at Bell Shoals Road in Figure 5-55. Loads from Buckhorn Springs are frequently equivalent to between 5 to 15 percent of the DIN loads at Bell Shoals, sometimes reaching as high as 27 percent during very low flows.

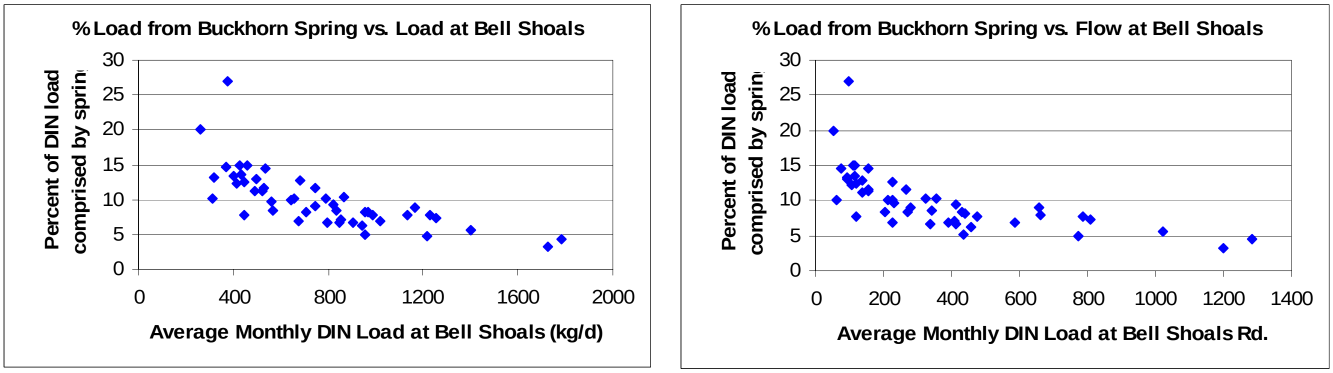


Figure 5-55. Percent of monthly DIN loads at Bell Shoals represented by loads from Buckhorn Springs vs. monthly DIN loads and flows at Bell Shoals

In sum, loads of inorganic nitrogen from both springs comprise the highest percentages of the river's nitrogen load in the dry season, especially the low flow period in late spring. The combined loads from Lithia and Buckhorn Springs can well exceed 50% of the total load to the lower river in the dry season. However, nitrate concentrations in the river at Bell Shoals Road are negatively correlated with flow (Figure 5-49), indicating that inputs of nitrogen-rich flow from Lithia Springs are diluted by stormwater runoff in the wet season.

Further downstream, flows from Buckhorn Springs contribute to high DIN concentrations in the upper part of the estuary, especially during low flows when spring discharges comprise a high proportion of total river flow. As discussed in the following section, these nutrient inputs combined with long residence times in the river allow large phytoplankton blooms to develop in the upper estuary during periods of low flows.

5.6.4 Data Sources for the River Below Bell Shoals Road

Unless noted otherwise, water quality data for the lower river presented in this report are restricted to the period 1999-2003. Water quality in the Lower Alafia River below Bell Shoals Road was monitored during this period by the same three agencies that took vertical profile measurements: the EPCHC, SWFWMD, and the Tampa Bay Water HMBP. However, the sampling design, length of record, and parameters that are measured vary between agencies. The EPCHC measures a large suite of water quality parameters at two fixed location stations in the river downstream of Bell Shoals Road. These stations are located at the US 41 (station 74) and US 301 (station 153) bridges (Figure 5-56). The parameters measured at these sites by EPCHC are the same as measured at Bell Shoals by Road. Data are collected monthly at these sites, with the period of record starting in 1974 for station 74 (USF 41) and 1999 for 153 (US 301). These stations are also part of EPCHC's regular water quality monitoring network where sampling has continued to present. More extensive statistical summaries of the complete list of parameters measured at these sites can be found in EPCHC publications (Boler 2001).

As part of the minimum flows study, the SWFWMD measured a large suite of water quality parameters at six fixed-location stations in the river and one fixed location in the Tampa Bay between May 1999 and 2003. The stations were at a subset of the stations where vertical profiles were measured, and were distributed at approximately two to three kilometer intervals with stations at kilometers -1.8 (bay), 0.8, 2.5, 5.9, 8.0, 11.4 and 13.8. Sampling occurred at a slightly less than monthly basis, with 36 samples during the course of the study. On these same sampling dates, the SWFWMD also collected water quality on four moving stations, which were based on the location of various isohalines in the river on each sampling day. Water quality samples were collected at the field location of the 0.5, 6, 12, and 18 psu isohalines at the time of sampling. This sampling design was intended to give comparable results to similar moving station water quality data that had been collected on the Peace and Little Manatee Rivers. Nutrients, chlorophyll *a*, total suspended solids, color and other parameters were measured at both the fixed location and moving SWFWMD stations.

Water quality sampling for the Tampa Bay Water HBMP uses the probabilistic design, as described for the vertical profile measurements on page 5-2. On a monthly basis, two samples for water quality analysis are collected from surface waters at each of the vertical profile stations within each of the seven sampling strata. A sample for water quality analysis is also collected from a fixed location station in Tampa Bay near the mouth of the river on the same sampling days. Compared to the EPCHC and SWFWMD water quality programs, a more limited set of water quality parameters are measured at the HBMP stations. In addition to the vertical profile data, water quality parameters measured by the HBMP include chlorophyll *a,* dissolved and total organic carbon, color, Secchi disk, and total suspended solids. Nutrients are not measured at the HBMP sites.

With the exception of dissolved organic carbon, which is not measured by the EPCHC, the parameters measured by the HBMP are also measured by the SWFWMD and EPCHC. Thus, many more observations are available for the parameters that are measured by all three agencies, which in this report are termed the core water quality parameters. The numbers of observations for core water quality parameters measured by each agency within three-kilometer segments in the river is shown in Figure 5-56. Because the HBMP samples are spatially distributed between strata, the number of HBMP samples per segments is fairly equal. The EPCHC sties reflect the three fixed station samples, while the combined SWFWMD fixed and moving station samples were oriented to the river reach between the mouth and kilometer 13. There are fewer samples at the bay segment, as only a single sample was taken there each trip by SWFWMD and the HBMP.

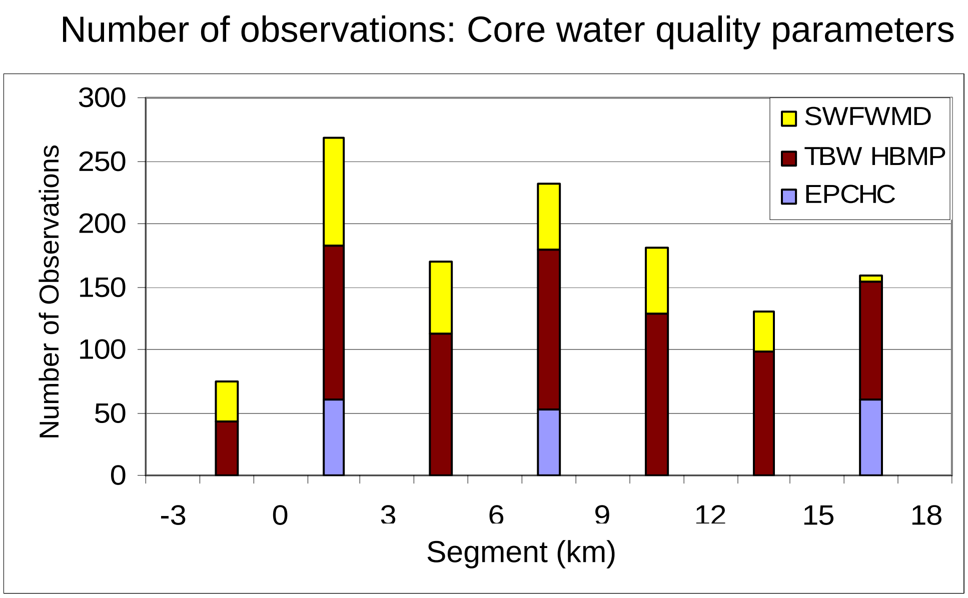


Figure 5-56. Number of observations for core water quality parameters common to the monitoring programs by SWFWMD, EPCHC, and the Tampa Bay Water HBMP.

The number of observations for nutrients and other expanded water quality parameters measured solely by the EPCHC and SWFWMD are shown in Figure 5-57. The number of observations for these parameters ranged between 53 and 144 for the six three-kilometer segments between the mouth of the river and Bell Shoals. The largest number of observations were in segments 0-3 and 6-9, due to the presence of EPCHC stations at US 41 and US 301. The EPCHC Bell Shoals station is included in segment 15-18 in Figures 5-56 and 5-57.

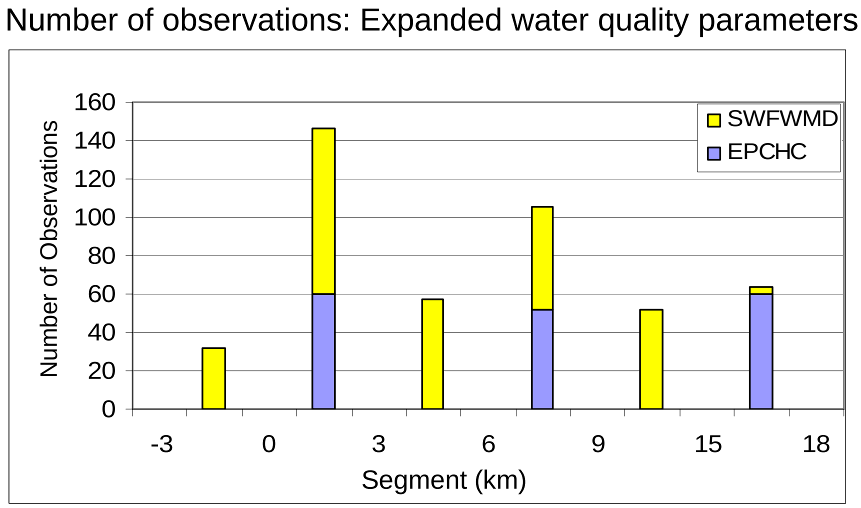


Figure 5-57. Number of observations for the expanded water quality parameters common to the monitoring programs by SWFWMD and the EPCHC.

5.6.5 Relationships of Water Quality Gradients in the Lower River Estuary to Freshwater Inflow

Water quality gradients in the Lower Alafia River estuary reflect the influence of constituent loadings transported by freshwater inflow, nutrient uptake and other processes occurring within the tidal river, and the effects of tidal exchange with Tampa Bay. Gradients in various water quality parameters in the estuary differ in how they are affected by these factors. If a water quality parameter is related to the rate of freshwater inflow, and reductions of inflow can result in changes to the associated natural systems of the estuary (biota), the response of that parameter can be important to the determination of minimum flows.

A notable characteristic of the Lower Alafia is the high ortho-phosphorus concentrations that occur throughout the lower river (Figure 5-58A). Although ortho-phosphorus concentrations are lower in the more downstream reaches due to the influence of flushing by more dilute waters of Tampa Bay, concentrations are almost always in excess of what is needed for plant growth. Though phosphorus limitation is sometimes observed in estuaries, it is much more common for estuaries to be nitrogen limited (Ryther and Dunstan 1971, Nixon 1986, Tomasky and Valiela 1995, National Research Council 2000). Nitrogen is the potential limiting nutrient in the Alafia (when not in excess), due very high phosphorus concentrations and loadings to the estuary from this phosphorus rich and highly altered basin (Flannery 1989, FDEP 2002). As with the Bell Shoals site, ortho-phosphorus concentrations are positively correlated with inflow throughout the lower river (Figure 5-59). Plots of ortho-phosphorus vs. inflow for the most upper and lower of the six three-kilometer segments in the estuary show this positive relationship with flow. Only during times of low inflow (< 150 cfs) do ortho-phosphorus concentrations < 0.1 mg/l occur in the segment near the river mouth.

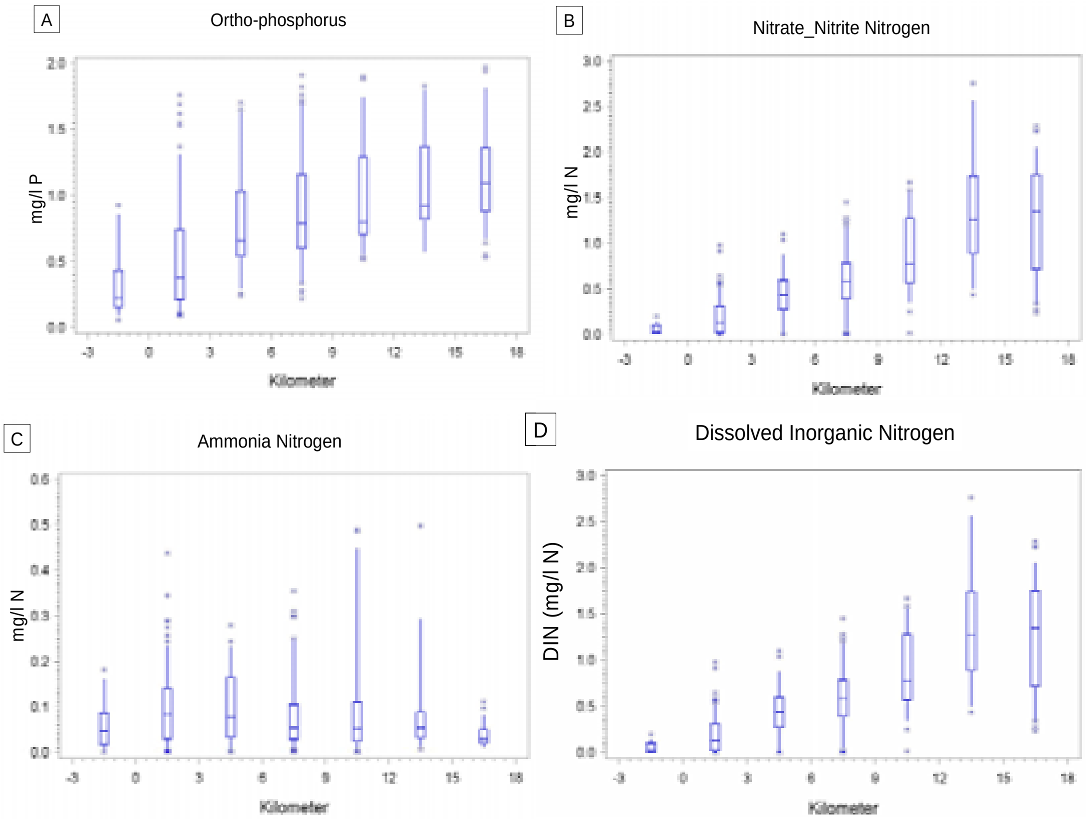


Figure 5-58. Boxplots of ortho-phosphorus and three nitrogen species in three-kilometers segments along the Lower Alafia River and a nearby station in Tampa Bay.

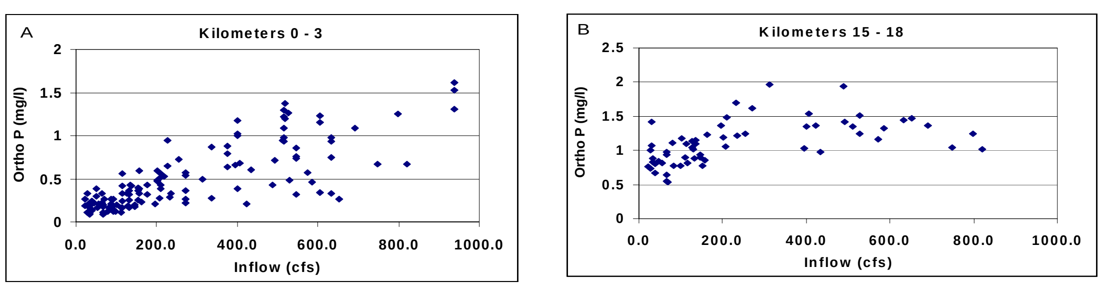


Figure 5-59. Plots of ortho-phosphorus vs. freshwater inflow to the upper estuary for two river segments: 0-3 km (A) and 15-18 km (B)

5.6.6 Inorganic Nitrogen

Boxplots of three forms of inorganic nitrogen are shown in Figures 5-58B, C, and D. Ammonium nitrogen is reduced inorganic nitrogen, which is most readily available for plant growth. This contributes to ammonium nitrogen usually being found in fairly low concentrations in the surface waters of many water bodies. Compared to other tidal rivers, ammonium nitrogen concentrations are relatively high in the Alafia River, with upper quartile values as high or higher that 1.0 mg/l in several river segments.

Oxidized forms of inorganic nitrogen are often reported as combined nitrate (NO_3) and nitrite (NO_2) nitrogen, though the vast majority of this total is usually nitrate in oxygenated surface waters. Dissolved inorganic nitrogen (DIN) is the sum of ammonium nitrogen and nitrate-nitrite, with nitrate-nitrite usually comprising most of this total. DIN concentrations in the Lower Alafia River are high, with median concentrations exceeding 0.4 mg/l in all river segments except near the mouth (Figure 5-58D). DIN concentrations progressively decrease from the head of the lower river to downstream, due to nitrogen uptake in the estuary and flushing by lower nutrient waters from Tampa Bay.

Salinity dilution curves are effective tools for examining if constituents in estuaries are behaving in a conservative manner, or are instead showing evidence of loss (e.g., uptake) or gain within the estuary. A modified form of a salinity dilution curve for DIN is shown in Figure 5-60 for data from 35 sampling trips conducted by SWFWMD in which at least six DIN samples were collected from the estuary, with at least one sample coming from fresh water and one sample in or very near Tampa Bay. If a constituent behaves conservatively, it's concentration will be diluted in the estuary at the same rate as salinity. If a constituent is not conservative, it may show concentrations in the estuary that are lower than that predicted by salinity dilution if there is uptake, or it may show concentrations that are higher than that predicted by dilution if there are releases within the estuary.

The first important point in Figure 5-60 is the generally high values of observed DIN relative to salinity. Only one DIN value less than 0.3 mg/l occurred at salinity values less than 10 psu, and only 13 percent of the DIN values were less than 0.1 mg/l across the entire salinity range. The predicted DIN values were calculated by dilution for each of the thirty-five dates separately. Since the salinity in the bay and the nitrogen concentrations in both the fresh and salt water end points differed between sampling trips, these points do not fall on a straight line, but instead reflect the predicted DIN concentrations based on the conditions on each sampling day. Like observed DIN, the predicted DIN concentrations decrease with salinity, reflecting the dilution of waters by Tampa Bay. The upturn in the fitted curve for predicted DIN near 5 psu is unusual, but it was affected by some very high nitrogen concentrations in the river on several sampling days.

Figure 5-60 indicates there is uptake of DIN in the lower river. As evidenced by the smoothed trend lines fitted to the data, the observed values are typically lower than those predicted by dilution, indicating the uptake of DIN in the estuary. This is probably due to phytoplankton growth, for as will be discussed further, the lower river has very high phytoplankton counts and chlorophyll *a* concentrations. The difference between the paired predicted DIN value and the observed values for each water sample are plotted against salinity in Figure 5-61.

These graphics indicate there is large uptake of DIN in the estuary, particularly in the salinity range of about 5 to 25 psu. The median value for DIN uptake (difference between predicted and observed) was 0.14 mg/l for the entire set of

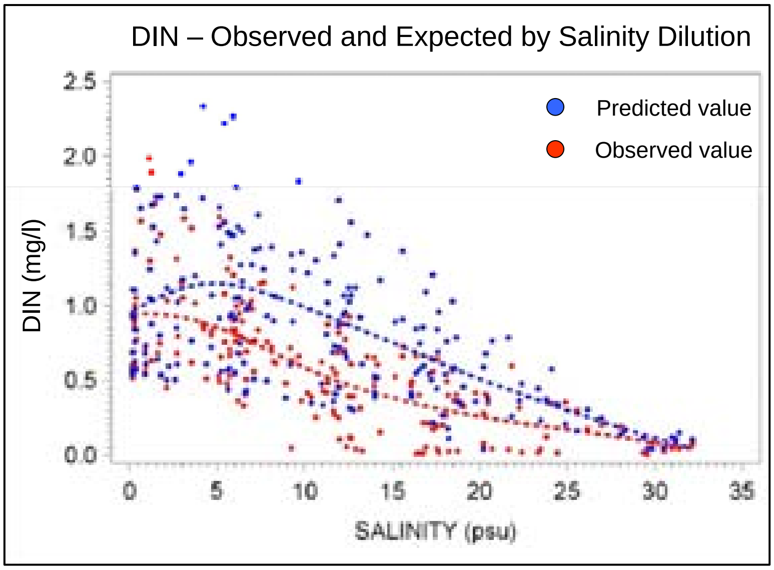


Figure 5-60. Dissolved inorganic nitrogen values vs. salinity for observed DIN values and valued predicted by salinity dilution curves for thirty-five sampling trips conducted by the SWFWMD with smoothed trend lines fitted to the data.

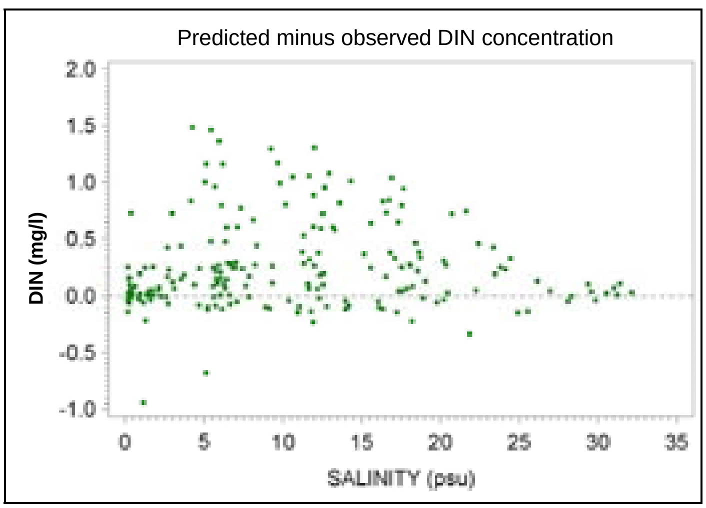


Figure 5-61. Difference in DIN concentrations: Value predicted by dilution minus the observed value for the data in Figure 5-60.

204 observations, but 0.25 mg/l for those observations with salinity in the range of 5 to 25 psu. The outliers with difference values less than -0.5 mg/l were recorded on one day when DIN values in upper estuary were greater than at the freshwater end member at Bell Shoals Road. This could have been due to the inflow of high nitrate water from Buckhorn Springs near kilometer 12.

In comparing Figures 5-60 and 5-61, it is reiterated that although there is strong uptake of DIN in the estuary, DIN values generally remain fairly high across the salinity range, reflecting the high degree of nitrogen loading to the system. Plots of DIN vs. freshwater inflow are plotted for the six three-kilometer segments in Figure 5-62. In the two most downstream segments (0-3 and 3-6 km), DIN values show a fairly consistent increase with flow, with values less than 0.1 mg/l largely limited to flows less than 300 cfs. However, at high flows (greater than 500 to 700 cfs), DIN concentrations tend to remain in the range of 0.4 to 0.6 mg/l. In the middle segment of the estuary (kilometer 6-9), concentrations below 0.1 mg/l are limited to very low flows (< 40 cfs), indicating conditions approaching nitrogen limitation in this section of the river are rare events that are restricted to very flow inflows. DIN concentrations increase with flow up to about 300 cfs, then like the downstream stations, decrease to values about 0.4 to 0.6 mg/l at high flows.

Similar relationships are found in kilometers 9-12. The low DIN values at low flows are due to phytoplankton stripping available nitrogen from the water column, while the high values in the flow range of 200-300 cfs appear to be nitrogen loading to the system in excess of phytoplankton needs. Since DIN concentrations are negatively correlated with flow at Bell Shoals Road (Figure 5-49C), the values in the range of 0.4 to about 0.6 mg/l at high flows appear to be related to concentrations at Bell Shoals during periods when high flows are providing excess nitrogen to the system. In the uppermost segment of the lower river (kilometer 15-18), DIN decreases with flow, reflecting flow/concentrations relationships at Bell Shoals Road.

Plots of DIN concentrations vs. pulse residence times within each segment show similar patterns as inflow (Figure 5-63). As described in Chapter 4, pulse residence time basically represents the travel time of water from the head of the estuary to each sampling location. Short residence times correspond to high flows, while long residence times correspond to low flows. DIN concentrations in the two most downstream segments (kms 0-3 and 3-6) decrease with residence time, being below 0.1 mg/l at long residence times, which corresponds to periods of low nitrogen loading during low inflows.

Similar to relationships with inflow, DIN concentrations in the next three upstream segments (kms 6-9, 9-12, and 12-15) show curvilinear relations with residence time. Relatively low DIN values at short residence times (high flows) reflect the negative correlation of DIN concentrations with flow at Bell Shoals. During these high flows, water is moving though the upper estuary too quickly for algal uptake. Maximum DIN concentrations occur at intermediate residence times in these segments, when flows in the mid-range are more enriched with nitrogen, but still moving through the upper segments quickly enough to exceed DIN depletion by phytoplankton. DIN concentrations are low at longer residence times due presumably to phytoplankton uptake in upper segments. The relationships of phytoplankton (as chlorophyll *a*) to flow and residence time are discussed in Section 5.6.6.

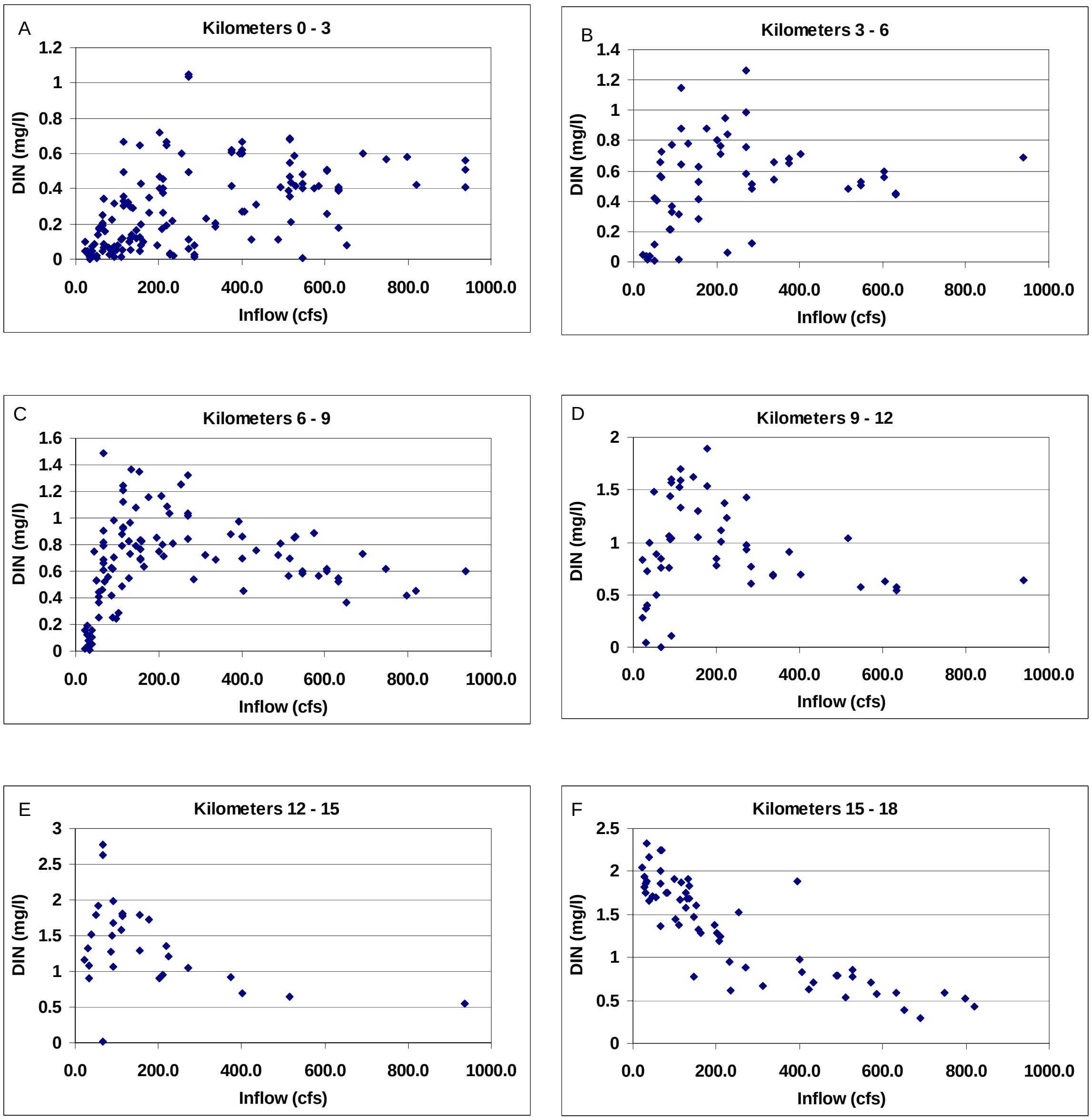


Figure 5-62. Plots of dissolved inorganic nitrogen vs. freshwater inflow for six three-kilometer segments in the Lower Alafia River.

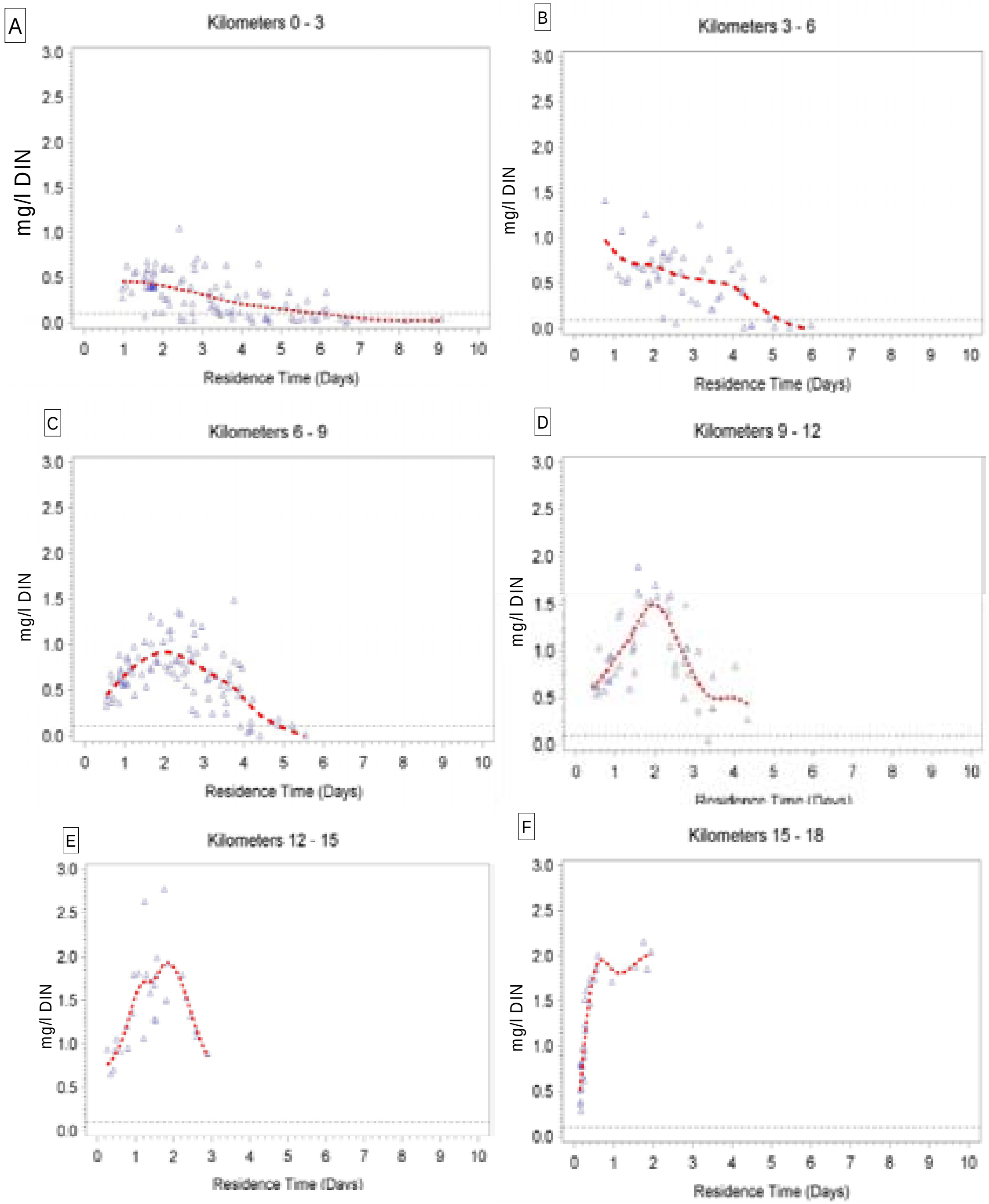


Figure 5-63. Plots of dissolved inorganic nitrogen concentrations vs. pulse residence time within six three-kilometer segments in the Lower Alafia River.

5.6.7 Color, Dissolved Organic Carbon, Secchi Disk and Total Suspended Solids

Boxplots of four other water quality parameters by river segment are shown in Figure 5-64. Both color and dissolved organic carbon concentrations generally increase upriver. These parameters were highly correlated with each other (r=0.92, p< .0001), and both were positively correlated with flow in each river segment. Secchi disk transparency values were lowest between kilometers 3-6, and highest in the upper river segment (Figure 5-64C). Secchi disk was negatively correlated with flow and color in each river segment. Thus, as flow and color went up, Secchi disk tended to go down. Total suspended solids (TSS) tended to show highest values in the bay and near the mouth of the river. However, TSS was only correlated with flow in the upper two river segments, where it tended to increase with flow, presumably due to the shift from groundwater dominated baseflow conditions to more surface runoff and transport of materials during high flows.

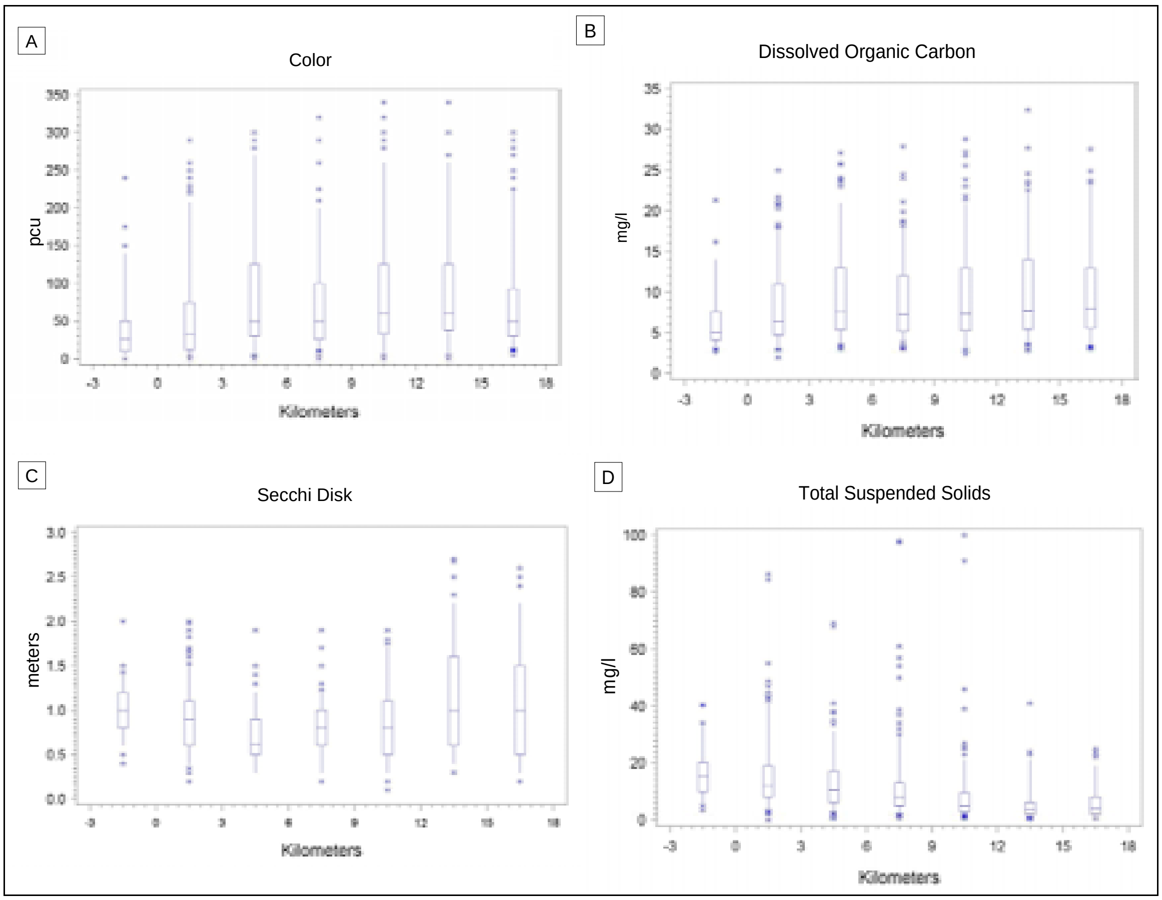


Figure 5-64. Boxplots of color, dissolved organic carbon, secchi disk, and total suspended solids in three-kilometers segments along the Lower Alafia River and a nearby station in Tampa Bay.

5.6.8 Spatial Distribution of Chlorophyll *a* and Relationships to Freshwater Inflow.

Chlorophyll *a* is the most abundant photosynthetic pigment in most species of phytoplankton. Since actual phytoplankton cell counts are time consuming, chlorophyll *a* concentrations are frequently used as an indicator of phytoplankton biomass in the water bodies. Phytoplankton are a critical part of the aquatic food webs, either through direct grazing or by sedimentation of phytoplankton to the sediment surface where their organic matter may be processed through benthic pathways (Mann 1988, Townsend and Cammen 1988, Gaston et al. 1998). The production of higher trophic levels such as fishes in coastal waters can be linked to the supply of nutrients and high phytoplankton biomass that occurs in these waters. However, excessive phytoplankton abundance can result in problem conditions, such as hypoxia and the over-enrichment of organic bottom sediments which can lead to high sediment oxygen demand.

Due to its high rate of nutrient loading, the Lower Alafia River has some of the highest chlorophyll *a* concentrations on the coast of west-central Florida. Although this may have benefits for supporting secondary production, the occurrence of excessive chlorophyll *a* can be considered be a problem since the Lower Alafia River has frequent problems with low dissolved oxygen concentrations. Although *in situ* studies of factors contributing to hypoxia in the lower river were not conducted, it can be reasonably concluded that factors that contribute to hypoxia in the river, such as excessive phytoplankton blooms, should be avoided. In that regard, the relationship of freshwater inflow to chlorophyll *a* concentrations could be important to the minimum flow determination, if changes in inflow affect the distribution or abundance of phytoplankton (as indicated by chlorophyll *a*) in the lower river.

Boxplots of chlorophyll *a* in the lower river are shown in Figures 5-65 and 5-66. Since chlorophyll *a* was measured by all three agencies monitoring the river, there are many more observations for chlorophyll *a* than for nutrients, total suspended solids, and many other water quality parameters. Given this large number of observations, chlorophyll *a* concentrations are plotted in one-kilometer intervals in Figures 5-65 and 5-66 to better show the spatial distribution of this parameter. Chlorophyll *a* concentrations tend to be highest in the middle portion of the river (kilometers 6-9), with a second tier of high values extending down to kilometer 3 and upstream to kilometer 11. This is also the region of the river with high organic sediments (Figure 3-9), which may be related to the prevailing locations of high chlorophyll concentrations.

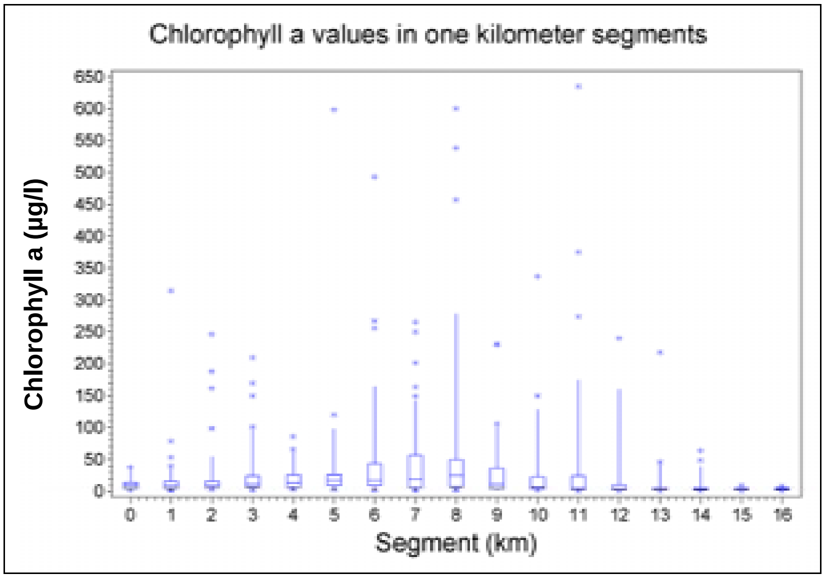


Figure 5-65. Boxplot of chlorophyll *a* in one-kilometer segments in the Lower Alafia River.

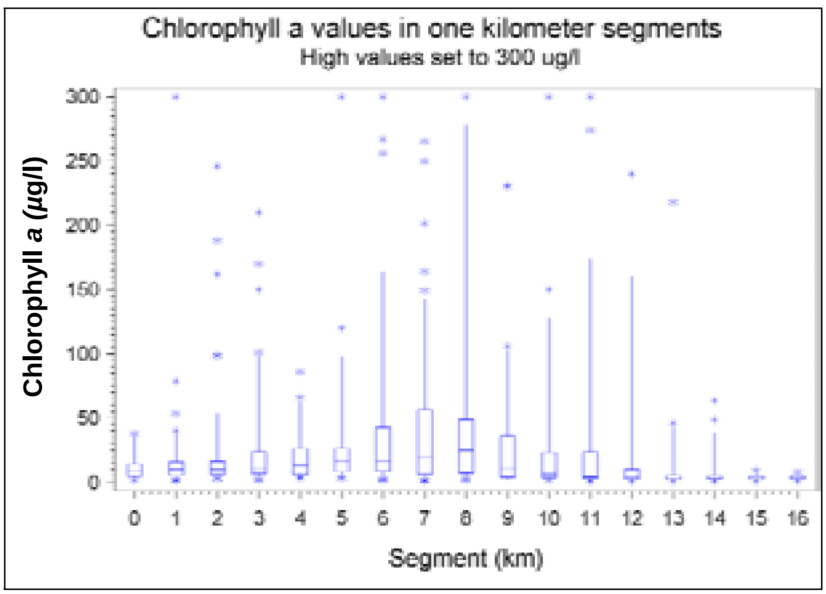


Figure 5-66. Boxplot of chlorophyll *a* in one-kilometer segments in the Lower Alafia River with high values set to 300 µg/l.

A striking characteristic of the boxplots are the very high concentrations that can occur in the Lower Alafia. Three values over 600 µg/l were recorded, and maximum values over 200 µg/l were recorded in twelve river segments. To illustrate the degree that chlorophyll concentrations in Alafia are enriched, chlorophyll data from the lower river are compared to similar data from the Peace and Little Manatee in Figure 5-67. The monitoring programs for all of these rivers include one sampling scheme in which chlorophyll *a* samples were consistently sampled at moving salinity-based stations, with stations at 0.5, 6, 12, and 18 or 20 psu. These results provide an interesting comparison in that the effects of salinity on phytoplankton and chlorophyll *a* is treated consistently among rivers. It is clear that chlorophyll *a* concentrations are generally higher in the Alafia than in the other two rivers. Median concentrations range from 24 to 32 µg/l at the 6 to 18 psu stations in the Alafia, but don't exceed 16 µg/l at the same stations on the other rivers. The periodic occurrence of very high concentrations in the Alafia are shown by upper quartile values of 56 to 84 µg/l at these same stations, while upper quartile concentrations did not exceed 30 µg/l at the other rivers.

Figure 5-67 also shows that chlorophyll concentrations tend to be highest in low to middle salinity zones in both the Alafia and Peace Rivers. In the Alafia, concentrations tend to be highest at the 12 psu zone, which corresponds to the middle portion of the estuary. Both the Peace and Alafia had lower concentrations at the tidal freshwater boundary (0.5 psu), indicating that phytoplankton blooms typically occur downstream of the tidal freshwater zones in these rivers in oligohaline and mesohaline waters. The Little Manatee was an exception to this pattern, as chlorophyll *a* concentrations were highest at the 0.5 psu zone, and were progressively less downstream.

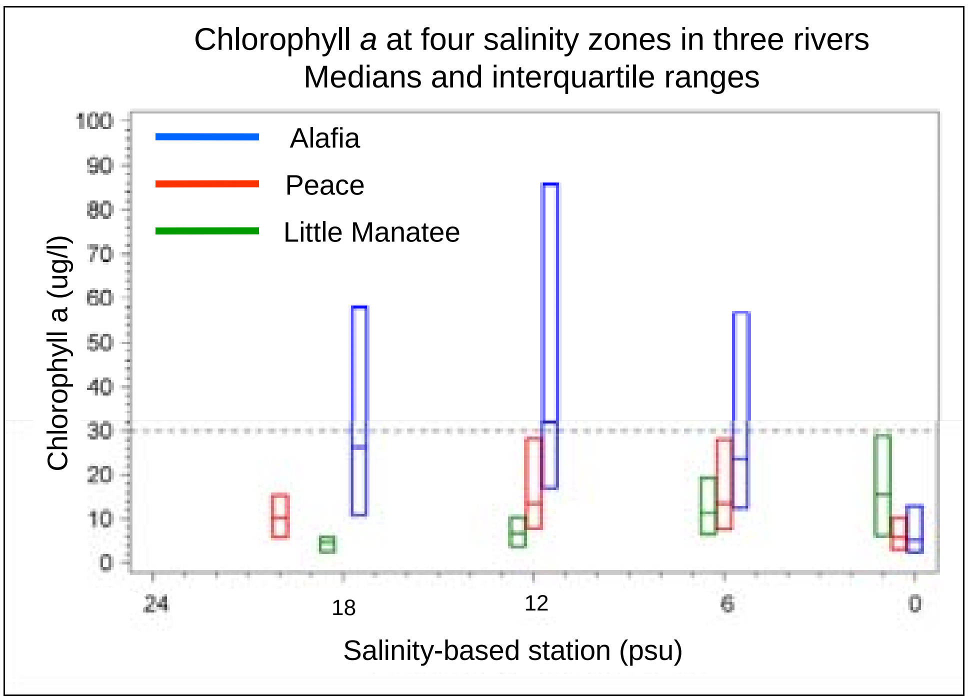


Figure 5-67. Box plots of medians and inter-quartile ranges for chlorophyll a at four moving salinity-based stations in the Lower Alafia, Peace, and Little Manatee River estuaries. Moving stations are at 0.5, 6, and 12 psu in all rivers, and at 18 psu in the Alafia and Little Manatee and 20 psu in the Peace.

Since nitrogen is the nutrient that is typically limiting to phytoplankton growth in Tampa Bay and its tributaries, concentrations of inorganic nitrogen relative to chlorophyll *a* are plotted for the Alafia, Peace, and Little Manatee Rivers in Figure 5-68. The Alafia is notable in that high DIN concentrations (e.g., 2 mg/) persist in the river even when chlorophyll *a* concentrations exceed 50 to 100 µg/l. The Peace shows a general decline with DIN with increasing chlorophyll, but values well above detection limits occur at very high chlorophyll levels. The Little Manatee is not entirely comparable, as only three observations had chlorophyll *a* values over 50 µg/l. However, there appeared to be a general inverse relationship between DIN and chlorophyll *a* concentrations.

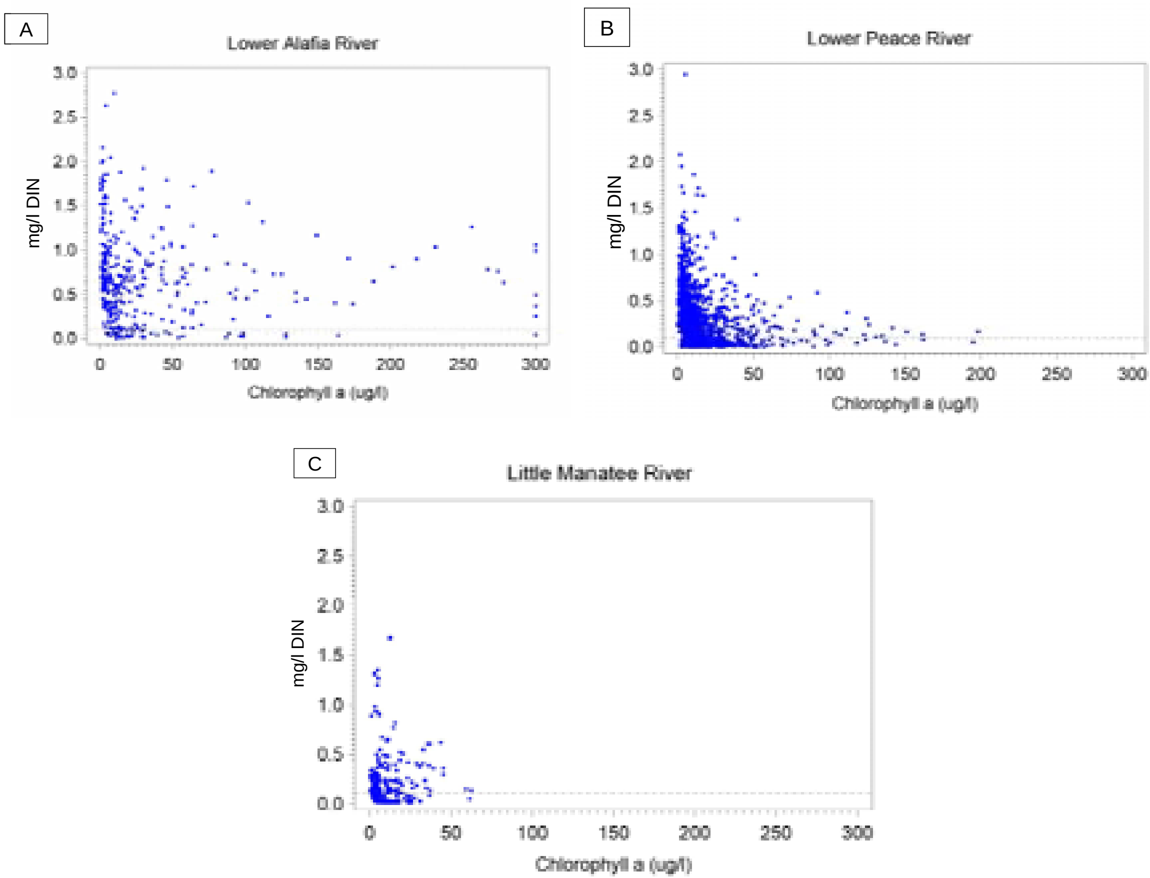


Figure 5-68. Plots of dissolved inorganic nitrogen vs. chlorophyll *a* in water samples for the Lower Alafia (A) Peace (B) and Little Manatee (C) River estuaries.

To investigate the effects of freshwater inflow on chlorophyll *a*, chlorophyll concentrations in the six three-kilometer segments are plotted versus inflow in Figure 5-69 and 5-70 (concentrations above 200 µg/l are set to that value in the latter figure to aid visual interpretation). In the segment nearest the river mouth, the highest concentrations occur in the flow range of 100 - 300 cfs. Lower values

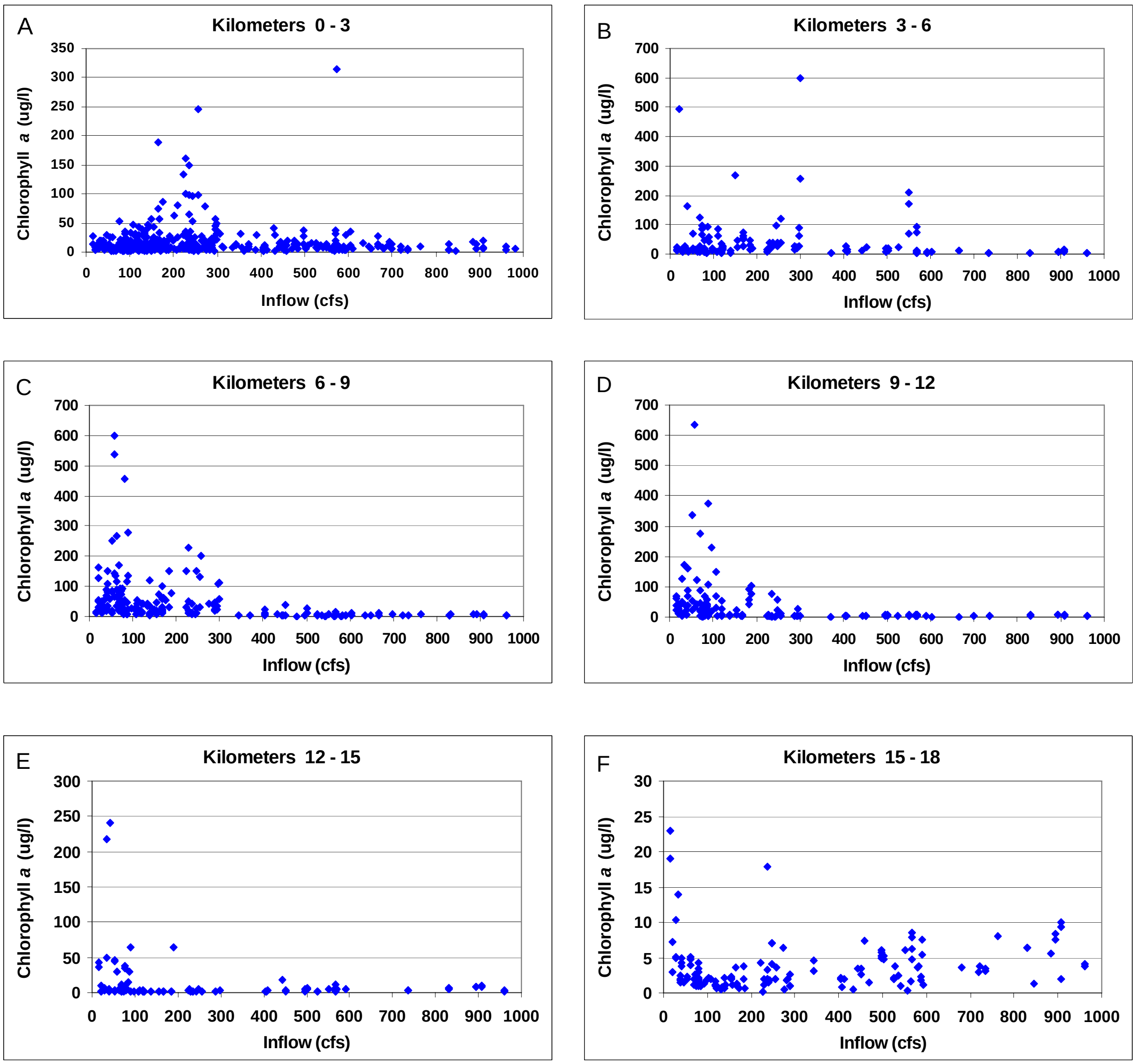


Figure 5-69. Chlorophyll *a* vs. freshwater inflow for six three-kilometer segments in the Lower Alafia River.

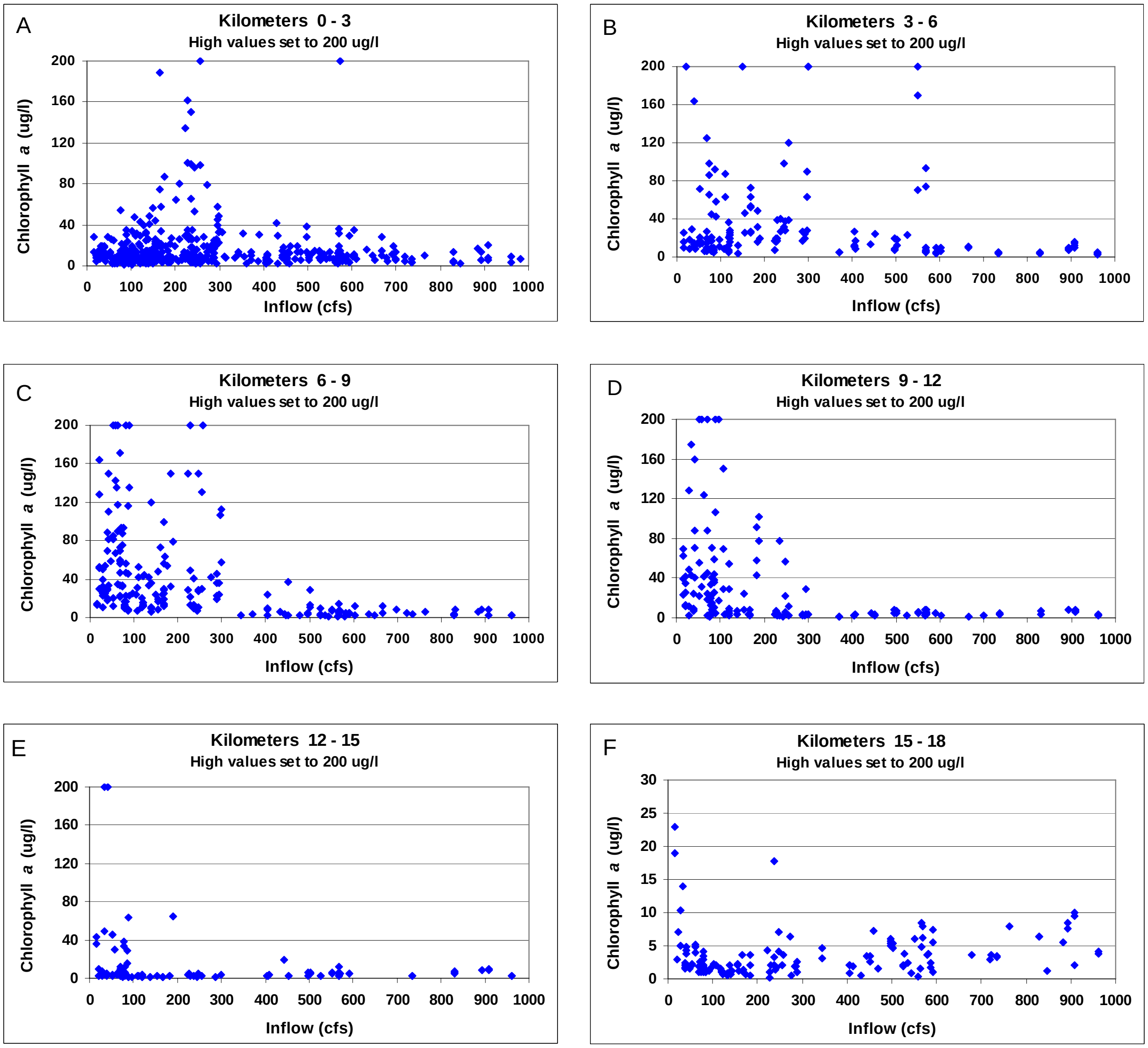


Figure 5-70. Chlorophyll a vs. freshwater inflow for six three-kilometer segments in the Lower Alafia River with high chlorophyll values set to 200 µg/l.

tend to occur near the mouth at very low flows (<50 cfs) and high flows, especially above about 700 cfs. There is a less consistent pattern in kilometers 3-6, but low values also occur at very high flows, apparently due to wash-out of large phytoplankton populations.

A common pattern occurs in zones further upstream, where high chlorophyll concentrations tend to occur at low flows. In particular, the highest concentrations tend to occur at flows less than 100 cfs. A secondary break also occurs at flows of about 300 cfs in the middle portion of the river, with lower chlorophyll concentrations typically found at higher flows. Further upstream (kilometers 12 to 18), chlorophyll concentrations above 10 µg/l are restricted to low flows (< 100 cfs) with only a couple of exceptions.

5.6.9 Relationships of Chlorophyll *a* Concentrations to Pulse Residence Time

The frequent co-occurrence of high concentrations of both DIN and chlorophyll *a* in the Lower Alafia indicates that physical factors, rather than nutrient limitation, control phytoplankton biomass in the lower river under most flow conditions. Similarly, the highest chlorophyll values in several segments of the river occur during low flows when nitrogen loading is comparatively low. Studies from other tidal rivers indicate that residence and flushing times can have a major effect on phytoplankton populations (Ingram et al. 1985, Vallino and Hopkinson 1998, Jassby 2005). As described in Chapter 4, this minimum flow analysis used hydrodynamic, particle transport simulations to estimate pulse residence times in one kilometer segments of the lower river as a function of freshwater inflow. This data base was then merged with water quality data collected from the river to assign a pulse residence time to each chlorophyll sample. This, in turn, allowed analyses of relations between chlorophyll concentrations with residence time in different segments of the lower river.

Chlorophyll *a* values are plotted against pulse residence times for six three-kilometer segments in the lower river in Figure 5-71. The residence time value plotted for each sample is the time it took for water to be transported to that location at the time that sample was taken. High flows result in short residence times plotted to the left in each graph, while low flows result in long residence times plotted to the right. Similarly, longer residence times occur near the mouth of the river, while shorter residence times occur upstream. The longest residence time in Figure 5-71 is about nine days in kilometer 0-3, while residence times of less than an hour occur in the most upstream segment.

Since residence time is a function of freshwater inflow, the scatter plots of chlorophyll *a* with residence time (Figure 5-71) shows similar patterns to relationships with inflow (Figure 5-71). However, residence time is also affected by the morphology and mixing characteristics within the different segments of the tidal river, thus greater insights on mixing and transport times that are affected by inflow can be gained. Also, it is useful to see if there are fairly consistent residence time values in different segments of the river that allow large phytoplankton blooms, or alternately, result in wash-out with consistently low chlorophyll a values.

Very high chlorophyll concentrations (> 50 ug/l) occurred in the most downstream segment when residence times were in the range of 1.5 to just under 4 days (Figure 5-71A). Comparatively low chlorophyll concentrations were found when residence times were less than 1.5 days, indicating that if water moves through the river in less than 1.5 days, day then very large phytoplankton blooms do not develop. A residence time value of about 1.5 days that prohibited high chlorophyll a values was also observed at several other segments in the estuary.

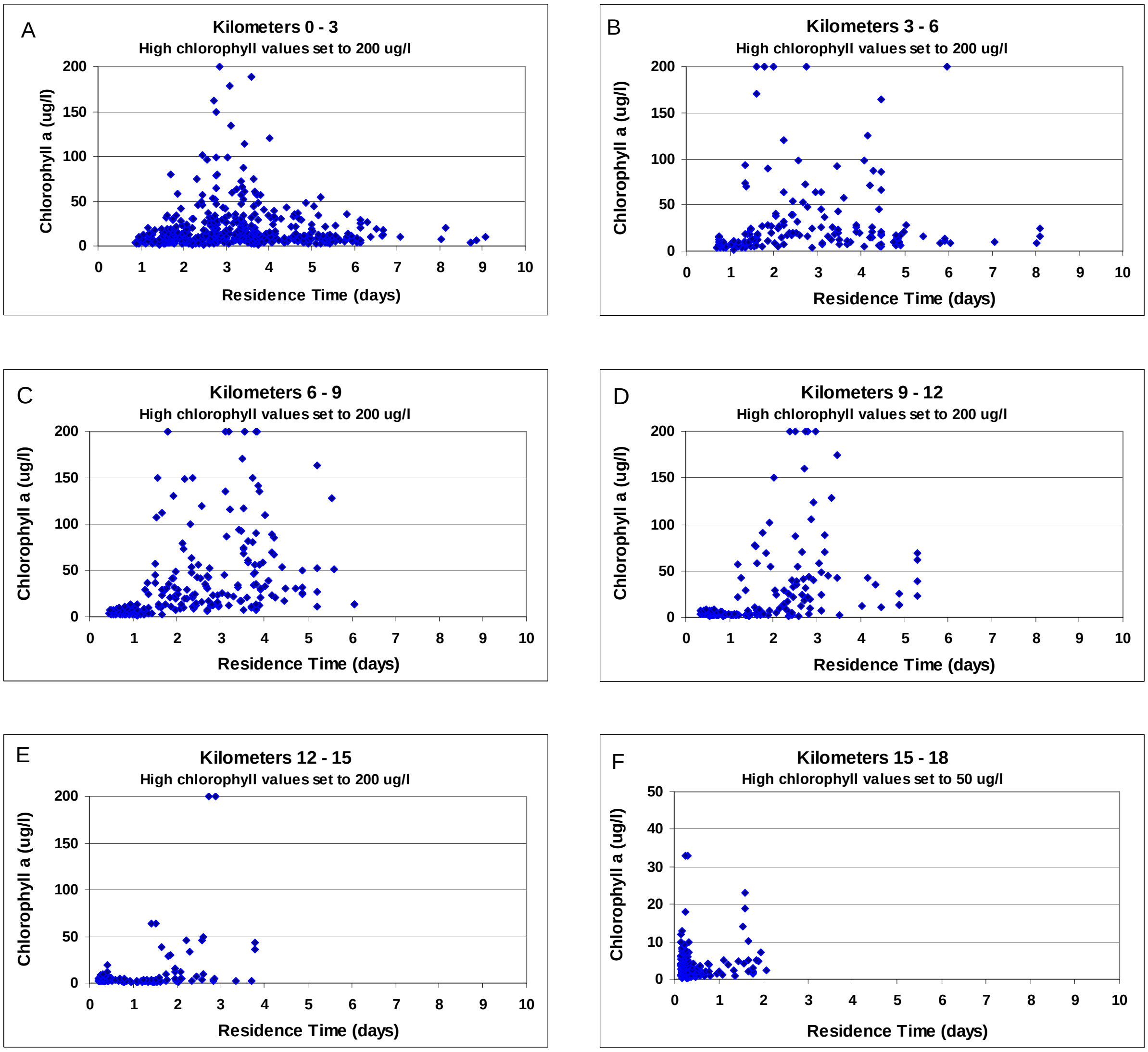


Figure 5-71. Chlorophyll *a* concentrations vs. pulse residence time for samples within six-three kilometer segments in the Lower Alafia River with high chlorophyll values set to 200 µg/l.

Very high chlorophyll peaks were observed in all segments up to kilometer 15 when residence time values were in the range of 1.5 to 4 or 5 days. In the most downstream segments, large blooms did not occur when residence time exceeded 5 to 6 days. It may be that near the mouth of the river, nutrient loading during low flows (and long residence times) is insufficient to support the very large phytoplankton blooms that are periodically found in the lower river.

Median values of pulse residence time and chlorophyll *a* in one kilometer segments are plotted in Figure 5-72. As described earlier for Figure 5-65, the highest median chlorophyll concentrations are found in the middle reaches of the river, where median residence time values are in the range of 2 to 3 days. Short

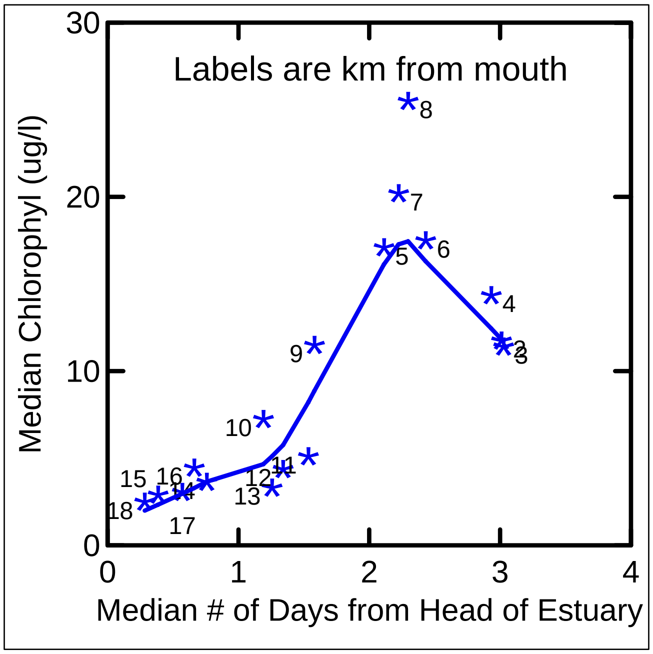


Figure 5-72. . Median values for Chlorophyll a and pulse residence time in one-kilometer segments in the Lower Alafia River.

residence times in segments upstream of kilometer 10 result in low median chlorophyll *a* values, while fairly high median chlorophyll values were found near the mouth of the river when median residence time values are near 3 days. Because the chlorophyll sampling was not entirely balanced (not every segment sampled each day), the corresponding median residence time values are not arranged along the x axis in perfect order, although the observed descending order from left to right is very close to the expected pattern.

Whereas plots of chlorophyll *a* concentration vs. inflow for the six river segments showed different thresholds at which bloom and wash-out occurred, residence time provides more of a normalizing variable that accounts for the different volumes of the segments. Therefore, compared to inflow, more consistent values were found among segments for residence time values that contributed to blooms or wash-out. In general, it appears that residence time values of less than 1.5 days prevents large phytoplankton blooms throughout the river, while residence time values in the range of 1.5 to 3 or 4 days allow large phytoplankton blooms.

The range of inflows that result in average residence time values of 1.5 to three days in each segment of the lower river are plotted in Figure 5-73, providing a summary of flows that result in bloom and wash-out in different regions of the lower river. Since the volume of the estuary becomes greater downstream, the range of flows that produce residence time values between 1.5 and 3 days becomes progressively greater toward the mouth of the river. Using the residence time values of 1.5 and 3 days as indicators of phytoplankton response, flows above 300 cfs prevent large blooms upstream of kilometer 6, but flows in the

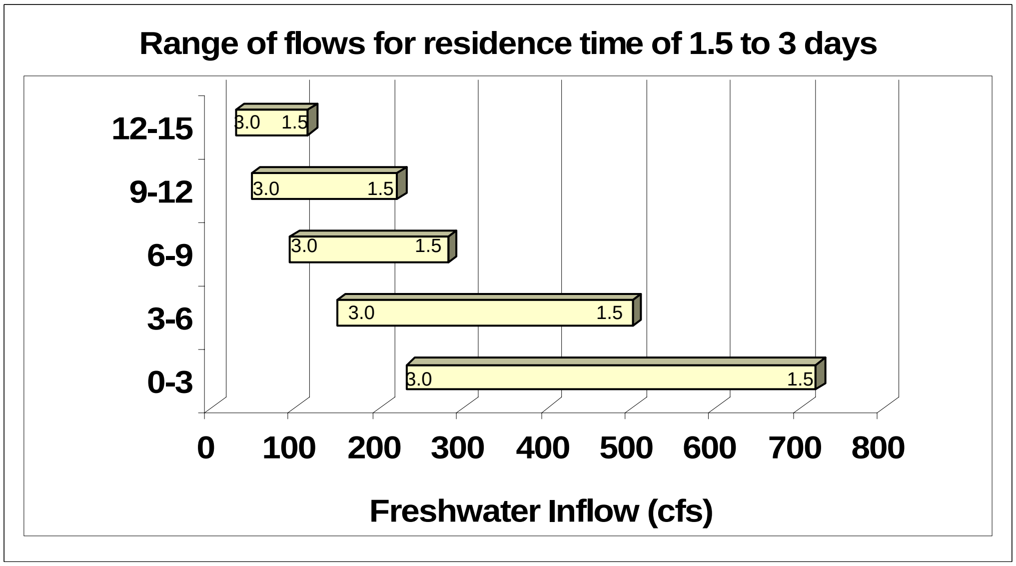


Figure 5-73. . Range of freshwater inflows corresponding to mean pulse residence times of 3 days and 1.5 days in three kilometer segments in the Lower Alafia River.

range of 300-500 cfs can result in large blooms in the two downstream segments (0 to 6 km). Similarly, flows greater than just over 100 cfs prevent large phytoplankton blooms above kilometer 12.

5.6.10 Logistic Regressions to Predict High Chlorophyll *a* Concentrations

Although residence time appears to be a direct physical factor controlling phytoplankton abundance, residence time is a function of freshwater inflow and minimum flow rules based on inflow would be much easier to implement. In that regard, logistic regressions were pursued to determine the probability or large phytoplankton blooms in the lower river as a function of freshwater inflow. In order to determine what threshold could be used to identify high chlorophyll *a* concentrations in the Alafia River for the logistic regression, comparisons were done on chlorophyll *a* data from the Alafia with data from the Lower Peace and Little Manatee River estuaries.

Plots of percentile values for chlorophyll concentrations in the Lower Alafia, Lower Peace, and Little Manatee Rivers are presented in Figure 5-74. Data are shown for values above the 50^{th} percentile, as chlorophyll *a* values don't differ greatly between the rivers at the lower percentiles. Figure 5-74B shows these values at a limited vertical scale (< 100 µg/l) to allow better visual comparison of the data. Based on these plots, it was concluded the Alafia diverged substantially from the other two rivers near the 90^{th} percentile values, or the chlorophyll *a* values that are exceeded about 10 percent of the time. The average of the 90^{th} percentile chlorophyll values for Peace and Little Manatee Rivers was 30 µg/l, whereas the

90th percentile value for the Alafia was 58 µg/l. Since values near 30 µg/l were exceeded approximately 10 percent of the time in the other two rivers, it was concluded this would be a reasonable threshold to identify high chlorophyll *a* conditions in tidal rivers in the region, and 30 µg/l was used as a threshold in logistic regression analyses of chlorophyll/inflow relations in the Lower Alafia.

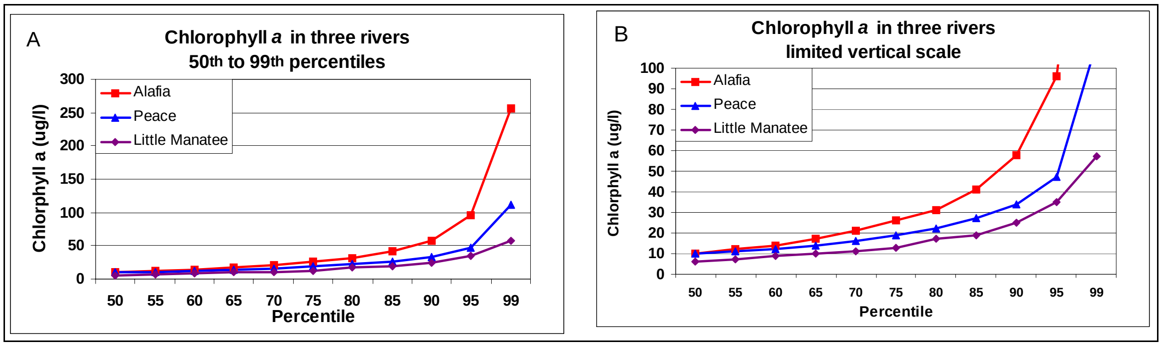


Figure 5-74. Percentile values of chlorophyll a concentrations in 5 percentile increments from the median to the 99th percentiles for the Lower Alafia, Peace, and Little Manatee River estuaries. Chlorophyll a values limited to 100 µg/l in B.

Based on the data set from 1999-2003, chlorophyll *a* values downstream of Bell Shoals Road exceeded 30 µg/l nearly 20 percent of the time, but the response of high chlorophyll *a* to inflow differed between segments. Plots of chlorophyll *a* values greater than or equal to 30 µg/l are plotted vs. inflow in Figure 5-75. These plots show similar relationships and breakpoints as the plots of all chlorophyll data vs. flow, but are easier to visually interpret since values below 30 µg/l are eliminated.

The logistic regression considered values greater than 30 µg/l as a binary condition, in that the magnitude of the concentration over 30 did not enter into the statistical test. Thus, the plots of in Figure 5-75 should be viewed in that manner. Results from the logistic regression analysis are presented in Table 5-7. There was no significant relationship found in Segment 0-3 km, and the McFadden's Rho^2 values was very low in the segment between 3 and 6 km, thus application of that regression is not suggested. Concordance tables that list the percent correct predictions above and below the threshold of 30 µg/l are listed in Appendix 5F. Fairly good relationships were found in three segments between kilometer 6 and 15. Regression curves to predict the probability of chlorophyll *a* greater than 30 µg/l in these segments in the river are plotted in Figure 5-75. All prediction curves are nonlinear, as there are ranges of flow where inflections occur. In all cases, the rate of increase in the probability of high chlorophyll concentration is greatest at low flows.

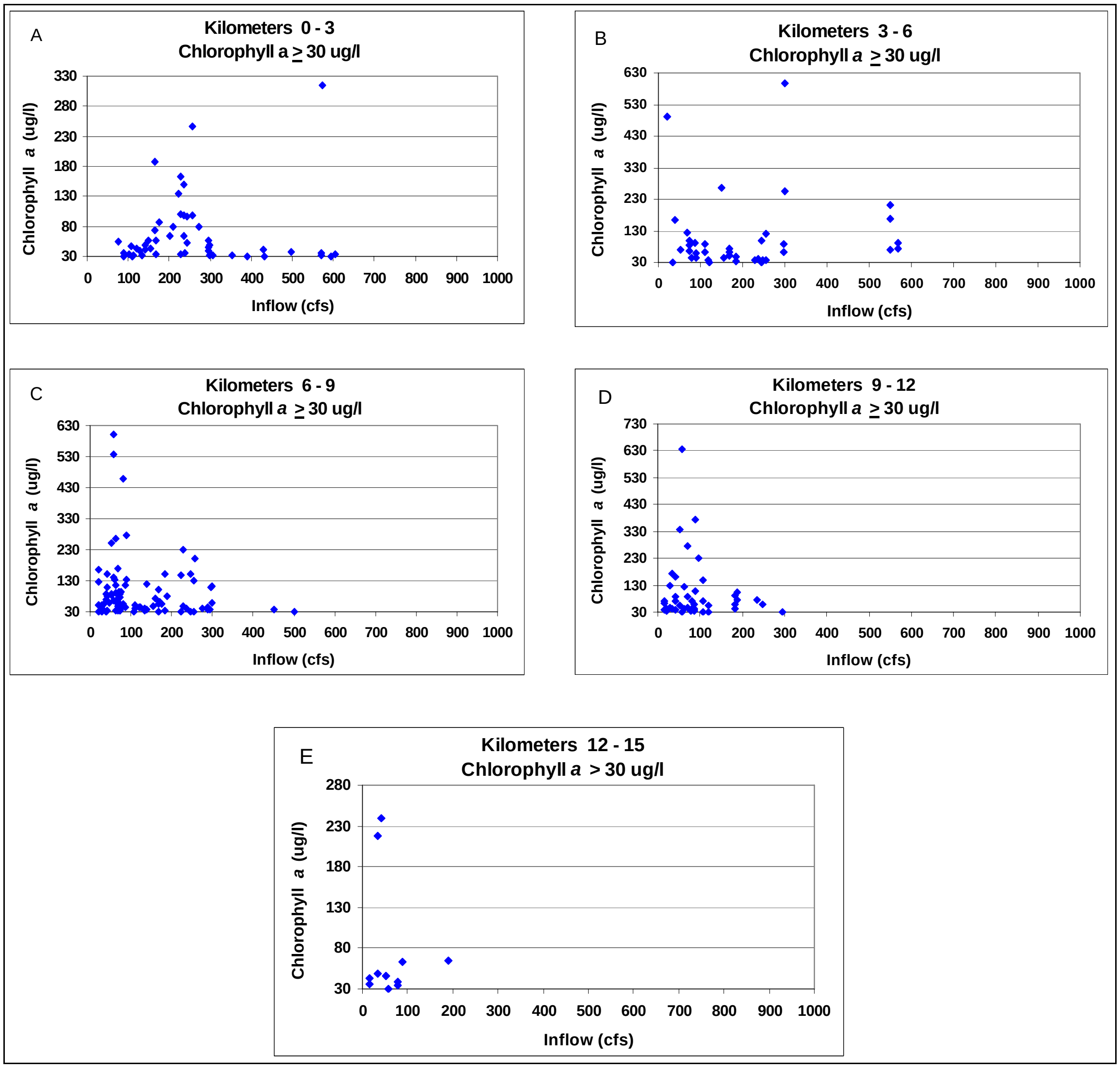


Figure 5-75. Chlorophyll *a* values greater than or equal to thirty µg/l vs. freshwater inflow in six three-kilometer segments in the Lower Alafia River.

Table 5-7. Regression coefficients for logistic regressions to predict chlorophyll a values greater than 30 µg/l in four segments in the Lower Alafia River.

Segment (km)	Intercept	Slope Inflow	rho^2	Inflow Transformation	Overall correct prediction percentage
3-6	-0.59	-0.00021	0.061	Inflow (untransformed)	66%
6-9	-0.93	-0.00696	0.248	Inflow (untransformed)	66%
9-12	0.73	-0.01304	0.312	Inflow (untransformed)	74%
12-15	-0.17	-0.0193	0.265	Inflow (untransformed)	87%

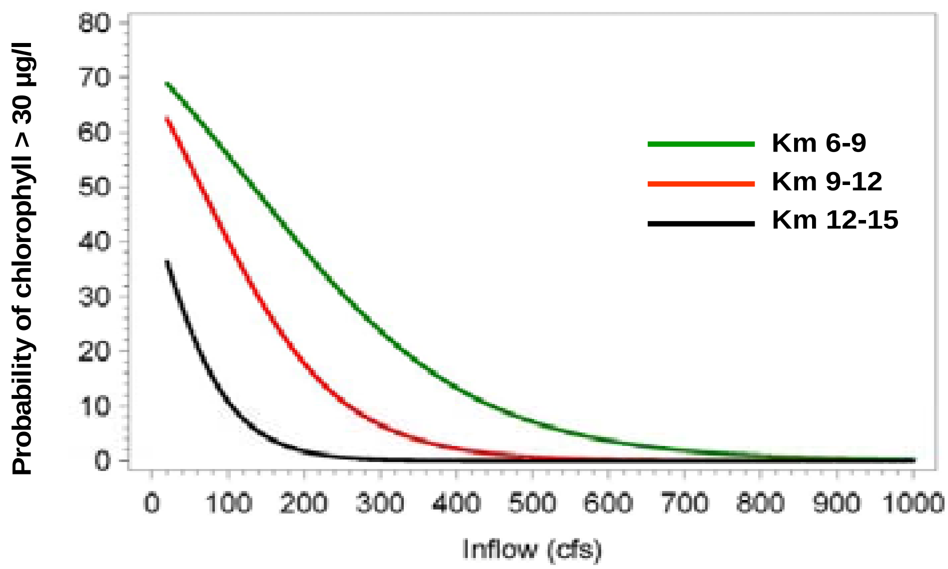


Figure 5-76. Logistic regression curves to predict the probability of chlorophyll *a* concentrations greater than or equal to 30 µg/l for three three-kilometer segments in the Lower Alafia River.

5.6.11 Relationship Between the Location of the Maximum Chlorophyll *a* Concentration and Freshwater Inflow

Analyses were conducted to determine if there are relations between freshwater inflow and the location of peak chlorophyll *a* concentrations in the lower river. The water quality data base was examined to identify sampling dates in which at least eight chlorophyll samples were collected from the river over a wide range of locations. On these sampling dates, the kilometer location of the station in the river with the highest chlorophyll *a* concentration was recorded.

Plots of the locations of the peak (maximum) chlorophyll concentrations vs. the preceding three-day mean inflow are presented in Figure 5-77. There was a significant relationship between the location of the chlorophyll *a* peak and freshwater inflow, as the location of the peak moved upstream with declining freshwater inflow. This agrees with the plots of chlorophyll *a* vs. freshwater inflow, where it was shown that large chlorophyll peaks occur in the upper river segments during low flows (Figure 5-69). A regression model was developed to predict the location of the chlorophyll peak as a function of inflow (Figure 5-77). The relationship is nonlinear, as the response of the location of the peak chlorophyll concentration is most sensitive to change at low flows. A reference line is drawn at 120 cfs, as there appears to be a shift in the relationship centered around this rate of flow.

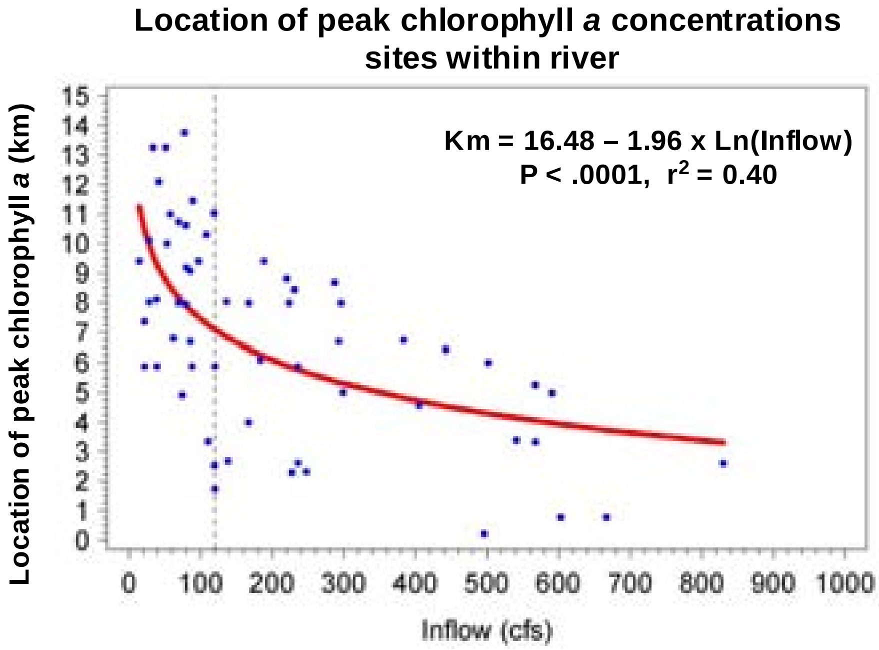


Figure 5-77. Location of chlorophyll *a* maximum vs. freshwater inflow (preceding three-day mean) and regression for predicted values, for sites within the river with a reference line at 120 cfs. The flow term is freshwater inflow to the upper estuary.

There was also evidence the concentration of the chlorophyll *a* peak increased as it moved upstream (Figure 5-78). This relationship was also nonlinear, as the chlorophyll concentrations were most sensitive to change during low flows when the chlorophyll peaks were located upstream.

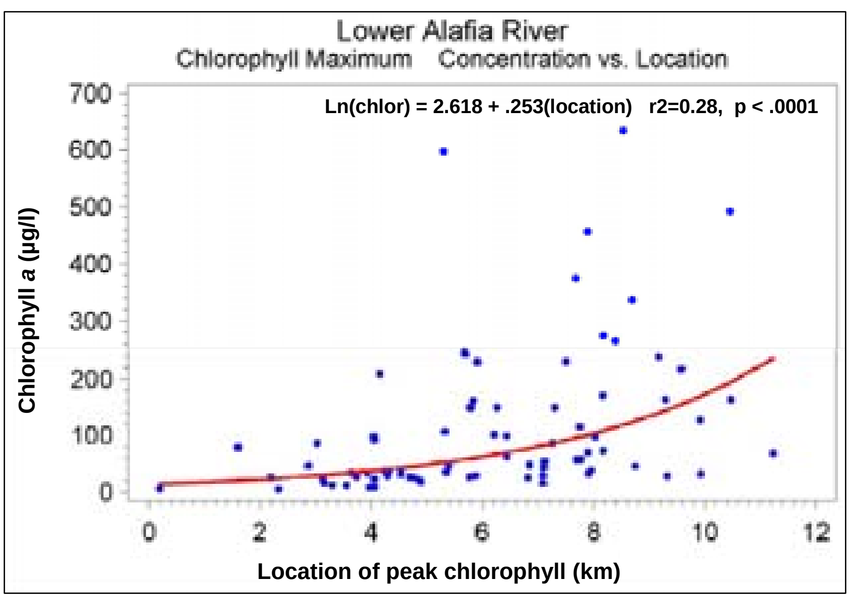


Figure 5-78. Location of the chlorophyll *a* maximum vs. the concentration of the chlorophyll maximum with fitted regression for sites within the river.

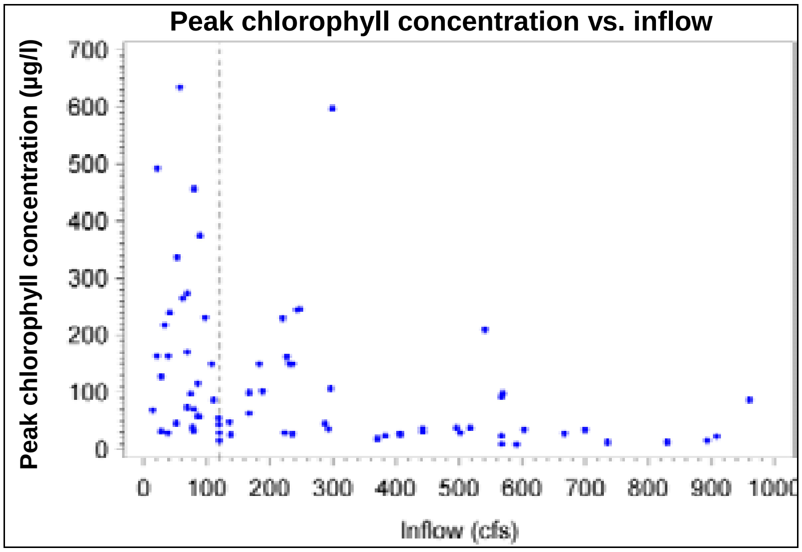


Figure 5-79. Concentration of peak chlorophyll *a* concentration in the river vs. freshwater inflow with reference line at 120 cfs.

The magnitude of the peak chlorophyll concentration was also related to the rate of freshwater inflow (Figure 5-79). A reference line is again drawn in at 120 cfs, showing a shift in the number of very high concentrations when flows are in the range of 100-120 cfs.

As discussed in Chapter Six, a report by Vargo et al. (2005) that assessed phytoplankton populations in the Lower Alafia River included results for chlorophyll *a*. Plots of freshwater inflow vs. chlorophyll *a* values within three ranges of concentration are reprinted from that report in Figure 5-80. The inflow term in these plots is flow at Bell Shoals Road, which does not include flow from Buckhorn Springs. There was no relationship between the location of chlorophyll *a* concentrations less than 20 µg/l and freshwater inflow. However, for chlorophyll *a* concentrations between 20 and 50 µg/l, there were apparent breakpoints near 100 and 300 cfs, with chlorophyll concentrations in that range being more frequent at upstream locations at low flows. Concentrations between 20 and 50 µg/l upstream of kilometer 10 were largely restricted to flows below 100 cfs. Chlorophyll concentrations within that same range were upstream of kilometer 4 only when flows were less than about 300 cfs. High flows pushed chlorophyll concentrations between 20 and 50 µg/l to near the mouth of the river or into the adjacent areas of Tampa Bay. The location of chlorophyll *a* concentrations above 50 µg/ were most closely related to freshwater inflow. Vargo et al. (2005) presented a significant linear regression of the relation between freshwater inflow and the location the chlorophyll concentrations within that range. Similar to the information presented above, these results demonstrate that the rate of freshwater inflow exerts an important influence on the location of large phytoplankton blooms in the lower river.

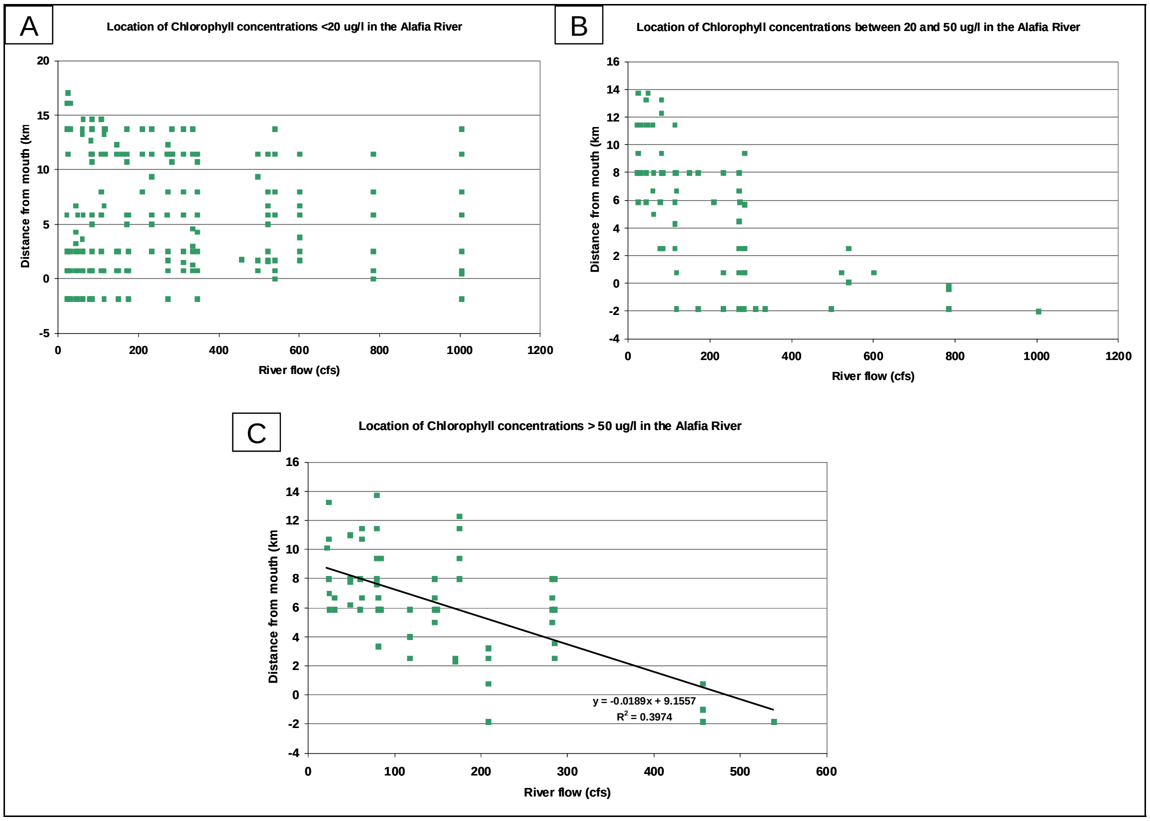


Figure 5-80. Freshwater inflow at Bell Shoals Road vs. the location of chlorophyll *a* concentrations: (A) < 20 µg/l in the Lower Alafia River; (B) 20-50 µg/l; and (C) > 50 µg/l (reprinted from Vargo et al. 2003)

5.6.12 Summary of Interactions Between Freshwater Inflow, Nutrients, and Chlorophyll *a*

The Lower Alafia River is one of the most nutrient enriched tidal rivers in southwest Florida, due a long history of industrial and agricultural activities in is watershed (Flannery 1989, FDEP 1996, 2002). Total phosphorus concentrations in the tidal river are well in excess of amounts needed for plant growth and inorganic nitrogen concentrations are also highly enriched. Due in part to high nutrient loading from the watershed, chlorophyll *a* concentrations in the Lower Alafia are also among the highest in the region, with concentrations that are markedly greater than comparable data from the Peace and Little Manatee Rivers. Nitrogen is frequently the nutrient that is limiting to phytoplankton growth in estuaries, and salinity dilution curves indicate there is strong uptake of inorganic nitrogen in Lower Alafia River. However, except for occasional conditions near the mouth of the river during very low flows, fairly high concentrations of inorganic nitrogen persist in the water column, indicating that nutrients are in excess throughout much of the tidal river and physical factors exert major effects on phytoplankton populations and chlorophyll *a* concentrations.

Analyses of interactions of chlorophyll *a* indicate that changes in freshwater inflow have a strong influence on both the distribution and concentration of chlorophyll *a* in the river. In the middle and upper reaches of the tidal river, very high chlorophyll concentrations tend to occur during periods of low flow. The location of the peak chlorophyll *a* concentration tends to move upstream with declining flow, while the concentration of the chlorophyll peak tends to increase at low flows as well. Analyses of pulse residence times indicate that increases in residence time with declining flows allow phytoplankton blooms to develop in different segments in the lower river. Conversely, decreases in residence time below 1.5 days with increased flows tend to wash chlorophyll out of these segments, and move the region of high chlorophyll *a* concentrations downstream. Most of these relationships are nonlinear, in that the movement of the chlorophyll maximum and the probability of having very high chlorophyll concentrations in the river are most sensitive to change at low flows.

The Lower Alafia River has frequent problems associated with hypoxia, or low dissolved oxygen concentrations. A principal cause of hypoxia in the river appears to be the unusually high degree of vertical salinity stratification in the Lower Alafia. Hypoxia increases with flow with flow in the lower sections of the river, but decreases with flow in the upper sections of the tidal river. Regardless of this opposite response between segments of the river, it is reasonable to conclude that the very high phytoplankton populations in the lower river contribute to the hypoxia problem, as phytoplankton can consume oxygen at night through respiration, and produce large quantities of organic matter that cause oxygen demand in both the water column and the sediments when the phytoplankton decompose.

Given the highly eutrophic condition of the Lower Alafia and frequent problems with hypoxia, interactions of freshwater inflow with chlorophyll *a* are a primary factor that must be considered in freshwater inflow management. In general, when inflows decline, problems with high phytoplankton populations become more pronounced in one or more segments of the lower river. As such, the effects of flow reductions on hypoxia and the occurrence of high chlorophyll *a* concentrations in the river is evaluated in the context of minimum flow determination in Chapter 8.

Chapter 6

Biological Characteristics of the Lower Alafia River and Relationships with Freshwater Inflow

6.1 Introduction

The biological characteristics of the Lower Alafia River have been the subject of extensive study in support of the determination of minimum flows. Estuaries serve as transitional zones between freshwater and marine ecosystems and are known to be areas of high biological productivity (Knox 1986, Kennish 1990). 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, meaning they spend at least a portion of their life cycle in the estuarine environment (Comp and Seaman 1985, Day et al. 1989). In that regard, freshwater inflows play a dominant role in determining not only the physical and chemical characteristics of estuaries, but their biological productivity as well. Significant reductions in the abundance of economically important fish and shellfish species have resulted in cases where the timing and volume of freshwater inflow to estuaries have been dramatically altered (Moyle and Leidy 1992, Mann and Lazier 1996, Baisre and Arboleya 2006).

In order to protect the biological resources of the Lower Alafia River from significant harm due to withdrawals, the District funded or required a series of hydrobiological studies to examine the relationships of freshwater inflows with the abundance and distribution of biological resources within the lower river. These studies have focused not only on fish and shellfish, but on other communities as well which interact to form the food webs and habitat mosaic that support fisheries production (plankton, benthic macroinvertebrates, oyster reefs and wetlands).

The findings of these biological studies are summarized below. With the exception of tidal wetlands, more extensive information on each of these biological communities can be found in separate reports that were generated as part of the minimum flows project or as part of the HBMP monitoring program conducted by Tampa Bay Water. Information on the distribution of tidal wetlands is presented in Chapter Three of this report and can also be found in two interpretive reports prepared for the HBMP (PBS&J 2003, 2006). A synthesis is provided below for the other major biological communities in the lower river, emphasizing how freshwater inflow influences the distribution, abundance, and trophic interactions of these communities.

Building upon this information, Chapter Seven identifies biological resources of concern in the lower river and how quantifiable relationships between inflow, salinity, and the abundance and distribution of these resources are used in the minimum flows analysis. Chapter Eight presents the results of model simulations to determine the effects of a series of potential flow reductions on physico-chemical and biological variables, and based on these findings, recommends minimum flows for the Lower Alafia River.

6.2 Phytoplankton

Phytoplankton counts were performed on water samples collected from the lower river as part of the District's water quality data collection program that was described in Chapter Five. Phytoplankton samples were collected on sixteen dates between March 1, 2000 and November 2, 2001 at four salinity-based stations in the lower river and a nearby fixed-location station in Tampa Bay. Samples from the salinity-based stations were collected at the locations of the 0.5, 6, 12 and 18 psu isohalines in the river on each sampling day. These isohalines were located by cruising the river by boat so that water and phytoplankton samples were collected within $\pm$1 psu of the targeted salinity. This sampling program was conducted to better assess the effects of salinity on phytoplankton species composition and ensure that samples were collected across the salinity gradient of the river on each day.

The locations of the salinity-based stations at which phytoplankton were collected are shown in Figure 6-1. The isohalines moved considerable distances depending on seasonal rainfall and freshwater inflow. To ensure that a sample was always collected near the mouth of the river, phytoplankton were also periodically collected at a fixed-location station located at kilometer 2.3 during dry periods when the 18 psu isohaline was located upstream of kilometer 3. Phytoplankton samples were preserved with Lugol's solution and provided to the City of Tampa's Bay Studies group, which has experience with taxonomic phytoplankton counts in Hillsborough Bay. Phytoplankton species were enumerated to the lowest practical taxonomic level, using methods described in Appendix 6-A. In some cases, taxa had to be listed as unidentified species within a major taxonomic group.

The design of the Alafia River phytoplankton sampling program provided results comparable to phytoplankton data that had been conducted on the Peace and Little Manatee Rivers using a similar moving, salinity-based sampling design. Phytoplankton have been collected near the 0.5, 6 and 12 psu isohalines in both rivers, and from the 18 psu isohaline in the Little Manatee and at the 20 psu isohaline in the Peace. The combined phytoplankton data from these three rivers were provided to researchers from the University of South Florida to conduct inter-river analyses of factors affecting phytoplankton populations. The results presented below for the Lower Alafia River are taken from the final report prepared for that project (Vargo et al. 2004).

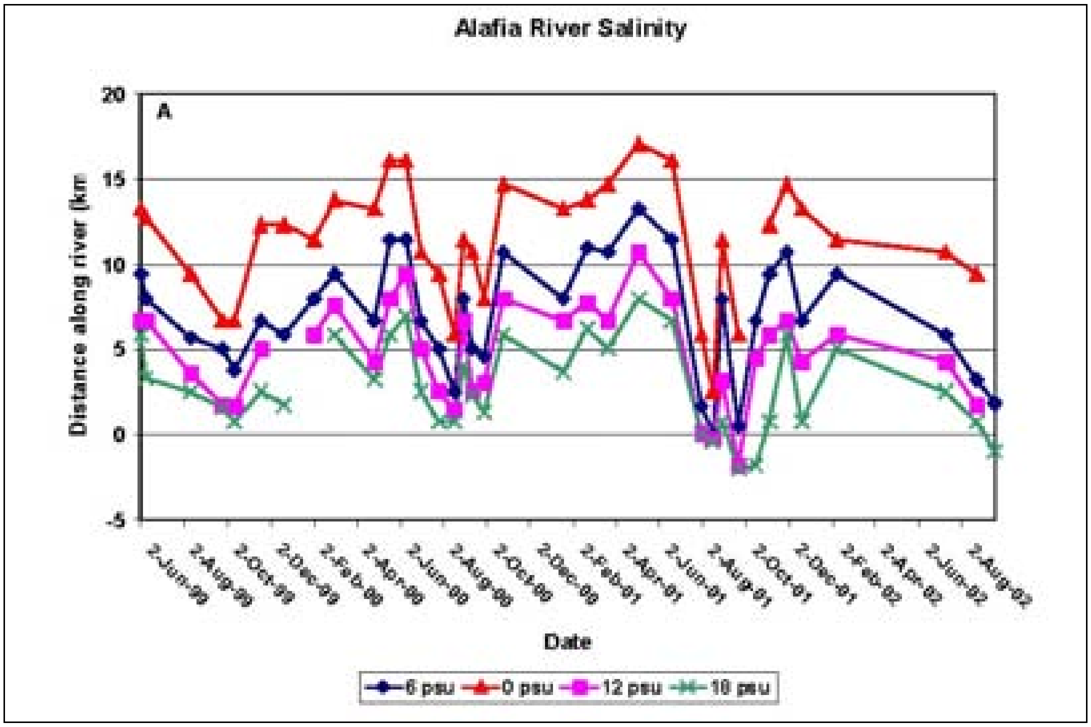


Figure 6-1. **Locations of the 0.5, 6, 12, and 18 psu salinity-based sampling stations in the Lower Alafia River during 1999 through 2002 showing the period of phytoplankton data collection at these sites.**

The phytoplankton counts confirmed that the Lower Alafia River is characterized by frequent and unusually large phytoplankton blooms. Mean values for total phytoplankton cells at the four salinity-based zones in the Alafia are plotted in Figure 6-2 along with values at the same salinity zones in the Peace and Little Manatee rivers (the 20 psu zone for Peace is plotted with the 18 psu zones from other rivers). Note that the scale for the Alafia River samples is an order of magnitude greater than that for the other two rivers. Even though the Peace River is generally considered to be a nutrient rich river (PBSJ, 2006), the total phytoplankton counts for the Alafia River are more than an order of magnitude greater for all salinity zones.

The Little Manatee River is unusual in that the highest phytoplankton counts are from the 0.5 psu zone, which is similar to the pattern shown for chlorophyll *a* concentrations (Figure 5-61). Average phytoplankton counts are roughly similar for the Alafia and Little Manatee at the 0.5 psu zone, but are nearly five times greater in the Alafia at the 6 psu zone and an order of magnitude greater at the 12 and 18 psu zones. Like the Peace, the Little Manatee has also experienced a substantial nutrient enrichment (Flannery et al. 1991), which makes the markedly higher chlorophyll and phytoplankton values for the Alafia even more striking. Stated another way, the unusually high phytoplankton counts for the Alafia River shown in Figure 6-2 are especially notable because the Alafia is not being compared to pristine, nutrient-poor rivers.

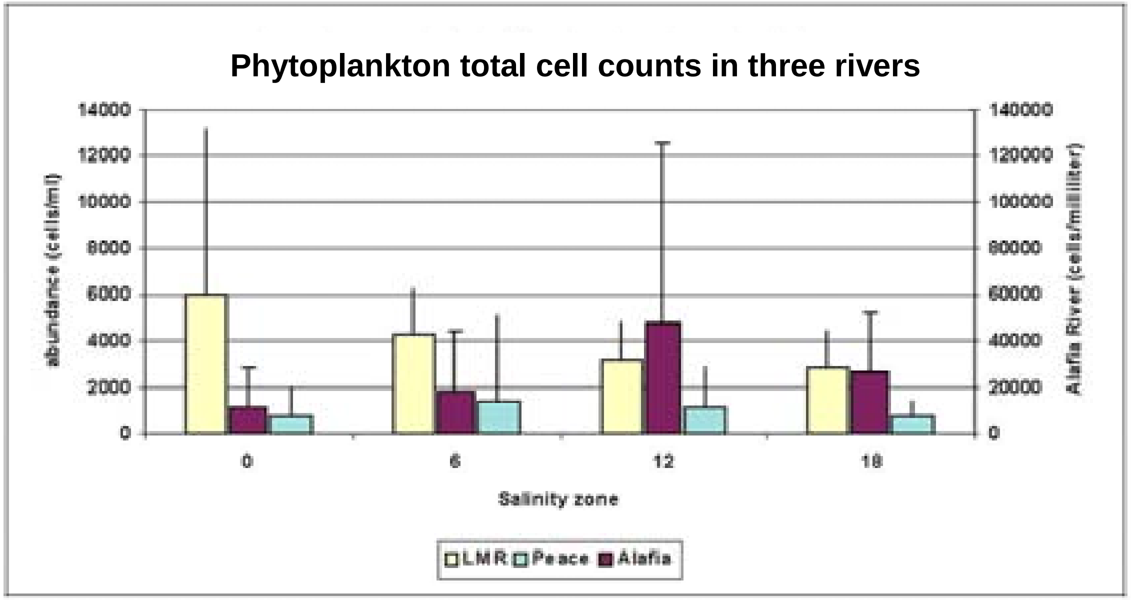


Figure 6-2. Mean values (+ one standard deviation) for total phytoplankton cells in the Little Manatee, Peace, and Lower Alafia Rivers. The y axis for the Alafia is shown separately on a scale that is an order of magnitude greater than for the other rivers.

As described in Chapter Five, the very high chlorophyll values that periodically occur in the Alafia River support the findings of unusually large phytoplankton cell counts in the lower river. Total phytoplankton cell counts and chlorophyll *a* concentrations for the four salinity-based stations in the Alafia River are plotted vs. flow at Bell Shoals Road in Figure 6-3. Like the results for chlorophyll *a* in fixed river segments presented in Chapter Five, these results show that the highest phytoplankton counts tend to occur during low flows.

Table 6-1 lists the 50 dominant phytoplankton taxa recorded in the lower river during the 2000 – 2001 study, ranked by mean abundance. The most abundant taxa in the lower river were usually diatoms and dinoflagellates, with an unidentified crytomonad also periodically occurring in high numbers. Two euglenoids also periodically had high cell counts. The mean abundances of five major phytoplankton groups are shown for the four salinity-based stations in Figure 6-4 along with mean values for the Lower Peace River. Flagellates, (including crytomonads, euglenoids and unidentified microflagellates) were the dominant group at the 0 and 6 psu stations in the Alafia, with diatoms most numerous at the 12 and 18 psu stations. Dinoflagellates reached their greatest mean abundance values at the 6 and 12 psu stations in the tidal river. Chlorophytes (green algae) and blue-green algae were much less abundant compared to the other three major groups.

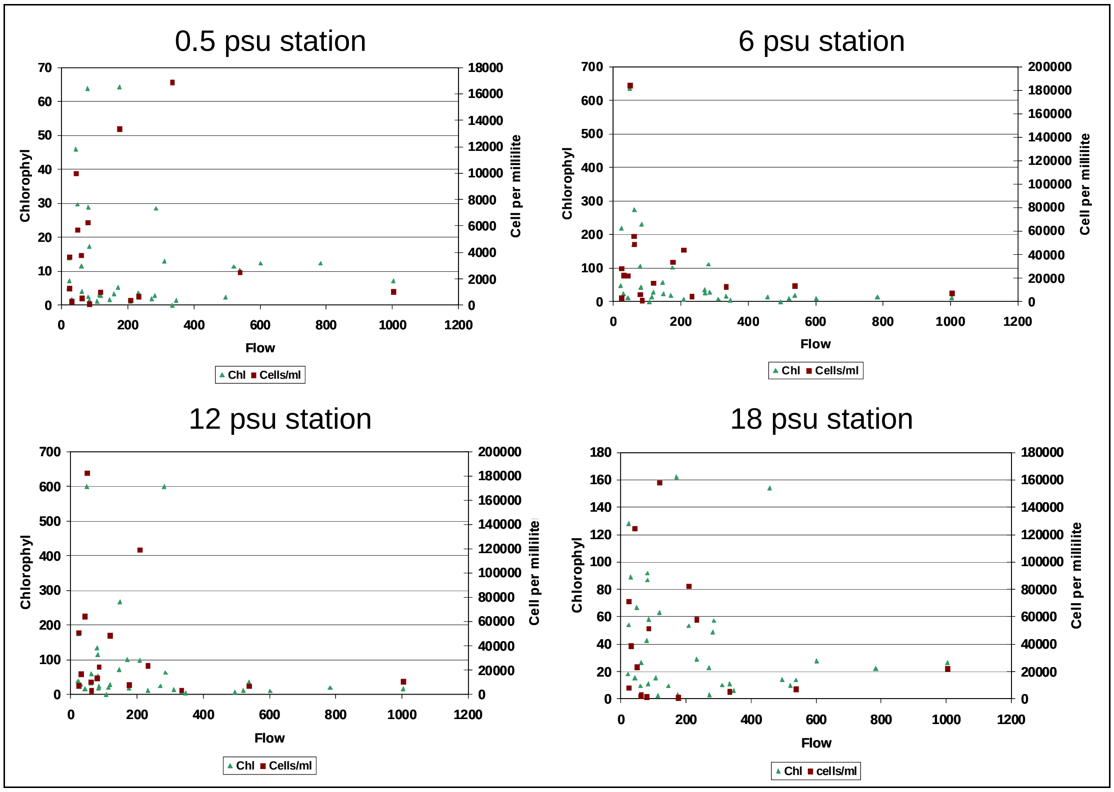


Figure 6-3. Chlorophyll *a* concentrations and total phytoplankton cells at four salinity-based stations in the lower river vs. inflow at Bell Shoals Road (cfs).

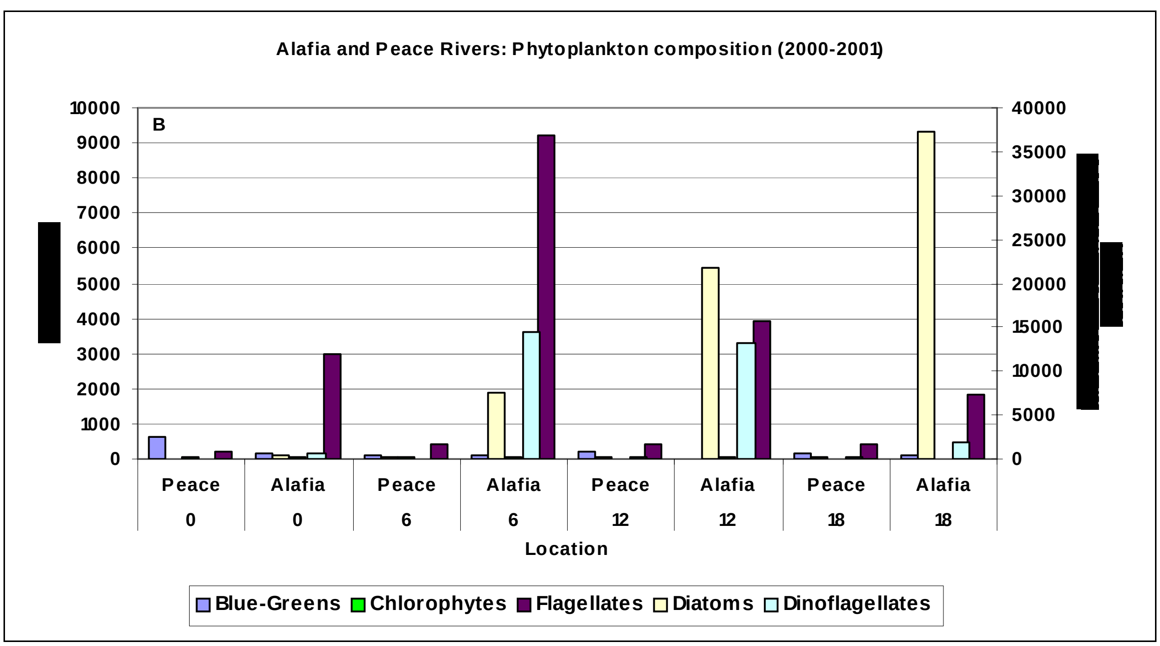


Figure 6-4. Mean values of total cell counts of major phytoplankton groups at four salinity-based stations in the Lower Alafia and Peace Rivers.

Table 6-1. Fifty most abundant phytoplankton taxa collected from the Lower Alafia River ranked by mean abundance.				
Rank	**Scientific Name**	**Common Group Name**	**Mean Count (cells/ml)**	**Maximum Count (cells/ml)**
1	Unknown diatom sp. D	Diatoms	7,230	104,353
2	*Skeletonema menezelli*	Diatoms	4,235	129,176
3	*Prorocentrum minimum*	Dinoflagellates	3,927	180,268
4	*Skeletonema costatum*	Diatoms	3,731	48,742
5	Unknown Cryptophyte sp.	Crytomonads	2,778	45,790
6	*Thalassiosira* sp.	Diatoms	1,650	61,877
7	Unknown Dinoflagellate sp.	Dinoflagellates	600	24,984
8	*Eutreptiella* sp.	Euglenas	361	31,491
9	Unknown diatom sp.	Diatoms	344	3,133
10	*Prorocentrum redfieldi*	Dinoflagellates	248	19,401
11	*Peridinium* sp.	Dinoflagellates	228	10,725
12	*Chaetoceros* sp.	Diatoms	225	4,579
13	Unknown *Katodinium* sp.	Dinoflagellates	199	15,183
14	*Eutreptia* sp.	Euglenas	196	8,556
15	*Prorocentrum* sp.	Dinoflagellates	153	7,431
16	*Nitzschia closterium*	Diatoms	153	2,290
17	*Chaetoceros gracile*	Diatoms	147	6,427
18	*Prorocentrum micans*	Dinoflagellates	126	5,342
19	*Nitzschia pungens*	Diatoms	117	1,808
20	*Pseudopedinella* sp.	Dictyochophytes	99	9,038
21	Unknown diatom sp. A	Diatoms	96	2,410
22	*Leptocylindricus danicus*	Diatoms	91	5,061
23	*Pyramimonas* sp.	Prasinophyte	73	723
24	*Chaetoceros subtilis*	Diatoms	55	3,073
25	*Leptocylindricus minimum*	Diatoms	54	1,205
26	*Glenodinium* sp.	Dinoflagellates	52	1,446
27	*Chaetoceros muelleri*	Diatoms	48	1,687
28	*Nitzschia delicatissima*	Diatoms	41	3,736
29	*Ceratium hircus*	Dinoflagellates	41	964
30	*Scenedesmus* sp.	Greens	36	763
31	*Asterionella japonica*	Diatoms	29	1,446
32	*Akistrodesmus* sp.	Greens	25	442
33	*Minutocellus* sp.	Diatoms	24	321
34	*Pyrophacus* sp.	Bluegreens	23	723
35	*Thalassionema nitzschoides*	Diatoms	21	603
36	*Navicula* sp. small	Diatoms	19	723
37	*Polykrikos* sp.	Dinoflagellates	19	1,687
38	*Aphanocapsa* sp.	Bluegreens	18	362
39	*Gonyaulax* sp.	Dinoflagellates	15	783
40	*Rhizosolenia setigera*	Diatoms	14	241
41	*Gymnodinium* sp.	Dinoflagellates	14	763
42	*Navicula* sp. large	Diatoms	14	241
43	*Tetraedron* sp.	Greens	14	201
44	*Coscinodiscus* sp.	Diatoms	14	562
45	*Prorocentrum gracile*	Dinoflagellates	12	683
46	Unknown Vegetative cell sp.	Unknown	11	482
47	*Apedinella radians*	Flagellates	11	241
48	*Rhizosolenia fragilissima*	Diatoms	10	482
49	Unknown diatom sp. 17	Diatoms	10	723
50	*Merismopedia* sp.	Bluegreens	9	522

Time series plots of the abundance of these major phytoplankton groups are presented in Figure 6-5. Total flagellates displayed spring and fall peaks in the 0.5 psu zone, while dinoflagellates reached peak numbers during the low flow period of winter-spring of 2001. Diatoms were frequently numerous and dominant at the 12 and 18 psu zones. The abundance of these groups at the four moving salinity-based stations are plotted vs. inflow in Figure 6-6. With the notable exception of high diatom counts that were recorded during a sampling event at flows near 800 cfs, there was a tendency for the highest phytoplankton counts to occur at low flows.

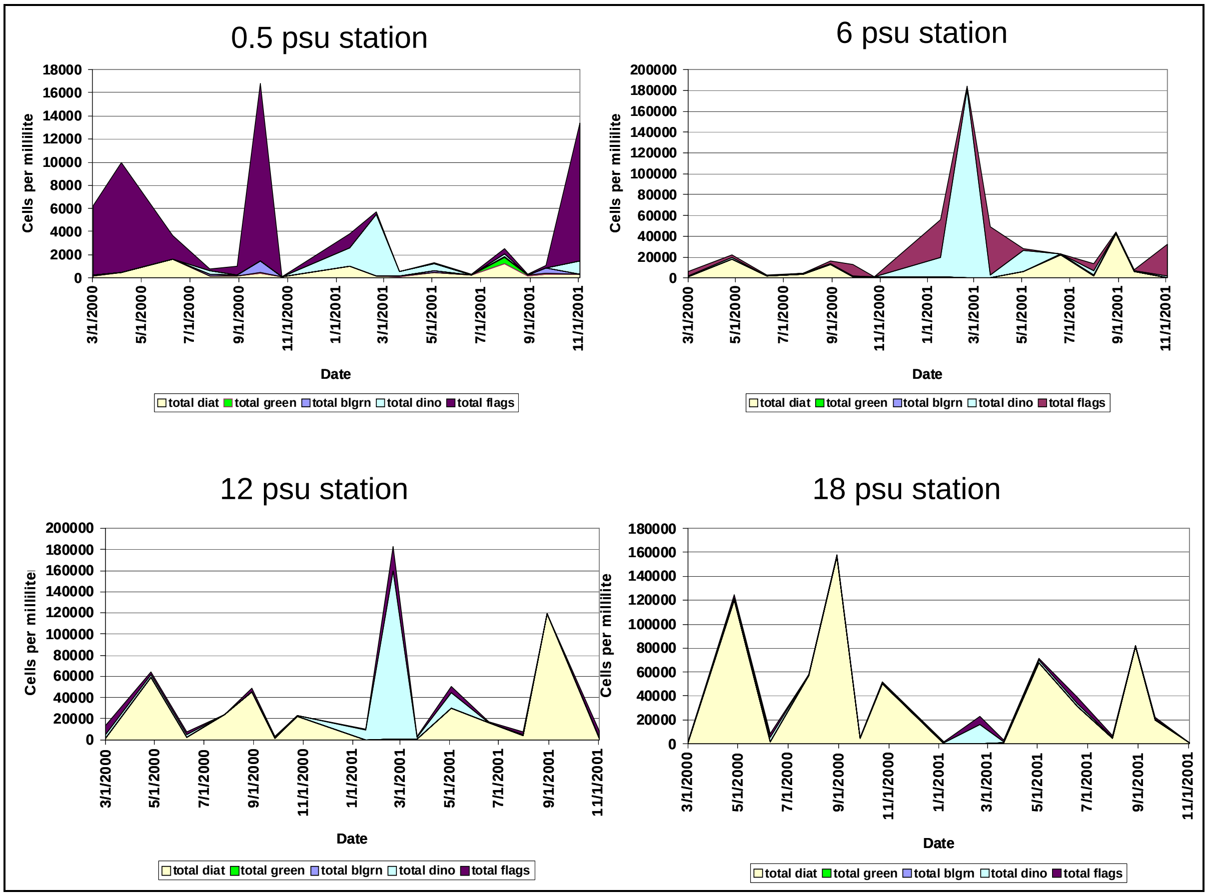


Figure 6-5. Total cell counts of major phytoplankton groups at four salinity-based stations in the Lower Alafia River from March 2000 through November 2001.

Similar to results presented in Chapter Five, the phytoplankton data indicate that physical factors in the river, particularly residence time, have strong controlling effects on phytoplankton abundance, since the occurrence of very high chlorophyll *a* concentrations and phytoplankton cell counts usually do not occur concurrent with periods of high nutrient loading during high flows. However, it is the generally high nutrient loading in the river, even in the dry season, which drives the unusually high phytoplankton and chlorophyll concentrations in the Lower Alafia. Though high flows reduce phytoplankton abundance in the river,

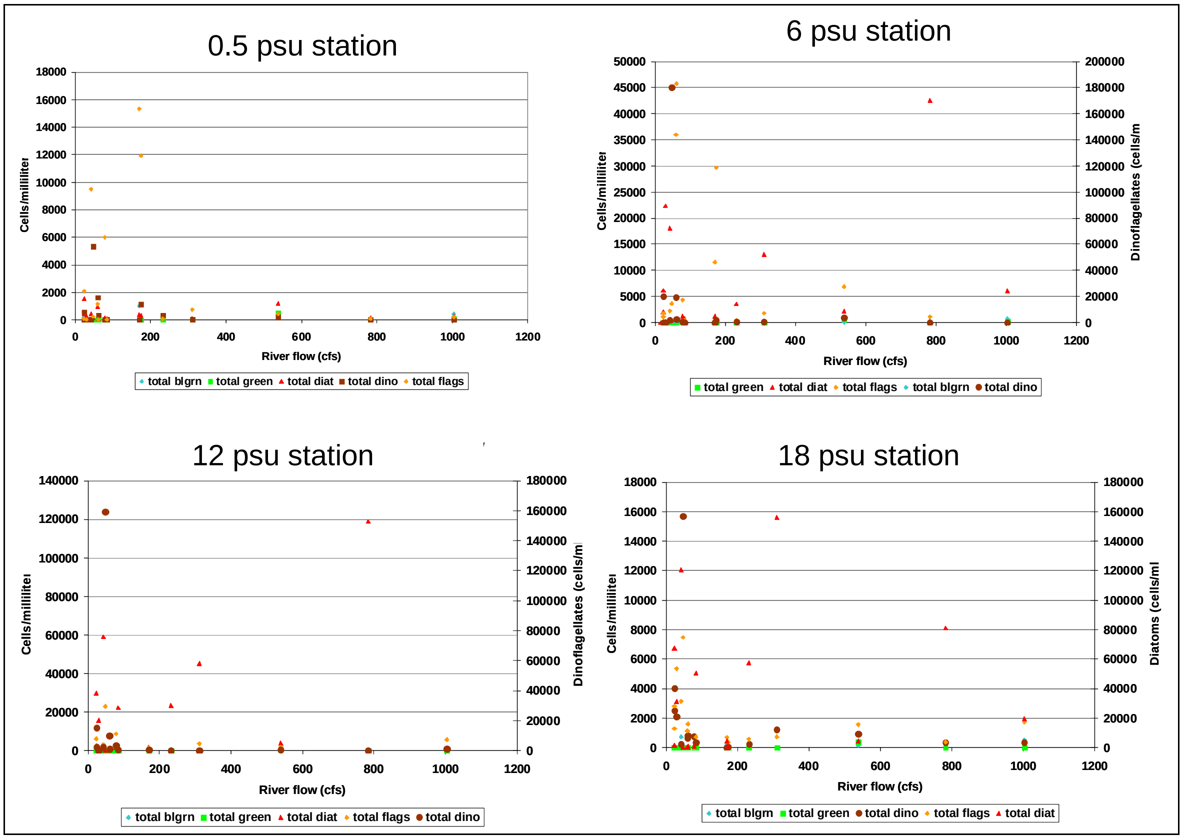


Figure 6-6. Total cell counts of major phytoplankton groups at four salinity-based stations vs. inflow at Bell Shoals Road.

large nutrient loads from the river during the wet season are transported to Tampa Bay, where high chlorophyll concentrations and periodic phytoplankton blooms often occur in the late summer (Johansson 2006). In that regard, the tidal river estuary is a transitional environment between the freshwater reaches of the river and the bay, in which circulation patterns, physicochemical conditions, residence times, and phytoplankton populations vary widely in response to changes in freshwater inflow.

6.3 Benthic macroinvertebrates

Benthic macroinvertebrates represent an important biological community that comprises a major component of food webs in estuaries. Benthic macroinvertebrates live in or on the bottom substrate, although some species also regularly swim into the water column. By processing organic material that has been deposited or is suspended near the river bottom, benthic macroinvertebrates are an important link in transferring energy to high trophic levels. Many macroinvertebrate species are known to be important prey items for juvenile fishes, forming an important link in the fish nursery function of estuaries (Barry et al. 1999, Meng and Powell 1999, Beck et al. 2001, Peebles 2005a).

Benthic macroinvertebrates have long been used in environmental assessments since they are often sensitive to changes in habitat degradation or water quality. Because they are much less motile than fishes, benthic macroinvertebrates often reflect the water quality of the region of a water body from which they are collected. Macroinvertebrate communities often show shifts in species composition in estuaries along the salinity gradient. With its direct relationship with salinity, freshwater inflow can exert a strong effect on distribution of benthic macroinvertebrate populations in estuarine systems.

Sediment composition can also influence the abundance and distribution of macroinvertebrates. Freshwater inflow can affect the distribution of benthic macroinvertebrates by influencing sediment characteristics, through its direct effects on circulation, deposition patterns, and the delivery of nutrients and organic matter to the estuary. Because of the critical role they play in trophic dynamics of estuarine systems and relationships of their distribution and abundance with freshwater inflows, benthic macroinvertebrates are an important component of District minimum flows analyses.

6.3.1 Sources of Data and Published Studies

Benthic macroinvertebrates have been sampled from the Lower Alafia River as part of three sampling efforts, two of which are discussed in this report. The Environmental Protection Commission of Hillsborough County (EPCHC) has monitored benthic macroinvertebrates in the Alafia River since 1995. Nearly all of the sampling has been conducted during the EPCHC index period, which occurs in late August or September. Sampling is conducted with a Young bottom dredge sampler, with samples processed using a sieve with a 0.5 mm mesh. Limited sampling was conducted in the Lower Alafia River between 1995 and 1998, with five samples collected per year (Grabe and Karlen 1999). Sampling was expanded in 1999 to present with 40 samples collected per year in the lower river. Sampling sites for the EPCHC program are geographically distributed between the river mouth and kilometer 17 using a spatially randomized design. Summaries of findings from this benthic sampling program are found in documents published by the EPCHC (Grabe et al. 2002, 2004).

Because the EPCHC sampling is limited to high flow conditions in the late summer, the EPCHC data were not assessed in this minimum flows report. Instead, the findings of benthic studies that are assessed below were taken from two programs that employed extensive spatial sampling of the Lower Alafia River, either in the wet and dry season by Mote Marine Laboratory (2003) or throughout the year by the Tampa Bay Water HBMP (PBS&J 2003).

6.3.2 Mote Marine Study

Mote Marine Laboratory was contracted by the District to conduct sampling and analysis of benthic invertebrates to support the establishment of minimum flows for the Lower Alafia River (Mote Marine Laboratory 2003). Two sampling events were conducted; the first in the spring dry season (May) of 1999 and the second in the late summer wet season (September) of 2001. Mote sampled benthic invertebrates at sampling transects distributed at one kilometer intervals in the lower river from kilometer 1 to kilometer 15, plus two fixed location stations in Hillsborough Bay for comparison.

Cores were typically used to sample benthic infauna at each transect site, but ponar grabs were used in cases where sediments would not stay in the cores. Seven samples were processed from each transect location, two from the shallows near each bank and three from the central deeper portion, yielding 105 samples from the lower river for each of the two sampling events. Two sweep net samples were also collected at each of the river transect sites to collect the more motile epifaunal organisms that live on the sediment surface. All benthos samples were processed using a sieve of 0.5 mm mesh. Sediments were also analyzed for total sediment organic matter, coarse sediment organic matter, and particle size distributions. Graphs of percent sand, silt, and clay from the seven sites along each sampling transect are shown in Chapter Three (Figure 3-10). More complete discussion of the sediment and biological processing methods employed by Mote Marine Lab can be found in their final report to the District (Mote Marine Laboratory 2003).

Abundance values in numbers of macroinvertebrate organisms per square meter were calculated for the core and ponar samples, with individual counts and density calculations made separately for each of the seven samples at a transect. Mean density values for each transect were then calculated as the average of these values. The sweep net samples provided data on the epifaunal species collected at each transect and relative abundance values per sampling effort, but these data could not be reliably expressed as density per square meter for direct comparison to areal abundance values for the infauna.

A list of the fifty most abundant species collected by Mote Marine Laboratory are listed in Table 6-2. As described in the next section, many more benthos samples have been collected in the lower river by the Tampa Bay HBMP since the time that the Mote sampling was completed. However, the Mote data are informative and useful for comparison to the HBMP data as they were collected using a different sampling design. The most abundant infauna taxa collected by Mote on the two sampling events included amphipods (*Ampelisca* sp., *Grandidierella bonnieroides*, *Acocorophium louisianum*), polychaetes (*Laeonereis culveri*, *Steblospio benedicti*, *Paraprionospio pinnata*), dipteran insects (chironomus sp., *Polypedilum halterlae* gp., *Tanytaursus* sp.), oligochaetes (Tubificidae), acorn worms (*Enteropneusta*) a bivalve (*Mytilopsis leucophaeta*), and a cumacean (*Cyclapsis varians*). As discussed later, there were distinct differences in the spatial distribution of various species within these and other taxonomic groups that were related to salinity gradients in the lower river.

Table 6-2. Fifty most abundant taxa of benthic macroinvertebrate infauna collected by Mote Marine Laboratory during sampling events during May, 1999 and September, 2001 ranked by mean abundance.			
Rank	**Taxon**	**Common Group Name**	**Class**
1	*Ampelisca abdita*	Amphipod	Malacostraca
2	*Laeonereis culveri*	Polychaete	Polychaeta
3	*Mytilopsis leucophaeta*	Bivalve	Bivalvia
4	*Grandidierella bonnieroides*	Amphipod	Malacostraca
5	*Cyclaspis varians*	Arthropod	Malacostraca
6	*Chironomus* sp.	Dipteran	Insecta
7	*cf. Cincinnatia floridana*	Dipteran	Insecta
8	*Streblospio benedicti*	Polychaete	Polychaeta
9	*Polypedilum Halterale*	Dipteran	Insecta
10	*Apocorophium louisianum*	Amphipod	Malacostraca
11	*Enteropneusta*	Acorn Worm	Enteropneusta
12	*Tubificidae*	Oliochaete	Oligochaeta
13	*Paraprionospio pinnata*	Polychaete	Polychaeta
14	*Tanytarsus* sp. G	Dipteran	Insecta
15	*Prionospio perkinsi*	Polychaete	Polychaeta
16	*Corophium*	Amphipod	Malacostraca
17	*Bivalvia sp.*	Bivalve	Bivalvia
18	*Oligochaeta sp.*	Oligochate	Oligochaeta
19	*Amphicteis gunneri*	Polychaete	Polychaeta
20	*Cladotanytarsus*	Dipteran	Insecta
21	*Amygdalum papyrium*	Bivalve	Bivalvia
22	*Almyracuma proximoculae*	Arthropod	Malacostraca
23	*Monticellina dorsobranchialis*	Polychaete	Polychaeta
24	*Gastropoda*	Snail	Gastropoda
25	*Carazziella hobsonae*	Polychaete	Polychaeta
26	*Pinnixa chaetopterana*	Tube Pea Crab	Malacostraca
27	*Mysella planulata*	Bivalve	Bivalvia
28	*Hobsonia floria*	Polychaete	Polychaeta
29	*Capitella capitata*	Polychaete	Polychaeta
30	*Edotea montosa*	Isopod	Malacostraca
31	*Polydora ligni*	Polychaete	Polychaeta
32	*Polypedilum scalaenum gp.*	Dipteran	Insecta
33	*Eteone heteropoda*	Polychaete	Polychaeta
34	*Limnodrilus hoffmeisteri*	Oligochaete	Oligochaeta
35	*Tagelus plebeius*	Bivalve	Bivalvia
36	*Mulina lateralis*	Bivalve	Bivalvia
37	*Amakusanthura magnifica*	Isopod	Malacostraca
38	*Sigambra tentaculata*	Polychaete	Polychaeta
39	*Caprellidae*	Skeleton Shrimp	Malacostraca
40	*Melinna maculata*	Polychaete	Polychaeta
41	*Dicrotendipes*	Dipteran	Insecta
42	*Oxyurostylis smithi*	Arthopod	Malacostraca
43	*Cumacea*	Cumacean	Malacostraca
44	*Cryptotendipes*	Dipteran	Insecta
45	*Mediomastus ambiseta*	Annelid	Polychaeta
46	*Macoma tenta*	Polychaete	Bivalvia
47	*Gammarus mucronatus*	Amphipod	Malacostraca
48	*Listriella barnadi*	Amphipod	Malacostraca
49	*Paramphinome* sp. B	Polychaete	Polychaeta
50	*Nemertea* sp. F	Ribbon Worm	Nemretea (Phylum)

Mote found that species richness (number of taxa) in the core samples was highest in the dry season, with high values near kilometers 1-3 and a secondary peak in the most upriver transects where more freshwater taxa were observed (Figure 6-7). The low taxonomic richness in the wet season was recorded on September 27, 2001, which was preceded by very high flows over the previous two weeks (e.g., daily maximum flow of 3,710 cfs on September 16th). The dramatic changes in salinity that accompanied these high flows (Figure 5-14) likely affected the presence of many infaunal species in the river. The pair of sweep net samples at each transect generally yielded fewer taxa than the suite of seven infaunal samples (Figure 6-8). However, similar to the infauna, the dry season sweep net samples had maximum species richness near kilometers 1-3, with a secondary peak in the upriver transects. Species richness in the sweep nets was reduced in the lower transects in the wet season, but were generally similar to the dry season results at the middle and upriver transects.

The remaining discussion of the Mote Marine data is limited to the infauna that were sampled by cores or petite ponar dredge. The density of total infaunal organisms in numbers per square was highest in the lower and middle-river zones in the dry season (Figure 6-9). Total densities were dramatically reduced at all transects in the wet season. An interesting finding presented by Mote Marine was the calculation of total organisms per kilometer of river, which was calculated by multiplying the mean density value for a transect by the bottom area within one kilometer of that transect. Although this makes a major assumption that the density at each transect is representative of that average faunal density within that kilometer reach, this approach is useful for integrating area and biological data to illustrate zones of the river that are estimated to support large numbers of benthic organisms. Again, using the same dry and wet season samples, the estimated total number of benthic invertebrates were much higher in the dry season (Figure 6-10). Compared to the plot of total organism density per square meter, estimates of total abundance show a strong peak between kilometers 2 though 4. This pattern is due in large part to the rapid expansion of the river area below kilometer 5 (Figure 3-8) combined with high invertebrate counts in that part of the river. As discussed later in this report, this region of the river is an important fish nursery zone that supports large numbers of juvenile fish.

Many species and taxonomic groups showed clear spatial distribution patterns within the lower river. For example, the abundance of total amphipods (an Order within the Sub-Phylum Crustacea) had an estimated abundance peak (numbers per kilometer) near kilometer 4, while total ditperans (an Order within the Class Insecta) were most abundant in the fresh and low salinity waters in the upper transects (Figure 6-11). Within the polychaetes (segmented worms), the dry season density of *Etenoe heterooda* was higher downstream compared to *Laeonereis culveri* (Figure 6-12). Many of the differences in the distribution of various species and groups of macroinvertebrates were related to different salinity tolerances of these taxa in relation to the horizontal salinity gradient in the lower river, though differences in substrate may have also been a factor.

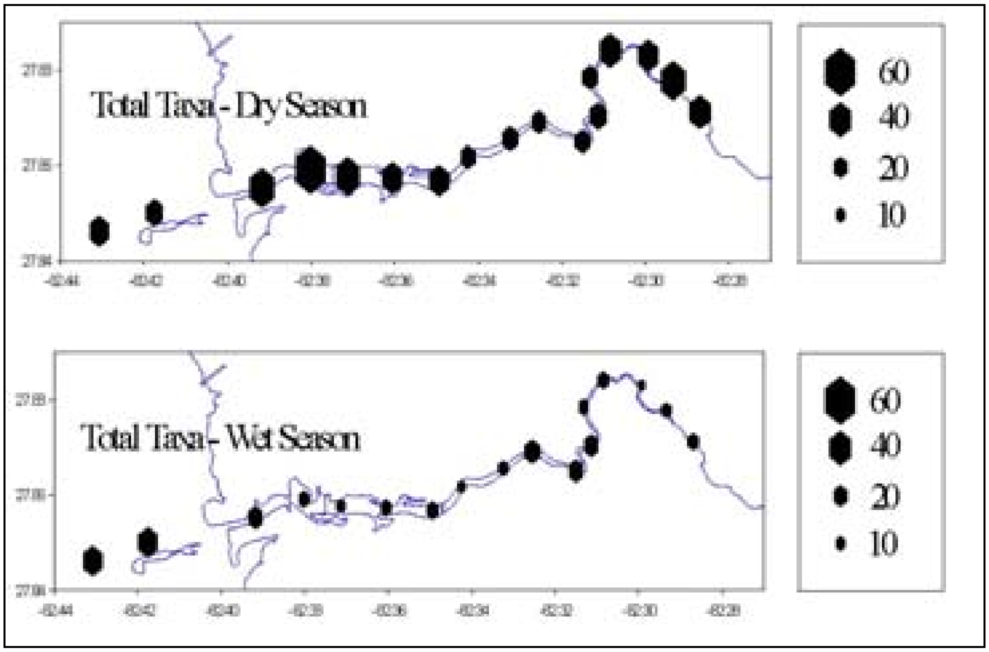


Figure 6-7. Total number of benthic macroinvertebrate taxa sampled by cores or ponar dredges at one kilometer sampling intervals in the Lower Alafia River and two stations in Hillsborough Bay by Mote Marine Laboratory during May 1999 (dry season) and September 2001 (wet season). Adapted from Mote Marine (2003).

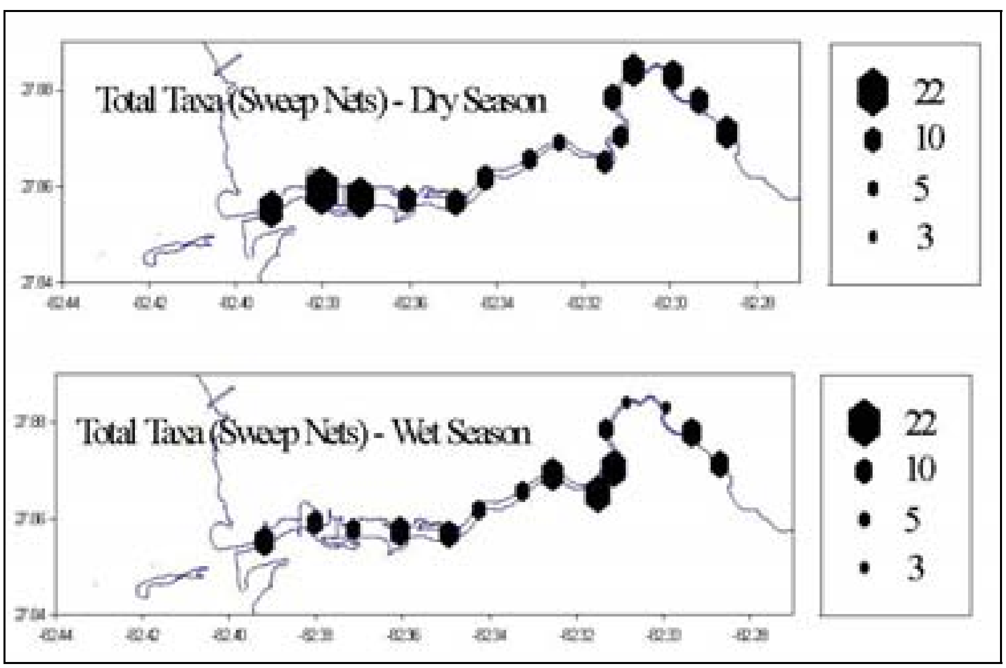


Figure 6-8. Total number of benthic macroinvertebrate taxa sampled by sweep nets at one kilometer sampling intervals in the Lower Alafia River by Mote Marine Laboratory during May 1999 (dry season) and September 2001 (wet season).

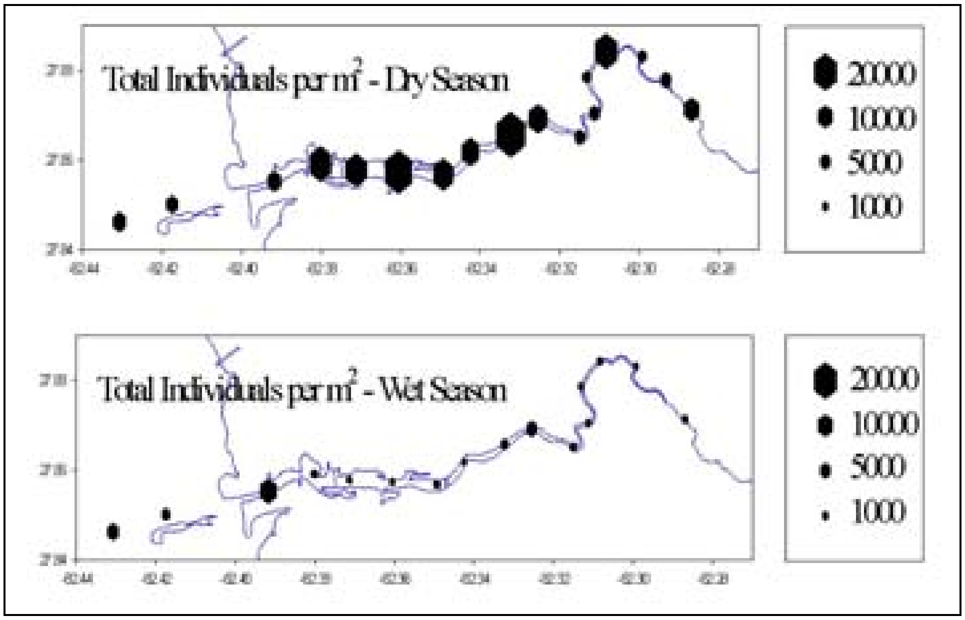


Figure 6-9. Total number of benthic macroinvertebrate individuals per square meter sampled by cores or ponar dredges at one kilometer sampling intervals in the Lower Alafia River and two stations in Hillsborough Bay by Mote Marine Laboratory during May 1999 (dry season) and September 2001 (wet season).

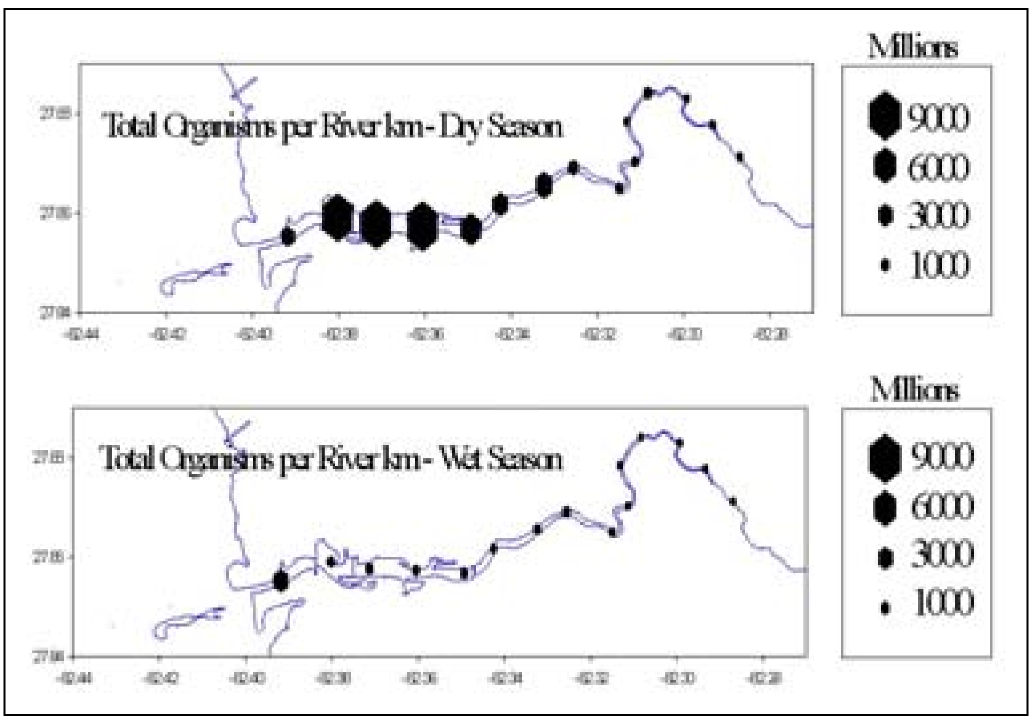


Figure 6-10. Total estimated number of benthic macroinvertebrate organisms within one kilometer intervals sampled by cores or ponar dredges or by Mote Marine Laboratory during May 1999 (dry season) and September 2001 (wet season).

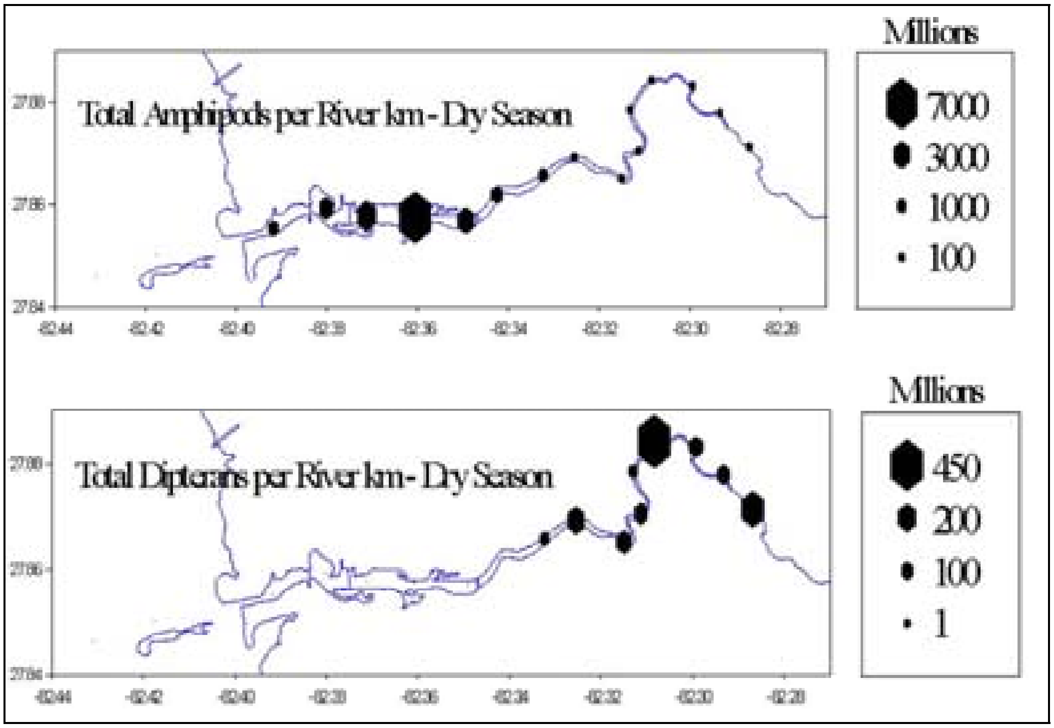


Figure 6-11. Total number of amphipods and dipterans within one kilometer intervals sampled by ponar dredges or cores by Mote Marine Laboratory during May 1999 (dry season) and September 2001 (wet season).

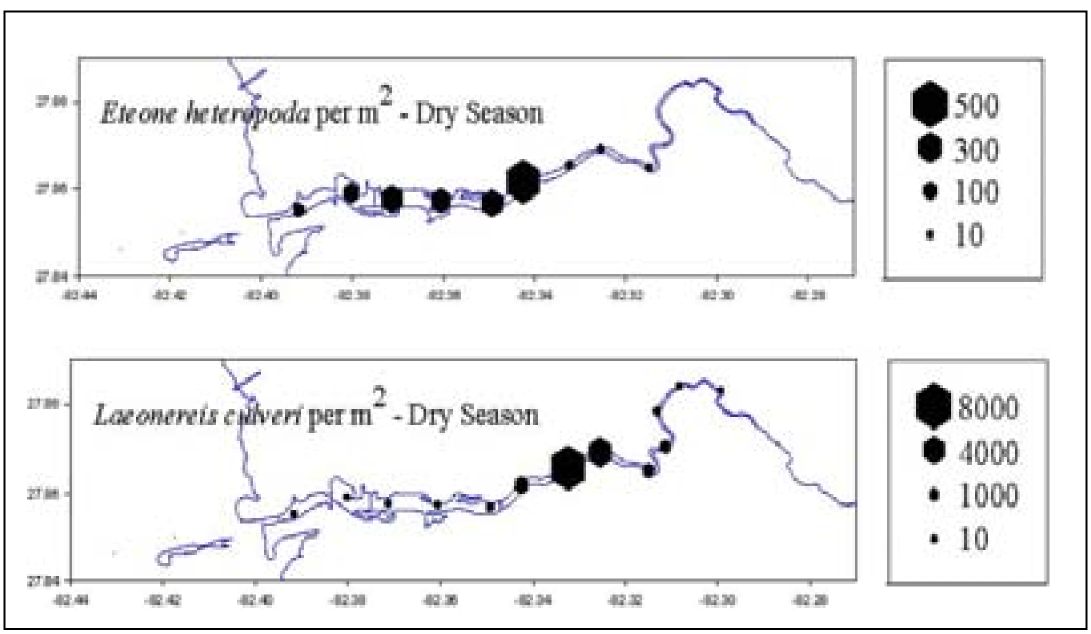


Figure 6-12. Number of individuals per square meter for two species of polychaetes in one kilometer intervals sampled by cores or ponar dredges by Mote Marine Laboratory during May 1999 (dry season) and September 2001 (wet season).

Mote Marine performed a series of analyses to describe salinity relationships of various species. Data from macroinvertebrate collections conducted by the EPCHC and the HBMP through December 2001 were provided to Mote and combined with the data they collected for certain analyses. Mote was also supplied with simulated average daily salinity values for cells in the river generated by the District's LAMFE model. For the model cell from which each biological sample was collected, Mote calculated the corresponding preceding 30-day mean bottom salinity from the model output. Density-weighted mean salinity at capture values were reported and densities were plotted vs. salinity at capture within the HBMP sampling strata. Though not tested for statistical differences, there appeared to be appreciable differences in the salinity ranges for many species based on these tabular and graphical outputs, which are presented in Mote Marine Laboratory (2003).

Using these same biological and modeled salinity values, cluster analysis was performed to examine relationships between salinity and macroinvertebrate community structure. Faunal abundance data were reduced to presence/absence within 25 discrete 1 psu salinity increments from 0 to 24 psu, with the clusters used to connect salinity groups based on faunal similarities in the presence/absence data (Figure 6-13). These results indicated there were two large principal clusters, ranging from 0 to 15 psu and from 16 to 24 psu. Secondary clusters within the lower of these two large clusters suggested some possible similarity in community structure within the 1 to 5 psu and 6 to 15 psu salinity ranges.

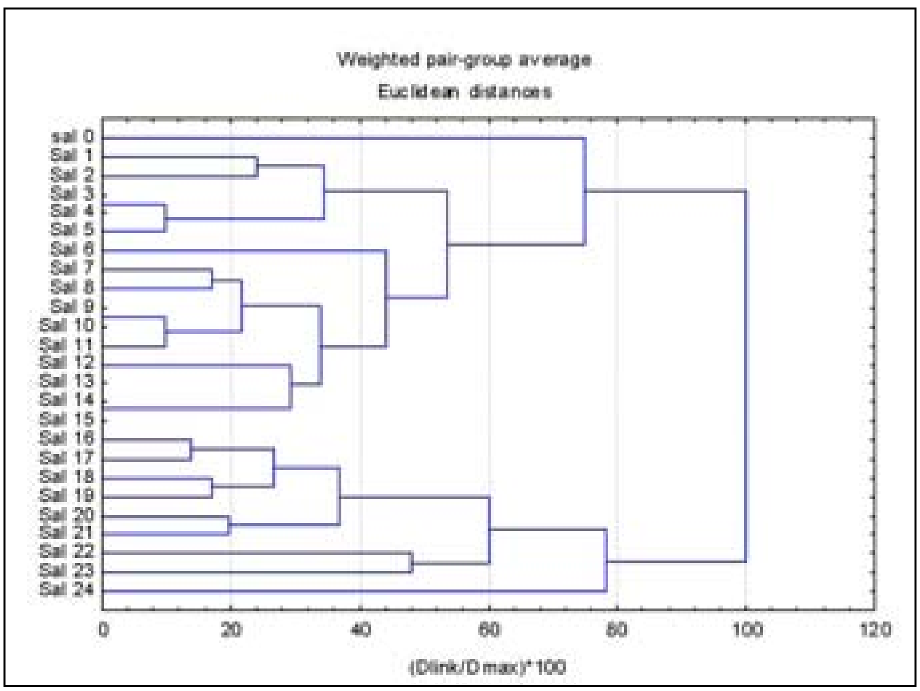


Figure 6-13. Cluster analysis for salinity with species presence/absence data with one psu salinity increments used as the matrix. Results based on the combined infaunal sampling during May 1999 and September 2001 conducted by Mote Marine Laboratory.

6.3.3 HBMP Macroinvertebrate Data

As described in Chapter 3, Tampa Bay Water is required to conduct an extensive hydrobiological monitoring program (HBMP) to support their water supply withdrawals from three waterways in the region, which include the Alafia River. Biological data collection in the Lower Alafia for the HBMP began in the spring of 2000 and continues through the present. A series of data and interpretive reports are submitted to the District as specified in the requirements of Tampa Bay Water's water use permit. To date, two interpretive reports have been submitted for the HBMP (PBS&J 2003, 2006).

Data collection for benthic macroinvertebrates in the lower river for the HBMP is based on a stratified probabilistic design, which is summarized in the study design document for the project (PBS&J, 1999). The lower river is divided into seven sampling strata, six of which are considered estuarine and the most upstream stratum which is considered freshwater (see Figure 5-1). Using a geographic randomization method, two samples are randomly located within each of the estuarine strata and one from the freshwater each month, yielding a total of 180 samples from the lower river per year. In addition, an inset stratum was overlain between kilometers 7 and 13 for additional sampling, with a total of 20 samples taken from this inset per year during the months June through August. This inset stratum was based on the recommendations of the Hillsborough County EPC, based on their prior knowledge of the river and their observations of where transitions in the species composition of the benthos typically occur in the wet season. All benthos samples collected from the lower river by the HBMP are sampled by a Young dredge and are sorted using a 0.5 mm sieve. This sampling is oriented to benthic infauna, although some epifauna are captured as well.

Results of benthic invertebrate analyses taken from two HBMP interpretive reports are summarized below. Results are also presented for HBMP benthos data collected between May 2000 through November 2003, which were analyzed by the firm of Janicki Environmental in support of the District's minimum flows analysis. The HBMP data base for benthic macroinvertebrates in the river is quite large. The 2000-2003 data analyzed by Janicki Environmental for this report included 684 benthos samples collected the lower river.

Box plots of species richness for the seven Alafia River strata are plotted for two years in Figure 6-14. As with the Mote data, species richness tended to increase toward the mouth of the river, reflecting the influence of Tampa Bay. Similar to this spatial pattern, species richness calculated for the entire lower river on a monthly basis tends to be higher in the spring dry season and lowest in the wet season (Figure 6-15). These findings are not surprising, as high salinity marine waters often have a more diverse benthos assemblage than estuarine waters (Kinne 1971, Kennish 1990). However, estuaries can be areas of very high

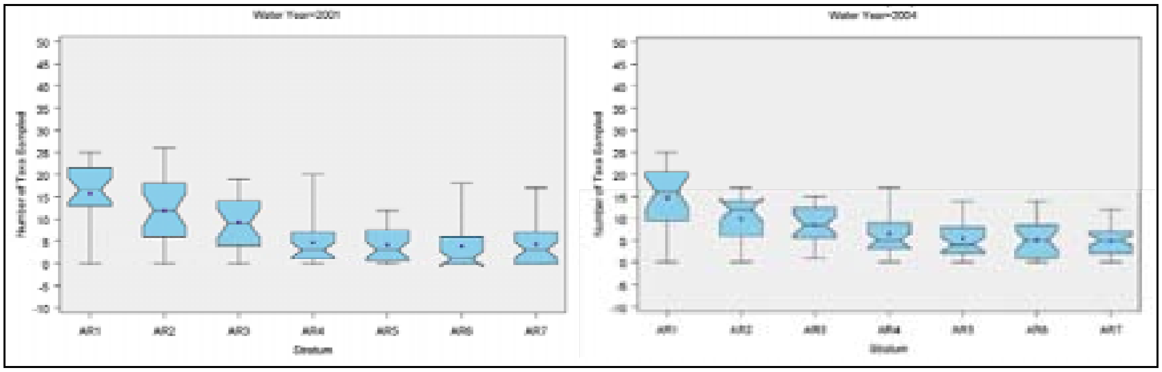


Figure 6-14. Box plots of species richness of benthic macroinvertebrates collected within the HBMP strata for the years 2001 and 2004.

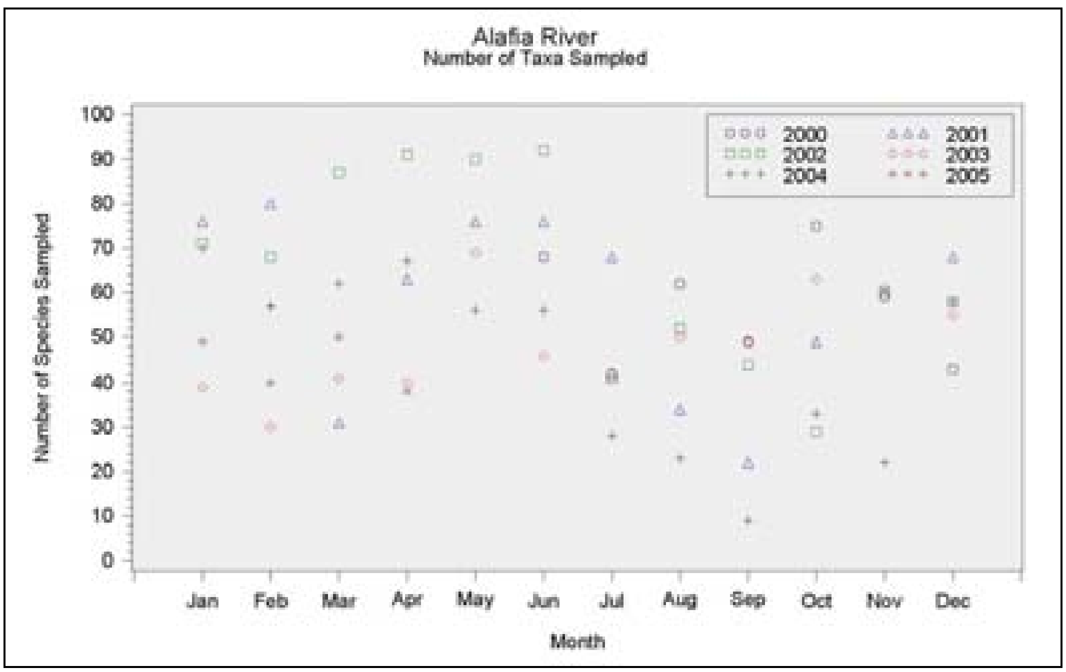


Figure 6-15. Species richness of benthic macroinvertebrates per month for six years of HBMP sampling in the Lower Alafia River.

biomass due to the abundance of the euryhaline organisms that can proliferate there (Carriker 1967, Wolff 1983). Similar to the findings of the Mote study, the number of total organisms in the HBMP samples were highest in the lower to mid-river zones (Figure 6-16). Based on data collected between 2000 to 2003, peak densities of total organisms were highest at kilometers 3 and 4, with mean values above 2,500 individuals per m^2 found in all segments below kilometer 9. Lower numbers of total organisms were collected at kilometers 9 and above. In general, this portion of the river has more coarse grained sediments that the lower river reaches.

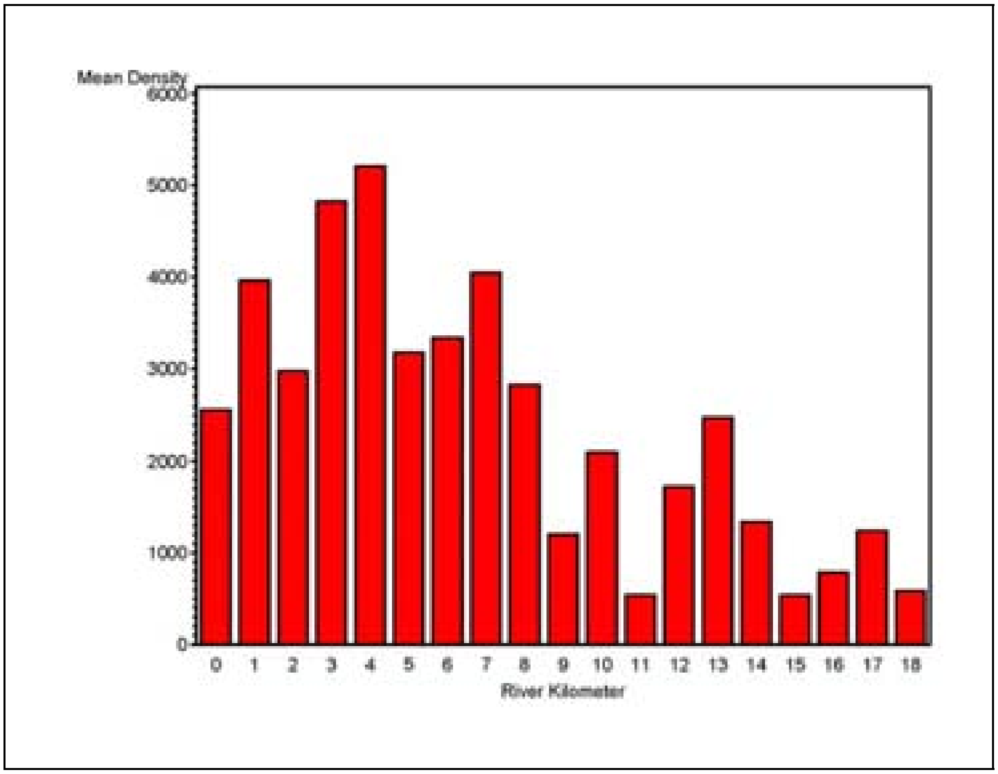


Figure 6-16. Mean values of total organisms per square meter for benthic macroinvertebrate infauna within one kilometer segments based on sampling by the HBMP program from June 2000 through November 2003.

Complete lists of all benthic macroinvertebrate taxa collected from the Lower Alafia River by the HBMP were presented in both of that project's interpretive reports (PBS&J 2003, 2006). However, results for the species abundance or presence/absence listed in those reports are limited to frequency of occurrence. Therefore, a statistical summary of abundance data for the fifty most frequently occurring taxa in the lower river are presented in Table 6-3 for data collected between 2000 and 2003. The species are ranked by frequency of occurrence, which for the most part closely matches the most recent ranking by frequency of occurrence presented in the 2006 HMBP report.

Table 6-3. Summary statistics for benthic infauna taxa collected in the Lower Alafia River by the HBMP program between May 2000 and November 2003. Taxa ranked by frequency of occurrence in all strata. All density values reported as number of individuals per square meter.

Rank	Taxon	Percent Ocurrence	Mean Density (all samples)	Mean Density (presence only)	Median Density (presence only)	Maximum Density
1	*Grandidierella bonnieroides*	33.9	308	907	138	21,000
2	*Laeonereis culveri*	33.9	153	452	125	10,200
3	Tubificidae	26.9	84	314	88	8,625
4	*Streblospio gynobranchiata*	26.3	200	759	200	17,350
5	Nemertea sp.	26.2	33	127	75	850
6	Chironomus sp.	24.3	111	456	100	8,575
7	Mytilopsis leucophaeta	21.5	313	1,454	100	45,475
8	Cyathura polita	19.4	29	151	75	1,375
9	Ampelisca abdita	16.7	336	2,019	125	45,000
10	Hobsonia florida	15.1	36	240	50	3,850
11	Polypedilum halterale group	14.9	27	182	50	4,700
12	Steninonereis martini	13.7	38	278	88	3,375
13	Polypedilum scalaenum group	12.7	24	186	50	2,975
14	Procladius sp.	12.6	9	74	25	750
15	Edotea montosa	12.1	20	162	75	2,350
16	Limnodrilus hoffmeisteri	11.8	18	152	50	1,000
17	Paraprionospio pinnata	11.7	17	143	50	1,325
18	Amygdalum papyrium	11.4	32	278	100	2,625
19	Mulinia lateralis	10.4	67	648	75	14,600
20	No organisms present	10.1	0	0	0	0
21	Thalassodrilides gurwitschi	9.7	22	223	75	2,425
22	Corbicula fluminea	9.1	7	82	50	400
23	Cyclaspis cf. varians	8.9	16	177	50	1,400
24	Neanthes succinea	8.9	8	84	50	575
25	Cryptochironomus sp.	8.8	5	56	25	275
26	Macoma tenta	8.8	13	148	63	975
27	Pinnixa sp.	8.5	12	136	75	825
28	Eteone heteropoda	8.3	6	71	25	925
29	Ampelisca holmesi	8.0	47	587	175	6,725
30	Glycinde solitaria	8.0	10	126	50	3,050
31	Heteromastus filiformis	8.0	10	121	50	1,625
32	Capitella capitata	7.6	9	117	50	850
33	Coelotanypus sp.	7.5	6	80	50	300
34	Glycera sp.	7.0	5	66	25	300
35	Hydrobiidae sp.	6.9	10	142	50	1,850
36	Palpomyia/Bezzia sp.	6.9	2	32	25	100
37	Glottidea pyramidata	6.6	71	1,079	100	10,300
38	Dubiraphia sp.	6.3	5	74	50	775
39	Tanytarsus sp.	6.1	10	160	50	1,200
40	Oxyurostylus cf. smithi	5.4	3	56	25	225
41	Phyllodoce arenae	5.4	3	59	25	425
42	Paramphinome sp.b	5.3	5	95	50	1,025
43	Rhithropanopeus harrisii	5.3	3	63	25	300
44	Monticellina dorsobranchialis	5.1	26	516	100	6,375
45	Tubificoides brownae	5.0	6	122	50	625
46	Balanus improvisus	4.8	49	1,017	75	25,000
47	Cladotanytarsus sp.	4.5	6	130	50	550
48	Gammarus mucronatus	4.5	9	197	100	1,125
49	Stylochus cf. ellipticus	4.4	4	82	50	400
50	Dicrotendipes sp.	4.2	6	139	25	1,250

The two most common taxa, the amphipod *Grandidierella bonnieroides* and the polychaete *Laenoeris culveri*, are frequently found in tidal river estuaries in Southwest Florida and were found in about one third of all samples recorded from the Lower Alafia. These two species and four other taxa within the ten most frequently collected taxa for the HBMP were among the top ten taxa ranked by the Mote study based on mean abundance (*Streblospio gynobranchiata*, Chironomus sp., *Mytilopsis leucophaeta*, *Ampelipsa abita*). In general, crustaceans and polychaetes are numerous in the lower and mid-river zones with oligochaetes and insect larvae more numerous upstream.

The same taxa are ranked by mean abundance in Table 6-4, with information added for mean values and salinity and river location at capture for the each taxon species. These results demonstrate how the taxa differ in their distributions and salinity relations in the river. For example, the most abundant species in the river the amphipod *Ampelisca abita*, has a mean salinity value of 22.5 and mean location of 4.1 km, while the second most common species, the clam *Mytilopsis leuchophaeta,* is found in lower salinity waters (mean salinity 6.8 psu) further upstream (mean kilometer 9.3).

The distributions of the eight most frequently collected taxa in the lower river are graphically displayed in Figure 6-17. The distribution of the oligochaete family, Tubificidae, upstream reflects that this group contains many freshwater species, while the more marine group Nemertea sp. are oriented toward the mouth of the river. The polychaetes *Laeonereis culveri* and *Streblospio gynobranchiata* differ in their distributions, due in part to their salinity preferences. The two most common crustaceans in the river, the amphipod *Grandidierella bonnieroides* and the isopod *Cyathura polita*, were distributed in the productive lower-middle reach of the river.

With regard to the upstream and downstream limits of various species, there appears to be a transitional region of the river around kilometer 3. The 2003 HBMP interpretive report presented a graphic of the first and last occurrence of macroinvertebtrate taxa that are encountered moving upstream (Figure 6-18). The number of first occurrences of species rises dramatically in the first three kilometers of the river, but the rate of increase levels off upstream. Similarly, the last occurrence of higher salinity fauna drops dramatically in the first three kilometers of the river, indicating that a faunal community indicative of the river replaces a fauna more influenced by the bay within this reach of the river. The first and last occurrence of insect taxa is also illustrated, demonstrating how this predominantly freshwater group is distributed more upstream.

Table 6-4. Benthic infauna taxa collected in the Lower Alafia River by the HBMP program ranked by mean abundance, with values for mean salinity and mean kilometer at capture.

Rank	Taxon	Mean Density (Number / m2)	Frequency Ocurrence	Mean salinity at capture (psu)	Mean Kilometer at capture (km)
1	*Ampelisca abdita*	336	16.7	22.5	4.1
2	*Mytilopsis leucophaeta*	313	21.5	6.8	9.3
3	*Grandidierella bonnieroides*	308	33.9	15.5	6.8
4	*Streblospio gynobranchiata*	200	26.3	17.4	5.9
5	*Laeonereis culveri*	153	33.9	8.7	8.7
6	Chironomus sp.	111	24.3	7.8	9.8
7	Tubificidae	84	26.9	3.1	13.6
8	*Glottidea pyramidata*	71	6.6	25.9	1.1
9	Mulinia lateralis	67	10.4	22.7	3.5
10	Balanus improvisus	49	4.8	19.4	5.1
11	Ampelisca holmesi	47	8.0	20.0	2.0
12	Steninonereis martini	38	13.7	14.8	8.3
13	Hobsonia florida	36	15.1	14.2	6.2
14	Nemertea sp.	33	26.2	17.8	4.2
15	Amygdalum papyrium	32	11.4	18.6	3.9
16	Cyathura polita	29	19.4	10.2	7.0
17	Polypedilum halterale group	27	14.9	0.9	13.9
18	Monticellina dorsobranchialis	26	5.1	27.6	1.9
19	Polypedilum scalaenum group	24	12.7	3.0	10.0
20	Thalassodrilides gurwitschi	22	9.7	13.2	7.1
21	Edotea montosa	20	12.1	16.8	5.9
22	Limnodrilus hoffmeisteri	18	11.8	0.3	14.8
23	Paraprionospio pinnata	17	11.7	19.0	2.4
24	Cyclaspis cf. varians	16	8.9	21.0	3.4
25	Macoma tenta	13	8.8	26.6	1.7
26	Pinnixa sp.	12	8.5	24.6	1.8
27	Glycinde solitaria	10	8.0	21.8	1.7
28	Tanytarsus sp.	10	6.1	0.9	12.8
29	Hydrobiidae sp.	10	6.9	7.3	8.9
30	Heteromastus filiformis	10	8.0	14.0	3.6
31	Procladius sp.	9	12.6	3.1	11.0
32	Capitella capitata	9	7.6	21.4	2.4
33	Gammarus mucronatus	9	4.5	20.8	2.5
34	Neanthes succinea	8	8.9	20.6	2.8
35	Corbicula fluminea	7	9.1	1.6	12.6
36	Tubificoides brownae	6	5.0	19.5	3.2
37	Coelotanypus sp.	6	7.5	1.2	13.8
38	Eteone heteropoda	6	8.3	17.7	6.7
39	Cladotanytarsus sp.	6	4.5	0.7	14.2
40	Dicrotendipes sp.	6	4.2	1.1	14.9
41	Paramphinome sp.b	5	5.3	24.7	1.4
42	Cryptochironomus sp.	5	8.8	0.7	14.2
43	Dubiraphia sp.	5	6.3	0.5	15.7
44	Glycera sp.	5	7.0	24.2	1.7
45	Stylochus cf. ellipticus	4	4.4	19.9	3.0
46	Rhithropanopeus harrisii	3	5.3	9.0	9.2
47	Phyllodoce arenae	3	5.4	25.6	2.3
48	Oxyurostylus cf. smithi	3	5.4	23.1	2.2
49	Palpomyia/Bezzia sp.	2	6.9	1.7	13.6
50	No organisms present	0	10.1	n/a	n/a

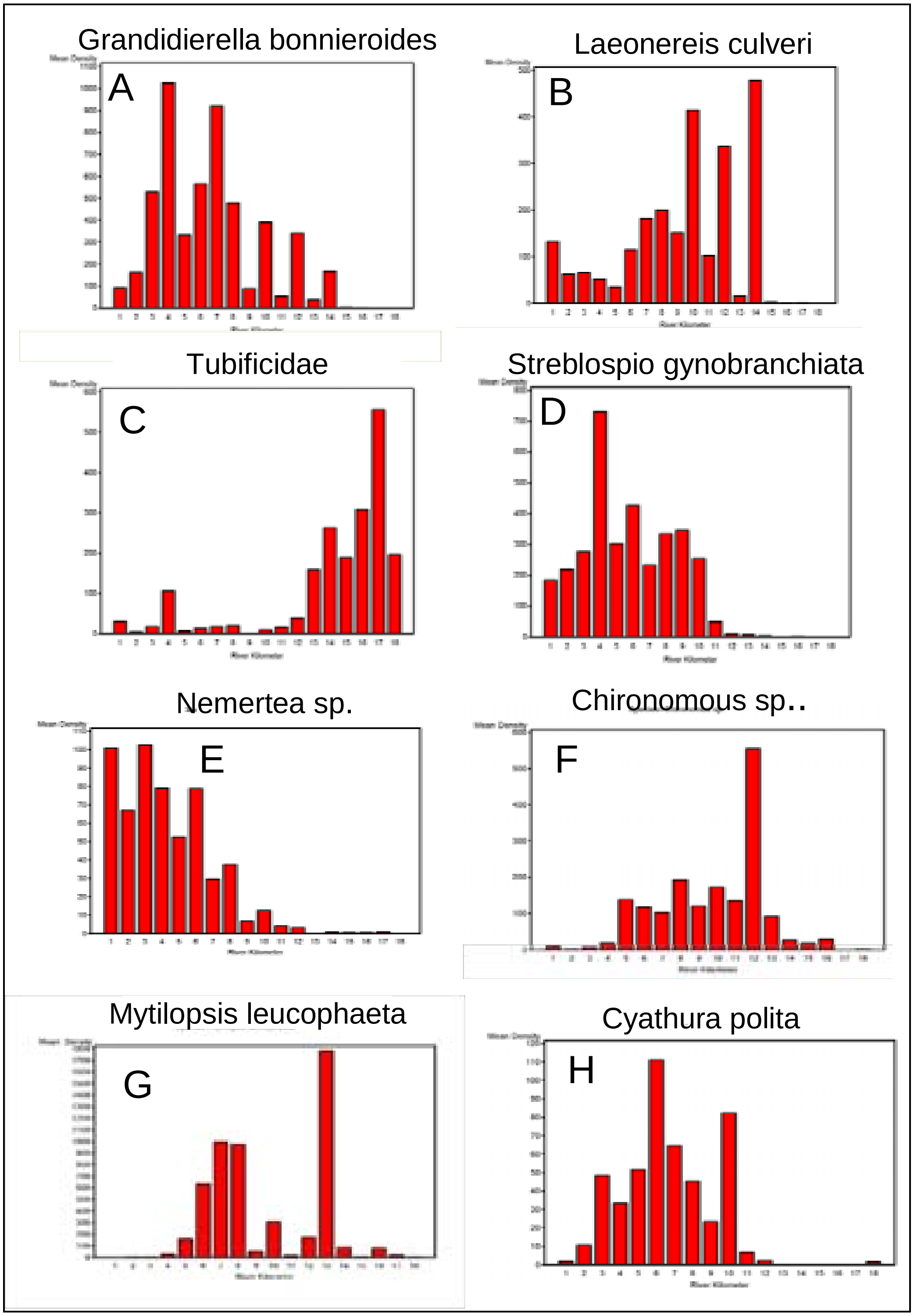


Figure 6-17. Mean numbers of individuals per square meter within one kilometer segments for the eight taxa with the highest frequency of occurrence in the Lower Alafia River as sampled by the HBMP program during June 2000 through November 2003.

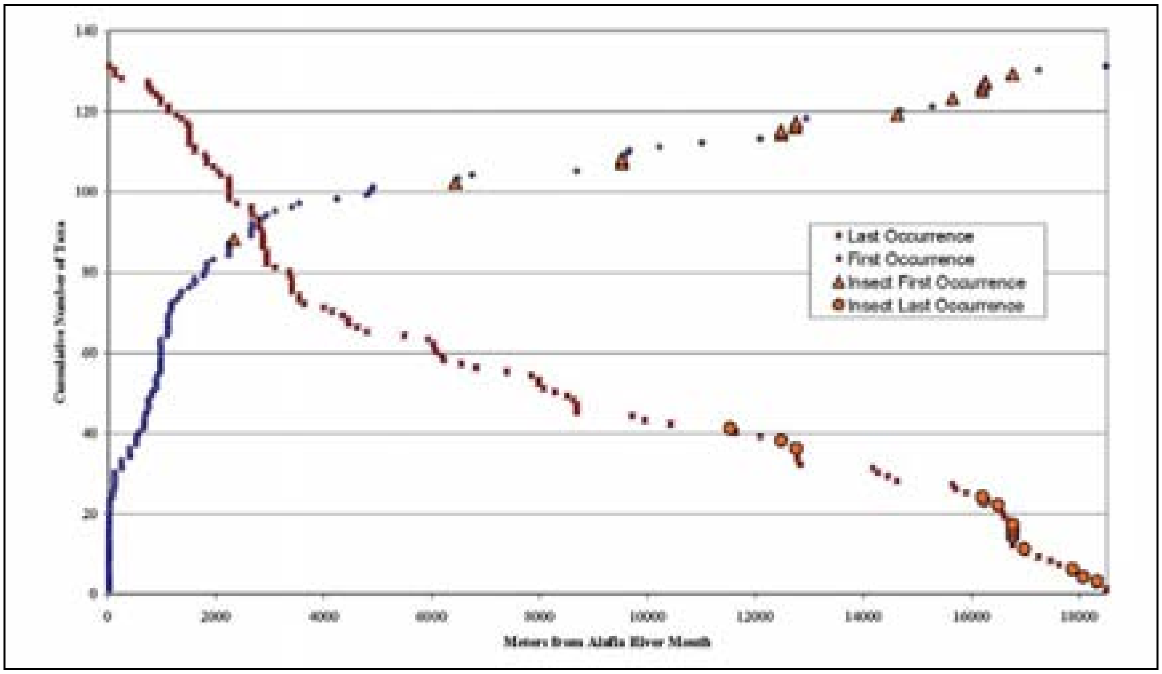


Figure 6-18. Cumulative numbers of the first and last occurrence of infauna taxa moving upstream as sampled by the HBMP program during June 1999 through November 2003 with insect taxa highlighted .

The results of both the Mote Marine and HBMP data collection efforts both show that many macroinvertebrate taxa display clear spatial distributional patterns along the length of the lower river. For many taxa, these distributional patterns are related to the salinity tolerances and preferences of those species. To investigate factors that affect the abundance and distribution of macroinvertebrates in southwest Florida rivers, Janicki Environmental (2007) performed statistical analyses on macroinvertebrate and water quality data complied from nine rivers in west-central Florida, including the Alafia This large data set allowed for robust analyses to assess relationships between salinity and abundance and distribution of macroinvertebrate taxa that are common in tidal rivers in the region.

Among other analyses, Janicki Environmental used Principal Components Analysis (PCA) to identify salinity and sediment classes based upon the ranges over which the macroinvertebrate infauna taxa occur. Bulger et al. (1993) used this approach in developing taxa specific salinity classes for mid-Atlantic estuarine nekton. The approach for benthic infauna was to establish a data matrix of salinities (in 1 psu increments) and taxa. The matrix was completed by noting the ranges of salinity where each of the taxa were present (1) and absent (0). PCA was then used to reduce the number of salinity variables to a smaller number of salinity classes, the principal components. The analyses were run on groups of tributaries to Charlotte Harbor, the Springs Coast and Tampa Bay, the latter of which included the Lower Alafia River (Janicki Environmental 2007).

Another multivariate analytical tool, "Similarity Percentage" analysis (SIMPER: Clarke and Warwick, 2001) was also applied to identify taxa that explained relatively large proportions of the similarity within a category (e.g., salinity class) as well as the dissimilarity between the categories resulting from PCA. The statistical significance of these comparisons was quantified using an “Analysis of Similarities” routine (PRIMER software, Clarke and Warwick, 2001). Individual rivers within the Tampa Bay group were compared to each other, but they were not compared to individual rivers from the other regions.

Five salinity classes were identified in the PCA for Tampa Bay Rivers (Figure 6-19). Analysis of Similarity suggested that the species compositions in Group 1 (0-7 psu) differed significantly from all other groups, while the only other significant difference was between Group 2 (7-16 psu) and Group 4 (>28 psu) (Table 6-5). Based on PCA analysis of data solely from the Alafia, JEI found very similar salinity breaks in the low and medium salinity zones, with Groups identified at < 6 psu and from 6 – 15 psu.

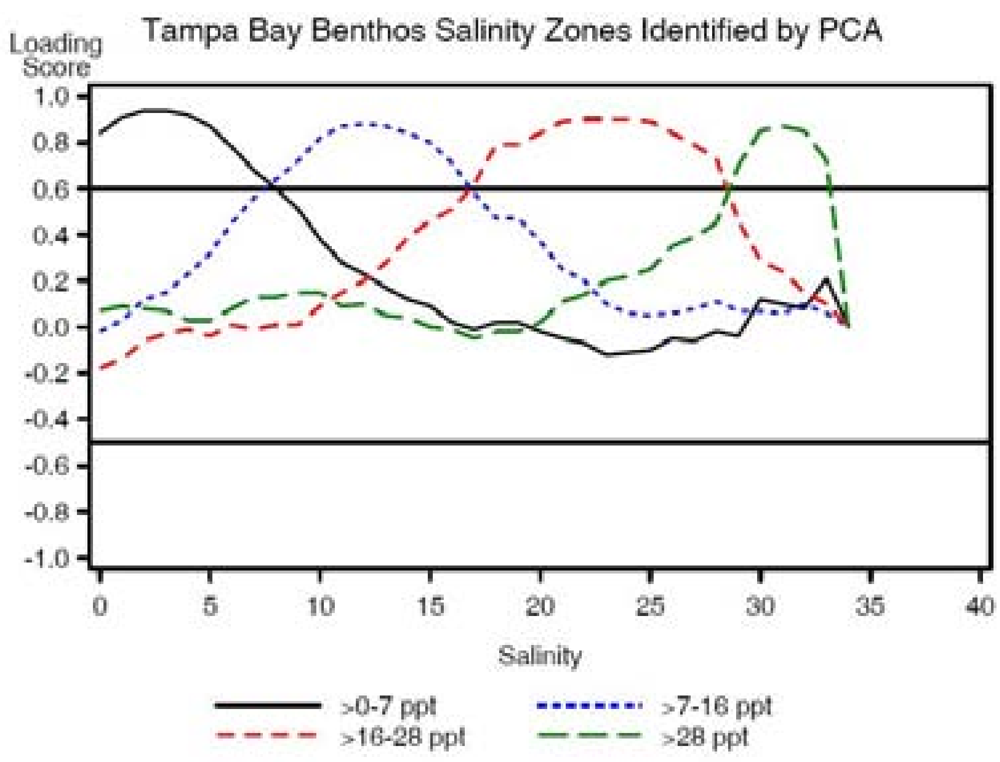


Figure 6-19. Results of a Principal Components Analysis of salinity and presence/absence data for benthic macroinvertebrate infauna taxa in Tampa Bay Rivers sampled by the HBMP program during June 2000 through November 2003.

Table 6-5. Results of ANOSIM comparison of Tampa Bay benthos Salinity PCA zone species compositions.

Salinity PCA Groups	ANOSIM R Statistic	Significance Level %
1, 2	**0.112**	**0.1**
1, 3	**0.192**	**0.1**
1, 4	**0.297**	**0.1**
2, 4	**0.13**	**0.1**
2, 3	**-0.002**	**57.8**
3, 4	**0.003**	**45.3**

The SIMPER analysis suggested that *Laeonereis culveri, Chironomus spp. Mytilopsis Leucophaeata and Grandidierella bonnierodes* were the most representative species of Group 1 (Table 6-6) comprising 50 percent of the overall within group similarity among samples. Species comprising 50 percent of the overall within-group similarity for the remaining groups are also presented in Table 6-6. The results of the SIMPER analysis that identify the principal species that characterized the dissimilarity between the groups are shown in Table 6-7. Generally, *L. culveri and Chironomus spp. c*haracterized the differences in species composition between Group 1 and all other groups.

In summary, both the Mote and HBMP studies have shown distinct longitudinal gradients in the distribution of many of the dominant benthic macroinvertebrate taxa in the Lower Alafia River. Comparison of these results to information on salinity ranges of various invertebrate taxa in the literature and the findings of recent analyses of relationships of macroinvertebrates and salinity from other rivers on the coast of west-central Florida demonstrate that salinity gradients play a major role in the distribution of nearly all species found in the lower river. The composition of the benthic macroinvertebrate community near the mouth of the lower river is more influenced by Tampa Bay, while the faunal communities towards Bell Shoals Road reflect the influence of the freshwater reach of the river. Between these two communities is an abundant tidal river community that supports high numbers of benthic macroinvertebrates, many of which are important fish food organisms.

The results of Principal Components Analysis were used to identify salinity ranges that are important for determining the composition of benthic macroinvertebrate communities in the lower river. As described in Chapter Seven, reductions in areas of salinity zones that are important to the distribution of benthic macroinvertebrates are criteria for establishing minimum flows for the lower river. Changes in areas of these zones that result from a series of reductions in freshwater inflows were simulated using the LAMFE model. These results are presented in Chapter Eight with other analyses that support the proposed minimum flows for the Lower Alafia River.

Table 6-6. Characteristic taxa for each of the PCA salinity groups.

Species	*Group 1*	Contrib %	Cum. %
LAEONEREIS CULVERI	0.44	25.02	25.02
CHIRONOMUS SP	0.29	12.11	37.13
MYTILOPSIS LEUCOPHAEATA	0.25	8.12	45.25
GRANDIDIERELLA BONNIEROIDES	0.29	8.09	53.34
Species	***Group 2***	**Contrib %**	**Cum. %**
STREBLOSPIO GYNOBRANCHIATA	0.39	12.14	12.14
LAEONEREIS CULVERI	0.34	10.26	22.40
GRANDIDIERELLA BONNIEROIDES	0.38	9.57	31.97
STENONINEREIS MARTINI	0.24	7.58	39.55
MYTILOPSIS LEUCOPHAEATA	0.22	4.76	44.31
CYATHURA POLITA	0.25	4.33	48.64
Species	***Group 3***	**Contrib%**	**Cum.%**
STENONINEREIS MARTINI	0.21	11.50	11.50
STREBLOSPIO GYNOBRANCHIATA	0.30	8.94	20.44
PARAPRIONOSPIO PINNATA	0.32	8.66	29.10
AMPELISCA ABDITA	0.28	7.61	36.71
GRANDIDIERELLA BONNIEROIDES	0.27	6.71	43.42
LAEONEREIS CULVERI	0.22	4.85	48.27
Species	***Group 4***	**Contrib%**	**Cum.%**
AMPELISCA ABDITA	0.41	15.46	15.46
PARAPRIONOSPIO PINNATA	0.30	6.76	22.22
STENONINEREIS MARTINI	0.14	5.58	27.81
GLYCINDE SOLITARIA	0.29	5.34	33.15
PINNIXA SP	0.30	5.06	38.21
CYCLASPIS CF VARIANS	0.29	4.49	42.70
MONTICELLINA DORSOBRANCHIALIS	0.29	4.31	47.01

Table 6-7. Results of Simper Analysis identifying taxa that contribute most to the dissimilarity among PCA groups

Average dissimilarity = 91.86

Species	**Group 1**	**Group 2**	**Contrib%**	**Cum.%**
LAEONEREIS CULVERI	0.44	0.34	4.71	4.71
CHIRONOMUS SP	0.29	0.17	3.74	8.45
GRANDIDIERELLA BONNIEROIDES	0.29	0.38	3.49	11.94
STENONINEREIS MARTINI	0.15	0.24	3.46	15.40
STREBLOSPIO GYNOBRANCHIATA	0.15	0.39	3.41	18.81
MYTILOPSIS LEUCOPHAEATA	0.25	0.22	3.40	22.21

Average dissimilarity = 94.75

Species	**Group 1**	**Group 3**	**Contrib%**	**Cum.%**
LAEONEREIS_CULVERI	0.44	0.22	4.59	4.59
STENONINEREIS_MARTINI	0.15	0.21	3.75	8.34
*CHIRONOMUS_SP_*	0.29	0.05	3.29	11.63
GRANDIDIERELLA_BONNIEROIDES	0.29	0.27	3.28	14.90
MYTILOPSIS_LEUCOPHAEATA	0.25	0.13	3.01	17.92
STREBLOSPIO_GYNOBRANCHIATA	0.15	0.30	2.94	20.86

Average dissimilarity = 96.80

Species	**Group 1**	**Group 4**	**Contrib%**	**Cum.%**
LAEONEREIS_CULVERI	0.44	0.12	3.97	3.97
AMPELISCA_ABDITA	0.07	0.41	3.36	7.32
STENONINEREIS_MARTINI	0.15	0.14	3.15	10.47
*CHIRONOMUS_SP_*	0.29	0.0	2.72	13.19
GRANDIDIERELLA_BONNIEROIDES	0.29	0.21	2.55	15.74
MYTILOPSIS_LEUCOPHAEATA	0.25	0.03	2.35	18.09

Average dissimilarity = 92.68

Species	**Group 2**	**Group 4**	**Contrib%**	**Cum.%**
STENONINEREIS_MARTINI	0.24	0.14	3.53	3.53
AMPELISCA_ABDITA	0.27	0.41	3.29	6.82
STREBLOSPIO_GYNOBRANCHIATA	0.39	0.18	2.86	9.68
LAEONEREIS_CULVERI	0.34	0.12	2.61	12.29
GRANDIDIERELLA_BONNIEROIDES	0.38	0.21	2.43	14.72
PARAPRIONOSPIO_PINNATA	0.22	0.3	2.42	17.14

6.4 Mollusk Survey and Analysis

A systematic spatial survey of mollusk populations in the lower river was conducted as part of the Mote Marine project 2001. The mollusk species collected in this survey were also collected by the benthic infauna sampling programs conducted by Mote Marine and the HBMP. However, the sampling design and gear for the mollusk survey was somewhat different and provided useful information for the lower river. A mollusk survey consisting of one set of complete samples along the length of the lower river was performed by Dr. Ernest Estevez of Mote Marine Laboratory between June 18 and July 12, 2001. Samples were collected at cross-river transects located at one-half kilometer intervals from the river mouth to Bell Shoals Road. Observations were also made at oyster reefs, channel markers, and known restoration sites.

Samples were collected from both subtidal and intertidal sites, with the elevation of mean low water separating these two sampling areas. Subtidal samples were collected by petite ponar grabs rather than pipe cores because larger mollusk species are often missed by cores. A sample was comprised of two ponar grabs at a given site. Five such subtidal sites were sampled at each half-kilometer transect. Contents of each sample were concentrated over a 3.0 millimeter sieve. Intertidal samples were usually collected by spade, although ponar grabs were occasionally used during high tides. Both live and dead specimens were collected at each site, with a reasonably intact valve constituting the presence of a dead specimen. A median size was determined for each species in each sample. For data analysis, a mean value of median sizes from all the samples was computed for each species.

Intertidal sampling effort and processing was the same as the subtidal effort, except that hand collections of particular species were sometimes added to the intertidal samples to record the presence of rare or cryptic species. For example, the gastropods *Neritina usnea* and *Littorina irrota* were often found in low numbers near the tops of the shoots of the black needlerush (*Juncus roemerianus*). Oysters and other mussels often grow cryptically behind mangrove roots within crevices of fallen wood. Usually, subtidal areas were visually reconnoitered by snorkeling, and intertidal areas were walked in search of rare occurrences. A complete description of methods for the mollusk survey can be found in Mote Marine Laboratory (2003).

Twenty mollusk taxa were found in the surveys, with eighteen identified to species. Ten species constituted 95 percent of the total specimen counts, with the remaining 10 taxa present only in low numbers or as one individual (Table 6-8). It should be noted the infauna sampling conducted by Mote collected over twice as many mollusk species, but the mollusk survey provided new information by using different gear, by sampling intertidal areas, and being spaced at closer intervals. Similar to both the Mote and HBMP infaunal sampling efforts, *Mytilopsis leucophaeta* was the most numerous mollusk found in the survey.

Table 6-8. Mollusk species collected in transect suveys of the Lower Alafia River conducted by Mote Marine Laboratory (2003), ranked by contribution to the number of total mollusks collected.

Species	**Cumulative percent**
Mytilopsis leucophaeata	36.7
Geukensia demissa granossissima	52.0
Polymesoda caroliniana	66.9
Crassostrea virginica	78.1
Mysella planulata	82.6
Tagelus plebeius	86.5
Neritina usnea	89.1
Corbicula fluminea	91.3
Tellina spp.	93.4
Unidentified bivalve	95.3
Littorina irrorata	97.0
Mulinia lateralis	98.3
Macoma tenta	99.0
Amygdalum papyrium	
Haminoea succinea	
Crepidula fornicata	
Abra aequalis	
Nassarius vibex	
Polinices duplicatus	
unidentified planospiral gastropod	

Mytilopsis is a small mussel with an opportunistic life history. It was found only from kilometers 8 to 11 and near kilometer 15, with live specimens found only at kilometers 9 and 9.5. Despite its narrow range, *Mytilopsis* was numerically dominant in the river because very large numbers of individuals can occur in small clumps. *Corbicula fluminea* was the only mollusk found upstream of kilometer 12, except for two occurrences of dead *Mytilopsis*.

A graph of the distribution of both live and dead shells for the eighteen mollusk taxa identified to species are shown in Figure 6-20. For some taxa, dead shells indicated a wider or more continuous distribution than the live shells. Figure 6-20 demonstrates clear shifts in the occurrence of various species along the length of the lower river, due in part to different salinity tolerances and preferences. Similar to the infauna (Figure 6-18), the mollusk data indicated a transitional point in the river around kilometers 2 to 4, as seven taxa did not extend upstream of kilometer 4, while seven taxa did not extend downstream of kilometer 2. Four taxa extended from the river mouth to roughly between kilometers 6 and 8. The habitats (e.g., subtidal, intertidal, roots, etc.) and river reaches where ten of the dominant taxa were found are discussed by Mote Marine Laboratory (2003).

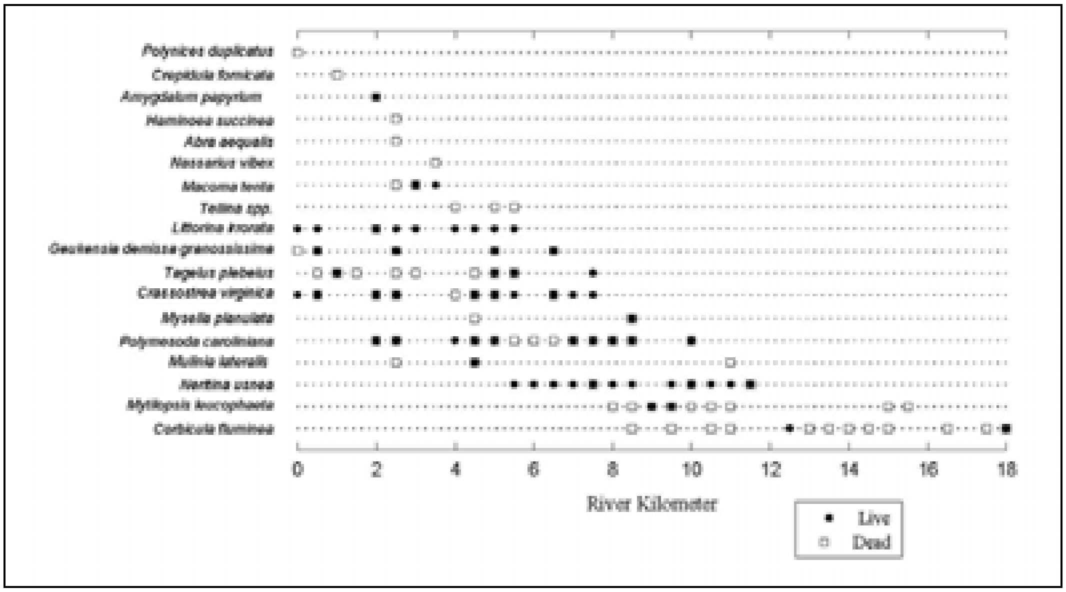


Figure 6-20. Distribution of live and dead mollusks recorded at ½ kilometer intervals by the Mote Marine mollusk survey.

Graphics of species richness and density per river kilometer are presented in the Mote report for both live and dead specimens from subtidal and intertidal samples. Graphics for combined live specimens are presented in this minimum flow report in Figure 6-21. The species richness of live mollusks was highest between kilometers 2 and 9, as this was where there was the greatest overlap of species with different salinity tolerances. The faunal density of live specimens was sporadic, however, with peak densities collected in the lower to mid reaches of the river (kilometers 2 to 7), due to the occurrence of *Geukensia, Polymesoda*, *Crassotrea, Tagelus*, *Neritina*, and *Littorina*. The distribution of dead shells indicated an upstream shift in faunal density due to the presence of numerous dead shells of *Mytilopsis leucophaeta,* which was not present in high numbers in the live counts*.*

6.4.1 Multi-River Mollusk Analysis

Similar mollusk surveys have now been conducted on ten other creek/river systems within the District, including tributaries to Charlotte Harbor, Tampa Bay, and rivers on the Springs Coast. Relationships of the abundance and distribution of mollusks with sediment and water quality variables in seven of these systems were examined in a multivariate, inter-river analysis performed by Dr. Paul Montagna of Texas A&M University (Montagna 2006). That report concluded that mollusks are controlled more by water quality than by sediment characteristics, and salinity was the water quality variable correlated with mollusk community parameters. Although total mollusk abundance is not a good indicator of salinity and freshwater inflow effects, certain indicator species have been identified that characterize salinity ranges in southwest Florida rivers.

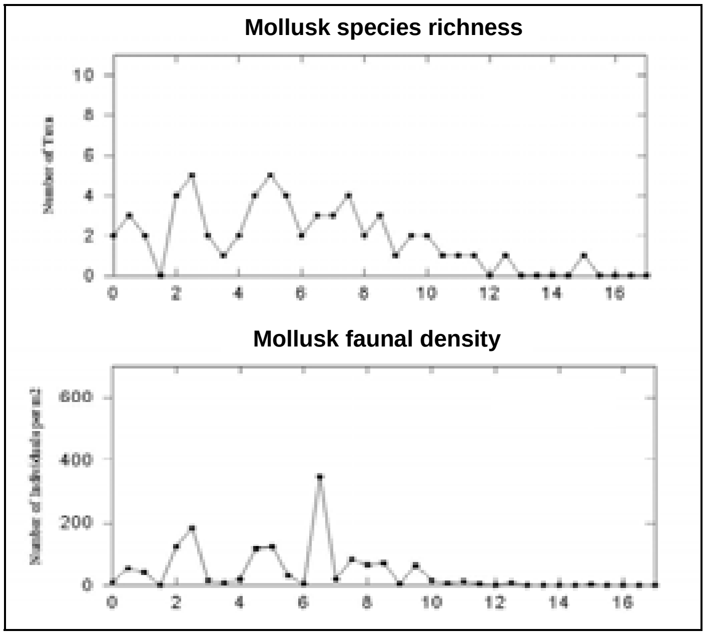


Figure 6-21. Species richness and density of live subtidal and intertidal mollusks collected by Mote Marine mollusk survey

Nonlinear regression analysis was used to predict mollusk community parameters and the abundance of certain mollusk species as a function of salinity. Predicted curves of species abundance as a function of salinity are shown for four species common to the Lower Alafia River in Figure 6-22. Though these regressions were strongly influenced by data from other rivers, they demonstrate that the abundance of these species show clear trends in relation to salinity. *Polymesoda caroliniana* and *Tagelua plebius* show a preference for low salinity waters, with peak abundances predicted in the range of about 5 to 8 psu, respectively. *Neritina usnea* is most abundant below 10 psu. Though this finding is heavily influenced by data from the Peace River, observations from the Alafia range between 4 to 10 psu. The eastern oyster *Crassostrea virginica* is found in higher salinity waters near the mouths of the tidal rivers. The distribution of oysters in the Lower Alafia River is discussed in more detail in the following section.

The collective findings of both the Alafia mollusk survey and the inter-river mollusk analysis demonstrate that salinity is a dominant factor controlling the distribution of mollusk species in the lower river. As described earlier for benthic infauna and discussed in Chapters 7 and 8, the area of bottom salinity zones less than 1, 6, and 15 psu were simulated with the LAMFE model to examine the effect of reducing freshwater inflows on salinity ranges that are suitable for benthic invertebrates. The selection of the 6 and 15 psu salinity zones were based on a Principal Components Analysis of benthic infauna data, which included mollusk species. Though a similar PCA analysis was not conducted for data collected by the mollusk surveys, the statistical modeling presented in

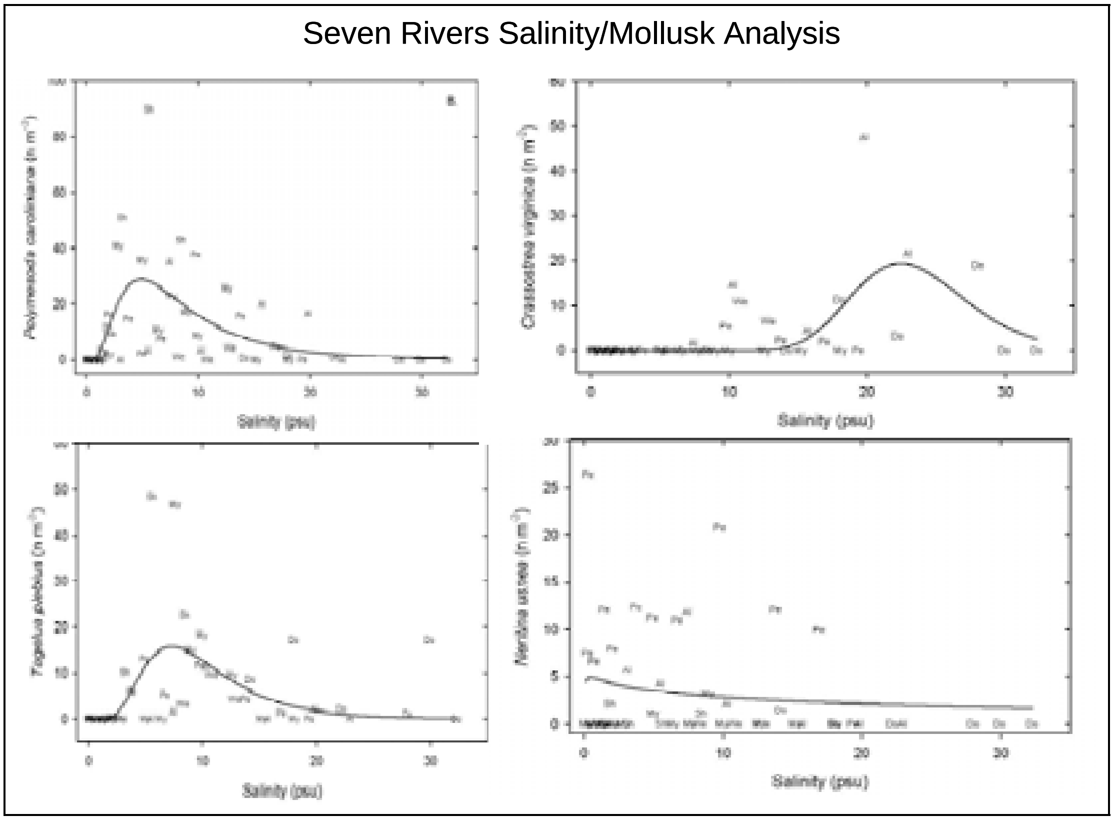


Figure 6-22. Density of four mollusk species vs. mean salinity at sampling locations in seven rivers in west-central Florida, adapted from Montagna (2006). Symbol Al = observation from Lower Alafia River.

the inter-river mollusk report (Montagna 2006), indicates these would be suitable salinity zones to simulate for potential impacts to mollusk distributions. Simulations of changes in the areas of these salinity zones as a function of changes in freshwater inflow are presented in Chapter 8.

6.5 Oyster reefs

The eastern oyster *Crassotrea virginica* was given special consideration among the mollusks in the minimum flows project because of the important roles that oysters can play in the habitat structure and biological productivity of estuaries. A review of the life history and ecological relationships of the eastern oyster was prepared for the District by the Florida Gulf Coast University (Volety and Tolley, 2005). Although oysters are not harvested for human consumption from the Alafia, oysters provide important ecological benefits to estuarine ecosystems including the Alafia by filtering large amounts of water and improving water quality, incorporating energy into benthic food webs, creating structurally complex reefs which harbor large amounts of associated benthic fauna, and providing important fish habitat (Volety and Tolley 2005). Lenihan and Peterson (1998) thus concluded that loss of oysters and oyster reef habitat may have important negative consequences for the sustainability, economic value, and biodiversity of estuarine ecosystems. Potential impacts to oysters have been employed in assessments of the inflow needs of estuaries in Texas (Longley, 1994) and the Apalachicola Bay (Wilber 1992) and were evaluated for the minimum flows assessment of the Lower Alafia River.

As part of their project with the District, Mote Marine Laboratory mapped the distribution of oyster reefs in the Lower Alafia River (Mote Marine Lab 2003). A spatially continuous mapping survey was conducted from the river mouth to the upstream extent of oysters in the river. Oyster reefs occurred between kilometers 1 and 4, with most oysters collected intertidally (Figure 6-23). Most reefs were associated with vegetated wetland systems with the largest reefs on the south shore of the river. Oyster samples were taken from representative sites and areas where the species occurred in large numbers. At each site, 20-30 of the largest individuals were returned to the boat and arranged by size. The largest 15 were then measured to the nearest millimeter. The greatest values of mean oyster height were found between kilometers 2 and 3 (Figure 6-24), with the largest oysters occurring on the largest reefs. The means salinity of this reach of the river was reported by Mote as approximately 19 to 20 psu, with a standard deviation of about 8 to 9 psu.

The findings of the Mote study and salinity data for the lower river were provided to the FGCU faculty who prepared a second report for the District that assessed potential effects of freshwater inflow alteration on oysters in the Lower Alafia (Volety and Tolley 2006). They concluded that while overall salinities are very conducive to the long-term development and growth of oyster reefs in the lower river, high flows that exceed 2000-3000 cfs for periods of greater than two weeks that reduce salinities in the oyster zone to less than 5 psu do occur. Persistence of these low salinities for extended periods would affect the viability of oyster populations. Also, while it appears that low flows are not presently a significant factor affecting oyster populations in the river, and though persistence of salinities of greater than 28 psu for one to two months may not cause significant harm to oysters, prolonged persistence of such high salinity conditions could allow predators such as oyster drills, whelks, star fish, boring sponges, and diseases such as Dermo (caused by *Perkinsus marinus*).

Based on these findings, Volety and Tolley (2006) suggested that salinities between river kilometers 1 and 4 be largely maintained between 12-25 psu, limiting periods of high (>28 psu) salinities to less than one month and low salinities (< 5 psu) to less than two weeks to ensure survival and growth of oyster reefs in the Lower Alafia River. However, since the Alafia is an unimpounded river, variations in salinity approaching or exceeding these recommendations can periodically occur due to unusual hydrologic events such as droughts or floods. Nevertheless, excessive freshwater withdrawals could potentially cause problems with prolonged high salinity. Simulations of potential changes in salinity in the oyster zone of the river that could result from reductions in freshwater inflows are presented in Chapter Eight.

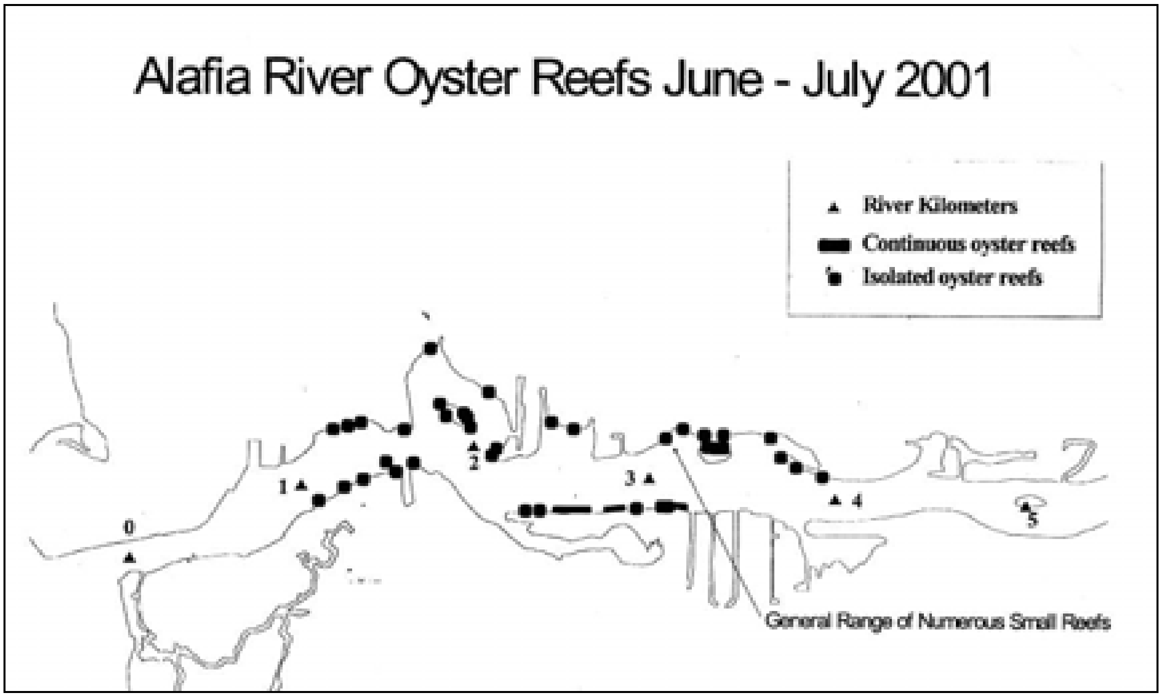


Figure 6-23. Distribution of oyster reefs in the Lower Alafia River.

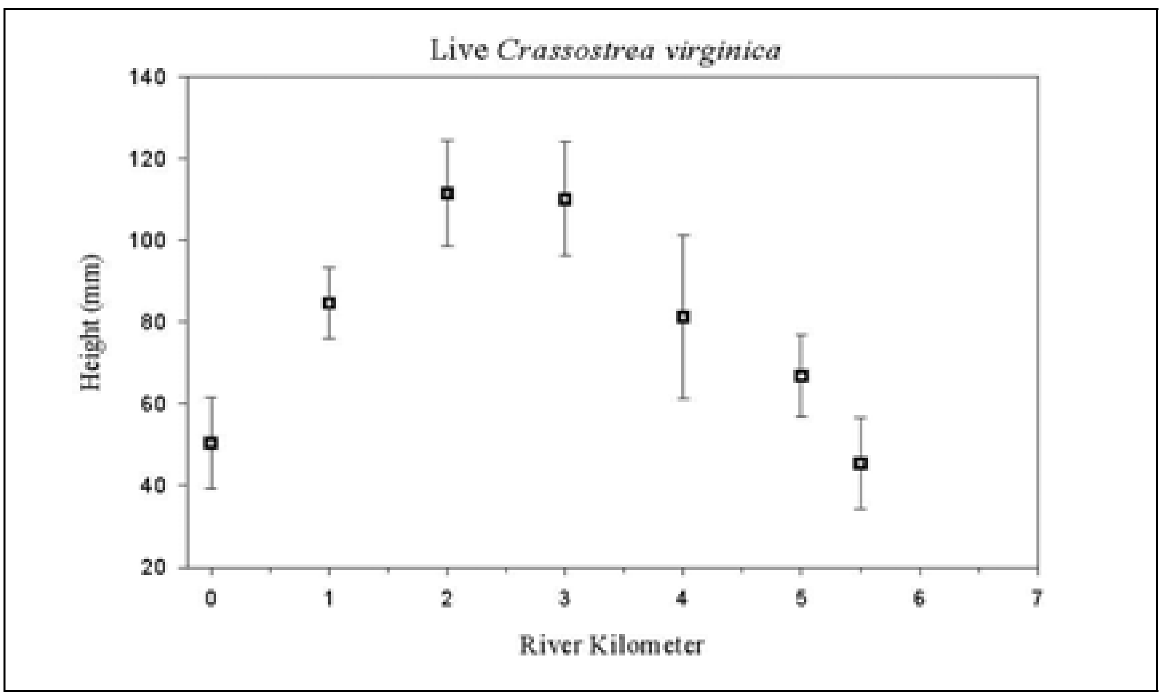


Figure 6-24. Mean height (+ s.d.) of largest living oysters recorded in reefs in the lower river.

6.6 Zooplankton and Fishes

Extensive data sets for zooplankton and fishes have been collected from the Lower Alafia River. These data sets provide information on the different fish communities that inhabit the lower river and how the river functions as nursery zone for certain fish and shellfish species that inhabit the Gulf of Mexico and Tampa Bay. As described in Sections 6.1 and Section 7.6.5 of this report, the Lower Alafia River serves as a nursery area for the early life stages of several species that comprise economically important sport and commercial fisheries in the Tampa Bay region. Equally important, the lower river serves as productive habitat for many other fishes and invertebrates that serve as prey for these species of economic importance.

Two ongoing data collection efforts for zooplankton, fishes, and invertebrate nekton (e.g. blue crabs, pink shrimp) have been conducted in the Lower Alafia River since the 1990s. These data collection efforts have been conducted by staff from the University of South Florida College of Marine Science (USF) and the Florida Wildlife Research Institute (FWRI) of the Florida Fish and Wildlife Conservation Commission. Both USF and FWRI prepared interpretive reports of their findings in support of the District's minimum flows project for the lower river (Peebles 2002a, 2005; Matheson et al. 2005). Since the spring of 2000, these data collection programs have continued as part of the HBMP and findings have been reported in HBMP reports prepared by consultants for Tampa Bay Water (2003, 2006). Data from the fish and zooplankton projects have also been analyzed in reports for Tampa Water (Janicki Environmental 2004a) and the Tampa Bay Estuary and Gulf of Mexico programs (Janicki Environmental 2004b).

Basic findings presented in these reports are summarized below, with emphasis on the two most recent reports prepared for the minimum flows project (Peebles 2005, Matheson et al. 2005). Statistical models presented in these two reports are further described in Chapter 7 and applied in Chapter Eight to examine the effects of potential reductions in freshwater inflows on the abundance and distribution of fish and zooplankton indicator species in the Lower Alafia River.

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

Both the USF (Peebles 2005) and the FWRI reports (Matheson et al. 2005) describe three types of fish species that inhabit tidal rivers based on their life histories: 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, as 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 in the Lower Alafia are 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, but they serve as important forage for wading birds and estuarine dependent fishes.

Estuarine dependent species are the focus of many freshwater inflow assessments because this group includes many fishfish and shellfish species of sport or commercial importance in coastal areas (e.g, mullet, snook, red drum, spotted seatrout, pink shrimp, blue crab). These species typically spend a portion of their early life cycle in the estuary, with a later return to higher salinity coastal waters as they mature. Peebles (2005) 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 Tampa Bay). 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 first captured in seine or trawl catches.

Several other ichthyoplankton and seine/trawl studies similar to those conducted in the Alafia have now been conducted in other tidal rivers in southwest Florida (Peebles and Flannery 1992, Peebles 2002b, 2002c, 2004; Greenwood et al. 2004, MacDonald et al. 2005, Peebles et al. 2006). These studies have consistently shown a migration of many estuarine dependent fish species into low salinity habitats as they grow from larval to juvenile stages. Based on data from ichthyoplankton nets, the decreasing salinity at capture with age is shown in Figure 6-25. This generally results in an up river migration with the concentration of juveniles often well within the tidal river. For example, on the Alafia the mean location of the bay anchovy 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. As described by Peebles (2005), the diets of the young fishes change as they mature from larval to juvenile stages, generally switching from zooplankton prey in higher salinity waters to larger benthic invertebrate prey in upstream, low salinity depositional areas.

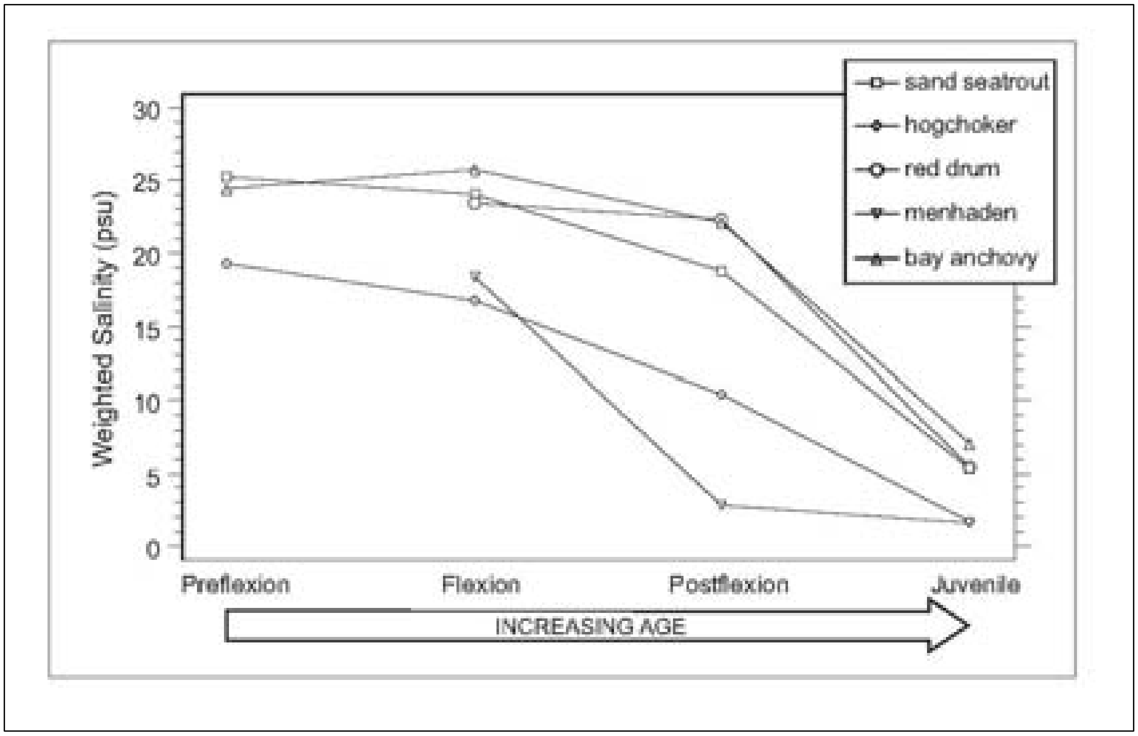


Figure 6-25. Example of declining mean salinity at capture with increasing age in plankton samples from the Little Manatee River (redrawn from Peebles and Flannery 1992).

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 essentially featureless bottom habitat in the upper reaches of estuaries, apparently taking advantage of depositional areas with fine grained sediments which 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 (2005) 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 rivers and creeks. 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.

6.6.2 Zooplankton and Early Life Stages of Fishes Sampled by USF Plankton Surveys

Since June 1998, USF has conducted plankton tows in the Lower Alafia River to capture the early life stages of fishes and many invertebrate species that occur in the water column. Initial sampling for the project that was funded by the District began in June 1998 and continued for 17 months (Peebles 2002a). Monthly sampling was resumed as part of the HBMP in April 2000 and continues to the present. The data analyzed for the minimum flows project is presented in a second report by Peebles (2005), which includes data from 62 monthly collections ending in December 2003. More limited analyses of plankton data collected for the HBMP through September 2005 can be found in the most recent interpretive report for the HBMP (PBS&J 2006).

The sampling zones for the District and HBMP studies varied only slightly, with oblique plankton tows collected in six segments of the lower river for each study. These sampling zones extended from near the mouth of the river to above kilometer 13 (Figure 6-26). Two samples were collected end to end in each zone, comprising a very extensive spatial coverage that spanned all or nearly all of the river's estuarine salinity gradient on most occasions (extreme dry conditions an exception). The sampling gear consisted of a conical plankton net with a ½ meter diameter mouth and 500 micron mesh, which is the same as the 0.5 mm sieve mesh to process benthic invertebrates by Mote Marine and the HBMP. The tow durations were five minutes with the tow times divided equally among bottom, mid-water and surface depths. The resulting tow lengths were about 400 meters with a total volume of water filtered of about 70-80 cubic meters.

All aquatic taxa (both vertebrate and invertebrate) collected by the plankton net were identified and counted, except for 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 may mesozooplankton (0.2 to 20 mm), macrozooplankton/micronekton (> 20 mm), and analogous sized hyperbenthos, which are animals associated with the river bottom that tend to suspend above it, rising higher into the water column at night or during certain times of year. The fish fauna that were collected included the planktonic eggs and larvae of fishes (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 (2002a, 2005).

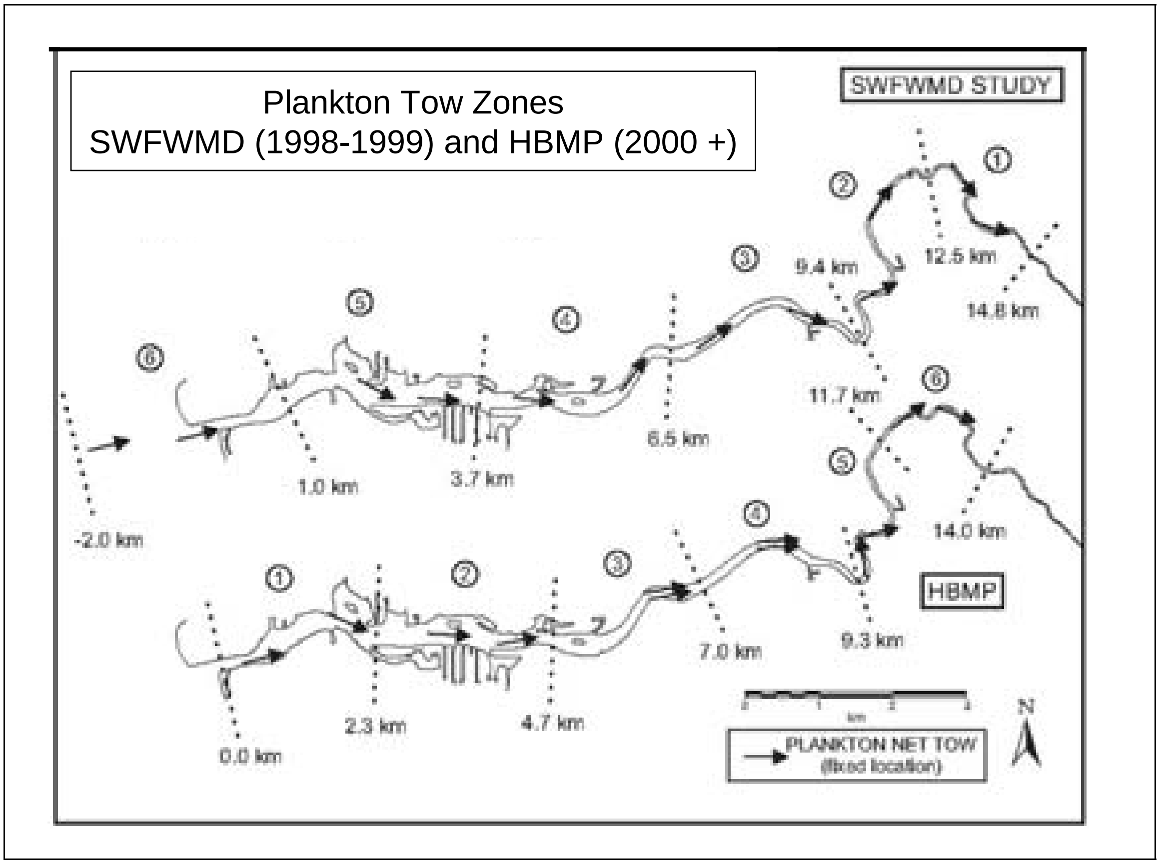


Figure 6-26. Location of sampling zones for ichthyoplankton/zooplankton tows collected during the studies sponsored by the District (SWFWMD) and the HBMP.

6.6.3 Plankton Catch Composition

Detailed catch statistics (abundance, frequency of occurrence) are provided by Peebles (2005) for all vertebrate and invertebrate taxa collected by the plankton surveys. The bay anchovy (*Anchoa mitchilli*) was the numerically dominant fish in the plankton catch, a pattern which has been observed in other rivers in the region (Peebles 2002b, 2002c 2004, Peebles et al. 2006). Late larval and metamorphic menhaden (primarily *Brevoortia smithii*) were also abundant, particularly during the relatively wet District survey in 1998 and 1999. Other abundant fishes were the sand seatrout (*Cynoscion arenarius*), hogchoker (*Trinectes maculatus*), silversides (*Menidia* sp.), skilletfish (*Gobiesox strumosus*) and gobies (primarily Gobiosoma spp. and Microgobious spp.) As a group, the gobies were second only to the bay anchovy in abundance.

The invertebrate catch was dominated by larval crabs, chaetognaths, calanoid copepods, gammaridean amphipods, mysid shrimp, isopods, cumaceans, and polychaetes. Peebles (2005) suggests that gammaridean amphipods were abundant, but not to the extent observed in other rivers, and were noticeably less abundant in the upstream areas, probably due to a lack of wetlands there. The results for benthic macroinvertebrates presented in this report also indicates that changes to a coarse substrate and periodic hypoxia in upper river areas may also be a factor, as gammaridean amphipods were abundant in lower and mid-river zones. The mysid assemblage within the interior of the tidal river was dominated by *Americamysis almyra*, while *A. stucki* was more prevalent in high salinity areas near the river mouth.

6.6.4 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. The bay anchovy probably spawns near or within the mouth of the Alafia River on occasion, but most of the juveniles that congregate within the tidal river probably originate from eggs spawned in nearby Hillsborough Bay or Middle Tampa Bay (Peebles et al. 1996). Sciaenid eggs that could not be readily identified from the plankton tows using visible characteristics could have belonged to several species, as the early larvae of three sciaenid species were spatially and temporally coincident with the eggs. Likely species include the silver perch (*Bairidiella chrysoura*), spotted seatrout (*Cynoscion nebulosus*) and sand seatrout (*Cynoscion areanarius*).

For species with such non-planktonic eggs, early larval stages are usually the first developmental stage to be present in the water column. This is true for many of the estuarine-resident fishes including silversides (*Menidia* sp.), gobies, blennies, and skillettfish. Many killifishes (*Fundulus* sp.) also are estuarine resident species that spawn within tidal rivers, with adhesive eggs that hatch at a relatively advanced larval stage. The presence of postfexion-stage killifishes in the plankton catch was therefore evidence of spawning near or within the lower river. Small juveniles of live-bearing species such as the eastern mosquitofish (*Gambusia holbrooki*), salifin molly (*Poecilia latiipinna*), chain pipefish (*Syngnathus louisianae*) and gulf pipefish (*S. scovelli*) indicate that the tidal river is serving as habitat for the earliest stages of these species.

6.6.5 Seasonality in Plankton Species Richness

The number of taxa present in the plankton catch increased markedly during spring and then decreased during fall, being generally highest from March through September. This pattern was observed for both fishes and invertebrates, except the trends in the invertebrate data were not as pronounced as those in the fish data (Figure 6-25). Seasonality was species specific. Some species, such as the bay anchovy, are present year-round. Others present a seasonal succession in their individual abundance peaks, specifically: menhaden, pinfish, spot and black drum (winter through early spring): sand seatrout, spotted seatrout, kingfishes, hogchoker, and crab and shrimp larvae (spring and summer); and red drum (fall). Red drum recruitment to the lower river is primarily evident in the seine catch (Matheson et al. 2005), since this species arrives in the

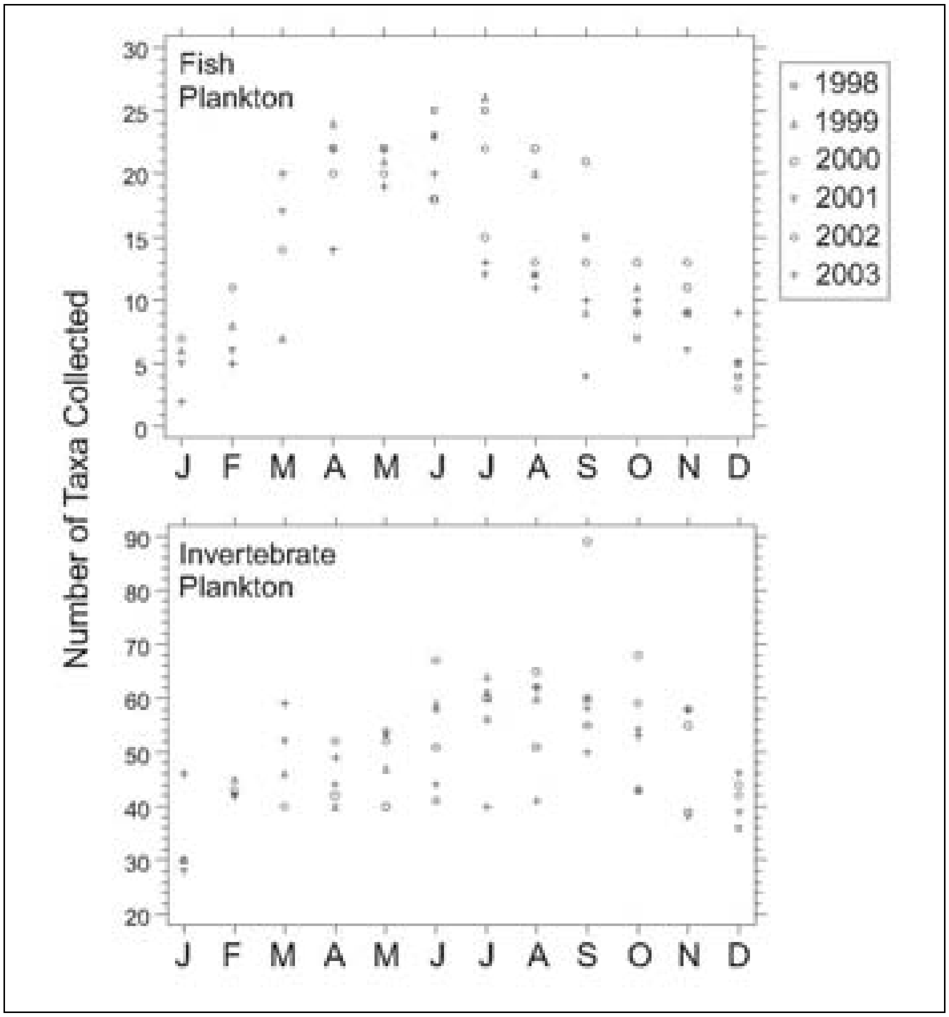


Figure 6-27. Number of fish and invertebrate taxa collected per month in plankton tows from the Lower Alafia River for 1998 – 2003.

river as juveniles rather than larvae. Although the season for the greatest potential impacts to early life stages from freshwater withdrawals could be the spring, due to the naturally low flows and increases in recruitment to the river, Peebles (2005) concluded there is no time of year when freshwater inflow management is free from potential impacts to the nursery function of the lower river.

6.6.6 Distribution Responses to Freshwater Inflow

Peebles (2005) summarizes a review by Young (1995) that discusses various 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. Truly planktonic animals appear to be the least adept at controlling their position, and are easily transported by prevailing water currents. Other animals may show migrational responses to a 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 changes in water depth of tide height.

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. Organisms that use selective tidal stream 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 6-25 likely result from these fishes gaining stronger swimming ability as they progress from larval to juvenile stages.

Peebles (2005) examined relationships between the distribution of fish and invertebrate species captured in the plankton tows and freshwater inflow. Significant responses were found for over 70 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 62 plankton surveys. All significant relationships had negative slopes, indicating the organisms moved downstream as freshwater inflow increases. Strong responses were evident among relatively strong swimmers, such as juvenile menhaden, and sometimes among relatively weak swimmers, such as the isopod *Edotea triloba*.

Example plots of the regressions of distribution with inflow are plotted in Figure 6-28. Taxa with very high intercepts (upstream location at zero flow) tend to be freshwater taxa, whereas taxa with low intercepts tend to be bay species that invade the tidal river during low inflow periods. Taxa with medium to high intercepts tend to be estuarine-resident or estuarine-dependent taxa whose distributions fluctuate over the middle portion of the lower river.

Various lengths of days of preceding flows terms were examined to produce regressions that produced the best fit to the observed data. This approach provided an indication of the temporal responsiveness of the various taxa to inflow variations. The distributions of most taxa responded quickly to changes in inflow, with preceding flow terms of < 5 days being most common. After classifying the taxa according to vertical position of their habitat, it was found that planktonic and vertically migrating animals responded faster than animals that spend most of their time at or near the bottom. The locations of the mysid *Americamysis almyra* and bay anchovy juveniles tracked each other better than either one tracked freshwater inflow, suggesting that other processes may interact to modify the distribution relationship with inflow.

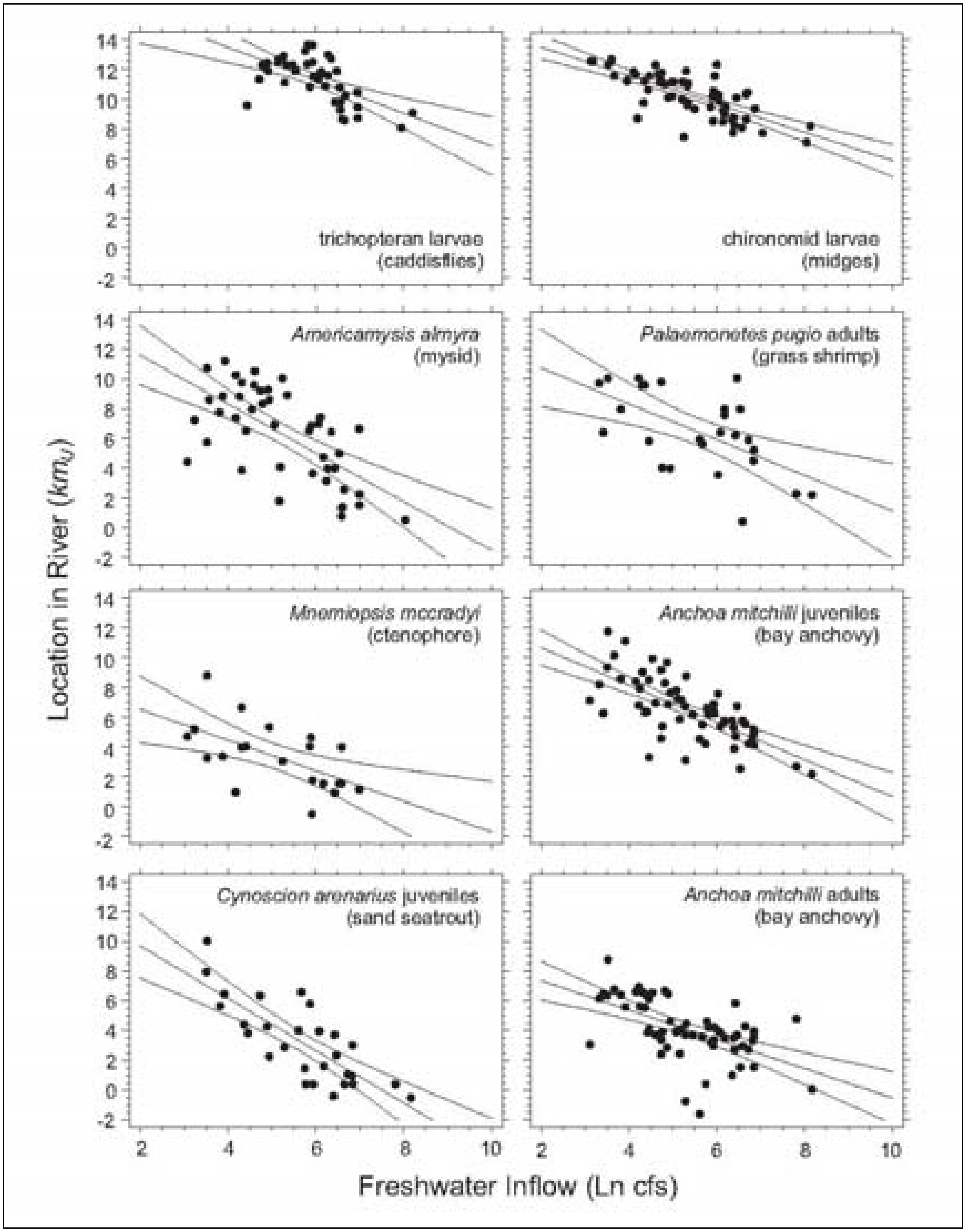


Figure 6-28. Relationships of location of center of catch per unit effort vs. freshwater inflow for eight fish and invertebrate taxa in the Lower Alafia River (reprinted from Peebles 2005).

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 3-5 and 3-8). The upstream movement of a population due to large inflow reductions could therefore compress that population into smaller regions of the tidal river with less habitat area and volume. As described in Chapter 7, shifts in Km_U were used as an ecological indicator in the determination of minimum flows for the Lower Alafia River. Shifts in Km_U with corresponding reductions in river area and volume are presented in Chapter 8 for a series of potential minimum scenarios.

6.6.7 Abundance responses to inflow

Peebles also evaluated the response of the abundance of species captured in the plankton catch to freshwater inflow. The density of catch in the plankton tows for various species was extrapolated to the volume of the tidal river. 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 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 (2005). 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 Lower Alafia 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. Peebles 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 Alafia River catch data appear to be genuine positive responses of animal abundance to freshwater inflow.

Peebles presented significant regressions for the abundance of different species/age classes as a function of freshwater inflow (separate age classes were evaluated in some cases). The Durbin-Watson statistic was generated that identified where serial correlation in the regressions was possible. However, plots of residuals vs. order generally revealed no actual serial correlation. The potential for resampling the same organisms on successive monthly surveys was discussed by Peebles, who described factors that diminish this occurrence. Peebles suggested that indications of serial correlation probably reflected successive months that had similar influences on abundance due to similar rates of inflow.

Both positive and negative slopes and a large range of intercepts were found in the abundance responses to inflow (Table 3.7.1 in Peebles 2005). 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. The organisms move away from the river during high inflow periods, giving them a negative correlation with flow.

There was often a general increase in total numbers of the estuarine-dependent and estuarine-resident species when inflows were elevated. These increases did not appear to be due to individuals moving into the survey area from an upstream area. Peebles discusses how the value of the slope term in the regressions reflects how the organisms respond to ranges of inflow. Organisms that have positive slopes between 0 and 1 undergo proportionately large increases in number as low inflows increase, although the abundance increase becomes more constant for organisms with slopes near 1. Many of the estuarine-dependent and estuarine-resident species fall within this category, making the protection of low inflows particularly important.

Peebles identified five species/age classes that could be used as indicator organisms to assess potential negative impacts from freshwater inflow reductions. These were non-freshwater organisms which had a positive response to inflow, which was a true abundance response rather than a catchability response or sampling artifact. Five species/age classes were suggested. Mysid shrimp, which are critically important prey for juvenile stages of estuarine depending fishes, were simulated for both adult and juvenile sizes. Sand seatrout (*Cynoscion areanarius*) is a biomass dominant in Gulf Coast estuaries. Grass shrimp (*Palaemonetes pugio*) are abundant within the Alafia River and are important prey for young estuarine-dependent fishes. The bay anchovy (*Anchoa mitchilli*) is a biomass dominant fish in estuaries throughout the southeastern U.S. and is important for food webs and trophic transfer of energy in estuarine systems. Regressions of the abundance of these species with freshwater inflow are reprinted from Peebles (2005) in Figure 6-29.

For three of these species/age classes (bay anchovy juveniles, adults and juveniles of mysid shrimp), Peebles found that the positive response to inflow did not hold during extremely high inflows when these organisms tended to move out of the lower river (wash-out). Wash-out events appeared to be caused by unknown combinations of inflow magnitude and duration that are difficult to quantify in preceding flow terms. A low inflow occurring near the end of a washout cycle is associated with different conditions than the same level of inflow at the start of a washout cycle. Since salinity integrates the inflow history, the location of the interpolated 7 psu surface isohaline observed during the plankton survey was chosen as the indicator of inflow history. Dates when the 7 psu isohaline was downstream of 2 km were excluded from the abundance regressions, which resulted in removal of 29 percent of the dates. The 2 km threshold generally coincided with what appeared to be likely washout events in the flow hydrograph. The scatter plots for *Americamysis adults* and juveniles and *Anchoa mitchilli* in Figure 6-29 are for the non-washout dates.

Another important species related to the management of inflows to river involved a negative relationship with flow. The ctenophore, *Mnemiposis mccradyi*, is a gelatinous comb-jelly animal that is a voracious predator on zooplankton and larval fish and blooms of *Mnemiopsis* or other gelatinous predators can reduce total numbers of zooplankton and larval and early juvenile fish (Larson 1987, Purecell 1985, Purcell and Arai 2001). Data from the Lower Alafia and other rivers have shown that *Mnemiopsis* and other gelatinous predators are most abundant during low flow conditions (Peebles 2005, MacDonald et al. 2005). A significant regression with a negative slope was established between *Mnemiopsis* abundance and inflow in the Lower Alafia. Large reductions of

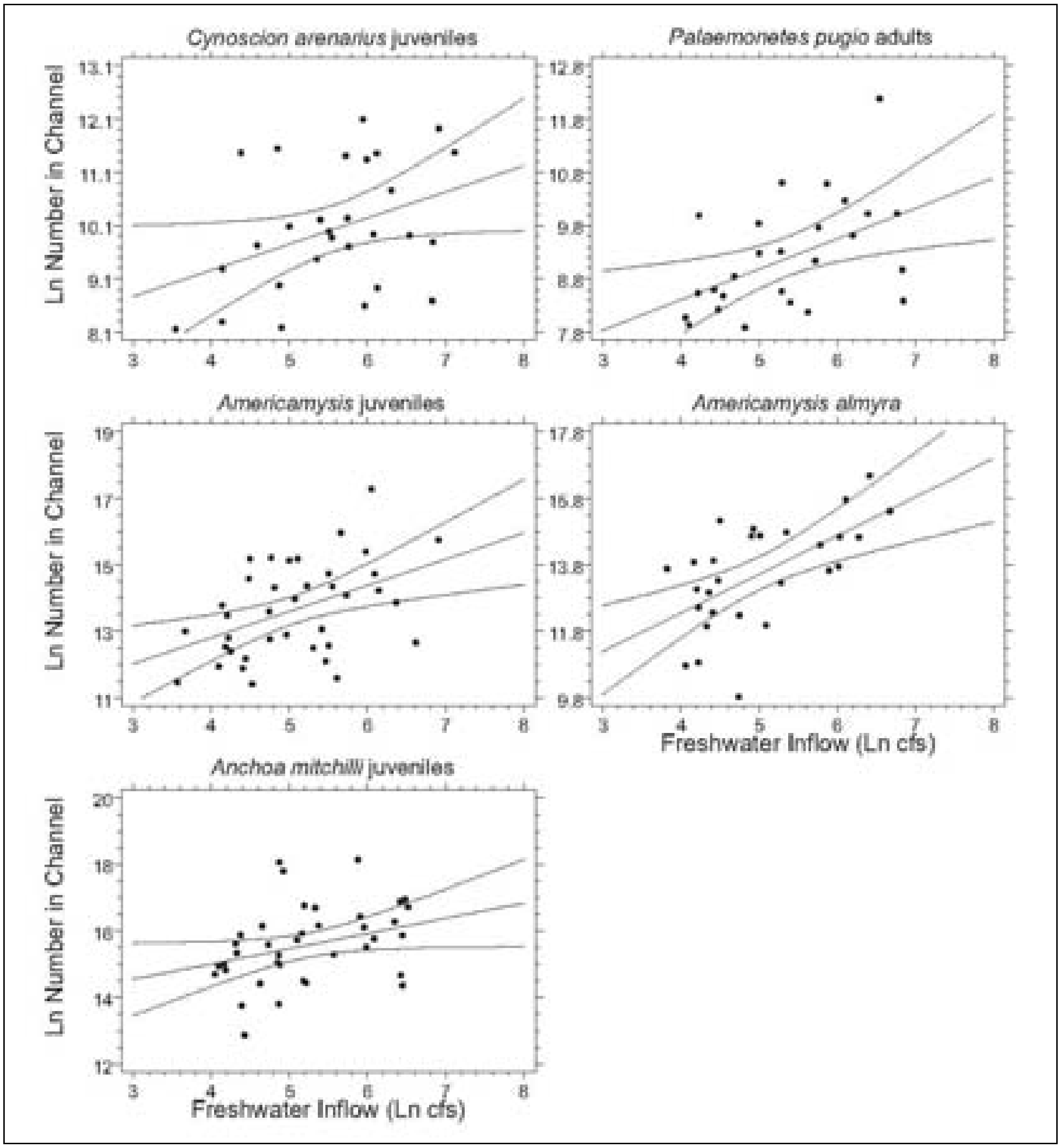


Figure 6-29. Relationship of total abundance in the river channel vs. freshwater inflow for five indicator species/age classes in plankton samples in the Lower Alafia River (reprinted from Peebles 2005).

inflows could potentially increase the frequency of occurrence and abundance of *Mnemiopsis mccradyi* in the Lower Alafia River. Using the regressions presented by Peebles, changes in the abundance of the five indicator species described above and *Mnemiopsis mccradyi* are simulated in Chapter 8 for baseline flows and a series of freshwater inflow reductions. These results are then used in the determination of the proposed minimum flows for the Lower Alafia River.

6.6.8 Fishes and Selected Macroinvertebrates in Seine and Trawl Surveys

A companion effort to the plankton project conducted by USF was a study of larger fishes and selected macroinvertebrates collected by seines and trawls in the lower river. This data collection and analysis program was conducted by the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute. An analysis of data collected by the project between 1996 and 2003 is presented in a report prepared for the District's minimum flow project by staff from the FWRI (Matheson et al. 2005). FWRI has continued seine and trawl sampling regime in the lower river as part of the HBMP, with data analysis conducted by consultants for Tampa Bay Water presented in periodic reports for the HBMP (PBS&J 2003, 2006).

Similar to the USF plankton study, the bulk of the seine and trawl sampling was conducted by two sequential studies sponsored by the District and the Tampa Bay Water HBMP. These data sets were supplemented with data from more spatially limited sampling programs conducted for the FWRI Fisheries Independent Monitoring Program between 1996 and 2003 and a study of red drum between 2000 and 2003 that captured other species as well. The time periods and sampling zones for the District and HBMP studies corresponded with the plankton sampling. The lower river was divided into six zones, with the boundaries differing slightly between the District and HBMP studies (Figure 6-25). Sampling was conducted monthly with two seines and one trawl collected from each zone each month. Trawling could not be carried out in the upstream segment of the study area, so an additional seine haul was carried out in each of the two upstream segments each month and an additional trawl was collected out in one of the downstream zones of the HBMD study. These combined sampling efforts for this project resulted in a large data base for the river – the FWRI report based on data through 2003 had information from 1,246 seine hauls and 467 trawls.

Seine hauls utilized a 21.3 meter bag seine with a 3.2 mm stretched mesh. Each haul sampled an area approximately 68 meters square. Trawl collections were made with a 6.1 meter otter trawl with a 38 mm stretched mesh and a 3.2 mm mesh liner. The trawl was deployed for five minutes at an average speed of 0.6 ms^{-1}, producing typical tow lengths of 180 meters covering about 720 square meters. 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:

1) To assess the composition of the nekton (finfish and selected macroinvertebrates) community from 1996 – 2003.

2) To examine habitat use for selected species of economic or ecological importance.

3) To analyze movement and relative abundance of nekton populations in relation to the quantity of preceding freshwater inflow.

4) To assess the relation between freshwater inflow and the nekton community composition.

Brief summaries of the findings for each of these objectives are presented below. Thirty-seven species were selected for detailed analysis, based on high abundance and recreational or commercial importance. Information on life histories of seventeen of these species was also presented. Quantitative relationships of freshwater inflows with the distribution and abundance of 66 different species/size classes were evaluated for the lower river.

6.6.9 Composition of the Seine and Trawl Catch

A total of 1,221,587 animals representing 124 taxa were collected nearshore in 1,211 seine hauls. The twenty-five most abundance taxa collected by seine are ranked by abundance in Table 6-9. The bay anchovy (*Anchoa mitchilli*) was by far the most abundant species collected, comprising 70.4 percent of the total catch. The third ranked species, the grass shrimp *Palaemonetes pugio*, was the most abundant invertebrate taxon collected. The ten most abundant taxa in Table 6-9 comprised 93.2 percent of the total catch. The silversides (*Menidia* spp.) was the second most abundant taxon, but was the most frequently collected, being present in over 80 percent of all samples.

A total of 85,236 animals from 87 taxa were collected in the river channel in 458 trawl hauls. The twenty-five most abundance taxa collected by trawl are listed in Table 6-10, ranked by abundance. Bay anchovies were again the most abundant species, comprising 64.8 percent of the total catch. The third ranked taxon, the blue crab *Callinectes sapidus*, was the most abundant invertebrate, and overall the most frequently occurring species among all taxa, being present in nearly 58 percent of all samples. The ten most abundant taxa collected by trawl comprised 96 percent of the total catch.

As discussed later in Section 6.6.12, the reported abundances for juvenile red drum in both seine and trawl samples reported by Matheson et al. (2005) were supplemented by hatchery reared fish during 200-2003. Subsequent genetics testing has allowed the differentiation of hatchery vs. wild fish, but these results are not reflected in Tables 6-9 or 6-10.

Table 6-9. Top forty most abundant fish and invertebrate nekton taxa collected during seine sampling in the nearshore habitat of the Lower Alafia River from 1996 – 2003 between kilometers 0 and 14.

Scientific Name	Common Name	Number	Percent occurrence	CPUE (No. 100 m^{-2})	
				Mean	Stderr
Anchoa mitchilli	Bay anchovy	860,290	58.4	1,044.7	236.6
Menidia spp.	Silversides	126,415	80.5	153.5	10.7
Palaemonetes pugio	Daggerblade grass shrimp	46,319	18.7	56.3	12.7
Leiostomus xanthurus	Spot	34,006	21.1	41.3	6.8
Eucinostomus spp.	Mojarra	18,448	38.6	22.4	3.2
Lagodon rhomboides	Pinfish	13,058	30.6	15.9	2.6
Lucania parva	Rainwater killifish	10,871	30.9	13.2	2.4
Brevoortia spp.	Menhaden	10,259	6.0	12.5	3.9
Fundulus majalis	Striped killifish	9,535	21.1	11.6	1.7
Mugil cephalus	Striped mullet	9,476	14.5	11.5	3.1
Bairdiella chrysoura	Silver perch	7,290	9.9	8.8	3.7
Anchoa hepsetus	Striped anchovy	6,792	10.7	8.3	3.4
Eucinostomus harengulus	Tidewater mojarra	6,766	45.2	8.2	0.9
Trinectes maculatus	Hogchoker	6,120	49.0	7.4	0.8
Sciaenops ocellatus	Red drum	6,030	31.9	7.3	1.0
Harengula jaguana	Scaled sardine	6,015	6.8	7.3	1.8
Fundulus grandis	Gulf killifish	3,476	25.4	4.2	0.4
Floridichthys carpio	Goldspotted killifish	3,300	15.5	4.0	0.8
Arius felis	Hardhead catfish	2,778	1.4	3.4	3.2
Fundulus seminolis	Seminole killifish	2,727	17.3	3.3	0.5
Membras martinica	Rough silverside	2,727	4.4	3.3	1.3
Cyprinodon variegatus	Sheepshead minnow	2,532	13.5	3.1	0.9
Eucinostomus gula	Silver jenny	2,130	13.5	2.6	0.4
Notropis petersoni	Coastal shiner	2,099	5.6	2.6	0.6
Menticirrhus americanus	Southern kingfish	1,813	7.02	2.2	0.7
Cynoscion arenarius	Sand seatrout	1,720	13.0	2.1	0.6
Diapterus plumieri	Striped mojarra	1,557	21.8	1.9	0.2
Poecilia latipinna	Sailfin molly	1,505	11.1	1.8	0.6
Gambusia holbrooki	Eastern mosquitofish	1,340	7.5	1.6	0.5
Farfantepenaeus duorarum	Pink shrimp	1,264	22.0	1.5	0.2
Lepomis macrochirus	Bluegill	1,065	12.8	1.3	0.3
Callinectes sapidus	Blue crab	1,020	26.1	1.2	0.1
Gobiosoma bosc	Naked goby	949	19.0	1.2	0.2
Oligoplites saurus	Leatherjacket	897	18.2	1.1	0.1
Mugil gyrans	Fantail mullet	839	4.3	1.0	0.4
Mugil spp.	Mullet	830	0.5	1.0	0.7
Microgobius gulosus	Clown goby	805	21.3	1.0	0.1
Cynoscion nebulosus	Spotted seatrout	702	15.2	0.9	0.1
Dorosoma petenense	Threadfin shad	554	3.0	0.7	0.5
Achirus lineatus	Lined sole	409	9.7	0.5	0.1

Table 6-10. Top forty most abundant fish and invertebrate nekton taxa collected during trawl sampling in the channel habitat of the Lower Alafia River during 1996 – 2003 between kilometers 0 and 12.

Scientific Name	**Common Name**	**Number**	**Percent occurrence**	**CPUE (No. 100 m^{-2})**	
				Mean	**Stderr**
Anchoa mitchilli	Bay anchovy	55,284	51.8	16.2	3.5
Trinectes maculatus	Hogchoker	7,290	57.0	2.3	0.4
Cynoscion arenarius	Sand seatrout	5,758	49.6	1.7	0.3
Leiostomus xanthurus	Spot	4,471	20.7	1.4	0.3
Menticirrhus americanus	Southern kingfish	3,043	29.7	0.9	0.2
Callinectes sapidus	Blue crab	2,174	57.9	0.7	0.1
Farfantepenaeus duorarum	Pink shrimp	1,821	34.3	0.5	0.1
Eucinostomus gula	Silver jenny	687	15.7	0.2	0.0
Lagodon rhomboides	Pinfish	642	16.2	0.2	0.1
Symphurus plagiusa	Blackcheek tonguefish	551	21.8	0.2	0.0
Arius felis	Hardhead catfish	400	28.2	0.1	0.0
Bairdiella chrysoura	Silver perch	365	10.5	0.1	0.0
Prionotus scitulus	Leopard searobin	330	15.3	0.1	0.0
Eucinostomus spp.	Mojarra	207	4.6	0.1	0.0
Limulus polyphemus	Horseshoe crab	187	8.3	0.1	0.0
Eucinostomus harengulus	Tidewater mojarra	173	14.2	0.1	0.0
Archosargus probatocephalus	Sheepshead	153	15.3	0.1	0.0
Achirus lineatus	Lined sole	143	11.1	0.0	0.0
Dasyatis sabina	Atlantic stingray	128	14.0	0.0	0.0
Orthopristis chrysoptera	Pigfish	122	5.0	0.0	0.0
Chaetodipterus faber	Atlantic spadefish	117	9.4	0.0	0.0
Diapterus plumieri	Striped mojarra	107	6.6	0.0	0.0
Anchoa hepsetus	Striped anchovy	97	2.8	0.0	0.0
Prionotus tribulus	Bighead searobin	94	8.1	0.0	0.0
Microgobius thalassinus	Green goby	81	6.3	0.0	0.0
Gobiosoma bosc	Naked goby	69	8.1	0.0	0.0
Ameiurus catus	White catfish	53	2.4	0.0	0.0
Micropogonias undulatus	Atlantic croaker	50	2.2	0.0	0.0
Anchoa cubana	Cuban anchovy	47	0.2	0.0	0.0
Microgobius gulosus	Clown goby	42	4.8	0.0	0.0
Opsanus beta	Gulf toadfish	41	6.8	0.0	0.0
Bagre marinus	Gafftopsail catfish	39	5.9	0.0	0.0
Syngnathus louisianae	Chain pipefish	38	5.0	0.0	0.0
Cynoscion nebulosus	Spotted seatrout	37	2.6	0.0	0.0
Chloroscombrus chrysurus	Atlantic bumper	33	1.3	0.0	0.0
Harengula jaguana	Scaled sardine	30	1.3	0.0	0.0
Gobiosoma spp.	Goby	26	2.0	0.0	0.0
Sciaenops ocellatus	Red drum	23	3.3	0.0	0.0
Lepisosteus osseus	Longnose gar	22	3.1	0.0	0.0
Paralichthys albigutta	Gulf flounder	22	3.3	0.0	0.0
Syngnathus scovelli	Gulf pipefish	22	4.2	0.0	0.0

6.6.10 Distribution, Seasonality, and Habitat Relationships of Selected Species

Information presented by FRWI for the 37 species with detailed analysis included 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 two important fish species in the river are reprinted below from the FWRI report (Matheson et al. 2005), which can be consulted for plots for other species.

Sand seatrout (*Cynoscion arenarius*) were most abundant in warm months from April through September, with declining numbers in the fall and nearly absent from the seine catch during January through March (Figure 6-30). Peak numbers were caught between kilometers 2 and 4, though they were also common up to kilometer 8. Sand seatrout were widely distributed among salinity classes ranging from oligohaline to polyhaline. They were most numerous among marsh and mangrove shorelines, but also abundant against hardened shorelines, although hardened shorelines sometimes may make fish easier to catch.

The hogchoker (*Trinectes maculatus*) is common in estuaries and is among the most abundant species in the upper portions of tidal rivers (Peebles and Flannery 1992, Wagner and Austin 1990). Hogchoker were abundant year-round, with some tendency for higher abundances in the fall and early winter (Figure 6-31). Hogchoker in shoreline habitats captured by seines were most abundant in the upper reaches of the estuary above kilometer 10 in limnetic waters. Matheson et al. (2005) reported that hogchoker spawn in the bay or in the tidal river, but in either case the larvae move upstream to low salinity nursery areas.

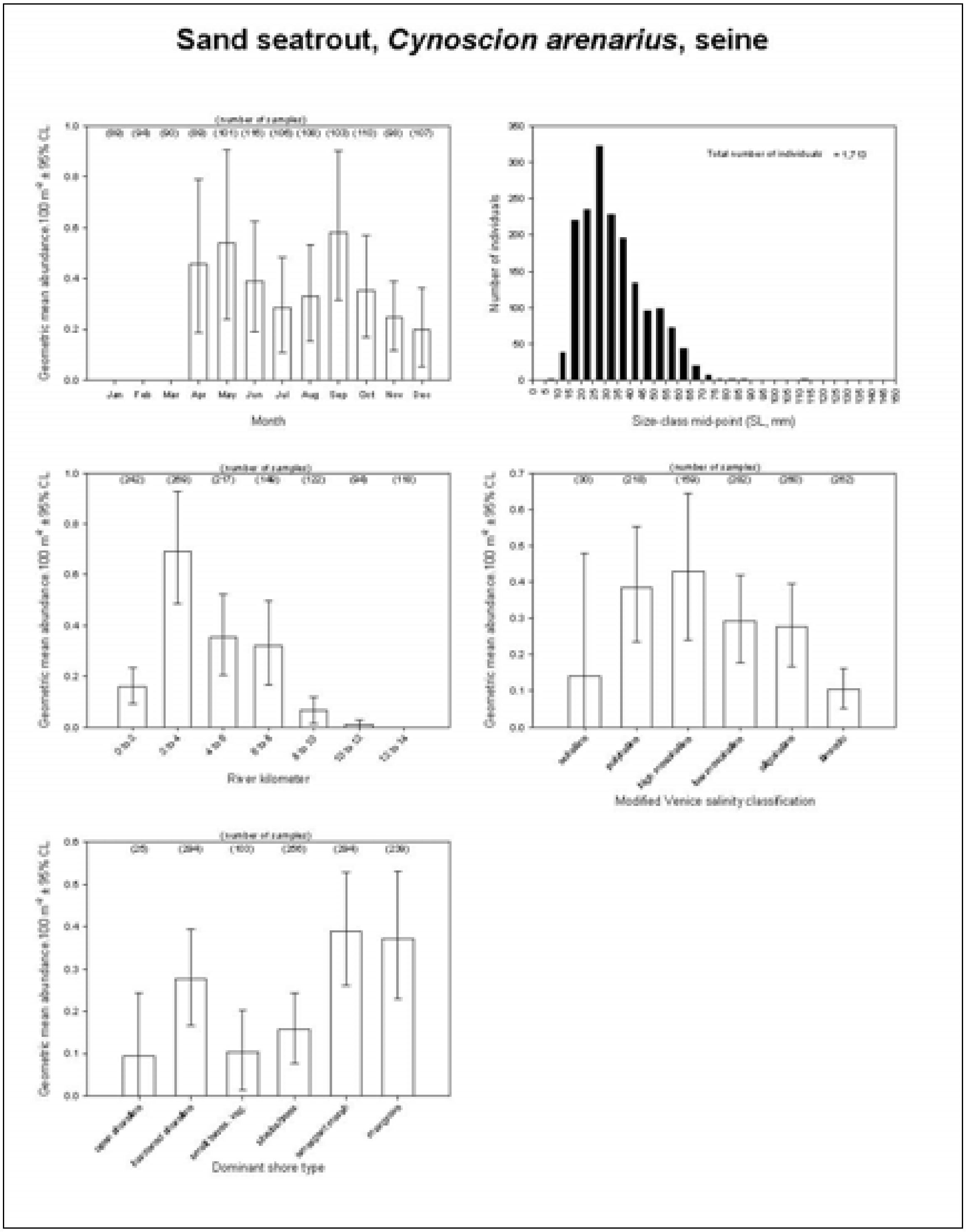


Figure 6-30. Abundance of sand seatrout, *Cynoscion arenarius*, in nearshore habitats (seine samples) by month, size class, river zone, salinity range, and shoreline habitat (reprinted from Matheson et al. 2005).

Hogchoker, *Trinectes maculatus*, seine

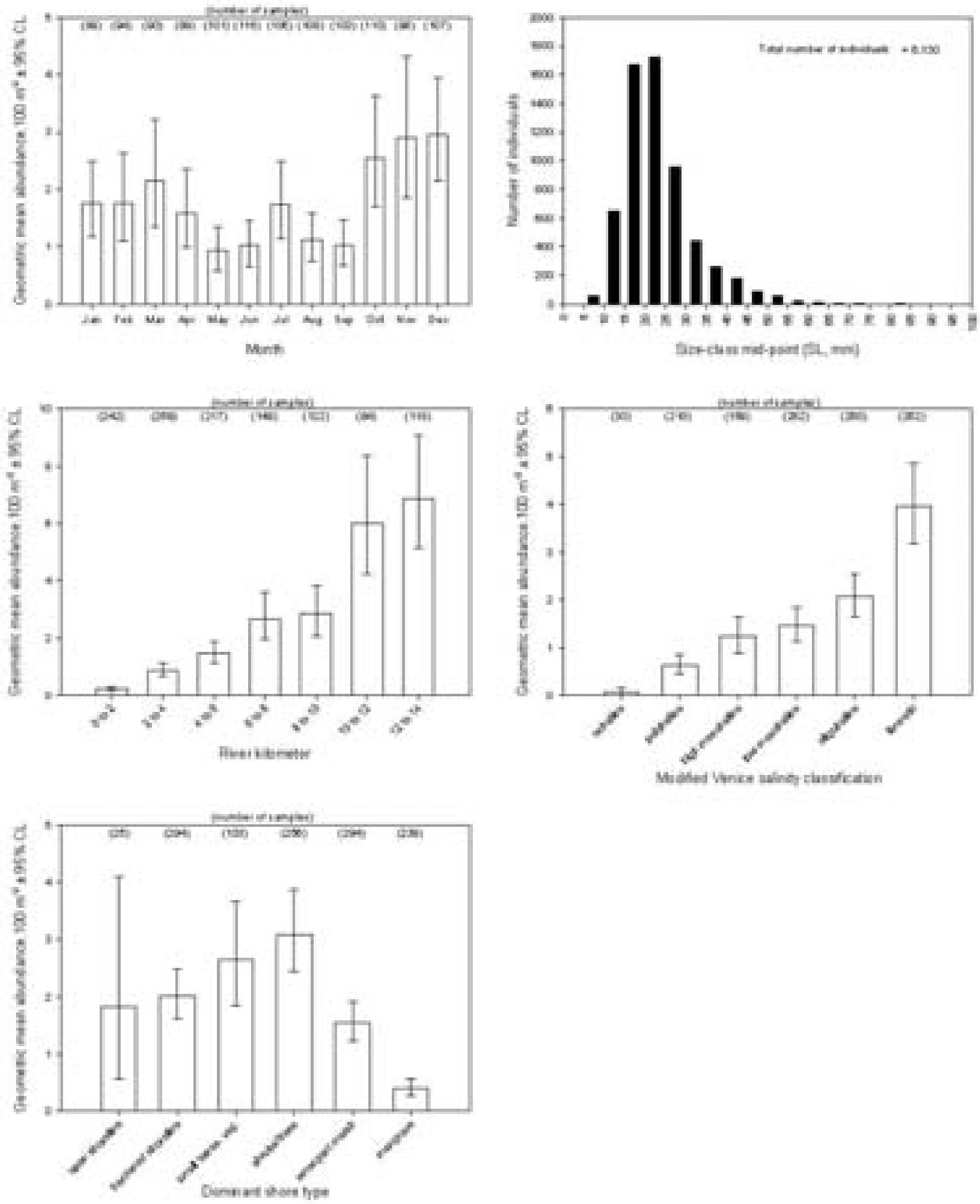


Figure 6-31. Abundance of hogchoker, *Trinectes maculatus*, in nearshore habitats (seine samples) by month, size class, river zone, salinity range, and shoreline habitat (reprinted from Matheson et al. 2005).

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

FRWI examined the response of the spatial distribution of many species in the river to freshwater inflow. These relationships were examined separately for different size classes of some species to account for possible ontogenetic (growth related) changes in the response to inflow. FRWI used the term pseudospecies to describe a specific size class for a given species. A total of 68 pseudospecies were selected for analysis of relationships of freshwater inflow with population distribution and overall population relative abundance. Similar to the USF plankton study, population distributions were estimated by calculating Km_U, which is a density weighted center of catch per unit effort 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 68 pseudospecies. Both the Km_U and inflow terms were ln-transformed in the models, and inflow terms of different preceding lengths were examined. Nearly half of the 68 pseudospecies that were examined had a significant relationship ($p<0.05$) between Km_U and inflow. In all but one case, population movement was downstream in relation to freshwater inflow. Although this response seems intuitively obvious, the opposite response has been observed in the highly modified and stratified Tampa Bypass Canal, where some species shift upstream with increasing freshwater inflow possibly due to the effects of inflow on two-layer circulation (Peebles 2004).

Using various inflow terms of different lengths, the best r^2 values for the different pseudospecies ranged from 5 percent to 62 percent, averaging 26 percent for all the significant relationships that were found (see Appendix 8 in Matheson et al. 2005). Pseudospecies centered in the downstream reaches (kilometers 0 - 3.9) were more likely to move in relation to inflow than those centered in the middle and upper river. FWRI used the term transient species to describe species that do not spend their entire life in the tidal river. The distributions of transient species that spawn outside the tidal river were more likely to respond to longer term preceding flows, while transient species that spawn inside the tidal river were more likely to respond to short or medium term flows. In general, estuarine resident species, did not move as often as transient species in response to changes in inflow.

The response of Km_U for thirteen pseudospecies to baseline flows and a series of potential freshwater flow reductions are presented in Chapter 8 (Table 8-14). Pseudospecies were selected for analysis based on their ecological importance and the presence of significant regressions with comparatively high r^2 values. It was concluded these taxa 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 river.

6.6.12 Regression Analyses of Abundance Response of Seine and Trawl Catch

FRWI also examined relations between relative abundance (number of animals as catch per unit effort) and freshwater inflow. Regressions were developed for groups of months when each pseudospecies was abundant in the lower river, including zero abundance values within the corresponding time window. All biological and inflow data were ln-transformed for analysis. Both linear and non-linear models were examined to determine the best fit. The non-linear models that produced the best results were quadratic formulae. Greater detail on the regression approach used by FWRI can be found in Matheson et al. (2005).

Fifty-four of the 68 pseudospecies examined had significant relations between abundance and inflow, although the regressions for many species had relatively low r^2 values, which is not surprising given the complexity of factors affecting biological populations. Example regressions for four pseudospecies are shown in Figure 6-32. Negative relationships with inflow over the entire flow regime were observed for some pseudospecies and gear types (Figure 6-32A). These species tend to favor higher salinity conditions in Tampa Bay, and thus invade the tidal river during low inflows and move out of the river when flow increase and conditions are less favorable.

More frequently, a convex non-linear relationship was observed in which a pseudospecies increased in abundance at low inflows, peaked at intermediate inflows, and then declined with high inflows (Figure 6-32B). This type of curve indicates that freshwater inflow has a positive effect up to a certain point, then at high flows the catch of that species declines, similar to the washout effect described by Peebles (2005). This does not necessarily mean that increased flows have a negative effect on the overall abundance of a species, as it may shift its distribution into Tampa Bay at high flows.

The results presented for juvenile red drum by Matheson et al. (2005) included individuals that were spawned at a FWRI hatchery and released to the lower river during 2000 through 2003 (MacDonald 2007). However, fin clips were taken from fish captured by FWRI in the lower river, which allowed subsequent genetics testing to differentiate wild fish from hatchery fish. These results were used by MacDonald (2007) to correct the catch data for the lower river, so that regressions with inflow were developed solely for wild fish. The regression for wild juvenile red drum in the 40-150 mm size class (Figure 6-32C) was similar to the regression developed for total catch presented on page 377 by Matheson et al. (2005), in that juvenile red drum abundance increased over most of the flow range of the river, with a slight downturn in abundance predicted at high flows.

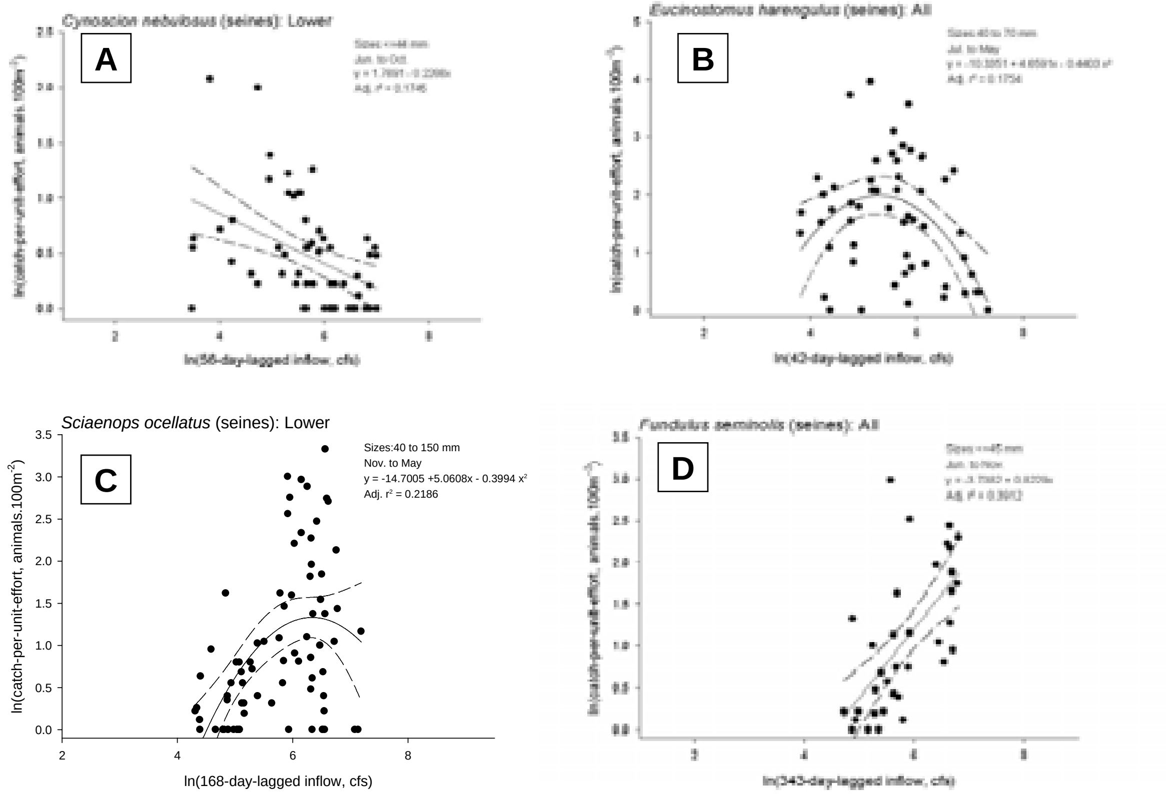


Figure 6-32. Relationships of relative abundance with freshwater inflow for four species/size classes captured by seines in the Lower Alafia River.

Positive relationships with inflow are the principal concern for minimum flow analyses, for these are species for which reductions in abundance in the river could occur as a result of flow reductions. An example of a consistent positive is shown for the Seminole killifish in figure 6-32D. Consistent positive relationships were typical of estuarine resident species that maintain their position in the tidal river and increase in abundance over a wide range of flows.

Positive relationships also occur in the convex nonlinear relationships described above, over the rising limb of the response curve at low to medium flows. For these species, large withdrawals during periods of prolonged low inflows could impact juvenile fish abundance in the river for one or more seasons, possibly affecting overall population size. Matheson et al. (2005) suggests that declines at low inflows may be attributable to declines in productivity, community structure changes, weakening of transport mechanisms**,** salinity stress, or a combination of factors that affect the complex interactions between inflow and the life history strategies of different species in the river.

Using the models presented by FWRI, simulations of the abundance of thirteen pseudospecies are presented in Chapter 8 for baseline flows and a series of flow reductions. These species were selected based on the suitability of the regression statistics (e.g., r^2) and their positive responses to freshwater inflow over part or all of the flow regime, in order to assess potential impacts that could occur to the river due to withdrawals.

6.6.13 Community Analyses of the Seine and Trawl Catch

FWRI also used multivariate analyses (e.g., similarity/dissimilarity, multi-dimensional scaling) to investigate changes in nekton community structure within the river during different seasons and year, which represent a range of inflow conditions. FWRI divided the year into four flow seasons: winter (January to March), spring (April and May), summer (June to October), and fall (November and December). Grass shrimp were excluded from the analysis because their enumeration did not occur over the entire study period, and the bay anchovy were excluded from the analyses due their extreme abundance and often aggregated distribution, which would tend to complicate interpretation of the results. Only the species collected by seine were included in the community level analyses , since previous studies of similar data have shown that the greater variability in trawl sampling, combined with the lower sampling effort conducted in this study, would make productive community-level analyses difficult to conduct.

FWRI found that nekton community structure changes along the river in each season and year. There was evidence of three assemblages being present in the river during the spring and fall, which were marine/bay, estuarine, and freshwater. High freshwater inflow often coincided with major changes in community structure occurring near the mouth of the river, due to decreased upstream penetration of higher-salinity species from the bay, as well as increased downstream penetration of species with freshwater affinities. Low freshwater inflow often coincided with major community changes occurring further upstream. Years with very high or very low inflow generally had patterns of community change that were very different from other years.

A recent paper by Greenwood et al. (2007) found that fish community structure was sensitive to changes in salinity and freshwater inflow above kilometer 9.3, but community structure further downstream was more influenced by seasonal life history patterns than by changes in abiotic variables.

6.7 Fish Analyses Presented in Reports Prepared for other Agencies

Analyses of fish catch data for both the plankton and seine/trawl sampling programs have also been presented in two interpretive reports prepared for the HBMP and two reports prepared by the firm of Janicki Environmental Inc. for: (1) Tampa Bay Water; and (2) the Gulf of Mexico Program with the Tampa Bay Estuary Program. These reports used the same data collected by USF and FWR described above, either for both the combined SWFWMD and HBMP sampling periods or for the HBMP sampling period alone. Though the District primarily used the information presented in the USF and FWRI reports for the minimum flows analysis, these reports are informative and provide useful information on fish and zooplankton populations in the Lower Alafia River and some findings from these studies are briefly summarized below.

6.7.1 HBMP Analyses of Plankton and Seine and Trawl Catch

Sampling for the HBMP began in the late spring of the year 2000 and continues to present. In contrast to the USF and FWRI reports, which included data from earlier sampling periods, the reports for the HBMP are limited to the period of data collection for that program. The most recent HBMP report, however, includes almost two more years of data than the FWRI and USF reports. The findings presented in the most recent HBMP report primarily emphasized intra-annual variation in the water quality and biological variables (Tampa Bay Water 2006). The biological data were not directly related to freshwater inflow and no predictive relationships for fish or zooplankton data were presented, thus summaries of the HBMP data presented in this minimum flows report are very brief and limited to the examples described below.

The reporting of the abundance of various indicator taxa by month and year for five-plus yeas of HBMP data collection were informative. The monthly boxplots in Figure 6-33 show the mean (dot), median (line), 25th and 75th percentiles (top and bottom of box) and minimum/maximum values. The notches around the median line represent the 95th percent confidence interval around the median. The catch per unit effort for the mysid shrimp *Americamysis almyra* and the isopod *Edotea tribola* in the plankton have very different seasonal patterns, with *Americamysis* peaking in November and December and *Edotea* clearly most abundant in the spring and early summer (Figure 6-33A and B). The comb jelly *Mnemiopsis mccraydyi* reached it highest numbers in the spring with a minor peak in November-December, while the catch of young life stages of the hogchoker *Trinectes maculatus* was highest in the spring and summer (Figure 6-33C and D). On an inter-annual basis, the abundance of mysid shrimp increased over the HBMP period, with the lowest values in the drought years of 2000 and 2001, but 2000 was not a full year of sampling (Figure 6-34).

Among the species caught by seine and trawl, the bay anchovy was abundant year-round, with mean abundances much higher then the medians (Figure 6-35A). The blue crab *Callinectes sapidus* was most abundant in the winter, with lowest numbers from June through October (Figure 6-35B). The silversides *Menidia* spp., which is the second most dominant fish based on frequency of occurrence and abundance, is most numerous in the summer, with reduced abundance in the winter (Figure 6-35C). Presentation of data for juvenile red drum confirmed that this species occurs from October through April, with peak abundance in November during the fall recruitment of juveniles to the river.

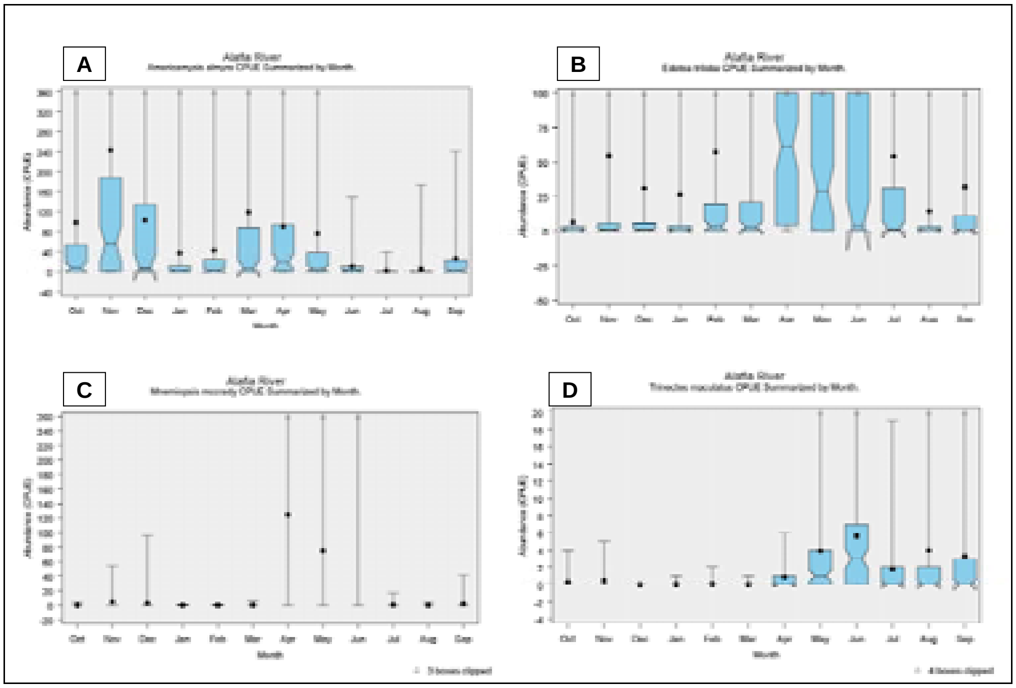


Figure 6-33. Boxplots of monthly catch per unit effort for three invertebrate and one fish species collected by plankton net reported by the HBMP for the period June 2000 – September 2005.

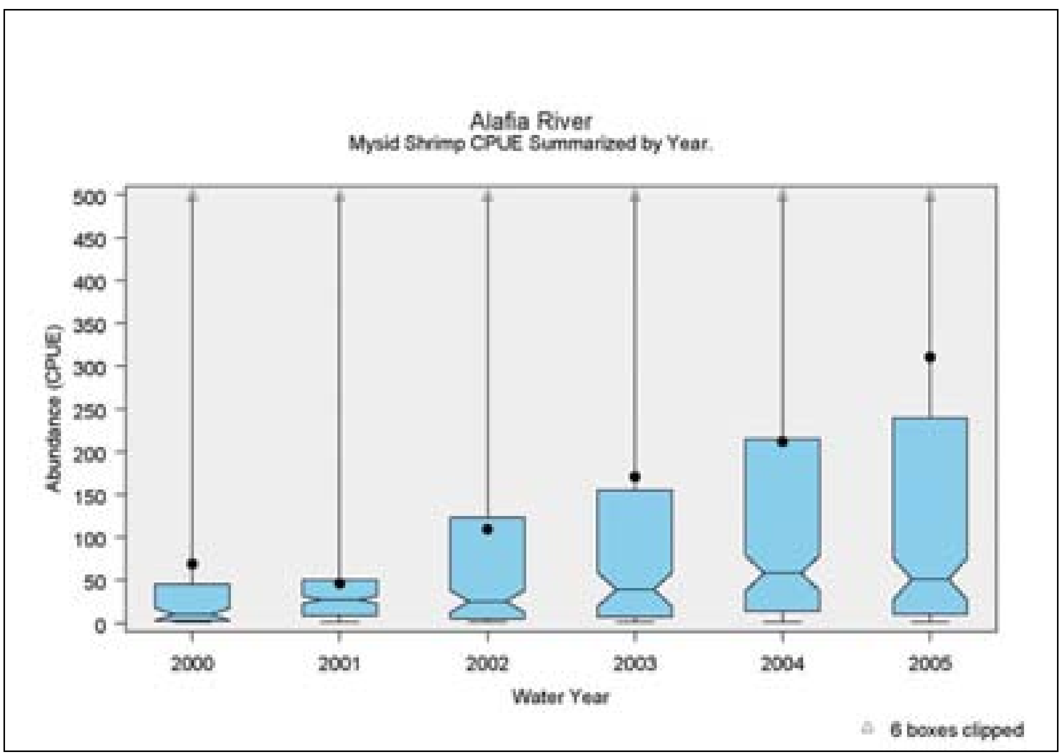


Figure 6-34. Box plots of annual catch per unit effort for combined mysid shrimp in plankton tows from June 1998 through September 2005.

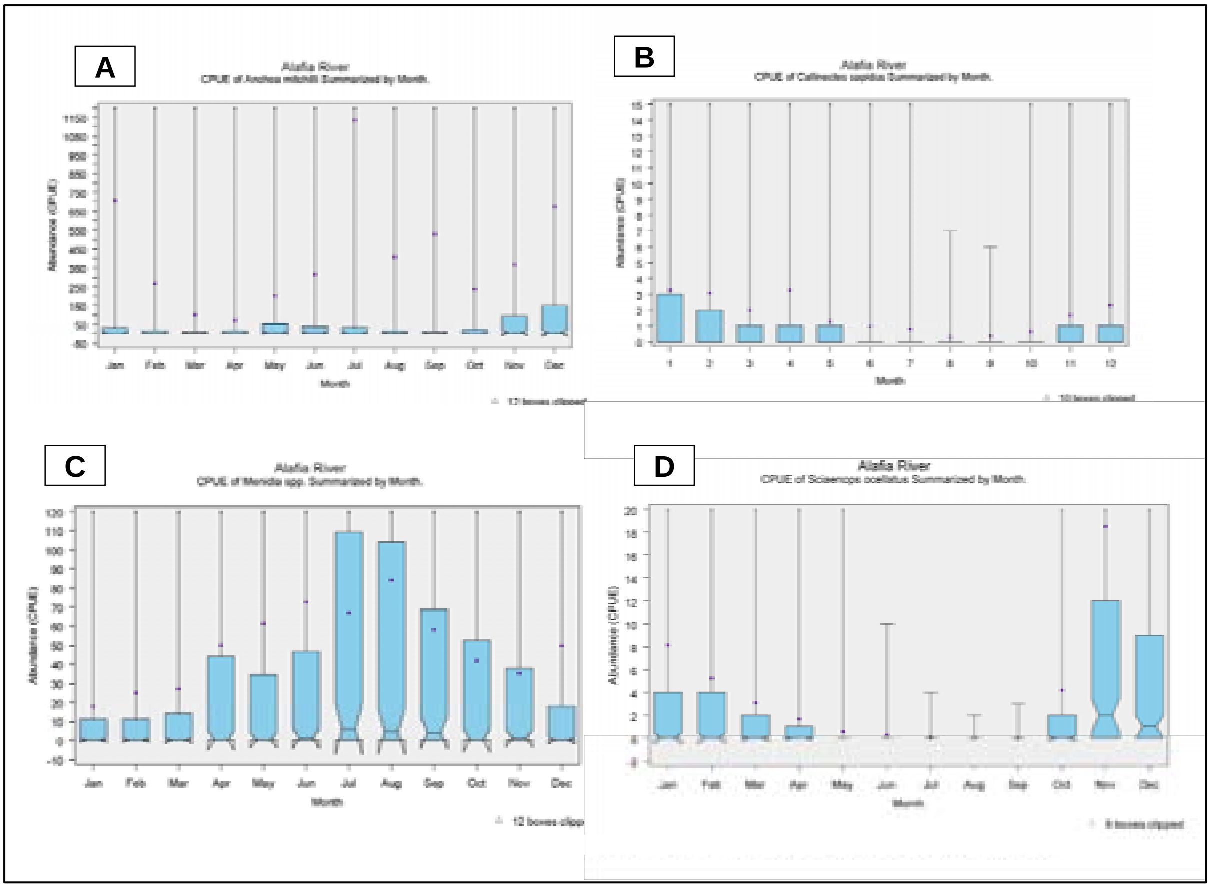


Figure 6-35. Boxplots of monthly catch per unit effort for four fish species collected by seines reported by the HBMP for the period June 2000 – September 2005.

6.7.2 Analyses of Relationships between Freshwater Inflow and Fish Abundance and Distribution Conducted by Janicki Environmental

Janicki Environmental Inc. (JEI) performed two projects to analyze data collected from the Lower Alafia River to evaluate relationships between freshwater inflow and biological variables, particularly chlorophyll *a* and fish abundance and distribution. The first project was funded by Tampa Bay Water (Janicki Environmental 2004a), while the second project was conducted jointly for the U.S. EPA Gulf of Mexico Program with the Tampa Bay Estuary program (Janicki Environmental (2004b). Some principal findings from these studies are summarized below.

The report prepared for Tampa Bay Water employed graphical and logistical regression analyses to examine relations between freshwater inflow, fish population parameters, salinity, and chlorophyll *a*. Fish data were limited to seine data collected by the FWRI discussed above, for the period from 1998 to 2002. Abundance relationships (ln of catch per unit effort per seine sample) were examined on annual and monthly basis. In order to avoid the potential confounding factors of seasonal influence, two overall variations of the bivariate plots were examined. Annual plots were produced to integrate variation over potentially confounding seasonal effects. Monthly plots were also produced in which the dependent variables were standardized by month over the time series.

The mean value for each month across all years (5 total) was subtracted from each individual value for that month, and each monthly value was divided by the standard deviation for the month across all years. Additionally, data that were log normally distributed were transformed to clarify observed relationships. This is an important distinction from the FWRI and USF studies in which abundance was not standardized to mean conditions per each month. One cautionary note could apply to characterizing mean conditions on a low number of years, which may not reflect the average long-term climate or streamflow conditions. This was the case for the 1998-2002 period, which had an unusual number of dry seasonal and yearly flows, including record or near record low flows in the springs of 2000, 2001 and 2002. However, the data were being standardized by month for analysis are from this same period, so the relative effect of differences in flows standardized to these mean conditions may still appear.

Inflow relationships were examined for 11 dominant fish species. Although based on only five years of data, there appeared to be positive relationships between freshwater inflow and the abundance of hogchokers and red drum. Standardized monthly abundance was examined as a function of 30-day lag flow (30-day preceding mean) for all species. Red drum showed the clearest pattern among the dominant species with an apparent positive relationship between monthly freshwater inflow and abundance. This relationship, however, included both wild juvenile red drum and hatchery raised juveniles that were introduced to the river during the years 2000 through 2002.

JEI (2004a) also examined inflow relationships of fishes from the lower river grouped into one of three life history categories, similar to the categories described by USF and FWRI but with some difference in the estuarine group described below.

1) Freshwater group - species which typically reside in fresh water but may be found in low salinity water;

2) Estuarine group - estuarine residents that spend their entire life cycle, including spawning, in the estuary OR species of marine origin which are frequently found in estuaries but may travel back and forth between the river and the gulf or bay.

3) Estuarine Dependent group - marine species that spend at least one phase of their life cycle in the estuary.

Not surprisingly, plots of monthly abundance of the freshwater group versus inflow indicated a positive relationship, while the plots for the estuarine and estuarine dependent group were unclear, though there was some indication of reduced abundance of the estuarine group at very high flows (> 700 cfs).

An interesting finding present by JEI pertained to seasonal variations in the size (standard length) of different species. Several of the dominant species, such as the bay anchovy and hogchoker, did now show a clear seasonal trend with regard to the size of the individuals caught (Figure 6-67A and B), while other species such as the red drum and spot demonstrated seasonal trends (Figures 6-67C and D), although small sample sizes influence the boxes for some months. Nevertheless, there appears to be a relationship of either growth of the fishes or immigration or larger individuals over time.

JEI (2004a) also reported that there was some evidence that the growth rate of red drum was positively associated with flow, except at very high flows (670 cfs). Overall, some of the strongest findings pertained to juvenile red drum, which showed positive relationships with inflow for year class strength, monthly and yearly abundance, and intra-annual growth rates.

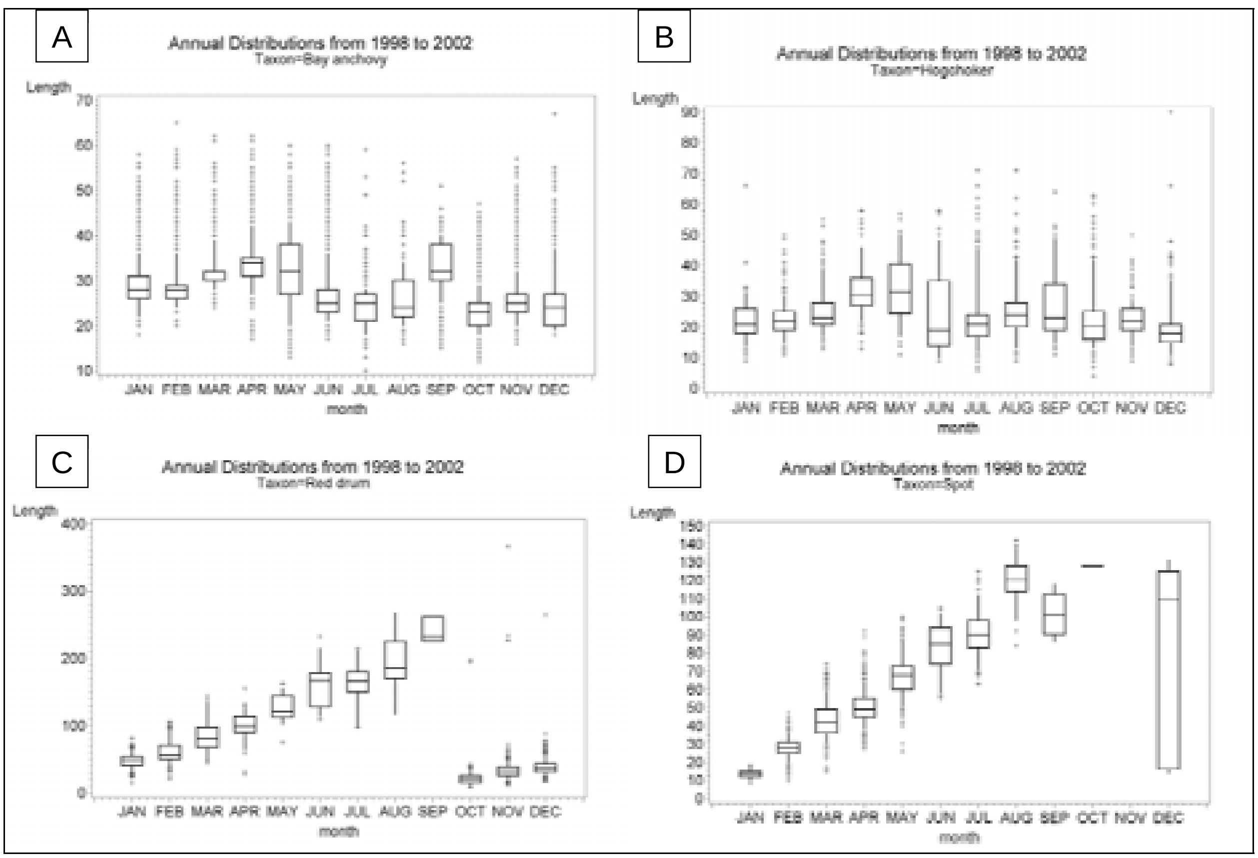


Figure 6-36. Monthly boxplots of standard lengths for four species collected by seine.

JEI (2004a) also performed logistic regression analyses to examine relationships between fish occurrence and salinity. Those results are extensive, and no representative graphs are reproduced in this minimum flows report. JEI did report that only three species were found consistently throughout the river and across all salinities: the bay anchovy, silversides, and tidewater mojarra. These species did not appear to be limited spatially or temporally in the tidal river. A number of species were found consistently across all months, but varied with salinity. Of species that were primarily limited to summer months, most had a higher probability of occurrence in middle to high salinities. For species with temporal distributions centered around winter months, salinity preferences for either high or low salinities were observed.

Analyses were also conducted to examine relationships between chlorophyll *a* and fish populations. The monthly data indicated the likely presence of relationships among fish, inflow, and chlorophyll for several fish taxa and population metrics. These relationships were likely the combination of direct and indirect responses of fish to phytoplankton populations (as indicated by chlorophyll a) or the co-variation of fish and chlorophyll a to an external factor. On a limited four-year data set, total annual fish abundance per seine sample was greater in years where chlorophyll concentrations at the EPCHC station at Kilometer 7.5 were greater. The strongest apparent relationship for any taxa were for two resident killifish species (*Lucania parva* and *Fundulus majalis*), which were inversely related to chlorophyll a at this same EPCHC station, however, it is likely these species and chlorophyll *a* were responding independently to freshwater inflow. Similarly, an inverse relationship between the freshwater group and chlorophyll was likely an independent relationship, as increased flows act to reduce both salinity and reduce chlorophyll a in the lower river.

JEI also conducted a related project funded by the U.S. EPA and the Tampa Bay Estuary Program to determine: (1) if there are biotic indicators in the river that exhibit demonstrable relationships with freshwater inflow; (2) which indicators are most sensitive to changes in inflow; and (3) which hydrologic characteristics appear to be most important in determining biotic indicator performance. In this project, JEI (2004b) analyzed both fish and zooplankton data collected either by plankton tows or seines by USF and FWRI respectively between 1998 and 2003.

JEI used Artificial Neural Network (ANN) analyses to develop predictive models for the abundance of a number of important indicator fish and invertebrate species in the lower river. JEI provides a review and discussion of ANN models in their report (JEI 2004b). They state that ANN has gained acceptance for a broad spectrum of applications and has been found to satisfactorily model complex ecological relationships even when causal factors may be poorly understood. Common to efforts is the use of the feed forward neural network model and backpropagation algorithm to estimate connection weights. Generally, neural networks contain an input layer, hidden layer, and output layer, each of which contain and process information. Each neuron from one layer is connected to all neurons of the next layer in the information pathway. In feed forward neural networks, neuron signals are transferred by axon in a unidirectional path from the input layer through the hidden layer to the output layer.   These are by far the most common types of ANN models used in ecological studies, and were used in the JEI report.

All fish and zooplankton abundance data were standardized by month, as described for the JEI project for Tampa Bay Water previously described. Flow data at Bell Shoals Road were averaged over consecutive data periods of 7, 15, 30, 60, and 90 days to obtain several measures of flow characteristics in the days prior to biological sampling. The biological data were segregated into upper, lower, and middle river zones for analysis.

JEI (2004b) initially applied the ANN approach to chlorophyll *a* concentrations for the 1998-2003 time period. Results indicated that 7-day average flow conditions (the shortest time period tested) contributed most to the predictive weight of the models. The models were able to approximate a function describing the concentration of chlorophyll in the three zones of the river. The highest peaks in chlorophyll *a* were associated with low flow conditions in all three river regions and the model appeared to adequately fit the observed data. Following the identification of an ANN model that could recognize dynamics of chlorophyll concentrations, additional models were developed for use with the zooplankton and fish data sets where more data were available to build more complex feed forward ANN models and test the utility of these models to predict abundance based on inflow conditions.

JEI applied ANN models to eight indicator species from the plankton data. Fifteen and thirty day average flow conditions were consistently among the flow variables retained in the final model runs, except for the ctenophore *Mnemiopsis mccradyi* and juvenile menhaden models, which had longer flow terms.(60 and 90 days)   The 7 and 15-day average flows drove the models for bay anchovy eggs and juveniles, while models for mysid shrimp and sand seatrout were driven mostly by 15 and 30 day average flows.

The amount of variation in animal abundance explained by the models varied considerably by species and river region. However, the models adequately explained species abundances in the river regions in which they were prevalent. The best model predictions were for grasss shrimp and menhaden. The grass shrimp data were used to validate the utility of the NN model to predict new information based on the trained network. For that exercise, the grass shrimp data set was randomly divided with approximately 65 percent of the data sequestered for training the network and the remaining data used as a validation data set.   The trained grass shrimp model was able to adequately predict abundance in the lower and middle reaches of the river once the seasonality component was reintroduced into the data, but predictions of abundance in the upper regions of the river was poor (Figure 6-37). The validation results indicated that additional data would be required to train a suitable model for the upper region while avoiding overparameterization of the model.

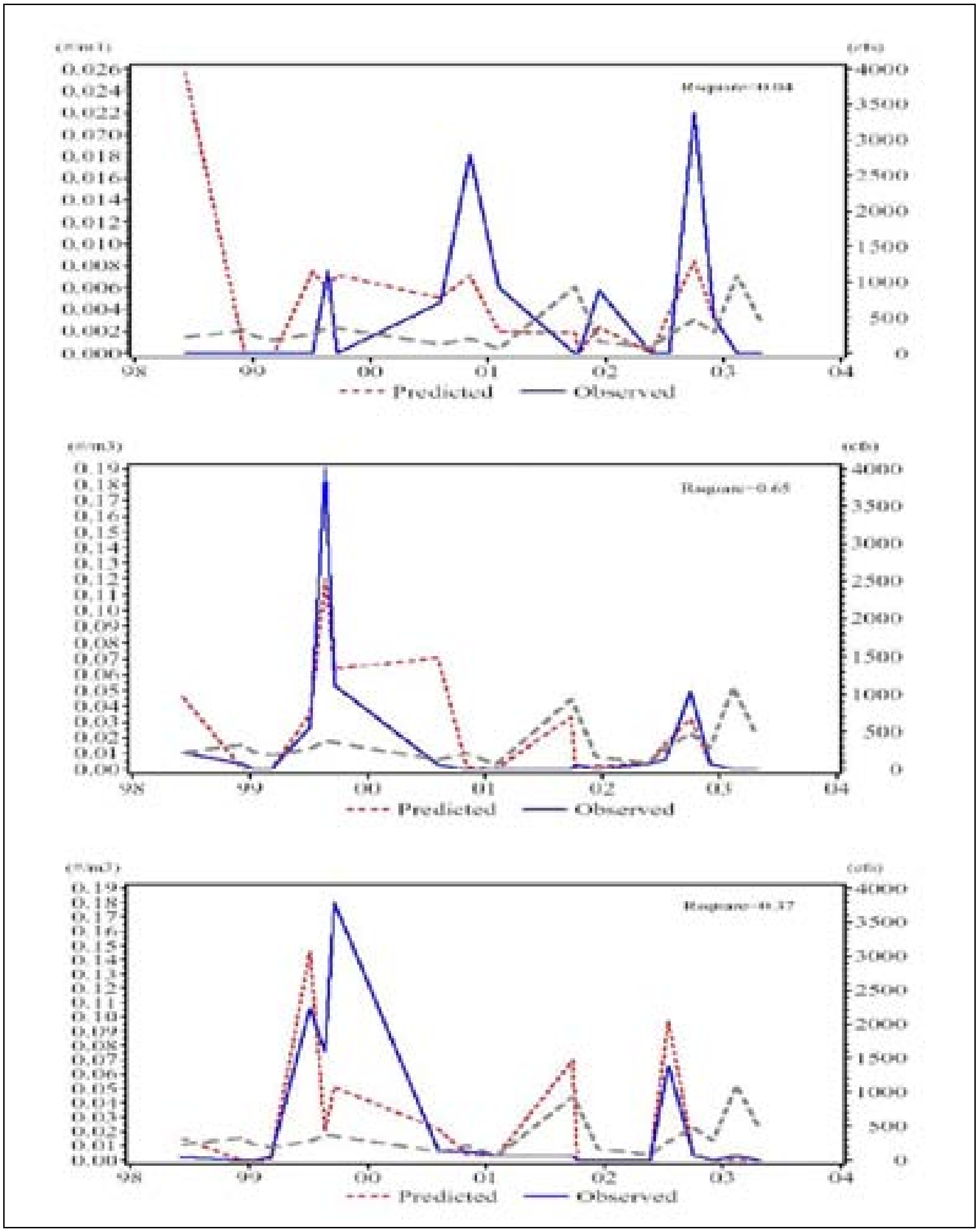


Figure 6-37. Predicted vs. observed plots for grass shrimp Neural Network validation efforts from plankton collections from1998 – 2004. Plots are arranged from top to bottom for the upper, middle, and lower regions defined by Janicki Environmental (2004b).

The modeling approach was also applied to ten dominant species that were collected by the FWRI seine sampling efforts. The same methodology was use for modeling the species caught by seine as for the plankton species. Red drum abundance was not modeled, due to the presence of hatchery reared fish in the catch data. Generally, the 30, 60, and 90-day flows were the most influential in predicting species abundance in the Alafia River. Generally, these models achieved good r^2 values when the predicted and observed data were regressed with one another, with many r^2 values over 0.60. The models generally fit the fish data well, as many models had r^2 values above 0.60, though some models exhibited considerable regional variation. The striped mullet, spot, and the mojarras achieved the best fit, as judged by the r^2 statistic. Species such as the bay anchovy, hogchoker, and silversides, which are present in the samples year-round, had somewhat lower r^2 values, but predictions appeared to be less influenced by extreme catches in a particular month. These species also displayed considerable variation in the predictive ability among river regions, indicating potential spatial and environmental interactions.

A cross validation study was conducted by randomly dividing the data for silversides with approximately 60 percent of the data sequestered for training the network and the remaining data used as a validation data set. The validation results indicated that additional data would be required to train suitable models while avoiding overparameterization of the model. The validation results indicated that occasional high peak abundance values were difficult to predict well if they were not included in the original model development data set. This observation is reflected by five underestimated predictions of observed silversides abundances where the observed abundance was greater than 400 per 100 square meters (Figure 6-38).

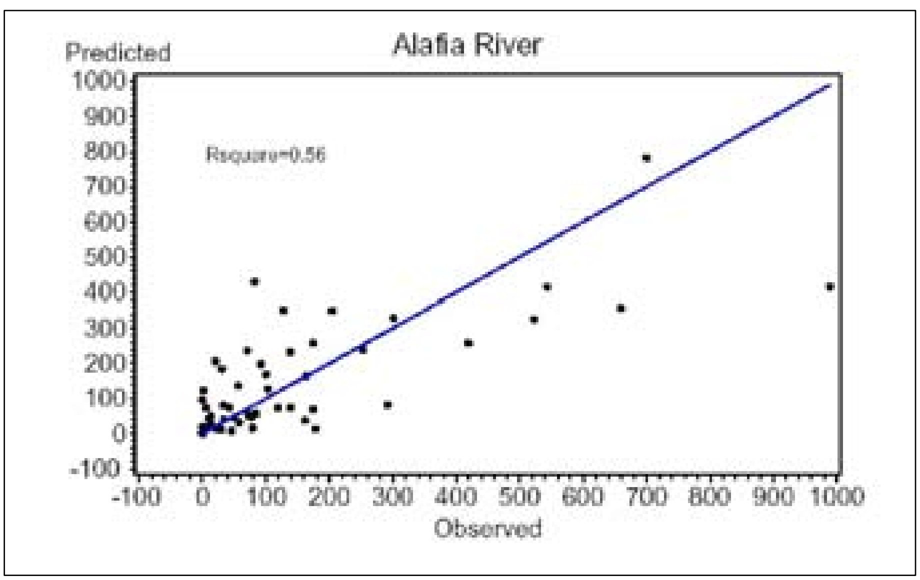


Figure 6-38. Predicted vs. observed plots for silversides (#/100 m2) for Neural Network model results for all regions of the Lower Alafia River.

JEI concluded that in this pilot study, ANN models were demonstrated to provide a powerful tool for studying relationships between biotic and abiotic factors in ecological modeling. The analysis established a foundation for further research into the application of feed forward neural network models as a tool to describe complex ecological relationships in the Lower Alafia River. They further concluded that although the models developed for the study were parameterized to the point of summarizing the relationships expressed in the observed data, they should not be applied directly to freshwater inflow resource management problems in their current state. As demonstrated by the validation results, the models are likely to be overparameterized, and would require refinements for application. In order to apply these models, one would need to identify biological resources of interest that are important, present in suitable abundance, and would provide an early indicator of flow changes. One would then reduce the number of parameters in the models until the prediction skill of the model was balanced with the validated robustness to prediction error.

Chapter 7

Resources of Concern and Technical Approach for Determining Minimum Flows for Lower Alafia River Estuary

7.1 Overview

The chapter presents the District's approach for determining minimum flows for the Lower Alafia River, or the tidal portion of the river that extends below Bell Shoals Road. The results and 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 define the geographic region in which potential impacts are to be evaluated, identify the ecological resources to be protected within that region, and describe the analytical methods by which potential impacts to these resources are to be evaluated.

7.2 Geographic Region for Analysis of Potential Impacts from Reductions of Freshwater Inflow

A first step in this process is to identify the geographic extent of the resources that are to be evaluated. The Lower Alafia River is a tidal river estuary that is connected to the larger Tampa Bay estuarine system. There is considerable hydraulic, chemical, and biological interaction between the bay and the lower river. For example, it is well documented that many fish species that spawn in either the nearshore regions of the Gulf or Mexico or Tampa Bay migrate into the river as early life stages and use the Lower Alafia River as nursery habitat (Peebles 2005, Matheson et al. 2005).

Large withdrawals from the Alafia River could potentially have a significant effect on the freshwater inflow budget and ecology of Hillsborough Bay (the northeastern lobe of Tampa Bay). However, the approach taken for this report is that ecological resources and processes that occur within the river are much more susceptible to changes and significant harm than resources or processes that occur in the bay. This conclusion is based on the much greater relative effect of inflows on the salinity, residence time, water quality, and ecology of the river compared to the bay, and the fact that there are distinct biological communities and processes that occur within the river. In other words, there are sensitive resources in the river to protect, which in all likelihood would experience significant harm from freshwater withdrawals from the river before harm would occur to resources in the bay. The analyses conducted for this report support this conclusion, and the geographic limit of the resources of concern evaluated for this minimum flows analysis are within the river between the its mouth and Bell Shoals

Road. However, to give some hydrologic perspective on the potential for impacts to the bay, the flow reductions represented by the proposed minimum flows are compared to the freshwater inflow budget of Hillsborough Bay in Chapter 8.

7.3 Application of the Percent-of-Flow Method

The District applied the percent-of-flow method to determine minimum flows for the Lower Alafia River. The percent-of-flow method allows water users to take a percentage of streamflow at the time of the withdrawal. In some cases, the instantaneous flow of the river can be used to calculate the withdrawal, or withdrawals can be based on a percentage for the previous day's average flow. 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. As described in Chapter 2, the largest water user on the Alafia River, Tampa Bay Water, is also regulated using the percent-of-flow method as their daily withdrawals cannot exceed 10 percent of the preceding day's flow of the river measured at Bell Shoals Road. The percent-of-flow method is also used to regulate withdrawals by Florida Power and Light Corporation from the Little Manatee River, and has been used in the District's Regional Water Supply plan to assess potential water supplies in the region (SWFWMD 2006a).

The Lower Alafia River is one of a series of tidal river estuaries in which the percent-of-flow method will be used to establish minimum flows during 2007 and 2008 (Lower Peace, Myakka, Anclote, and Little Manatee Rivers). The method is oriented for use on unimpounded rivers that still retain a largely natural flow regime (Flannery et al. 2002). The percent-of-flow method has been applied to determine and adopt minimum flows for a series of unimpounded freshwater streams in the District, including the freshwater reaches of the Alafia River, the Myakka River, and the middle reach of the Peace River.

A goal of the percent-of-flow method is that the natural flow regime of the river be maintained, albeit with some flow reduction for water supply. Natural flow regimes have short-term and seasonal variations in the timing and volume of streamflow that reflect the drainage basin characteristics of the river in question and the climate of the region. In recent years, that has been considerable progress in the field of freshwater stream ecology and flow management in identifying the physical and biological processes that are linked to and dependent upon natural flow regimes (Poff et al. 1997, Instream Flow Council 2002, Postel and Richter 2003). As summarized in the District's MFL report for the freshwater reach of the Alafia River, these include geomorphic processes related to sediment transport and channel maintenance and biological processes related to fish passage, the inundation of instream and floodplain habitats, and providing conditions for the growth and reproduction of fishes and invertebrates by maintaining adequate water levels and velocities (SWFWMD 2005a, 2005b, 2005c).

Application of the percent-of-flow method to estuaries involves a special set of considerations, since these tidal brackish ecosystems are hydraulically and ecologically different than freshwater streams. The District has sponsored an extensive program of research on the relationships of freshwater inflows to estuarine systems, and the first applications of the percent-of-flow method were based on regulatory assessments of potential impacts to estuarine zones associated with the Peace, Little Manatee and Alafia Rivers. Flannery et al. (2002) described how findings from the District's estuarine research program were used to conceptually develop the percent-of-flow method. A key finding that supports the percent-of-flow method for estuaries is that the response of many key ecological parameters in estuaries such as isohaline positions, residence time, and the distribution and abundance of many fishes and invertebrates respond to freshwater inflow in a nonlinear manner and are most sensitive to change at low flows. By scaling the withdrawals to the rate of inflow, the percent-of-flow method prevents significant impacts that could result from large withdrawals in the dry season, when estuaries are most vulnerable to the effects of inflow reductions. In the wet season, withdrawals can go up as inflows rise.

As with freshwater stream ecology, management issues regarding freshwater inflows to estuaries have received considerable attention in recent decades. A national symposium on inflows to estuaries was held in 1980 (Cross and Williams 1981), and a special issue of the journal *Estuaries* devoted to freshwater inflows was produced by the Estuarine Research Federation in 2002 (Montagna et al. 2002), which included the paper by Flannery et al. (2002). Since its introduction, the District's percent-of-flow method has received attention as a progressive method for water management in the national technical literature (Alber 2002, Postel and Richter 2003, and the National Research Council 2005) and its use for water supply planning and regulation has been established regionally in District documents (SWFWMD 1992, 2006).

7.4 Identification of a Baseline Period and Appropriate Hydrologic Terms for the Minimum Flow Assessment and Implementation

The percent-of-flow method is a top-down approach in that flow scenarios are run in which withdrawals removed from the daily flow regime of a river and changes in important ecological parameters are simulated to determine at what level of withdrawal significant harm will occur. In doing this analysis, existing withdrawals are added back into the flow record so that a natural flow regime is reconstructed. The effects of any structural or physical changes in the watershed on the river’s flow regime are assessed, so that, if necessary, the effects of these changes can be accounted for in the minimum flows determination. Considering these factors, a suitable baseline period is identified against which the effects of potential flow reductions are evaluated. If necessary, this baseline flow regime may be adjusted to account for structural alterations and changes in the watershed which have altered the flow regime of the river and need to be accounted for in the minimum flows determination.

An evaluation of changes in flows in the Alafia River and relationships to human factors in the watershed are discussed in Chapter Two and in the District's MFL report for the freshwater reach of the Alafia (SWFWMD 2005b). Low flows in the Alafia River were augmented in previous decades by point source discharges and runoff from phosphate mines in the watershed. Since the early 1980s, however, these discharges have largely abated due to changes in the mining industry, including much more efficient water use.

Trend analyses of different flow variables indicate the flow regime of the river has not changed since the mid-1980s, and it was concluded that the river's current flow regime does not require any adjustments to account for human alterations in the minimum flows analysis, other than adding existing withdrawals back into the flow record.

Considering the above, it was concluded the hydrologic record from 1987 to 2003 would serve as a suitable baseline period for the minimum flow analysis of the Lower Alafia River (see Tables 2-9 and 2-10). The beginning year of 1987 was chosen for this is when flow measurements began on Buckhorn Springs. Beginning the baseline in 1987 thus allows inclusion of all the measured flow terms in the Alafia River basin. Although Buckhorn Springs provides only about three percent of the mean annual flow to the total river, it can provide a significant proportion of flow in the dry season. Furthermore, it discharges into Buckhorn Creek, which flows directly into the brackish part of the river, and discharges from the spring may have a significant effect on salinity distributions in the upper and middle regions of the tidal river estuary in the dry season.

The evaluation and subsequent implementation of a minimum flows rule involves linking withdrawals to some hydrologic variable. Optimally, this variable should be measured frequently with a high degree of accuracy and represent a large proportion of the total freshwater inflow to the estuary. As described in Chapter Two, measured inflows to the Lower Alafia River estuary consist of daily flow records at the USGS streamflow gage and semi-weekly to weekly flow measurements from Lithia and Buckhorn Springs. The current water use permit issued to Tampa Bay Water is based on a percent-of-flow approach that uses estimated flow at Bell Shoals Road, which is calculated by multiplying the flows at the UGSG Alafia River at Lithia gage by a factor of 1.117 and then adding the flows from Lithia Springs. Since flows from the springs change fairly slowly, it is reasonable to use the semi-weekly and weekly springflow measurements for regulation of withdrawals. In this report, however, interpolation was done from the periodic springflow measurements to develop a daily flow record for the minimum flows analysis.

Based on these factors, it was concluded that the principal hydrologic term for the minimum flows analysis should be the estimated flow at Bell Shoals Road as calculated above, summed with the flow from Buckhorn Springs. As described in Chapter Two and used throughout this report, this hydrologic term is called freshwater inflow to the upper estuary. Although this flow term involves a watershed ratio factor to estimate ungaged flows between the USGS gage and Bell Shoals Road, this ratio is small and is unlikely cause much error in the day to day estimation of flows in the river. Including flow from Lithia and Buckhorn Springs in the flow term captures the remaining two measured sources of flow in the basin, which can comprise a significant proportion of the flow of the river during dry periods when the estuary is most sensitive to changes in flow.

The estuary also receives ungaged flows from below the USGS streamflow gage, which are estimated to average about twenty-four percent of the total freshwater inflow to the lower river at its mouth (Table 2-3). Without an extensive network of rain gages and a sophisticated runoff model, it is difficult to get accurate estimates of flows from these areas. More importantly, it would take time to generate these estimates, which prohibits their use in a percent-of-flow management strategy for the river that is based on short-term temporal variations in the river's flow. It was therefore concluded that it was not practical to incorporate ungaged flows in the final proposed minimum flows for the Lower Alafia River.

Ungaged flows were included in a final flow term for hydrodynamic model simulations conducted in this report to develop the minimum flow. However, changes in metrics in the estuary generated by this model (e.g., area of salinity zones) were evaluated by taking away withdrawals that were calculated as percentages of freshwater inflow to the upper estuary, with the ungaged flow unaffected. Similarly, the empirical models to predict the response of fish, salinity, chlorophyll a, and dissolved oxygen concentrations in the river use freshwater inflow to the upper estuary as the independent variable. These relationships were all highly significant, with ungaged flows likely contributing to unexplained error in the models. In sum, it was concluded that freshwater inflow to the upper estuary is a measured hydrologic term that explains a large proportion of the variability in the estuary and was a practical and meaningful term for freshwater inflow management.

7.5 Percent Withdrawals and Low-Flow Thresholds

The District evaluated a range of potential percent flow reductions to the lower river, going as high as forty percent reductions in daily flows. Based on an initial analysis of flows in ten percent intervals, the District narrowed the potential withdrawals to a smaller range of flow reduction intervals, finally using intervals of one percent to evaluate the response for some key environmental characteristics. The analysis also involved the evaluation of low-flow thresholds, or a flow rate below which no withdrawals would be allowed. Low-flow thresholds are sometimes warranted because a river is so sensitive to impacts at very low rates of flow that no withdrawals should be allowed. Low-flow thresholds are currently in effect for the water use permit for Tampa Bay Water’s withdrawal from the Alafia River, and also for permits for withdrawals from the Peace 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. In these freshwater streams, low-flow thresholds were based on maintaining minimum water levels for fish passage over shallow shoals in the rivers. This criterion does not apply in estuaries, as tides largely control water levels at low flows and fish passage is usually not a concern. In estuaries, however, there are other factors that can be sensitive to change at low flows and be used to justify low-flow thresholds. However, it may not be necessary to apply low-flow thresholds to all tidal rivers using the percent of flow approach. As described in Chapter 8, a low-flow threshold is proposed for the Lower Alafia River based on the response of a number of variables in the estuary to freshwater inflow.

7.6 Technical Approach for Addressing the Freshwater Inflow Requirements of Resources of Concern

An important component of a minimum flow evaluation for a river or estuary is determining what ecological resources or characteristics associated with the water body are to be protected from impacts that can result from withdrawals. This approach can be expressed as a series of resource management goals. A goal can identify specific groups of organisms such as oysters or sport fishes that require protection, or a goal can identify an ecological process or condition that is related to the rate of inflow, such as the occurrence of hypoxia. Each goal can in turn include a group of ecological indicators, which are resources or characteristics of the resource for which hydrologic requirements can be identified and the effect of reduced flows evaluated.

The nature of the indicators used to assess changes in the resources of concern can vary. For example, the hydrologic requirements of a single species, such as a highly prized gamefish, can be quantified and used as a valuable indicator. Another approach is to identify the suitable habitat for a group of species with similar life histories, and quantify changes in the amount of suitable habitat as a function of water levels or flow. In many cases, relationships between the amount of suitable habitat and flow can be quantified better than the direct response of a species to a change in flow. By providing suitable habitats, it can be reasonably assumed that the hydrologic requirements of the species using those habitats will be met. The identification of habitats can vary, ranging from inundation of woody snags in a freshwater stream to areas within suitable salinity ranges in estuarine ecosystems.

On many water bodies it is desirable to employ a variety of ecological indicators to account for different components of the ecosystem. These indicators should be ecologically important, in that they account for major components or processes within the ecosystem in question. Collectively, they should be as comprehensive as possible and address the hydrologic requirements of several key resources. Since some components of the ecosystem may be more susceptible to flow reductions than others, it is important that sensitive indicators be selected if they are resources of concern or important to ecosystem function. Lastly, the relationship between the indicator and flow should be quantifiable, so that changes in the indicator can be expressed as a function of flow. Such indicators then become quantifiable metrics for which change can be quantified and used to determine the minimum flows.

7.6.1 Identifying Acceptable Levels of Change - Preventing Significant Harm

Once a set of ecological indicators and 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 cases where a direct quantitative relationship can be established between flow and the abundance of one or more species of concern, a level of reduction in the abundance of those species can be established as a threshold for significant harm. Or, as described above, it may be appropriate to base a determination of significant harm on the reduction on the quantity of available habitat. In some cases, there may be obvious inflections in relationships between flows and available habitat or species abundance which can help determine where significant harm occurs. In many cases, however, reductions in abundance or habitat 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 using a habitat based approach 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). This interpretation was based largely on interpretation of Physical Habitat Simulation Model (PHABSIM) results for freshwater stream communities. 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 reductions in habitat and temporal reductions of hydrologic habitat connection.

In a recent review of proposed minimum flows for the Upper Hillsborough River (SWFWMD 2007), the 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.

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 for the determination of significant harm. However, extensive data collection on the Lower Alafia River is continuing and is periodically reexamined in the HBMP process. These data also allow for periodic re-evaluations of relationships of changes in habitat availability to population parameters in order to better determine significant harm.

The question of habitat availability can be avoided if direct predictive relations can be established between flow and the abundance or distribution of the resource 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 a later section, the District used regressions developed by the University of South Florida (Peebles 2005) and the Florida Wildlife Research Institute (Matheson et al. 2005) to predict changes in the abundance for a number of life stages of fish and invertebrate species in the Lower Alafia River as a function of freshwater inflow. Although changes in abundance can vary between wet and dry seasons and years, a change of 15 percent in median conditions, accompanied by evaluation of changes in the overall frequency distributions of abundance values, was considered as the threshold for determining significant harm. The use of a fifteen percent threshold does not preclude the use of other criteria, such as durations of salinity values, if such criteria can be justified for a species or community based on the literature and assessment of those communities within the river. As described in Section 7.6.3, salinity duration criteria were used to assess potential impacts to oyster reefs in the Lower Alafia River.

The minimum flows analysis of the lower river found that some ecological indicators were much less sensitive to the effects of flow reductions than others. Therefore, levels of change that would be considered significant harm were met at lower flow reductions for some indicators than others. As the minimum flows analysis progressed, it was apparent that not all indicators had to be tested for flow reductions in one percent intervals. However, the final minimum flows that are proposed based on close interval analysis of the sensitive indicators were tested against the less sensitive indicators to ensure that significant harm to those resources did not occur as well.

The resource management goals for the minimum flows assessment of the Lower Alafia River are listed below along with a brief description of the analytical approach of how these goals were addressed. The analytical tools used for the minimum flow analysis, such as the LAMFE hydrodynamic model and various regression models, were described in earlier chapters and their application to the assessment of potential flow reductions are also discussed in Chapter 8.

7.6.2 Maintain River Bottom Areas Within Appropriate 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 maintaining food webs that support the nursery function for many sport and commercially important fishes. 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 estuarine dependent fishes that migrate into and use the tidal river as nursery habitat. Numerous studies, including extensive collections from the Lower Alafia River, have shown that salinity gradients exert a strong influence on the distribution of macroinvertebrate communities. Furthermore, many invertebrate taxa that are known to be important prey items for fishes show maximum concentrations in oligohaline and mesohaline zones of tidal rivers.

Accordingly, the maintenance of river bottom areas within biologically relevant salinity zones can be used as a goal for inflow management and the determination of minimum flows. As described in Chapter 6, Principal Component Analysis (PCA) of data for salinity and benthic invertebrate populations in tributaries to Tampa Bay identified transitions in the species composition of benthic invertebrate communities that corresponded to the < 7 psu and 7-15 psu salinity zones (JEI 2007). Similar analyses of data collected solely from the Alafia identified similar salinity zones at < 6 psu and 6-15 psu (Janicki Environmental 2005).

The PCA results from the Alafia were provided to the District in time to be incorporated in the minimum flows analysis. Although many species may show salinity preferences or tolerances that are wider or do not conform exactly to these zones, these bottom salinity zones can be used effectively as indicators to assess the effect of flow reductions on salinity distributions that affect the distribution of benthic macroinvertebrate communities in the lower river. The area of salinity less than 1 psu was also evaluated to determine how a salinity zone approximating tidal freshwater is also affected by changes in freshwater inflow.

To assess changes in salinity zones for benthic macroinvertebrates, the District relied on simulations using the LAMFE hydrodynamic model. The LAMFE model is an effective tool for this purpose, as it can simulate bottom areas in different salinity zones throughout the lower river on a continuous basis for a series of years. The period for which the LAMFE model was run was for 4½ years between May 1999 and December 2003. During this period, average daily values for the bottom area less than 1, 6, and 15 psu were output for various flow reductions. The District then constructed cumulative distribution functions of the amount of bottom area within these salinity zones and evaluated changes that would occur. It was determined that reductions in bottom area greater than 15 percent in any zone would constitute significant harm.

7.6.3 Maintain a Suitable Salinity Regime for Oysters Between River Kilometers 1 and 4.

As described in Chapter 6, oysters are found as small reefs and isolated clumps in the Lower Alafia River between kilometers 1 and 4 (Mote Marine Laboratory 2003). Faculty from the Florida Gulf Coast University with expertise in oyster life history and freshwater inflow relationships visited the Alafia, reviewed the Mote Marine findings, and prepared a report for the District that included recommendations for salinity values to protect the viability of the oyster reefs in the lower river (Volety and Tolley 2006). They concluded that while overall salinities are very conducive for the long-term development and growth of oyster reefs in the Alafia, high flows that exceed 2000-3000 cfs for periods greater than two weeks result in salinities less than 5 psu. These salinities, if they persist for extended periods of time, would pose significant harm to the oyster populations in the Alafia River.

Volety and Tolley (2006) also concluded that while it appears that low flows are presently not a significant factor impacting oyster populations in the Alafia River, salinity conditions exceeding 28 ppt do periodically exist in areas where oyster reefs are present. They cautioned that while low flows resulting in salinities exceeding 28 ppt for periods of less than 1 to 2 months may not cause significant harm, prolonged persistence of these high salinity conditions invite predators such as oyster drills, whelks, star fish, boring sponges, and diseases such as Dermo (caused by *Perkinsus marinus*). It was therefore suggested that salinities at river kilometers 1-4 be maintained between 12 and 25 psu, limiting periods of high (> 28 psu) salinities to < 1 month and those of low salinities (< 5 psu) to less than 2 weeks to ensure survival and growth of oyster reefs in Lower Alafia River.

These recommendations must be viewed within the context that the Alafia is a free-flowing river and variations in salinity rapidly respond to seasonal rainfall and streamflow conditions. With regard to managing withdrawals from the river, flow reductions during high flow periods when salinity values are less than 5 psu should pose no problem for oysters in the river. Withdrawals during the dry season, however, could potentially result in salinity values greater than 28 psu between kilometers 1 to 4 during periods when such high salinity values would otherwise not have occurred. To evaluate this possibility, the District ran simulations of the LAMFE model and the empirical salinity model for the lower river to evaluate to what extent potential minimum flows would increase or extend the period of salinity greater than 28 psu in the oyster zone of the Lower Alafia River.

7.6.4 Maintain Surface Isohaline Locations within Ranges that Protect the Distribution of Low-Salinity Shoreline Vegetation Communities.

The distribution of tidal wetlands in the Lower Alafia River were described in Chapter Three. Mangroves are located below kilometer 4, while salt marshes are largely distributed between kilometers 2.5 and 6.5. Narrow bands of brackish and freshwater marshes are found upstream of kilometer six, while limited amounts of freshwater wetland forests are found primarily upstream of kilometer nine. Compared to other tidal rivers in the region, the spatial distribution and abundance of these brackish and freshwater plant communities are relatively limited in the Lower Alafia due to the river's incised banks and human alterations to the river shoreline. Nevertheless, these low-salinity wetlands provide valuable functions with regard to shoreline stability and wildlife habitat (Odum et al. 1984, FFWCC 2005), and are criteria 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 preformed for this study. It can be reasonably inferred, however, especially for wetlands near the river channel such as the bands of vegetation in the Lower Alafia, 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. 2006).

The assessment of isohaline positions in rivers is a useful tool for assessing potential impacts to wetland communities that could result from river withdrawals. The seasonal locations of isohaline positions can be assessed from empirical data and related to the distribution of vegetation communities. Models can be developed to simulate the movements of isohalines as a function of changes in river flow. 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 (SFWMD 2002, Water Research Associates et al. 2006). 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 bullrush), were most common where median surface salinity values were less than 4 psu. These plants also occurred in somewhat higher salinity waters, but were rarely found where median salinity values exceeded 12 ppt. Similarly, in a study of the Suwannee River estuary, Clewell et al. (1999) found that the transition from sawgrass to saltmarsh species occurred where maximum salinities in the dry season were near 10 ppt.

These findings indicate that the evaluation of shifts in selected isohalines in the river channel can be used to evaluate potential impacts to tidal wetland communities, especially the transitional brackish, low-salinity and tidal freshwater wetlands. As described in Chapter Two, empirical models were developed to predict the locations of five isohalines (0.5, 2, 4, 11, and 18 psu) in surface waters in the Lower Alafia River. Simulated shifts in the median positions of these isohalines that could result from potential minimum flows are presented in Chapter Eight. These results are compared to the changes in the lengths of total shoreline and wetland shoreline upstream of these isohalines in the Lower Alafia River to evaluate potential impacts to wetlands communities, with particular emphasis on the 2, 4, and 11 psu isohalines. As described in Section 7.6.2, the LAMFE model was used to calculate changes in the bottom areas of salinity zones in the river for the protection of benthic macroinvertebrate populations.

7.6.5 Protect the Nursery Function of the Lower Alafia River by Maintaining the Distribution and Abundance of Important Fish and Invertebrate Taxa

One of the most important ecological functions of the Lower Alafia River is its use as a nursery area by estuarine dependent fish and shellfish species. As described in Chapter 6, the lower river serves as a nursery area for the early life stages of several species that comprise economically important sport and commercial fisheries in the Tampa Bay Region, including snook, mullet, red drum, pink crab, spotted seatrout and blue crab. Many other ecologically important fish and invertebrate species that serve as prey (i.e., food) for these economically important species also use the lower river as habitat (e.g., bay anchovies, mojarras, killifishes, amphipods, opossum shrimp). Extensive biological data collection in the lower river by the University of South Florida (Peebles 2005) and the Florida Fish and Wildlife Research Institute (Matheson et al. 2005) found that the distribution and/or abundance of many of these economically and ecologically important species in the Lower Alafia River are affected by the rate of freshwater inflow.

With regard to distribution of these taxa in the river, the typical response to inflow is characterized by the center of abundance (actually 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 or oxygenated waters for fishes, or regions of shallow, oxygenated organic sediments for benthic invertebrates. It is known that the area and volume of the tidal river decrease upstream (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

Both Peebles (2005) and Matheson et al. (2005) 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 equations were developed for taxa collected either by plankton nets, seines, or trawls. 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 in the lower river. The District then compared these upstream shifts in animal distributions with corresponding changes in the area and volume of the lower river to evaluate the extent that reductions in available physical habitat would occur as a result of reduced flows.

As described in Section 6.7, both the USF and FWRI reports 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-square values and fit of the regression to the observed data.

In Chapter 8, various percent flow reductions are applied to the regressions presented by Peebles (2005) and Matheson et al. (2005) to predict abundance or catch-per-unit effort. Changes in the reductions of various key species were evaluated. As would be expected, the amount of change differed between taxa for a given minimum flow reduction. The results for all the selected taxa were reviewed, but with emphasis placed on several species which are particularly important for economic or ecological reasons. As described further in Chapter 8, a flow reduction that resulted in a 15 percent reduction in the catch-per-unit effort of red drum was chosen as the key parameter on which to base the minimum flow, with the abundance or catch-per-unit effort of some taxa changing more and others changing less.

7.6.6 Evaluate Changes in Low Dissolved Oxygen Concentrations in the Lower Alafia River

As described in Section 5.5, the Lower Alafia River has frequent problems with low dissolved oxygen (DO) concentrations. In all segments of the lower river, the occurrence of low DO in bottom waters is related to the rate of freshwater inflow. These relationships differ, however, between the upper and lower segments of the lower river. DO concentrations tend to decrease with rising flow in the lowermost six kilometers of the lower river, but DO concentrations tend to increase with rising flow upstream. Furthermore, the breakpoints at which low DO problems are alleviated differ among the upstream segments, with lower rates of flow required to alleviate low DO problems further upstream. Much of these DO relationships appear related to salinity stratification and the movement of the salt wedge in the river that accompanies changes in freshwater inflow. As inflows decline, the salt wedge moves upstream resulting in low DO concentrations in the upper portions of the lower river. As inflow increase, the salt wedge moves downstream resulting in low DO concentration in the lower portions of the tidal river.

The District evaluated changes in DO in the river as a function of flow using two methods. First, regressions were developed to predict DO concentrations in bottom waters as a function of inflow and water temperature. Using median temperature values for the segments in the lower river, DO concentrations in waters greater than 2 meters deep were predicted for a range of minimum flow scenarios. Although low DO concentrations are common in waters shallower than 2 meters, this method was considered a sensitive test to evaluate the effects of inflows since the deep waters are most prone to problems with low DO concentrations.

The District also used logistic regressions to evaluate the probability of hypoxia in bottom waters in six segments of the lower river as a function of freshwater inflow. As with DO concentrations, the probability of hypoxia increases with rising inflow in the most downstream six kilometers of the lower river, but decreases with rising inflow in the upper portions of the lower river. Given this opposite response, it was difficult to use the occurrence of hypoxia as a minimum flow criterion, unless it could be concluded that the downstream or upstream section of the lower river could be prioritized for management. Since valuable oxygen-dependent resources occur throughout the lower river, such a prioritization could not be made. However, it is valuable to know how hypoxia in the river will respond to minimum flows, and the probability of hypoxia in different segments of the lower river are presented for several minimum flow scenarios in Chapter 8.

7.6.7 Evaluate Changes in the Distribution and Probability of High Chlorophyll *a* Concentrations in the Lower River

As described in Section 5.6 and 6.2, the Lower Alafia River is characterized by very high chlorophyll *a* concentrations and phytoplankton counts. With chlorophyll *a* concentrations frequently exceeding 100 µg/l and sometimes exceeding 600 µg/l, these concentrations are well in excess of what is needed to create productive food webs in an estuarine system. Given the frequent problems that the Lower Alafia River has with hypoxia, and the likelihood that large phytoplankton populations contribute to these conditions, the occurrence of high chlorophyll *a* concentrations in the lower river can be considered a management criterion that should not be appreciably worsened by flow reductions.

In contrast to DO, there are no opposite responses of chlorophyll *a* to freshwater inflow in the lower river. Logistic regression analysis found that the probability of high chlorophyll *a* concentrations (> 30 µg/l) had no significant relationship with inflow in the most upstream and downstream river segments, but in all other segments the probability of high chlorophyll *a* rises as flows decline. Since nutrients are usually in excess over much of the lower river, this response appears related to increases in residence time at low flows which allow large phytoplankton blooms to develop.

The District's analysis also found that as freshwater inflow goes down, the location of the peak (maximum) chlorophyll concentration in the river tends to move upstream. Some evidence indicates the position of the zone of maximum phytoplankton abundance can influence the distribution of some zooplankton and fishes (Friedland et al. 1996, Peebles 2005). Therefore, the upstream movement of the chlorophyll maximum away from the broader downstream regions of the estuary to more narrower upstream reaches could potentially result in a loss of secondary production. Data from the Lower Alafia also show that as flows decline and the chlorophyll maximum moves upstream, the concentration of the maximum chlorophyll value increases as well. In other words, the highest chlorophyll concentrations in the lower river tend to occur in the upper portion of the lower river during low flows. Since the occurrence of low DO in this portion of the river also increases at low flows, excessive upstream movement of the chlorophyll maximum is a criterion for inflow management.

Based on these findings, the District applied the logistic regressions presented in Section 5.6.8 to the minimum flow scenario to determine to what extent the probability of high chlorophyll *a* concentrations (>30 µg/l) would be increased in different segments of the Lower Alafia River. Similarly, the regression presented in Figure 5-77 was used to predict the movement in the position of the chlorophyll maximum as a result of minimum flow scenarios. Finally, graphical analyses were used determine if either the location or concentration of the chlorophyll maximum show any breakpoints at low flows which could be used to determine a low-flow threshold for the cessation of withdrawals.

Chapter 8

Results of the Minimum Flows Analysis

8.1 Introduction

Minimum flows for the Lower Alafia River were determined by evaluating the effects of a series of potential percent flow reductions that were applied against the baseline flow regime of the lower river. As described in chapter 7, the baseline flow regime had existing withdrawals from Tampa Bay Water and Mosaic Fertilizer added back into the flow record. Where possible, all analyses of the effects of withdrawals used the entire baseline period (1987 to 2003), but simulations using the LAMFE model were restricted to a four and one-half year period between May 1999 and December 2003, for this is when data for all boundary conditions for the model were available.

The LAMFE model and various empirical regression models were used to evaluate the response of a group of quantifiable ecological indicators (metrics) to a series of percent flow reductions. These indicators correspond to the management goals and resources of concern identified for the Lower Alafia River in Chapter 7. Some ecological indicators were more sensitive to the effects of flow reductions than others, thus levels of change that would be considered significant harm were met at lower flow reductions for these resources. The initial analysis of potential minimum flow scenarios involved the simulation of flow reductions in ten percent increments between 10 percent and 40 percent of baseline flows. These results were examined to determine in what range of flow reduction significant harm would occur to the most sensitive resources in the lower river. Percent flow reductions in one percent intervals were then simulated within that range.

As described later in this chapter, the most sensitive indicators to reductions in freshwater inflow were the abundance and distribution of some key fish and invertebrate species. The distribution and abundance of these species pertain directly to one of the Lower Alafia River's most valuable resource functions, that being its role as a nursery area for estuarine dependent fish and shellfish of sport and commercial importance. Significant harm was therefore determined based on changes in the abundance of some of these species, in particular the abundance of mysid shrimp (*Americamysis almyra*) and juvenile red drum (*Sciaenops ocellatus*). Mysid shrimp are a key prey item (i.e., food source) for the juvenile stages of many estuarine dependent fishes, and red drum is one of the most highly prized sport fish species in Florida. As the minimum flows analysis progressed it was apparent that allowable percent flow reductions determined for these key indicator species would not cause significant harm to the less sensitive ecological indicators in the lower river.

Based on these findings, the results for the assessment of the abundance and distribution of key fishes and invertebrates are presented first below. The minimum flows that are proposed based on close interval analysis of these relationships are then applied to the other, less sensitive indicators in the river to quantify how much they will change as a result of the proposed minimum flows. The predicted changes in these other indicators are also shown for the suite of flow reductions from 10 to 40 percent to demonstrate their sensitivity to changes in freshwater inflow.

8.2 Predicted Changes in Abundance for Flow Reduction Scenarios that use the Existing Permitted Diversion Capacity

The majority of results presented for the flow reduction scenarios in this report were simulated assuming there was no limit to the diversion capacity for withdrawals from the Alafia River. For example, if the baseline flow was 5,000 cfs for a given day and a 20 percent flow reduction was being simulated, then the flows were reduced by 1,000 cfs. Although this is probably unrealistic for this specific day, the effect of an unlimited withdrawal capacity is dampened and may not be so unrealistic when viewed over the entire flow range of the river. For example, inflows to the upper estuary were over 1,113 cfs only five percent of the days during the 1987-2003 baseline. A 20 percent flow reduction from 1,113 cfs yields a diversion of 222 cfs. For comparison, the capacity of the diversion facility on the smaller Little Manatee River to the south is 190 cfs. It is not inconceivable that large withdrawals could be considered for the Alafia River in the future depending on evolution of water supply plans in west-central Florida.

Flow reduction scenarios were also evaluated that limited the diversion capacity to that of the existing permitted water supply facilities currently on the Alafia River. The existing diversion capacity for the Tampa Bay Water facility on the Alafia is 80 cfs, so percent withdrawals from 10 to 40 percent of baseline flow were simulated assuming the continuation of this facility. Withdrawals from Lithia and Buckhorn Springs were added to this capacity by assuming the existing demand of approximately 7.5 cfs from Lithia Springs. Withdrawals from Buckhorn Springs were not added to this total, as Buckhorn Springs is largely used as a back-up supply source when withdrawals cannot be made for Lithia Springs. So, in addition to flow reduction scenarios with unlimited withdrawal capacity, flow reduction scenarios were also run assuming a maximum diversion capacity of 87.5 cfs from the Alafia River. The relevance of the results that employed the existing permitted diversion capacity to the proposed minimum flow rules are discussed in Section 8.4.3.

8.3 Low-flow threshold Analysis

A second component of the District's minimum flows analysis was the evaluation of a low-flow threshold, or a low rate of freshwater inflow below which no surface-water withdrawals would be allowed. Low-flow thresholds have been implemented for minimum flow and level rules adopted for the freshwater reaches of the Myakka and Middle Peace Rivers and the freshwater reach of the Alafia River upstream of Bell Shoals Road. A low-flow threshold of 124 cfs is also required in the water use permit issued to Tampa Bay Water for withdrawals from the Alafia River at Bell Shoals Road. This regulatory threshold is based on the estimated flow at Bell Shoals Road, which is similar to the freshwater inflow to the upper estuary flow term used in this report, except that it does not include flows from Buckhorn Springs.

Although the abundance of certain fish and invertebrate species show the greatest change resulting from percent flow reductions simulated over the entire flow range of the river, other indicators exhibit responsive relationships with freshwater inflow over a more restricted range of flows (e.g., 0 to 200 cfs). In some cases, there are inflections or apparent breaks in the relationship of these indicators with freshwater inflow within a narrow range of flows. As described in chapter 5, this type of response was pronounced for chlorophyll *a* and dissolved oxygen concentrations at low rates of inflow. Other parameters such as residence time and the abundance of certain fishes and invertebrates also displayed nonlinear responses to flow, being most sensitive to changes at low flows. Consequently, implementation of a low-flow threshold would prevent any changes to these indicators over the flow range in which they are most sensitive to impacts. The justification for a low-flow threshold of 120 cfs for freshwater inflow to the upper estuary is presented below. This threshold is then applied in the analysis of potential percent flow reductions to determine what effect the implementation of this threshold would have on predicted changes in the resources of concern.

Several lines of evidence indicate that problems with extremely high chlorophyll *a* concentrations are most pronounced at low flows. Graphical analyses indicate that the incident of very high chlorophyll concentrations (> 100 µg/l) were most common in the upper segments of the lower river at flows less than 100 cfs (Figures 5-63 and 5-64). Logistic regression curves of the probability of chlorophyll *a* concentrations greater than 30 µg/l show an increasing rate of occurrence between flows of 100 and 300 cfs (Figure 5-70). The location of the chlorophyll maximum showed a significant nonlinear relationship with flow, with the scatter plot of the data indicating a possible breakpoint in the relationship near 120 cfs (Figure 5-71).

The occurrence of supersaturation of dissolved oxygen (DO) concentrations also indicates the presence large phytoplankton populations in the river. Graphical analyses indicate a breakpoint in the occurrence of DO supersaturation (>120 percent saturation) at flows less than 100-120 cfs at segments between kilometers 6 and 15 (Figure 5-46). Logistic regression of the probability of supersaturation with inflow also indicates a strong increase in the probability of supersaturation below flows in the range of 100 – 200 cfs, with the steepest part of the curves occurring below 100 cfs (Figure 5-48). Collectively, these chlorophyll *a* and DO supersaturation values indicate that high phytoplankton counts in the lower river are most common at very low flows, and are particularly sensitive to changes in freshwater inflow below flow rates of about 100 – 150 cfs.

Bottom dissolved oxygen (DO) concentrations had a significant relationship with inflow in five of the six three-kilometer segments in the lower river. Between kilometers 6 and 15, bottom DO values declined with decreasing flow (Figure 5-39). Graphical analyses of the data indicate a dramatic increase in low DO concentrations when inflows go below about 150 cfs in kilometer 12 to 15, with a piecewise logistic regression for this zone indicating an inflection at 200 cfs below which DO was more sensitive to changes in flow (Figure 5-42). Though a significant relationship with inflow was not found between kilometers 15 and 18, graphical analyses indicate that low DO values are restricted to flows less than about 150 cfs in this segment (Figure 5-39). Logistic regression of the proportion of bottom DO less than 2 mg/l showed a steep slope at flows less than 200 cfs for segments between kilometers 12 and 18 (Figure 5-43).

The occurrence of low DO values in the upper river is related to density stratification (Figure 5-40). Empirical models that predict isohaline locations as a function of freshwater inflow show that the response of these isohalines is nonlinear, with isohaline movements being most sensitive to changes at low flows (Figures 5-24 and 5-26). As flow declines, the salt wedge moves upstream, resulting in increased density stratification which contributes to reductions in DO concentrations in bottom waters.

Implementation of a 120 cfs low-flow threshold would prohibit withdrawals from causing any impacts to DO concentrations in the upper portions of the river when those concentrations are most susceptible to the effects of flow reductions. Though DO is negatively correlated with flow in the two most downstream segments of the river (kilometers 0 to 6), the slope of these relationships are fairly flat in kilometers 1 to 3, but somewhat steeper for kilometers 3 – 6 (Figure 5-43). Implementation of a low-flow threshold would allow DO concentrations to fluctuate solely in response to freshwater inflow at flow rates less than 120 cfs. Compared to a scenario of allowing withdrawals at low flows, implementation of a low-flow threshold would have a positive effect on DO concentrations in the upper portion of the lower river, while DO concentrations could undergo some slight decreases in the lowermost portion at flow rates below 120 cfs.

Finally, as described in Chapter 6, some of the significant relationships of fishes and invertebrates with inflow were highly nonlinear, with the abundance of a number of key species (e.g., pink shrimp, red drum, tidewater mojarra) increasing most rapidly with inflow at low flows, peaking at mid-range flows, and declining at high rates of flow. Implementation of a low-flow threshold would allow small, periodic flow pulses within prolonged periods of inflow to have the maximum beneficial effect on the abundance of these species.

An opposite response in freshwater inflow is observed for the comb jelly, *Mnemiopsis mccradyi*, which increases in abundance as flow decline. As described in Chapter 6, *Mnemiopsis* is a predator on zooplankton and larval fish and its presence in large numbers can be detrimental to the food supply and productivity of larval and juvenile fish. *Mnemiopsis* has been shown to be most abundant in tidal rivers in southwest Florida during times of low flow, as higher inflow rates tend to displace these gelatinous predators from the tidal rivers (Peebles, 2005). Although it is difficult to quantify the precise effect that the implementation of a low-flow threshold would have on *Mnemiopsis* in the Lower Alafia River, a low-flow threshold would be a conservative measure to not worsen conditions that contribute to blooms of *Mnemiopsis* during times of low flow.

In summary, a number of water quality and biological indicators in the Lower Alafia River are most sensitive to changes in freshwater inflow at low flow rates, and the implementation of a low-flow threshold for the Lower Alafia River is clearly justified. Various lines of evidence indicate a low flow in the range of 100 to 200 cfs could be valuable for resource protection, although the response of many indicators becomes more acute as flows go lower. Based on graphical and regression analyses of chlorophyll *a,* DO supersaturation in surface waters, bottom DO concentrations, hypoxia, and the inflow-abundance relationships of a number of key fish and invertebrate species, a flow rate of 120 cfs is proposed as a logical breakpoint to establish a low-flow threshold.

This low-flow threshold corresponds very closely with the 124 cfs low-flow threshold currently mandated as part of the water use permit for Tampa Bay Water. However, the 120 cfs low-flow threshold proposed in this report includes flows from Buckhorn Springs, which allows slightly more water use. For example, when flows for the low-flow threshold are at 120 cfs, the regulatory limit for Tampa Bay Water would average about 132 cfs, so they could stay on the river slightly longer. However, to stay consistent with other minimum flow applications, the 120 cfs low-flow threshold proposed in this report is a rate below which withdrawals cannot reduce flow. For example, if the flows were 124 cfs, the water users would get 4 cfs. Tampa Bay Water is currently not regulated in this manner, as they get 12.4 cfs at a flow rate of 124 cfs at Bell Shoals. In sum, the inclusion of Buckhorn Springs in the low-flow threshold versus its method of implementation cancel each other out to some degree with regard to Tampa Bay Water, so that the effect of the 120 cfs low-flow threshold for the minimum flow is very similar to the current regulation for that water use permit. After adoption, the low flow cutoff for that permit should be changed to comply with the low-flow threshold established for the minimum flow.

The proposed low-flow threshold would also apply to other existing and all future water users on the river, including the current withdrawals from Lithia and Buckhorn Springs by Mosaic Fertilizer, Inc. This longstanding water use permit has never had a low-flow threshold applied to it. However, as described in Chapter Two, flows from Lithia and Buckhorn Springs can comprise a substantial proportion of the total flow in the river during dry periods. Application of a 120 cfs low-flow threshold would therefore preserve the beneficial effects of flow from the springs when it is most critical to the flow regime of the lower river.

With regard to the frequency of implementation, freshwater inflow to the upper estuary was below 120 cfs eighteen percent of the time during the baseline period. The average percent of days below 120 cfs by month is shown in Figure 8-1, in which three four-month periods are apparent. The river was rarely below the low-flow threshold during the four month period from July through October. Although rainfall declines in October, flows tend to remain high during that month following the summer wet season (Figure 2-7). Inflows were below the low-flow threshold between 14 and 17 percent of the time during the winter period from November through February. The time below the low-flow threshold shows a clear peak in the months from March through June, ranging from 24 percent in March to 51 percent in June. The high frequency of implementation of the low-flow threshold during the spring dry season constitutes a protective measure for the estuary for this is when water temperatures are rising, which contributes to the occurrence of low DO concentrations. By preventing the upstream migration of the salt wedge during the driest portions of the spring, the low-flow threshold helps prevent hypoxia in the upper reaches of the tidal river when it is most sensitive to its effects.

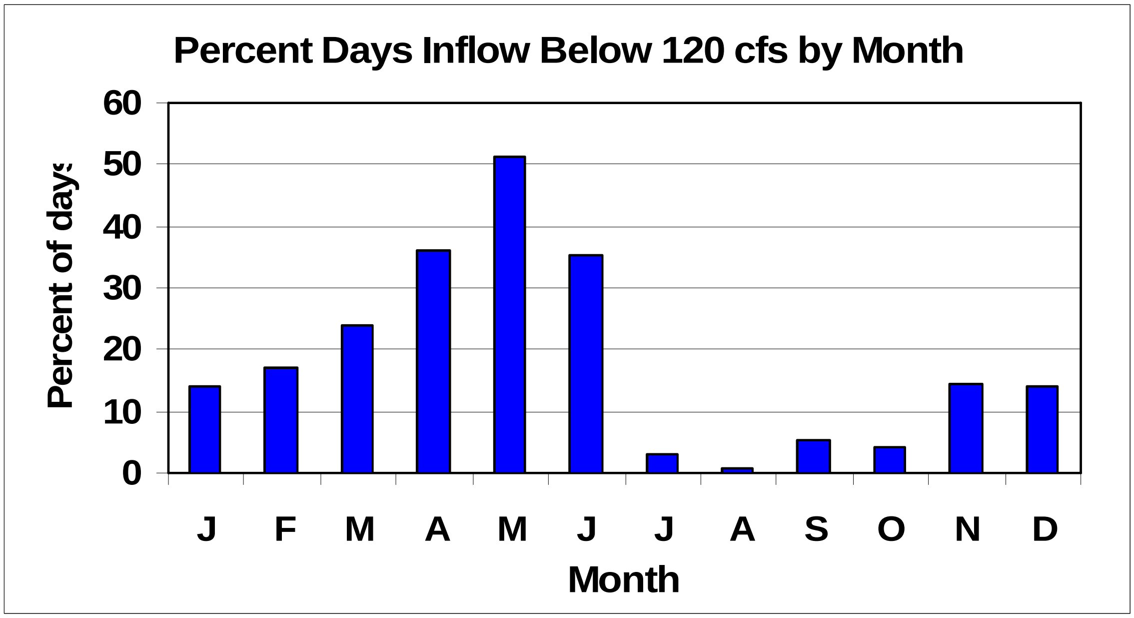


Figure 8-1. Percent of days per month that freshwater inflow to the upper estuary was below 120 cfs for the period 1987 – 2003.

As described in Chapter 6, biological data also show that the spring is a time of maximum recruitment of larval fishes into the tidal river estuary (Figure 6-27). Preventing changes to salinity distributions, residence times, and other physicochemical characteristics of the estuary during the driest periods of the spring could have benefits to those organisms whose abundance and distribution are related to these physicochemical characteristics.

Percent minimum flow scenarios are presented in the following section with and without application of the 120 cfs low-flow threshold. Comparison of these results demonstrates the relative effect of the low-flow threshold on the response of various ecological indicators to potential minimum flows.

8.4 Response of Fishes and Invertebrates to Freshwater Inflows

As described in Chapter 6, extensive data collection efforts and interpretive analyses have been conducted that examine relationships between freshwater inflows and the relative abundance (abundance) and distribution of fishes and selected macroinvertebrates in the Lower Alafia River estuary. These studies were conducted by the University of South Florida College of Marine Science for organisms captured by a 505 micron plankton net (Peebles 2005) and by the Florida Fish and Wildlife Research Institute for organisms captured by seines and trawls (Matheson et al. 2005).

Both of these efforts included the development of regressions between freshwater inflows and the distribution and abundance of different age/size classes for a number of species of fish and macroinvertebrates in the Lower Alafia River. These species included several species of sport or commercial importance, such as blue crab, pink shrimp, spotted seatrout, mullet, and red drum. These studies also included regressions to predict the distribution and abundance of a large number of fish and invertebrate taxa that serve as prey or forage for economically important species, such as grass shrimp, mysid shrimp, and a large number of numerically dominant fishes in the river including bay anchovies, hogchokers, killifishes, and mojarras (see Sections 6.6.6, 6.6.7, 6.6.11 and 6.6.12).

Regressions for different size/age classes for a number of species were selected for the minimum flows analysis (Table 8-1). This included five species sampled by plankton nets and nine species sampled by either seines or trawls. More than one size/age class was examined for five of these taxa. In the case of mysid shrimp *(Americamysis almyra*), the identification of juveniles could not be taken to the species level, so these stages are listed to genus. However, for the sake of brevity in this report, the term species is used to denote the taxa and age/size class combinations listed in Table 8-1. Reference to a particular stage, size class, or gear is used where necessary to identify the particular species/age-size class listed in Table 8-1 that is being discussed.

Table 8-1. Regressions between freshwater inflow and the estimated abundance or relative abundance of species-age/size classes that were used in the mimimum flow analysis. Regressions for plankton taxa taken from Peebles (2005) and regressions for taxa collected by seine or trawl taken from Matheson et al. (2005), except for red drum which were provided by MacDonald (2007). The flow term is the number of days used to calculate the preceding mean flow. Both abundance and flow data were natural log (ln) transformed in the regressions. DW denotes possible serial correlation based on p<0.05 for the Durbin-Watson statistic. Abundances for plankton taxa noted by asterisks were computed using regressions that did not include data for high-flow wash-out dates. Abundances for seine or trawl samples marked by double asterisks are predicted for the lower river zone only.

USF Plankton Sampling

Taxon	Common Name	Gear	age/size class	Months	Response	df	DW	r^2	Flow Term (days)
Americamysis almyra*	mysid shrimp	plankton	adults	all	linear	27	x	0.36	90
Americamysis almyra	mysid shrimp	plankton	adults	all	linear	44	x	0.13	117
Americamysis sp.*	mysid shrimp	plankton	juveniles	all	linear	37		0.21	60
Palaemonetes pugio	daggerblade grass shrimp	plankton	adults	all	linear	25		0.24	70
Mnemiopsis mccradyi	comb jelly, ctenophore	plankton	all	all	linear	20		0.45	16
Cynoscion arenarius	sand seatrout	plankton	juveniles	all	linear	27		0.14	30
Anchoa mithchilli*	bay anchovy	plankton	juveniles	all	linear	38		0.1	120

* regression with high flow wash-out dates removed

FWRI Seine and Trawl Sampling

Taxon	Common Name	Gear	age/size class	Months	Response	df	DW	r^2	Flow Term (days)
Farfantepenaeus duorarum	pink shrimp	seines	all	Jul. to Mar.	quadratic	96	x	0.16	63
Farfantepenaeus duorarum**	pink shrimp	trawls	17 - 36 mm	Aug. to Mar.	quadratic	40	x	0.27	70
Anchoa mithchilli	bay anchovy	trawls	>=36 mm	all	quadratic	58	x	0.13	35
Fundulus seminolis	seminole killifish	seines	<= 45 mm	Jun. to Nov.	linear	33		0.39	343
Fundulus seminolis	seminole killifish	seines	> 46 mm	all	linear	59	x	0.34	343
Eucinostomus harengulus	tidewater mojarra	seines	40 to 70 mm	Jul. to May	quadratic	52	x	0.17	42
Diapterus plumieri	striped mojarra	seines	<= 45 mm	Jun. to Sep.	quadratic	21		0.14	140
Sciaenops ocellatus**	red drum	seines	<= 39 mm	Oct. to Jan.	quadratic	42	x	0.2	42
Sciaenops ocellatus**	red drum	seines	40 to 150 mm	Nov. to May	quadratic	75	x	0.22	168
Gobiosoma bosc	naked goby	seines	>= 20 mm	May to Mar.	quadratic	54	x	0.17	196
Microgobius gulosus	clown goby	seines	all	May to Oct.	quadratic	32		0.23	301
Trinectes maculatus	hogchoker	seines	<= 29 mm	all	linear	59	x	0.18	168
Trinectes maculatus	hogchoker	trawls	<= 29 mm	all	quadratic	58	x	0.13	147

** regressions for lower river zone only

The criteria for inclusion of a species in the minimum flows analysis was that it was an estuarine resident or estuarine dependent species which had a positive relationship with inflow, over at least a portion of the river's natural flow range. Reductions of freshwater inflows could therefore potentially result in unacceptable reductions in the abundance of these species.

One exception to these criteria was the comb jelly, *Mnemiopsis mccradyi*, which has a negative response with freshwater inflow (high flows reduce abundance). As previously discussed, *Mnemiopsis* is a predator on zooplankton, fish eggs and larvae that is generally most abundant in rivers in west-central Florida during low inflows (Peebles 2005). Reductions of inflows could, therefore, result in unacceptable impacts to the fishery resources of the river by increasing *Mnemiopsis* abundance. Potential increases in *Mnemiopsis* abundance were therefore evaluated in the minimum flows analysis.

The studies by USF and FWRI found that a number of freshwater fishes and invertebrates have positive relationships with freshwater inflows, due to the expansion of the freshwater zone as inflows rise (see Figure 5-21). Freshwater taxa, however, were not considered critical indicators for this minimum flows analysis, as it was assumed that abundant freshwater habitats would be found upstream in the river even during the lowest flow conditions. It is reiterated, however, that tidal freshwater segments are important and distinct components of the tidal river ecosystems, including the Lower Alafia. Current velocities in the tidal freshwater segments can be much slower than in the upstream freshwater reaches, allowing some freshwater zooplankton (e.g., copepods and cladocera) to be much more abundant in the tidal freshwater zone than further upstream.

Although it was concluded that estuarine species would be the critical indicators evaluated for the minimum flows analysis of the lower river, some inferences about potential impacts to freshwater species can be gained by the simulation of salinity zones presented in Section 8.6, which includes results for reductions in the area and volume of the <1 psu salinity zone. As will be discussed, those results indicate that minimum flows that are determined based on impacts to estuarine resources in the brackish portions of the lower river will protect the resources in the tidal freshwater zone as well.

The results of the regression analyses to predict abundance and distribution of estuarine organisms in the lower river are handled sequentially below, with the results for the abundance analysis presented first. The fish and invertebrate taxa that were used for regression analysis of relative abundance with freshwater inflows are listed in Table 8-1, along with the degrees of freedom, flow term, and coefficient of determination values (r^2) for each regression. A more complete list of regression parameters (e.g., slope, intercepts) and scatter plots with the fitted lest squares lines are presented in the reports by Peebles (2005) and Matheson et al. (2005), with the regression for red drum juveniles taken from MacDonald et al. (2007). Those reports also present detailed information on the form of the regressions and how the length of the flow terms (in preceding days) were chosen for each species-age/size class. Scatter plots and regressions for the species - age/size classes in Table 8-1 are also presented in Appendix 8A of this District report, taken from the reports by Peebles (2005), Matheson et al. (2005), and McDonald et al. (2007).

8.4.1 Taxa Collected by Plankton Tows

Four taxa collected by plankton tows that are listed in Table 8-1 were proposed by Peebles (2005) as ecological indicators for the minimum flows analysis. These are the mysid shrimp (*Americamysis almyra*), the daggerblade grass shrimp (*Palaemonetes pugio)*, and juvenile stages of the sand seatrout (*Cynoscion arenarius*) and the bay anchovy (*Anchovy mitchilli*). Regressions are listed for both the juvenile and adult stages of mysid shrimp. The adults are identified as *Americamysis almyra,* with the juveniles simply identified as *Americamysis* species, although most of these are probably *Amerciamysis almyra*. Since both juvenile and adult mysid shrimp are abundant in the river, it was concluded that analyses of both stages was warranted.

As described in Chapter 6, Peebles was able to generate estimates of total abundance of these taxa in the river channel for each of the sampling dates and then regress these values against corresponding freshwater inflows. Peebles observed that some of the regressions between inflow and abundance could be improved when data collected during high flow events were removed from the analysis. These high flow events, called wash-out events, were when high flows displaced the target species from the tidal river reducing their abundance, although their response to inflow was positive at lower flow ranges. As discussed in Section 6.6.7, Peebles identified wash-out events as when the 7 psu isohaline was downstream of kilometer 2. inRather than try do duplicate this occurrence in the baseline flow record for the minimum flows analysis, the flows over which the non-washout regressions were applied were limited to the flow ranges illustrated in Figure 3.8.4 of the Peebles report. In cases where high flow wash-out events were not incorporated, the remaining regressions still covered most of the flow range of the river. In the case of mysid shrimp, the regression that included wash-out dates was also applied, although it had a considerably lower r^2 value.

It should also be noted that the regressions developed by Peebles were developed from observations when the species was present in the river (collections with zero abundance were not included in the regressions). Thus, the regressions for plankton taxa in Table 8-1 predict the abundance of these taxa during times when they are present in the river. This was considered to be acceptable for the minimum flows analysis, as this still allows for the calculation of changes in relative abundance of these species as a function of freshwater inflow.

Peebles (2005) reported that several forms of the regressions were examined for the plankton taxa, with linear models with natural log (ln) transformation of both the inflow and abundance variables giving the best model. Peebles (pages 45 and 46) discusses how the ranges of values in the intercept and slope terms of these regressions reflect how these taxa respond to freshwater inflows. Similarly, the shape of the response curves can be used to identify inflow ranges which have proportionally large influences on abundance. For example, the predicted curves for abundance versus freshwater inflow is plotted for four plankton taxa using untransformed data in Figure 8-2. Mysid shrimp have a near linear response to freshwater inflow (excluding wash-out dates), while daggerblade grass shrimp and sand seatrout are more sensitive to changes at

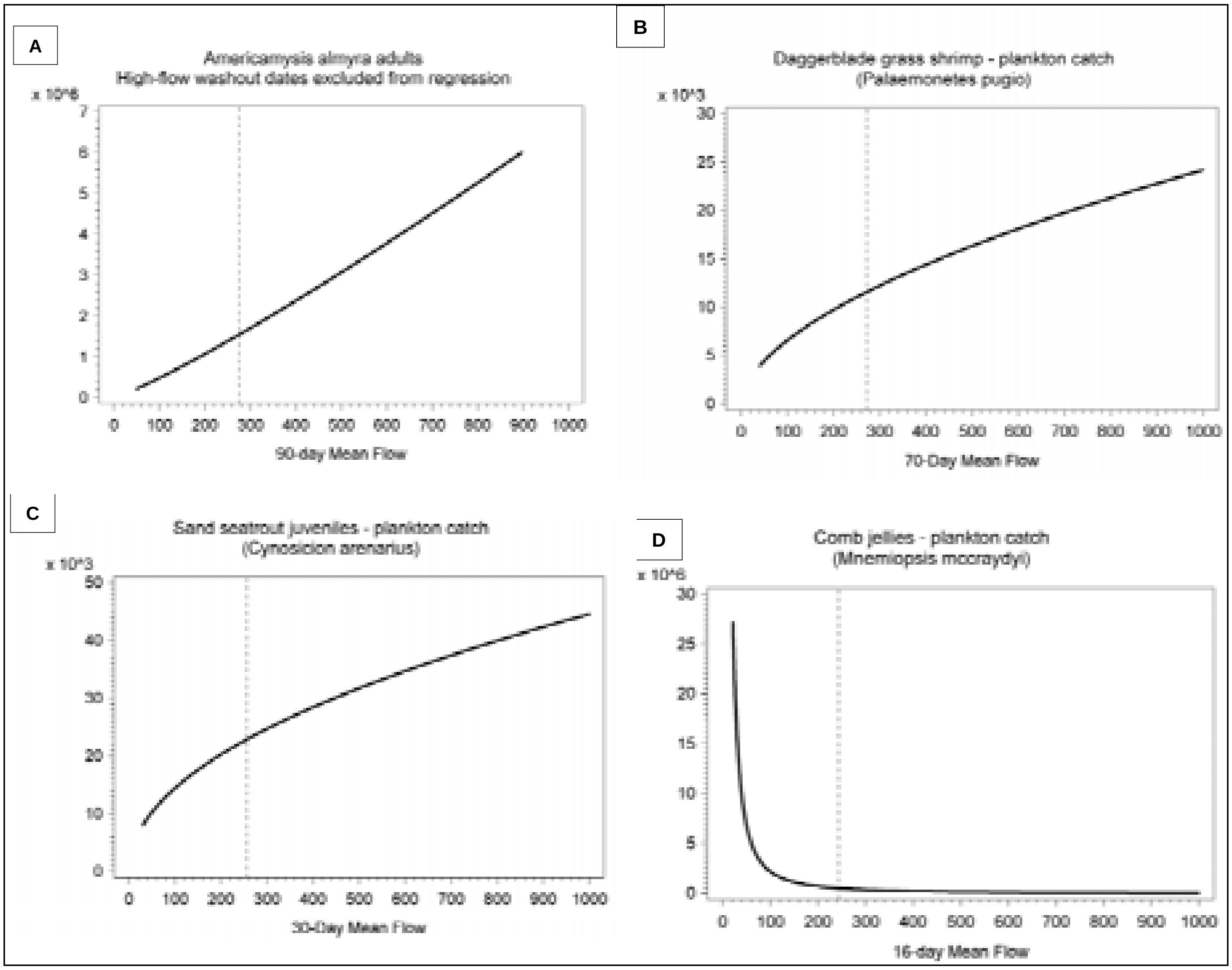


Figure 8-2. Predicted number of individuals in the river channel vs. the corresponding flow term in regressions listed in Table 8-1 for four taxa collected by plankton net (A = *Americamysis almyra*, B = *Palaemonetes pugio*, C = *Cynoscion arenarius*, D = *Mnemiopsis mccradyi*) . Vertical reference lines represent the median value for each flow term for the period 1987-2003.

low inflows. *Mnemiopis* has a strongly nonlinear, inverse relationship with flow, with rapid changes in abundance predicted at flows less than 100 cfs.

8.4.2 Taxa Collected by Seines and Trawls

The regressions developed by FWRI for taxa collected by seine and trawls predict relative abundance as catch per unit effort, which is the number of animals present per 100 square meters (m^2) of area sampled by that specific gear. For brevity, these values are sometimes referred to as abundance in this report. Though it was not possible to extrapolate these values to estimates of total abundance in the river, changes in relative abundance are equally useful for assessing potential changes in fish populations as a function of changes in freshwater inflow.

The regressions for the taxa collected by seines or trawls by the FWRI were divided into specific size classes for a number of species to better differentiate possible ontogenetic shifts in salinity relations of these species as they mature. In contrast to the plankton data, FWRI included zero catch observations in the data used to develop the abundance regressions. The regressions for some species were limited to specific ranges of months when that species typically occurs in the river. For some species the abundance regressions were restricted to the river zone in which the species was typically found. The months and the zones of the river to which these regressions apply are listed for the seine and trawl taxa used in the minimum flows analysis in Table 8-1. As described in Section 6.6.12, the regressions presented for red drum juveniles by Matheson et al. (2005), were later replaced by regressions by regressions in which the catch of juvenile red drum were adjusted to account for the presence of hatchery raised fish (MacDonald 2007). The final regressions for red drum juveniles presented in Table 8-1 and Figure 8-3 are for wild fish which were spawned in the bay or gulf.

FWRI also investigated different forms of regression models, and resolved that either linear or quadratic models using natural log transformed flow and biological data yielded the best results (Table 8-1). These model forms reflect the different responses to freshwater inflow exhibited by the various taxa. For a number of species described by quadratic models, abundance increased rapidly at low flows, peaked at intermediate flows, and declined at higher flow rates. Examples of this type of response are shown in Figure 8-3 for different size classes of pink shrimp, red drum, and the clown goby. The medians of the flow terms used in the regressions for these species are also shown to give some perspective of the flow ranges over which these different responses occur. Of these three taxa, the rapid increase at low flows was most pronounced for pink shrimp and the clown goby, with the inflection in the flow relationship occurring below the median flow (Figures 8-3 A and D). The increase in abundance at low flows was more gradual for juvenile red drum, but the reduction at high flows was also more gradual and occurred at a much higher rate of flow (Figure 8-3C). Juvenile red drum thus have a positive relationship with inflow over a larger flow range than the other two species.

A positive response over the entire flow range was observed for the Seminole killifish, which is an estuarine resident species that spends its entire life cycle in the tidal river (Figure 8-B). This type of relationship is described by the linear models presented by Matheson et al. (2005) that are listed in Table 8-1. This is the same model form as presented by Peebles (2005), and although it produces a consistent relationship with flow (always positive or negative), the relationship may be near linear or strongly nonlinear depending on the value of the slope term.

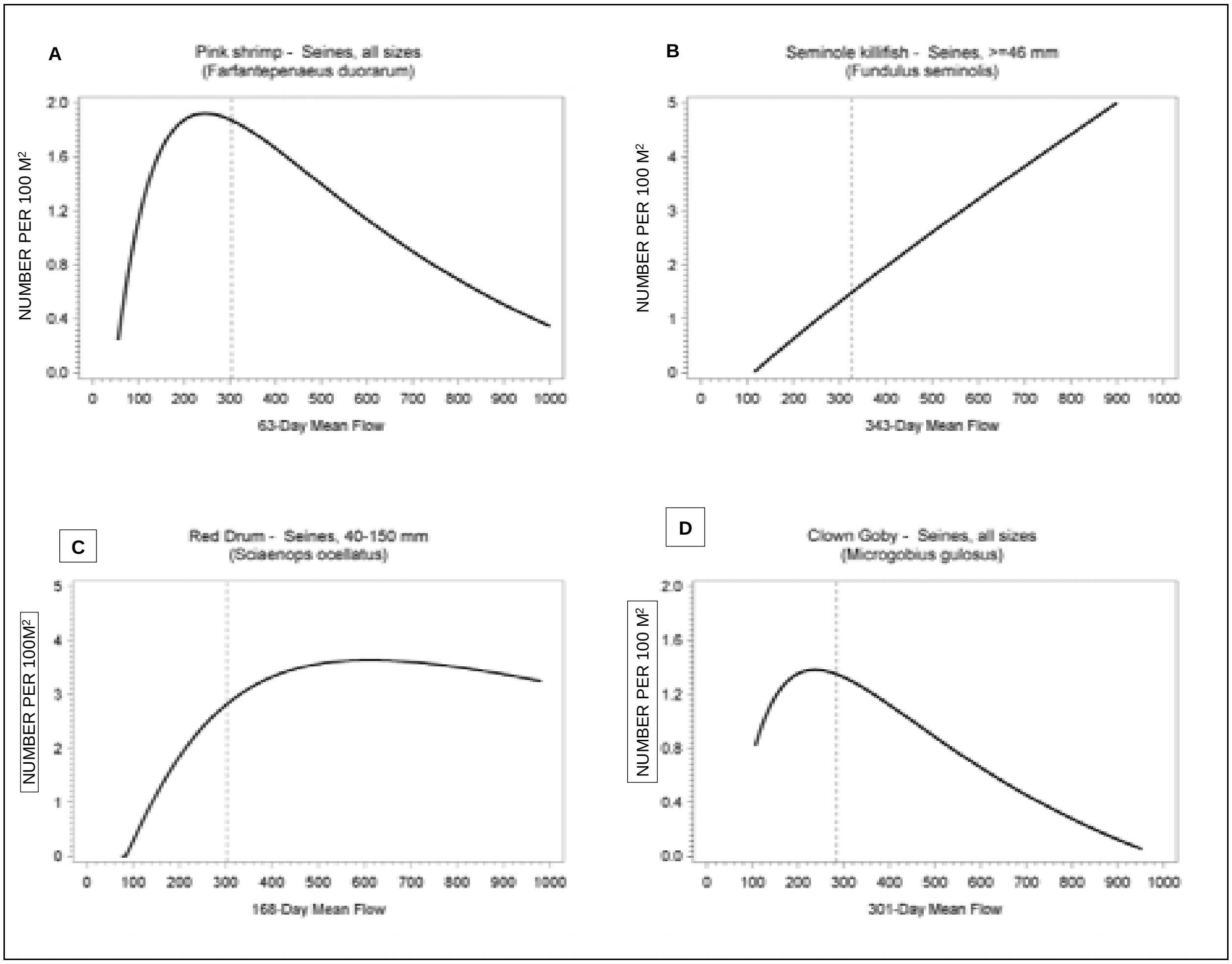


Figure 8-3. Predicted number of individuals (catch-per-unit-effort) vs. the corresponding flow term in regressions listed in Table 8-1 for four taxa collected by seine or trawl (A = *Farfanepenaeus duorarum*, B = *Fundulus seminolis*, C = *Scieanpos ocellatus*, D =*Microgobius gulosus*). Vertical reference lines represent the median value for each flow term for the period 1987-2003.

8.4.3 Applications of Regressions in the Minimum Flows Analysis

Inspection of the r^2 values in Table 8-1 and the scatter plots of the regressions shown in Peebles (2005) and Matheson et al. (2005) indicate that some of the models explained considerably more variation due to inflow than others. R-square values for the taxa listed in Table 8-1 ranged from 0.10 to 0.45, meaning that between 10 percent and 45 percent of the variation in abundance could be explained by freshwater inflow. It is not surprising that these r^2 values are relatively low, considering that the relationships between biological variables and inflow are complex and many factors can affect fish abundance. Regardless, these regressions indicate that freshwater inflow can have a significant effect on the abundance of a number of species, albeit the response to inflow is stronger for some species than others.

For many of the regressions, both Peebles (2005) and Matheson et al. (2005) reported that the Durbin-Watson statistic indicated that serial correlation in the data was possible, which is denoted in Table 8-1. However, Peebles reports that plots of residuals for order of collection for the plankton data generally revealed no actual serial correlation. Instead, indications of serial correlation probably reflect successive months that have similar influences on abundance due to similar rates of inflow. Given these considerations, it was concluded the possible presence of serial correlation in the data did not prohibit use of these regressions in the minimum flows analysis.

The relative abundance of all the species and age/size classes listed in Table 8-1 were predicted for baseline flows and a series of flow reductions ranging from 10 to 40 percent. Predicted abundance values as number of individuals in the river channel for plankton taxa and number per 100 m^2 for taxa collected by seines or trawls are listed in Table 8-2 for the baseline flow regime. The listed values are various percentile values that were taken from cumulative distribution functions of the predicted daily values for the period from 1987-2003. These percentiles (5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}, and 95^{th}) were selected to represent predictions that cover the flow range of the river. With the exception of *Mnemiopsis,* the low percentile values for the plankton taxa correspond to predictions at low flows, while the high percentile values for abundance correspond to high flows. The opposite is true for the comb jelly, *Mnemiopsis mccradyi,* since it has a negative relationship with inflow. Bay anchovies and mysid shrimp were numerically the most abundant plankton taxa simulated for the minimum flows analysis.

Predicted relative abundance values as catch-per-unit-effort for baseline flows are also listed for thirteen species/age-size class combinations collected by seine or trawl (Table 8-2). In contrast to the plankton taxa, which consistently used linear models (on natural log transformed data), it cannot be assumed that the low percentile values for abundance in the seine and trawl data correspond to low flows, as the regressions that used quadratic models may predict the lowest abundance values at high flows. Size classes of juvenile red drum, hogchokers, and tidewater mojarra were the numerically most abundant fishes collected by seine or trawl for which abundance regressions were used in the minimum flows analysis.

Table 8-2. Predicted values for abundance or relative abundance of selected species/age-size classes for the baseline flows using regressions presented by Peebles (2005) or Matheson et al. (2005). Predictions are specifed for either all individuals, adults, juveniles, or specific size classes for different taxa.

Abundance for Baseline Flows										
USF Plankton sampling				**Total number in river * 1,000**						
Taxon	**Common Name, Stage**	**Gear**		**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
Americamysis almyra*	mysid shrimp, adults	plankton	adults	448	559	859	1,423	2,531	3,691	5,154
Americamysis almyra	mysid shrimp, adults	plankton	adults	381	446	590	874	1,322	1,932	2,197
Americamysis sp.*	mysid shrimp, juveniles	plankton	juveniles	520	617	856	1,240	1,828	2,632	3,299
Palaemonetes pugio	grass shrimp, adults	plankton	adults	6	7	9	16	16	22	25
Mnemiopsis mccradyi	comb jelly, ctenophore	plankton	all	44	80	205	507	1,188	2,364	3,471
Cynoscion arenarius	sand seatrout, juveniles	plankton	juveniles	13	14	17	23	29	38	45
Anchoa mithchilli*	bay anchovy, juveniles	plankton	juveniles	4,401	4,786	5,549	6,776	8,376	10,031	10,564

* abundance predicted using regression with high-flow wash-out dates removed

Relative Abundance for Baseline Flows										
FWRI seine and trawl sampling				**Catch per unit effort for 100 m^2**						
Taxon	**Common Name, Gear, Size Class**			**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
Farfantepenaeus duorarum	pink shrimp	seines	all	0.20	0.42	1.18	1.66	1.86	1.91	1.92
Farfantepenaeus duorarum**	pink shrimp	trawls	17 - 36 mm	0.00	0.02	0.20	0.30	0.35	0.36	0.37
Anchoa mithchilli	bay anchovy	trawls	>=36 mm	0.09	0.44	1.23	1.80	2.16	2.24	2.25
Fundulus seminolis	seminole killifish	seines	<= 45 mm	0.60	0.74	1.10	1.67	2.59	3.83	4.78
Fundulus seminolis	seminole killifish	seines	> 46 mm	0.26	0.47	0.92	1.48	2.36	3.00	4.16
Eucinostomus harengulus	tidewater mojarra	seines	40 to 70 mm	0.81	1.76	4.09	5.47	6.10	6.28	6.30
Diapterus plumieri	striped mojarra	seines	<= 45 mm	0.48	0.91	1.36	1.81	2.04	2.10	2.10
Sciaenops ocellatus**	red drum	seines	<= 39 mm	1.31	1.62	3.39	4.94	5.87	6.05	6.09
Sciaenops ocellatus**	red drum	seines	40 to 150 mm	0.72	0.97	1.81	2.85	3.51	3.61	3.63
Gobiosoma bosc	naked goby	seines	>= 20 mm	0.36	0.54	0.99	1.50	1.70	1.76	1.77
Microgobius gulosus	clown goby	seines	all	0.20	0.59	1.01	1.25	1.36	1.38	1.38
Trinectes maculatus	hogchoker	seines	<= 29 mm	2.90	3.21	3.94	5.23	6.93	8.48	8.90
Trinectes maculatus	hogchoker	trawls	<= 29 mm	0.50	0.70	0.93	1.15	1.30	1.34	1.34

** abundance predicted for lower river zone only

Cumulative distribution function (CDF) plots are shown for four of the plankton taxa and four of the seine or trawl taxa that are listed in Table 8-2 (Figures 8-4 for plankton taxa and Figure 8-5 for seine/trawl taxa). For each of these taxa, CDF curves are plotted for predictions for baseline flows and for flow reductions ranging from 10 to 40 percent. For *Mnemiopsis* the CDF plot shows that high values occur only over a small portion of the frequency distribution, which corresponds to very low flows in the river (Figure 8-4D). For other taxa described by linear models, the CDF curves for the flow reduction scenarios are consistently below the curves for the baseline predictions [e.g., mysid shrimp (8-4A), grass shrimp (8-4B)],and Seminole killifish (8-5B). For species that are described by quadratic models with strong inflections [e.g., pink shrimp (8-5A), clown goby (8-5D)], CDF curves for the baseline condition are lower than the CDF curves for the flow reduction scenarios at the low percentile values. This pattern occurs because the lowest values for these species occur during high flows. Flow reductions reduce high flows, thus increase the abundance of these taxa relative to baseline conditions.

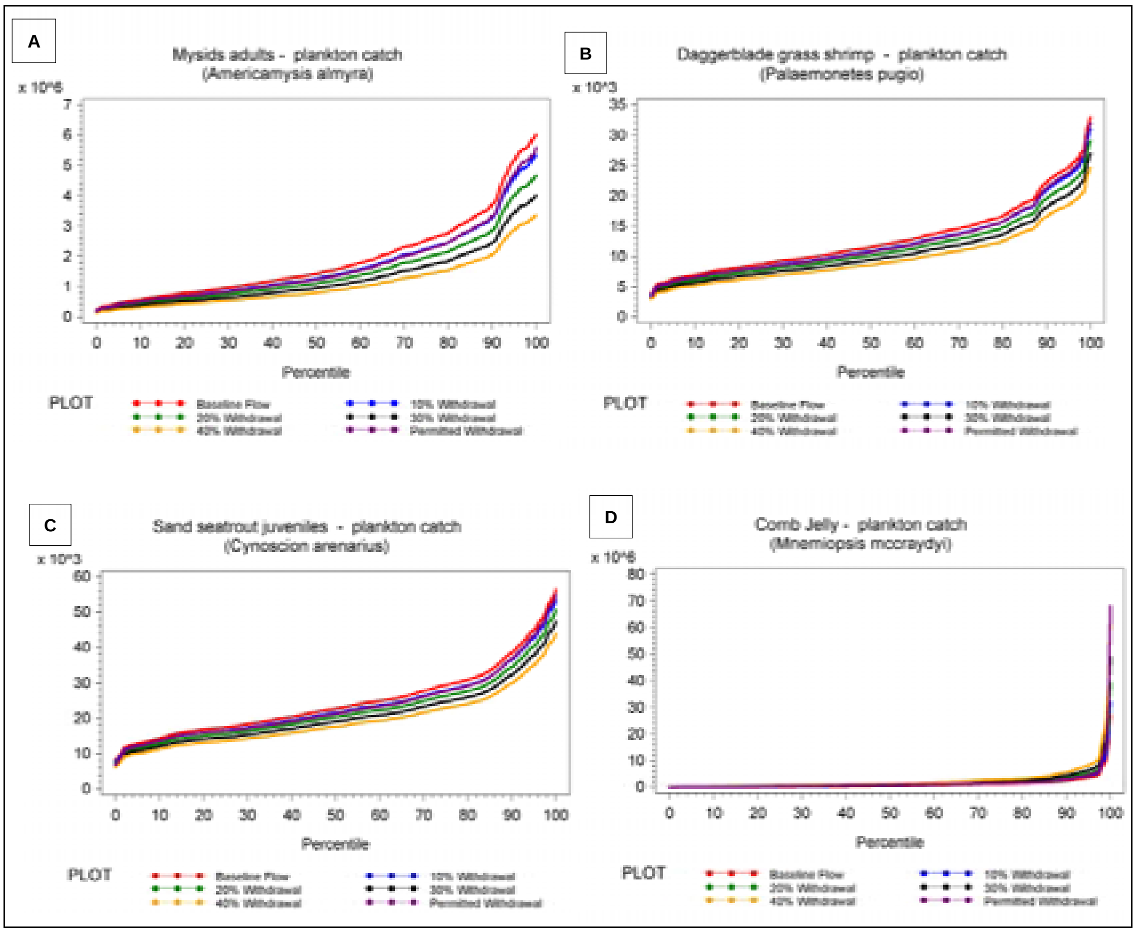


Figure 8-4. Cumulative distribution functions of the predicted number of individuals (catch per unit effort) for four taxa collected by plankton net for baseline flows, existing permitted withdrawals, and four percent flow reduction rates using regressions listed in Table 8-2. (A = *Americamysis almyra*, B = *Palaemonetes pugio*, C = *Cynoscion arenarius*, D = *Mnemiopsis mccradyi*)

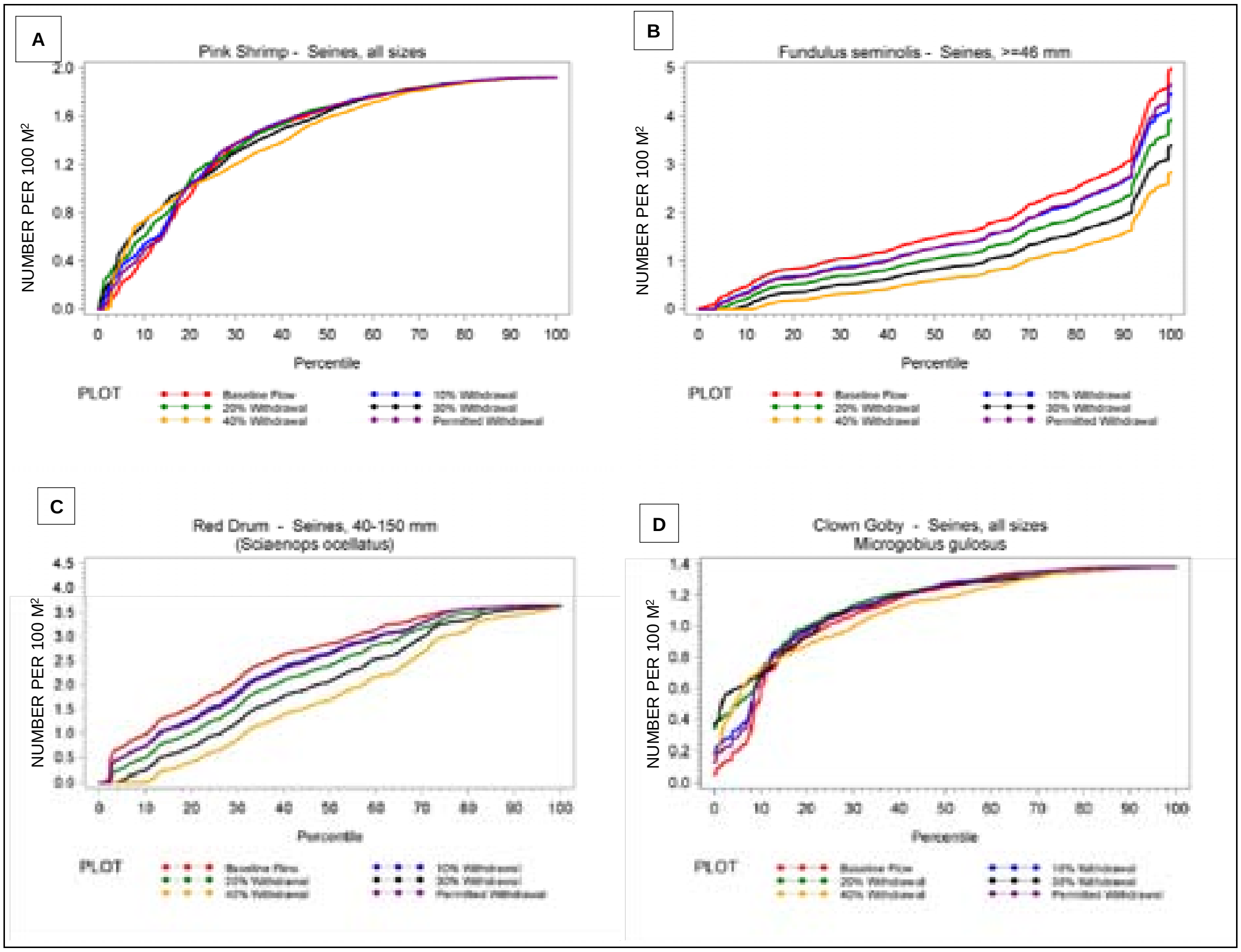


Figure 8-5. Cumulative distribution functions of the predicted number of individuals (catch per unit effort) for four taxa collected by seine or trawl for baseline flows, existing permitted withdrawals from the river, and four percent flow reduction rates using regressions listed in Table 8-2. (A = *Farfanepenaeus duorarum*, B = *Fundulus seminolis*, C = *Sciaenops ocellatus*, D =*Microgobius gulosus*).

Tables for percent reductions in abundance relative to baseline are shown for 10 percent, 20 percent and 40 percent flow reductions in Tables 8-3, 8-4, and 8-5, respectively. In these tables the predicted abundance values for the various percentiles are expressed as percentages of the corresponding percentile values for the baseline condition. As described in Section 7.6.1, the District uses a fifteen percent reduction from baseline to identify changes that constitute significant harm. In that regard, reductions for the different percentiles that exceed fifteen percent are highlighted in gray to illustrate patterns in the results. It should be noted that given the confidence limits of the regressions, changes of 15 percent are probably not statistically significant. However, the approach is taken that these are reasonable estimates of changes in these resources of concerns and such changes can be used for management purposes.

It is further noted that the regressions for some species had better r^2 values than others. Fortunately, two species which has comparatively high r^2 values are also ecologically

Table 8-3. Percent of abundance or relative abundance for selected fish and invertebrate species/age-size classes predicted for 10% flow reductions relative to predictions for baseline flows (Table 8-2). All values derived using regressions presented by Peebles (2005) or Matheson et al. (2005), except for red drum (MacDonald 2007). Values are listed for either all individuals, adults, juveniles, or various size classes. Percentages less than 85% for a specific percentile are shaded in gray.

10% Flow Reductions - Percent of Abundance Compared to Baseline Flows

USF Plankton Sampling			Percent of Total Number in River Channel						
Taxon	**Common Name, Stage**	**Gear**	**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
Americamysis almyra*	mysid shrimp, adults	plankton	89%	89%	89%	89%	89%	89%	89%
Americamysis almyra	mysid shrimp, adults	plankton	91%	92%	92%	92%	92%	92%	92%
Americamysis sp.*	mysid shrimp, juveniles	plankton	92%	92%	92%	92%	92%	92%	92%
Palaemonetes pugio	grass shrimp, adults	plankton	94%	94%	94%	95%	95%	95%	93%
Mnemiopsis mccradyi	comb jelly, ctenophore	plankton	119%	119%	119%	119%	119%	119%	119%
Cynoscion arenarius	sand seatrout, juveniles	plankton	95%	95%	95%	95%	96%	95%	95%
Anchoa mithchilli*	bay anchovy, juveniles	plankton	95%	95%	95%	95%	95%	95%	95%

* abundance predicted using regression with high-flow wash-out date removed

10% Flow Reductions - Percent of Relative Abundance Compared to Baseline Flows

FWRI Seine and Trawl Sampling		Percent of Catch per Unit Effort per 100 m^2						
Taxon	**common name, gear, size class**	**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
Farfantepenaeus duorarum	pink shrimp, seines, all	170%	128%	104%	101%	100%	100%	100%
Farfantepenaeus duorarum **	pink shrimp, trawls, 17-36 mm	295%	274%	113%	103%	101%	100%	100%
Anchoa mithchilli	bay anchovy, trawls, >=36 mm	235%	130%	110%	105%	101%	100%	100%
Fundulus seminolis	seminole killifish, seines, <=45mm	78%	81%	84%	87%	89%	90%	90%
Fundulus seminolis	seminole killifish, seines, >=46mm	58%	73%	82%	85%	88%	88%	89%
Eucinostomus harengulus	tidewater mojarra, seines, 40-70 mm	136%	120%	104%	101%	100%	100%	100%
Diapterus plumieri	striped mojarra, seines, <=45 mm	87%	99%	101%	99%	100%	100%	100%
Sciaenops ocellatus**	red drum, seines, <=39 mm	79%	118%	91%	96%	99%	100%	100%
Sciaenops ocellatus**	red drum, seines, 40-150 mm	70%	76%	86%	94%	100%	100%	100%
Gobosoma bosc	naked goby, seine, >=20 mm	132%	128%	110%	102%	101%	101%	100%
Microgobius gulosus	clown goby, seines all	169%	119%	104%	102%	100%	100%	100%
Trinectes maculatus	hogchoker, seines, <=29 mm	93%	93%	94%	94%	94%	94%	94%
Trinectes maculatus	hogchoker, trawls, <= 29 mm	76%	85%	95%	99%	99%	100%	100%

** abundance predicted for lower river zone only

Table 8-4. Percent of abundance or relative abundance for selected fish and invertebrate species/age-size classes predicted for 20% flow reductions relative to predictions for baseline flows (Table 8-2). All values derived using regressions presented by Peebles (2005) or Matheson et al. (2005), except for red drum (MacDonald 2007). Values are listed for either all indiviuals, adults, juveniles, or various size classes. Percentages less than 85% for a specific percentile are highlighted in gray.

20% Flow Reductions - Percent of Abundance Compared to Baseline Flows									
USF Plankton Sampling			Percent of Total Number in River Channel						
Taxon	common name, stage	Gear	5th Percentile	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile
Americamysis almyra*	mysid shrimp, adults	plankton	77%	77%	77%	77%	77%	77%	77%
Americamysis almyra	mysid shrimp, adults	plankton	83%	83%	83%	83%	83%	83%	83%
Americamysis sp.*	mysid shrimp, juveniles	plankton	84%	84%	84%	84%	84%	84%	84%
Palaemonetes pugio	grass shrimp, adults	plankton	88%	88%	88%	88%	89%	89%	87%
Mnemiopsis mccradyi	comb jelly, ctenophore	plankton	144%	144%	144%	145%	145%	145%	145%
Cynoscion arenarius	sand seatrout, juveniles	plankton	90%	89%	90%	90%	91%	90%	89%
Anchoa mithchilli*	bay anchovy, juveniles	plankton	90%	90%	90%	90%	90%	90%	90%

* abundance predicted using regression with high-flow wash-out dates removed

20% Flow Reductions - Percent of Relative Abundance Compared to Baseline Flows								
FWRI Seine and Trawl Sampling		Percent of Catch per Unit Effort per 100 m^2						
Taxon	common name, gear, size class	5th Percentile	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile
Farfantepenaeus duorarum	pink shrimp, seines, all	197%	144%	104%	101%	100%	100%	100%
Farfantepenaeus duorarum **	pink shrimp, trawls, 17-36 mm	baseline = 0	462%	127%	107%	102%	100%	100%
Anchoa mithchilli	bay anchovy, trawls, >=36 mm	394%	164%	121%	109%	102%	101%	100%
Fundulus seminolis	seminole killifish, seines, <=45mm	56%	61%	68%	73%	77%	79%	80%
Fundulus seminolis	seminole killifish, seines, >=46mm	15%	45%	63%	71%	75%	77%	78%
Eucinostomus harengulus	tidewater mojarra, seines, 40-70 mm	179%	141%	91%	93%	100%	100%	100%
Diapterus plumieri	striped mojarra, seines, <=45 mm	43%	82%	100%	97%	98%	100%	100%
Cynoscion nebulosus	spotted seatrout, seines, 45-100 mm	82%	85%	86%	88%	90%	90%	91%
Sciaenops ocellatus**	red drum, seines, <=39 mm	50%	105%	82%	91%	96%	100%	100%
Sciaenops ocellatus**	red drum, seines, 40-150 mm	39%	51%	70%	84%	96%	100%	100%
Gobosoma bosc	naked goby, seine, >=20 mm	171%	150%	113%	99%	101%	101%	100%
Microgobius gulosus	clown goby, seines all	246%	117%	106%	101%	99%	100%	100%
Trinectes maculatus	hogchoker, seines, <=29 mm	86%	86%	87%	87%	88%	88%	88%
Trinectes maculatus	hogchoker, trawls, <= 29 mm	50%	66%	85%	98%	99%	100%	100%

** abundance predicted for lower river zone only

Table 8-5. Percent of abundance or relative abundance for selected fish and invertebrate species/age-size classes predicted for 40% flow reductions relative to predictions for baseline flows (Table 8-2). All values derived using regressions presented by Peebles (2005) or Matheson et al. (2005). Values are listed for either all indiviuals, adults, juveniles, or various size classes. Percentages less than 85% for a specific percentile are highlighted in gray.

40% Flow Reductions - Percent of Abundance Compared to Baseline Flows

USF Plankton Sampling			Percent of Total Number in River Channel						
Taxon	common name, stage	Gear	5th Percentile	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile
*Americamysis almyra**	mysid shrimp, adults	plankton*	56%	56%	56%	56%	56%	56%	56%
Americamysis almyra	mysid shrimp, adults	plankton	65%	65%	65%	65%	65%	65%	65%
*Americamysis sp.**	mysid shrimp, juveniles	plankton*	67%	67%	67%	67%	67%	67%	67%
Palaemonetes pugio	grass shrimp, adults	plankton	75%	75%	75%	56%	75%	76%	74%
Mnemiopsis mccradyi	comb jelly, ctenophore	plankton	232%	233%	232%	232%	232%	232%	232%
Cynoscion arenarius	sand seatrout, juveniles	plankton	78%	78%	78%	78%	79%	78%	78%
*Anchoa mithchilli**	bay anchovy, juveniles	plankton*	79%	79%	79%	79%	79%	79%	79%

* abundance predicted using regression with high-flow wash-out dates removed

40% Flow Reductions - Percent of Relative Abundance Compared to Baseline Flows

FWRI Seine and Trawl Sampling		Percent of Catch per Unit Effort per 100 m^2						
Taxon	common name, gear, size class	5th Percentile	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile
Farfantepenaeus duorarum	pink shrimp, seines, all	199%	175%	93%	96%	99%	100%	100%
*Farfantepenaeus duorarum***	pink shrimp, trawls, 17-36 mm	baseline =0	889%	142%	112%	103%	100%	100%
Anchoa mithchilli	bay anchovy, trawls, >=36 mm	765%	227%	141%	115%	102%	100%	100%
Fundulus seminolis	seminole killifish, seines, <=45mm	9%	20%	35%	45%	53%	57%	59%
Fundulus seminolis	seminole killifish, seines, >=46mm	0%	0%	25%	40%	49%	52%	56%
Eucinostomus harengulus	tidewater mojarra, seines, 40-70 mm	244%	145%	99%	99%	100%	100%	100%
Diapterus plumieri	striped mojarra, seines, <=45 mm	0%	22%	63%	86%	97%	99%	100%
*Sciaenops ocellatus***	red drum, seines, <=39 mm	0%	42%	51%	77%	92%	98%	100%
*Sciaenops ocellatus***	red drum, seines, 40-150 mm	0%	0%	34%	59%	86%	95%	97%
Gobosoma bosc	naked goby, seine, >=20 mm	116%	130%	112%	101%	100%	100%	100%
Microgobius gulosus	clown goby, seines all	265%	124%	92%	95%	99%	100%	100%
Trinectes maculatus	hogchoker, seines, <=29 mm	70%	70%	72%	73%	74%	75%	75%
Trinectes maculatus	hogchoker, trawls, <= 29 mm	0%	20%	50%	83%	98%	100%	100%

** abundance predicted for lower river zone only

important species in the tidal river, and changes in the abundances of these species were emphasized. As previously discussed, large *Mnemopsis mccradyi* (r^2=0.45) populations can have a negative on larval fish abundance, and changes in this species were evaluated. Mysid shrimp are abundant and an important prey for the early life stages of many fish species. Most of the mysid shrimp are the species *Americamysis almyra*, for which the abundance regression had an r^2 of 0.36 for non-washout dates. Red drum (*Sciaenops ocellatus*) is one of the most highly prized saltwater game fish species in the region, and the abundance of juvenile stages would be expected to have a significant effect of the abundance of the population of harvestable, adult fishes. Though the r^2 value for the larger juveniles (40-150 mm) captured by FWRI was 0.22, this size class was emphasized in the minimum flows analysis because of the direct, significant relationship between freshwater inflow and the abundance of this economically important gamefish species.

Ten percent flow reductions show a very small effect on the taxa listed in Table 8-3, including the three priority species. Mysid shrimp abundance values (non-washout) are 89 percent of the baseline, while the median value for red drum juveniles was 94 percent of the baseline value. The 5^{th} percentile value for red drum was 70 percent of the corresponding baseline value, but the higher percentile values were as high as the baseline value. *Mnemiopsis* values for the 10 percent flow reductions show a 19 percent gain compared to the baseline. It should be noted that due to the form of the plankton regressions, flow reductions based on a fixed percentage of flow result in consistent percent reductions in abundance across the range of percentiles.

Twenty percent flow reductions reduce the non-washout abundance of mysid shrimp to 77 percent of the baseline value, with the regression for all flow producing a value of 84 percent (Table 8.4). The median abundance of *Mnemiopsis mccradyi* increased by 45 percent. However, the results for *Mnemiopsis* should be considered with caution, for although there may be a 45 percent increase over the flow regime, the abundance values for most of the flow regime are low (Figure 8-2D). These percent increases therefore represent small increases in the actual number of individuals, except at low flows when *Mnemiopsis* populations can be large. The percent reduction in red drum juveniles is substantial for the lower flow percentiles, with a 16 percent reduction in median values (flow reduction abundance 84 percent of baseline) and reductions exceeding 20 percent at the 25th percentile and 50 percent at the 5^{th} and 10^{th} percentiles.

Forty percent flow reductions show marked reductions in all the plankton taxa, with reductions in abundance exceeding 20 percent for grass shrimp, and juveniles of sand seatrout and bay anchovy (Table 8-5). Adult mysid shrimp abundances were reduced by 44 percent using the non-washout regression and 35 percent using the regression for all flow conditions. Juvenile mysid shrimp juveniles were reduced by 33 percent using the non-washout regression. *Mnemiopsis* numbers were predicted to increase by 232 percent, but again this is relevant only for the higher percentiles which occur during low flows. The median abundance of juvenile red drum was predicted to decrease by 41 percent, with greater percent reductions at the lower percentiles.

Differences in the frequency distributions of these predicted values provide a useful tool for evaluating potential impacts of reductions of freshwater inflow on the abundance of these key species. However, the actual effects of inflow reductions will likely differ from the percentile distributions of daily values represented in Tables 8-2 through 8-5, depending on the generation time of the species. For example, although thousands of days of flow records were used to generate the frequency distributions of red drum abundance, it is unlikely that actual red drum abundance will fluctuate on a daily basis. Instead, overall red drum abundance during the months when juveniles are present in the river (October through May) will likely be affected by the prevailing volumes of freshwater inflow over that period, with abundance gradually changing within that season due in part to changes in freshwater inflow.

For species whose generation times are shorter, variations in abundance may fluctuate more greatly within a season due to changes in inflow over shorter time scales (days or weeks). While acknowledging the limitations of models that predict animal abundance on a daily basis, the results of the regression analyses presents by Peebles (2005) and Matheson et al. (2005) can be used to evaluate potential minimum flows. Predicted changes in abundance near the median value are indicative of the reductions of inflow during normal flow conditions. For species that exhibit a linear positive relationship with flow, predicted changes in abundance at the low percentiles likely reflect changes during periods of low flow, with changes at high flows reflected in the high percentile abundance values. Species that have strongly non-linear or quadratic relations with flow diverge from this pattern, but flow relationships can still be assessed. Although animal abundance does not change on a daily basis, predicted reductions in abundance can be used to determine changes in freshwater flow over various flow ranges that could result in significant harm.

The results in Table 8-5 clearly indicate that flow reductions of 40 percent would result in significant harm using 15 percent reductions in abundance of red drum and mysid shrimp for this determination. Using a 15 percent change in abundance as a criterion, the results in Tables 8-3 and 8-4 indicate that flow reductions somewhere between 10 and 20 percent would represent the threshold for significant harm. Predicted abundance values for red drum and adults and juveniles of mysid shrimp using the non-washout regressions are expressed as percentages of baseline abundance in Table 8-6 for flow reductions ranging from 15 to 20 percent. Reductions in abundance exceeding 15 percent are listed for adult mysid shrimp for all these flow reductions, while reductions in abundance for mysid juveniles greater than 15 percent are achieved at 20 percent flow reductions. Reductions in juvenile red drum abundance vary depending on the percentile examined. Using the median as a measure of typical change, a 19 percent flow reduction resulted in a 15 percent change. Using the change at the median abundance as a measure of significant harm, nineteen percent flow reductions represent a preliminary target minimum flow, acknowledging that reductions in abundance might be greater during low flows and less at higher flows.

Table 8-6. Percent of baseline abundance for mysid shrimp and juvenile red drum (40-150 mm) for flow reductions ranging from 15 to 20% of baseline flows. Percentages less than 85% for a specific percentile are highlighted in gray.

Americamysis almyra								
mysid shrimp, adults	plankton*	Percent of Total Number in River Channel						
Flow Reduction		5th Percentile	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile
15 % reduction		83%	83%	83%	83%	83%	83%	83%
16 % reduction		82%	82%	82%	82%	82%	82%	82%
17 % reduction		81%	81%	81%	81%	81%	81%	81%
18 % reduction		80%	80%	80%	80%	80%	80%	80%
19 % reduction		79%	79%	79%	79%	79%	79%	79%
20 % reduction		77%	77%	77%	77%	77%	77%	77%

** abundance predicted using regression with high-flow wash-out dates removed*

Americamysis sp.								
mysid shrimp, juveniles	plankton*	Percent of Total Number in River Channel						
Flow Reduction		5th Percentile	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile
15 % reduction		88%	88%	88%	88%	88%	88%	88%
16 % reduction		87%	87%	87%	87%	87%	87%	87%
17 % reduction		86%	86%	86%	86%	86%	86%	86%
18 % reduction		85%	85%	85%	85%	85%	85%	85%
19 % reduction		85%	85%	85%	85%	85%	85%	85%
20 % reduction		84%	84%	84%	84%	84%	84%	84%

** abundance predicted using regression with high-flow wash-out dates removed*

Sciaenops occellatus, 40-150 mm								
Red drum	seines	Percent of Total Number in River Channel						
Flow Reduction		5th Percentile	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile
15 % reduction		56%	64%	78%	89%	98%	101%	100%
16 % reduction		51%	61%	76%	88%	98%	101%	100%
17 % reduction		48%	58%	75%	87%	98%	101%	100%
18 % reduction		45%	56%	73%	86%	97%	100%	100%
19 % reduction		42%	53%	72%	85%	97%	100%	100%
20 % reduction		39%	51%	70%	84%	96%	99%	99%

As described in Section 8.2, the District proposes to implement a low-flow threshold of 120 cfs as part of the minimum flow rule for the Lower Alafia River. The changes in abundance presented in Table 8-6, were reexamined using flow reduction scenarios that included the 120 cfs low flow cutoff. Predicted abundances of these taxa expressed as percent of baseline are listed in Table 8-7 for 19 percent flow reductions, with and without the 120 cfs low-flow threshold. The median abundance for mysid shrimp changed only slightly between these two scenarios, but the reductions at the lower percentiles improved substantially, with the 15 percent reductions in abundance now not exceeded for the 25th percentile and lower. Percent reductions in abundance do not exceed 15 percent for juvenile mysids for either of the flow scenarios, but again the reductions are improved substantially at the lower percentiles by application of the low-flow threshold.

The median percent reduction in abundance for red drum improves slightly from 85 to 86 percent. Although the 120 cfs threshold had little effect on the higher percentile abundances for red drum and the other species as well, application of the low-flow threshold greatly improved the amount of reduction at the 5th and 10th percentiles. By prohibiting withdrawals at very low flows, the low-flow threshold greatly improves the reductions in abundance values at the low percentiles, which correspond to low flows for these species.

Table 8-7. Percent of baseline abundance for mysid shrimp and juvenile red drum (40-150 mm) for 19% flow reductions, with and without a 120 cfs low-flow threshold below which no withdrawals are allowed. All values derived from regressions presented by Peebles (2005) or Matheson et al. (2005), except for red drum (MacDonald 2007). Percentages less than 85% for a specific percentile are highlighted in gray.

Americamysis almyra								
mysid shrimp, adults	**plankton***	**Percent of Total Number in River Channel**						
19% Flow Reduction		**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
No low flow threshold		79%	79%	79%	79%	79%	79%	79%
120 cfs low flow threshold		93%	92%	84%	80%	79%	79%	79%

** abundance predicted using regression with high-flow wash-out dates removed*

Americamysis almyra								
mysid shrimp, juveniles	**plankton**	**Percent of Total Number in River Channel**						
19% Flow Reduction		**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
No low flow threshold		85%	85%	85%	85%	85%	85%	85%
120 cfs low flow threshold		97%	96%	89%	85%	85%	85%	85%

** abundance predicted uisng regressino with high-flow wash-out dates removed*

Sciaenops ocellatus, 40-150 mm								
Red drum**	**seines**	**Percent of Total Number in River Channel**						
19% Flow Reduction		**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
No low flow threshold		42%	53%	72%	85%	97%	100%	100%
120 cfs low flow threshold		77%	75%	77%	86%	97%	100%	100%

***abundane predicted for lower river zone only*

The abundance values presented in Tables 8-2 though 8-7 are taken from cumulative distribution functions of abundance values predicted for these taxa based on daily flow records from 1987-2003. In an analysis of minimum flows for the Lower Hillsborough River, the District examined differences in CDF curves to determine how much gain there would be in the volume of the < 5 psu salinity zone if water was released to that river from the Hillsborough River Reservoir (SWFWMD, 2006). In that study, differences in the area beneath the CDF curves for different flow scenarios were calculated to determine the overall gain in volume that integrated the sizes of the gains and the amount of time they occurred when totaled across the entire cumulative distribution functions.

Though similar to the comparison of the results discussed above, the District did not strictly apply this method to the Lower Alafia River. Since more than one critical indicator was involved, comparisons of the results for juvenile and adult mysid shrimp and juvenile red drum were used to derive a flow reduction that generally achieved a 15 percent reduction in abundance for these species. Though the change was slightly greater than 15 percent for adult mysid shrimp at the higher percentiles (which corresponded to higher flows), reductions in abundance were less at the lower percentile values due to application of the low-flow threshold. Using the regression for mysid abundance that included all sampling dates, the changes in predicted abundance were 16 percent at the median and higher percentiles and less at percentiles (Table 8-8). Changes in the predicted abundance of juvenile mysids were 15 percent at the median and higher percentiles, and less at the lower percentile values. The median change in juvenile red drum abundance was 14 percent with the 19 percent flow reduction and the 120 cfs low-flow threshold, with less percent reductions at high percentiles (higher flows) and greater reductions at low flows. Using the median as a measure of typical change, the results for juvenile red drum comply with the targeted 15 percent change in abundance. Increasing the percent diversions to 20 percent resulted in a reduction in median abundance of just over 15 percent and slightly increased the reductions in abundance at the lower percentile values.

In summary, a 19 percent reduction in flow with a 120 cfs low-flow threshold is the proposed minimum flow based on the predicted changes in the abundance of mysid shrimp and juvenile red drum using the regressions developed by Peebles (2005) and Matheson et al. (2005), as modified by MacDonald (2007). The predicted changes for all the taxa that were simulated for the minimum flows analysis are shown for this flow reduction scenario in Table 8-8. Predicted changes in abundance are less than 15 percent for most other species, with the exception of the Seminole killifish (*Fundulus seminolis*), which is a small estuarine resident species that spends its entire life cycle in the tidal river. One interesting finding is the results for *Mnemiopsis mccradyi*, for which the changes in the 90th and 95th percentiles values are negligible compared to baseline flows. As previously discussed, the 90th and 95th percentile values for *Mnemiopsis* correspond to the high abundance values that occur during low flows (Figure 8-2D). The similarity of the abundance values for the baseline and the proposed minimum flow result from application of the 120 cfs low-flow threshold. Though the actual effect of the low-flow threshold in the river will not really be this precise, the overall findings for *Mnemiopsis* presented in this report and by Peebles (2005) make a strong case that alteration of very low flows in the Lower Alafia River should be prohibited.

Table 8-8. Percent of abundance (plankton) or relative abundance (seines and trawls) for selected fish and invertebrate taxa predicted for 19% flow reductions with a 120 cfs low-low threshold and unlimited withdrawal capacity relative to predictions for baseline flows (Table 8-2). All values derived using regressions presented by USF (Peebles, 2005) or FWRI (Matheson et al., 2005), except for red drum (MacDonald 2007). Values are listed for either all indiviuals, adults, juveniles, or various size classes. Percentages less than 85% for a specific percentile are highlighted in gray.

19% Flow Reductions WITH 120 cfs low flow threshold - Percent of Abundance Compared to Baseline Flows

USF Plankton Sampling			Percent of Total Number in River Channel						
Taxon	**common name, stage**	**Gear**	**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
Americamysis almyra*	mysid shrimp, adults	plankton	93%	92%	84%	80%	79%	79%	79%
Americamysis almyra	mysid shrimp, adults	plankton	96%	93%	87%	84%	84%	84%	84%
Americamysis sp.*	mysid shrimp, juveniles	plankton	97%	96%	89%	85%	85%	85%	85%
Palaemonetes pugio	grass shrimp, adults	plankton	97%	97%	92%	90%	89%	90%	88%
Mnemiopsis mccradyi	comb jelly, ctenophore	plankton	141%	142%	141%	141%	128%	101%	100%
Cynoscion arenarius	sand seatrout, juveniles	plankton	100%	99%	93%	91%	91%	90%	90%
Anchoa mithchilli*	bay anchovy, juveniles	plankton	98%	96%	93%	91%	91%	91%	91%

* abundance predicted using regression with high-flow wash-out dates removed

19% Flow Reductions with 120 cfs low flow cutoff - Percent of Relative Abundance Compared to Baseline Flows

FWRI Seine and Trawl Sampling		Percent of Catch per Unit Effort per 100 m^2						
Taxon	**common name, gear, size class**	**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
Farfantepenaeus duorarum	pink shrimp, seines, all	243%	165%	112%	102%	100%	100%	100%
*Farfantepenaeus duorarum***	pink shrimp, trawls, 17-36 mm	baseline=0	443%	126%	107%	103%	100%	100%
Anchoa mithchilli	bay anchovy, trawls, >=36 mm	377%	160%	120%	110%	102%	101%	100%
Fundulus seminolis	seminole killifish, seines, <=45mm	71%	72%	75%	77%	79%	80%	81%
Fundulus seminolis	seminole killifish, seines, >=46mm	50%	61%	70%	69%	80%	78%	79%
Eucinostomus harengulus	tidewater mojarra, seines, 40-70 mm	179%	143%	113%	103%	100%	100%	100%
Diapterus plumieri	striped mojarra, seines, <=45 mm	96%	107%	107%	99%	99%	100%	100%
*Sciaenops ocellatus***	red drum, seines, <=39 mm	106%	140%	87%	92%	96%	100%	100%
*Sciaenops ocellatus***	red drum, seines, 40-150 mm	77%	75%	77%	86%	97%	100%	100%
Gobiosoma bosc	naked goby, seine, >=20 mm	180%	153%	190%	102%	101%	101%	100%
Microgobius gulosus	clown goby, seines all	237%	130%	109%	102%	100%	100%	100%
Trinectes maculatus	hogchoker, seines, <=29 mm	94%	93%	90%	89%	89%	89%	89%
Trinectes maculatus	hogchoker, trawls, <= 29 mm	84%	83%	91%	99%	99%	100%	100%

** abundance predicted for lower river zone only

8.4.4 Simulations of Reductions in Fish and Invertebrate Abundance for Scenarios that use the Existing Permitted Diversion Capacity

The results presented above were simulated assuming an unlimited diversion capacity for withdrawals from the Alafia River. As described in Section 8.2, simulations were also run using a diversion capacity of 87.5 cfs, which corresponds to the capacity of the existing permitted water supply facilities on the river. Reducing the diversion capacity from an unlimited quantity to 87.5 cfs changed the percent flow limits which resulted in targeted, allowable changes to the indicator species (mysid shrimp and juvenile red drum). These changes in results occurred because the effects of a limited diversion capacity during high flow periods, which are primarily in the late summer, were manifested in the preceding mean flow terms used in the regressions, which ranged from 40 to 168 days for these species (Table 8-1).

Additional simulations that incorporated the permitted diversion capacity indicated that allowable diversions that would not result in unacceptable changes in the target species were in the range of 20 to 25 percent. Table 8-9 lists the predicted abundance values for these taxa as a percent of baseline for flow reductions ranging from 20 to 25 percent, without a low-flow threshold. One thing of note is that the results for the plankton taxa differ from the unlimited withdrawal scenarios, in that there is no longer a consistent reduction in abundance for the different percentile values. With a limited diversion capacity, reductions for the higher percentiles are less than for lower percentiles, since the flow reductions are proportionately less at higher flows due to the limited withdrawal capacity.

Application of the 120 cfs low-flow threshold to these simulations found that a 24 percent flow reduction with the permitted diversion facilities could be achieved without causing unacceptable reductions in these species. The predicted abundances of all the taxa simulated for the minimum flows analysis are listed in Table 8-10 for this scenario. The predicted change in the median abundance value for juvenile red drum is 15 percent, but reductions are greater for the lower percentiles (which occur during low flows), and less at the higher percentiles (which occur at high flows). The predicted change in the median value for adult mysid shrimp is 21 percent, but reductions are less for the lower and higher percentiles and also less for the regression that included wash-out dates. The improvement in the reductions in the lower percentiles compared to the results in Table 8-9 results from application of the 120 cfs low-flow threshold.

These results alone indicate that flow reductions could be adjusted to 24 percent with a 120 cfs low flow cutoff without causing significant harm to fish and invertebrate populations, as long as the permitted withdrawal facilities on the river remain in place. This interpretation, however, is not part of the proposed rule for the Lower Alafia River, as additional withdrawals may be requested in the future. For example, Tampa Bay Water recently proposed that their intake capacity can presently be increased to 60 mgd (93 cfs), but such an enlargement was not simulated for this report. This increase in diversion capacity, however, does fall within the simulations that assumed an unlimited diversion capacity from the river, and in a recent emergency water shortage order, Tampa Bay Water was allowed to temporarily increase their capacity to 93 cfs if they keep their withdrawal rate within the 19 percent minimum flow limit proposed in this report (SWFWMD 2007).

The effects of limits to the diversion capacity from the river would also have to be compared to the complete suite of resources of concern. Predicted changes in ecological indicators using 24 percent withdrawals with a 87.5 cfs diversion limit are presented in the following sections of this report. However, extensive data are still being collected on the Alafia River as part of Tampa Bay Water's HBMP program. Any variance from the proposed rule criteria in which withdrawals are constrained by the limits to the diversion facilities should be supported by further analysis of the expanded data set for the river to ensure that criteria for significant harm are not exceeded. The potential application of additional data that have been collected in the lower river are discussed in the final section of this report.

Table 8-9. Percent abundance relative to baseline for mysid shrimp and red drum juveniles (40 - 150 mm) for flow reductions ranging from 20 to 25% of baseline flows with maximum diversions limted to the existing capacity (87.5 cfs). All values derived from regressions presented by Peebles (2005). Percentages less than 85% for a specific percentile are highlighted in gray.

Americamysis almyra

mysid shrimp, adults	**plankton***	**Percent of Total Number in River Channel**						
Flow Reduction		**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
20 % reduction		78%	77%	78%	79%	82%	87%	89%
21 % reduction		77%	76%	77%	78%	82%	86%	89%
22 % reduction		76%	75%	76%	78%	81%	86%	88%
23 % reduction		75%	74%	75%	77%	81%	86%	88%
24 % reduction		74%	73%	74%	76%	80%	86%	88%
25 % reduction		73%	72%	73%	76%	80%	86%	88%

** abundance predicted using regression with high-flow wash-out dates removed*

***Americamysis sp.*, juveniles**

mysid shrimp, juveniles	**plankton***	**Percent of Total Number in River Channel**						
Flow Reduction		**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
20 % reduction		84%	84%	84%	85%	87%	92%	93%
21 % reduction		83%	85%	83%	84%	86%	92%	93%
22 % reduction		82%	82%	82%	83%	86%	92%	92%
23 % reduction		81%	81%	82%	83%	86%	91%	92%
24 % reduction		80%	81%	82%	82%	86%	91%	92%
25 % reduction		80%	80%	80%	82%	85%	91%	92%

** abundance predicted using regression with high-flow wash-out dates removed*

Scieanops ocellatus, 40-150 mm

Red Drum**	**seines**	**Percent of Total Number in River Channel**						
Flow Reduction		**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
20 % reduction		40%	52%	71%	87%	99%	100%	100%
21 % reduction		37%	50%	69%	86%	99%	100%	100%
22 % reduction		34%	47%	68%	86%	99%	100%	100%
23 % reduction		31%	45%	67%	85%	99%	100%	100%
24 % reduction		28%	43%	65%	85%	99%	100%	100%
25 % reduction		25%	41%	64%	84%	99%	100%	100%

**abundance predicted for lower river zone only

Table 8-10. Percent of abundance or relative abundance for selected fish and invertebrate species/age-size classes predicted for 24% flow reductions with a 120 cfs low-low threshold and the existing permitted withdrawal capacity (87.5 cfs) relative to predictions for baseline flows (Table 8.2). All values derived using regressions presented by Peebles (2005) or Matheson et al. (2005), except for red drum (MacDonald 2007). Values are listed for either all indiviuals, adults, juveniles, or various size classes. Percentages less than 85% for a specific percentile are highlighted in blue.

24% Flow Reductions with a 120 cfs low flow threshold wih existing diversion capacity
Percent Abundance compared to Baseline flows

USF Plankton Sampling			Percent of Total Number in River Channel						
Taxon	**common name, stage**	**Gear**	**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
Americamysis almyra*	opossum shrimp, mysid	plankton	100%	91%	82%	79%	81%	86%	88%
Americamysis almyra	opossum shrimp, mysid	plankton	95%	92%	85%	83%	88%	91%	92%
Americamysis sp.*	opossum shrimp, juveniles	plankton	97%	95%	87%	83%	86%	91%	92%
Palaemonetes pugio	daggerblade grass shrimp	plankton	97%	96%	90%	91%	91%	95%	94%
Mnemiopsis mccradyi	comb jelly, ctenophore	plankton	115%	123%	142%	154%	132%	101%	100%
Cynoscion arenarius	sand seatrout, juveniles	plankton	99%	99%	92%	89%	92%	95%	96%
Anchoa mithchilli*	bay anchovy, juveniles	plankton	97%	96%	92%	91%	92%	95%	95%

* abundance predicted using regression with high-flow wash-out dates removed

24 % Flow Reductions with 120 cfs low flow cutoff with existing diversion capacity
Percent of Relative Abundance Compared to Baseline Flows

FWRI Seine and Trawl Sampling		Percent of Catch per Unit Effort per 100 m^2						
Taxon	**common name, gear, size class**	**5th Percentile**	**10th Percentile**	**25th Percentile**	**50th Percentile**	**75th Percentile**	**90th Percentile**	**95th Percentile**
Farfantepenaeus duorarum	pink shrimp, seines, all	153%	131%	105%	99%	100%	100%	100%
Farfantepenaeus duorarum*	pink shrimp, trawls, 17-36 mm	0%	251%	119%	108%	103%	100%	100%
Anchoa mithchilli	bay anchovy, trawls, >=36 mm	205%	132%	119%	112%	103%	101%	100%
Fundulus seminolis	seminole killifish, seines, <=45mm	68%	69%	75%	82%	85%	87%	90%
Fundulus seminolis	seminole killifish, seines, >=46mm	42%	57%	70%	81%	85%	86%	89%
Eucinostomus harengulus	tidewater mojarra, seines, 40-70 mm	126%	119%	110%	102%	100%	100%	100%
Diapterus plumieri	striped mojarra, seines, <=45 mm	92%	101%	99%	96%	98%	100%	100%
Cynoscion nebulosus	spotted seatrout, seines, 45-100 mm	91%	91%	90%	91%	93%	95%	96%
Sciaenops ocellatus**	red drum, seines, <=39 mm	106%	107%	80%	86%	95%	100%	100%
Sciaenops ocellatus**	red drum, seines, 40-150 mm	74%	72%	73%	85%	99%	100%	100%
Gobiosoma bosc	naked goby, seine, >=20 mm	136%	130%	113%	99%	101%	101%	100%
Microgobius gulosus	clown goby, seines all	157%	123%	106%	100%	99%	100%	100%
Trinectes maculatus	hogchoker, seines, <=29 mm	93%	92%	89%	89%	92%	94%	94%
Trinectes maculatus	hogchoker, trawls, <= 29 mm	82%	80%	88%	95%	98%	100%	100%

** abundance predicted for lower river zone only

8.4.5 Reductions in Abundance During Dry Periods

As previously discussed, the abundance values that have been presented in the preceding tables were taken from cumulative frequency distributions of predicted values which were generated using all the daily flow records for the 1987-2003 baseline period. In order to stay within the domain of the regressions, the flow data used to predict abundance were limited to the range of flows used to develop each regression. This eliminated relatively few flow records as the extensive biological data sets on which the regressions were based covered a very wide range of flows.

Taking Tables 8-8 and 8-10 at face value, it could be interpreted that the proposed minimum flows will have very little effect on the abundance of some species, and possibly even increase the abundance of some species (e.g. pink shrimp, tidewater mojarra, naked goby). These are the species for which the relationship of inflow to abundance was described by quadratic equations in which the abundance of these species in the river peak at intermediate flows and are reduced by high flows (e.g. Figures 8-3A and 8-3D). As a result, low abundance values for these species can occur during high flow events, and the increases in abundance at these percentiles for the flow reduction scenarios compared to the baseline occur because the flow reductions actually increase the abundance of these taxa during high flows in the river.

It is important to stress that this relationship does not apply during low flows, and the application of the minimum flows are an effective tool for managing the abundance of these taxa during extended dry periods. To explore this relationship, CDF plots of the abundance of pink shrimp and the clown goby were calculated for baseline flows and for four flow reductions, with the flow data limited to less than the median value of the flow term used in the regressions for each species (Figures 8-6 A and B). Viewed in this manner, the abundance values for the baseline scenario are consistently above the flow reduction scenarios with the greatest difference at low percentiles**,** again reiterating these predictions and CDF curves are restricted to the driest half of the baseline period**.**

Limiting flows to the median value used in the regression for each species in Tables 8-8 and 8-10, abundance values were re-calculated for baseline flows and a series of flow reduction scenarios for those taxa collected by seine or trawl that had quadratic formula in their regressions. The results are listed for a 20 percent flow reduction in Table 8-11, with the abundance for the flow reduction scenario expressed as percent of the baseline. While reiterating these percentiles apply to only half the year, these results are very different for the same flow scenario that used the entire flow record (Table 8-4), since the effects of high flows on predicted abundances are eliminated from the analysis.

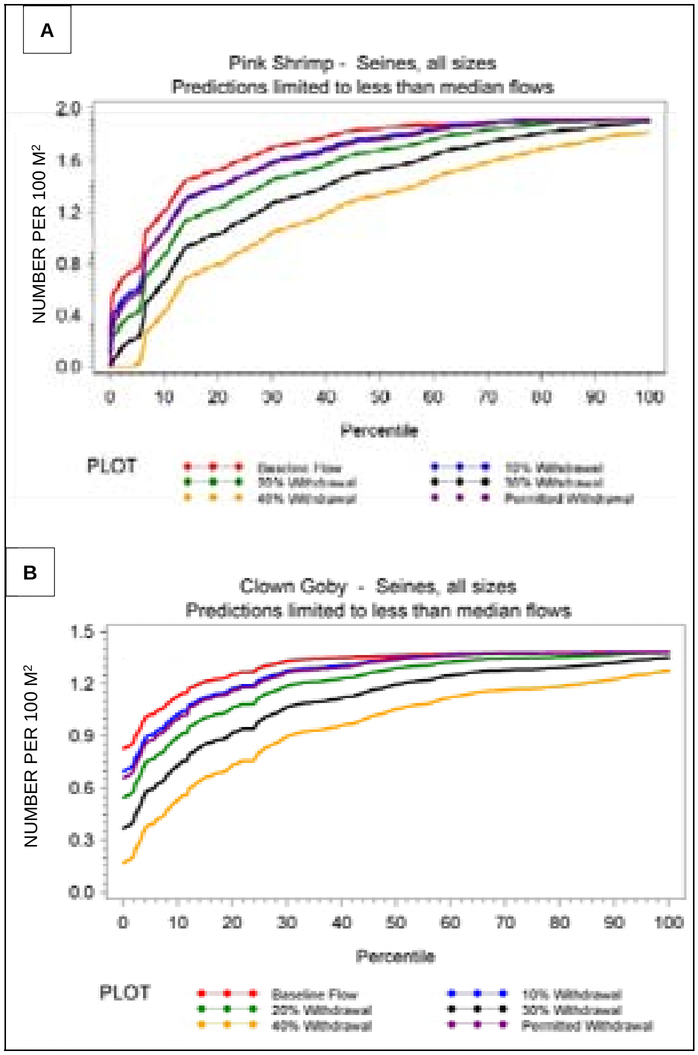


Figure 8-6. Cumulative distribution functions of the predicted number of individuals (catch per unit effort) for two species collected by seine or trawl for baseline flows, existing permitted withdrawals from the river, and four percent flow reduction rates using regressions listed in Table 8-1. <u>Predictions and corresponding percentile values limited to days when corresponding flow term was less than its median value for the period 1987-2003.</u> (A = *Farfantepenaeus duorarum*, B =*Microgobius gulosus*).

Table 8-11. Percent of abundance or relative abundance for selected fish and invertebrate species/age-size classes predicted for 20% flow reductions relative to predictions for baseline flows. **Predictions limited to those taxa-size classes modeled by FWRI (Matheson et al. 2005, MacDonald 2007) which had quadratic regression to predict abundance. Predictions also limited to days when baseline flows were below the median value for the corresponding season and flow term for each taxon during the 1987-2003 period.** Values are listed for either all individuals, adults, juveniles, or various size classes. Percentages less than 85% for a specific percentile are highlighted in gray**.**

20% Flow Reductions - Percent of Relative Abundance Compared to Baseline for Flows < Median								
FWRI Seine and Trawl Sampling		Percent of Catch per Unit Effort per 100 m^2						
Taxon	common name, gear, size class	5th Percentile	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile
Farfantepenaeus duorarum	pink shrimp, seines, all	55%	78%	83%	91%	98%	100%	100%
Farfantepenaeus duorarum*	pink shrimp, trawls, 17-36 mm	96%	107%	105%	102%	101%	100%	100%
Anchoa mithchilli	bay anchovy, trawls, >=36 mm	102%	107%	103%	102%	101%	100%	100%
Eucinostomus harengulus	tidewater mojarra, seines, 40-70 mm	81%	87%	99%	100%	101%	100%	100%
Diapterus plumieri	striped mojarra, seines, <=45 mm	0%	35%	71%	80%	88%	92%	93%
Sciaenops ocellatus*	red drum, seines, <=39 mm	18%	46%	67%	74%	83%	87%	88%
Sciaenops ocellatus*	red drum, seines, 40-150 mm	15%	39%	58%	70%	79%	81%	82%
Gobiosoma bosc	naked goby, seine, >=20 mm	61%	72%	82%	94%	101%	100%	100%
Microgobius gulosus	clown goby, seines all	75%	79%	87%	95%	98%	105%	100%
Trinectes maculatus	hogchoker, trawls, <= 29 mm	0%	50%	68%	78%	86%	90%	91%
** abundance predicted for lower river zone only								

These results strongly suggest implementation of minimum flow regulations could have significant benefits for protecting the abundance of these species during periods of extended low flow in the river. The CDF plots for pink shrimp and the clown goby in Figure 8-6 were generated without application of the 120 cfs low-flow threshold, and application of the threshold would help prevent reductions to these species during flow flows. Table 8-12 presents percent abundance values for the species with quadratic abundance relationships for the proposed minimum flow scenario (19 percent with low-flow threshold) relative to the baseline, but with the data limited to days when the baseline flows were less than the median flow value used in the regression for each species. Reiterating that the percentile values in this table apply to only half the year, the changes in abundance are quite different than the values for the same flow scenario in Table 8-8 in which high flow are included. Also, compared to marked reductions in abundance for pink shrimp and clown goby shown in Figure 8-6, the slight reductions in abundance at low percentile values for these and other species are due to the effect of the 120 cfs low-flow threshold. Table 8-13 presents similar results for the 24 percent flow reduction scenario with a 120 cfs low-flow threshold and the existing permitted diversion facilities. These results are similar to the 19 percent minimum flow scenario with unlimited withdrawal capacity in Table 8-12.

In summary, these results indicate that the proposed minimum flow rule with the low 120 cfs low-flow threshold is an effective tool for preventing reductions in these species during periods of low flow. Also, the reduction of the abundance of some species in the river at high flows does not necessarily mean that freshwater inflow is deleterious to the overall abundance of these species in the overall estuarine system. The Lower Alafia River is closely linked both hydraulically and ecologically with Tampa Bay. During high flows, these species shift their distributions into Tampa Bay and exploit mesohaline habitats that now occur there. Since Tampa Bay receives freshwater inflow from many sources, it is unlikely that the proposed minimum flows will result in adverse impacts to resources occurring in the bay. The effect of the proposed minimum flow rule on the inflow budget of Hillsborough Bay is evaluated in Section 8.9.

As described in Section 7.2, it was concluded that the natural resources associated with the Lower Alafia River that are most susceptible from significant harm occur within the tidal river over most of the river's flow regime. As described in the preceding section, the abundance of mysid shrimp and juvenile red drum (and a number of other species) meet this criterion and can be used for minimum flows determination. The implementation of minimum flows will also serve to protect those species that have maximum abundance in the river at intermediate flows during the dry times of the year. During times of high flows, the flow reductions allowed by the proposed minimum flows should have no deleterious effect on the abundance of these other species in the river.

Table 8-12. Percent of relative abundance for selected fish and invertebrate species/age-size classes predicted for 19% flow reductions with a 120 cfs low-flow threshold and unlimited withdrawl capacity relative to predictions for baseline flows (Table 8-2). **Predictions limited to those taxa-size classes modeled by FWRI (Matheson et al. 2005) which had quadratic regressions to predict relative abundance. Predictions also limited to days when baseline flows were below the median value for the corresponding season and flow term for each taxon during the 1987-2003 period**. Values are listed for either all individuals, adults, juveniles, or various size classes. Percentages less than 85% for a specific percentile are highlighted in gray.

19% Flow Reductions with 120 cfs low flow cutoff - Percent of Relative Abundance Compared to Baseline Flows								
FWRI Seine and Trawl Sampling		Percent of Catch per Unit Effort per 100 m^2						
Taxon	common name, gear, size class	5th Percentile	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile
Farfantepenaeus duorarum	pink shrimp, seines, all	99%	96%	89%	93%	98%	100%	100%
Farfantepenaeus duorarum**	pink shrimp, trawls, 17-36 mm	86%	92%	97%	101%	100%	100%	100%
Anchoa mithchilli	bay anchovy, trawls, >=36 mm	109%	109%	105%	102%	101%	100%	100%
Eucinostomus harengulus	tidewater mojarra, seines, 40-70 mm	102%	102%	103%	98%	99%	100%	100%
Diapterus plumieri	striped mojarra, seines, <=45 mm	75%	75%	84%	87%	92%	94%	95%
Sciaenops ocellatus**	red drum, seines, <=39 mm	59%	65%	56%	60%	64%	68%	70%
Sciaenops ocellatus**	red drum, seines, 40-150 mm	62%	80%	74%	75%	77%	78%	79%
Gobiosoma bosc	naked goby, seine, >=20 mm	18%	43%	53%	78%	115%	129%	135%
Microgobius gulosus	clown goby, seines all	86%	87%	91%	97%	99%	100%	100%
Trinectes maculatus	hogchoker, trawls, <= 29 mm	70%	84%	83%	84%	88%	91%	92%

** abundance predicted for lower river zone only

Table 8-13. Percent of relative abundance for selected fish and invertebrate species/age-size classes predicted for 24% flow reductions with a 120 cfs low-flow threshold and existing withdrawl capacity (87.5 cfs) relative to predictions for baseline flows (Table 8-2). **Predictions limited to those taxa-size classes modeled by FWRI (Matheson et al. 2005, MacDonald 2007)) which had quadratic regressions to predict relative abundance. Predictions also limited to days when baseline flows were below the median value for the corresponding season and flow term for each taxon during the 1987-2003 period**. Values are listed for either all individuals, adults, juveniles, or various size classes. Percentages less than 85% for a specific percentile are highlighted in blue.

24% Flow Reductions with 120 cfs low flow cutoff - Percent of Relative Abundance Compared to Baseline Flows								
FWRI Seine and Trawl Sampling		Percent of Catch per Unit Effort per 100 m^2						
Taxon	common name, gear, size class	5th Percentile	10th Percentile	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile
Farfantepenaeus duorarum	pink shrimp, seines, all	99%	94%	88%	91%	97%	100%	100%
*Farfantepenaeus duorarum***	pink shrimp, trawls, 17-36 mm	82%	89%	97%	102%	101%	100%	100%
Anchoa mithchilli	bay anchovy, trawls, >=36 mm	110%	110%	106%	103%	101%	100%	100%
Eucinostomus harengulus	tidewater mojarra, seines, 40-70 mm	101%	101%	102%	97%	98%	100%	100%
Diapterus plumieri	striped mojarra, seines, <=45 mm	72%	70%	82%	85%	91%	94%	94%
*Sciaenops ocellatus***	red drum, seines, <=39 mm	59%	65%	55%	57%	61%	66%	68%
*Sciaenops ocellatus***	red drum, seines, 40-150 mm	55%	77%	70%	71%	75%	77%	79%
Gobiosoma bosc	naked goby, seine, >=20 mm	80%	87%	89%	96%	101%	100%	100%
Microgobius gulosus	clown goby, seines all	84%	86%	91%	97%	98%	100%	100%
Trinectes maculatus	hogchoker, trawls, <= 29 mm	66%	81%	81%	82%	87%	90%	91%

** abundance predicted for lower river zone only

8.5 Effects of Minimum Flows on the Distribution of Life Stages of Key Fish and Invertebrate Species

Although potential impacts to the abundance of fishes and invertebrates were a priority consideration with regard to the establishment of minimum flows, changes in the distribution of these same species was also considered in the minimum flows analysis. Both Peebles (2005) and Matheson et al. (2005) found that the distributions of many fish and invertebrate taxa in the river shifted with changes in freshwater inflow. With one exception, these distributions moved downstream with increased freshwater inflow and upstream with decreased freshwater inflow. Although this response seems intuitively obvious, the opposite response has been observed in the highly modified and stratified Tampa Bypass Canal, where some species shift upstream with increasing freshwater inflow, possibly due to the effects of inflow on two-layer circulation (Peebles 2004).

An excessive shift of fish and invertebrate populations upstream could result in adverse impacts if it causes a population to move away from the preferred habitat for that species (Browder and Moore, 1991). Some fish species use vegetated shoreline habitat as cover during their juvenile stage to avoid predation (Edwards 1989, NOAA 2001). Other estuarine zones that could be preferred habitat might be well oxygenated compared to other regions, or be zones where there is a high density of prey or other food sources. An important consideration is the reduction in area and volume of the estuary that typically occurs upstream, as many tidal rivers are funnel shaped with the broadest regions of the estuary located in the downstream reaches (McPherson and Hammett 1991, Estevez et al. 1991).

As described in Chapter Six, both Peebles (2005) and Matheson (2005) developed regressions to predict the center of catch per unit effort (Km_U) as a function of freshwater inflow for a large number of fish and invertebrate species in the tidal river. In general, species for which significant regressions were established between inflow and abundance also had significant regressions between inflow and distribution ($Km_{U)}$, but this was not always the case. In the case of the Seminole killifish (*Fundulus seminolis*), the r^2 for the relationship of inflow with abundance was considerably higher than the r^2 for the relationship with distribution. This species is an estuarine resident which spends its entire life cycle in the estuary, and apparently does not shift much with changes in freshwater inflow, although inflow may affect factors that contribute to its increased abundance. In many cases, however, higher r^2 values were obtained for relationships of inflow with distribution than with abundance. This was particularly the case for plankton species, as the distribution of these taxa would be expected to be influenced more by the physical effects of changes of inflow on circulation in the tidal river.

The District incorporated analyses of the effects of changes on freshwater inflows on various age/size classes of twenty fish and invertebrate species in the lower river. More than one age/size class was evaluated for the bay anchovy in both the plankton and seine or trawl samples. Samples were selected for analysis based on their ecological importance and the presence of significant regressions with comparatively high r^2 values. It was concluded these taxa 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 river.

The species age/size class combinations for which inflow/distribution analysis was performed are listed in Table 8-14, along with information on the respective regressions (degrees of freedom, r^2, flow term and Durbin-Watson statistic). Additional information for these regressions (e.g., level of significance (p), slope and intercept values, scatter plots) can be found in Peebles (2005) and Matheson et al (2005). The scatter plots and regressions for the species/age classes in Table 8-14 are also presented in Appendix 8A of this District report, taken from the reports by Peebles (2005) and Matheson et al. (2005).

Both distribution data (Km_U) and inflow data were log transformed in the seine and trawl species, while only the flow data were log transformed for the plankton species. In contrast to the abundance regressions, the distribution regressions for seine and trawl species consistently used linear models on data collected throughout the whole river for the entire year (Table 8-14).

Similar to the analyses of inflow-abundance relationships, Km_U was predicted for both baseline flows and a series of flow reductions. To relate shifts in Km_U to changes in available fish and invertebrate habitat, predicted locations of Km_U for each species were related to corresponding shifts in the area, volume, or shoreline length between the 10^{th} and 90^{th} percentile locations of Km_U for each flow scenario. The amount of river area and volume between these percentiles were calculated for plankton organisms, while the amount of river area was calculated for taxa collected by trawls and the amount of in river shoreline was calculated for species collected by seines. These habitat values were calculated for the different flow scenarios, and percent changes in available habitat (as defined between the 10 and 90^{th} percentile locations of Km_U) were quantified relative to baseline to evaluate how that potential habitat is reduced by changes in freshwater inflow.

The minimum flows analysis indicated that changes in the abundance for the priority species in the river (and other taxa as well) were more sensitive to change in inflows than were changes in habitat that corresponded to changes in distribution. In other words, the allowable percent flow reductions established on abundance relations would not cause significant harm based on changes in habitat that correspond to shifts in Km_U. For this reason, shifts in Km_U and changes in available habitat are presented only for the proposed minimum flows. These results indicate that significant harm to these species should not occur due to reductions in available habitat that result from implementation of the proposed minimum flows.

Table 8-14 Regressions between freshwater inflow and the location of the center of catch-per-unit-effort for species/age-size classes that were used in the mimimum flow analysis. Regressions for USF plankton samples taken from Peebles (2005) and regressions for FWRI seine and trawl samples taken from Matheson et al. (2005). The flow term is the number of days used to calculate the preceding mean flow. Both location and flow data were natural log (ln) transformed in the regressions for seine and trawl data, while only the flow data were ln transformed for the plankton data.

USF Plankton Sampling

Taxon	Common Name	Gear	age/size class	Months	Response	df	DW	r^2	Flow Term (days)
Americamysis almyra	opossum shrimp, mysid	plankton	all	all	linear	44		0.43	3
Edotea tribola	isopod	plankton	all	all	linear	60		0.7	1
Amphipods	unidentified gammarideans	plankton	all	all	linear	61	x	0.18	54
Cyathura polita	isopod	plankton	all	all	linear	21		0.52	105
Palaemonetes pugio	daggerblade grass shrimp	plankton	adults	all	linear	25		0.35	1
Mnemiopsis mccradyi	comb jelly, ctenophore	plankton	all	all	linear	20	x	0.35	3
Cynoscion arenarius	sand seatrout	plankton	juveniles	all	linear	27		0.62	1
Anchoa mithchilli	bay anchovy	plankton	juveniles	all	linear	61	x	0.48	1
Anchoa mithchilli	bay anchovy	plankton	adults	all	linear	61	x	0.32	1
Brevoortia smithi	yellowfin menhaden	plankton	juveniles	all	linear	17		0.65	17

FWRI Seine and Trawl Sampling

Taxon	Common Name	Gear	age/size class	Months	Response	df	DW	r^2	Flow Term (days)
Farfantepenaeus duorarum	pink shrimp	trawls	17 - 36 mm	Jan to Dec.	linear	25		0.48	14
Palaemonetes pugio	daggerblade grass shrimp	seines	all	Jan to Dec.	linear	35		0.44	175
Anchoa mithchilli	bay anchovy	trawls	<= 24 mm	Jan to Dec.	linear	23	x	0.34	21
Anchoa mithchilli	bay anchovy	trawls	<= 36 mm	Jan to Dec.	linear	30	x	0.15	14
Eucinostomus harengulus	tidewater mojarra	seines	40 to 70 mm	Jan to Dec.	linear	51	x	0.29	364
Diapterus plumieri	striped mojarra	seines	46 to 100 mm	Jan to Dec.	linear	17		0.29	21
Cynoscion nebulosus	spotted seatrout	seines	45 to 100 mm	Jan to Dec.	linear	30		0.l8	112
Cynoscion arenarius	sand seatrout	trawls	40 to 100 mm	Jan to Dec.	linear	29		0.29	1
Cynoscion arenarius	sand seatrout	trawls	<= 39mm	Jan to Dec.	linear	33		0.l2	56
Bairdiella chrysoura	silver perch	seines	46 to 100 mm	Jan to Dec.	linear	18		0.32	49
Menticirrhus americanus	southern kinhgfish	trawls	40 to 155 mm	Jan to Dec.	linear	17	x	0.43	56
Sciaenops ocellatus	red drum	seines	40 to 150 mm	Jan to Dec.	linear	55		0.25	119

The results of the inflow-Km_U analysis are presented first for plankton organisms, then for taxa collected by seine or trawl. The kilometer locations of the 10th, 50th (median) and 90th percentile values for the predicted locations of KmU for the plankton taxa are listed in Table 8-15 for baseline flows and flow reduced by 19 percent with a 120 cfs low-flow threshold and an unlimited withdrawal capacity; and 24 percent with a 120 cfs low-flow threshold and a 87.5 cfs withdrawal capacity.

These results show the regions of the river over which Km_U typically varies for the various species. The median locations for the listed taxa for baseline flows range from 2.8 to 6.7 kilometers, demonstrating how important this zone of the river is to biological use of the river. The downstream (10th percentile) locations of Km_U range between 1.7 and 5.2 kilometers for the different taxa, while the upstream (90th percentile) locations range from 3.6 to 7.7 kilometers. Shifts in Km_U resulting from the 19 percent and 24 percent flow reduction scenarios mainly ranged between 0.1 and 0.3 kilometers from baseline conditions, with shifts of 0.4 to 0.6 kilometers observed in the median locations of four taxa in one or both of the two flow reduction scenarios. These shifts in the 10th, 50th, and 90th percentile locations in Km_U are illustrated for four of the plankton taxa in Figure 8-7. The small to negligible shifts in the 90th percentile values are due to the effect of the 120 cfs low flow cutoff.

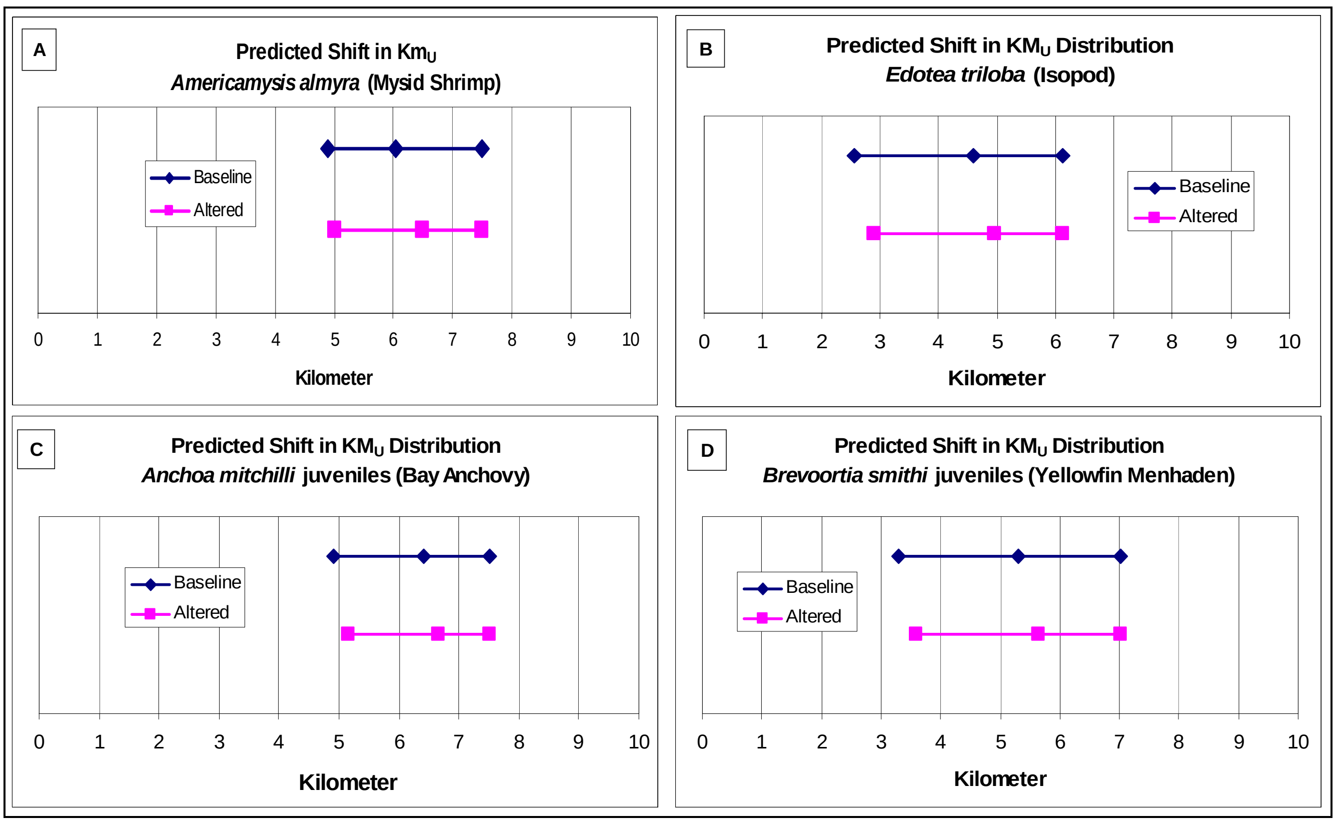


Figure 8-7. Predicted 10th, 50th, and 90th percentile locations of the center of catch per unit effort (Km_U) for four fish or invertebrate species collected by plankton net for baseline flows and flows reduced by 19 percent with a 120 cfs low-flow threshold and an unlimited withdrawal capacity (A = *Americamysis almyra* (mysid shrimp); B= *Edotea tribola* (isopod); *Anchoa mitchilli* juveniles (bay anchovy); *Brevoortia smithi* juveniles (yellowfin menhaden).

Table 8-15. Median, 10th and 90th percentile values for predicted river kilometer locations of the center of catch per unit effort (KmU) for selected taxa collected in plantkton tows in the Lower Alafia River. Predictions made using the regressions of KmU with freshwater inflow presented by Peebles (2005). Values presnted for baseline flows and flows reduced by: (A) 19% with a 120 cfs low flow threshold and an unlimited diversion capactiy ; and (B) flows reduced by 24% with a 120 cfs low flow threshold and a diversion capactiy of 87.5 cfs.

A. 19% flow reduction with 120 cfs low flow threhold and unlimited diversion capacity		**Kilometers**					
		10th percentile		**median**		**90th percentile**	
Taxon	**Common Name**	**baseline**	**19% 120 cfs**	**baseline**	**19% 120 cfs**	**baseline**	**19% 120 cfs**
Anchoa mitchilli	Bay Anchovy, adults	2.9	3.1	4.0	4.2	4.9	4.9
Mnemiopsis mccradyi	Comb Jelly (Ctenophore)	2.0	2.2	3.1	3.3	4.0	4.0
Unidentified Gammarideans	Amphipods	3.2	3.3	4.2	4.4	5.2	5.3
Palaemonetes pugio	Daggerblade Grass Shrimp, adults	5.2	5.5	6.7	6.9	7.7	7.7
Anchoa mitchilli	Bay Anchovy, juveniles	4.9	5.2	6.4	6.7	7.5	7.5
Cyathura polita	Isopod	1.8	2.0	2.8	3.0	3.6	3.7
Brevoortia smithi	Yellowfin Menhaden, juveniles	3.3	3.6	5.3	5.6	7.0	7.0
Edotea triloba	Isopod	2.6	2.9	4.6	5.0	6.1	6.1
Cynoscion arenarius	Sand Seatrout, juveniles	1.7	2.0	3.7	4.1	5.3	5.3
Americamysis almyra	Opossum Shrimp, Mysid	4.9	5.0	6.0	6.5	7.5	7.5

B. 24 % flow reduction with 120 cfs low flow threhold and a diversion capacity of 87.5 cfs		**Kilometers**					
		10th percentile		**median**		**90th percentile**	
Taxon	**Species**	**baseline**	**24% 120 cfs**	**baseline**	**24% 120 cfs**	**baseline**	**24% 120 cfs**
Anchoa mitchilli	Bay Anchovy, adults	2.9	3.0	4.0	4.3	4.9	4.9
Mnemiopsis mccradyi	Comb Jelly (Ctenophore)	2.0	2.1	3.1	3.3	4.0	4.0
Unidentified Gammarideans	Amphipods	3.2	3.3	4.2	4.5	5.2	5.3
Palaemonetes pugio	Daggerblade Grass Shrimp, adults	5.2	5.4	6.7	7.0	7.7	7.7
Anchoa mitchilli	Bay Anchovy, juveniles	4.9	5.1	6.4	6.7	7.5	7.5
Cyathura polita	Isopod	1.8	1.9	2.8	3.0	3.6	3.7
Brevoortia smithi	Yellowfin Menhaden, juveniles	3.3	3.6	5.3	5.7	7.0	7.0
Edotea triloba	Isopod	2.6	2.8	4.6	5.1	6.1	6.1
Cynoscion arenarius	Sand Seatrout, juveniles	1.7	1.9	3.7	4.2	5.3	5.3
Americamysis almyra	Opossum Shrimp, Mysid	4.9	5.1	6.0	6.6	7.5	7.5

The kilometer locations of Km_U listed in Table 8-15 were used to calculate the area and volume between the 10th and 90th percentile values for each species for the baseline and the two flow reduction scenarios. These values and the percent change from baseline conditions are listed in Table 8-16 for the 19 percent minimum flow scenario. All changes in volume between the 10th and 90th percentiles are 15 percent or less, except for daggerblade grass shrimp which changed by 16 percent. Changes in area between the baseline and minimum flow scenarios were 15 percent or less, with the exception of daggerblade grass shrimp and bay anchovy juveniles. It should be noted changes in abundance were considerably less for these species (Table 8-8). Reductions in area and volume for the 24 percent flow reduction scenario with existing withdrawal facilities are presented in Table 8-17. These changes are similar to, but in many cases less, than reductions for the 19 percent minimum flow scenario because the upstream shifts of the 10th percentile Km_U values are less due to limiting maximum withdrawals to 87. 5 cfs, compared to the effect of no withdrawal capacity used for the 19 percent flow reduction scenario.

Table 8-16. River volume and area between the 10th and 90th percentile values for the predicted locations of the center for catch per unit effort (Km_U) for selected taxa collected in plankton tows by Peebles (2005). Results correspond to Km_U locations predicted for baseline flows and flows reduced by 19% wth a 120 cfs low flow threshold listed in Table 8-15A. Also listed are the percent reductions in volume and area from the baseline to the flow reduction scenario.

		VOLUME (m^3 x 10,000) between the 10th and 90th percentiles for KmU		
Taxon, stage	**Common name**	**Baseline**	**19 % flow reductions with 120 cfs cutoff**	**Percent change in volume**
***Anchoa mitchilli* adults**	Bay Anchovy	88.5	78.9	-10.8%
Mnemiopsis mccradyi	Comb Jelly, Ctenophore	120.9	102.3	-15.4%
Unidentified Gammarideans	Amphipods	84.5	82.4	-2.5%
***Palaemonetes pugio* adults**	Daggerblade Grass Shrimp	63.2	53.0	-16.1%
***Anchoa mitchilli* juveniles**	Bay Anchovy	70.6	59.8	-15.4%
Cyathura polita	Isopod	118.7	108.1	-8.9%
***Brevoortia smithi* juveniles**	Yellowfin Menhaden	127.9	111.2	-13.0%
Edotea triloba	Isopod	143.2	126.0	-12.0%
***Cynoscion arenarius* juveniles**	Sand Seatrout	189.5	168.8	-10.9%
Americamysis almyra	Opossum Shrimp, Mysid	70.6	67.1	-4.9%
		AREA (hectares) between the 10th and 90th percentiles for KmU		
Taxon, stage	**Common name**	**Baseline**	**19 % flow reductions with 120 cfs cutoff**	**Percent change in area**
***Anchoa mitchilli* adults**	Bay Anchovy	57.1	51.5	-9.8%
Mnemiopsis mccradyi	Comb Jelly, Ctenophore	75.8	64.7	-14.6%
Amphipods, Gammarideans	Amphipods	55.9	52.2	-6.6%
***Palaemonetes pugio* adults**	Daggerblade Grass Shrimp	36.0	29.2	-19.1%
***Anchoa mitchilli* juveniles**	Bay Anchovy	42.1	34.4	-18.4%
Cyathura polita	Isopod	76.3	68.0	-10.9%
***Brevoortia smithi* juveniles**	Yellowfin Menhaden	81.3	70.3	-13.5%
Edotea triloba	Isopod	91.5	80.8	-11.7%
***Cynoscion arenarius* juveniles**	Sand Seatrout	119.7	108.6	-9.2%
Americamysis almyra	Opossum Shrimp, Mysid	42.1	39.7	-5.6%

Table 8-17. River volume and area between the 10th and 90th percentile values for the predicted locations of the center for catch per unit effort (Km_U) for selected taxa collected in plankton tows by Peebles (2005). Results correspond to Km_U locations predicted for baseline flows and flows reduced by 24% wth a 120 cfs low flow threshold and a diversion capacity of 87.5 cfs that are listed in Table 8-15B. Also listed are the percent reductions in volume and area from the baseline to the flow reduction scenario.

		VOLUME (m^3 x 10,000) between the 10th and 90th percentiles for KmU		
Taxon, stage	**Common name**	**Baseline**	**24 % flow reductions with 120 cfs cutoff**	**Percent change in volume**
***Anchoa mitchilli* adults**	Bay Anchovy	88.5	83.85	-5.3%
Mnemiopsis mccradyi	Comb Jelly, Ctenophore	120.9	111.18	-8.0%
Unidentified Gammarideans	Amphipods	84.5	82.35	-2.5%
***Palaemonetes pugio* adults**	Daggerblade Grass Shrimp	63.2	56.27	-11.0%
***Anchoa mitchilli* juveniles**	Bay Anchovy	70.6	63.5	-10.1%
Cyathura polita	Isopod	118.7	118.59	-0.1%
***Brevoortia smithi* juveniles**	Yellowfin Menhaden	127.9	111.24	-13.0%
Edotea triloba	Isopod	143.2	131.16	-8.4%
***Cynoscion arenarius* juveniles**	Sand Seatrout	189.5	179.31	-5.4%
Americamysis almyra	Opossum Shrimp, Mysid	70.6	63.5	-10.1%

		AREA (hectares) between the 10th and 90th percentiles for KmU		
Taxon, stage	**Common name**	**Baseline**	**19 % flow reductions with 120 cfs cutoff**	**Percent change in area**
***Anchoa mitchilli* adults**	Bay Anchovy	57.1	54.5	-4.7%
Mnemiopsis mccradyi	Comb Jelly, Ctenophore	75.8	70.2	-7.4%
Amphipods, Gammarideans	Amphipods	55.9	54.8	-2.0%
***Palaemonetes pugio* adults**	Daggerblade Grass Shrimp	36.0	31.2	-13.5%
***Anchoa mitchilli* juveniles**	Bay Anchovy	42.1	37.1	-11.9%
Cyathura polita	Isopod	76.3	73.7	-3.4%
***Brevoortia smithi* juveniles**	Yellowfin Menhaden	81.3	70.3	-13.5%
Edotea triloba	Isopod	91.5	83.9	-8.3%
***Cynoscion arenarius* juveniles**	Sand Seatrout	119.7	114.4	-4.4%
Americamysis almyra	Opossum Shrimp, Mysid	42.1	37.1	-11.8%

Table 8-18. Median, 10th and 90th percentile values for predicted river kilometer locations of the center of catch-per-unit-effort (Km_U) for selected species/age-size classes collected by seines or trawls in the Lower Alafia River. Predictions made using the regressions of Km_U with freshwater inflow presented by Matheson et al. (2005). Values presnted for baseline flows and flows reduced by: (A) 19% with a 120 cfs low flow threshold and an unlimited diversion capactiy ; and (B) flows reduced by 24% with a 120 cfs low flow threshold and a diversion capactiy of 87.5 cfs.

A. 19% flow reductions with 120 cfs threshold and unlimited diversion capacity				**Kilometers**					
				10th percentile		**median**		**90th percentile**	
Taxon	**Common Name**	**Gear**	**Size Class**	**baseline**	**19% 120 cfs**	**baseline**	**19% 120 cfs**	**baseline**	**19% 120 cfs**
Farfantepenaeus duorarum	Pink Shrimp,	trawls	17 - 36 mm	1.8	2.0	2.5	2.7	3.6	3.5
Palaemonetes pugio	Daggerblade Grass Shrimp	seines	all	3.6	3.6	4.7	5.3	7.1	7.4
Anchoa mitchilli	Bay Anchovy	trawls	<= 24 mm	4.0	4.4	5.7	6.0	7.3	7.3
Anchoa mitchilli	Bay Anchovy	trawls	<= 36 mm	2.9	3.0	3.9	4.1	5.0	5.0
Eucinostomus harengulus	Tidewater Mojarra	seines	40 to 70 mm	4.0	4.4	5.2	5.5	6.5	6.9
Diapterus plumiere	Stripped Mojarra	seines	46 to 100 mm	5.0	5.2	6.3	6.6	7.6	7.6
Cynoscion nebulosus	Spotted Seatrout	seines	45 to 100 mm	1.6	1.7	2.4	2.6	3.3	3.4
Cynoscion arenarius	Sand Seatrout	trawls	40 to 100 mm	3.2	3.4	4.4	4.7	5.6	5.6
Cynoscion arenarius	Sand Seatrout	trawls	<= 39mm	2.1	2.2	3.0	3.2	4.2	4.3
Bairdiella chrysoura	Silver Perch	seines	46 to 100 mm	1.9	2.1	3.0	3.3	4.4	4.5
Menticirrhus americanus	Southern Kingfish	trawls	40 to 155 mm	1.9	1.9	2.7	2.9	3.9	4.0
Sciaenops ocellatus	Red Drum	seines	40 to 150 mm	2.7	2.8	3.6	3.9	4.7	4.9

B. 24% flow reductions with 120 cfs threshold and 87.5 cfs diversion capacity				**Kilometers**					
				10th percentile		**median**		**90th percentile**	
Taxon	**Common Name**	**Gear**	**Size Class**	**baseline**	**24% 120 cfs**	**baseline**	**24% 120 cfs**	**baseline**	**24% 120 cfs**
Farfantepenaeus duorarum	Pink Shrimp	trawls	17 - 36 mm	1.8	2.0	2.5	2.8	3.6	3.5
Palaemonetes pugio	Daggerblade Grass Shrimp	seines	all	3.6	3.7	4.7	5.4	7.1	7.5
Anchoa mitchilli	Bay Anchovy	trawls	<= 24 mm	4.0	4.3	5.7	6.1	7.3	7.3
Anchoa mitchilli	Bay Anchovy	trawls	<= 36 mm	2.9	3.0	3.9	4.2	5.0	5.0
Eucinostomus harengulus	Tidewater Mojarra	seines	40 to 70 mm	4.0	4.3	5.2	5.4	6.5	6.9
Diapterus plumiere	Stripped Mojarra	seines	46 to 100 mm	5.0	5.1	6.3	6.6	7.6	7.6
Cynoscion nebulosus	Spotted Seatrout	seines	45 to 100 mm m	1.6	1.7	2.4	2.6	3.3	3.4
Cynoscion arenarius	Sand Seatrout	trawls	40 to 100 mm	3.2	3.3	4.4	4.7	5.6	5.6
Cynoscion arenarius	Sand Seatrout	trawls	<= 39mm	2.1	2.2	3.0	3.3	4.2	4.3
Bairdiella chrysoura	Silver Perch	seines	46 to 100 mm	1.9	2.0	3.0	3.3	4.4	4.6
Menticirrhus americanus	Southern Kingfish	trawls	40 to 155 mm	1.9	1.9	2.7	2.9	3.9	4.0
Sciaenops ocellatus	Red Drum	seines	40 to 150 mm	2.7	2.8	3.6	3.9	4.7	4.9

The kilometer locations of the 10th, 50th (median) and 90th percentile values for the predicted locations of Km_U for the taxa collected by seines or trawls are listed in Table 8-18 for baseline flows and flow reduced by the two flow reduction scenarios (on preceding page). Similar to the findings for plankton taxa, these results show that the region of the river between kilometers 2 and 7 is where the distributions of most of the seine and trawl species are centered. The median location of the seine and trawl taxa for baseline flows in Table 8-18 range from 2.4 to 6.3 kilometers. The downstream (10th percentile) locations of KmU range between 1.6 and 5.0 kilometers, while the upstream (90th percentile) locations range from 3.6 to 7.6 kilometers for the different taxa.

Shifts in median Km_U values resulting from the two flow reduction scenarios mainly ranged between 0.2 and 0.3 kilometers from baseline conditions, with the shift in the median value for daggerblade grass shrimp reaching 0.6 to 0.7 kilometers (Table 8-18). Shifts in the 10th, 50th, and 90th percentile locations in KmU are illustrated for four of the taxa collected by seines or trawls in Figure 8-8. As with the plankton taxa, the small to negligible shifts in the 90th percentile values are due to the effect of the 120 cfs low-flow threshold.

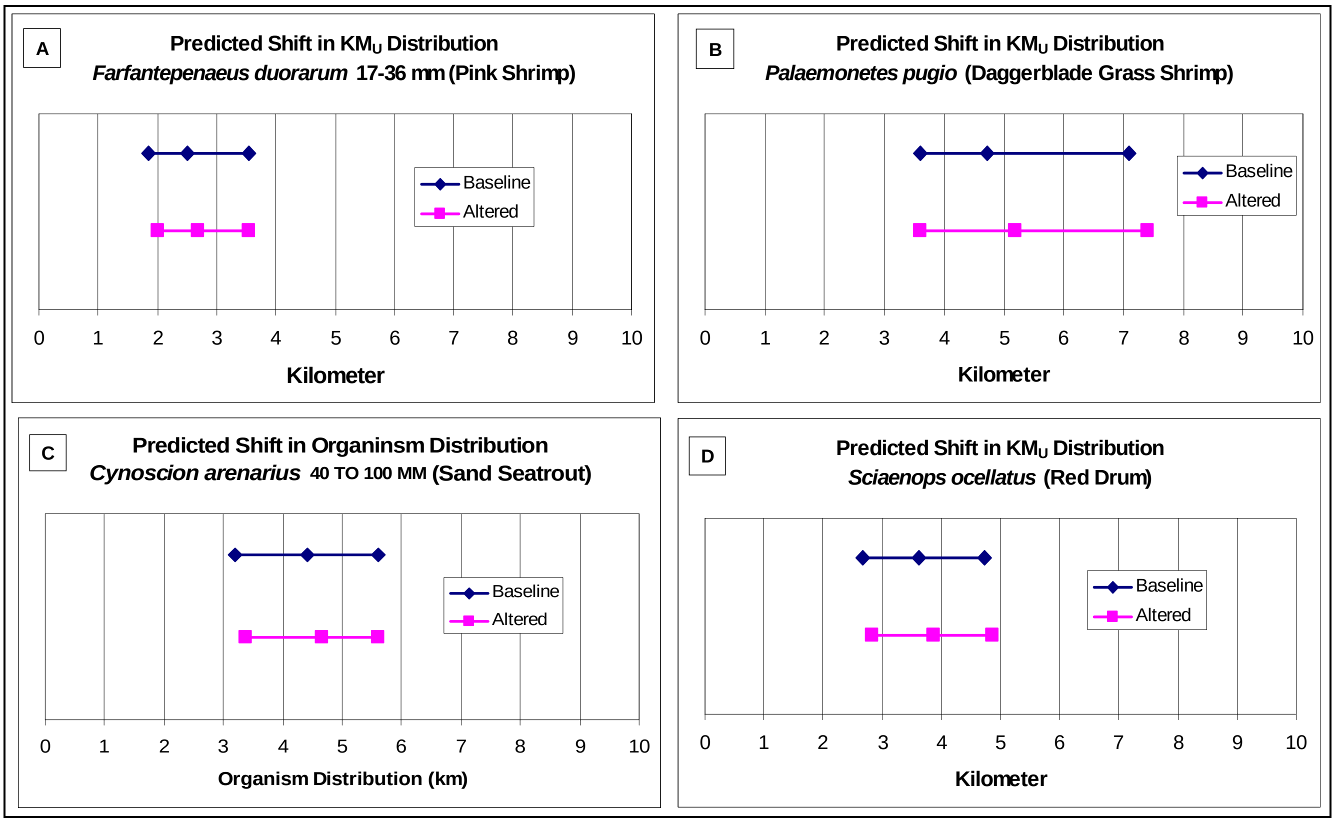


Figure 8-8. Predicted 10th, 50th, and 90th percentile locations of the center of catch per unit effort (KmU) for four fish or invertebrate species collected by seine or trawl for baseline flows and flows reduced by 19 percent with a 120 cfs low-flow threshold and an unlimited withdrawal capacity (A = *Farfantepenaeus duorarum* (pink shrimp); B= *Palaemonetes pugio* (daggerblade grass shrimp); *Cynoscion arenarius* juveniles 40-100 mm (sand seatrout); *Sciaenops ocellatus* juveniles 40- 150 mm (red drum).

The kilometer values of Km_U listed in Table 8-18 were used to calculate the area and shoreline length between the 10^{th} and 90^{th} percentile values for each seine or trawl species for the baseline and the two minimum flow scenarios. Changes in area were calculated for the species collected by trawls, while changes in shoreline length were calculated by those species collected by seines. These values and the percent changes from baseline conditions are listed in Table 8-19 for the 19 percent minimum flow scenario. All changes in area between the 10^{th} and 90^{th} percentiles are less than 15 percent (maximum change of 13 percent). Similarly, all changes in shoreline length between the 10^{th} and 90^{th} percentiles are less than 15 percent (maximum change of 11 percent).

Reductions in area and shoreline length for the 24 percent flow reduction scenario with existing withdrawal facilities are presented in Table 8-20. These results are very similar to the 19 percent minimum flow scenario with unlimited withdrawal capacity, with no reductions in area or shoreline length greater than 15 percent. It is interesting to note that in a few cases, the flow reductions actually increased the amount of area or shoreline length between the 10^{th} and 90^{th} percentile values relative to the baseline condition. This occurs because in some short segments of the river, the amount of area and shoreline can increase for some distance upstream (see Figures 3-8 and 3-12). In these regions of the river, an upstream shift in either the downstream or upstream limit of the specie's distribution can result in a small increase in area or shoreline length, though this is not the response observed for most taxa.

In summary, predictive models were applied to evaluate the effects of a series of flow reductions on changes in both the distribution and abundance of key fish and invertebrate species. For the most part, a higher proportion of the variability in species distribution was explained by the distribution models, as evidenced by their generally higher r^2 values. Abundance, however, is the key variable of interest, which could be influenced by factors other than habitat availability, such as prey abundance. The proposed minimum flows were based on predicted reductions in abundance of key species in the river that were determined to be within acceptable limits. The results from the assessment of changes in distributions are very supportive of the proposed minimum flows, for the predicted changes in available habitat are small and not expected to result in significant harm to the lower river.

Table 8-19. River area and shoreline length between the 10th and 90th percentile values for the predicted locations of the center of catch-per-unit-effort (Km_U) for selected taxa collected in seines and trawls by FWRI (Matheson, 2005). Resuslts correspond to Km_U locations predicted for baseline flows and flows reduced by 19% with a 120 cfs low flow threshold listed in Table 8-18A. Also listed are the percent reductions in area and shoreline length from the baseline to the flow reduction scenario. Area values are listed for taxa collected either by seine or trawl. Shoreline values are listed for taxa collected by seine.

				AREA (hectares) between the 10th and 90th percentiles for KmU		
Taxon	**Common Names**	**Gear**	**Trawls**	**Baseline**	**17 % flow reductions with 120 cfs cutoff**	**Percent change in volume**
Farfantepenaeus duorarum	Pink Shrimp	Trawls	17 to 36 mm	67.2	61.4	-8.6%
Palaemonetes pugio	Daggerblade Grass Shrimp	Seines	All	71.5	74.8	4.6%
Anchoa mitchilli	Bay Anchovy	Trawls	<=24 mm	58.4	53.6	-8.2%
Anchoa mitchilli	Bay Anchovy	Trawls	>=36 mm	59.5	56.9	-4.5%
Eucinostomus harengulus	Tidewater Mojarra	Seines	40 to 70 mm	51.8	48.8	-5.8%
Diapterus plumiere	Stripped Mojarra	Seines	46 to 100 mm	40.6	35.2	-13.1%
Cynoscion nebulosus	Spotted Seatrout	Seines	45 to 100 mm	68.4	68.8	0.6%
Cynoscion arenarius	Sand Seatrout	Trawls	40 to 100 mm	64.5	56.9	-11.8%
Cynoscion arenarius	Sand Seatrout	Trawls	<=39 mm	74.5	71.2	2.8%
Bairdiella chrysoura	Silver Perch	Seines	46 to 100 mm	90.7	82.6	-8.9%
Menticirrhus americanus	Southern Kingfish	Trawls	40 to 115 mm	79.2	81.6	2.9%
Sciaenops ocellatus	Red Drum	Seines	40 to 150 mm	60.0	60.2	-3.1%

				SHORELINE (kilometers) between the 10th and 90th percentiles for KmU		
Taxon	**Common Names**	**Gear**	**Size**	**Baseline**	**17 % flow reductions with 120 cfs cutoff**	**Percent change in shoreline**
Palaemonetes pugio	Daggerblade Grass Shrimp	Seines	All	13.7	14.4	5.1%
Eucinostomus harengulus	Tidewater Mojarra	Seines	40 to 70 mm	8.3	8.3	0.0%
Diapterus plumiere	Stripped Mojarra	Seines	46 to 100 mm	6.5	5.8	-10.7%
Cynoscion nebulosus	Spotted Seatrout	Seines	45 to 100 mm	10.3	11.4	10.3%
Bairdiella chrysoura	Silver Perch	Seines	46 to 100 mm	16.9	16.6	-1.8%
Sciaenops ocellatus	Red Drum	Seines	40 to 150 mm	13.4	13.3	-0.8%

Table 8-20. River area and shoreline length between the 10th and 90th percentile values for the predicted locations of the center of catch-per-unit- effort ($Km_{U)}$ for selected species/age-size claseses collected in seines and trawls by FWRI (Matheson, 2005). Results correspond to Km_U locations predicted for baseline flows and flows reduced by 24% with a 120 cfs low flow threshold and a 87.5 cfs diversion capacity listed in Table 8-23B. Also listed are the percent reductions in area and shoreline length from the baseline to the flow reduction scenario. Area valus are listed for taxa collected either by seine or trawl. Shoreline values are listed for taxa collected by seine.

				AREA (hectares) between the 10th and 90th percentiles for KmU		
Taxon	**Common Names**	**Gear**	**Trawls**	**Baseline**	**24 % flow reductions with 120 cfs cutoff**	**Percent change in volume**
Farfantepenaeus duorarum	Pink Shrimp	Trawls	17 to 36 mm	67.2	61.4	-8.6%
Palaemonetes pugio	Daggerblade Grass Shrimp	Seines	All	71.5	72.5	1.4%
Anchoa mitchilli	Bay Anchovy	Trawls	<=24 mm	58.4	56.3	-3.6%
Anchoa mitchilli	Bay Anchovy	Trawls	>=36 mm	59.5	56.9	-4.5%
Eucinostomus harengulus	Tidewater Mojarra	Seines	40 to 70 mm	51.8	51.5	-0.5%
Diapterus plumiere	Stripped Mojarra	Seines	46 to 100 mm	40.6	38.0	-6.4%
Cynoscion nebulosus	Spotted Seatrout	Seines	45 to 100 mm	68.4	68.8	0.6%
Cynoscion arenarius	Sand Seatrout	Trawls	40 to 100 mm	64.5	60.8	-5.8%
Cynoscion arenarius	Sand Seatrout	Trawls	<=39 mm	74.5	71.2	-4.5%
Bairdiella chrysoura	Silver Perch	Seines	46 to 100 mm	90.7	91.9	1.4%
Menticirrhus americanus	Southern Kingfish	Trawls	40 to 115 mm	79.2	81.6	3.0%
Sciaenops ocellatus	Red Drum	Seines	40 to 150 mm	60.0	60.2	0.5%

				SHORELINE (kilometers) between the 10th and 90th percentiles for KmU		
Taxon	**Common Names**	**Gear**	**Size**	**Baseline**	**24 % flow reductions with 120 cfs cutoff**	**Percent change in shoreline**
Palaemonetes pugio	Daggerblade Grass Shrimp	Seines	All	13.7	13.9	1.1%
Eucinostomus harengulus	Tidewater Mojarra	Seines	40 to 70 mm	8.3	8.5	2.4%
Diapterus plumiere	Stripped Mojarra	Seines	46 to 100 mm	6.5	6.1	-6.6%
Cynoscion nebulosus	Spotted Seatrout	Seines	45 to 100 mm	10.3	11.4	11.5%
Bairdiella chrysoura	Silver Perch	Seines	46 to 100 mm	16.9	17.5	3.4%
Sciaenops ocellatus	Red Drum	Seines	40 to 150 mm	13.4	13.3	-0.4%

8.6 Simulations of Shifts in Salinity Distributions

Salinity distributions exert a major influence on the zonation of biological communities in estuaries, and biological studies of the Lower Alafia River have found distinct gradients in the species composition and abundance of phytoplankton, wetland plants, mollusks, benthic invertebrates, zooplankton and fishes along the horizontal salinity gradients that extend along the length of the lower river. Accordingly, a key component of the minimum flows analysis was to examine potential changes in salinity distributions that could result from reductions in freshwater inflow. These changes are in turn related to potential effects on biological communities in the lower river.

Changes in salinity distributions were evaluated by application of the LAMFE model and the empirical isohaline regressions developed by Janicki Environmental (Appendix 5B). The LAMFE model was used to predict average daily values of river volume and area of river bottom in 1 psu increments. The LAMFE model was also used to assess changes in salinity in the zone of the river which supports oysters. The LAMFE model was used to predict average daily values of river volume and area of river for the period from May 10, 1999 to December 23, 2003, for this is when data for all hydrologic inputs and boundary conditions for the model were available. As discussed in Section 2.8 and later below, this was a relatively dry period which made the predicted changes in salinity distributions conservative (effect of withdrawals maximized). The empirical isohaline regressions were run on the entire baseline period from 1987 through 2003, which as described in Section 2.3, was more representative of the long-term flow conditions of the river.

Ecologists have long described estuaries in terms of salinity zones, based on the general distributions of estuarine biota. One of the oldest and most commonly used salinity classification systems is the Venice System, which has the following salinity zones: Limnetic (< 0.5 psu), oligohaline (0.5 to 5 psu), mesohaline (5 to 18 psu), polyhaline (18 to 30 psu), and euhaline (> 30 psu). This system was developed in the 1950s based on the observations and judgment of experienced scientists at that time (Anonymous 1959). More recently, Bulger et al. (1993) performed Principal Components Analysis (PCA) on observed salinity ranges for 336 species/life stages from the mid-Atlantic region and developed five overlapping salinity zones: freshwater to 4 psu, 2 - 14 psu, 11 - 18 psu, 16 - 27 psu, and 24 psu to marine**.**

As described in Section 6.7.4.2, Janicki Environmental applied PCA to data for benthic invertebrate fauna from the Lower Alafia River and other Tampa Bay tributaries to delineate salinity zones among which invertebrate communities showed differences in species composition. In contrast to fishes, which can readily migrate up and down the river, benthic invertebrates are more sessile and their distributions in the river are closely linked to salinity distributions. Benthic invertebrates are also important components of the estuarine food web and prey for fishes. It was therefore concluded to base the assessment of allowable changes in salinity zones on salinity ranges that would maintain the composition and zonation of benthic invertebrate communities in the river.

The PCA analysis of the Alafia River data by Janicki Environmental identified five salinity ranges that had significant relationships to the composition of macroinvertebtate communties in the lower river. Of these five, the 0-6 and 6-15 psu groups were included in the minimum flows analysis because they most frequently occur in the river and cover most of its bottom area, as opposed to the higher salinity ranges which are often found off the mouth of the river or in the dredged zone below kilometer 1 near the barge turning basin. As described below, the lower salinity ranges are more sensitive to changes in freshwater inflow than the higher salinity ranges, which are more influenced by flushing from Tampa Bay. Also, the minimum flows analysis examined reductions in the < 15 psu zone rather than the 6-15 psu zone, since the 6-15 zone often compresses with increasing freshwater inflow due to the more pronounced downstream movement of the 6 psu isohaline relative the 15 psu isohaline. Therefore, to be conservative, the < 15 psu zone was chosen for analysis since the District was interested in the entire area or volume of low salinity water, and the size of the < 15 psu zone consistently increased with freshwater inflow.

The <6 psu and 6-15 salinity zones are similar to the oligohaline and combined oligohaline and mesohaline zones of the Venice classification system. The Tampa Bay Estuary Program has identified oligohaline zones (0.5 to 5 psu) as priorities for management, because of their ecological importance and historic loss in estuaries due to human impacts (TBEP 2006). Studies of fish and invertebrate populations in other regional rivers have found centers of catch-per-unit-effort (Km_U) for many species in the < 6 psu to and 6-15 psu zones (Peebles 2002b, MacDonald et al. 2005, Peebles et al. 2006). Though developed for benthic invertebrates, management conclusions base on changes in the < 6 and <15 psu salinity zones would likely have good application to suitable salinity zones for fishes, as these salinity zones are documented to be prime habitats for fish nursery use and are populated by many invertebrate species that are important fish food organisms.

The District also included a <1 psu salinity zone in the minimum flows analysis to assess changes in the tidal freshwater habitats in the lower river. Recent PCA analyses of fish data from the Lower Hillsborough and Peace Rivers have found breaks in the species composition of fish communities around 2 psu, due largely to the presence of freshwater species in this low salinity range (SWFWMD 2006b, 2007b). Based on the FRWI sampling in the Alafia, Greenwood et al. (2007) similarly found a distinct fish community in the upper portions of the lower river that was comprised of freshwater and low salinity species. Benthic surveys of the Lower Alafia River have also found many freshwater invertebrate species in the upper reaches of the lower river, though they did not show up as a distinct group in the PCA analysis. The District did not include freshwater species as resources of concern in the minimum flows analysis, because abundant freshwater habitat exists in the Alafia River above Bell Shoals Road. However, there are some freshwater taxa (especially zooplankton) that probably proliferate in the tidal freshwater zone due to its slower current velocities. Also, the freshwater zone can be quite large when it expands into the broader reaches of the lower river during medium to high flows (see Figure 5-21). Given these considerations, the freshwater zone was considered in the minimum flows analysis by examining changes in the volume and bottom area of salinity less than 1 psu, although direct impacts to freshwater species were not examined.

8.6.1 Simulations Using the LAMFE Model

To evaluate effects of reduced freshwater inflow on salinity distributions, percent flow reductions were applied to the baseline of the river in rates ranging from 10 to 40 percent. The period from May 10, 1999 to December 23, 2003 was then simulated using the LAMFE model to evaluate changes in the amount of volume and bottom area in the river less than salinity values of 1, 6, and 15 psu. Average daily salinity values were calculated in each cell and layer combination in the river for this analysis. Cumulative distribution functions of the areas of river bottom less than 1, 6, and 15 psu for baseline flows and flow reductions ranging from 10 to 40 percent are shown in Figure 8-9. The response of these salinity zone areas to inflow is consistently positive, thus the effects of low flows are represented in the low percentile values to the left of the graphs and high flows are represented in the high percentiles to the right. Because high flows influence the large range of area values that occur above the 90th percentile, the CDF plots are also shown for the lower 50 percent of values so that the effects of flow reductions during times of low flow can be better illustrated.

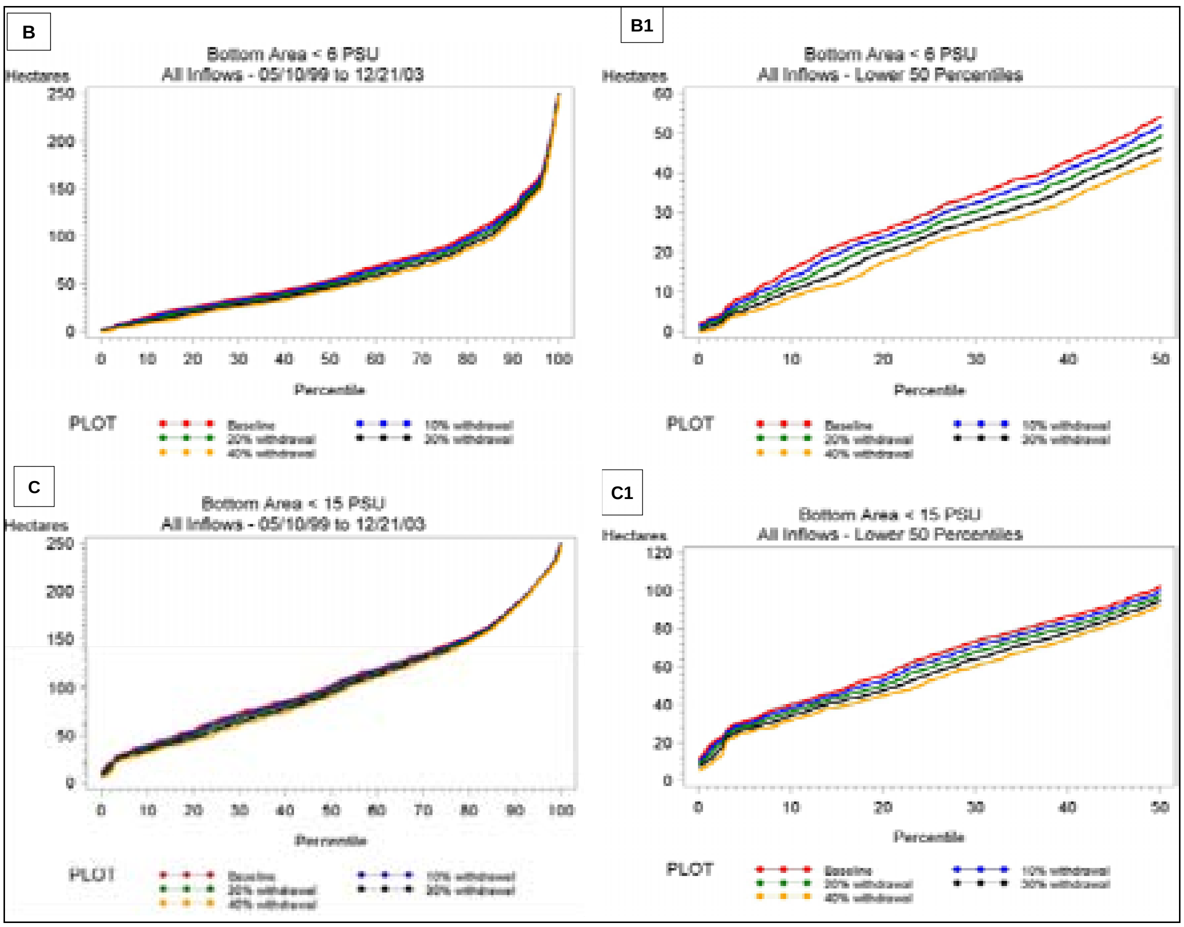


Figure 8-9. Cumulative distribution function of simulated bottom area values in the Lower Alafia River less than 1 psu and less than 15 psu for baseline flows and four percent flow reductions. CDF plots shown for days during the LAMFE modeling period and for the lower 50 percentile values to better illustrate differences in values for the flow scenarios at low inflows.

Selected percentile values (5th, 15th, 25th, 50th, 75th, 85th, and 95th) of area values from the CDF curves for these flow scenarios are listed in Table 8-21A, with values for the baseline flows expressed as hectares and values for the flow reductions as percent of the baseline values. Reductions in area for a given percentile greater than 15 percent are highlighted in gray. Reductions greater than 15 percent are most common for the < 1 psu zone, intermediate for the < 6 psu zone, and least for the < 15 psu zone, indicating that the lower salinity zones are the most sensitive to changes that would result from flow reductions. Also, the reductions from baseline are greatest for the lower percentile values, indicating that changes in salinity distributions are most sensitive at low flows. In general, however, the reductions in habitat resulting from the flow reductions listed in Table 8-21A are fairly small, as reductions in the median values for the zones do not exceed 15 percent of area at flow reductions of 20 percent for < 1 psu zone, 30 percent for the < 6 psu zone, and 40 percent for the <15 psu zone.

The flow reductions and changes in bottom area described above were simulated without the application of a low-flow threshold. As described in Sections 8.1 and 8.3, the proposed minimum flows for the lower river were based on predicted changes in the abundance of key fish and invertebrate species in the river, combined with a low-flow threshold that was based on water quality and ecological factors. Reductions in bottom areas for the proposed 19 percent minimum flow and the 24 percent scenario with existing permitted facilities are also listed in Table 8-21, with both scenarios employing the 120 cfs low-flow threshold. Changes in median values for the proposed minimum flow do not exceed 15 percent, with changes in the median values of the <6 and < 15 psu zones ranging between 6 and 9 percent. Interestingly, changes in the median values were typically the greatest for each flow scenario. Changes in the low percentile values (5th and 15th percentiles) were small for both flow reduction scenarios due to the effect of the low-flow threshold, while changes in the higher percentile values were small as well because the salinity distributions are not as sensitive to change at higher flow rates. The small reduction in area at high flows for the < 6 and < 15 psu zones might be affected by these zones moving past the model boundary. However, small reductions in area from the baseline at high flows were also found for the < 1 psu zone, which remains within the tidal river over the range of flows that were evaluated.

Reductions in areas were also expressed for bottom areas between 1 and 6 psu and between 6 and 15 psu for the proposed minimum flows relative to baseline (Table 8-21B). Compared to the total bottom areas less than 6 psu and less than 15 psu, reductions of bottom areas within the 1 to 6 psu and 6 to 15 psu salinity intervals considerably smaller. As described above, these results must be viewed with caution, particularly for the 6-15 psu values, as this zone may move outside the model domain at high flows. Notwithstanding this constraint, increased flows may actually cause a reduction in the area within a salinity interval in the river, as the zone may compress with increased flows. As described on page 8-48, the total areas < 6 and < 15 psu were used in the minimum flows analysis to be more conservative and consider the total amounts of bottom area less than these salinity thresholds.

Table 8-21A. Selected percentiles for daily values of percent of bottom area less than 1, 6, and 15 psu salinity resulting from different flow reductions relative to baseline flows. Bottom areas for baseline flows expressed in hectares upstream of kilometer 1.8. All other area values are expressed as percentage of baseline. The 19% flow reduction scenario with the 120 cfs low flow threshold assumes an unlimited withdrawal capacity, while the 24% scenario with a 120 cfs low flow thresold assumes an 87.5 cfs diversion capacity. All other scenarios have no low flow threshold. Percent area reductions less than 85% for a specific percentile and flow reduction are highlighted in gray.

			Percentile						
Salinty Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
< 1 psu	Baseline	Hectares	3.4	8.8	16.7	36.2	66.4	83.8	120.5
	10% reduction	% of baseline	84%	87%	87%	93%	95%	96%	96%
	20% reduction	% of baseline	67%	74%	74%	87%	90%	92%	92%
	30% reduction	% of baseline	46%	61%	64%	80%	84%	87%	88%
	40% reduction	% of baseline	26%	48%	51%	72%	78%	82%	84%
	19% reduction	% of baseline	66%	74%	73%	85%	89%	91%	91%
	19% 120 cfs low flow	% of baseline	98%	97%	92%	86%	89%	91%	92%
	24% 120 cfs, existing capacity	% of baseline	98%	97%	91%	83%	88%	93%	95%
			Percentile						
Salinty Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
< 6 psu	Baseline	Hectares	9.1	21.8	30.1	54.0	89.3	113.8	157.3
	10% reduction	% of baseline	89%	90%	93%	96%	96%	97%	98%
	20% reduction	% of baseline	74%	79%	87%	91%	92%	93%	96%
	30% reduction	% of baseline	60%	68%	81%	86%	88%	89%	94%
	40% reduction	% of baseline	50%	55%	74%	80%	84%	85%	92%
	19% reduction	% of baseline	70%	78%	86%	90%	91%	91%	95%
	19% 120 cfs low flow	% of baseline	91%	96%	96%	91%	91%	92%	95%
	24% 120 cfs, existing capacity	% of baseline	91%	96%	95%	89%	91%	93%	96%
			Percentile						
Salinty Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
< 15 psu	Baseline		31.3	47.3	65.8	102.5	143.8	165.0	210.9
	10% reduction	% of baseline	95%	96%	95%	98%	99%	99%	100%
	20% reduction	% of baseline	92%	93%	90%	95%	98%	99%	99%
	30% reduction	% of baseline	87%	88%	85%	92%	97%	98%	99%
	40% reduction	% of baseline	81%	82%	80%	90%	95%	97%	99%
	19% reduction	% of baseline	89%	91%	89%	94%	96%	97%	98%
	19% 120 cfs low flow	% of baseline	97%	98%	96%	94%	96%	97%	98%
	24% 120 cfs, existing capacity		97%	98%	95%	94%	97%	98%	98%

Table 8-21B. Percentile values of bottom areas with salinty values between 1 to 6 and 6 to 15 psu. Percentiles presented for baseline flows and flows reducted by the proposed minimum flows. Reductions in bottom areas expressed as percents of the baseline for each percentile value.

			Percentile (area)						
Salinty Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
1 to 6 psu	Baseline	Hectares	5.5	11.5	13.4	17.1	24.4	29.2	38.6
	19% 120 cfs low flow	Hectares	5.0	11.2	13.0	16.5	23.6	28.1	39.7
	Percent of baseline	% of baseline	91%	97%	97%	96%	97%	96%	103%
			Percentile (area)						
Salinty Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
6 to 15 psu	Baseline	Hectares	19.4	24.4	30.2	40.9	51.8	59.0	70.4
	19% 120 cfs low flow	Hectares	19.3	24.2	30.3	41.2	53.2	61.8	73.9
	Percent of baseline	% of baseline	99.6%	98.8%	100.3%	100.5%	102.7%	104.7%	105.0%

CDF curves for the volumes of the river corresponding to the baseline flows and percent flow reductions ranging from 10 to 40 percent are shown in Figure 8-10. Again, the CDF curves are also shown for just the lower 50 percent of the values to better illustrate the effect of flow reductions at low flows. Selected percentiles of volume values from these plots are listed in Table 8-22A, in the same format used for the salinity area values. The changes in volumes for the flow reductions are again greatest for the < 1 psu salinity zone, least for the < 15 psu zone, with greatest changes for each zone and flow scenario observed at low flows. Because volume and bottom are highly correlated, the percent changes in volume and bottom area for the flow reductions are very similar. Also, as with the results for reductions in bottom area, the proposed 19 percent minimum flow and the 24 percent scenario with existing facilities result in very small changes in the median values for volumes less than 1, 6, or 15 psu. Even smaller changes occur at the low and high percentiles due to the factors previously described. Changes in the water volumes between 1 to 6 psu and 6 to psu were also assessed for the proposed 19 percent minimum flow (Table 8-22B). As with bottom area, the relative changes in the volumes of these salinity intervals were smaller than the changes in the less than 6 psu and the less than 15 psu zones. Again, the volumes <6 psu and <15 psu were used in the minimum flows analysis to be more conservative.

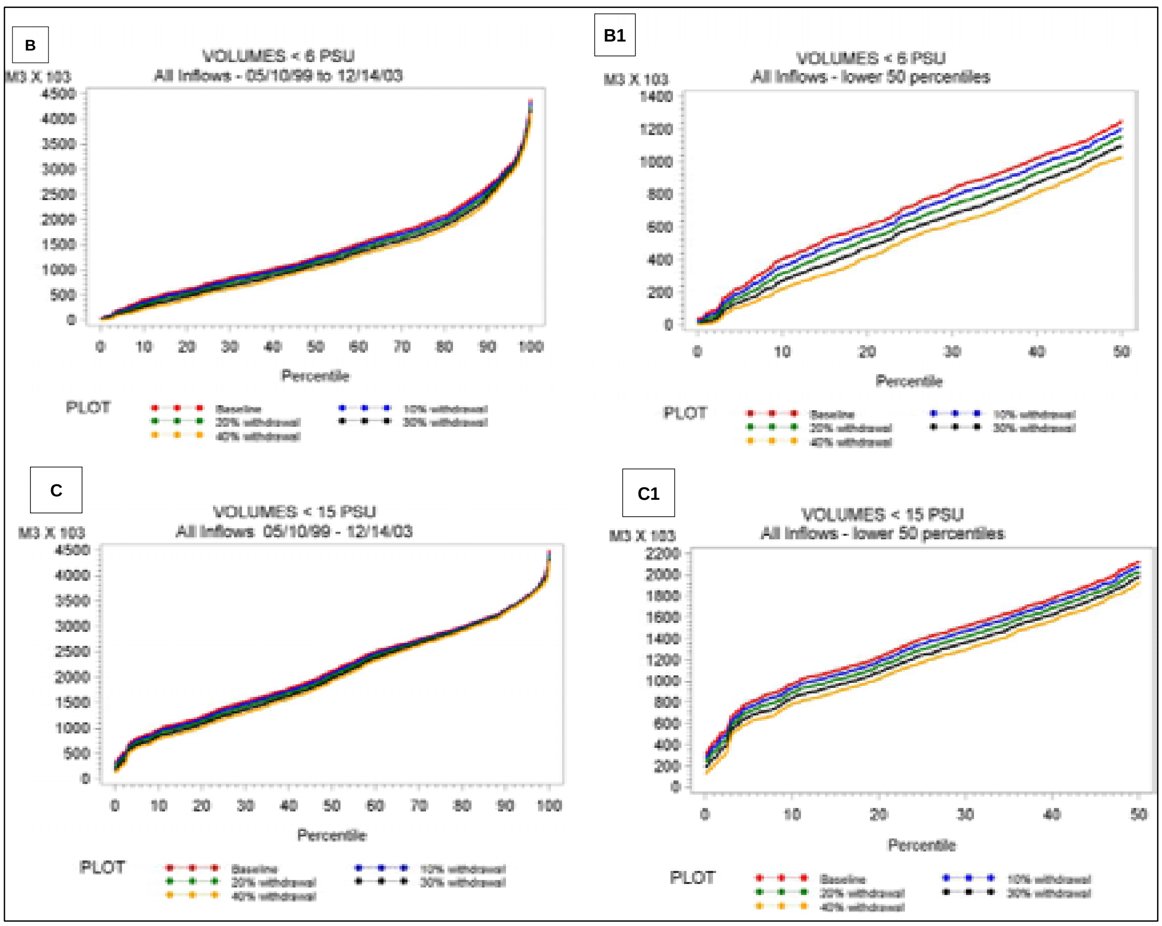


Figure 8-10. Cumulative distribution function of simulated water volumes in the Lower Alafia River less than 1 psu and less than 6 psu for baseline flows and four percent flow reductions. CDF plots shown for days during the LAMFE modeling period and for the lower 50 percentile values to better illustrate differences values for the flow scenarios at low inflows.

Table 8-22A. Selected percentiles of percent of water volumes less than 1, 6, and 15 psu salinity resulting from different flow reductions relative to baseline flows. Volumes for baseline flows expressed as cubic meters x 10^3 upstream of kilometer 1.8 All other volume values are expressed as percentage of baseline. The 19% flow reduction scenario with the 120 cfs low flow threshold assumes an unlimited diversion capacity for the river, while the 24% flow reduction scenario with a 120 cfs low flow threshold assumes an 87.5 cfs diversion capacity. All other scenarios have no low flow threshold. Percentages less than 85% are highlighted in gray.

			Percentile						
Salinty Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
< 1 psu	Baseline	meters^3 x 10^3	70	203	386	817	1354	1643	2265
	10% reduction	% of baseline	77%	86%	87%	93%	97%	97%	97%
	20% reduction	% of baseline	54%	72%	75%	87%	92%	93%	94%
	30% reduction	% of baseline	33%	59%	62%	80%	88%	89%	91%
	40% reduction	% of baseline	16%	44%	49%	73%	83%	85%	86%
	19% reduction	% of baseline	56%	73%	77%	87%	92%	94%	94%
	19%, 120cfs low flow	% of baseline	100%	100%	95%	88%	93%	94%	94%
	24%, 120 cfs, existing capacity	% of baseline	100%	100%	94%	85%	93%	95%	97%
			Percentile						
Salinty Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
< 6 psu	Baseline	meters^3 x 10^3	227	522	725	1251	1916	2343	3062
	Permitted	% of baseline	79%	89%	95%	95%	96%	97%	99%
	10% reduction	% of baseline	87%	91%	94%	96%	97%	97%	99%
	20% reduction	% of baseline	74%	82%	88%	92%	93%	91%	97%
	30% reduction	% of baseline	61%	71%	81%	88%	90%	91%	96%
	40% reduction	% of baseline	49%	59%	73%	82%	86%	87%	94%
	19% reduction	% of baseline	75%	83%	89%	93%	93%	95%	97%
	19%, 120cfs low flow	% of baseline	100%	100%	98%	93%	94%	95%	97%
	24%, 120 cfs, existing capacity	% of baseline	100%	100%	98%	91%	94%	96%	99%
			Percentile						
Salinity Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
< 15 psu	Baseline	meters^3 x 10^3	794	1101	1400	2120	2867	3148	3611
	Permitted	% of baseline	90%	95%	97%	97%	99%	99%	100%
	10% reduction	% of baseline	95%	96%	96%	98%	99%	100%	99%
	20% reduction	% of baseline	90%	92%	93%	95%	98%	99%	99%
	30% reduction	% of baseline	84%	87%	89%	94%	97%	98%	99%
	40% reduction	% of baseline	77%	81%	84%	91%	96%	97%	98%
	19% reduction	% of baseline	90%	93%	93%	96%	98%	99%	99%
	19%, 120cfs low flow	% of baseline	100%	100%	98%	96%	98%	99%	99%
	24%, 120 cfs, existing capacity	% of baseline	100%	100%	98%	95%	99%	99%	100%

Table 8-22B Percentile values of water volumes with salinity values between 1 to 6 psu and 6 to 15 psu. Percentiles presented for baseline flows and flows reducted by the proposed minimum flows. Reductions in water volumes expressed as percent of the baseline for each percentile value.

			Percentile (volume)						
Salinty Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
1 to 6 psu	Baseline	m^3 x 10^3	148	290	336	415	536	631	810
	19% 120 cfs low flow	m^3 x 10^3	149	291	334	411	530	628	820
	Percent of basline	% of baseline	100.6%	100.3%	99.5%	99.0%	98.8%	99.4%	101.3%
			Percentile (volume)						
Salinty Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
6 to 15 psu	Baseline	m^3 x 10^3	364	527	577	699	891	1019	1222
	19% 120 cfs low flow	m^3 x 10^3	385	537	591	711	937	1060	1302
	Percent of basline	% of baseline	105.8%	101.9%	102.4%	101.7%	105.2%	104.0%	106.5%

These results for the simulation of reductions in the area and volume of biologically important salinity zones indicate that adoption and implementation of the proposed minimum flow will have a very small impact on salinity distributions in the Lower Alafia River, and are not expected to cause significant harm to biological communities associated with salinity gradients in the river. These conclusions are drawn from LAMFE modeling scenarios conducted over the period from May 1999 through December 2003. As discussed in Section 2.8, this modeling period included a major prolonged drought during 2000 and 2001 and the low and middle flows for this modeling period were drier than the long-term conditions for the river (Table 2.10). In general, this makes the modeling period a very conservative period to evaluate salinity changes due to flow reductions, as salinity distributions are most sensitive to change at low flows. On the other hand, the river was below the 120 cfs low-flow threshold more often during this period, which tends to minimize withdrawal effects since no withdrawals are simulated for longer periods of time. However, the flow scenarios listed in Table 8-21A and 8-22A that had no low-flow thresholds show relatively small changes over most of the cumulative frequency distributions, although the low-flow threshold was effective at minimizing reductions in the area and volume of salinity zones during low flows.

8.6.2 Simulation of Salinity Changes in the Oyster Zone of the River

As discussed in Section 6.6, Mote Marine Laboratory (2003) documented the presence of oyster reefs in the Lower Alafia River between kilometers 1 and 4 (Figure 6.23). Oyster biologists from Florida Gulf Coast University reviewed the Mote Report and salinity-freshwater inflow relationships in the lower river and presented recommendations for maintaining salinity distributions in the river that would prevent impacts to the oyster population there (Volety and Tolley 2006). They point out that while overall salinity values in the river are very conducive for the long-term development and growth of oysters, high flows exceeding 2000 – 3000 cfs for periods greater than two weeks do occur. These flows result in prolonged salinities of less than 5 psu, which can pose significant harm to the oyster population in the river. However, such high flows are natural occurrences which do result in periodic impacts to the oyster population of the river. Reductions of high flows due to withdrawals clearly will not exacerbate these impacts, and to some extent may lessen the impacts of high flows on the oyster community, thus flow reductions at high flows were not a factor in the minimum flows analysis.

Volety and Tolley also caution that high salinities exceeding 28 psu do periodically occur where oysters are present in the river, and it should be cautioned that while low flows resulting in salinities exceeding 28 psu for periods of one to two months may not cause significant harm, persistence of these high salinity conditions invite predators such as oyster drills, whelks, star fish boring sponges and diseases such as Dermo (*Perkinsus marinus*). It was thus suggested that salinities at between river kilometers 1 and 4 be maintained between 12 and 25 psu, limiting periods of salinity values over 28 psu to less than one month.

The 2000-2001 drought and the continued dry conditions during the spring of 2002 offer an excellent period to examine high salinity values in the Lower Alafia River. Plots of observed salinity from vertical profiles and the USGS recorder at kilometer 1.5 were presented in Figures 5-17 and 5-19. With data collected every 15 minutes, this recorder provides continuous data near the downstream end of the oyster zone. Data from the top recorder, which has an elevation of -0.33 m NGVD, is representative of the shallow portion of the water column in which oysters occur. During the three years between 2000 and 2002, mean daily salinity values at the top recorder were above 28 psu for 168 days. This included a 44-day period in the spring of 2000, a 50-day period extending from December 2000 through March 2001, a 51-day period during May and June 2001, and 23 day period during the spring of 2002. These high salinity values were primarily due to natural hydrologic conditions, although withdrawals by Mosaic Fertilizer from Lithia Springs that averaged 7 cfs continued during these periods.

The LAMFE model is an effective tool for examining the effect of potential minimum flow scenarios on salinity in the oyster zone of the river. As described in the preceding section, alteration of salinity distributions (measured as reductions in the area and volume of salinity zones) were less sensitive to flow reductions than were the changes in the abundance of key fish and invertebrate species. Given this finding, the LAMFE model was used to assess the effects of the proposed minimum flow on salinity values at two fixed locations in the oyster zone of the lower river, to examine how salinity in this region of the river would change as a result of the proposed minimum flows.

Time series plots of mean daily salinity values at kilometers 1.7 and 3.8 are shown in Figure 8-11 for the 19 percent minimum flow scenario. The daily salinity values in these plots were computed as the daily average within a vertical layer that extends from 0.1 to -1.0 meters NGVD elevation, which is also representative of the portion of the water column in which oysters occur. It is apparent from these figures that the effects of the proposed minimum flows are minimal on salinity in this portion of the river. This is especially the case during periods of high salinity, due in part to the effect of the 120 cfs low-flow threshold. Though not shown, the 24 percent flow reduction scenario with existing permitted withdrawal facilities showed very similar results. These simulations indicate these flow reduction scenarios pose no threat of significant harm to oyster populations in the river beyond that posed by natural variability. However, potentially harmful high salinity values do periodically occur in the river, emphasizing the need for management of the river's flow regime, especially the low flows that typically occur in the spring.

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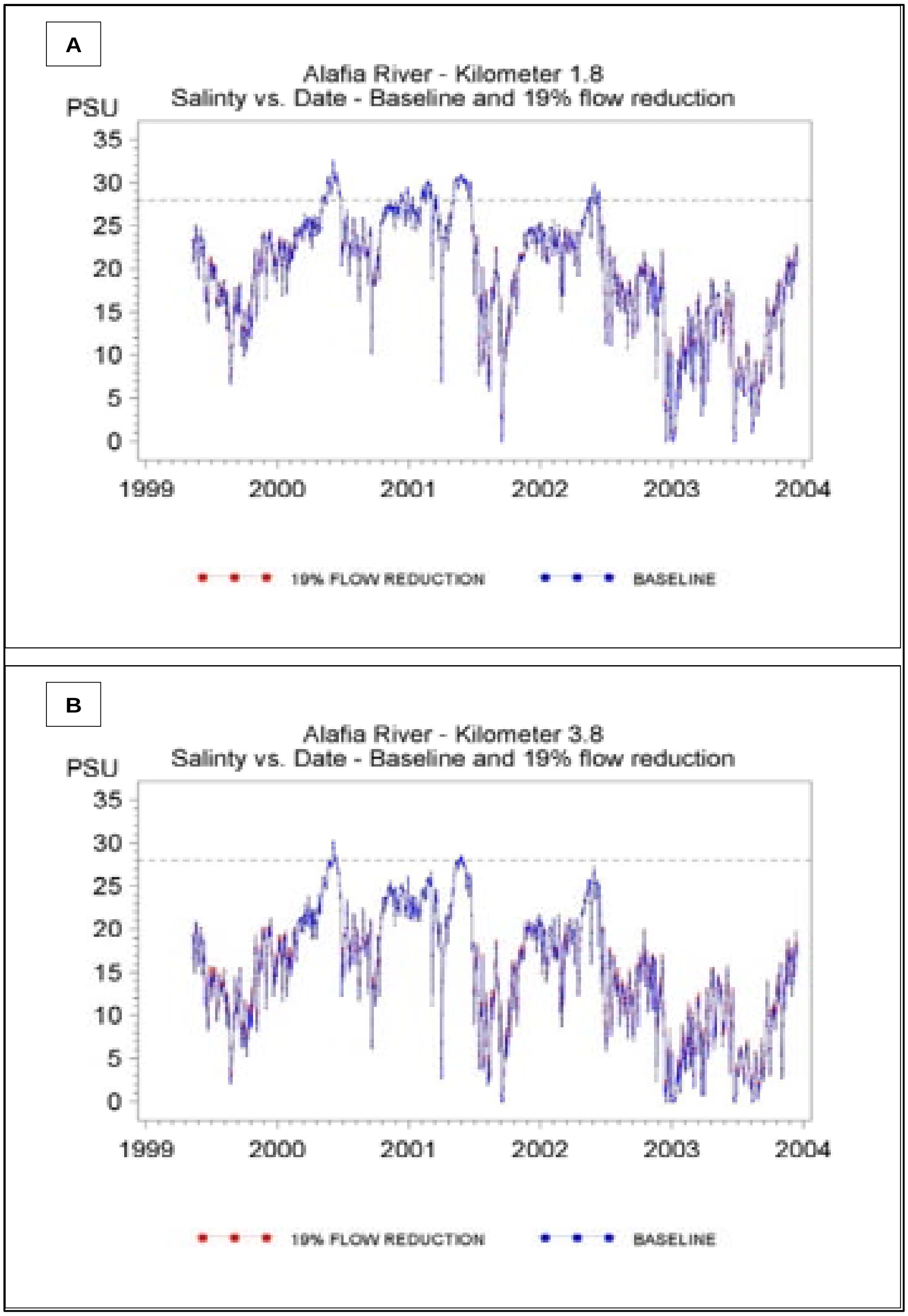

Figure 8-11. Time series of simulated average daily salinity values between elevations of -1.0 and 0.1 meters NGVD at two locations in the oyster zone of the Lower Alafia River for baseline flows and flows reduced by 19 percent with a 120 cfs low-flow threshold and an unlimited withdrawal capacity (A = kilometer 1.7, B=kilometer 3.8). Salinity values predicted using the LAMFE model for the lower river.

8.6.3 Simulations of Surface Isohaline Movements

The third manner in which changes in salinity distributions were examined was by simulation of the shifts in isohalines in the river channel. Isohalines are lines of equal salinity, which for practical purposes in a narrow river like the Alafia, can be expressed as the one-dimensional, kilometer location of that salinity concentration in the river channel. As described in Section 5.4.6, Janicki Environmental developed a series of empirical regression models to predict the location of five isohalines (0.5, 2, 4, 11 and 18 psu) in the river channel as a function of freshwater inflow (also see Appendix 5B). As described in Chapter Section 7.6.4, surface values of the 2, 4, and 11 psu isohalines were prioritized for the minimum flow analysis, as these isohalines can be used to assess changes in salinity that could affect the distribution of wetland plants along the river shoreline. Though suitable regression models for bottom isohalines were also developed, shifts in bottom isohalines are not presented in this report because it was concluded that the LAMFE model provided the most useful results for assessing changes in salinity distributions on the bottom of the river.

Results are also presented below for the 0.5 and 18 psu surface isohalines to demonstrate how these isohalines respond to changes in freshwater inflow. In a study of the Lower Alafia River conducted by the U.S. Geological Survey, Giovannelli (1981) developed a regression model to predict the average water column location of 1,000 µmhos/cm specific conductance concentration in the river as a function of freshwater flow and tide stage. Along with other analyses, this model was applied in the initial evaluation of the water use permit application for Tampa Bay Water's withdrawals from the river. Using the formulae to estimate salinity from specific conductance that were employed for this report, a value of 1,000 µmhos/cm specific conductance corresponds to a salinity value of about 0.45 psu. Though the form of the regression differed, the 0.5 psu isohaline that was simulated for this report is roughly comparable to for the 1,000 µmhos/cm conductance value that was evaluated by Giovannelli (1981) and applied in the water use permit evaluation.

Cumulative distribution functions for the predicted locations of four surface isohalines (0.5, 2, 4, and 11 psu) are plotted in Figure 8-12 for baseline flows and flows reductions of 10, 20, 30, and 40 percent. The 0.5 psu isohaline was the only isohaline that was predicted to extended upstream of kilometer 14. As with salinity area and volume values simulated by LAMFE, the CDF plots of the predicted isohaline locations represent a consistent response to freshwater inflow, as greater flows push the isohalines downstream, while lesser flows cause the isohalines to move upstream. Therefore, the low percentile values near the left side of the CDF plots represent high flows when the isohalines are located downstream, while the right side of the plots represents low flow conditions with the isohalines located upstream (high kilometer values).

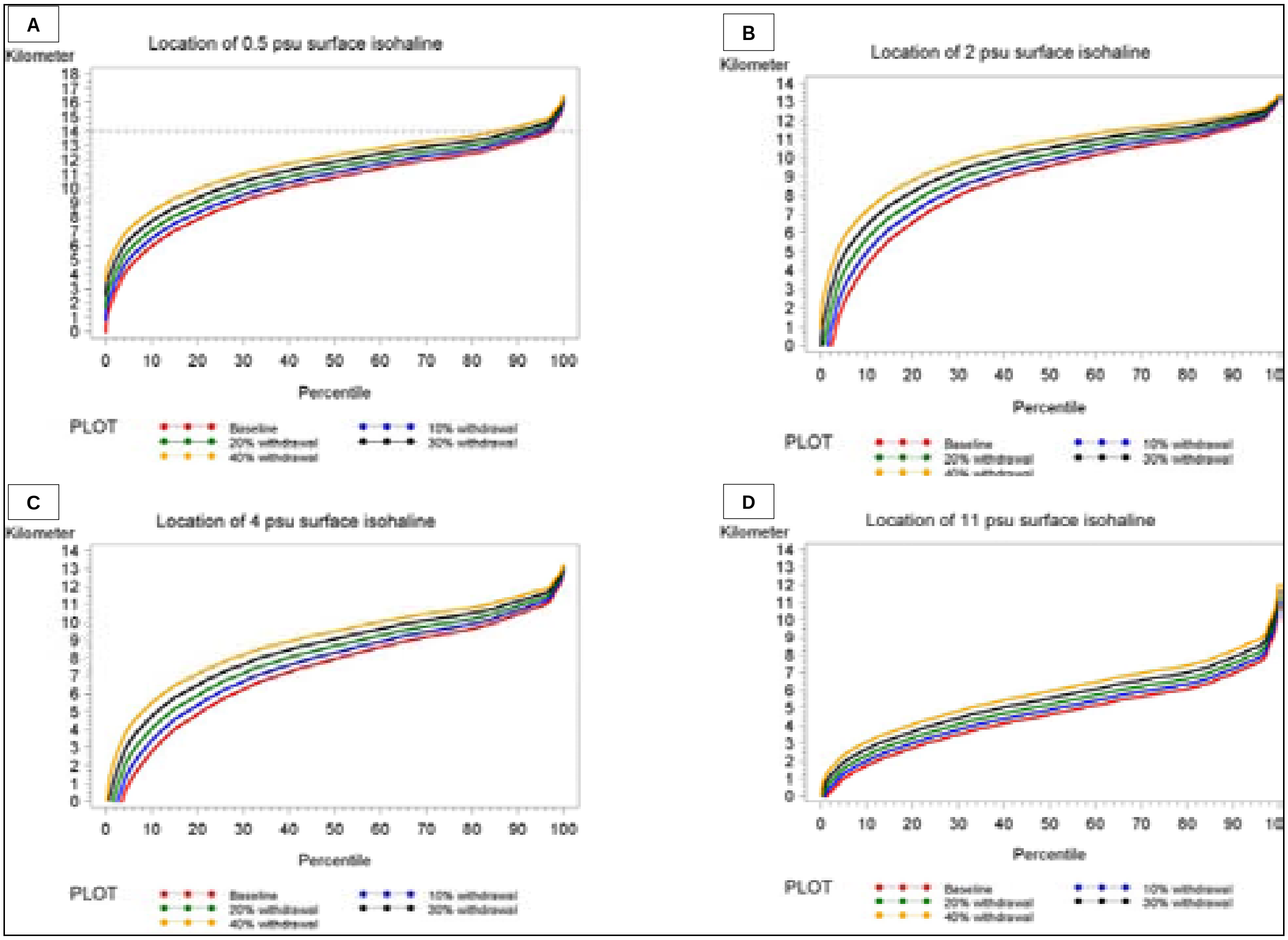

Figure 8-12. Cumulative Distribution Functions for the predicted locations four surface isohalines in the Lower Alafia River for baseline flows and four flow reduction scenarios ranging from 10 percent to 40 percent of baseline flows (A= 0.5 psu; B= 2 psu; C= 4 psu; D = 11 psu).

As shown by these CDF plots, the simulated shifts in isohaline movements resulting from the percent flow reductions are slightly greater at high flows. The minimum flows analysis compared shifts in the isohaline movements to the distribution wetland vegetation communities on the river shoreline, which are basically stationary features in the river ecosystem. During high flows, critical isohalines are pushed downstream of the sensitive wetland plant communities in the river. Therefore, shifts in isohaline positions in the wet season were not of as much concern as shifts in the dry season, when brackish waters are found in the parts of the river where salt-sensitive oligohaline and tidal freshwater plant communities occur. Based on the findings of various studies summarized in Chapter 7, it was concluded that shifts in the median positions of the isohalines would be evaluated for both for the whole year (yearly median) and the height of the spring dry season, which was defined as April 15 through June 15 (springtime median). The environmental metrics against which these isohaline shifts were compared were the amounts of total shoreline and wetland shoreline upstream of each isohaline within the lower river (downstream of kilometer 18).

As described in Section 3.5, tidal wetlands are not as abundant on the Lower Alafia River as other rivers in the region, as wetlands upstream of kilometer 7 largely consist of narrow bands of fringing wetlands along the shore of the river. As shown in Figure 8-13, this is particularly the case above kilometer 9, and wetlands shorelines are very limited in the highly incised portion of the river above kilometer 10.5 (source = Tampa Bay Water permit application, see pages 3-12, 3-16 and 3-17). Although low salinity wetlands are not as dominant an ecosystem component on the Alafia as on other rivers, the comparison of isohaline movements to the distribution of tidal wetlands is meaningful and informative metric to assess the effects of reductions in freshwater inflows.

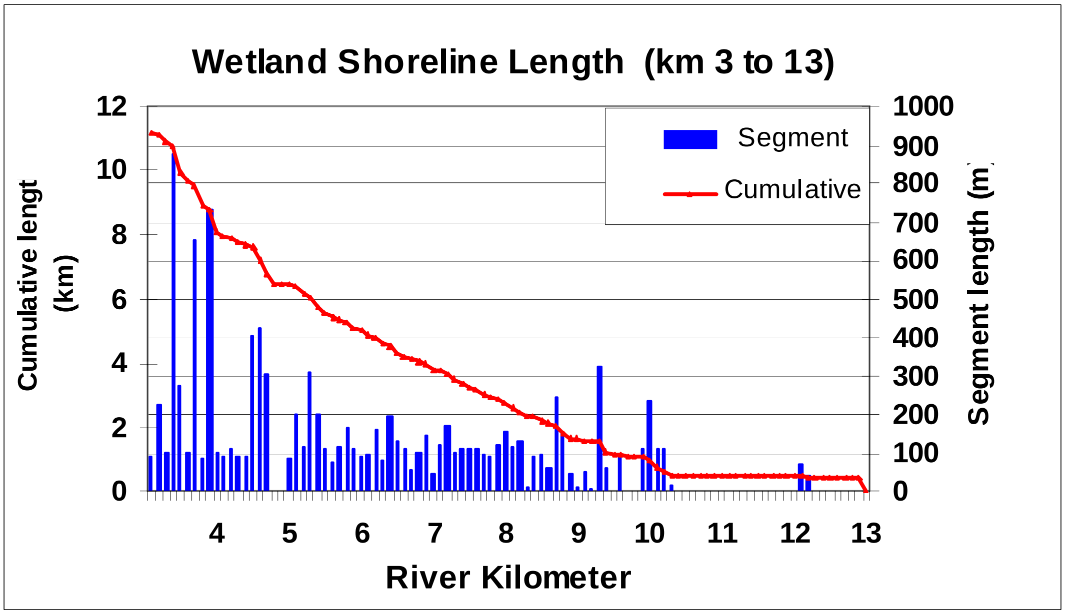

Figure 8-13. Meters of wetland shoreline in tenth kilometer segments and total kilometers of wetland shoreline accumulated in a downstream direction. Data limited to kilometers 3 to 13 to better illustrate the distribution of wetlands in the upper portion of the lower river.

The yearly median locations of the five surface isohalines are listed in Table 8-23A for baseline flows and flow reductions ranging from 10 to 40 percent, with 5 percent increments between 10 and 30 percent. Also listed are the amounts of total shoreline upstream of the median isohaline location for each flow scenario, expressed as meters of shoreline and as a percent of the meters for the baseline condition (source also Tampa Bay Water permit application). Reductions in total shoreline were generally fairly small for the flow reduction scenarios, as reductions above 15 percent were not observed until flow reductions rates ranged between 25 and 40 percent for the lower isohalines (0.5, 2, and 4 psu).

The amounts of shoreline between paired surface isohalines is listed in Table 8-23B. Results are presented for the river kilometers (on centerline) and the kilometers of shoreline between 0.5 and 2 psu, 2 and 4 psu, 4 and 11 psu, and 11 and 18 psu isohalines. Reductions in the amounts of shoreline between these isohalines are presented relative to baseline for the same flow scenarios as Table 8-23A. Reductions in shoreline lengths greater than 15% were limited to the 2 to 4 psu zone for 20% flow reductions and greater. Since lower salinity values are suitable for the health of oligohaline and tidal freshwater plants, Table 8-23B is shown for only for interest, and all further analyses of shorelines within salinity zones use the amount of shoreline less than the specified salinity values.

Table 8-23A. Median locations of five surface water isohalines, the length of total river shoreline upstream of these median positions, and the percent reduction in the shoreline length upstream of the meidan postion of each isohaline for eight flow scenarios relative to baseline flows. Reductions in total shoreline length greater than 15% relative to baseline are highlighted in gray.

	Median river kilometer location of isohalines							
	baseline flows	**Permitted**	**10% withdrawal**	**15% withdrawal**	**20% withdrawl**	**25% withdrawal**	**30% withdrawal**	**40% withdrawal**
0.5 ppt (km)	10.7	11.2	11.1	11.3	11.5	11.7	11.9	12.3
2 psu (km	9.6	10.0	9.9	10.0	10.2	10.4	10.5	10.9
4 psu (km)	8.0	8.4	8.3	8.5	8.7	8.9	9.1	9.5
11 psu (km)	4.6	5.0	4.9	5.1	5.2	5.4	5.6	6.0
18 psu (km)	2.5	2.7	2.7	2.8	2.8	3.0	3.1	3.3
	Meters of total shoreline upstream of median location of isohalines							
	baseline flows	**Permitted**	**10% withdrawal**	**15% withdrawal**	**20% withdrawl**	**25% withdrawal**	**30% withdrawal**	**40% withdrawal**
0.5 ppt (km)	17035	15411	15615	15201	14792	14384	13972	13060
2 psu (km	20005	19065	19270	19065	18246	17647	17441	16028
4 psu (km)	25681	24406	24797	24151	22467	21973	21520	20214
11 psu (km)	35155	33048	33317	32620	32347	31061	30655	29840
18 psu (km)	47946	47081	47081	46618	46618	45900	45696	44359
	Percent of total shoreline upstream of median location of isohalines compared to median baseline condtions							
	baseline flows	**Permitted**	**10% withdrawal**	**15% withdrawal**	**20% withdrawl**	**25% withdrawal**	**30% withdrawal**	**40% withdrawal**
0.5 ppt (km)	17035	90%	92%	89%	87%	84%	82%	77%
2 psu (km	20005	95%	96%	95%	91%	88%	87%	80%
4 psu (km)	25681	95%	97%	94%	87%	86%	84%	79%
11 psu (km)	35155	94%	95%	93%	92%	88%	87%	85%
18 psu (km)	47946	98%	98%	97%	97%	96%	95%	93%

Table 8-23B. Total shoreline quantities between paired isohaline locations for baseline flows and seven flow reductions, including; (1) river kilometers between median values for paired isohaline locations; (2) Meters of toal shoreline between median values of paired isohaline locations, and (3) percent reductions of total shoreline between paired isohaline locations compared to baseline conditions. Reductions greater than 15% are shaded in gray.

Isohaline interval	River kilometers between median values of paired isohaline locations							
	baseline flows	19% minimum flow	Permitted	10% withdrawal	15% withdrawal	20% withdrawl	30% withdrawal	40% withdrawal
0.5 to 2 psu (km)	1.2	1.3	1.2	1.2	1.2	1.3	1.3	1.4
2 to 4 psu (km)	1.6	1.5	1.6	1.6	1.5	1.5	1.5	1.4
4 to 11 psu (km)	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.6
11 to 18 psu (km)	2.1	2.4	2.3	2.3	2.3	2.4	2.5	2.6

Isohaline interval	Meters of total shoreline between median values of paired isohaline locations							
	baseline flows	19% minimum flow	Permitted	10% withdrawal	15% withdrawal	20% withdrawl	30% withdrawal	40% withdrawal
0.5 to 2 psu (km)	2970	3789	3654	3655	3864	3454	3469	2968
2 to 4 psu (km)	5676	5150	5341	5527	5086	4221	4079	4186
4 to 11 psu (km)	9474	8413	8642	8520	8469	9880	9135	9626
11 to 18 psu (km)	12791	14271	14033	13764	13998	14271	15041	14519

Isohaline interval	Percent of total shoreline between paired isohaline locations compared to baseline conditions							
	baseline flows	19% minimum flow	Permitted	10% withdrawal	15% withdrawal	20% withdrawl	30% withdrawal	40% withdrawal
0.5 to 2 psu (km)	n/a	128%	123%	123%	130%	116%	117%	100%
2 to 4 psu (km)	n/a	91%	94%	97%	90%	74%	72%	74%
4 to 11 psu (km)	n/a	89%	91%	90%	89%	104%	96%	102%
11 to 18 psu (km)	n/a	112%	110%	108%	109%	112%	118%	114%

Compared to data from the entire year, when the data are limited to the height of the spring dry season the reductions in the amount of shoreline upstream of each springtime median isohaline location are even less relative to the baseline. Using the amounts of shoreline less than either 0.5, 2, 4, 11, and 18 psu isohalines, there were no reductions in shoreline exceeding 15 percent up to 30 percent withdrawals (Table 8-24).

Tables 8-25 and 8-26 present similar results for the length of river shoreline classified as wetlands. Fifteen percent reductions in the amount of wetland shoreline are exceeded at 15 percent flow reductions for the 4 psu isohaline, and 20 and 25 percent, for the 2 and 11 psu isohalines, respectively (Table 8-25). When viewed for springtime conditions (Table 8-26), fifteen percent flow reductions were exceeded at 20 percent flow reductions for the 4 and 11 psu isohalines, but no reductions were observed for wetlands upstream of the 0.5 and 2 psu isohalines, as the shifts in these isohalines did not occur over the region of isolated wetlands located near kilometer 12 (Figure 8-13).

These results collectively indicate that flow reductions in the range of 15 to 20 percent will largely prevent reductions in excess of 15 percent of either total shoreline or wetland shoreline that are upstream of biologically important isohalines. This roughly corresponds with the 19 percent minimum flow scenario that was determined based in predicted changes in the abundance of key fish and invertebrate species. To graphically illustrate the effects of the proposed 19 percent minimum flow and the 24 percent scenario with existing facilities on the distribution of surface isohalines, boxplots of the locations of the 0.5, 2, 4, and 11 psu isohalines are presented for these scenarios in Figures 8-14 and 8-15, respectively. The graphics for each isohaline look similar for the two flow scenarios, given the close intervals of the two flow reductions.

The amounts of total shoreline and wetland shoreline upstream of the median positions of the four modeled isohalines were computed for the 19 percent and 25 percent flow reduction scenarios for the entire year and the spring dry season. The results for 19 percent minimum flow are presented in Tables 8-27 through 8-30. When viewed for the year as a whole, shifts of 0.5 to 0.6 kilometers were found for the median positions of the 0.5, 2, 4, and 11 psu isohalines, while the 18 psu isohaline shifted 0.3 kilometers. The reductions in percent total shoreline upstream of these isohalines were relatively small, with a maximum reduction of 12 percent for the 0.5 psu isohaline (Table 8-27). The application of the 120 cfs low-flow threshold did not affect the median positions of these isohalines when computed over the entire year.

Table 8-24. Median locations of five surface isohalines in the spring dry season (April 15 - June 15), the length of total river shoreline upstream of the median postion of each isohaline, and the percent reduction in the shoreline length upstream of each isohaline for eight flow scenarios relative to baseline flows. Reductions in total shoreline length greater than 15 percent relative to baseline are highighted in gray.

	Median river kilometer location of isohalines in spring dry season							
	baseline flows	Permitted	10% withdrawal	15% withdrawal	20% withdrawl	25% withdrawal	30% withdrawal	40% withdrawal
0.5 ppt (km)	12.4	12.6	12.7	12.8	13.0	13.1	13.3	13.6
2 psu (km	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.9
4 psu (km)	9.6	9.8	9.8	10.0	10.1	10.3	10.4	10.8
11 psu (km)	6.0	6.2	6.3	6.4	6.6	6.8	6.9	7.3
18 psu (km)	3.4	3.6	3.6	3.7	3.8	4.0	4.1	5.5

	Meters of total shoreline upstream of median location of isohalines in spring dry season							
	baseline flows	Permitted	10% withdrawal	15% withdrawal	20% withdrawl	25% withdrawal	30% withdrawal	40% withdrawal
0.5 ppt (km)	12772	12350	12155	11909	11491	11282	10816	10161
2 psu (km	15817	15615	15411	15201	14995	14792	14590	13972
4 psu (km)	20005	19572	19572	19065	18784	17872	17647	16230
11 psu (km)	29840	29432	29224	29017	28589	28179	27961	27143
18 psu (km)	42951	41330	41330	40576	39992	37085	36885	35255

	Percent of total shoreline upstream of median location of isohalines compared to baseline condtions							
	baseline flows	Permitted	10% withdrawal	15% withdrawal	20% withdrawl	25% withdrawal	30% withdrawal	40% withdrawal
0.5 ppt (km)	12772	97%	95%	93%	90%	88%	85%	80%
2 psu (km	15817	99%	97%	96%	95%	94%	92%	88%
4 psu (km)	20005	98%	98%	95%	94%	89%	88%	81%
11 psu (km)	29840	99%	98%	97%	96%	94%	94%	91%
18 psu (km)	42951	96%	96%	94%	93%	86%	86%	82%

Table 8-25. Median locations of five surface isohalines, the length of wetland shoreline upstream of the median value for each isohaline, and the percent reduction in the wetland shoreline length upstream of the median postion of each isohaline in the dry season for eight flow scenarios. Reductions in wetland shoreline length greater than 15 percent relative to baseline are highlighted in gray.

	Median river kilometer of isohalines							
	baseline flows	Permitted	10% withdrawal	15% withdrawal	20% withdrawl	25% withdrawal	30% withdrawal	40% withdrawal
0.5 ppt (km)	10.7	11.2	11.1	11.3	11.5	11.7	11.9	12.3
2 psu (km	9.6	10.0	9.9	10.0	10.2	10.4	10.5	10.9
4 psu (km)	8.0	8.4	8.3	8.5	8.7	8.9	9.1	9.5
11 psu (km)	4.6	5.0	4.9	5.1	5.2	5.4	5.6	6.0
18 psu (km)	2.5	2.7	2.7	2.8	2.8	3.0	3.1	3.3
	Meters of wetland shoreline upstream of median location of isohalines							
	baseline flows	Permitted	10% withdrawal	15% withdrawal	20% withdrawl	25% withdrawal	30% withdrawal	40% withdrawal
0.5 ppt (km)	488	488	488	488	488	488	488	418
2 psu (km	1155	1063	1063	1063	723	507	488	488
4 psu (km)	2573	2220	2314	2121	1812	1666	1604	1158
11 psu (km)	6758	6370	6455	6168	6054	5546	5363	4881
18 psu (km)	12104	11570	11570	11420	11319	11203	11110	10785
	Meters	Percent of wetland shoreline upstream of median location of isohalines compared to baseline						
	baseline flows	Permitted	10% withdrawal	15% withdrawal	20% withdrawl	25% withdrawal	30% withdrawal	40% withdrawal
0.5 ppt (km)	488	100%	100%	100%	100%	100%	100%	86%
2 psu (km	1155	92%	92%	92%	63%	44%	42%	42%
4 psu (km)	2573	86%	90%	82%	70%	65%	62%	45%
11 psu (km)	6758	94%	96%	91%	90%	82%	79%	72%
18 psu (km)	12104	96%	96%	94%	94%	93%	92%	89%

Table 8-26. Median locations of five surface isohalines in the spring dry season (April 15 - June 15), the length of wetland river shoreline upstream of the median postion of each isohaline, and the percent reduction in the wetland shoreline length upstream of each isohaline for eight flow scenarios relative to baseline flows. Reductions in wetland shoreline length greater than 15 percent relative to baseline are highlighted in gray.

	Median river kilometer of isohalines in the spring dry season							
	baseline flows	**Permitted**	**10% withdrawal**	**15% withdrawal**	**20% withdrawl**	**25% withdrawal**	**30% withdrawal**	**40% withdrawal**
0.5 ppt (km)	12.4	12.6	12.7	12.8	13.0	13.1	13.3	13.6
2 psu (km	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.9
4 psu (km)	9.6	9.8	9.8	10.0	10.1	10.3	10.4	10.8
11 psu (km)	6.0	6.2	6.3	6.4	6.6	6.8	6.9	7.3
18 psu (km)	3.4	3.6	3.6	3.7	3.8	4.0	4.1	4.4
	Meters of wetland shoreline upstream of median location of isohalines in the spring dry season							
	baseline flows	**Permitted**	**10% withdrawal**	**15% withdrawal**	**20% withdrawl**	**25% withdrawal**	**30% withdrawal**	**40% withdrawal**
0.5 ppt (km)	378	378	378	378	378	378	378	378
2 psu (km	488	488	488	488	488	488	488	488
4 psu (km)	1155	1063	1063	1063	955	615	507	488
11 psu (km)	4881	4623	4541	4347	4107	3946	3800	3361
18 psu (km)	9910	9537	9537	8888	8800	7969	7877	7585
	Meters	**Percent of wetland shoreline upstream of median location of isohalines compared to baseline**						
	baseline flows	**Permitted**	**10% withdrawal**	**15% withdrawal**	**20% withdrawl**	**25% withdrawal**	**30% withdrawal**	**40% withdrawal**
0.5 ppt (km)	378	100%	100%	100%	100%	100%	100%	100%
2 psu (km	488	100%	100%	100%	100%	100%	100%	100%
4 psu (km)	1155	92%	92%	92%	83%	53%	44%	42%
11 psu (km)	4881	95%	93%	89%	84%	81%	78%	69%
18 psu (km)	9910	96%	96%	90%	89%	80%	79%	77%

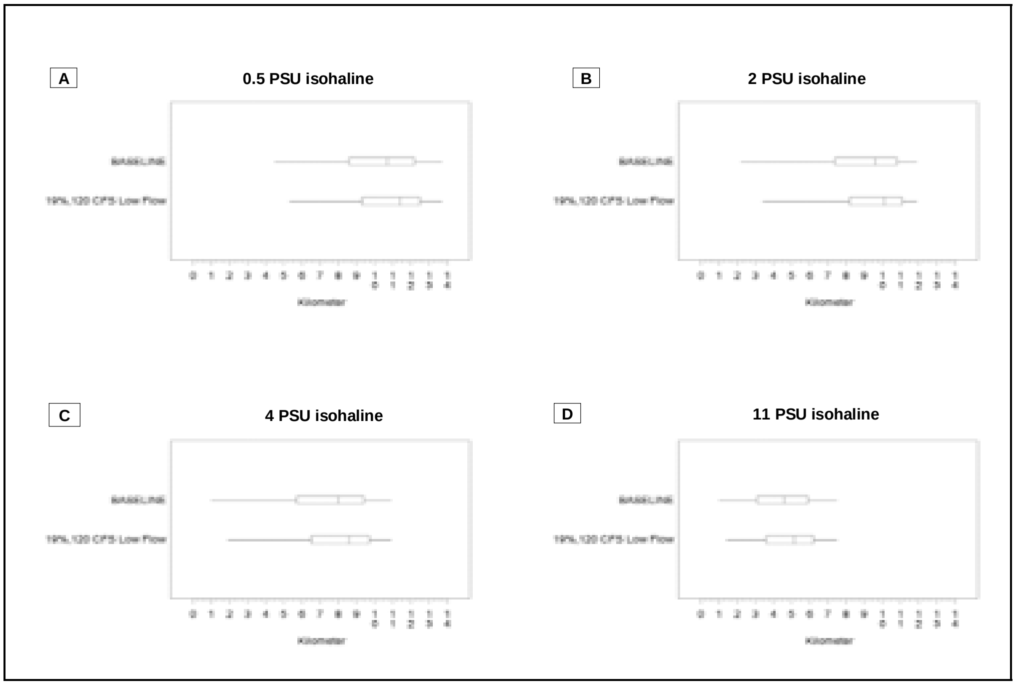

Figure 8-14. Box and whisker plot of the predicted location of four surface isohalines for baseline flows and flows reduced by 19 percent with a 120 cfs low-flow threshold and unlimited diversion capacity (A = 0.5 psu; B = 2 psu; C = 4 psu; D = 11 psu).

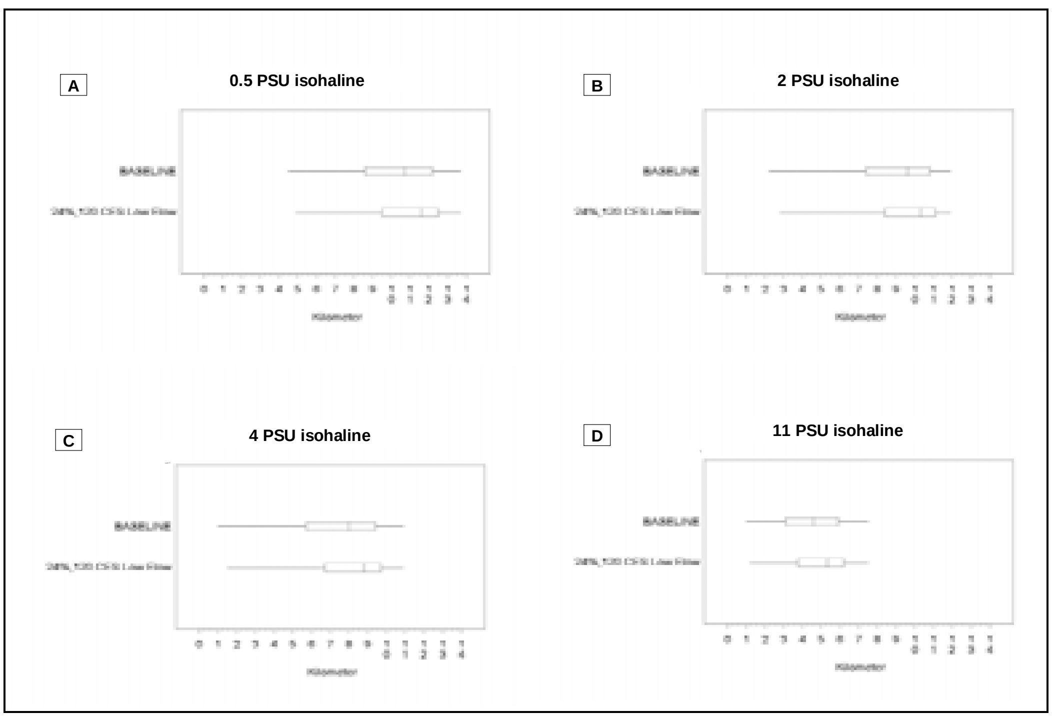

Figure 8-15. Box and whisker plot of the predicted location of four surface isohalines for baseline flows and flows reduced by 24 percent with a 120 cfs low-flow threshold and the existing permitted diversion capacity (A = 0.5 psu; B = 2 psu; C = 4 psu; D = 11 psu).

The median springtime locations of these same isohalines are listed in Table 8-28 for the 19 percent flow reduction, with and without the 120 cfs flow threshold. Shifts in the median springtime positions are between 0.4 and 0.6 kilometers for the different isohalines without the low-flow threshold, but are only 0.1 or 0.2 kilometers when the low-flow threshold is applied. As a result, reductions in the percent of total shoreline upstream of each isohaline are very small ($\leq$ 2 percent). Analogous results are presented for wetland shorelines for the entire year and the spring dry season in Tables 8-29 and 8-30. Reductions of 17 and 20 percent are observed for the length of wetland shorelines upstream of the 2 and 4 psu isohalines for the entire year (Table 8-29), but application of the 120 cfs low-flow threshold keeps reductions in wetland shorelines above these isohalines very small (< 9 percent) during the spring dry season (Table 8-30).

Results for the proposed 24 percent flow reduction scenario with the existing permitted 87.5 cfs diversion capacity are listed in Tables 8-31 through 8-34. The yearly median locations of the isohalines shift slightly farther than for the 19 percent scenario, moving 0.7 to 0.9 kilometers for all isohalines, except 18 psu (Table 8-31). However, the reductions in total river shoreline upstream of these isohalines is less than 15 percent when viewed for the entire year (Table 8-31) or the spring dry season, especially in the latter case when the 120 cfs low-flow threshold is applied (Table 8-32).

Greater reductions are observed for the amount of wetland shoreline above the median locations of the 2 and 4 psu isohalines, with a 47 percent reduction in the wetlands above the 2 psu isohaline and a 35 percent reduction above the 4 psu isohaline. These large percent reductions occur because the isohalines are shifting in the upper regions of the wetland distributions, where small shifts in isohaline positions can change the proportion of wetland upstream of the isohaline, largely because the total amount of wetlands is fairly small.

For both the 19 percent and 24 percent flow reduction scenarios the median location of the 2 psu isohaline is shifting near the 10 kilometer mark, where stands of vegetated non-forested wetlands and mixed forested wetlands occur (Figure 3-17C and D). The 4 psu isohaline is shifting in the region between 8 and 9 kilometers, where stands of cattail and needlerush/cattail mix occur (Figure 3-17B and C). It is important to note the greater percent reductions in the 24 percent scenario vs. the 19 percent scenario are due to an increased upstream movement of only 0.1 to 0.2 kilometers (Tables 8-29 and 8-33), demonstrating that it is the small amount of wetlands in this part of the lower river that makes this relationship so sensitive to change. When median isohaline locations are computed for the spring dry season, the percent reductions is wetland area upstream of all the isohalines are fairly small when the 120 cfs low-flow threshold is applied (Table 8-34).

Table 8-27. Median locations of five surface water isohalines, the length of total river shoreline upstream of each isohaline, and the percent reduction in the shoreline length upstream of each isohaline for a 19% flow reduction scenarios relative to baseline flows.

	Baseline Flows		19% flow reduction		
Surface isohaline	**Kilometer**	**Meters of Total Shoreline**	**Kilometer**	**Meters of Total Shoreline**	**Percent of baseline**
0.5 ppt	10.7	17035	11.4	14995	-12%
2 psu	9.6	20005	10.1	18784	-6%
4 psu	8.0	25681	8.6	23934	-7%
11 psu	4.6	35155	5.2	32347	-8%
18 psu	2.5	47946	2.8	46618	-3%

Table 8-28. Median locations of five surface water isohalines during the spring dry season (April 15 - June 15), the length of total river shoreline upstream of each isohaline, and the percent reduction in the shoreline length upstream of each isohaline for two 19% flow reduction scenarios relative to baseline flows. Scenarios were run with and without a 120 cfs low-flow threshold for cessation of withdrawals.

Surface Isohaline	Median river kilometer location of isohalines in the spring dry season		
	baseline flows	**19% no low-flow threshold**	**19% - 120 cfs low-flow threshold**
0.5 psu	12.4	12.9	12.5
2 psu	11.0	11.4	11.1
4 psu	9.6	10.1	9.7
11 psu	6.0	6.6	6.2
18 psu	3.4	3.8	3.6
	Meters of total shoreline upstream of median location of isohalines		
	baseline flows	**19% no low-flow threshold**	**19% - 120 cfs low-flow threshold**
0.5 psu	12772	11692	12558
2 psu	15817	14995	15615
4 psu	20005	18784	19784
11 psu	29840	28589	29432
18 psu	42951	39992	41330
	Percent of total shoreline upstream of median location of isohalines compared to median baseline condtions		
	baseline flows	**19% no low-flow threshold**	**19% - 120 cfs low flow threshold**
0.5 psu	na	-8%	-2%
2 psu	na	-5%	-1%
4 psu	na	-6%	-1%
11 psu	na	-4%	-1%
18 psu	na	-7%	-4%

Table 8-29. Median locations of five surface water isohalines, the length of wetland shoreline upstream of each isohaline, and the percent reduction in the wetland shoreline length upstream of each isohaline for a 19% flow reduction scenarios relative to baseline flows.

	Baseline Flows		19% flow reduction		
Surface isohaline	**Kilometer**	**Meters of Wetland Shoreline**	**Kilometer**	**Meters of Wetland Shoreline**	**Percent of baseline**
0.5 psu	10.7	488	11.4	488	0%
2 psu	9.6	1155	10.1	955	-17%
4 psu	8.0	2573	8.6	2059	-20%
11 psu	4.6	6758	5.2	6054	-10%
18 psu	2.5	12104	2.8	11420	-6%

Table 8-30. Median locations of five surface water isohalines in the spring dry season (April 15 - June 15), the length of wetland shoreline upstream of each isohaline, and the percent reduction in the wetland shoreline length upstream of each isohaline for two 19% flow reduction scenarios relative to baseline flows. Scenarios were run with and without a 120 cfs low-flow threshold for cessation of withdrawals. All locations were predicted with the regressions listed in Appendix 5-X. Reductions in shoreline length greater than 15% relative to baseline are highligted in gray.

	Median river kilometer location of isohalines in the spring dry season		
	baseline flows	**19% no low-flow threshold**	**19% - 120 cfs low flow threshold**
0.5 psu	12.4	12.9	12.5
2 psu	11.0	11.4	11.1
4 psu	9.6	10.1	9.7
11 psu	6.0	6.6	6.2
18 psu	3.4	3.8	3.6
	Meters of wetland shoreline upstream of the median location of isohalines in the spring dry season		
	baseline flows	**19% no low-flow threshold**	**19% - 120 cfs low flow threshold**
0.5 psu	378	378	378
2 psu	488	488	488
4 psu	1155	955	1063
11 psu	4881	4107	4623
18 psu	9910	8801	9537
	Percent of wetland shoreline upstream of median location of isohalines in the spring dry season compared to baseline condtions		
	baseline flows	**19% no low-flow threshold**	**19% - 120 cfs low flow threshold**
0.5 psu	378	0%	0%
2 psu	488	0%	0%
4 psu	1155	-17%	-8%
11 psu	4881	-16%	-5%
18 psu	9910	-11%	-4%

Table 8-31. Median locations of five surface isohalines, the length of total river shoreline upstream of each isohaline, and the percent reduction in the shoreline length upstream of each isohaline for a 24 % flow reduction scenario with existing diversion capacity relative to baseline flows.

	Baseline Flows		**24 % flow reduction with existing facilities**		
Surface Isohaline	**Kilometer**	**Meters of Total Shoreline**	**Kilometer**	**Meters of Total Shoreline**	**Percent of baseline**
0.5 psu	10.7	17035	11.6	14590	-14%
2 psu	9.6	20005	10.3	17871	-11%
4 psu	8.0	25681	8.8	22229	-13%
11 psu	4.6	35155	5.3	31261	-11%
18 psu	2.5	47946	2.9	46416	-3%

Table 8-32 Median locations of five surface isohalines during the spring dry season (April 15 - June 15), the length of total river shoreline upstream of each isohaline, and the percent reduction in the shoreline length upstream of each isohaline for two 24% flow reduction scenarios with the existing diversion capacity (87.5 cfs) relative to baseline flows. Scenarios were run with and without a 120 cfs low-flow threshold for cessation of withdrawals.

	Median river kilometer location of isohalines in the spring dry season		
	baseline flows	**24% no low-flow threshold**	**24% - 120 cfs low flow threshold**
0.5 psu	12.4	13.1	12.5
2 psu	11.0	11.5	11.1
4 psu	9.6	10.3	9.7
11 psu	6.0	6.7	6.2
18 psu	3.4	3.9	3.6
	Meters of total shoreline upstream of median location of isohalines		
	baseline flows	**24% no low-flow threshold**	**24% - 120 cfs low flow threshold**
0.5 psu	12772	11282	12558
2 psu	15817	14792	15615
4 psu	20005	17871	19784
11 psu	29840	28375	29432
18 psu	42951	37289	41330
	Percent of total shoreline upstream of median location of isohalines compared to median baseline condtions		
	baseline flows	**24 % no low-flow threshold**	**24% - 120 cfs low flow threshold**
0.5 psu	17035	-12%	-2%
2 psu	20005	-6%	-1%
4 psu	25681	-11%	-1%
11 psu	35155	-5%	-1%
18 psu	47946	-13%	-4%

Table 8-33. Median locations of five surface isohalines, the length of wetland river shoreline upstream of each isohaline, and the percent reduction in the wetland shoreline length upstream of each isohaline for a 24% flow reduction scenario with existing withdrawl capacity relative to baseline flows. Reductions in shoreline length greater than 15% relative to baseline are highligted in gray.

	Baseline Flows		24 % flow reduction with existing facilities		
Surface isohaline	**Kilometer**	**Meters of Total Shoreline**	**Kilometer**	**Meters of Total Shoreline**	**Percent of baseline**
0.5 psu	10.7	488	11.6	488	0%
2 psu	9.6	1155	10.3	615	-47%
4 psu	8.0	2573	8.8	1666	-35%
11 psu	4.6	6758	5.3	5746	-15%
18 psu	2.5	12104	2.9	11319	-6%

Table 8-34. Median locations of five surface isohalines during the spring dry season (April 15 - June 15), the length of wetland river shoreline upstream of each isohaline, and the percent reduction in wetland shoreline length upstream of each isohaline for two 24% flow reduction scenarios with the existing diversion capacity (87.5 cfs) relative to baseline flows. Scenarios were run with and without a 120 cfs low-flow threshold for cessation of withdrawals.

	Median river kilometer location of isohalines in the spring dry season		
	baseline flows	**24% no low-flow threshold**	**24% - 120 cfs low flow threshold**
0.5 ppt (km)	12.4	13.1	12.5
2 psu (km	11.0	11.5	11.1
4 psu (km)	9.6	10.3	9.7
11 psu (km)	6.0	6.7	6.2
18 psu (km)	3.4	3.9	3.6
	Meters of wetland shoreline upstream of median location of isohalines		
	baseline flows	**24% no low-flow threshold**	**24% - 120 cfs low flow threshold**
0.5 ppt (km)	378	378	378
2 psu (km	488	488	488
4 psu (km)	1155	615	1063
11 psu (km)	4881	4050	4623
18 psu (km)	9910	8071	9537
	Percent of wetland shoreline upstream of median location of isohalines compared to median baseline condtions		
	baseline flows	**24 % no low-flow threshold**	**24% - 120 cfs low flow threshold**
0.5 ppt (km)	378	0%	0%
2 psu (km	488	0%	0%
4 psu (km)	1155	-47%	-8%
11 psu (km)	4881	-17%	-5%
18 psu (km)	9910	-19%	-4%

These results collectively indicate that the proposed minimum flow should not be modified to account for movements of surface isohalines in relation to the distribution of wetland plant communities in the Lower Alafia River. Four salinity-shoreline metrics were examined for each isohaline - the median locations of the isohaline for the entire year and the spring dry season, with each of these median locations used to compute the amount of total shoreline and wetland shoreline upstream of the isohaline. Of these four metrics, only the yearly median positions of the 2 and 4 psu isohalines showed reduction in wetland shoreline length of over 15 percent. These results were influenced by the patchy distribution of the limited amounts of wetlands near the median positions of these isohalines, and reductions in wetland shoreline length were much smaller when shifts in the dry season medians were examined, during which time application of the 120 cfs low-flow threshold acts to minimize the effects of withdrawals.

8.7 The Effects of Reduced Freshwater Inflows, Including the Proposed Minimum Flows, on the Occurrence of Low Dissolved Oxygen Concentrations

As described in Section 5.5, dissolved oxygen (DO) concentrations in the Lower Alafia River exhibit significant relationships with freshwater inflows, due in large part to the effects of inflow on vertical salinity stratification in the river. These relationships, however, differ between the lower and upper reaches of the tidal river. Increased flows act to reduce DO concentrations In the first six kilometers near the river mouth, while in the upper river increased flows tend to improve DO concentrations. These relationships were frequently non-linear, however, with apparent breakpoints in the data in some reaches of the river.

The effects of potential flow reductions on DO concentrations in the lower rive were evaluated using the regressions presented in Section 5.5. Similar to the assessment of changes in salinity distributions, DO concentrations were calculated for flow reductions ranging from 10 to 40 percent and for the 19 percent minimum flow and the 24 scenario, which both included a 120 cfs low-flow threshold. Assessment of these scenarios were performed to determine how DO would respond to potential flow reductions, and whether the proposed minimum flow would cause significant harm to the river by resulting in unacceptable impacts to DO concentrations.

Since waters deeper than 2 meters depth were most prone to hypoxia (Figure 5-31), it was concluded that examining changes in DO concentrations in deep waters (> 2 meters) would be a sensitive test to evaluate the effects of flow reductions on DO concentrations in the lower river. Selected percentile values for predicted DO concentrations in deep waters for five of the three-kilometer segments in the river are listed in Table 8-35 for the tested flow scenarios. These values were predicted using the regressions that are listed in Tables 5-1 and 5-2 and described in Appendix 5D and 5E. A regression for segment 15-18 was not employed, but plots of the data show clearly show that low DO values were clearly restricted to low flows (< 150 cfs, Figure 5-39A).

The results in Table 8-35 show that hypoxic waters are predicted to periodically occur in all river segments during baseline flow conditions. The lower quartile values (25th percentile) values are all above 2.0 mg/l for baseline flows, but DO concentrations below 2

Table 8-35 Percentile values of predicted daily dissolved oxygen concentrations (mg/l) in waters greater than two meters deep in five river segments for eight flow scenarios. DO values are predicted using the regressions listed in Tables 5-1 and 5-2. Predicted values that differ by more than 0.5 mg/l from basline are highlighted in gray.

		Percentile					
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**95**
km 0 - 3	Baseline	1.8	2.3	2.7	3.7	5.3	6.8
	10% reduction	1.9	2.4	2.8	3.8	5.4	6.9
	20% reduction	1.9	2.5	2.8	3.8	5.4	6.9
	30% reduction	2.0	2.5	2.9	3.9	5.5	7.0
	40% reduction	2.1	2.6	3.0	3.9	5.6	7.1
	19% reduction	1.9	2.5	2.8	3.8	5.4	6.9
	19%, 120 cfs low flow	1.9	2.5	2.8	3.8	5.4	6.9
	24%, 120 cfs, existing capacity	1.9	2.5	2.8	3.8	5.4	7.0
		Percentile					
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**95**
km 3 - 6	Baseline	1.6	1.9	2.1	3.1	5.0	6.8
	10% reduction	1.6	1.9	2.1	3.1	5.0	6.8
	20% reduction	1.6	1.9	2.2	3.2	5.1	6.8
	30% reduction	1.7	2.0	2.2	3.2	5.1	6.9
	40% reduction	1.7	2.0	2.3	3.3	5.2	6.9
	19% reduction	1.6	1.9	2.2	3.2	5.1	6.8
	19%, 120 cfs low flow	1.6	1.9	2.2	3.1	5.0	6.8
	24%, 120 cfs, existing capacity	1.6	1.9	2.2	3.2	5.0	6.9
		Percentile					
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**95**
km 6 - 9	Baseline	1.7	2.0	2.3	3.3	4.4	5.9
	10% reduction	1.7	2.0	2.3	3.1	4.4	5.7
	20% reduction	1.6	2.0	2.3	2.9	4.4	5.5
	30% reduction	1.6	1.9	2.2	2.8	4.4	5.4
	40% reduction	1.6	1.9	2.2	2.7	4.3	5.4
	19% reduction	1.6	2.0	2.3	3.0	4.4	5.5
	19%, 120 cfs low flow	1.6	2.0	2.3	2.9	4.4	5.5
	24%, 120 cfs, existing capacity	1.6	2.0	2.3	3.0	4.4	5.6
		Percentile					
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**95**
km 9 - 12	Baseline	1.4	2.0	2.4	3.5	4.6	6.0
	10% reduction	1.4	1.9	2.3	3.4	4.5	5.8
	20% reduction	1.3	1.8	2.2	3.2	4.3	5.8
	30% reduction	1.3	1.7	2.0	3.0	4.1	5.4
	40% reduction	1.2	1.6	1.9	2.8	3.8	5.2
	19% reduction	1.3	1.8	2.2	3.2	4.3	5.8
	19%, 120 cfs low flow	1.4	1.9	2.2	3.3	4.3	5.8
	19%, 120 cfs, existing capacity	1.4	1.8	2.1	3.2	4.3	5.8
		Percentile					
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**95**
km 12 - 15	Baseline	1.7	3.0	3.9	5.0	5.6	7.1
	10% reduction	1.6	2.7	3.6	5.0	5.6	7.0
	20% reduction	1.4	2.4	3.2	4.8	5.6	7.0
	30% reduction	1.2	2.1	2.9	4.2	5.2	6.8
	40% reduction	1.0	1.8	2.5	3.9	5.1	6.8
	19% reduction	1.4	2.4	3.3	4.9	5.6	7.0
	19%, 120 cfs low flow	1.7	2.7	3.4	4.9	5.6	7.0
	19%, 120 cfs, existing capacity	1.7	2.7	3.3	4.8	5.4	7.0

mg/l occur at some frequency below the lower quartile in all segments. Predicted DO concentrations are slightly better in the most upstream segment tested (kilometer 12-15), but predicted 25th and 50th percentile concentrations were below 3 mg/l and 4 mg/l, respectively, in all other segments. The segment between kilometers 12 and 15 was the only segment where the median deepwater DO value predicted for baseline flows was above the State instantaneous DO standard of 4 mg/l for Class III waters.

As described in Chapter 5, reduced flows tend to improve bottom DO concentrations in the two most downstream segments, between the mouth of the river and kilometer six. Thus, the predicted DO values for the flow reductions are slightly greater (0.1 to 0.2 mg/l) than the predicted values for baseline flows. In the segments upstream of kilometer six, predicted DO concentrations are less for all the flow reduction scenarios, but the differences are fairly small. To illustrate patterns in these results, predicted DO concentrations that differ by more than 0.5 mg/l from the baseline condition are highlighted in gray. With only two exceptions, differences of more than 0.5 mg/l were limited to flow reductions of 30 percent or greater in these segments. It is emphasized, however, that the confidence intervals around these regressions are broad, and none of these differences were statistically significant. Regardless, the predictions in Table 8-35 provide some useful measure of the potential effects of flow reductions in the river.

The predicted values for the proposed 19 percent minimum flow and the 24 percent flow reduction scenario with existing facilities are listed as the in the bottom two rows for each river segment in Table 8-35. Both of these scenarios employ a 120 cfs low-flow threshold for the cessation of withdrawals. The implementation of this threshold diminishes the predicted reductions in DO concentrations at the low percentile values, with predicted changes ranging from 0.0 to 0.2 mg/l in the lower quartile, with the only exceptions being changes of 0.5 and 0.6 mg/l in segment 12-15 at the 25th percentile value. With one exception, predicted changes at the higher percentile values range between 0.0 and 0.3 mg/l, with most of these reductions occurring when DO values are above 4 mg/l.

The probability of the occurrence of hypoxia (DO < 2 mg/l) was similarly related to freshwater inflow in the lower river, and logistic regressions were developed to predict the probability of hypoxia in deep water (> 2 meters) in the lower river (see Table 5-3). These regressions were then used in the minimum flows analysis to predict daily values of the probability of hypoxia in each of the six, three kilometer segments of the lower river for the eight freshwater inflow scenarios (Table 8-36). For illustrative purposes, values that differed from the baseline by more than a 10 percent probability are highlighted in gray.

As with the prediction of DO concentrations, the probability of hypoxia goes down with decreasing flow in the two segments between the river mouth and kilometer six, though these changes are fairly small. Logistic regressions for all other segments predict that the probability of hypoxia increases as flows are reduced. The slope of the regression for the middle segment in the river (kilometer 6-9) was very flat (Figure 5-43), and predicted changes in the probability of hypoxia for this segment of the river were very small (Table 8-36). The predicted response in the upper segments was more steep, particularly in the segments upstream of kilometer 12 (Figure 5-43). In these segments, the flow reduction scenarios result in increases in the probability of hypoxia compared to baseline flow for the upper percentile values (50^{th} and higher). These higher percentile values (50^{th} and greater) occur during low flows, when the salt wedge has migrated into the upper segments of the lower river, thus increasing the probability of hypoxia. Increases in probability of hypoxia greater than 10 percent, however, are limited to flow reductions of thirty percent or greater, with the exception of kilometer 12-15, where 20 percent flow reduction cause some increases in probability of greater than 10 percent for some percentiles. These results, however, were simulated with no low-flow threshold. Application of the 120 cfs low-flow threshold for the proposed minimum flow keeps all predicted increases within 10 percent of the predicted baseline value, while only the 75^{th} percentile values exceeded 10 percent of baseline for the 24 percent withdrawal scenario for the 12-15 km segment.

Results are also presented in Table 8-36 as an area-weighted average for the whole lower river, which was computed by weighting the probability predicted for each segment by the area of deep water within that segment. Viewed in this manner, the flow reduction scenarios actually result in a decreased probability of hypoxia when viewed river-wide, due to a reduction of hypoxia in the broad downstream segments on the river-wide average.

As described in Section 5.5.5, logistic regressions to predict bottom DO in bottom waters in the Lower Alafia River were also performed as part of the HBMP monitoring program conducted for Tampa Bay Water. This effort differed from the minimum flows analysis in that all bottom DO measurements in the river were analyzed, and the threshold for identifying low DO was 2.5 mg/l. Also the HBMP analysis was based only on flows above 112 cfs , for this represents the remaining flow after Tampa Bay Water has taken water at the lowest flow rate allowed by their permit (124 cfs). Percentile values of probabilities of DO < 2.5 mg/l predicted by the HBMP logistic regressions are shown for the eight flow scenarios analyzed in this minimum flows report in Table 8-37. Again, predicted values that are more than 10 percent greater than the baseline value are highlighted in gray.

The only scenarios for which values are 10 percent greater than the baseline are the 30 and 40 percent flow reduction scenarios in HBMP strata that extent from kilometer 7 to near kilometer 12. Similar to the results predicted by the District for deep waters in Table 6-6, the proposed minimum flow shows no increases in the probability of low DO in the lowermost strata (AR1 and AR2), where reduced flows act to reduce the probability of hypoxia. Also similar to the District analysis, the proposed minimum flow is predicted to increase hypoxia slightly in the upper strata (kilometers 7 to 12), but the changes are very small, with an average increase of only 5.4 percent above the median values, which is well within the uncertainly limits of these models. It is reiterated these predictions are only for flows greater than 112 cfs. This is likely why the HMBP analysis did not find any significant relationships between flow and hypoxia above kilometer 12, as hypoxia conditions in the upper regions of the only river only occur at very low flows (Figures 5-39 E and F), which were not included in the analysis (PBS&J 2006). However, since the recommended minimum flows prohibit withdrawals below 120 cfs, the results presented for the HBMP regressions closely correspond to the flow range over which the minimum flows will have an effect on the probability of hypoxia in the lower river.

Table 8-36. Percentiles of daily values of the probability of dissolved oxygen concentrations less than 2 mg/l in waters > two meters deep in six river segments and an area-weighted average for eight flow scenarios. Probabilities predicted using the logistic regressions listed in Table 5-3. Values that are greater than the baseline value by more than 10 percent are highlighted in gray.

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 0 - 3	Baseline	0%	0%	0%	3%	24%	39%	66%
	10% reduction	0%	0%	0%	3%	22%	36%	62%
	20% reduction	0%	0%	0%	3%	20%	33%	58%
	30% reduction	0%	0%	0%	2%	18%	30%	54%
	40% reduction	0%	0%	0%	2%	16%	27%	50%
	19% reduction	0%	0%	0%	3%	20%	34%	58%
	19%, 120 cfs low flow	0%	0%	0%	3%	20%	34%	59%
	24%, 120 cfs, existing capacity	0%	0%	0%	3%	20%	32%	61%

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 3 - 6	Baseline	0%	1%	2%	23%	59%	72%	83%
	10% reduction	0%	1%	2%	21%	57%	70%	82%
	20% reduction	0%	1%	2%	20%	54%	68%	81%
	30% reduction	0%	1%	1%	18%	52%	65%	79%
	40% reduction	0%	0%	1%	16%	49%	63%	77%
	19% reduction	0%	1%	2%	20%	55%	68%	81%
	19%, 120 cfs low flow	0%	1%	2%	21%	54%	68%	81%
	24%, 120 cfs, existing capacity	0%	1%	2%	20%	53%	67%	82%

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 6 - 9	Baseline	5%	11%	15%	34%	55%	61%	68%
	10% reduction	6%	13%	15%	38%	56%	62%	69%
	20% reduction	6%	14%	16%	41%	56%	62%	69%
	30% reduction	7%	14%	16%	44%	56%	63%	69%
	40% reduction	7%	15%	16%	46%	58%	64%	69%
	19% reduction	6%	13%	16%	40%	56%	62%	69%
	19%, 120 cfs low flow	6%	14%	16%	41%	56%	62%	69%
	24%, 120 cfs, existing capacity	6%	13%	15%	40%	56%	62%	69%

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 9 - 12	Baseline	0%	4%	10%	30%	57%	69%	79%
	10% reduction	0%	6%	13%	33%	61%	71%	80%
	20% reduction	1%	8%	16%	37%	64%	73%	81%
	30% reduction	1%	11%	19%	42%	67%	75%	82%
	40% reduction	2%	15%	23%	46%	70%	76%	83%
	19% reduction	1%	8%	16%	36%	63%	73%	81%
	19%, 120 cfs low flow	1%	7%	15%	36%	64%	71%	80%
	24%, 120 cfs, existing capacity	0%	7%	15%	38%	65%	72%	81%

Table 8-36 continued. Percentiles of daily values of the probability of dissolved oxygen concentrations less than 2 mg/l in waters > two meters deep in six river segments and an area-weighted average for eight flow scenarios. Probabilities predicted using the logistic regressions listed in Table 5-3. Values that are greater than the baseline value by more than 10 percent are highlighted in gray.

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 12 - 15	**Baseline**	0%	0%	0%	4%	24%	42%	68%
	10% reduction	0%	0%	0%	7%	31%	49%	72%
	20% reduction	0%	0%	0%	11%	37%	55%	75%
	30% reduction	0%	0%	1%	16%	45%	62%	77%
	40% reduction	0%	0%	3%	24%	54%	68%	80%
	19% reduction	0%	0%	0%	10%	37%	54%	75%
	19%, 120 cfs low flow	0%	0%	0%	10%	33%	48%	68%
	24%, 120 cfs, existing capacity	0%	0%	0%	12%	37%	50%	68%

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 15 - 18	**Baseline**	0%	1%	2%	6%	15%	21%	39%
	10% reduction	0%	0%	2%	7%	18%	25%	44%
	20% reduction	0%	1%	3%	9%	21%	29%	49%
	30% reduction	1%	2%	4%	11%	26%	35%	55%
	40% reduction	1%	2%	5%	15%	32%	41%	62%
	19% reduction	0%	1%	3%	9%	21%	29%	48%
	19%, 120 cfs low flow	0%	1%	3%	9%	18%	21%	38%
	24%, 120 cfs, existing capacity	0%	1%	3%	10%	18%	21%	39%

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
Area Weighted Average	**Baseline**	1%	2%	4%	16%	42%	54%	72%
	10% reduction	1%	2%	4%	16%	41%	53%	71%
	20% reduction	1%	3%	4%	17%	40%	52%	69%
	30% reduction	1%	3%	4%	17%	39%	51%	67%
	40% reduction	1%	3%	5%	17%	38%	49%	65%
	19% reduction	1%	3%	4%	16%	40%	52%	69%
	19%, 120 cfs low flow	1%	3%	4%	17%	40%	52%	69%
	24%, 120 cfs, existing capacity	1%	3%	4%	17%	40%	51%	70%

Table 8-37. Percentiles of daily values of the probability of dissolved oxygen concentrations less than 2.5 mg/l in bottom waters in five river strata (segments) in the Alafia River predicted by logistic regressions developed for the Tampa Bay Water HBMP. Predictions are for bottom depths that represent the 75th percentile depth in each stratum. Values that are greater than the baseline value by more than 10 percent are highlighted in gray.

		Percentile						
Strata	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
AR 1 (km 0 - 2.3)	**Baseline**	12%	13%	13%	14%	18%	21%	29%
	10% reduction	12%	12%	13%	14%	17%	19%	26%
	20% reduction	12%	12%	12%	13%	16%	18%	24%
	30% reduction	12%	12%	12%	13%	15%	17%	22%
	40% reduction	12%	12%	12%	13%	14%	16%	20%
	19% reduction	12%	12%	12%	13%	16%	18%	24%
	19%, 120 cfs low flow	12%	12%	12%	13%	16%	18%	24%
	24%, 120 cfs, existing capacity	12%	12%	12%	13%	16%	19%	26%

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
AR2 (km 2.3 - 4.7)	**Baseline**	28%	28%	29%	31%	36%	40%	49%
	10% reduction	27%	28%	28%	30%	34%	38%	46%
	20% reduction	27%	27%	28%	30%	33%	36%	44%
	30% reduction	27%	27%	28%	29%	32%	35%	41%
	40% reduction	27%	27%	27%	28%	31%	33%	38%
	19% reduction	27%	27%	28%	30%	33%	37%	44%
	19%, 120 cfs low flow	27%	27%	28%	30%	33%	37%	44%
	24%, 120 cfs, existing capacity	27%	27%	28%	29%	33%	37%	0%

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
AR3 (km 4.7 - 7.0)	**Baseline**	7%	11%	13%	16%	18%	19%	19%
	10% reduction	8%	12%	14%	17%	18%	19%	19%
	20% reduction	9%	13%	15%	17%	19%	19%	20%
	30% reduction	10%	14%	15%	18%	19%	20%	20%
	40% reduction	11%	15%	16%	18%	20%	20%	20%
	19% reduction	9%	12%	14%	17%	19%	19%	20%
	19%, 120 cfs low flow	9%	12%	14%	17%	19%	19%	19%
	24%, 120 cfs, existing capacity	8%	8%	14%	18%	19%	19%	19%

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
AR4 (km 7.0 - 9.3)	**Baseline**	2%	10%	20%	42%	54%	57%	60%
	10% reduction	3%	13%	25%	46%	56%	59%	61%
	20% reduction	5%	18%	30%	49%	59%	61%	63%
	30% reduction	8%	23%	35%	53%	61%	63%	65%
	40% reduction	12%	30%	41%	56%	63%	65%	67%
	19% reduction	5%	17%	29%	49%	58%	61%	63%
	19%, 120 cfs low flow	5%	17%	29%	49%	54%	61%	62%
	24%, 120 cfs, existing capacity	3%	3%	29%	51%	60%	62%	62%

		Percentile						
	flow	**5**	**15**	**25**	**50**	**75**	**85**	**95**
AR5 (km 9.3 - 11.7)	**Baseline**	0%	1%	3%	17%	33%	40%	44%
	10% reduction	0%	1%	4%	21%	38%	44%	48%
	20% reduction	0%	2%	7%	26%	42%	48%	52%
	30% reduction	0%	4%	10%	32%	47%	52%	55%
	40% reduction	1%	7%	16%	38%	52%	56%	59%
	19% reduction	0%	2%	6%	26%	42%	47%	51%
	19%, 120 cfs low flow	0%	2%	6%	26%	42%	47%	49%
	24%, 120 cfs, existing capacity	0%	0%	6%	28%	44%	49%	49%

In summary, the Lower Alafia River has significant problems with low dissolved oxygen concentrations, which in many areas of the river are related to the rate of freshwater inflow. Reductions in DO concentrations and the increased frequency of hypoxia in upriver areas can be considered a negative effect of flow reductions due to withdrawals. However, the predicted reductions in DO concentrations and increases in hypoxia are fairly small, especially for percent flow reductions of less than 20 percent. Also, application of the 120 cfs low-flow threshold greatly reduces any negative effects of the proposed minimum flow scenarios by prohibiting withdrawals during periods of very low flows. As described in Section 8.3, this low-flow threshold will prohibit withdrawals approximately 18 percent of the time. Importantly, the time that withdrawals will be prohibited in the spring dry season is considerably higher (Figure 8-1). Since the spring is a time when water temperatures are rising and flows are declining, the low-flow threshold acts to minimize the effects of the proposed minimum flows during this sensitive time of year.

Flow reductions due to the proposed minimum flow will not have a negative impact on DO concentrations in the river downstream of kilometer 6, where reduced flows act to raise DO concentrations. Also, negligible changes in the occurrence of low DO are predicted between kilometers 6 and 9, where the response of DO concentrations and probability of hypoxia is very flat. As described in Chapter 5 and in Section 8.5, the center of abundance for many important fish and invertebrate taxa are concentrated in the river between kilometers 3 and 8, where changes in DO concentrations due to flow reductions are not problematic. In summary, the proposed minimum flow, which incorporates the percent flow method with a low-flow threshold, should not result in significant harm to the lower river due to overall effects on dissolved oxygen concentrations.

8.8 The Effect of Reduced Freshwater Inflows on the Occurrence of Large Phytoplankton Blooms in the Lower River

As discussed earlier in this report, the Lower Alafia River has very high phytoplankton counts and concentrations of chlorophyll *a* compared to other rivers in southwest Florida. Though phytoplankton produce dissolved oxygen when photosynthesizing during daylight hours, they can also consume DO by respiration at night, causing large diurnal swings in DO concentrations when phytoplankton are in high densities. Also, decomposition of large amounts of phytoplankton, whether in the water column or at the sediment surface, can create oxygen demand. It is likely that problems with hypoxia and high chlorophyll *a* concentrations in the Alafia River are related, and any effects of flow reductions on the increased occurrence of large phytoplankton populations or high chlorophyll concentrations in the river are of concern.

Relationships of the magnitude and locations of peak chlorophyll *a* concentrations in the lower river with freshwater inflows were discussed in Sections 5.6.6 through 5.7 and 7.6.7. Graphical analyses of relationships between chlorophyll *a* and inflow were also discussed in Section 8.3 to justify the low flow cutoff of 120 cfs, because very high chlorophyll values in the river are most common at low flows. This low-flow threshold will be in effect on average about 18 percent of the time during the year and about 37 percent of the time during the four month period of March through June. When inflows are above 120 cfs, freshwater withdrawals could have some effect on both the magnitude and location of peak chlorophyll concentrations in the lower river.

As previously discussed, reduced flows tend to both move the location of the peak chlorophyll concentration upstream and increase the concentration of the peak chlorophyll value. Though a significant relationship was observed between the magnitude and location of the peak chlorophyll concentration (Figure 5-72), this regression is not used for predictive purposes in this report, since the need to first predict the location of the peak chlorophyll concentration compounds the error in the predictions. However, three empirical models were used in the minimum flows analysis to evaluate the response of chlorophyll *a* concentrations or DO supersaturation values to reductions in inflow and the effect of the proposed minimum flow. These modeling results are presented below.

8.8.1 Simulations of the probability of DO supersaturation resulting from reductions in freshwater inflow

As discussed in section 5.5.6, the frequent occurrence of unusually high supersaturated values for DO in the surface waters of the lower river is likely related to the presence of very high phytoplankton populations. For purposes of this study, supersaturation was defined as DO concentrations in excess of 120 percent of saturation. In all sections of the lower river except the most upstream (kilometer 15-18), the probability of supersaturation was significantly related to the rate of inflow, with declining flow increasing the probability of supersaturation in all segments. However, the predicted increases in supersaturation were largely confined to flows below about 200 cfs, with particularly steep responses at flows less than 100 cfs (Figure 5-48).

To examine the effect of reduced inflows on the probability of supersaturation in the lower river, the logistic regressions listed in Table 5-4 were run for baseline flows and the seven flow scenarios previously discussed. Selected percentile values for the predicted probabilities of DO supersaturation in five river segments for these flow scenarios are listed in Table 8-38. For illustrative purposes, cases where the probability of supersaturation is increased by more than 10 percent compared to baseline are highlighted in gray. The only cases where increases of more than 10 percent were observed are at 30 and 40 percent flow reductions for the segment between kilometers 6 and 9. Most importantly, the application of the 120 cfs low-flow threshold keeps the changes in supersaturation for the proposed minimum flow virtually unchanged from the baseline condition. Though DO supersaturation is an indirect measure of phytoplankton abundance, these results indicate that by preventing large reductions of inflows, and no reductions of low inflows, the proposed minimum flow will maintain flushing of the lower river so that increases in DO supersaturation are not likely to occur.

8.8.2 Simulations of the increased probability of high chlorophyll *a* concentrations

The logistic regressions described in Section 5.6.8 were used to predict the probability of the occurrence of high chlorophyll concentrations (> 30 µg/l) in the lower river that would result from reduced flows, including the proposed minimum flow. Percentile values of the

Table 8-38. Percentiles of daily probabilities of dissolved oxygen saturation values greater than 120% (supersaturation) for four river segments for eight flow scenarios. Probability values were predicted by the logistic regressions listed in Table 5-4. Values that differ from the baseline by more than 10 percent are highlighted in gray.

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 3 - 6	**Baseline**	3%	4%	6%	9%	12%	15%	19%
	10% reduction	3%	5%	6%	9%	13%	16%	21%
	20% reduction	3%	5%	7%	10%	15%	17%	22%
	30% reduction	4%	6%	7%	11%	16%	18%	24%
	40% reduction	4%	6%	8%	13%	18%	20%	26%
	19% reduction	3%	5%	6%	10%	14%	17%	22%
	19% 120 cfs low flow	3%	5%	6%	10%	14%	14%	19%
	24% 120 cfs, existing capacity	3%	5%	7%	11%	14%	15%	19%

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 6 - 9	**Baseline**	1%	2%	3%	6%	12%	15%	25%
	10% reduction	1%	2%	3%	7%	13%	18%	28%
	15% reduction	1%	2%	3%	7%	14%	19%	30%
	20% reduction	1%	2%	3%	8%	15%	20%	32%
	30% reduction	1%	2%	4%	10%	18%	23%	36%
	40% reduction	1%	3%	5%	12%	22%	27%	40%
	19% reduction	1%	2%	3%	8%	15%	20%	31%
	19% 120 cfs low flow	1%	2%	3%	8%	14%	15%	25%
	24% 120 cfs, existing capacity	1%	2%	4%	9%	14%	15%	25%

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 9 - 12	**Baseline**	0%	1%	1%	3%	6%	7%	13%
	10% reduction	0%	1%	1%	3%	6%	9%	15%
	20% reduction	0%	1%	2%	4%	8%	10%	17%
	30% reduction	0%	1%	2%	5%	9%	12%	20%
	40% reduction	1%	1%	2%	6%	11%	14%	23%
	19% reduction	0%	1%	2%	4%	7%	10%	17%
	19% 120 cfs low flow	0%	1%	2%	4%	7%	7%	13%
	24% 120 cfs, existing capacity	0%	1%	2%	4%	7%	7%	13%

		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 12 - 15	**Baseline**	0%	0%	1%	1%	2%	2%	4%
	10% reduction	0%	0%	1%	1%	2%	3%	4%
	20% reduction	0%	0%	1%	1%	2%	3%	5%
	30% reduction	0%	1%	1%	2%	3%	3%	5%
	40% reduction	0%	1%	1%	2%	3%	4%	6%
	19% reduction	0%	0%	1%	1%	2%	3%	5%
	19% 120 cfs low flow	0%	0%	1%	1%	2%	2%	4%
	24% 120 cfs, existing capacity	0%	0%	1%	1%	2%	2%	4%

probability of high chlorophyll concentrations in four river segments and an area weighted average predicted for baseline flows and seven flow reduction scenarios are listed in Table 8-39. No significant relationship between inflow and the probability of high chlorophyll *a* was observed in the most downstream and upstream segments. In all other segments the probability of high chlorophyll *a* increases as flow declines (Figure 5-70). However, the only cases where the probability of any percentile value increased by more than 10 percent over the corresponding baseline value is for 30 and 40 percent flow reductions. Increases for the proposed 19 percent minimum flow and the 24 percent flow reduction scenarios are small, ranging from 0 to 9 percent for any percentile. There are no changes in the predicted values for percentiles corresponding to high probability (85th and 95th percentiles), as the low-flow threshold prevents impacts to the river during low flows when the probability of high chlorophyll is the greatest. In sum, the proposed minimum flow is not expected to result in significant harm to the lower river that would result from an increased frequency of high chlorophyll *a* concentrations.

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Table 8-39. Percentile values of probabities of chlorophyll *a* concentrations of > 30 µg/l in six river segments and an area weighted average for eight flow scenarios. Probabilities predicted using the logistic regressions listed in Table 5-6. Percentile values that are more than 10 percent greater than the baseline are highlighted in gray.

Segment km 0 - 3	no predictions, no sigificant relationship							
		Percentile						
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 3 - 6	Baseline	9%	15%	19%	26%	29%	30%	32%
	10% reduction	8%	16%	21%	27%	30%	31%	33%
	15% reduction	9%	17%	21%	27%	30%	31%	33%
	20% reduction	9%	17%	22%	28%	30%	31%	33%
	30% reduction	11%	19%	23%	28%	31%	32%	33%
	40% reduction	13%	21%	25%	29%	32%	32%	33%
	19% reduction	9%	17%	22%	27%	30%	30%	32%
	19%, 120 cfs, low flow	9%	17%	22%	27%	30%	30%	32%
	24%, 120 cfs, existing	8%	17%	22%	28%	30%	30%	32%
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 6 - 9	Baseline	0%	4%	13%	35%	49%	54%	60%
	10% reduction	0%	6%	16%	38%	52%	56%	62%
	15% reduction	0%	7%	18%	40%	53%	57%	62%
	20% reduction	1%	8%	20%	42%	54%	57%	63%
	30% reduction	1%	12%	25%	46%	56%	59%	64%
	40% reduction	2%	17%	31%	49%	59%	61%	65%
	19% reduction	1%	8%	20%	42%	53%	57%	62%
	19%, 120 cfs, low flow	0%	8%	20%	42%	52%	54%	60%
	24%, 120 cfs, existing	0%	7%	21%	44%	52%	54%	60%
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 9 - 12	Baseline	0%	0%	2%	15%	31%	37%	48%
	10% reduction	0%	1%	3%	18%	34%	40%	50%
	15% reduction	0%	1%	4%	20%	36%	41%	50%
	20% reduction	0%	1%	5%	22%	37%	43%	51%
	30% reduction	0%	2%	8%	26%	41%	46%	53%
	40% reduction	0%	4%	11%	31%	45%	49%	55%
	19% reduction	0%	1%	5%	21%	35%	37%	48%
	19%, 120 cfs, low flow	0%	1%	5%	21%	35%	37%	48%
	24%, 120 cfs, existing	0%	1%	5%	24%	35%	37%	48%
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
km 12 - 15	Baseline	0%	0%	0%	1%	6%	9%	17%
	10% reduction	0%	0%	0%	2%	7%	11%	19%
	15% reduction	0%	0%	0%	2%	8%	12%	20%
	20% reduction	0%	0%	0%	3%	9%	13%	21%
	30% reduction	0%	0%	0%	4%	11%	15%	23%
	40% reduction	0%	0%	1%	6%	14%	18%	25%
	19% reduction	0%	0%	0.1%	3%	8%	9%	17%
	19%, 120 cfs, low flow	0%	0%	0%	3%	8%	9%	17%
	24%, 120 cfs, existing	0%	0%	0%	3%	8%	9%	17%
Segment km 15 - 18	No predictions, no significant relationship							
Segment	**flow**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
Area-Weighted Average	Baseline	4%	9%	14%	25%	33%	36%	40%
	10% reduction	5%	10%	16%	27%	34%	37%	41%
	15% reduction	5%	11%	17%	28%	35%	38%	41%
	20% reduction	5%	12%	18%	29%	36%	38%	42%
	30% reduction	6%	14%	20%	31%	37%	39%	43%
	40% reduction	8%	16%	23%	33%	39%	41%	44%
	19% reduction	5%	12%	17%	28%	35%	36%	40%
	19%, 120 cfs, low flow	5%	12%	17%	28%	35%	36%	40%
	24%, 120 cfs, existing	4%	11%	18%	30%	35%	36%	40%

8.8.3 Simulations of shifts in the location of peak chlorophyll *a* concentrations

As described in Section 5.6.9, the location of the peak chlorophyll a concentration in the lower river on a given date is related to the rate of freshwater inflow. As flows decline, the location of the peak concentration moves upstream. A regression was developed to predict the location of the peak chlorophyll concentration as a function of the preceding three-day mean freshwater inflow to the upper estuary (Figure 5-77).

This regression was used to predict the location of the peak chlorophyll concentrations for baseline flows and seven flow reduction scenarios, including the proposed minimum flow and the 24 percent withdrawal scenario. The predicted locations for the 10^{th}, 50^{th}, and 90^{th} percentile values are listed in Table 8-40. Forty percent flow reductions result in shifts of 1.0 kilometer for the listed percentiles, which represent high, medium, and low inflows. The proposed minimum flow results in movements of 0.5 kilometers for the 10^{th} and 50^{th} percentile values and no movement in the 90^{th} percentile value, due to the effect of the low-flow threshold preventing any reductions in flows below 120 cfs.

Overall, the proposed minimum flow tends to shorten the length of river over which the peak chlorophyll concentration moves, as flow reductions during high flows move the downstream positions of the chlorophyll maximum upstream, but the low-flow threshold keeps the low flow position the same as the baseline.

Table 8-40. Predicted values for the location of peak chlorophyll *a* concentrations in the Lower Alafia River for eight flow scenarios. All locations predicted with the regression for river sites shown in Figure 5-77.

Flow Scenario	Kilometers		
	10th percentile	Median	90th percentile
Baseline	4.1	6.0	7.7
10%	4.4	6.2	7.9
20%	4.6	6.5	8.2
30%	4.8	6.7	8.4
40%	5.1	7.0	8.7
19%	4.6	6.5	8.1
19%, 120 cfs low flow	4.6	6.5	7.7
24%, 120 cfs, existing capacity	4.5	6.6	7.7

The area and volume values between the 10th and 90th percentile positions of peak chlorophyll concentration are listed for the same flow scenarios in Table 8-41. The proposed minimum flow will result in the peak chlorophyll concentration moving over 81 percent of the volume and 80 percent of the river area compared to baseline conditions. The 24 percent flow reduction scenario actually results in less reduction in area and volume, because the downstream position of the chlorophyll maximum is moved less, due to limiting wet season diversions to 87.5 cfs.

Table 8-41. Volumes and areas between the 10th and 90th percentile values for predicted locations of the peak chlorophyll *a* concentrations listed in Table 8-40 for seven flow scenarios and comparison to baseline values.

Flow Scenario	VOLUME (m^3 x 10,000) between the 10th and 90th percentiles	Percent of baseline volume
Baseline	103.9	n/a
10%	96.5	93%
20%	93.6	90%
30%	91.7	88%
14%	88	85%
19%	91.3	88%
19%, 120 cfs low flow	83.9	81%
24%, 120 cfs, existing capacity	88.5	85%

Flow Scenario	AREA (hectares) between the 10th and 90th percentiles	Percent of baseline area
Baseline	63.1	n/a
10%	58.9	93%
20%	54.9	87%
30%	53.1	84%
40%	49.5	78%
19%	53.8	85%
19%, 120 cfs low flow	50.2	80%
24%, 120 cfs, existing capacity	53.9	85%

The shifts in the predicted locations of the chlorophyll maximum are graphically displayed by boxplots in Figure 8-16 for baseline flows and the proposed 19 percent flow reduction scenario with the 120 cfs low-flow threshold. The proposed minimum flows will keep the location of the chlorophyll peak fluctuating in the mid-river zone. As discussed in Section 8.5, this is the zone of the river which is the primary nursery area for many estuarine dependent fishes.

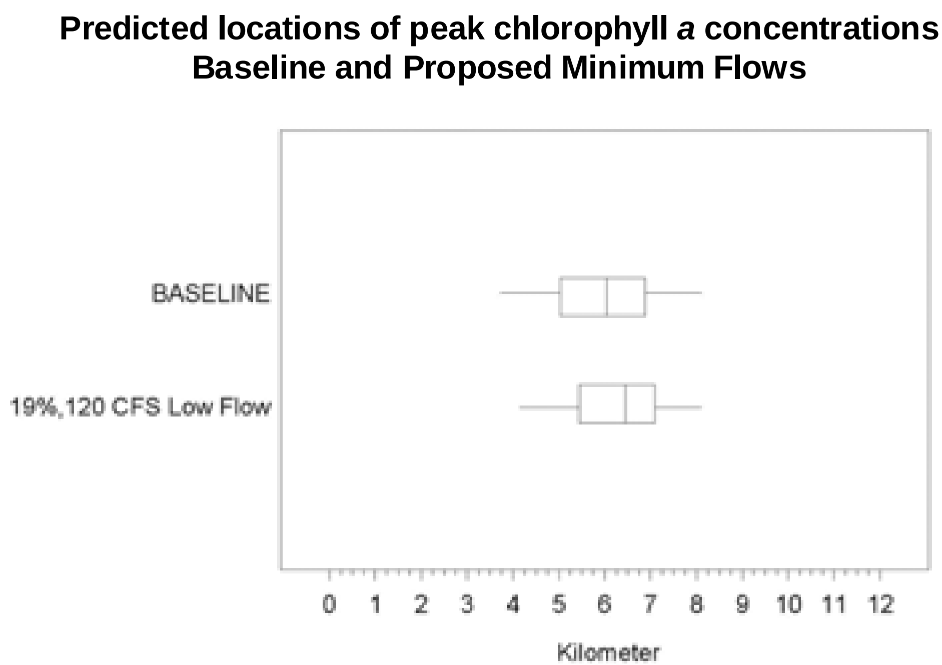

Figure 8-16. Boxplots of the predicted locations of peak chlorophyll *a* concentrations in the Lower Alafia River for baseline flows and flows reduced by 19 percent with a low-flow threshold of 120 cfs.

Given the generally high chlorophyll *a* values throughout the Lower Alafia, it is questionable if an upstream shift in the chlorophyll peak would be of concern for fish nursery use, for there will still likely be abundant phytoplankton throughout the river to drive aquatic food webs that support fish nursery production. Instead, a more legitimate concern might be that an upstream shift in the chlorophyll peak might contribute to greater hypoxia in upstream oligohaline areas, especially since the river tends to deepen above kilometer 10 (Figure 3-4). However, the shift in the peak chlorophyll concentrations that are predicted for the proposed minimum flow are generally in the range of one-half of a kilometer, and it is not expected that these shifts will result in significant harm to the river due to losses of productivity of increases in hypoxia due to changes in the location of maximum phytoplankton biomass, as evidenced by chlorophyll a. Also, implementation of the low-flow threshold will prevent any upstream migration of the chlorophyll peak during the driest times of year.

8.9 Effects of the proposed minimum flows on the freshwater inflow budgets of the Lower Alafia River and Hillsborough Bay.

As described in Chapter 7, a series of quantifiable ecological indicators were used to determine minimum flows for the Lower Alafia River. Using a series of empirical models and a hydrodynamic model of the lower river, changes in these indicators were simulated for a series of percent flow reductions to determine changes that would constitute significant harm. In this process, changes in freshwater inflows, per sé, were not an indicator of concern. It is informative, however, to examine the degree that the proposed minimum flows will reduce inflows to the Lower Alafia River.

The Lower Alafia River contributes freshwater inflow to Hillsborough Bay, which is the northeastern lobe of the larger Tampa Bay system. As described in Section 7.1, the District assumed that significant harm from freshwater withdrawals would occur within the river before the bay, so the minimum flows analysis was confined to within the river. However, it is also valuable to quantify the proportion of the freshwater inflow to Hillsborough Bay that is comprised by the flow reductions that would be allowed by the proposed minimum flows for the Lower Alafia River.

8.9.1 Total inflows to the Lower Alafia River and flows to the upper estuary

Average monthly flows in the Lower Alafia River for the period 1989-2003 were listed in Table 2-3 and are repeated in Table 8-42 below, along with the average withdrawals allowed by the proposed minimum flow and the 24 percent withdrawal scenario. The average withdrawal allowed by the 19 percent minimum flow is greater than the average withdrawal allowed by the 24 percent scenario, because 19 percent minimum flow assumes an unlimited withdrawal capacity, while the 24 percent minimum flow assumes the existing withdrawal capacity (87.5 cfs) currently permitted for the river. The average withdrawal for the 19 percent minimum flow averages 15.4 percent of the total flow of the lower river for the 1989-2003 period. The average withdrawal for the 24 percent scenario averages 11.5 percent of the total flow for the same period, when estimates of ungaged flow were available.

Table 8-42. Mean flows for sources of freshwater inflow to the Lower Alafia River for the period 1989 – 2003.

Source	Mean flow (cfs)	Percent of Total flow
Gaged flow	279	64.4%
Lithia Springs	40	9.2%
Buckhorn Springs	13	3.0%
Ungaged Flow	102	23.6%
Total inflow	433	100.0%
Existing permitted quantities to Tampa Bay Water and Mosaic Fertilizer	34.6	7.8%
Withdrawals 19%, 120 cfs low flow Unlimited diversion capacity	66.6	15.4%
Withdrawals 24%, 120 cfs low flow Existing permitted diversion capacity	49.7	11.5%

Bar graphs of the average monthly percentages of total inflow to the lower river for these two flow reduction scenarios are shown in Figure 8-17. The lowest monthly percent withdrawals for the 19 percent minimum flow occurs in May, while the lowest percent withdrawal for the 24 percent scenario occurs in September, due to the limiting effect of the existing diversion capacity during this high flow month. Figure 8-18 shows a time series of monthly baseline flows and the flows remaining after water is removed per the limitations of these two scenarios. Limiting withdrawals to a percentage of flow causes both flow scenarios to mimic the natural seasonal pattern of baseline flows. Baseline flows and both flow scenarios differ very little during dry periods due to application of the 120 cfs low-flow threshold, which is most apparent during the year 2000 drought.

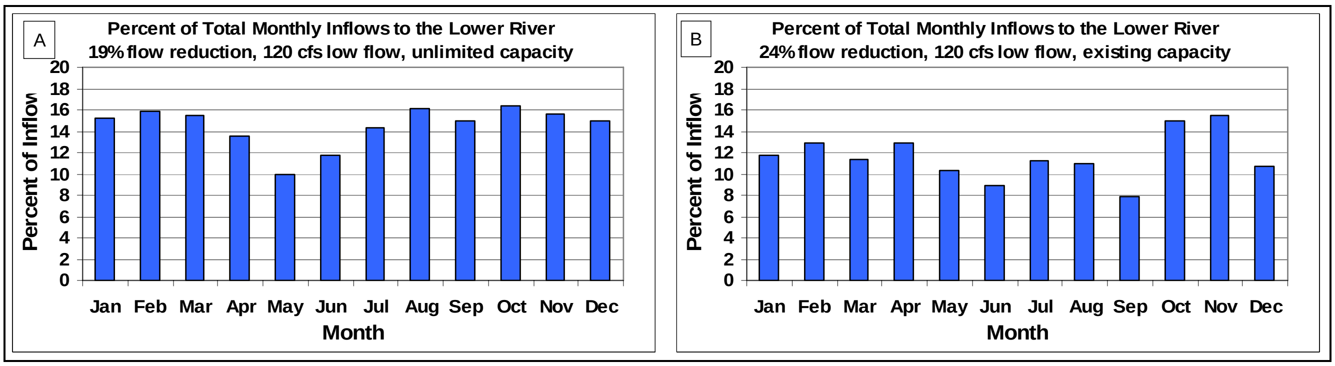

Figure 8-17. Average monthly values for percent of total freshwater inflow to the Lower Alafia River comprised by: (a) withdrawals allowed by the proposed 19% flow reduction with a 120 cfs low-flow threshold and an unlimited withdrawal capacity, and: (B) the a 24% flow reduction combined with a 120 cfs low-flow threshold and the existing permitted withdrawal capacity.

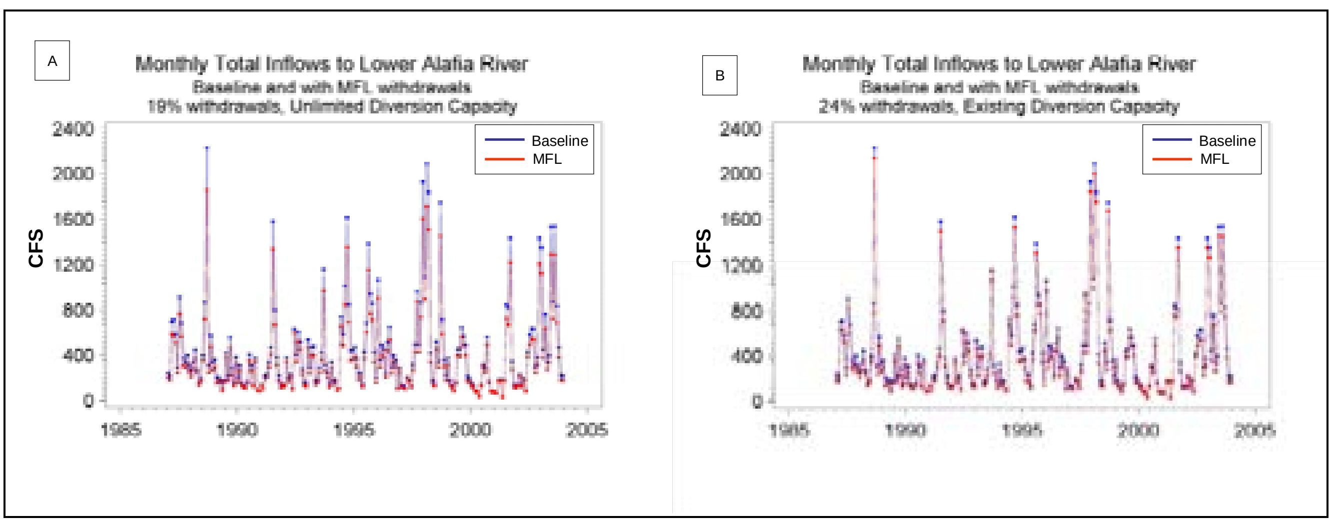

Figure 8-18. Monthly total freshwater inflows to the Lower Alafia River during 1987-2003 for baseline flows and: (A) daily flows reduced by 19% with a 120 cfs low-flow threshold and an unlimited withdrawal capacity; and (B), 24% daily flow reductions with a 120 cfs low-flow threshold and the existing permitted withdrawal capacity of 87.5 cfs. Total inflows include gaged flows from the Alafia River at Lithia gage and Lithia and Buckhorn Springs and ungaged flows estimated by modeling.

A hydrograph is presented that compares total monthly flows to the Lower Alafia River under the proposed 19% minimum flow scenario to flows that would result if all withdrawals were realized under the existing water use permits to Tampa Bay Water and Mosaic Fertilizer (Figure 8-19). The monthly variation in these two flow scenarios is very similar due to the application of the percent-of-flow method to the minimum flow scenario (19% reduction) and the existing Tampa Bay Water permit (10% reduction). The relative difference between the minimum flow and the existing permitted scenarios is greatest at high flows, due in part to the effect of the unlimited diversion capacity in the minimum flow scenario. The simulated withdrawal rates for these two scenarios are compared directly in Figure 8-20, where the effect of high diversions (> 100 cfs) are apparent for the minimum flows scenario.

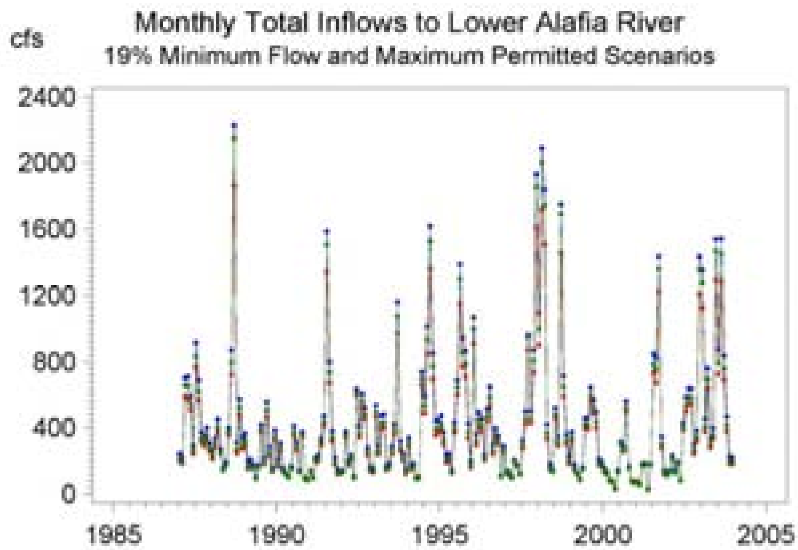

Figure 8-19 Monthly total flows for the baseline (blue), minimum flow (red), and maximum permitted (green) scenarios.

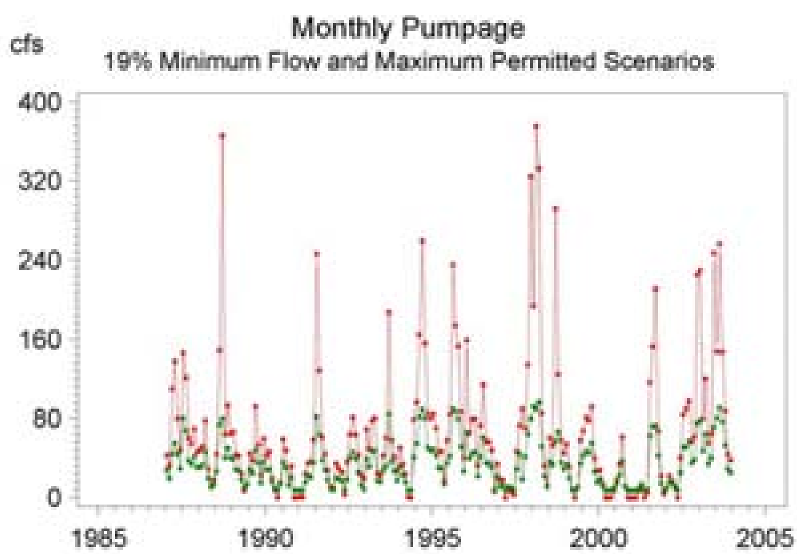

Figure 8-20. Monthly withdrawals for the minimum flow (red) and maximum permitted (green) scenarios.

The values discussed above are for total inflows to the Lower Alafia River, which include estimated flows from ungaged areas. As described in Section 7.4, it was concluded that the determination of minimum flows for the Lower Alafia River would not include estimates of ungaged flows, due to uncertainty in these estimates and difficulty of employing ungaged flow estimates in the real time management of withdrawals from the lower river. Instead, the proposed minimum flow is based on estimated flows to the upper estuary, which involves multiplying the flow at the Alafia River at Lithia streamflow gage by a small watershed ratio (1.117) to estimate flows at Bell Shoals Road and adding flows from Lithia and Buckhorn Springs. It was assumed that ungaged flows to the lower river fluctuate somewhat in synchrony with this hydrologic term, due to similarity in the periodicity of rainfall events in the watershed.

The average freshwater inflow to the upper estuary for the 1987-2003 baseline period was 373 cfs. Withdrawals allowed by the 19 percent minimum flow average 17.8 percent of this value, while the 24 percent withdrawals average 13.3 percent. Similar to the assessment of total inflows, bar graphs are presented for the average monthly percentages inflow to the upper estuary represented by these withdrawal allowed by these two flow reduction scenarios (Figure 8-20). As expected, these graphs show the same monthly relationships as shown for total inflows, but at slightly higher percentages. Time series plots of monthly baseline flows to the upper estuary and the two flow reduction scenarios also show a similar pattern, with the flow reduction scenarios closely tracking the baseline flows (Figure 8-21). The greatest difference between the hydrographs for the 19 percent and 24 percent flow reduction scenarios are during high flow periods, when the 24 percent scenario is closer to the baseline flows due to the limitations of the 87.5 cfs diversion capacity.

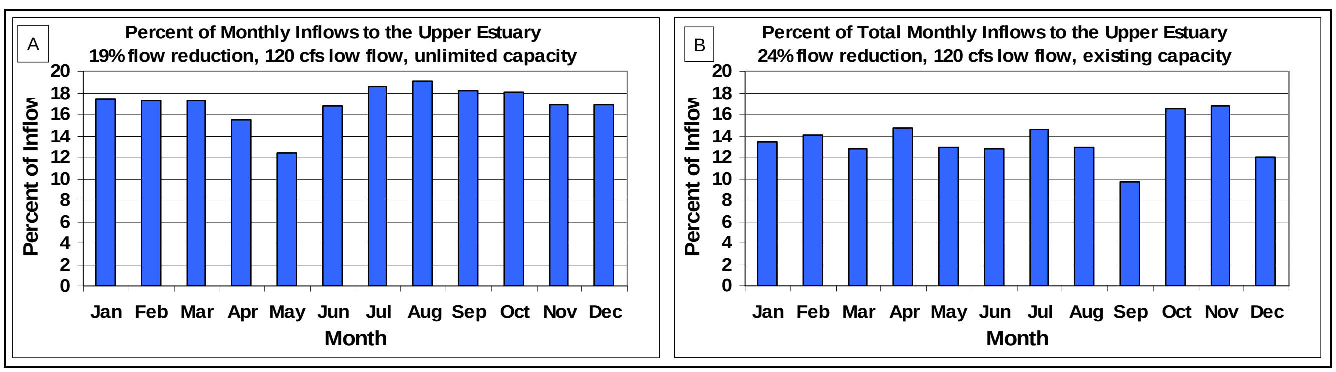

Figure 8-21. Average monthly values for percent of freshwater inflow to the upper estuary in the Lower Alafia River comprised by: (a) withdrawals allowed by the proposed 19 percent flow reduction with a 120 cfs low-flow threshold and an unlimited withdrawal capacity, and: (B) a 24 percent flow reduction combined with a 120 cfs low-flow threshold and the existing permitted withdrawal capacity.

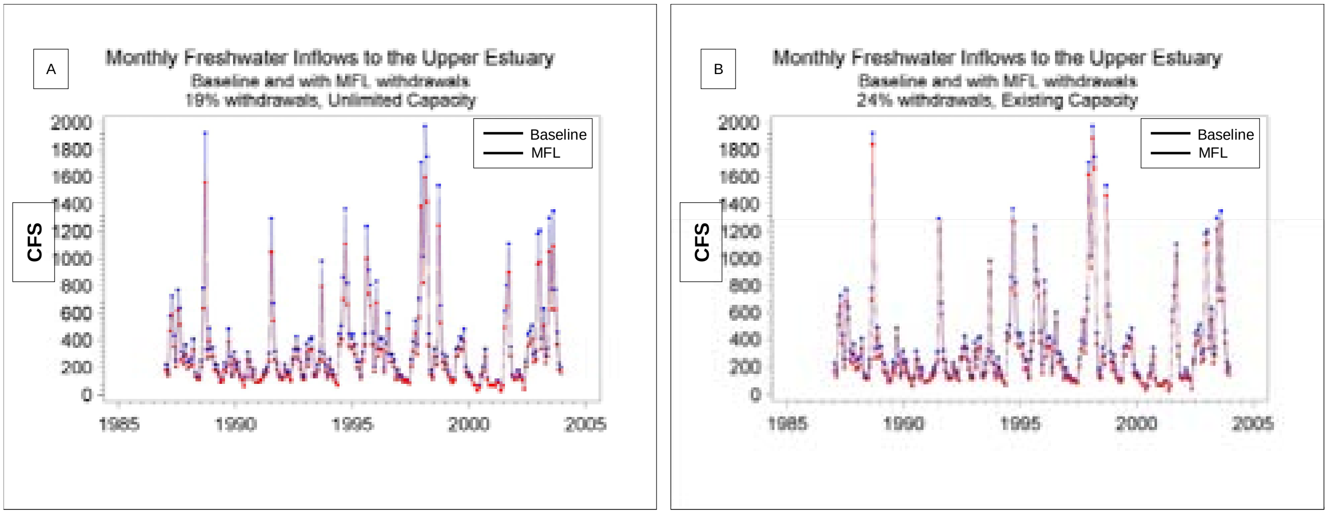

Figure 8-22. Monthly freshwater inflows to the upper estuary during 1987-2003 for baseline flows and: (A) daily flows reduced by 19 percent with a 120 cfs low-flow threshold and an unlimited withdrawal capacity; and (B) 24 percent daily flow reductions with a 120 cfs low-flow threshold and the existing permitted withdrawal capacity of 87.5 cfs.

8.9.2 Freshwater Inflows to Hillsborough Bay

As part of an ongoing program to update nutrient loading estimates to Tampa Bay, the Tampa Bay Estuary Program (TBEP) had periodically contracted consultants to update hydrologic and nutrient loading estimates to the bay. These estimates include values of monthly freshwater inflows to the Tampa Bay from a number of sources, including atmospheric deposition (direct rainfall to the bay), domestic point source discharges, industrial point source discharges, groundwater discharge directly to the bay, gaged springflow, and non-point sources, which represent the sum of gaged streamflow and estimated flows from the ungaged portions of the bay watershed. Hydrologic loads are made in monthly time steps using an approach first described by Zarbock et al. (1994). A regression based approach that used monthly rainfall and runoff coefficients for various land uses is used to estimate ungaged flow. The remaining hydrologic terms are taken from measured or reported values (e.g. rainfall, gaged streamflow, point source discharges).

The most recent estimates of hydrologic and nutrient loads were for the 1999-2003 period, which were presented in a report prepared for the TBEP by the firm of Janicki Environmental (TBEP 2005). Janicki Environmental had been involved in previous updates of the hydrologic and nutrient loads, and has updated the original loading data set that included loading estimates going back to 1985. Janicki Environmental provided the hydrologic loading data set for the years 1987-2003 to the District so that the effect of the proposed minimum flows for the Lower Alafia River on inflows to Tampa Bay could be quantified.

The District concluded that withdrawals from the Alafia River have a greater relative effect on Hillsborough Bay than on the whole of Tampa Bay, and limited its assessment of the effect of the proposed minimum flows on inflows to Hillsborough Bay. Of all the major segments of Tampa Bay, Hillsborough Bay is the segment most often characterized by mesohaline waters and estuarine function, although Old Tampa Bay above the Courtney Campbell Causeway also periodically has low salinity waters in the wet season.

Estimated average inflows to Hillsborough Bay for the 1987-2003 baseline period are listed in Table 8-43, along with the average withdrawals that would be allowed by the two proposed 19 percent minimum flow for the Lower Alafia River and the 24 percent withdrawal schedule with the existing permitted facilities. Atmospheric deposition (direct rainfall) contributes 13 percent of the average inflow to Hillsborough Bay, while springs and streamflow and runoff contribute a total of 69 percent. The springs represented in this total include Lithia and Buckhorn Springs in the Alafia River and Sulphur Springs in the Hillsborough River, which are totaled separately from gaged streamflow in the TBEP sponsored analyses.

Table 8-43. Average values for estimated freshwater inflows to Hillsborough Bay and maximum possible withdrawals from the Alafia River for the proposed 19% minimum flow and 24% withdrawals. Both scenarios are applied with a 120 cfs low-flow threshold for the period 1987-2003. Estimated inflows to Hillsborough Bay were provided by Janicki Environmental using methods described by Zarbock et al. (1994).

Source	Mean flow (cfs)	Percent of Total Bay Inflow
Atmospheric Deposition	154	13%
Domestic Point Source	109	9%
Groundwater to Bay	68	6%
Industrial point source	30	3%
Streamflow and Runoff	716	62%
Springs	75	7%
Total Bay Inflow	**1152**	**100%**
MFL withdrawals	**Mean flow (cfs)**	**Percent of Total Bay Inflow**
Withdrawals, 19%, 120 cfs low flow Unlimited diversion capacity	66.6	5.8 %
Withdrawals, 24%, 120 cfs low flow Existing permitted diversion capacity	49.7	4.3%

The average freshwater inflow to Hillsborough Bay for the baseline period was 1152 cfs. Of this quantity, withdrawals corresponding to the 19 percent minimum flow with unlimited diversion capacity would comprise 5.8 percent of average bay inflow if all withdrawals allowed by the minimum flow were taken from the river. The 24 percent flow reduction scenario comprises a smaller percentage of bay inflows (4.3 percent), due to the effect of limiting the diversion capacity to 87.5 cfs. The average inflow to Hillsborough Bay, if direct rainfall is not included, is 998 cfs. Withdrawals corresponding to the 19 percent minimum flow comprise 6.7 percent of this total, while withdrawals corresponding to the 24 percent withdrawal schedule comprise 5.0 percent of this total.

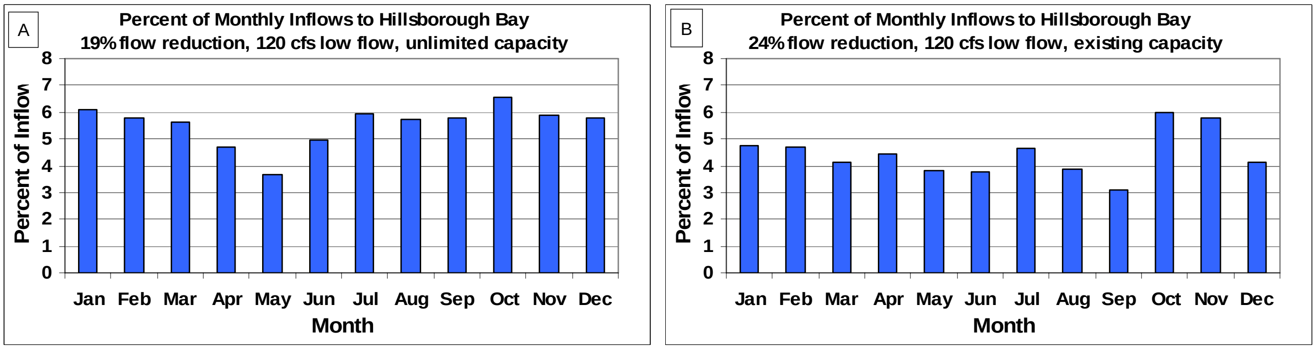

Figure 8-23. Average monthly values for percent of freshwater inflow to Hillsborough Bay comprised by: (a) withdrawals allowed by the proposed 19 percent flow reduction with a 120 cfs low-flow threshold and an unlimited withdrawal capacity, and: (B) a 24 percent flow reduction combined with a 120 cfs low-flow threshold and the existing permitted withdrawal capacity.

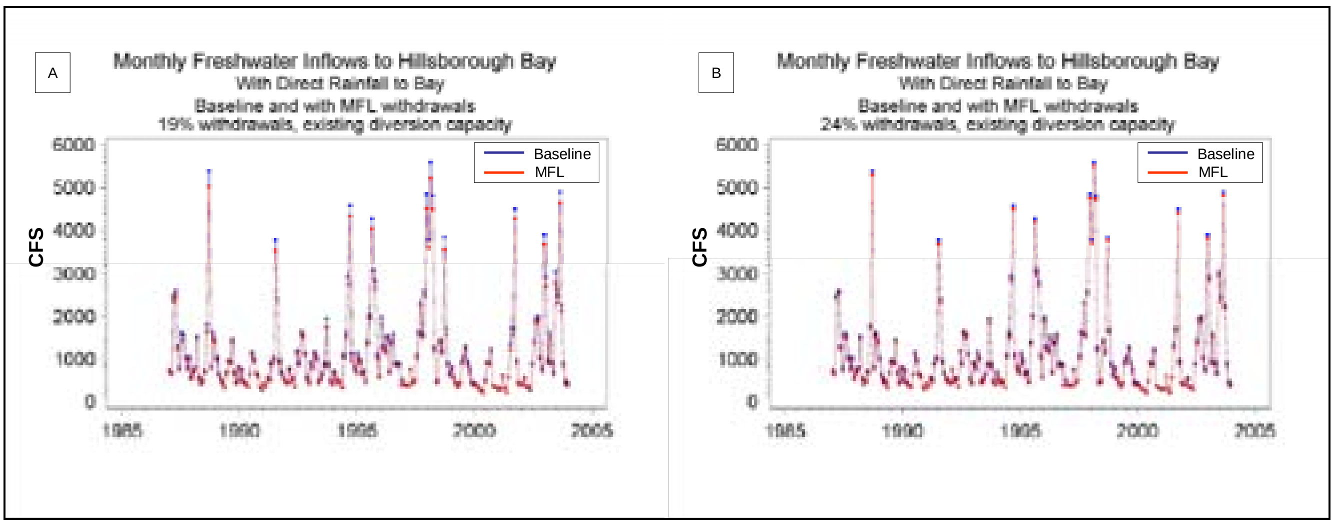

Figure 8-24. Monthly freshwater inflows to Hillsborough Bay during 1987-2003 for baseline flows and daily flows reduced by 19 percent with a 120 cfs low-flow threshold and an unlimited withdrawal capacity, and: (B) a 24 percent flow reduction combined with a 120 cfs low-flow threshold and the existing permitted withdrawal capacity.

Bar graphs of the percentages of average monthly inflows to Hillsborough Bay comprised by withdrawals for the 19 percent and 24 percent flow reduction scenarios are shown in Figure 8-22. The seasonal differences between the two flow scenarios are largely due to the effect of limiting the diversion capacity to 87.5 cfs in the 24 percent scenario. Time series plots of monthly inflows to Hillsborough Bay show the relatively small effect of the proposed minimum flow on inflows to Hillsborough Bay (Figure 8-23).

8-10. Summary and Application of the Proposed Minimum Flow Rules for the Lower Alafia River

This report presents the technical assumptions, ecological criteria, and analytical results that were used to recommend minimum flow rules for the Lower Alafia River, which is geographically defined as the Alafia River downstream of Bell Shoals Road. Minimum flows for a watercourse are defined in Florida Statues (Section 373.042) as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area". Since the Lower Alafia River is a tidal estuarine ecosystem, minimum flows are recommended only in terms of flow rates without a water level component, as tides are the dominant factor affecting water levels throughout most of the lower river over much of the river's flow regime.

As part of the District's standard procedure for adopting minimum flow rules, this report will receive scientific peer review by an independent panel to determine if the assumptions, criteria, and analyses employed in the report sufficiently support the proposed minimum flows. Minimum flows for the freshwater segment of the Alafia River were proposed in a previous report (SWFWMD 2005b), which has undergone independent peer review. That review was generally favorable and supported the District findings and recommended rules for the freshwater portion of the river, which have been adopted by the District Governing Board.

Minimum flow rules will apply to all existing and potential new water users on the Alafia River. Withdrawals will not be able to violate minimum flows for any downstream reach, and the most limiting minimum flow will apply. For example, an upstream withdrawal from the Alafia River must not violate either the minimum flows for the freshwater segment of the Alafia River or minimum flows for the Lower Alafia River. Water use permit applications will be reviewed for compliance with both minimum flow rules. If an existing water use permit is not in compliance with either minimum flow rule, a recovery strategy is adopted with the minimum flow rule(s) that specifies timelines and strategies to bring the permit(s) into compliance.

The District employed the percent-of-flow method for determining minimum flows for the Lower Alafia River. Using a set of ecological criteria specific to freshwater streams, this method was also used to determine minimum flows for the freshwater segment of the Alafia River (SWFWMD 2005b). The percent-of-flow method has been used by the District to regulate major water use permits for surface withdrawals from the Peace and Little Manatee Rivers and the existing withdrawals from the Alafia River permitted to Tampa Bay Water. The environmental analyses to support the percent flow limits in these water user permits were based primarily on potential impacts to downstream, tidal estuarine resources. The technical basis for the percent-of-flow method has been described in other District reports (SWFWMD, 2005a, 2005c, 2007b), a journal article (Flannery et al. 2002), and discussed by other workers (Alber, 2002; Postel and Richter, 2003; National Research Council, 2005).

Minimum flows for the Lower Alafia River were evaluated assuming an unlimited diversion capacity for withdrawals from the river. Simulations were initially run for surface water withdrawals ranging from 10 to 40 percent of daily baseline flows. Based on the response of sensitive ecological indicators, scenarios in one percent increments were run within a narrower range in which significant harm was likely to occur. Baseline flows were established by adding all existing withdrawals back into the flow record of the river, where applicable. Based on an analysis of flow trends in the river, the years from 1987-2003 were determine to be a suitable period on which to evaluate changes from baseline flows.

The hydrologic variable on which the minimum flows are based is inflows to the upper Alafia River estuary, which is calculated by multiplying the measured flows at the Alafia River at Lithia gage by a factor of 1.117 and then adding flows from Lithia and Buckhorn Springs. This multiplication factor is based on a watershed ratio to account for estimated ungaged flows between that the Alafia River at Lithia gage and Bell Shoals Road. The District concluded it would not be appropriate to include estimates of total ungaged runoff in the minimum flow rule, due to uncertainty in these estimates and the practicality of employing such estimates in the real-time management of the hydrology and withdrawals from the river.

The proposed minimum flow rule for the Lower Alafia River is 19 percent reduction of daily flows to the upper estuary, assuming there is an unlimited withdrawal capacity from the river. A low-flow threshold of 120 cfs is recommended which will not allow withdrawals to reduce flows below that amount. For example, if the flow is 125 cfs, water users will be able to withdrawal 5 cfs. A full 19 percent withdrawal will be available when flows reach 148 cfs. The implementation of a low-flow threshold on the Lower Alafia was based on the nonlinear relationship of a number of important ecological variables with inflow, including an increased sensitivity to impacts from flow reductions at low flows. In particular, given the very high nutrient loading to the river, the Lower Alafia is very susceptible to problems with large phytoplankton blooms at low flows due to increased residence times in the river. Other variables such as salinity distributions, the abundance of some fish and invertebrate species, and hypoxia (low dissolved oxygen concentrations) in the upper reaches of the lower river are also sensitive to changes at low flows.

The 120 cfs low-flow threshold will be in effect about 18 percent of the time during the year, and about 37 percent of the time during the months of March through June. The more frequent application of the low-flow threshold during low flows in the springtime is an effective tool for ecosystem protection, for the spring is when fish nursery use of the river is at its peak, and problems with hypoxia in upper river segments can be pronounced due to the interaction of decreasing flows and increasing water temperatures.

The nineteen percent minimum flow recommendation was based on analyses of a suite of resources of concern in the lower river. For each of these resources, ecological indicators were identified and predictive models developed so that changes in these indicators could be simulated as a function of changes in flow. As part of the minimum flows analysis, the District evaluated the effects of reductions of freshwater inflow on salinity distributions important to the zonation of benthic macroinvertebrates, oysters, and tidal wetlands, the abundance and distribution of economically and ecologically important fish and invertebrate species, and the occurrence of hypoxia and high chlorophyll *a* concentrations in the lower river. Based on a series of simulations over a range of percentage flow withdrawals, changes in the abundance of two key fish and invertebrate species (juvenile red drum and mysid shrimp) were the indicators most sensitive to change, and the resources on which the minimum flows were ultimately based. Red drum are one of the most highly sought recreational saltwater sport fish on the Gulf Coast of Florida, and mysid shrimp are a major prey item for the juveniles of many estuarine dependent fish species.

The District concluded that an approximate 15 percent change in these resources would be the limit for significant harm to the Lower River. Although the percent-of-flow method works to prevent major changes to resources over the entire flow regime, the predicted changes in these resources vary somewhat between low and high flows, in part because the low-flow threshold keeps changes minimum during prolonged periods of very low flows. Given this variability over the flow regime, a median reduction of 15 percent for juvenile red drum was the final determinant for the final minimum flow recommendations. However, frequency analyses of predicted changes for mysids, juvenile red drum, and other indicators found the reductions in these resources were not large over any portion of the flow regime, and less than 15 percent over certain ranges of flows.

Though juvenile red drum and mysid shrimp were criteria that served as the final determinant of the minimum flows, the District evaluated the effect of the proposed minimum flows on the full suite of ecological indicators employed for the study. The predicted changes in several of these indicators suggested that the recommended minimum flows were slightly more restrictive than what would have been proposed if those indicators had turned out to be the most sensitive to change. In other words, the analyses of a number of indicators indicated the proposed minimum flows based on the abundance of mysid shrimp and red drum were slightly more restrictive, but not substantially different, than what analyses of other these indicators would suggest.

Freshwater withdrawals from the Lower Alafia River will have the general tendency to increase salinity in the estuary, move isohalines and the salt wedge upstream, increase hypoxia in upper river segments but reduce it in lower river segments, increase the occurrence for high chlorophyll *a* concentrations, and reduce the abundance of some desirable fish and invertebrate species. The District evaluated changes in the occurrence of each of these processes and parameters and established withdrawal limits that would allow only small changes that would not constitute significant harm. Comparisons to the flow regime of the river indicate that application of the percent-of-flow method with implementation of the 120 cfs low-flow threshold will keep ecological changes in the river very small compared to changes that occur seasonally due to natural climatic variations.

In conclusion, based on the findings of this report, the proposed minimum flow for the Lower Alafia River is as follows:

The minimum flow rule for the Lower Alafia River is a nineteen percent reduction of the daily inflows to the upper estuary, which are calculated by multiplying the average daily flows at the Alafia River at Lithia streamflow gage by a factor of 1.117 and adding the pre-withdrawal flows from Lithia and Buckhorn Springs. Withdrawals by all water users will not be allowed to reduce inflow to the upper estuary below a rate of 120 cubic feet per second.

If adopted by the Governing Board, this proposed minimum flow rule for the Lower Alafia River could be revised at a future date, pending additional analyses that demonstrate that significant harm will not occur to the natural resources of the lower river. Extensive data continue to be collected for the Lower Alafia River as part of the Tampa Bay Water HBMP. It is possible that additional ecological modeling or other analyses of an updated data base could indicate that other percentage withdrawal rates would not cause significant harm to the lower river. Any such findings, however, would have to be compared and contrasted with this current report, which identifies the resources of concern in the lower river, describes relationships of important ecological variables with freshwater inflow, and presents analyses to determine acceptable changes in these variables that will not cause significant harm. In addition to new technical analyses, any future revision to an adopted minimum flow rule for the Lower Alafia River would have to be accomplished following procedures that accompany formal rule making, including peer review, public hearings, and adoption by a vote of the District Governing Board.

Literature Cited

AgraBaymont, Inc. 2002. Delineation of wetland communities associated with the Alafia River downstream of Bell Shoals Road. Files submitted to the Southwest Florida Water Management District. Brooksville, Florida.

Alber, M. 2002. A conceptual model for instream flow management. *Estuaries*. 25(6B): 1246-1261.

Aleem, A. A. 1972. Effect of river outflow management on marine life. *Marine Biology.* 15:200-208.

Anderson, D. M., P. M. Gilbert, J. M. Burkholder. 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. *Estuaries*. 25(4B): 704-726.

Baisre, J. A. and Z. Arboleya. 2006. Going against the flow: Effects of river damming in Cuban fisheries. *Fisheries Research* 81:283-292.

Barry , J, P. M. M. Yoklavich, G. M. Cailliet, D. A. Ambrose, B. S. Antrim. 1996. Trophic ecology of the dominant fishes in Elkhorn Slough, California, 1974-1980. *Estuaries* 19:115-138.

Basso, R. and R. Schultz. 2003. Long-term variation in rainfall and its effect on Peace River flow in west-central Florida. Southwest Florida Water Management District. Brooksville, Florida

Beck, M. W., K. L. Heck, K. W. Able, D. L. Childers, D. B. Eggleston, B. M. Gillanders, B Halperin, C. G. Hays, K. hoshino, T. J. Minello, R. J. Orth, P. F. Sheridan and M. P. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. *BioScience* 51:633-641.

Beecher, H. 1990. Standards for Instream Flows. *Rivers* 1: 97-109.

Bidlake, W. R. and P.F. Boetcher. 1997. Near-surface water balance of an undeveloped upland site in west-central Florida. Water Supply Paper No. 2452. U.S. Geological Survey, Denver, CO.

Boler, R. 2001. Surface Water Quality 1998-2000. Publication of the Environmental Protection Commission of Hillsborough County. Tampa Florida.

Breitburg, D. 2002. Effects of hypoxia, and the balance between hypoxia and enrichment, on coastal fishes and fisheries. *Estuaries* 25: 767-781.

Browder, J. A. and D. Moore. 1981. A new approach to determining quantitative relationship between fishery production and the flow of freshwater to estuaries, p. 409-430. In Cross, R. and D. Williams (eds.). 1981. Proceedings of the National Symposium on Freshwater Inflow to Estuaries. Report FWS/OBS-81/04. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.c.

Bulger, A. J., B. P. Hayden, M. E. Monaco, D. M. Nelson, M. G. McCormick-Ray. 1993. Biologically-based estuarine salinity zones derived from a multivariate analysis. *Estuaries* 16:311-322.

Carriker, M. R. 1967, Ecology of estuarine benthic invertebrates: A perspective, p. 442-487. *In* G. H. Lauff (ed.), Estuaries, American Association for the Advancement of Science. Washington.

Chen, X. and Flannery, M.S., 1998. Use of a hydrodynamic Model for Establishing Minimum Freshwater Flow to the Lower Hillsborough River. In: M.L. Spaulding and A.F. Blumberg (Editors), *Estuarine and Coastal Modeling, Proceedings of 5th International Conference*, ASCE, pp.663-678.

Chen, X., Flannery, M.S. and Moore, D.L., 2000. Response Times of Salinity in Relation to Changes in Freshwater Inflows in the Lower Hillsborough River, Florida. *Estuaries*, 23(5): 735-742.

Chen, X., 2003. An Efficient Finite Difference Scheme for Simulating Hydrodynamics in Narrow Rivers and Estuaries. *International Journal for Numerical Methods in Fluids*, 42: 233-247.

Chen, X., 2004. Modeling hydrodynamics and salt transport in the Alafia River estuary, Florida during May 1999- December 2001. *Estuarine, Coastal and Shelf Science*, 61: 447-490.

Chen, X. 2007 (in press). A laterally averaged two-dimensional trajectory model for estimating transport time scales in the Alafia River estuary, Florida. Estuarine, Coastal, and Shelf Science.

Cichra, C. E., C. N. Dahm, D.T. Shaw. 2005. A review of "Alafia River Minimum Flows and Levels: Freshwater Segment including Lithia and Buckhorn Springs" and "Proposed Minimum Flows and Levels for the Upper Segment of the Myakka River, from Myakka City to SR 72. Panel review report prepared for the Southwest Florida Water Management District. Brooksville, Florida.

Cichra, C. E., C. N. Dahm, A. Locke, D.T. Shaw, M. Stewart. 2007. A review of "Proposed Minimum Flows and Levels for the Upper Segment of the Hillsborough River, from Crystal Springs to Morris Bridge, and Crystal Springs." Panel review report prepared for the Southwest Florida Water Management District. Brooksville, Florida

Clark, K. R. and R. M. Warwick. 2001. Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. Second Edition. PRIMER_E Ltd. Plymouth Marine Laboratory, United Kingdom

Clewell, A. F., R. S. Beaman, C. L. Coultas, M. E. Lasley. 1999. Suwannee River Tidal Marsh Vegetation and Its Response to External Variables and Endogenous Community Processes. Suwannee River Water Management District. A.F. Clewell, Inc., Quincy, Florida. 240 p.

Clewell, A. F., M. S. Flannery, S.S. Janicki, R. D. Eisenwirth, R.T. Montgomery. 2002. An analysis of vegetation-salinity relationships in seven tidal rivers on the coast of west-central Florida. Technical Report of the Southwest Florida Water Management District. Brooksville, Florida

Comp, G. S. and W. Seaman. 1985. Estuarine Habitat and Fishery Resources of Florida. p. 337-435 In (W. Seaman (ed.). Florida Aquatic Habitat and Fishery Resources. Publication of the Florida Chapter of the American Fisheries Society.

Correll, D. L. 1978. Estuarine Productivity. *BioScience*, Vol. 28(10) p. 646-650.

Cox, R.A., F. Culkin, J.P. Riley. 1967. The electrical conductivity/chlorinity relationship in natural seawater. *Deep Sea Research* 14: 203

Cross, R. and D. Williams (eds.). 1981. Proceedings of the National Symposium on Freshwater Inflow to Estuaries. Report FWS/OBS-81/04. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C.

Day, J.W. Jr., Hall, C.A.S., Kemp, W.M., Yanez-Arancibia, A., 1989. *Estuarine Ecology*. John Wiley & Sons, New York, NY.

Diaz, R.J. 2001. Overview of hypoxia Around the World, J*. Environ. Qual.* 30(2) 275-277.

Diaz, R.J. and R. Rosenberg. 1995. Marine benthic hypoxia: a review of its ecological effects and the behavioral responses of benthic macrofauna. *Oceanogr Mar Biol Annu Rev* 33: 245-303.

Dooris, P. M. and G. M. Dooris. 1985. Surface flows to Tampa Bay: Quantity and Quality Aspects. P 88-106 In: Treat, S.F, J.L. Simon, R.R. Lewis, R.L. Whitman (Eds.). Proceedings, Tampa Bay Area Scientific Information Symposium. Bellweather Press.

Drinkwater, K.F. and K.T. Frank. 1994. Effects of river regulation and diversion on marine fish and invertebrates. *Aquatic Conservation: Freshwater and Marine Ecosystems* 4:135-151.

Ecological Society of America. 2006. Hypoxia fact sheet. http://www.esa.org/education/edupdfs/hypoxia.pdf

Edwards, R. E. 1991. Nursery habitats of important early-juvenile fishes in the Manatee River esturary of Tampa Bay. pp. 237-252 *In* Treat, S. F. and P. F. Clark (eds.) Proceedings, Tampa Bay Scientific Information Symposium 2. Tampa Bay Regional Planning Council. St. Petersburg, FL.

Enfield, D. A. Mestas-Nunez, and P. Trimble. 2001. The Atlantic multidecadal oscillation and its relations to rainfall and river flows in the continental U.S. *Geophysical Research Letters* 28(10): 2077-2080

Estevez, E. D., L. K. Dixon, M. S. Flannery. 1991a. West-coastal rivers of peninsula Florida, p. 187-221 In R. J. Livingston (ed). Rivers of Florida. Ecological Studies No 83. Springer-Verlag, New York.

Estevez, E. D., R. E. Edwards, and D. M. Hayward. 1991b. An ecological overview of Tampa Bay's tidal rivers. pp. *236-76* In Treat, S. F. and P.A. Clark (eds.) Proceedings, Tampa Bay Scientific Information Symposium 2. Tampa Bay Regional Planning Council. St. Petersburg, FL.

Fanning, K. A. and L. M. Bell. 1985. Nutrients in Tampa Bay. p 88-106 In: Treat, S.F, J.L. Simon, R.R. Lewis, and R.L. Whitman (Eds.). Proceedings, Tampa Bay Area Scientific Information Symposium. Bellweather Press.

Fehring, W. K. 1985. History of the Port of Tampa, In Treat, S.F., J.L. Simon, and R. R. Lewis (Eds.), Proceedings of the Tampa Bay Area Scientific Information Symposium, May 1982. Bellweather Press

Flannery, M. S. 1989. Tampa and Sarasota Bay's watershed and tributaries. pp. 18-48 in E. D. Estevez (ed.) Tampa and Sarasota Bays: Issues, resources, status, and management. NOAA Estuary-of-the-Month Seminar Series No. 11. Washington, DC

Flannery, M. and M. Barcelo. 1998. Spatial and temporal patterns of streamflow trends in the Upper Charlotte Harbor watershed. In Proceedings of the Charlotte Harbor Public Conference and Technical Symposium. Charlotte Harbor National Estuary Program. Technical Report 98-02.

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

Flannery, M. S., H. C. Downing, Jr., J.A. McGarry, and M.O. Walters. 1991. Increased nutrient loading and baseflow supplementation in the Little Manatee River watershed. pp. 369-395. In Treat, S. F. and P. F. Clark (eds.) Proceedings, Tampa Bay Scientific Information Symposium 2. Tampa Bay Regional Planning Council. St. Petersburg, FL.

Florida Department of Environmental Protection. 1996. Water Quality Assessment for the State of Florida, 1996, Main 305B Report. Florida Department of Environmental Protection. Tallahassee Florida.

Florida Department of Environmental Protection. 2002. Group 2 Basin Status Report. Tampa Bay Tributaries Including the Hillsborough, Alafia, Little Manatee, and Manatee Rivers. Florida Department of Environmental Protection, Division of Water Resource Management. Tallahassee Florida.

Florida Fish and Wildlife Conservation Commission. 2005. Florida's Wildlife Legacy Initiative. Florida's Comprehensive Wildlife Conservation Strategy. Tallahassee, Florida, U.S.A.

Friedland, K. D., D.W. Ahrenholz and J. f. Guthrie. 1996. Formation and seasonal evolution of Atlantic menhaden juvenile nurseries in coastal estuaries. *Estuaries* 19:105-114.

Gaston, G. R., C. F. Rakocinski, S. S. Brown, and C. M. Cleveland. 1998. Trophic function in estuaries: response of macrobenthos to natural and contaminant gradients, *Mar. Freshwater Res*. 49:833-46.

Geurink, J., M. Nachabe, M. Ross. P. Tara. 2001. Development of Interfacial Boundary Conditions for the Southern District Ground Water Model of the Southwest Florida Water Management District. University of South Florida.

Giovanelli, R. F. 1981. Relations between freshwater flow and salinity distributions in the Alafia River, Bullfrog Creek, and Hillsborough Bay, Florida. Water Resources Investigation Report. 80-102. U.S. Geological Survey, Tallahassee, Florida

Goodman, L. R. and J. G. Campbell. 2007. Lethal levels of hypoxia for gulf coast estuarine animals, *Mar. Biol.* 152:37-42.

Gore, J. A., C. Dahm, and C. Klimas. 2002. A review of "Upper Peace River: An analysis of minimum flows and levels". Peer review report prepared for the Southwest Florida Water Management District. Brooksville Florida.

Grabe, S. A. and D. Karlen. 1999. Benthic habitat status of the Lower Alafia River Estuary (1995-1998). Report prepared by the Environmental Protection Commission of Hillsborough County for the Southwest Florida Water Management District. Brooksville, Florida.

Grabe, S. A., L. Guitierrez-Antrim, C. M. Holden, and B. Goetting. 2002. Benthic habitat status of the Lower Hillsborough, Palm, Alafia, and Little Manatee Rivers, 1995-2002. . Report prepared by the Environmental Protection Commission of Hillsborough County for the Southwest Florida Water Management District. Brooksville, Florida.

Grabe, S. A., D. J. Karlen, C. M. Holden, B. Goetting, T. Dix, S. Markam, C. Pearson, M. Rian, and J. Rhora. 2004. Hillsborough Independent Monitoring Program: Pre-operational Characterization of Benthic Habitats of the Alafia and Little Manatee Rivers. Environmental Protection Commission of Hillsborough County.

Greenwood, M. F. D., R. E. Matheson, T. C. MacDonald, and R. H. McMicheal. 2004. Assessment of Relationships between Freshwater inflow and Populations of Fish and Selected Macroinvertebrates in the Peace River and Shell Creek. Report prepared by the Florida Fish and Wildlife Research Institute for the Southwest Florida Water Management District. Brooksville, Florida.

Greenwood, M. F. D., R. E. Matheson, R. H. McMicheal, T.C. MacDonald. 2007. Community structure of shoreline nekton in the estuarine portion of the Alafia River, Florida: Differences along a salinity gradient and inflow-related changes. *Estuarine Coastal and Shelf Science* 74:223-238

Hackney, C. T., and A. A. De La Cruz. 1978. Changes in interstitial water salinity of a Mississippi tidal marsh. *Estuaries* 1(3):185-188.

Hackney, C., S. Brady, L. Stemmy, M. Boris, C. Dennis, T. Hancock, M. O'Bryon, C. Tilton, and E. Barbee. 1996. Does intertidal vegetation indicate specific soil and hydrologic conditions? *Wetlands* 16(1): 89-96

Hall, E. R., M. M. Booth, J. J. Delfino. 2006. Sedimentary organic matter in the Alafia and Little Manatee Rivers in West-Central Florida. *Florida Scientist* 69: 224-235.

Head P. C. (ed.). Practical Estuarine Chemistry: A Handbook. 1985. Cambridge Univeristy Press. New York.

Hensher, D. and L. W. Johnson. 1981. Applied Discrete Choice Modeling. Croom Helm, London.

Hickey, J. 1998. Analysis of streamflow and rainfall at selected sites in west-central Florida. SDI Environmental Services. Tampa, Florida.

Hill, M. T., W. S. Platts, and R. L. Beschta. 1991. Ecological and geological concepts for instream and out-of-channel flow requirements. *Rivers* 2(3): 198-210.

Huang, W. and M. Spaulding. 2002. Modeling residence-time response to freshwater input in Apalachicola Bay, Florida, USA. *Hydrological Processes* 16: 3051-3064.

Huang, W. and X. Liu. 2007. Hydrodynamic modeling of the Little Manatee River. Report submitted by the Department of Civil Engineering, FAMU-FSU College of Engineering, to the Southwest Florida Water Management District, Brooksville Florida.

Hupalo, R., C. Neubauer, L. Keenan, D. Clapp and E. Lowe. 1994. Establishment of minimum flows and levels for the Wekiva River system. Technical Publication SJ94-1 St. Johns River Water Management District, Palatka, Florida.

Ingram, R.G.,L.L. Legendre, Y Simard, and S. Lepage.1985. Phytoplankton response to freshwater runoff: The diversion of the Eastmain River, James Bay*. Canadian Journal of Fisheries and Aquatic Sciences* 42:1216-1221

Instream Flow Council. 2002. Instream flows for riverine resource stewardship. Instream Flow Council, U.S.

Janicki, A. and D. Wade. 1996. Estimating critical nitrogen loads for the Tampa Bay estuary: an empirically-based approach to setting management targets. Tech. Publ. 06-96, Tampa Bay Estuary Program. St. Petersburg, FL.

Janicki Environmental, Inc. 2004a. Relationships between Freshwater Inflow and Fish communities in the Lower Alafia River. Report prepared for Tampa Bay Water. Clearwater, Florida.

Janicki Environmental, Inc. 2004b. Effects of Changes of Freshwater Inflow on Biological Resources of Tampa Bay Tributaries. Report prepared for the Gulf of Mexico Program and the Tampa Bay Estuary Program.

Janicki Environmental, Inc. 2006. Written communication to the Southwest Florida Water Management District presenting analyses of data for benthic macroinvertebrates in the Lower Alafia River.

Janicki Environmental, Inc. 2007. Development of Analytical Tools for Quantifying Minimum Flows in Southwest Florida Tidal Rivers Based Upon Benthic Macroinvertebrate Communities. Report prepared for the Southwest Florida Water Management District. Brooksville, Florida

Jassby AD. 2005. Phytoplankton regulation in a eutrophic tidal river (San Joaquin River, California). *San Francisco Estuary and Watershed Science*. 3(1), Article 3.http://repositories.cdlib.org/jmie/sfews/vol3/iss1/art3

Johansson, J.O.R. 2006 Vertical distribution of chlorophyll-a in Tampa Bay. P. 6-51—6-57. In Poe, A., A.J. Janicki and H. Greening (eds.), Baywide Environmental Monitoring Report, 2002-2005. Tampa Bay Estuary Program Technical Report #6-06.

Keister, J. E., E. D. Houde and D. L. Breitburg. 2000. Effects of bottom-layer hypoxia on abundances and depth distributions of organisms in Patuxent River, Chesapeake Bay, *Marine ecology. Progress series: (Halstembek)* 205:43-59.

Kelly, M. H. 2004. Florida River Flow Patterns and the Atlantic multi-decadal oscillation. Southwest Florida Water Management District. Brooksville, Florida

Kennish. M. J. 1986. Ecology of Estuaries: (I) Physical and Chemical Aspects. CRC Press. Boca Raton, Florida.

Kennish, M.J. 1990. Ecology of Estuaries: (II) Biological Aspects. CRC Press, Boca Raton, Florida

Kinne, O., Salinity. Animal-Invertebrates, in *Marine Ecology*, Vol. 1 (Part 2), Kinne, O., (ed.), Wiley-Interscience, London 1971, 821.

Larson, R. J. 1987. In situ feeding rates of the ctenophore *Mnemiopsis mccradyi*. *Estuaries* 10(2):87-91

Latham, P. J., L. G. Pearlstine, and W. M. Kitchens. 1991. Spatial distributions of the softstem bulrush, *Scirpus validus*, across a salinity gradient. *Estuaries* 14(2): 192-198

Lee, T.M. and A. Swancar. 1997. The influence of evaporation, ground water, and uncertainty, in the hydrologic budget of Lake Lucerne, a seepage lake in Polk County, Florida. Water Supply Paper 2439. U.S. Geological Survey, Denver, CO.

Lenhilan, H. S. and C. H. Peterson. 1998 How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. *Ecological Applications* 8:128-140

Longley, W.L. (ed.). 1994. Freshwater inflows to Texas Bays and estuaries: Ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, Texas.

MacDonald.T. C. 2007. Written communication – Letter from the Florida Fish and Wildlife Conservation Commission to the Southwest Florida Water Management District regarding identification of hatchery-reared and wild juvenile red drum in the Lower Alafia River and revision of regressions to predict the abundance of juvenile red drum as a function of freshwater inflow.

MacDonald, T.C., Peebles, E. B., M.F. D. Greenwood, R. D. Matheson, and R. H. McMichael. 2005. Freshwater inflow effects on fishes and invertebrates in the Hillsborough River estuary. Joint report of the Florida Fish and Wildlife Conservation Commission and the University of South Florida College of Marine Science submitted to the Southwest Florida Water Management District. Brooksville, Florida.

Mallin, M. A., H. W. Paerl, J. Rudek, and R. W. Bates. 1993. Regulation of estuarine primary production by watershed rainfall and river flow. *Marine Ecology Progress Series* 93: 199-203.

Mann, K.H. 1988 production and use of detritus in various freshwater, estuarine and coastal marine systems. *Limnol. Oceanogr.* 33:910-930

Mann, K.H. and J. R. N. Lazier. 1996. Dynamics of Marine Ecosystems. Biological- Physical Interactions in the Ocean. Blackwell Science, Cambridge Massachusetts.

Matheson, R. E., M. F. D. Greenwood, T. C. Macdonald, R. H. McMichael. 2005. Assessment of Relationships Between Freshwater inflow and Populations of Fish and Selected Macroinvertebrates in the Lower Alafia River, Florida. Report prepared by the Florida Fish and Wildlife Research Institute for the Southwest Florida Water Management District. Brooksville, Florida.

Mattson, R. 2002. A resource-based framework for establishing freshwater inflow requirements for the Suwannee River estuary. *Estuaries* 25(6B):1333-1342.

McPherson, B. F.and K. M. Hammett. 1991. p. 32-46 In R. J. Livingston (ed). Rivers of Florida. Ecological Studies No 83. Springer-Verlag, New York

Meng, L. and J. C. Powell. 1999. Linking juvenile fish and their habitats: an example from Narragansett Bay, Rhode Island. *Estuaries* 22:905-916.

Miller DC, Poucher SL, Coiro L (2002). Determination of lethal dissolved oxygen levels for selected marine and estuarine fishes, crustaceans, and a bivalve. *Mar Biol* 140 : 287-296.

Miller, R.L. and B.F. McPherson. 1991. Estimating estuarine flushing and residence times in Charlotte Harbor, Florida, via salt balance and a box model. *Limnology and Oceanography* 36:602-612.

Montagna, P. 2006. A Multivariate Statistical Analysis of Relationships Between Freshwater Inflows and Mollusk Distributions in Tidal Rivers in Southwest Florida. Report prepared for the Southwest Florida Water Management District. Brooksville, Florida.

Montagna, P., M. Alber, P. Doering, M.S. Connor. 2002. Freshwater inflow: science policy, management. Estuaries 25(6B):1243-1245

Mote Marine Laboratory. 2003. An investigation of relationships between freshwater inflows and benthic macroinvertebrates in the Alafia River estuary. Report prepared by Mote Marine Laboratory for the Southwest Florida Water Management District, Brooksville, Florida.

Moyle, P. B. and R. A. Leidy. 1992. Loss of biodiversity in aquatic ecosystems: Evidence from fish faunas, p.127-169. In P. L. Fiedler and S. K. Jain (eds.). Conservation, Preservation, and Management. Chapman and Hall, New ork.

National Oceanic and Atmospheric Administration. 2001. Wetlands and Fish: Catch the Link. Publication of the NOAA National Marine Fisheries Service. Silver Spring, MD.

National Research Council. 2000. Clean Coastal Waters: Understanding and Reducing the Effects of Nutrients Pollution. National Academy Press. Washington, D.C.

National Research Council. 2005. The Science of Instream Flows: A Review of the Texas Instream Flow Program. The National Academy Press. Washington, D.C.

National Science and Technology Council. 2003. An Assessment of Coastal Hypoxia and Eutrophication in U.S. Waters. National Science and Technology Council, Committee on Environment and Natural Resources, Washington, D.C.

Nixon, S. W. 1986. Nutrient dynamics and the productivity of marine coastal waters, p. 91-115. *In* D. Clayton and M. Behbehani (eds.), Coastal Eutrophication. The Alden Press, Oxford, U.K.

Odum, W. E., Smith, III, T. J., Hoove, J. K., McIvor, C. C., 1984. The ecology of tidal freshwater marshes of the United States east coast: a community profile: U.S. Fish and Wildlife Service, FWS/OBS-83/17

Officer, C. B., R. B. Biggs, J. L. Taft, L. E. Cronin, M. A. Tyler, and W. R. Boynton. 1984. Chesapeake Bay Anoxia: Origin, Development, and Significance, *Science* 223: 22-27.

Olsen, S. B., T. Padma, and B. Richter. 2007. Managing Freshwater Inflows to Estuaries: A Methods Guide. The Nature Conservancy, Washington, D.C.

Paerl, H.W., J.L. Pinckney, J.M. Fear, and B. Peierls. 1998. Ecosystem responses to internal and watershed organic matter loading: Consequences for hypoxia in the eutrophying Neuse River estuary, North Carolina, USA. *Marine Ecology Progress Series* 166:17-25.

PBS&J, Inc. 1999. Tampa Bypass Canal/Alafia River Water Supply Projects: Hydrobiological Monitoring Program. Report prepared for Tampa Bay Water, Clearwater, Florida.

PBS&J, Inc. 2003. Tampa Bypass Canal/Alafia River Water Supply Projects: Hydrobiological Monitoring Program: Year Three Interpretive Report. Report prepared for Tampa Bay Water, Clearwater, Florida.

PBS&J, Inc. 2006. Tampa Bypass Canal/Alafia River Water Supply Projects: Hydrobiological Monitoring Program: Water Year 2006 – Year 6 Interpretive Report. Report prepared for Tampa Bay Water, Clearwater, Florida.

Pearlstine, L. G., W. M. Kitchens, P.J. Latham, and R. D. Barltleson. 1993. Tide gage influences on a tidal marsh. *Water Resources Bulletin* 29(6): 1009-1020.

Peebles, E. B. 2002a. An Assessment of the Effects of Freshwater Inflows on Fish and Invertebrate Habitat Use in the Alafia River Estuary. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District. Brooksville, Florida.

Peebles, E. B. 2002b. An Assessment of the Effects of Freshwater Inflows on Fish and Invertebrate Habitat Use in the Peace River and Shell Creek Estuaries. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District. Brooksville, Florida

Peebles, E. B. 2002c. An Assessment of the Effects of Freshwater Inflows on Fish and Invertebrate Habitat Use in the Manatee and Braden River Estuaries. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District. Brooksville, Florida

Peebles, E. B. 2004. An Analysis of Fish and Invertebrate Data Related to the Establishment of Minimum Flows for the Tampa Bypass Canal. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District. Brooksville, Florida

Peebles, E. B. 2005. An Analysis of Freshwater Inflow Effects on the Early Stages of Fish and Their Invertebrate Prey in the Alafia River Estuary. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District. Brooksville, Florida.

Peebles, E. B. 2005a. Review of feeding habitats of juvenile estuarine-dependent fishes and blue crabs: identification of important prey items. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District. Brooksville, Florida.

Peebles, E. B. and M. S. Flannery. 1992. Fish nursery use of the Little Manatee River Estuary (Florida): Relationships with freshwater discharge. Report prepared by the University of South Florida College of Marine Science for the Southwest Florida Water Management District. Brooksville, Florida.

Peebles, E. B., J. R. Hall, and S. G. Tolley. 1996. Egg production by the bay anchovy *Anchoa mitchilli* in relation to adult and larval prey fields. *Mar. Ecol. Prog. Ser*. 131:61-73.

Peebles, E. B., T. C. MacDonald, M.F. D. Greewood, R. E. Matheson, S. E. Burgart, R. H. McMichael. 2006. Freshwater inflow effects on fishes and invertebrates in the Myakka River and Myakkahatchee Creek Estuaries. Joint report of the Florida Fish and Wildlife Conservation Commission and the University of South Florida College of Marine Science submitted to the Southwest Florida Water Management District. Brooksville, Florida.

Perry, J. E., and R. B. Atkinson. 1997. Plant diversity along a salinity gradient of four marshes on the York and Pamunkey Rivers in Virginia. *Castanea* 62(2): 112.

Peterson, M. S. and M. R. Meador. 1994. Effects of salinity on freshwater fishes in coastal plain drainages in the southeastern U.S. *Reviews in Fisheries Science* 2(2): 95-121.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. *Bioscience* 47: 769-784.

Postel, S. and B. Richter. 2003. Rivers for Life: Managing Water for People and Nature. Island Press, Washington, D.C.

Purcell, J. E. 1985. Predation of fish eggs and larvae by pelagic cnidarians and ctenophores. *Bull Mar. Sci.* 37(2): 739-755.

Purcell, J. E. and M. N. Arai. 2001. Interactions of pelagic cnidarians and ctenophores with fish: a review. *Hydrobiologia* 251:27-44

Rabalais N. N. and R. E. Turner (eds.). 2001. Coastal Hypoxia. Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58. American Geophysical Union, Washington, D.C.

Richter, B. D., J. V. Baumbartner, R. Wigington, and D. P. Braun. 1997. How much water does a river need? *Freshwater Biology* 37: 231-249.

Rouseau, J. C., G.L. Faulkner, C.W. Hendry, R. W. Hull. 1977. Springs of Florida. Bulletin 31 of the Florida Bureau of Geology.

Ryther, J. and W Dunstan. 1971. Nitrogen phosphorus and eutrophication in the coastal marine environment. *Science.* 171: 1008-1112.

SDI Environmental Services, Inc. 2003. Cumulative risk of decreasing streamflow in the Peace River basin. Prepared for Charlotte County, Lee County, and the Peace River/Manasota Regional Water Supply Authority.

Shaw, D. T., C. F. Dahm, S. W. Golladay. 2005. A review of "Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia. Panel review report prepared for the Southwest Florida Water Management District. Brooksville, Florida.

Sheldon, J. E. and M. Alber. 2002. Residence times in the Altamaha River estuary. *Estuaries* 25: 1304-1317.

Shen, J. and L. Haas. 2004. Calculating age and residence time in the tidal York River using three-dimensional model experiments. *Estuarine, Coastal, and Shelf Science*. 61(3): 449 – 461.

Sklar, F. H. and J. A. Browder. 1998. Coastal environmental impacts brought about by alterations to freshwater flow in the Gulf of Mexico. *Environmental Management* 22: 547-562.

South Florida Water Management District. 2002. Technical Documentation to Support Development of Minimum Flows and Levels for the Northwest Fork of the Loxahatchee River. South Florida Water Management District. West Palm Florida

Southwest Florida Water Management District. 1994. Estimated Water Use in the Southwest Florida Water Management District. 1991 and 1992. Southwest Florida Water Management District, Brooksville,Florida

Southwest Florida Water Management District. 1992. Water Supply Needs and Sources. 1990-2020. Technical Report of the Southwest Florida Water Management District. Brooksville, Florida.

Southwest Florida Water Management District. 2001a. The Hydrology and Water Quality of Select Springs in the Southwest Florida Water Management District. Technical Report of the Southwest Florida Water Management District. Brooksville, Florida.

Southwest Florida Water Management District. 2001b. Alafia River Comprehensive Watershed Plan. Southwest Florida Water Management District. Brooksville Florida.

Southwest Florida Water Management District. 2005a. Proposed Minimum Flows and Levels for the Upper Segment of the Myakka River, from Myakka City to SR72. Technical Report of the Southwest Florida Water Management District. Brooksville. Florida.

Southwest Florida Water Management District. 2005b. Alafia River Minimum Flows and Levels – Freshwater Segment. Technical Report of the Southwest Florida Water Management District. Brooksville. Florida.

Southwest Florida Water Management District. 2005c. Proposed Minimum Flows and Levels for the Middle Segment of the Peace River, from Zolfo Springs to Arcadia. Technical Report of the Southwest Florida Water Management District. Brooksville. Florida.

Southwest Florida Water Manageament District. 2006a. Regional Water Supply Plan. Southwest Florida Water Management District. Brooksville Florida.

Southwest Florida Water Management District. 2006b. Lower Hillsborough River Low Flow Study Results and Minimum Flow Recommendation. Technical Report of the Southwest Florida Water Management District. Brooksville, Florida.

Southwest Florida Water Management District. 2007a. Proposed Minimum Flows and Levels for the Upper Segment of the Hillsborough River, from Crystal Springs to Morris Bridge. Technical Report of the Southwest Florida Water Management District. Brooksville, Florida.

Southwest Florida Water Management District. 2007b. Proposed Minimum Flows and Levels for the Lower Peace River and Shell Creek. Technical Report of the Southwest Florida Water Management District. Brooksville, Florida.

Somville, M. and N. De Pauw. 1982. Influence of Temperature and River Discharge on Water Quality of the Western Scheldt Estuary, *Water Res*. 16:1349-1356.

Stoker, Y. E., V.A. Levesque, and W. A. Woodham.1996. The effect of discharge and water quality of the Alafia River, Hillsborough River, and the Tampa Bypass Canal on nutrient loading to Hillsborough Bay, Florida. U.S. Geological Survey Water-Resources Investigation Report 95-4107. Tallahassee, FL.

Tamasky, G. and I. Valiela. 1995. Nutrient limitation of phytoplankton growth in Waquit, Massachusetts. *Biol. Bull*. 189:257-258

Tampa Bay Estuary Program. 2005. Estimates of Total Nitrogen, Total Phosphorus, Total Suspended Solids, and Biochemical Oxygen Demand Loadings to Tampa Bay, Florida: 1999-2003. Report prepared by Janicki Environmental for the Tampa Bay Estuary Program. St. Petersburg, Florida.

Tampa Bay Estuary Program. 2006. Charting the Course for Tampa Bay: The Comprehensive Conservation and Management Plan for Tampa Bay, updated in May 2006. TBEP, St. Petersburg, FL.

Tampa Bay Regional Planning Council (TBRPC). 1986. Ecological assessment, classification, and management of Tampa Bay tidal creeks. Tampa Bay Regional Planning Council. St. Petersburg, FL.

Tara, P. E., R. Rokicki, and M.A. Ross. 2001. Estimation of ungaged flows in the Alafia River. Report prepared by the University of South Florida Center for Modeling Hydrologic and Aquatic Systems for the Southwest Florida Water Management District, Brooksville, Florida.

Townsend, D.W. and l.M. Cammen. 1988. potential importance of the timing of spring plankton blooms to benthic-pelagic coupling and recruitment of juvenile demersal fishes. *Biol. Oceanogr*. 5:15-229

Uncles, R. J., and J. A. Stephens. 1993. The freshwater-saltwater interface and its relationship to the turbidity maximum in the Tamar Estuary, United Kingdom. *Estuaries* 16: 126-141.

US EPA (United States Environmental Protection Agency) .2002. Ambient aquatic life water quality criteria for dissolved oxygen (saltwater): Cape Cod to Cape Hatteras. EPA -822-R-00-012. Office of Water, Washington, D.C.

United States Geological Survey. 2006. Hypoxia. http://toxics.usgs.gov/definitions/hypoxia.html

Vallino, J.J. and C.S. Hopkinson. 1998. Estimation of dispersion and mixing times in Plum Island Sound estuary. *Estuarine, Coastal and Shelf Science 46:333-350.*

Vargo, G. A. W. R. Richardson, D. Howard, and J. H. Paul. 1991. Phytoplankton production in Tampa Bay and two tidal rivers, the Alafia and Little Manatee. P 317-340 In: Treat, S.F, and P.A. Clark (Eds.). Proceedings, Tampa Bay Area Scientific Information Symposium 2. TEXT, Tampa , FL.

Vargo, G. A., M. B. Neeley, and R. Montgomery. 2004. An investigation of relationships between phytoplankton populations, water quality parameters, and freshhwater inflows in three tidal rivers in west-central Florida. Report of the University of South Florida College of Marine Science submitted to the Southwest Florida Water Management District, Brooksville, Florida.

Volety, A. K. and S. G. Tolley. 2005. Life History and Ecological Aspects of the American (Eastern) Oyster, *Crassostrea virginica*. Report prepared by Florida Gulf Coast University for the Southwest Florida Water Management District. Brooksville, Florida.

Volety, A. K. and S. G. Tolley. 2006. Analyses of the effects of freshwater inflow alterations on oysters (*Crassostrea virginica*) in the Lower Alafia River. Report prepared by Florida Gulf Coast University for the Southwest Florida Water Management District. Brooksville, Florida.

Wang, P. F., J. Martin, G. Morrison. 1999. Water Quality and eutrophication of Tampa Bay, Florida. *Estuarine, Coastal and Shelf Science* 49:1-20.

Wang, H., Y. P. Hsieh, M. Harwell, and W. Huang. 2007. Modeling soil salinity distribution along topographic gradients in tidal salt marshes in Atlantic and Gulf coastal regions. *Ecological Modeling* 201(3-4) 429-439.

Wannamaker, C. M. and J. A. Rice. 2000. Effects of Hypoxia on movements and behavior of selected estuarine organisms from the southeastern United States. *Journal of experimental marine biology and ecology* 249(2)145-1 63.

Water Resource Associates, Inc., Janicki Environmental, Inc., and SDII Global Corporation, 2005. Technical Report - MFL Establishment for the Lower Suwannee River & Estuary, Little Fanning, Fanning, & Manatee Springs. Report prepared for the Suwannee River Water Management District, Live Oak, FL.

West Coast Regional Water Supply Authority. 1998. Application for use of the Alafia River, the Tampa Bypass Canal, and the Hillsborough River as water supply sources. Water Use Permit Application submitted to the Southwest Florida Water Management District. Brooksville, Florida.

Wilber, D. H. 1992. Association Between Freshwater Inflows and Oyster Productivity in Appalachicola Bay, Florida, *Estuarine, Coastal and Shelf Science* 35(2) 179-190.

Wetzel, P. R., W. M. Kitchens, J. M. Brush and M.L. Dusek. 2004. Use of a reciprocal transplant study to measure the rate of plant community change in a tidal march along a salinity gradient. *Wetlands* 24(4): 879-890

Wolfe, S. H. and Drew, R. D. 1990. An ecological characterization of the Tampa Bay Watershed. Biological Report 90(20) of the U.S. Fish and Wildlife Service, Washington, D. C.

Wolff, W. J., Estuarine benthos, In *Estuaries and Enclosed Seas*, Ketchum, B. H., (Ed)., Elsevier, Amsterdam, 1983,151.

Young, C.M. 1995. Behavior and locomotion during the dispersal phase of larval life. P 249-248 In L. McEdward (ed.) Ecology of Marine Invertebrate Larvae, CRC Press, Boca Raton, Florida.

Zarbock, H., A. Janicki, D. Wade, D. Heimbuch, and H. Wilson. 1994. Estimates of total nitrogen, total phosphorus, and total suspended solids loadings to Tampa Bay, Florida. Technical Publication #04-94. Prepared by Coastal Environmental, Inc. Prepared for Tampa Bay National Estuary Program, St. Petersburg, FL.

Zimmerman, J. T. F. 1976. Mixing and flushing of tidal embayments in the western Dutch Wadden Sea. Part I: Distribution of salinity and calculation of mixing time scales. *Netherlands Journal of Sea Research* 10: 149-191.

Appendix 1A

Report of the Scientific Peer Review Panel

For

The Determination of Minimum Flows for the Lower Alafia River Estuary

Appendix 1A

Report of the Scientific Peer Review Panel

For

The Determination of Minimum Flows for the Lower Alafia River Estuary

REVIEW OF MINIMUM FLOWS AND LEVELS FOR THE LOWER ALAFIA RIVER, FLORIDA

Scientific Peer Review Report

February 13, 2008

Prepared For:
Southwest Florida Water Management District
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Scientific Peer Review of The Determination of Minimum Flows for the Lower Alafia River Estuary, Florida

EXECUTIVE SUMMARY

These studies were conducted by the Southwest Florida Water Management District (the District) because Florida Statutes (§373.042) mandate the District's evaluation of minimum flows and levels (MFLs) for the purpose of protecting the water resources and the ecology of the Lower Alafia River Estuary from "significant harm" related to the continued and expanding municipal and industrial freshwater diversions from the Alafia River to meet water demands of the fast growing Tampa coastal region. With appropriate water management, including science-based MFL rules for environmentally safe operation of water supply impoundments and diversions, the District can ensure that the Lower Alafia River and its associated tidal (estuarine) marshes and brackish wetlands will continue to provide essential food and cover for the myriad of marine and estuarine-dependent fish and wildlife that need them. These measures can also help to restrict the invasion of marine predators, parasites and disease organisms that can negatively affect or even destroy an entire year-class of young organisms, potentially decreasing the surplus production of resident fishery populations that provide seafoods in harvestable quantities.

The Review Panel was generally impressed by the District's investment in obtaining adequate data for the study (e.g., 3032 vertical profiles of salinity, temperature, DO, etc. in the 1999-2003 database), and the thoroughness of the MFL analyses described in the document. The District's goals, indicators and definitions, as developed and explained in the subject report, seem reasonable and appropriate. The Panel finds reasonable the District's conclusion that the proposed MFL will not cause habitat and population losses greater than 15% from the river's use as a water supply source. The Panel also believes that the District's selection of an appropriate low flow threshold of 120 cfs is both reasonable and essential to the success of the MFL in protecting living estuarine resources in the Lower Alafia River.

The Review Panel supports the District’s finding that changes in the shallow-water distribution of estuarine-dependent fishes and invertebrates is related to freshwater inflow. Increasing freshwater discharges attract these organisms, particularly the young-of-the-year, into areas that provide instream habitat (i.e., food and cover) in which they can survive and grow. However, the weak relationships found between inflows and the abundances of major fish and invertebrate species indicate that other physical, chemical and biological conditions are limiting biotic production in the Lower Alafia River. Since these factors are discussed in detail by the District, the Review Panel concludes that the consideration of fish and invertebrates was adequate. For example, the river suffers from periodic algal blooms and low dissolved oxygen concentrations. Complicating matters, there are strong seasonal cycles in temperature, salinity and dissolved oxygen, related to the cooler, dry (winter-spring) seasons versus the warmer, wet (summer-fall) seasons. The Review Panel concurs with the District’s finding that dissolved oxygen, especially near the bottom, is often undesirably low (hypoxic) and can increase mortality of inhabiting fish, shellfish and other organisms.

The Review Panel finds that the District’s hydrological analyses and discussion are adequate, as are the numerical simulations. To the Review Panel, it appears that the LAMFE model application has the required accuracy and resolution to adequately simulate circulation and salinity patterns of the future water management scenarios in enough detail for use in decision-making.

And finally, there is the larger issue of freshwater inflows to Hillsborough Bay, a secondary bay of the Tampa Bay complex most often containing mesohaline water and exhibiting estuarine function due, at least in part, to the fact that the Alafia River has the second largest contributing watershed in the entire Tampa Bay watershed. The District’s evaluation of water supply withdrawals allowed under the proposed MFL rule indicates that the withdrawals will constitute only a small percentage of the freshwater resources to

Hillsborough Bay and, thus, the Panel agrees that it is not likely to produce any "significant harm" to the Bay's ecological health and productivity.

Overall, the Review Panel finds that the District's technical assumptions, ecological criteria, and analytical results that were used to develop an appropriate MFL rule for this estuary are adequate and reasonable, but the Panel strongly recommends continued monitoring to verify that the MFL is having its intended effect of protecting ecological health and productivity of the estuary.

INTRODUCTION

The Southwest Florida Water Management District (the District) is mandated by Florida statutes to establish minimum flows and levels (MFLs) for state surface waters and aquifers within its boundaries for the purpose of protecting the water resources and the ecology of the area from "significant harm" (Florida Statutes, 1972 as amended, Chapter 373, §373.042). The District implements the statute directives by annually updating a list of priority water bodies for which MFLs are to be established and identifying which of these will undergo a voluntarily independent scientific review. Under the statutes, MFLs are defined as follows:

1. A minimum flow is the flow of a watercourse below which further water withdrawals will cause significant harm to the water resources or ecology of the area; and
2. A minimum level is the level of water in an aquifer or surface water body at which further water withdrawals will cause significant harm to the water resources of the area.

Revised in 1997, the Statutes also provide for the MFLs to be established using the "best available information," for the MFLs "to reflect seasonal variations," and for the District's Board, at its discretion, to provide for "the protection of nonconsumptive uses." In addition, §373.0421 of the Florida Statutes states that the District's 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….” As a result, the District has identified a baseline condition that realistically considers the changes and structural alterations in the hydrologic system when determining MFLs. While this is always important, it is especially important in a riverine estuary where up to 19% of streamflows are potentially going to be withdrawn in the future to provide water supplies for the region’s growth.

Current state water policy, as expressed by the State Water Resources Implementation Rule (Chapter 62-40.473, Florida Administrative Code) contains additional guidance for the establishment of MFLs, providing 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.”

The District also has continued to voluntarily commit to independent scientific peer review of its MFLs determinations as good public policy.

After a site visit on October 26, 2007 to perform a reconnaissance survey of the Lower Alafia River study area , the Scientific Review Panel discussed the scope of the review and subsequently prepared their independent scientific reviews of the draft report and associated study documents. The reviews were compiled by the Panel Chair and edited by all Panel Members into the consensus report presented herein.

BACKGROUND

The quantity, quality and timing of freshwater input are characteristics that define an estuary. Freshwater inflows affect estuarine (tidal) areas at all levels; that is, with physical, chemical and biological effects that create a vast and complicated network of ecological relationships (Longley 1994). The effects of changes in inflows to estuaries are also described in Sklar and Browder (1998) and reviewed in Alber (2002). This scientific literature describes and illustrates how changing freshwater inflows can have a profound impact on estuarine conditions: circulation and salinity patterns, stratification and mixing, transit and residence times, the size and shape of the estuary, and the distribution of dissolved and particulate material may all be altered in ways that negatively effect the ecological health and productivity of coastal bays and estuaries.

Inflow-related changes in estuarine conditions consequently will affect living estuarine resources, both directly and indirectly. Many estuarine organisms are directly linked to salinity: the distribution of plants, benthic organisms and fishery species can shift in response to changes in salinity (Drinkwater and Frank 1994; Ardisson and Bourget 1997). If the distributions become uncoupled, estuarine biota may be restricted to areas that are no longer suitable habitat for their survival, growth and reproduction. Potential effects of human activities, particularly freshwater impoundment and diversion, on the adult and larval stages of fish and invertebrates include impacts on migration patterns, spawning and nursery habitats, species diversity, and distribution and production of lower trophic (food) level organisms (Drinkwater and Frank 1994; Longley 1994). Changes in inflow will also affect the delivery of nutrients, organic matter and sediments, which in turn can effect estuarine productivity rates and trophic structure (Longley 1994).

There are a number of approaches for setting the freshwater inflow requirements of an estuary. The District has selected to use a "percent-withdrawal" method that sets upstream limits on water supply diversions as a proportion of river flow. This links daily withdrawals to daily inflows, thereby preserving natural streamflow variations to a large extent. This type of inflow-based policy is very much in keeping with the approach that is often advocated for river management, where flow is considered a master variable because it is correlated with many other factors in the ecosystem (Poff et al. 1997; Richter et al. 1997). In this case, the emphasis is on maintaining the natural flow regime while skimming off flows along the way to meet water supply needs. Normally, regulations are designed to prevent impacts to estuarine resources during sensitive low-inflow periods and to allow water supplies to become gradually more available as inflow increases. The rationale for the District's MFL, along with some of the underlying biological studies that support the percent-of-flow approach, is detailed in Flannery et al. (2002).

REVIEW

Setting minimum flow rules requires several steps: (1) setting appropriate management goals; (2) identifying indicators to measure characteristics that can be mechanistically linked to the management goals; (3) reviewing existing data and collecting new data on the indicators; and (4) assembling conceptual, qualitative, and quantitative models to predict behavior of the indicators under varying flow regimes. The first two steps above represent the overall approach to setting the minimum flow rule.

The District's management goals for the Lower Alafia River were developed to sustain the ecological integrity of this tidal river segment by maintaining a biologically appropriate salinity regime and associated dissolved oxygen (DO) level in this hypereutrophic (excessively nutrient rich) riverine estuary. This nutrient enriched condition makes the river susceptible to developing high concentrations of phytoplankton and nuisance algae during low flow periods that supersaturate the water with DO during the day and then cause hypoxic (severe low DO) at night that can greatly increase the mortality of fish and invertebrate populations. As a result, an additional and very important part of the District's proposed MFL is the identification of a low-flow threshold below which no water diversions would be allowed to cause any DO impacts in the river. The District also concludes that a reduction in the median abundance of a species found sensitive to freshwater inflow (juvenile red drum, *Sciaenops ocellatus*) greater than 15% is not acceptable without triggering "significant harm" to this and other living fish and wildlife resources that may not be as sensitive.

The Review Panel agrees that the District has conducted a comprehensive technical study to determine minimum streamflow requirements for use in managing water resources of the Lower Alafia River, an estuary of the Tampa Bay complex. A criteria of no more than a 15% change in any percentile of abundance, as compared to the estuary's baseline condition, was used as the threshold for "significant harm." While the use of 15% as a threshold is a management decision, the Panel agrees that this is a reasonable approach for avoiding the most serious negative impacts on the ecosystem. The remainder of this report is focused on review of the data, methods and analyses used as a basis for the District's recommended MFL.

The analysis primarily revolves around using regression equations relating several common physical, chemical and biological variables to freshwater inflows at Bell Shoals Road, which is located about 18 km from the mouth of the river (see Figure 1).

Specifically, the District's proposed MFL was determined based on the following procedure:

1. Regressions were developed between inflow and abundance of a suite of fish and invertebrates based on empirical analyses of samples collected in the Lower Alafia River (via both plankton tows and seine and trawl samples).

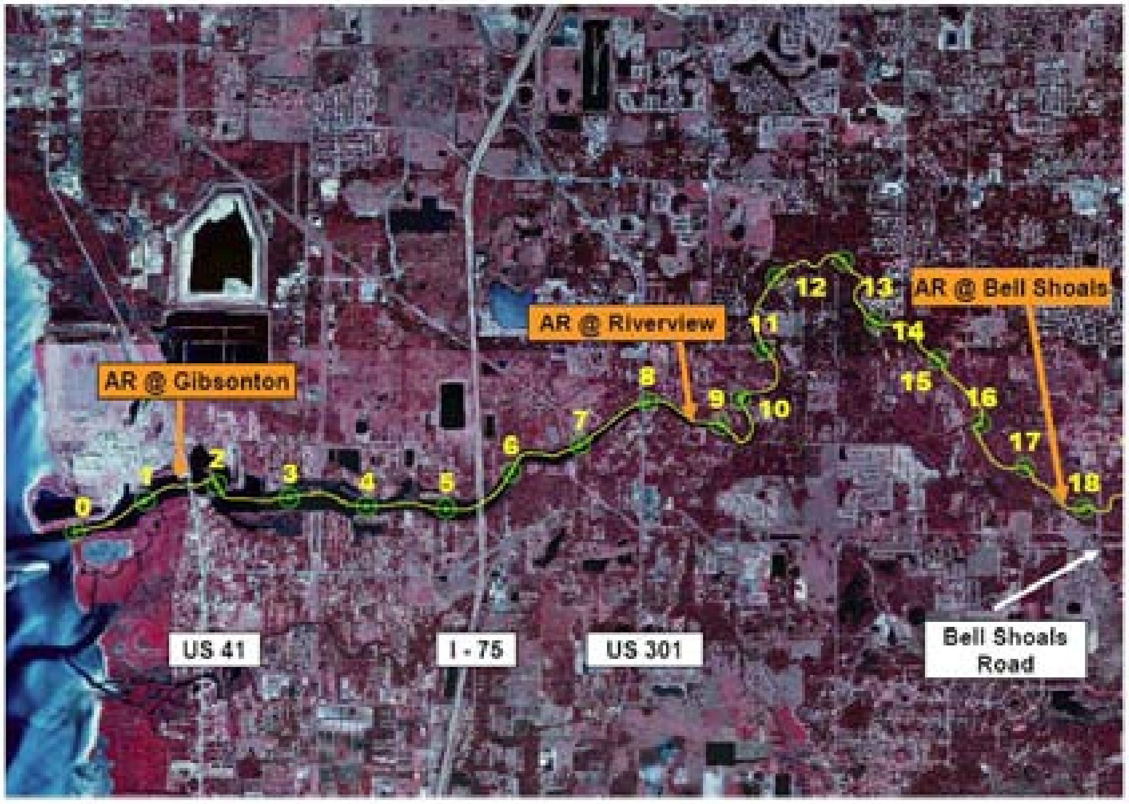

Figure 1. Lower Alafia River, river kilometer at centerline, major roads, and three USGS continuous water quality recorder sites.

2. Daily inflows to the estuary were calculated for the baseline period of 1987 – 2003, given different withdrawal scenarios (with and without a minimum cut-off of water supply diversions).

3. The regression equations were used to predict abundance under the various withdrawal schedules based on the calculated daily inflows associated with each scenario.

4. Predicted abundances were used to construct a cumulative distribution function for the suite of organisms under consideration for each scenario.

5. The predicted cumulative distribution functions (CDF) of organism abundance were compared to CDFs under baseline conditions to determine the % change in

each percentile. A criteria of no more than a 15% change in any percentile of abundance as compared to baseline was used as the threshold for "significant harm."

The proposed minimum flow limit for the Lower Alafia River is an allowable reduction of up to 19% of inflow to the upper estuary (calculated as the sum of the estimated flow at Bell Shoals Road plus flow at Buckhorn Springs), with a low flow cut-off of 120 cfs. This scenario was shown to keep the predicted negative changes in abundance of all species to less than 15%. The District's analysis focused on the abundance of mysid shrimp and juvenile red drum associated with each scenario, because these indicator organisms are biologically important and sensitive to changes in inflow. They are also key species in the estuary (mysid shrimp as an important food source for larval fish; red drum as an ecologically and economically important game fish).

Next, the District evaluated the effect of the proposed MFL on numerous other indicators of estuarine condition (i.e., abundance and distribution of other fish and invertebrates, DO concentration, chlorophyll concentration and the location of peak chlorophyll, location of isohalines and their relationship to both wetland habitat and bottom area). In each case, the steps outlined above were followed, except that the relationships between inflow and the characteristic in question were not always regressions and the predicted changes associated with different inflow scenarios were sometimes obtained by hydrodynamic modeling. In the end, the District concludes that applying the proposed MFL would be protective of these other characteristics as well, since they all proved less sensitive to changes in inflow than mysid shrimp and juvenile red drum.

The District has done a thorough job with the technical part of this document. The report provides a more or less complete picture of the Lower Alafia River. Moreover, the overall analytical approach is sound science. Additional technical comments on various parts of the District's MFL report are provided below:

Theoretical Aspects of Hydrodynamic River Models

In addition to the regression analyses of empirical (observed) data, the District applied a numerical simulation model (i.e., LAMFE) to determine the change in volume and bottom area of saline water as a function of freshwater inflow into the Lower Alafia River. A particle tracking subroutine contained in LAMFE also was used to compute estimates of the riverine estuary's hydraulic residence time and pulse-residence time.

Over the past 25 years, there have been many free-surface hydrostatic numerical hydrodynamic models developed for application in rivers, reservoirs, estuaries and coastal bay areas. Generally, the major delineation between models pertains to their spatial dimensionality. Every hydrodynamic model starts from equations that represent the three-dimensional (3-D) conservation of mass and momentum in a water body. If salinity and/or temperature are to be simulated, there will also be 3-D transport equations for the conservation of salt and/or heat. Models developed for unsteady flow computations in rivers generally make the assumption that the flow is fairly uniform over the cross section of the river and the governing 3-D equations are integrated over the cross section to yield one-dimensional (1-D) equations that can be solved for the variation of the flow and water surface along the river. These 1-D numerical hydrodynamic models are often used for flood routing in major rivers (e.g., Mississippi, Ohio, etc.).

In the relatively shallow bays and estuaries, the flow and water density often don't vary significantly over the water depth. Therefore, the governing 3-D equations are integrated over the water depth to yield two-dimensional (2-D) vertically-averaged equations. In these models, the variation of the flow and the salinity and/or temperature is computed in the horizontal plane of the water body. These models are referred to as 2-D vertically-averaged hydrodynamic models. Some of these models account for the horizontal variation of water density in the momentum equations.

In relatively narrow and deep reservoirs, the temperature over the water depth can become stratified, while there may be very little variation of the flow and temperature over the width of the reservoir. Similarly, in relatively narrow estuaries the salinity can be stratified over the water depth but exhibit little variation over the width of the estuary. For these types of water bodies, the governing 3-D equations are integrated over the width to yield 2-D laterally-averaged equations. With such models, the variation of the flow and salinity or temperature in the water column profile is computed longitudinally down the primary axis of the reservoir or estuary. These models, including the District's LAMFE model, are referred to as 2-D laterally-averaged hydrodynamic models.

The LAMFE model accounts for the influence of water density variations, caused by differences in the concentration (weight) of the salt in various water layers, on the flow field in the momentum equation (i.e., baroclinic terms are included). Having a model that includes more resolution of the vertical (depth) dimension was essential in the Lower Alafia River application because the vertical salinity gradient in the water column (i.e., stratification) of the riverine estuary is generally quite pronounced. For example, the median salinity difference between the surface and near bottom of the water column at the Riverview gage is about 10 psu, as computed from salinity data collected from 1999 to 2003 at the surface, which is lighter and fresher, and at > 2 meters depth where the water is heavier and saltier.

The second most used delineation of numerical hydrodynamic models is related to the numerical solution scheme employed to solve the governing conservation equations. The two most used solution schemes are referred to as the finite difference method and the finite element method. In the finite difference method, derivatives in the governing equations are replaced with differences in discrete values of the dependent variables specified on a numerical grid to compute the solution to the equations. By comparison, a solution is assumed (usually as a polynomial) in the finite element method and the governing equations are used to minimize the error in the assumed solution.

Usually finite difference solutions are made on a structured numerical grid, whereas finite element solutions are made on unstructured nets or meshes. This normally results in finite difference models being more computationally efficient than finite element models; however, finite element models can often reproduce the geometry of the study area in a more recognizable form with higher resolution. Other available solution methods include the boundary element method and the finite volume method. Finite volume models can be viewed as a special case of finite element models. Finite difference models that utilize grids where the computed variables are staggered over the cell faces and at the cell center, such that mass fluxes are computed in and out of the cell, are basically structured grid finite volume models. The LAMFE model utilizes the finite difference method of solution and, thus, is a 2-D laterally-averaged, finite difference model.

Numerical models can be classified as using explicit, implicit or semi-implicit mathematical code. In explicit models, all terms in all the governing equations are evaluated at the old time step in the time integration scheme. This results in limitations being placed on the computational time-step allowed for stable computations. Generally the most restrictive limitation relates to the free-surface gravity wave. In other words, the time-step must be less than the time required for the free-surface gravity wave to travel over the length of a spatial computational cell. Other limitations are related to the speed of the water not being allowed to travel over more than one cell within a time-step, diffusion criteria, friction criteria and internal density waves due to water column stratification. Totally implicit models evaluate all terms in the governing equations at the new time-step in the time integration and there are no limitations on the allowable time-step from a stability consideration. However, there still may be accuracy considerations. Semi-implicit finite difference models evaluate some terms at the new time-step and some at the old time-step, resulting in some limitations on the time-step being removed while others remain. For example, it is highly desirable to remove the extremely restrictive limitation on the time-step related to the speed of the free-surface gravity wave. With the above understanding, the District's LAMFE model can be classified as a semi-implicit, 2-D laterally averaged, finite difference, hydrodynamic (circulation) and conservative mass (salinity) transport simulation model.

There are different finite solution schemes for solving the governing difference equations. LAMFE uses what is called a "predictor-corrector scheme." Initially, the longitudinal velocity is computed over the vertical for each column in the grid with only the vertical viscosity and bottom and side friction taken implicitly. Once the longitudinal velocity is determined over the vertical for each column, the vertical velocity and water surface elevation are determined. This is referred to as the "predictor step." If the computations stop at this point, one could consider the computations to have advanced values for the longitudinal velocity, vertical velocity and water surface elevation to the next time-step. However, the time-step would be restricted by the speed of the free-surface gravity wave and the model would not be very efficient for long-term computations. In LAMFE, the computations continue for the longitudinal velocity, which are now advanced to the next time-step with the water surface elevation (baratropic) term expressed implicitly in the momentum equation.

Ultimately, an equation is derived for the water surface elevations computed at the new time-step at all longitudinal locations in a numerical grid that involves a tri-diagonal system of linear equations that can be solved very efficiently. Once the water surface elevations at the new time step are determined, it is very easy to solve for the longitudinal velocity and the vertical velocity over the longitudinal and vertical dimensions in the numerical grid. This is called the "corrector step." The salinity is then advanced to the next time-step using the new velocity field with the vertical diffusion term expressed implicitly.

The Review Panel finds that the numerical solution scheme employed in the LAMFE model results in free-surface gravity wave speeds and values of vertical viscosity/diffusion and friction that do not restrict the allowable computational time-step. The time-step is still restricted by the speed of a transient water particle; however, this is not normally overly restrictive in this type of application. This means that the LAMFE model is extremely computationally efficient. For example, given the numerical grid employed on the Lower Alafia River and a simulation time-step of 240 seconds, the ratio of real time to computational time is in excess of 18,000—a very impressive accomplishment considering that typical ratios of real time to computing times of some other 2-D vertically averaged models, such as the older and more popular RMA2 river model, normally don't exceed 100.

Another thing that differentiates numerical hydrodynamic models from each other is the coordinate system employed to represent the geometry of the water body. The LAMFE model utilizes a Cartesian coordinate system in both the longitudinal and vertical direction. In some 2-D vertically averaged and 3-D finite difference models, a transformed boundary-fitted coordinate system is utilized in the horizontal dimensions. In some 2D laterally averaged and 3D models, a type of vertical boundary-fitted coordinate system that is commonly referred to as a "sigma grid" is utilized. With a vertical sigma coordinate system, a coordinate line always follows the free surface and another line always follows the bottom topography. Interior lines and the line following the water surface then move in time with the rise and fall of a water surface that fluctuates with marine tidal flows and river flows. Such a grid system is able to model the bottom topography quite well, whereas if a Cartesian grid is utilized alone in the vertical, then the bottom topography appears "stair stepped" and jagged.

The problem with a sigma vertical coordinate system is that water column stratification cannot be simulated very well near significant slopes in the bottom topography unless the grid resolution is quite fine. This problem is not encountered in models that utilize a Cartesian vertical grid, since derivatives of the horizontal pressure gradient terms in the momentum equations are evaluated along levels of constant pressure. Thus, a grid system that utilizes a Cartesian vertical grid but still models the bottom topography accurately would seem to be the best of both worlds. The LAMFE model does this by representing the bottom topography in a piece-wise linear fashion, while still utilizing a Cartesian system over the remainder of the water depth. This procedure does result in some rather complicated control water volumes along the bottom of the river channel, but once the numerical computer coding is accomplished, it presents no particular complication in the computations.

Another interesting feature of the LAMFE model is how it models the free surface of the water. In many models using a Cartesian vertical coordinate, the top layer is initially set to be thick enough that as the water surface declines, it can never fall though the bottom of the top layer, which would constitute an instability causing the model to “bomb.” In many of the early laterally averaged models, such as LARM and the early CEQUAL-W2 (based on LARM), the water surface is allowed to move between vertical layers, but the top layer has to be the same for all longitudinal columns. However, the LAMFE model allows for the water surface to move among vertical layers without it having to be in the same vertical layer in every longitudinal column. As with the treatment of the bottom, this is accomplished by constructing control volumes in which computations are made that can extend over more than one layer.

An important component of both 3-D and laterally averaged 2-D hydrodynamic models is the computation of vertical turbulence, as reflected through the eddy coefficients for viscosity and diffusivity. There are several vertical turbulence models that have been employed in the past. These include algebraic formulations and what are known as one and two-equation subroutines that involve solving partial differential equations for the kinetic energy of turbulence and either the dissipation or the length of the turbulence, when the two-equation form is employed. The LAMFE model allows the user to select from several options for computing the vertical eddy coefficients for diffusion and viscosity.

A one-equation form, referred to as the Total Kinetic Energy (TKE) version, was used in the District’s application of the LAMFE model to the Lower Alafia River. The TKE turbulence model solves a partial differential equation for the turbulent kinetic energy by assuming a particular shape for the length scale of turbulence, subject to certain constraints. The vertical eddy coefficients are then computed using these two variables. In general, the Review Panel believes that the two-equation form, referred to as the K-$\in$ model, performs better. An interesting exercise that is beyond the scope of this review would involve running the LAMFE model on the Lower Alafia River using both the TKE and the two-equation K-$\in$ turbulence models, and comparing the results obtained from the two different numerical simulations.

The LAMFE model also contains a numerical subroutine for computing the transport of mass-less particles for use in computing their residence times in a water body. If the particles are released uniformly over the entire estuary, then an estuarine residence time for a particular percent of particles to pass through the lower boundary can be computed. If the particles are released at the head of the estuary, then a pulse residence time can be computed for any particular area of interest within an estuary on the basis of the percent of particles that move past the location in a specified time interval.

The advective transport of each particle from one time-step to the next is computed using the flow velocities previously computed by LAMFE. As is done in many particle-tracking models, the diffusive movement is computed using a random walk procedure. The total movement of the particle is then the sum of the two. In LAMFE, if a particle hits the bottom or free surface, it is inserted back into the water column. Except for the complexities involved in inserting the particle back into the water column due to how the bottom and free surfaces are treated in LAMFE, the particle-tracking subroutine in LAMFE is very similar to others in the scientific literature.

Part of the process of convincing the scientific community to accept a numerical hydrodynamic model is to demonstrate that the model solves the correct equations and that those equations are programmed in a computer code correctly. The District's work in the discipline of numerical modeling has produced several relevant papers in the peer-reviewed scientific journals. The Review Panel agrees that the theoretical aspects of the LAMFE model are acceptable and efficient for the problem it is being applied to by the District, and that the model has been rigorously tested through application to several test cases for which analytic solutions already exist. These include a seiche oscillation (sloshing) problem in a water body with a sloping bottom, a co-oscillating wave problem in a closed channel with a sloping bottom, and a test commonly called the "dead-sea" problem. In the latter test, a vertical salinity profile is specified that is constant over the horizontal dimensions in a water body with a sloping bottom. With no outside forcing applied, there should be no movement of the water.

The LAMFE computations were extremely accurate for all of the above test cases, demonstrating that the proper equations have been coded without any "bugs" in the computer code. Therefore, the Panel concludes that the LAMFE computer code is a well-developed numerical hydrodynamic model that contains all the physics required to accurately simulate water bodies that can be represented in a laterally-averaged sense.

Application of the LAMFE Model to the Lower Alafia River

An adequate model code is only the beginning of predicting an estuary's circulation and salinity patterns. It is essential that enough hydrographic data be collected to be able to define boundary conditions, which may also be fluctuating, and to determine the internal topography and bathymetry of the estuary's domain. The Panel acknowledges the District's investment in making sure that adequate data for the estuary were available for the MFL analyses.

LAMFE was applied to an approximate 4.5 year period, from May 10, 1999 to December 23, 2003. Observed water surface elevations and salinities were available for specifying boundary conditions, in this case tidal flows, at the mouth of the river. Freshwater inflows for specifying boundary conditions at the upstream end of the modeled river segment were obtained at the Lithia streamgage located about 24 km above the mouth.

Variables computed are the longitudinal and vertical components of the streamflow velocity, the longitudinal and vertical variation of the salinity, and the water surface elevation along the river. Although temperature was not computed, its effect on water density was included by using measured values in the field and then interpolating over the numerical grid at each time-step. All significant forces affecting the circulation and salinity patterns were included in the model's computations except for wind, which the

District and the Panel agree is minimal under more or less normal (non-hurricane) wind conditions because the river is relatively narrow and sheltered.

Numerical Grid--The model's numerical grid only contains 84 computational cells in the longitudinal direction, yet covers a total distance of 24 river kilometers. This means there is room for more cells to improve the resolution of hydrodynamic problems near river reaches of interest because of the model's exceptionally low run-time on commonly available personal computers. There were up to 22 layers of water simulated in the water column (depth) profile of each computational cell. The horizontal cell dimensions varied from 100 to 400 m, while the thickness of the vertical layers varied from 0.3 to 0.6 m. Bell Shoals, at about river kilometer 18 above the mouth, acts under most conditions as an internal hydraulic control similar to that of a broad-crested weir across the river. Above the shoals, the river bottom rises fairly rapidly so that the bottom elevation becomes higher than the water surface elevation downstream of the shoals. Consequently, the model grid must be extended upstream to the Lithia streamgage at river kilometer 24, instead of stopping at Bell Shoals or at the streamgage slightly upstream of Bell Shoals, which is used in all of the subsequent regression analyses of chemical and biological variations that are associated with the ecological health and productivity of the study area. The Panel finds that there is no meaningful conflict between the upstream boundary of the regressions and the simulation model that can not be easily accounted for in the MFL determination.

The features described above in the discussion of hydrodynamic modeling concerning how the free surface and bottom topography are treated in the LAMFE model are of great utility in the model's application to the Lower Alafia River. In other words, the District developed and applied the right model for its intended use on their particular river problem.

Available Data--There were four USGS gage locations with water surface elevation and salinity data available for setting the downstream boundary conditions and for comparison with model results. These data stations were (1) Gibsonton near the river mouth, which provided lower boundary conditions; (2) near Gibsonton, located about 2.73 km above the lower boundary of the model, (3) Riverview, located about 7 km above the lower boundary, and (4) the Bell Shoals gage, located a few hundred meters upstream of the shoals near river kilometer 18. Salinity data were available at three depths in the water column at the Gibsonton gage; however, similar data were only available near the bottom at the other gage near Gibsonton and near surface and bottom at the Riverview gage.

No velocity data were available for model calibration/validation. The Panel suggests that velocity measurements at the river's lower boundary with the coastal bay over several characteristic tidal cycles (72-hour minimum) would provide valuable modeling information. Acoustic Doppler Current Profilers (ADCP's) are specifically designed to easily collect 3-D current patterns at high resolution and integrate them into highly accurate estimates of water entering or leaving the river over the cycle of flood and ebb tides.

Calibration/Validation--In numerical hydrodynamic model applications, generally part of the available data is used to calibrate the model through the adjustment of model parameters such as friction and perhaps parameters in the turbulence routine employed. In the Alafia River application, the first 900 days of the data period were used for model calibration, with the remaining 780 days used for model validation.

During calibration of the LAMFE model, the side friction, bottom friction, and two parameters in the TKE turbulence routine were varied to reduce the differences (error) between the simulated water surface elevations and salinity, and those actually observed and measured by the District. Model results for water surface elevations compared extremely well for the entire simulation period at the near Gibsonton and Riverview gages. Since these two gages are close to the lower boundary where water surface elevations are specified, not simulated, this would be expected. However, the results weren't as good 18 km upstream at the Bell Shoals gage. The differences are more pronounced during episodic storm events over the upper Alafia River basin (e.g., simulation hours 2520; 16,570; and 20,650 as reported by SWFWMD 2007). There are also noticeable differences during times of low flow.

The poor comparisons during storms may be related to geometry errors (i.e., river widths upstream of the shoals that are input to the model may not be as accurate as needed). During the low flow periods when model performance isn't quite as good, Bell Shoals may be exercising some hydraulic control over the flow that isn't modeled directly through an internal boundary condition in the LAMFE model. However, the District reports collecting adequate data in the shoals area for use in specifying the river's bathymetry for the model's application. Regardless of the reasons for the discrepancy between the modeled water surface elevations and the observed elevations at the Bell Shoals gage, this has virtually no influence on the salinities being simulated below the shoals and, thus, does not restrict the District's use of the LAMFE model in the MFL analysis.

The salinity differences (modeling error) between those measured in the field and those computed by the LAMFE model at the near Gibsonton and Riverview gages also aren't as good as the Panel would like to see; nevertheless, the model does replicate the general patterns and proper responses to freshwater inflows and marine tidal flows from water surface set ups and set downs in Tampa Bay and the nearby Gulf of Mexico. In general, it appears that the computed and observed means of the time-varying salinities at the two gages compare relatively well; whereas, at the Riverview gage, the actual tidal fluctuation is significantly larger than that computed by the LAMFE model. The Panel suggests a couple of reasons for this: (1) If the model is computing a greater intrusion of the saline front into the river than actually occurs, then the observed data would be expected to show more variation with tides than that computed by the model. The vertical turbulence routine in the model would have some influence on this. (2) The upstream tidal prism computed by the model could have some error, which might result from an inaccurate specification of river widths in the top layer. The District will have to explore this problem a little more in order to improve the river's simulation with this model. This does not mean that the model is not accurate enough to be used for simulating and comparing the differences in effects of water withdrawal scenarios on river flows and salinities.

There are times in the simulation when the difference in the computed and measured salinity of the middle study reach of the river at the Riverview gage differs by as much as 10 psu, a large discrepancy considering that freshwater is near 0 psu and full-strength seawater is only about 35 psu. The Panel suspects that this is related to the volumes of ungaged flow estimated by the HSPF rainfall runoff model from the watershed downstream of the Bell Shoals gage. As noted by the District, estimating ungaged flows can involve considerable error at times. This is partly due to the limitations of the watershed model, but the Panel believes that it is related, in large part, to the interpolation of spatially-limited, spot rainfall records to cover the entire watershed being modeled.

The District has noted that convectional storms, which dominate the summer rainy season, can be very localized, with large differences in rainfall occurring over short distances on the ground. This is unfortunate because the 87 square miles of ungaged area represents approximately 21% of the total Alafia River drainage basin and the rainfall runoff from this area (ungaged inflow) is estimated to average at least 23.6 % of the total freshwater inflows to the Lower Alafia River from 1989-2003 (SWFWMD 2007). One solution might be to gage more of the ungaged drainages that flow into the river. Another might be to investigate the use of Doppler radar to estimate rainfall over more of the drainage area than what is recorded at the few weather stations available.

Model Simulation Results--Although the salinity validation is not extremely good, the Panel believes that the manner in which the model is used in the MFL analysis negates this issue. In other words, the model wasn't used to predict absolute values of salinity without error, but rather was used to simulate salinity differences due to changes in the freshwater inflows. In this case, changes in water volume and bottom area for ranges of salinity (e.g., < 1 psu, < 6 psu and < 15 psu) were computed as a function of freshwater inflows. These model results were then used by the District to define and support the recommended MFL's operating rules for river management that do not allow changes in water volume and bottom area for the target salinity ranges to be reduced by more than 15%, the point at which larger reductions could cause “significant harm” to living resources under Florida statutes.

The LAMFE model was also used to assess the impact of streamflow reductions on oyster beds located 1 to 4 km upstream of the river’s mouth. Again, model results showed that the MFL will have little impact on this important biotic community that cannot easily or quickly move in response to changes (Note: the Eastern oyster, *Crassostrea virginicia,* is scientifically recognized as a “foundation” species because it biogenically creates habitat for itself and other biota). In this region, the river is wider and there are certainly some lateral variations of salinity that would have been revealed by a more complete 3-D model, but the results of the 2-D LAMFE model are adequate to show little impact on oyster reefs in this reach of the river.

In another relevant application, the LAMFE model was driven with a series of non-dynamic (constant) inflows to compute estuary and pulse residence times using the model’s particle-tracking subroutine. There were 18 different inflows tested ranging from 14 to 1826 cfs. With a 14 cfs streamflow, the riverine estuary’s residence time was 4 days (d) for 50% of the particles and 19.9 d for 95% of the particles to exit the lower boundary and flow into the bay. At a streamflow of 1826 cfs, the estuary residence time was 0.4 d for 50% removal and 1.0 d for 95% removal. On the other hand, the pulse residence time varies depending on the location selected to start from within the estuary, longer for far away areas and shorter for those closer to the bay.

The particle tracking exercise is useful for assessing the impact of flow reductions on estuarine residence times because they can directly impact the amount of phytoplankton and nuisance algae that can buildup in the lower river without being “washed out” to the bay. Interestingly, it also clearly showed that the LAMFE model computes the proper behavior of the flow field near saline fronts. In such areas, the flow tends to move upward, which is reflected by the particles moving upward into the top layer of the water column in the model’s simulation after their uniform virtual insertion over water depth.

Statistical Regression Models

The District used the period 1987 and 2003 for the statistical analyses. The District's report provides data to demonstrate that this was a representative time period because it included a prolonged drought during 2000 and 2001, which would tend to produce conservative results when interpreted for use in setting the MFL for the Lower Alafia River. Various withdrawal scenarios were then applied to the baseline hydrograph to yield a time series of daily flows that could be used either as input to the LAMFE model to predict salinity (although only flows between 5/10/99 and 12/23/03 were used for LAMFE), or as direct input to empirical analyses that statistically predict the abundance of various living resources where there were sufficiently strong relationships between antecedent inflow and the abundance of a given fish or invertebrate. The Panel finds this to be a reasonable approach.

Statistical regression models also were used to predict the locations of various isohalines (salinity concentrations) as a function of freshwater inflows for both surface and near bottom (> 2 m depth) waters at all tide stages. The predictions for location of the surface water isohalines were used to evaluate how changes in flow would influence the availability of shoreline and wetland habitat for fish and wildlife. The fact that these relationships are empirically-based means that all the many physical factors that can affect isohaline location do not have to be explicitly stated in the statistical regression models because they are already inherently included. The Panel concurs that this is an acceptable approach for evaluating changes in flow and the statistical models presented in Appendix 5-B (SWFWMD 2007) do a reasonable job (i.e., regression coefficients range from 0.6 to 0.95).

The District presents several other regression models to predict salinity, none of which were used in the MFL analysis. Since it appears to the Panel that only the locations of surface water isohalines were used in determining the MFL, it would be clearer to include these equations in the main report and put the rest of the information in the appendices.

Moreover, the Panel recommends discussing only the regressions for isohaline location and deleting the others, some of which (e.g., Appendix 5-C) are difficult to follow.

<u>Water Quality Relationships</u>

The District collected water quality data regularly between 1999 and 2003 at both fixed stations and variable location (moving) stations keyed to specific salinity values of interest along the estuary's salinity gradient. The District used this data, as well as information collected by Tampa Bay Water HBMP and EPCHC, in the MFL study. These data sets were sufficient to provide an understandable and more or less complete overview of water quality in the region.

Dissolved Oxygen – Several different aspects of DO were evaluated in the MFL study:

1. Regressions were developed to predict bottom water DO in specific segments of the river based on flow and temperature [for river kilometers 0 to 9, $r^2 = 0.48 – 0.72$; for river kilometers 9 to 15, $r^2 = 0.53 – 0.63$] and these were used to evaluate the effects of various withdrawal scenarios. Focusing on bottom water seems reasonable to the Panel, since that is where severe hypoxia (deficiency of oxygen) is most often observed stressing fish and most other aquatic species to the point of mortality. The proposed MFL of 19% streamflow reduction with a 120 cfs low flow cut-off did not change the predicted DO concentration by more than 0.5 mg/L in any segment of the lower river.

2. Logistic relationships that relate inflow to the probability of DO < 2 mg/L in bottom waters of various river segments were also used by the District to evaluate the effects of water supply withdrawals. The percentage of correct predictions with the logistic regressions ranged from 66% to 82% ($r^2 = 0.66 – 0.82$). The District's proposed MFL did not increase the probability of hypoxia by more than 10% in any segment.

3. Other logistic relationships developed for the Tampa Bay Water Program (which predicted the occurrence of bottom waters with DO < 2.5 mg/L when flows were > 112 cfs) were also applied with similar results. As a result, this additional set of predictions does not add anything to the District's own analysis; however, taken together, these analyses provide robust support for the notion that the occurrence of bottom water hypoxia would not be increased by more than 10% under the proposed MFL. In this regard, the 120 cfs low flow cut-off is a particularly important operational rule protecting fish and other inhabiting organisms because bottom DO decreases extremely rapidly at low flows, particularly below 120 cfs in the Lower Alafia River, especially from about river kilometer 6 to 12.

The Panel notes that DO concentrations were often estimated to be < 2 mg/L, even under "naturalized" baseline flow conditions without any withdrawals from this hypereutrophic riverine estuary. This creates potential violations of Florida's state water quality standards, which contain DO criteria for Class III marine waters such as these that call for an instantaneous minimum of 4 ppm and a daily average of not less than 5 ppm (4 and 5 mg/L DO concentration, respectively). This standard may be practical and scientifically appropriate for inland freshwaters, but it is problematic in warm shallow estuaries with high biological productivity. For example, with 100% saturation of 25ºC (77ºF) freshwater (0 psu) at sea level atmospheric pressure (760 mm), the DO concentration is 8.4 mg/L, declining to 6.2 mg/L when both salinity and temperatures are high (35 psu at 30ºC or 86ºF), and this is for sterile water with no biological or chemical oxygen demand. If the coastal waters are alive with biota and contain any pollutant runoff, then there is no way to consistently maintain DO concentrations above 4 mg/L at night when plants switch from O_2 production (i.e., sunlight-driven photosynthesis) to O_2 consumption (i.e., plant respiration).

Most fishes and macro-invertebrates that are adapted to live in shallow tropical or sub-tropical coastal estuaries are also adapted to tolerate the low (~2 mg/L) DO concentrations that frequently occur in these warm waters at night. However, they generally require DO saturation to be above 30% for continued survival, which at 30ºC is equivalent to ~2.5 mg/L DO. Waters below 30% saturation are referred to as "hypoxic," a condition that induces great physiological stress and mortality in most aquatic animals. When hypoxia occurs, most free-swimming organisms will stop using the area's habitats. This effect was observed in the Lower Alafia River where fish and shrimp were found to avoid hypoxic areas (Peebles 2005; Matheson et al., 2005), just as they do in other urbanized riverine estuaries along the Florida Gulf coast (e.g., Lower Hillsborough River, MacDonald et al. 2006).

Although it is beyond the scope of this MFL study, the existing situation is unlikely to change without effective implementation of a total maximum daily load (TMDL) program that includes watershed controls and better management of stormwater drainage. In terms of the MFL, the Panel concludes that the District's goal of not increasing the probability of occurrence of low DO and high chlorophyll-*a* concentrations from blooms of phytoplankton and nuisance algae is realistic for this urbanized river segment.

Phytoplankton – Several different aspects of the phytoplankton response to flow were evaluated:

1. Logistic regressions that relate inflow to the probability of DO supersaturation (an indication of high phytoplankton production during the day) were used by the District to evaluate the effects of water supply withdrawals. The percentage of correct predictions with these logistic regressions ranged from 81% to 95%. The District's proposed MFL did not change the probability of supersaturation by more than 10% in any segment of the lower river.

2. Logistic regressions were also developed that relate inflow to the probability of high (> 30 µg/L) chlorophyll-*a* concentrations that can indicate eutrophic (nutrient rich) conditions (> 40 µg/L is hypereutrophic). These were used by the District to evaluate the effects of withdrawal. The percentage of correct predictions from these logistic regressions ranged from 66% to 87%. The

District's proposed MFL did not change the probability of high chlorophyll-*a* concentrations by more than 10% in any segment of the lower river.

3. Regression relationships that predict the location of peak chlorophyll-*a* concentrations as a function of inflow were used by the District to evaluate the effects of water supply withdrawals, but the coefficient of determination [r^2] for river stations is only 0.40 in this statistical equation. The proposed MFL moved the location of both the median (50th percentile) and 10th percentile peak chlorophyll-*a* concentrations by ~0.5 km (i.e., from river kilometer 6.0 to 6.5 and river kilometer 4.1 to 4.6, respectively), but it did not affect the location of the 90th percentile peak concentration, which is associated with low river flows. The volume and area between the 10th and 90th percentile locations were reduced by 19% and 20%, respectively, due to the downstream movement of the 10th percentile location during higher inflows. As the District points out, the 0.5 km shift is not likely to matter, since phytoplankton concentrations tend to be very high in the middle portion of this hypereutrophic river anyway.

4. The District also presents results for a regression analysis that takes into account both river and bay stations [$r^2 = 0.52$], with very similar results to that described above. The District should consider deleting this portion of the analysis (Fig. 5-71 B), since there are other controlling factors besides river flow that likely influence phytoplankton in the open bay system. The r^2 increases due to the higher number (n) of observations with bay stations added, but they appear to mostly add scatter and bring the statistical curve down so that the predicted location of the chlorophyll-*a* peak is likely too far downstream at higher river flows.

The chlorophyll-*a* concentrations are extremely high in the Lower Alafia River when compared to nearby streams, such as the Little Manatee and Peace Rivers. However, the data presented suggest that the occurrence of supersaturation of DO, the occurrence of high chlorophyll-*a* concentrations, and the location of the peak chlorophyll-*a* concentration will not be changed substantially by the implementation of the proposed MFL. Once again, the low flow cut-off for water supply withdrawals is important because chlorophyll-*a* concentrations peak at flows < 100 cfs, particularly in the middle segments (river kilometers 6 to 15) of the riverine estuary. Moreover, the logistic regressions show that the probability of chlorophyll-*a* values exceeding 30 µg/L in these segments increases greatly at low flows. At flows less than 120 cfs, the chlorophyll-*a* peak also moves upstream to nursery habitats more vulnerable to the resulting hypoxia.

<u>Inflow Effects on Fish and Invertebrates</u>

Smaller fish and invertebrates collected by plankton tows (Peebles 2005) and larger organisms collected by seine and trawl (Matheson et al. 2005) were all evaluated using the same approach. For the various organisms collected, relationships were developed between inflow and both their overall abundance and their center of distribution in the estuary. From the plankton net data, five potential indicator organisms were used by the District in the MFL analysis. Similarly, nine species from the seine and trawl sampling were identified as indicators of biological change.

Abundance--Peebles (2005) describes the steps used to develop regressions between inflow and abundance for the ichthyoplankton and other larval species, which included using only data where the species was observed (i.e., no zeros in the statistical data), eliminating high flow days where the target organisms were washed out of the river, using variable antecedent inflow to optimize the regression coefficient, and focusing on the longer-term recruitment responses to inflow (as opposed to relationships that show only "catchability"). The final regressions had antecedent inflows that varied between 16 and 120 d, and r^2 values that ranged from 0.1 to 0.45.

The regressions developed to predict the abundance of larger fish and invertebrates were handled differently than those for the larval (planktonic) stages of the indicator species (Matheson et al. 2005). Observations where the organisms were not found (the zeros) were included in the statistically analyzed data set, some relationships were limited to the months when that species was in the river or in particular zones of the river, and various model forms were applied. In this case, the antecedent inflow period ranged from 35 to 343 d, and the r^2 values ranged from 0.13 to 0.39. The Panel notes that the relationships for red drum were modified by MacDonald (2007) to correct for hatchery-reared fish in the field collections. This is because between 2000 and 2003 over one million juvenile red drum were released into the Alafia River; nevertheless, wild red drum represented 93.4% of red drum collections in 2000 and only declined to 68.0% in 2002 before rising again to 76.7% in 2003. Interestingly, the catch-per-unit-effort peaked at about 400 cfs (42-d and 168-d lagged inflow), suggesting an optimum inflow response.

Inflow-abundance regressions were used to predict animal abundance in the river under “naturalized” baseline flows without water supply withdrawals and under various withdrawal scenarios. The predicted difference in abundance between the proposed MFL (19% streamflow diversion with 120 cfs cutoff) and the baseline condition was less than 15% for all species caught in the plankton net samples, except adult mysid shrimp, which are an important prey item for drums, croakers, and other estuarine-dependent fishes (Figure 8-8, SWFWMD 2007). When all the sample data was included, adult mysid shrimp abundance was estimated to decline 16% when inflows were low (below the median), close enough to the 15% limit to be more or less equivocal; however, when high “washout” flow events were removed from the data set, the statistical results showed declines in abundance in the range of 19% to 20%. Thus, it could be concluded that the mysid shrimp adults, not the juveniles, require higher inflows (>130 cfs) to maintain their median abundance than the other organisms examined (Fig. 3.8.5, Peebles 2005). The juvenile mysids seem to be able to utilize the estuarine nursery habitats in the Lower Alafia River and maintain their median abundance with only about 100 cfs of inflow. None of the predicted decreases was >15% at median and higher flows because the low flow cut-off of water supply withdrawals helps to maintain abundances at lower flows.

Statistical analysis of the seine and trawl sample data showed some predicted reductions in abundance greater than 15% under the proposed MFL. Predicted reductions in the Seminole killifish (*Fundulus seminolis*) abundance were greater than 15% across the board (Table 8-8). Although this resident fish species spends its entire life cycle in the river and can tolerate fluctuating salinity, its abundance is highest in the upstream areas (see Fig. 56, Matheson et al. 2005). As flow decreases, especially during drought, this fish species will likely move upstream into tidal freshwater areas.

The red drum or "redfish" was identified as an economically and ecologically important species that is sensitive to changes in inflow and could serve as an indicator species. Red drum response to changes in inflow is difficult to interpret because the regression for inflow vs. abundance takes the form of a quadratic equation, so the percent flow reductions from baseline were less than 15% at higher percentiles (corresponds to higher flows) and greater than 15% at low percentiles (corresponds to low flows). When the 120 cfs low flow withdrawal limit is applied as proposed in the MFL, the greater reductions at low flows are offset by the lesser reductions at higher percentiles (Tables 8-7 and 8-8, SWFWMD 2007) that occur for the red drum at moderately high inflows (Figures 6-32C and 8-3C, SWFWMD 2007). The above analysis was done using the entire flow record, and not just dry periods. When the analysis is limited to only those days when the baseline flows were below the median, corresponding to a dry period, the median abundance of very small red drum (< 39 mm) is reduced 40% and larger juvenile red drum (40-150 mm) are reduced 25% (Table 8-12, SWFWMD 2007). This means that reductions in fish abundance during prolonged dry periods can occur as a result of water supply withdrawals. This, in turn, causes the Panel some concern that red drum needs may not be met during drought intervals, in spite of the fact that no water supply withdrawals will be made below 120 cfs under the MFL rule.

One final point is that the comb jellies (*Mnemiopsis*) showed an opposite response to changes in flow: as flow decreases, salinity increases in the lower end of the river and the abundance of comb jellies increases with it. An increase in *Mnemiopsis* abundance is undesirable because these organisms can consume a lot of plankton and, in so doing, become very detrimental to the food supply and survival of larval and juvenile fishes. However, except at very low freshwater inflows (Figure 8-4, SWFWMD 2007), the abundance of comb jellies only increases gradually. The Panel notes that the predicted abundance of *Mnemiopsis* at very low flows (> 90th percentile) is the same as the baseline condition due, again, to the MFL's 120 cfs low flow cut-off; therefore, stabilizing the population at the low end of the distribution curve with the low-flow limit is both desirable and appropriate.

Distribution--The approach taken for this part of the report was similar to that described above, except that regressions were developed that relate inflow to the location of the center of distribution of each organism rather than its overall abundance. A total of 9 species were evaluated from the plankton net data and 10 species were evaluated from the larger fish and invertebrate data from the seines and trawls. Regressions for the planktonic species used antecedent inflows that varied between 1 and 105 d, and produced r^2 values that ranged from 0.18 to 0.7. Regressions for the larger fish and invertebrates used antecedent inflows that varied between 1 and 364 d, and produced r^2 values that ranged from 0.12 to 0.48.

The difference between the proposed MFL and the baseline conditions in terms of the predicted location of the Km_u (distribution center of the catch-per-unit-effort) for each species was always less than 15%. For species caught in plankton nets, shifts ranged from 0 to 0.5 km; whereas for the larger fish and invertebrates, they ranged from 0 to 0.6 km. In both cases shifts were smallest at the 90th percentile, which reflects the beneficial effects of the MFL's low flow cut-off at 120 cfs. The difference between the location of the 10th and 90th Km_u was used to estimate both the volume of water and area of river bottom in which the organisms were distributed. In order to determine how the habitat available to an organism might shift, the predicted shifts in Km_u were used to predict changes in volume and area that would occur under different flow conditions. Under the District's proposed MFL, only grass shrimp (*Palaemonetes*) and bay anchovies (*Anchoa*) showed predicted decreases in volume and area greater than 15%.

For the seine and trawl data, differences in Km_u were used to predict changes in area and shoreline length (rather than volume). Under the proposed MFL, none of these predicted changes were greater than 15%. The Panel appreciates the District's recognition that a shift in Km_u could affect organisms if they are shifted to areas with less desirable habitat.

The Panel is also impressed with the detailed approach the District has taken with this part of the MFL document. The Peebles (2005) and Matheson et al. (2005) reports provided a wealth of data on fish and invertebrates, and the statistical and graphical analyses were quite thorough. Some of the regression coefficients are very low (i.e., r^2 = 0.1 – 0.2), which is not surprising given that many other factors besides flow can influence organism abundance and distribution in an estuary, including predator-prey relationships and the availability of food and cover, particularly in prime nursery habitats. The Panel is reassured by the collective biotic response to the District's proposed MFL and finds that the MFL is predicted to be protective of numerous species, and not just one indicator species, using sound scientific and statistical methods.

Sessile habitat

Bottom Area-- The LAMFE model was used to predict changes in salinity under different flow scenarios and the results for each case were used to produce cumulative distribution functions for the amount of bottom area and river volume that would be exposed to different salinity ranges (< 1, < 6, and <15 psu), which were compared to baseline conditions. The proposed MFL (with the low flow cut-off) did not change the amount of bottom area or volume in any salinity range by more than 15%. Upon the request of the Panel, these results were broken down further by the District to evaluate the interval within each salinity range (1-6, 6-15 psu) and in each case the difference between the proposed MFL and the baseline condition, in terms of both bottom area and volume, was far less than 15%.

Isohaline Location-- Regression models developed by Janicki Environmental to predict the location of the 0.5, 2, 4, 11, and 18 psu surface isohalines were used to determine how the different flow scenarios would affect the location of each isohaline, the length of total shoreline upstream of each isohaline, and the length of classified wetlands along the shoreline upstream of each isohaline. These scenarios were run for both the whole year and the springtime dry season, since the latter period would be the maximum salinities to which salt-sensitive plants might be exposed. For the whole year, the 19% withdrawal rate changed the locations of the isohalines by 0.3 – 0.7 km (Table 8-27), which did not change the length of total shoreline by more than 15%. It did, however, cause larger decreases in the length of wetland shoreline upstream of both the 2 and 4 psu isohalines. At the Panel's request, these results were broken down further by the District to evaluate the amount of shoreline available between the specified isohalines. In the 15 – 20% withdrawal scenarios, the distance between the 2 and 4 psu isohalines were changed by only 0 to 0.1 km; nevertheless, the change in location translated to a reduced amount of shoreline associated with this interval. Specifically, the interval between 2 and 4 psu was reduced 26% under the 20 % withdrawal scenario, whereas the other intervals increased in length. Data on wetland shoreline were not given, but presumably this would decrease as well between 2 and 4 psu, and the lower salinity range (0.5 – 2 psu) would be expanded. The District did not address any biotic threshold problems with this slight change in the estuary's salinity gradient.

For the dry spring season, the location of the isohalines under baseline conditions was already shifted upstream (0.9 – 1.4 km) in comparison to their median locations for the whole year. Applying the proposed MFL (with the low flow cut-off) changed them only slightly (an additional shift of 0.1 – 0.2 km). Neither the length of total shoreline nor the length of wetland shoreline was reduced by more than 15% when compared to baseline dry season conditions. Part of this is due to the fact that the isohalines are already shifted upstream past that portion of the shoreline with the most vegetated wetland habitats. This can affect nursery habitats for juvenile fish and shrimp that use these wetland areas for food and cover. Moreover, the increasing salinities bring with them more marine conditions, including the invasion of marine predators, parasites and disease organisms (Overstreet 1978 and Overstreet et al. 1977). To the Panel, this means that it is possible that wetland shoreline losses, though small (< 15%), could have a larger impact than expected. Potentially, the District's proposed low-flow limit in the MFL will help mitigate, but can not protect, these young organisms from natural drought during their peak seasonal utilization of estuarine nursery habitats in the springtime.

Oyster Zone – The District used the location of oyster reefs (river kilometers 1 to 4), as mapped by Mote Marine Lab, coupled with analysis of optimal salinities for oysters, defined as 12 to 25 psu. Simulations with the LAMFE model predicted how various flow scenarios might affect surface/intertidal (0.1 to -1.0 m) salinities between river kilometers 1.7 and 3.8. Salinities at these locations ranged from near 0 to 33 psu (seawater = 35 psu), and the proposed MFL did not cause any noticeable change.

Other Indicators – There is information in the main body of the District's report detailing how LAMFE model predictions were used to evaluate potential changes in both benthic macroinvertebrates and mollusks, but these results were not included in the MFL analysis.

<u>The District's Proposed MFL</u>

The District has put together an impressive amount of information about the Lower Alafia River, both in terms of field data collection, empirical analyses and simulation modeling. Taken together, the Panel finds that the District's overall approach is reasonable and scientifically sound. The report provides physical, chemical and biological support for the District's proposed MFL, which allows for water supply withdrawals up to 19% of streamflow in the Lower Alafia River with a 120 cfs low flow cut-off of diversions. As a policy decision that has been employed in other MFL efforts, the District set 15% loss of ecological resources as the limit beyond which "significant harm" was likely to occur. When the proposed MFL was applied to the Lower Alafia River, it did not allow water supply operations to cause more than a 15% change in the large majority of key measures and living resources considered. The low flow cut-off is critically important to the success of the MFL, as is demonstrated by the fact that so many of the negative impacts were ameliorated by adding the low flow limit to the proposed MFL, including the thresholds for plankton blooms and low DO (hypoxia) stress on most aquatic organisms of interest.

There is also the larger issue of freshwater inflows to Hillsborough Bay, a secondary bay of the Tampa Bay complex most often containing mesohaline water and exhibiting estuarine function. The Alafia River has the second largest contributing watershed in the entire Tampa Bay watershed and is characterized as having a mean average streamflow of 433 cfs (Table 2-3, SWFWMD 2007). The District's evaluation of water supply withdrawals made under the proposed MFL rule indicates that the withdrawals will constitute only an average 5.8% of total bay inflow (Table 8-45, SWFWMD 2007), 6.7% if direct precipitation on the bay is not included. The Panel agrees that this low percentage is not likely to produce any "significant harm" to the bay's ecological health and productivity.

The proposed MFL will allow the amount of water supply drawn from the river to double over current withdrawals, if not the existing permits. At present, existing withdrawals average 34.6 cfs, which represents 7.8% of the total freshwater inflow to the Lower Alafia; whereas, under the proposed MFL (with unlimited diversion capacity), the amount available averages 66.6 cfs, or 15.1% of the total inflow (based on mean average inflows during the baseline period).

As the District moves forward to supply water in the future to the people, their economy and their environment, the Panel highly recommends that the District continue to monitor the Lower Alafia River for the purpose of verifying that the MFL is having its intended effect; that it is adequately protective of ecological health and productivity in this estuarine area of the Tampa Bay complex. The verification monitoring should include streamflows, tidal flows, basic water quality, salinity, DO, chlorophyll, comb jellies, mysid shrimp and red drum, particularly during the dry season, which coincides with the spring peak utilization of nursery habitats in the Lower Alafia River by estuarine-dependent species.

The Panel also recognizes that some studies continue and more data (e.g., plankton surveys, fish and invertebrate surveys, water quality samples) are being collected that were not possible to include in the District's MFL analysis. The principle of adaptive management suggests that it would be useful for the District to revisit this topic periodically, as enough new data become available. And finally, the Panel believes that the District recognizes the fact that, although inflows may be sufficient, living estuarine resources may still suffer at times due to stresses associated with other environmental perturbations (i.e., ammonia or phosphate concentrations) and pollutants (i.e., urban runoff). Therefore, the MFL is geared towards ensuring that the resources are not harmed due to low flow.

Other Comments

The District is to be commended for their thorough response to the questions raised by the Panel Members after their initial reading of the District's draft report. There are a number of items in the District's response that could be useful and informative to readers if they were included in the District's final report. These are given below for the District's consideration and potential inclusion:

1. The information in Table R-1, showing the existing permitted withdrawals in relation to the proposed MFL. Figures R-1 and R-2 are also helpful informative.

2. A presentation of nutrient input from the springs and the relative importance of dissolved inorganic nitrogen (DIN) from Buckhorn Spring to the riverine ecosystem's productivity. Additional information, particularly during the dry season, should be included if it is in the best available data compiled by the District on this riverine estuary

3. Information on nutrient loading in relation to flow. Even though nutrient loading is usually driven by flow, especially during pulsed-events from storm runoff, a

graph of load vs. flow, or effective loading rate (mass load divided by hydraulic residence time) versus flow, would be more useful than Figure R-4.

4. Information on bottom area and shoreline length between isohalines that were presented in Tables R-4, R-5 and R-6).

5. Appendix 4-B introduces a new term ("transient") into the discussion of "pulse residence time" (Miller and McPherson 1991), which could be eliminated because the fact that particles can move back and forth before exiting the estuary's lower boundary and escaping into the bay does not affect the amount of time it takes them to leave an area like the level of inflows does. The report could also include a discussion of the fact that chlorophyll concentration represents a biological response to the interaction between the availability of nutrients to fuel phytoplankton growth and the matter of whether the water mass stays in a particular place long enough for the phytoplankton to respond.

6. An Appendix showing the plots presented by Peebles (2005) and Matheson et al. (2005) for the indicator species used in the MFL would be helpful, since they are so important in the District's MFL analysis.

REFERENCES

Alber, M. 2002. A Conceptual Model of Estuarine Inflow Management. *Estuaries* 25: 1246-1261.

Ardisson, P.-L. and E. Bourget. 1997. A study of the relationship between freshwater runoff and benthos abundance: a scale-oriented approach. *Estuarine, Coastal and Shelf Science* **45**: 535-545.

Drinkwater, K. F. and K. T. Frank. 1994. Effects of river regulation and diversion on marine fish and invertebrates. *Aquatic Conservation: Freshwater and Marine Ecosystems* **4**: 135-151.

Flannery, M. S., E. B. Peebles and R. T. Montgomery. 2002. A percentage-of-streamflow approach for managing reductions of freshwater inflows from unimpounded rivers to southwest Florida estuaries. *Estuaries* **25**: 1318-1332.

Longley, William L., (ed.) et al. 1994. Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, TX. 386 pp.

MacDonald, T.C., M.F.D. Greenwood, R.E. Matheson, Jr., S.F. Keenan, C.D. Bradshaw, and R.H. McMichael, Jr. 2007. Assessment of relationships between freshwater inflow and populations of fish and selected macroinvertebrates in the Little Manatee River, Florida. Florida Fish and Wildlife Conservation Commission, St. Petersburg, FL. 335 pp.

Matheson, R.E., Jr., M.F.D. Greenwood, T.C. MacDonald, and R.H. McMichael, Jr. 2005. Assessment of relationships between freshwater inflow and populations of fish and selected macroinvertebrates in the lower Alafia River, Florida. Florida Fish and Wildlife Conservation Commission, St. Petersburg, FL. 382 pp.

Miller, R. L. and B. F. McPherson. 1991. Estimating estuarine flushing and residence times in Charlotte Harbor, Florida, via salt balance and a box model. *Limnology and Oceanography* **36**: 602-612.

Overstreet, R. M., and H. D. Howse. 1977. Some Parasites and Diseases of Estuarine Fishes in Polluted Habitats of Mississippi. Annals of the New York Academy of Sciences, **298**: 427-462.

Overstreet, R. M. 1978. Marine Maladies: Worms, Germs, and Other Symbionts From the Northern Gulf of Mexico. Mississippi-Alabama Sea Grant Consortium, MASGP-78-021, 140 pp.

Peebles, E.B. 2005. An analysis of freshwater inflow effects on the early stages of fish and their invertebrate prey in the Alafia River Estuary. University of South Florida, St. Petersburg, FL. 77 pp. + Appendices 60 pp.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks and J. C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. *BioScience* **47**: 769-784.

Richter, B. D., J. V. Baumgartner, R. Wigington and D. P. Braun. 1997. How much water does a river need? *Freshwater Biology* **37**: 231-249.

Sklar, F. H. and J. A. Browder. 1998. Coastal environmental impacts brought about by alterations to freshwater flow in the Gulf of Mexico. *Environmental Management* **22**: 547-562.

Southwest Florida Water Management District (Anon.). 2007. The Determination of Minimum Flows for the Lower Alafia River Estuary. Prepared by the Southwest Florida Water Management District, Brooksville, FL. 391 pp. + Appendices 255 pp.

Appendix 1B

Response of the District to Questions

from the Scientific Peer Review Panel

For

The Determination of Minimum Flows for the Lower Alafia River Estuary

Appendix 1B

Response of the District to Questions

from the Scientific Peer Review Panel

For

The Determination of Minimum Flows for the Lower Alafia River Estuary

From the District **Responses to questions from Dr. Alber are provided in Arial font below. References to Tables and Figures in the Lower Alafia Minimum Flows report are cited by their numbers in that report. Tables and Figures presented in this response are given the prefix R. Documents cited in this response are listed in the Literature Cited section of the minimum flows report.**

Scientific Review of Draft Document, "The Determination of Minimum Flows and Levels for the Lower Alafia River Estuary"

Submitted by: Merryl Alber Dept. of Marine Sciences, Univ. of Georgia

October 31, 2007

This draft document, written by the Southwest Florida Water Management District, proposes a Minimum Flow for the Lower Alafia River Estuary. The report describes the physical, chemical, and biological characteristics of the estuary and presents information on the relationships between these characteristics and freshwater inflow. These relationships are then used to evaluate how reducing inflow would affect different aspects of the estuary.

The proposed MFL was identified based on the following procedure: 1) Regressions were developed between inflow and abundance of a suite of fish and invertebrates based on empirical analyses of samples collected in the Lower Alafia (via both plankton tows and seine and trawl samples). 2) Daily inflows to the estuary were calculated for the baseline period of 1987 – 2003, given different withdrawal scenarios (with and without a minimum threshold). 3) The regression equations were used to predict abundance under the various withdrawal schedules based on the calculated daily inflows associated with each scenario. 4) Predicted abundances were used to construct a cumulative distribution function for the suite of organisms under consideration for each scenario. 5) The predicted cumulative distribution functions of organism abundance were compared to CDFs under baseline conditions to determine the % change in each percentile. A criteria of no more than a 15% change in any percentile of abundance as compared to baseline was used as the threshold for "significant harm."

The proposed minimum flow for the Lower Alafia is a 19% reduction of inflow to the upper estuary (calculated as the sum of the estimated flow at Bell Shoals Rd. plus that at Buckhorn Springs), with a low-flow threshold of 120 cfs. This scenario was shown to keep the predicted changes in abundance of all species to less than 15%. The analysis focused on the abundance of mysid shrimp and juvenile red drum associated with each scenario, as these emerged as being particularly sensitive to changes in inflow. They are also key species in the estuary (mysid shrimp as an important food source for larval fish; red drum as an economically important game fish).

The report then goes on to consider the effect of the proposed MFL on numerous other indicators of estuarine condition (i.e. abundance and distribution of other fish and invertebrates, dissolved oxygen concentration, chlorophyll concentration and the location of peak chlorophyll, location of isohalines and their relationship to both wetland habitat and bottom area). In each case, the steps outlined above were followed, except that the relationships between inflow and the characteristic in question were not always regressions and the predicted changes associated with different inflow scenarios were sometimes obtained by modeling. The report concludes that applying the proposed MFL would be protective of these other characteristics as well, as they all proved less sensitive to changes in inflow than mysid shrimp and juvenile red drum.

The District has done a thorough job with this document. The report provides a complete picture of the lower Alafia River, and their overall analytical approach is sound. I have reviewed the draft document and provide a detailed response below. My comments are divided into 4 sections: general and then more specific issues I would like to see addressed/clarified to aid in the final assessment of the MFL, followed by editorial suggestions for improving the document and a list of typographical errors.

1. General questions

1. Flow

a. What are the historical changes in either land use or dredging that may have altered flow patterns? Did these alterations occur before the baseline period? (for example, the lower 1.4 km of the channel is dredged to a depth of 5-6—when did this occur, and how often is it re-dredged). When was the shoreline modified? Are there other structural alterations that should be considered?

Alterations to the mouth of the river and the initial dredging of the barge turning basin were completed by the 1930s. Maintenance dredging of the turning basin is performed approximately every 10 years to remove sediments and keep the turning basin close to its original design depth. These changes, which all occur within the first kilometer of the river, have had no effect on the volume of freshwater inflow to the lower Alafia River. However, they have had a major effect on tidal water exchange, salinity, and flushing near river mouth, which are manifested to some extent upstream.

Modifications to the shoreline of the lower river in Gibsonton and Riverview are longstanding, with most changes (e.g., fill) occurring by the 1960s and 1970s. Further upstream, the watershed of the Alafia is continuing to experience land use changes with increasing urbanization. The most notable historical physical change in the watershed, however, has been the large amount of phosphate mining, much of which was done before the 1980s. The standards and methods for reclamation of phosphate lands have changed over the years, and the cumulative physical effects of phosphate mining on streamflow has been the source of discussion in the region (pages 2-40 to 2-56 in the minimum flows report for the freshwater reach of the Alafia River (SWFWMD 2005b).

In determining minimum flows, Florida Statutes (373.042 (1a)) direct the Districts to "consider changes or 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 an 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."

In keeping with this legislative directive, the District established MFLs for the Lower Alafia River based on its current physical configuration. A baseline period of 1987-2003 was used in the minimum flows analysis to simulate the effect of potential withdrawals on the flow regime of the river. As described on pages 2-38 to 2-40 of the report, earlier years were not included in the baseline period because low flows in the river had been substantially augmented by excess water coming from the mining industry. Also, 1987 was when flow records from Buckhorn

Springs began. Trend analyses of long-term and recent (post-1979) streamflow data presented in the report indicate that the effects of these anthropogenic factors have subsided, and this baseline period suitably represents the current flow regime of the river given the existing physical modifications to the watershed.

b. It makes sense to use the gaged flows as the basis to set the regulation, but just to be clear, did the baseline data used in the analysis include ungaged flow?

All regression analyses (including salinity, logistic regressions of DO and chlorophyll a, fishes and invertebrates) used the same inflow term, which was the flow at Bell Shoals Road plus flow from Buckhorn Springs. With the exception of a small watershed ratio factor (1.117) applied to the Alafia River at Lithia streamflow gage, these are gaged flows. The report concluded it was most practical and scientifically sound to base the minimum flow rule on this flow term.

Ungaged flows are included simulations that employed the LAMFE model, which was used to assess changes in the area and volume of specified salinity zones as a result of potential flow reductions. However, these flow reductions were calculated as percentages of the gaged inflow term described above (which were calculated for each day) and applied in the model with the ungaged flows left unaltered. In this manner, simulations to assess salinity changes were conducted using the total flow regime of the lower river, but allowable percent flow reductions were evaluated as percentages of the gaged flow term.

c. How do the current flow conditions compare with the baseline flow and the various flow scenarios assessed in the report? I recognize that Tampa Bay Water is permitted for up to 10% withdrawal, but what proportion of the total freshwater inflow (as calculated for the baseline flow modeling) do they actually take, in combination with Mosaic Fertilizer?

Since the actual withdrawals by Tampa Bay Water began in 2003, it is most informative to simulate the flows would have resulted had Tampa Bay Water's withdrawals been in effect during the entire baseline period. This is referred to as the maximum permitted scenario, which is portrayed for 1999-2003 in Figure 2-18 (page 2-19). Mosaic Fertilizer's withdrawals are also included in this scenario. It is reiterated that Tampa Bay Water may take 10% of daily flow at Bell Shoals Road, but they must cease withdrawals when flows at Bell Shoals are below 124 cfs, and they are restricted to a diversion capacity of 60 mgd (93 cfs). Mosaic Fertilizer withdrawals approximately 7.5 cfs from Lithia Springs on a generally continuous basis without the restrictions of a low-flow cutoff.

Average withdrawals for the maximum permitted scenario are listed in the bottom row of Table R1 below, which is adapted Table 8-44 in the report. These withdrawals average 34.6 cfs, equal to 7.8% percent of the average total inflow to the lower river, compared to 15.1 % of the average total inflow represented by the proposed minimum flows with an unlimited withdrawal capacity. The larger quantity under the minimum flow scenario is due to the larger percent withdrawal limit (19% vs. 10%) and the simulation of an unlimited diversion capacity.

- go to next page -

Table R1. Mean flows for sources of freshwater inflow to the Lower Alafia River for the period 1987 – 2003 (adapted from Table 8-44)		
Source	**Mean flow (cfs)**	**Percent of Total flow**
Gaged flow	287.1	64.9%
Lithia Springs	39.5	8.9%
Buckhorn Springs	12.9	2.9%
Ungaged Flow	102.6	23.2%
Total inflow	442.1	100.0%
Withdrawals, 19%, 120 cfs low flow Unlimited diversion capacity	66.6	15.1%
Existing permitted withdrawals to Tampa Bay Water and Mosaic Fertilizer.	**34.6**	**7.8%**

A hydrograph of monthly baseline flows and flows reduced by the 19% minimum flow and the maximum permitted scenarios are shown in Figure R1 below. For greater visual clarity, the pumpage amounts with the 19% minimum flow and the maximum permitted scenarios are shown in Figure R2 on the following page. The larger withdrawal quantities for the minimum flow scenario are apparent during most months. However, the lower withdrawal quantities for the minimum flow scenario during very dry months are due to implementation of the 120 cfs low flow threshold, since a low-flow threshold is not applied to Mosaic Fertilizer in the maximum permitted scenario.

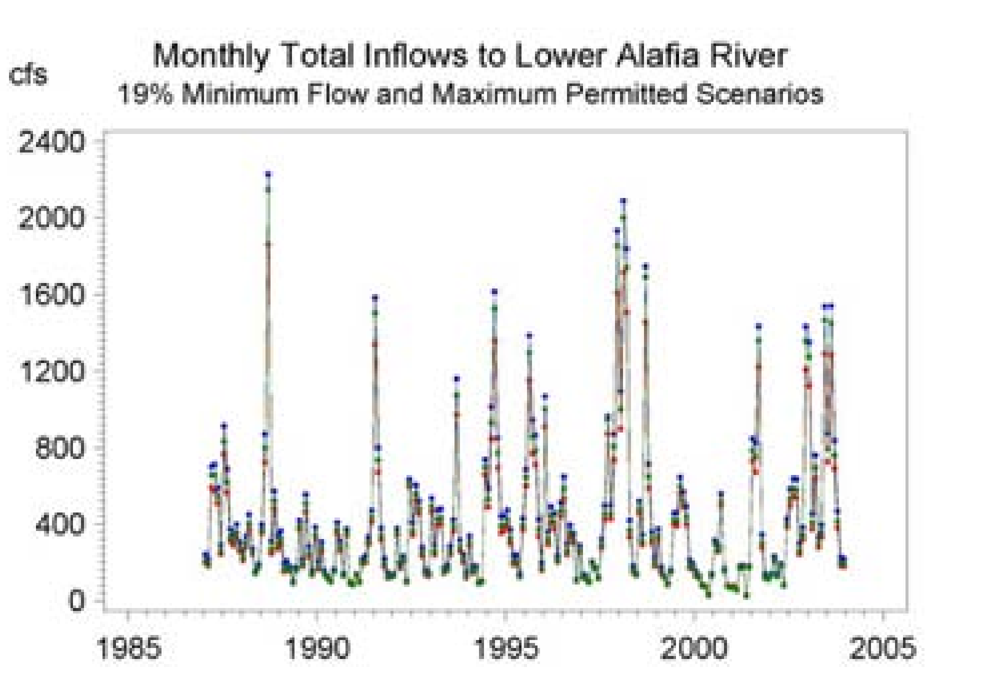

Figure R1. Monthly flows for the baseline (blue), minimum flow (red) and maximum permitted (green) scenarios.

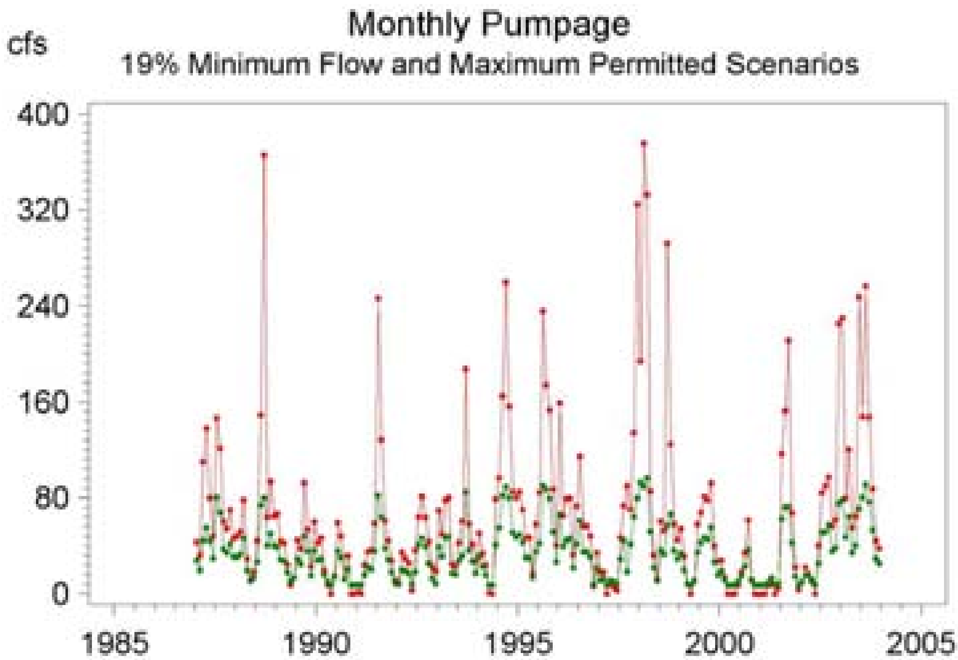

Figure R2. Monthly withdrawals for the minimum flow (red) and maximum permitted (green) scenarios.

2. Nutrients

a. Water quality data for the springs would be helpful (particularly the relative importance of NO_3 during the dry season). How would including this affect/explain the observations of DIN distribution in the river? Would an additional source of DIN help explain the patterns of chlorophyll? This comes up in several places: For example p. 5-57, 3rd paragraph assumes only input is upstream so an additional input might affect the dilution curves, p. 5-59 2nd paragraph talks about N-loading to the system but doesn't mention groundwater, p. 5-59 3rd paragraph, how is DIN in the lower river affected by GW, 7-4 2nd and 3rd paragraph – what proportion of both flow and DIN comes in with the creeks during the dry season?

Water Quality data for Lithia and Buckhorn Springs are available from District sampling programs which are conducted on a roughly a bi-monthly basis. Summary statistics for both springs for the period 1991- 2003 are listed in Table R2. Both springs are highly enriched with inorganic nitrogen, with nearly all of this comprised by nitrate. Nitrate nitrogen values averaged 2.96 mg/l N in Lithia Springs. Both springs are not nearly as phosphorus enriched as the river - compare mean total phosphorus concentrations of 0.09 and 0.08 mg/l for the springs to a mean total P concentration of 1.39 mg/l for the river at Bell Shoals on page 5-51 of the report.

Table R2. Water Quality Statistics for Litha and Buckhorn Springs during 1991- 2003 with values for springflow and DIN loadings in kilograms per day.

Lithia Springs						
Variable	**Units**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Springflow	cfs	78	33.9	11.9	11.2	64.5
Water Temperature	^{0}C	94	25.1	0.7	23.8	29.1
PH	pH	94	7.4	0.1	7.0	7.8
Specifc Conductance	µs/cm	98	487	38	400	563
Nitrate N	mg/l	77	2.96	0.50	1.70	4.36
Ammonia N	mg/l	93	0.01	0.01	0.01	0.10
Dissovled Inorganic N	mg/l	75	3.00	0.48	1.80	4.37
Ortho Phosphorus	mg/l	91	0.06	0.01	0.03	0.13
Total Phosphorus	mg/l	88	0.09	0.12	0.04	0.80
DIN Load	Kg/Day	69	251	97	59	492
Buckhorn Springs						
Variable	**Units**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**
Springflow	cfs	78	12.8	1.9	9.3	18.0
Water Temperature	^{0}C	85	24.7	1.0	22.5	29.7
PH	pH	85	7.5	0.1	7.3	7.6
Specifc Conductance	µs/cm	89	468	23	365	527
Nitrate N	mg/l	78	2.03	0.38	1.11	3.73
Ammonia N	mg/l	86	0.02	0.03	0.01	0.12
Dissovled Inorganic N	mg/l	76	2.06	0.38	1.21	3.74
Ortho Phosphorus	mg/l	83	0.05	0.04	0.02	0.35
Total Phosphorus	mg/l	81	0.08	0.13	0.03	1.11
DIN Load	Kg/Day	70	65	16	31	104

With regard to river chemistry and the questions posed above, it is useful to describe the effects of the two springs separately. Lithia Springs flow into the river above Bell Shoals Road. Though not shown here, nitrate concentrations in Lithia Springs showed no relationship rate with springflow (Pearson product moment correlation $r = -.03$, $p < .80$), and the mean nitrate concentration in the spring dry season (March – June) was nearly identical to the yearly mean.

Nitrate concentrations in the river at Bell Shoals Road average about 2 mg/l during low flows (Figure 5-49C), when discharge from Lithia Springs comprises the highest percentage of flow at that location. Since nitrate concentrations in the river at Bell Shoals during dry periods are less than concentrations in Lithia Springs, the other baseflow the river receives must have lower DIN concentrations that the spring discharge. Nitrate concentrations at Bell Shoals Road are negatively correlated with flow (Figure 5-49), indicating that during wet periods, inputs of nitrogen-rich flow from Lithia Springs are diluted even further by stormwater runoff. Regardless, nutrient inputs from the springs are reflected in the water chemistry of the river at Bell Shoals, so the data presented for the Bell Shoals site in the report include the effects of Lithia Springs on nitrogen concentrations and dilution curves in the upper part of the estuary.

Buckhorn Springs is a different story, as it enters the river via Buckhorn Creek about 5 kilometers downstream of Bell Shoals at kilometer 12.3. As Dr. Alber suggests, nutrient concentrations and inputs from Buckhorn Springs are important to the lower river and should have been discussed in the report. Buckhorn Springs is also nitrogen enriched, averaging 2.03 mg/l nitrate nitrogen. There was a slight, positive relationship between nitrate concentration and flow in Buckhorn Springs ($r = .20$, $p < 0.09$). However, as described in Chapter 2 of the report, flows from Buckhorn Springs have very little seasonal variation, averaging 12.7 cfs.

It is likely that nitrate rich flows from Buckhorn Springs contribute to high DIN concentrations in the upper part of the estuary, especially during low flows when spring discharges comprise a high proportion of total river flow and long residence times allow phytoplankton blooms to develop in the upper estuary. This would influence the dilution and uptake curves presented in Figures 5-54 and 5-55, with inputs at Km 12.3 possibly contributing to the high observed DIN concentrations frequently observed in waters of near 5 to 8 psu salinity.

With regard to the last part of the question 2a, Lithia Springs on average contributes 25% of the inflow to the upper river during the spring dry season from April 15 through June 15, while Buckhorn Springs contributes an average of 12% of inflow. Percentages of daily flow, however, can vary considerably depending on the occurrence of rainfall events in the dry season. Percentile values of the percentage of inflow to the upper estuary represented by Lithia and Buckhorn Springs during the dry season are listed in Table R3. The proportion of DIN loading comprised by the two spring systems is discussed in response to question c. 6-8.

Tables R2 and R3 and a discussion of the water quality of discharge from the springs will be presented in the final report, along with material pertaining to nutrient loading presented in the response to questions c. 6-7 and 6-8 below.

Table R3. Percentile values of percent of inflow to the upper estuary comprised by flows from Lithia and Buckhorn Springs during the spring dry season (April 15 – June 15) in the baseline period.

	Percentile						
	Min	**10th**	**25th**	**50th**	**75th**	**90th**	**Max**
% Lithia Springs	2%	12%	19%	25%	30%	37%	52%
% Buckhorn Sp.	1%	5%	7%	10%	14%	20%	43%

b. 6-7 The document refers to nutrient loads, but they have not been presented. This would be useful to see, because the information we have only shows that DIN concentrations decrease during high flows (fig. 5-49) so increased flow dilutes input at Bell Shoals Rd. Load may still be higher but it needs to be presented since the argument is couched this way.

See reply to next question

c. 6-8 There's no info. presented on seasonality of nutrient inflow—do the highest DIN concentrations occur during low flow?

A record of estimated daily nutrient loadings of DIN in kilograms per day (kg/day) were calculated at Bell Shoals Road for the minimum flows project, but were not presented in the report. Nutrient loads were calculated by developing a regression between DIN concentrations and flow at Bell Shoals for the 1999-2003 period, then multiplying those concentrations by daily flow record to yield daily loads. The relationship of DIN with flow at Bell shoals Road is shown in Figure R3.. Based on a tendency for the regression to overpredict DIN concentrations at low flows, a DIN concentration of 2 mg/l was assigned to all flows below 35 cfs (ln transformed value of 3.6), a flow rate that has been exceeded 98 percent of the time during the baseline period. Also, the regression was not used to predict DIN concentrations above a flow rate of 2440 cfs (ln transformed value of 7.8), above which a DIN concentration of 0.2 mg/l was assigned.

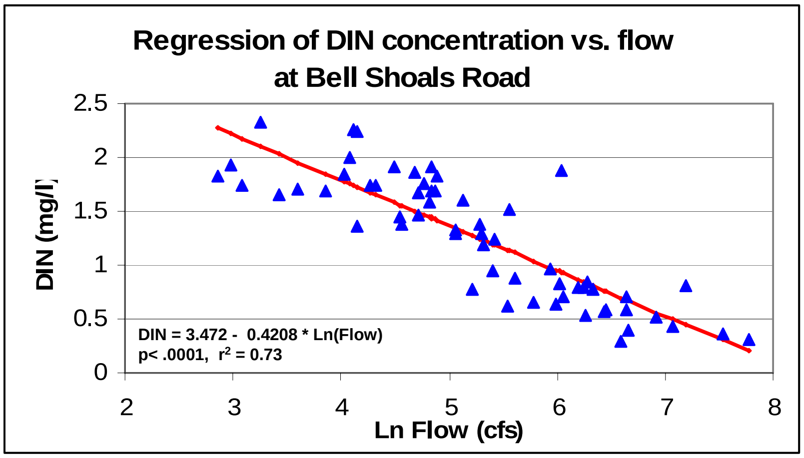

Figure R3. Relationship of DIN and Streamflow at Bell Shoals Road with fitted regression.

The average rate of DIN loading at Bell Shoals Rd. is 686 kilograms per day. This corresponds to an areal flux rate of about 2.6 kg per hectare per day from the watershed upstream of this location. A plot of the average monthly values for percent of total yearly DIN load at Bell Shoals Road is presented in Figure R4, with similar values included for monthly streamflow. As expected, the monthly pattern of DIN loading follows the pattern of monthly streamflow. Since streamflow varies much more than nutrient concentrations, large variations in streamflow are the dominant factor controlling nutrient loading. However, since DIN concentrations in the river are highest at low flows, the proportion of yearly DIN loading is higher than the proportion of yearly streamflow in the dry season, with the maximum differences occurring in April and May. In the late summer there is a higher proportion of flow relative to load due to nitrate concentrations being lower in the river during high flows.

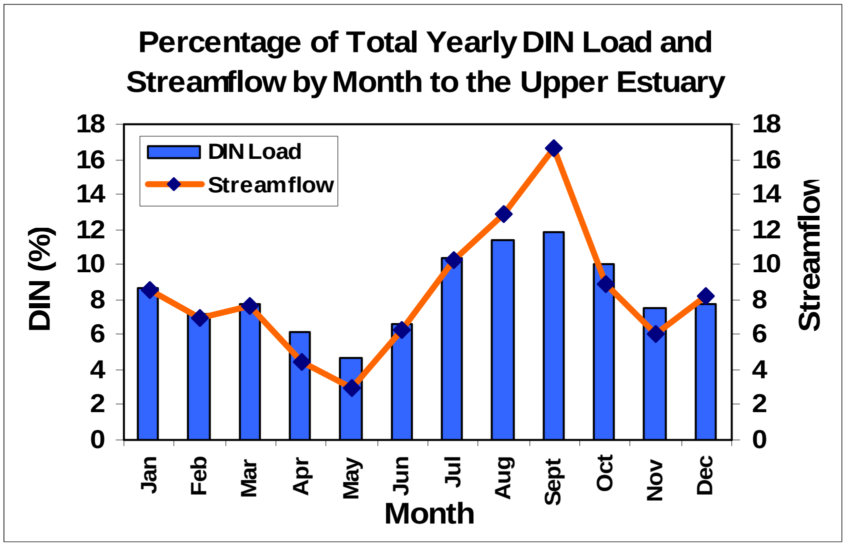

Figure R4. Proportion of total yearly DIN loading and total yearly streamflow by month, based on average monthly loading and streamflow rates.

Daily DIN loadings were also calculated for Lithia and Buckhorn Springs in response to peer review of the report. Mean values for DIN loading were presented in Table R2 on page 6. The average DIN loading rate for Lithia Springs is 251 kg/day, while the average DIN loading rate for Buckhorn Springs is 65 kg/day. Since water quality monitoring form the springs is largely bi-monthly, with data missing for certain months, there was no attempt to estimate a daily record of nutrient loadings from the springs. Instead, average DIN loads in kg/day were calculated for individual months during the 1991 – 2003 period assuming the flow and concentration on the sampling day was characteristic of that month

Plots of average monthly loads at Bell Shoals Road are overlain with loadings from Lithia and Buckhorn Springs in Figures R5 and R7. It is reiterated that the loads from Lithia Springs are included in the loads at Bell Shoals, so Figure R5 illustrates the proportion of load at Bell Shoals comprised by Lithia Springs on those months when loads from Lithia Springs were calculated. Due in part to the high nitrate concentrations in Lithia Springs, loading from the springs comprises a high proportion of the DIN at Bell Shoals during low flows.

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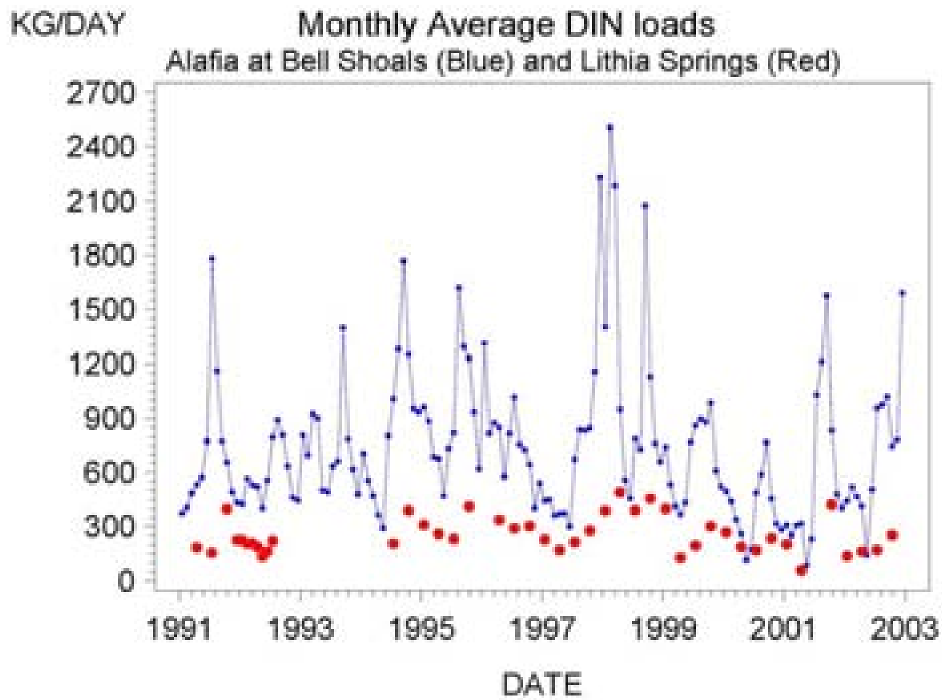


Figure R5. **Monthly nutrient loading at Bell Shoals Road (blue) and from Lithia Springs (red) for 1991-2003.**

This relationship is also shown below in Figure R6 where the percent of average monthly DIN loads at Bell Shoals comprised by the DIN loads from Lithia Spring are plotted separately vs. monthly loads and flows at Bell Shoals Road. The percent load at Bell Shoals comprised by Lithia Springs is frequently in the range of 30 to 60 percent when flows at Bell Shoals are less than 400 cfs, and can range as high as near 70 percent during very low flows.

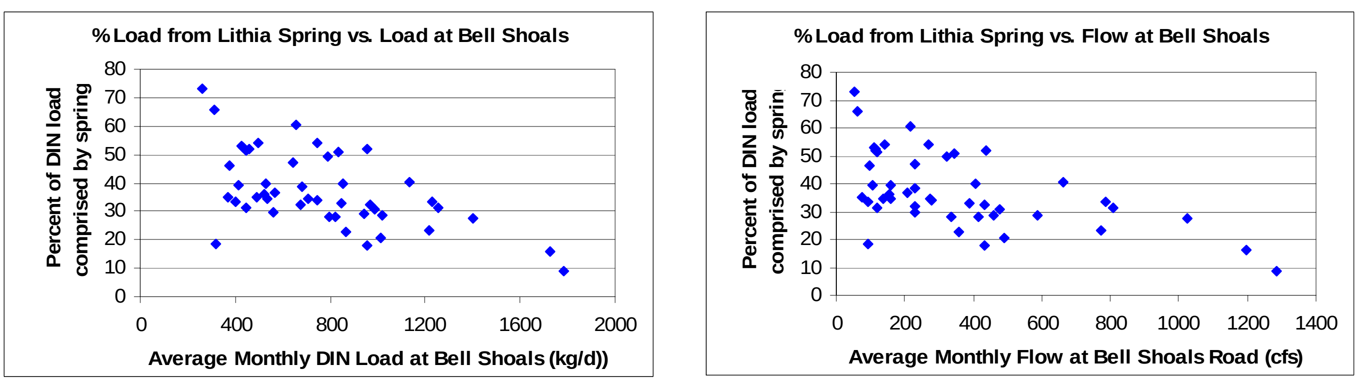


Figure R6. **Percent of average monthly DIN loads at Bell Shoals comprised of DIN loads provided by Lithia Springs vs. average monthly DIN loads and flows at Bell Shoals.**

Dissolved inorganic nitrogen loads from Buckhorn Springs are additive, in that they are not included in the load at Bell Shoals. A plot of average monthly loads at Bell Shoals is overlain with monthly loads from Buckhorn Springs in Figure R7. Because of its lower rate of flow and lower DIN concentrations, loads from Buckhorn Springs comprise much smaller fractions of loads than do loads from Lithia Springs.

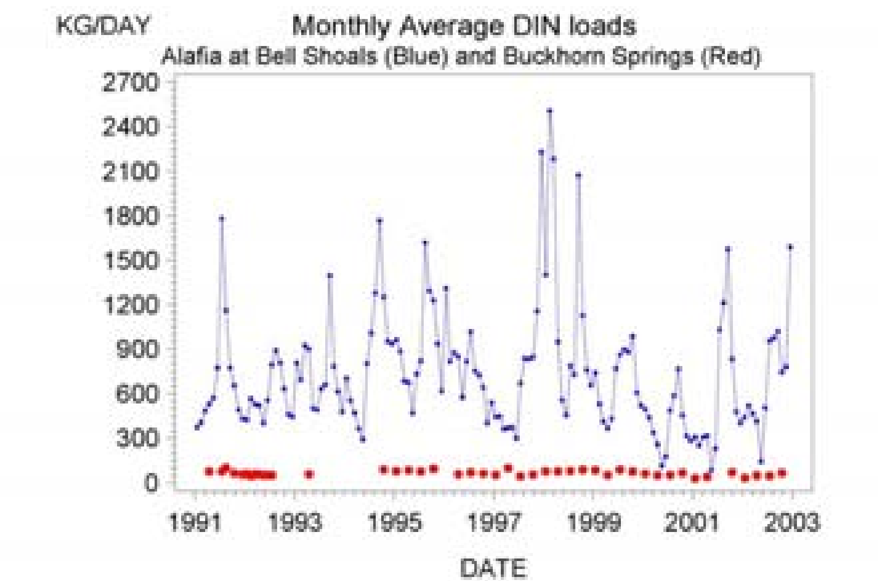
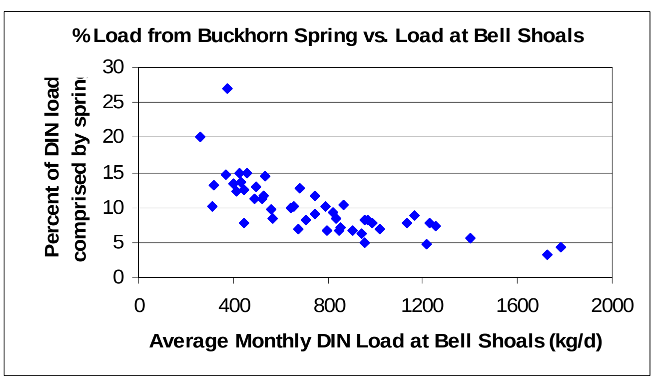


Figure R7. Monthly nutrient loads at Bell Shoals Road (blue) and from Buckhorn Springs (red) for 1991-2003.

The percent of average monthly DIN loads at Bell Shoals represented by the DIN loads from Buckhorn Springs are plotted separately vs. average monthly loads and flows at Bell Shoals Road in Figure R8. Loads from Buckhorn Springs are frequently equivalent to between 5 to 15 percent of the DIN loads at Bell Shoals, sometimes reaching as high as 27 percent during very low flows.



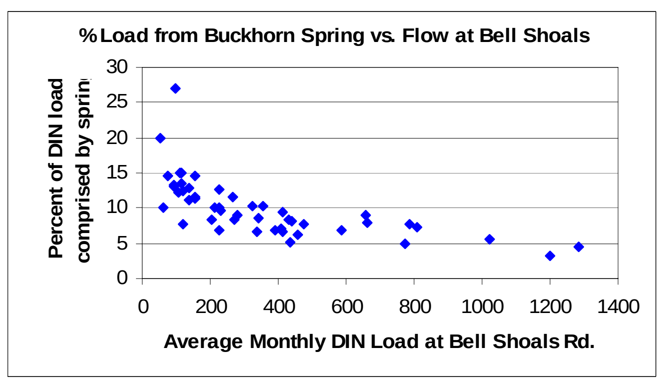


Figure R8. Percent of monthly DIN loads at Bell Shoals represented by loads from Buckhorn Springs vs. monthly DIN loads and flows at Bell Shoals

3. Fish and Invertebrates

a. The Matheson report uses a limit number of specified antecedent flow periods for regressions: 7, 14, 30, 45, 60, 90, 180, 365 d – but the regressions in the MFL used variable flow-averaging periods (Table (8-1). Were the regressions redone for the MFL analysis?

Table 1 in Appendix 12 of the Matheson et al. report lists the best-fit regressions for seine and trawl abundance (catch-per-unit-effort) using the flow term on which the minimum flow rule is based (described in question 1.b above). Scatter plots with predicted regressions and confidence limits are also presented in this Appendix. The regressions and preceding-day flow factors presented in Table 8-1 of the District MFL report were taken from Appendix 12 of the Matheson et al. report.

b. In the Peebles report, it says on p. 68 that the regressions were "refined" and it looks like these are the ones used in the MFL document. Does that mean that he used the inflow with 2nd peak in R2 (so looked at reproductive rather than catchability response?)

That is correct.

c. Why aren't the red drum data considered for the dry period? (p. 8-34). Table 8-12 shows that for this portion of the year the populations always have > 15% reduction. Is that a concern?

Section 8.4.5 was inserted to demonstrate that for some species which experience declines in abundance in the river at high flows, flow reductions can still cause declines in abundance during low flows. However, these results must be viewed within the context of the entire season that a species commonly occurs. As described on page 8-30, the percentile abundance values listed in Tables 8-11, 8-12, and 8-13 were calculated for the driest half of the season of occurrence for each species. Thus, the amount of time these percentiles would apply should be divided by two when considering the effects on abundance over the entire season. Also, the baseline abundance values they are compared against do not represent the population of abundance values for each species over the entire season.

The regressions were used to calculate changes in species abundance on a daily basis, since the independent variables were based on the daily flow regime of the river. Though these regressions are useful and important predictive tools, the unlikelyhood of species abundance changing on a daily basis is discussed in the first two paragraphs on page 8-22. Instead, abundance within the seasons that species/life stage is present will be affected by prevailing volumes of freshwater inflow within that season, with abundance gradually changing over time due to changes in freshwater inflow. In this way, the regressions can be used to predict abundance over periods of low, medium, and high flows, acknowledging that changes in flows during a season will affect the overall year class.

The District focus on changes in abundance focused on 15% changes in median abundance over the entire flow record. For some species, including red drum, the percent flow reductions from baseline were less than 15% at high percentiles and greater than 15% at low percentiles (which corresponded to low flows). In the case of red drum, when the 120 cfs low-flow threshold is applied the greater reductions at low flows are offset the lesser reductions at higher percentiles (Table 8-7 and 8-8), which in the case of red drum occur at moderately high flows (Figures 6-32C and 8-3C) . Interpretation of the changes in the different abundance percentiles in this manner is discussed on pages 8-24 and 8-25 to justify the proposed minimum flow.

4. Shoreline/Wetland extent

a.. Is it possible to split out the results into the intervals between the target isohalines analyzed starting on p. 8-48? (now need to get it by subtraction in Table 8-21). It would be nice to know if the 1-6 or 6-15 psu interval were reduced separately. For example, p. 8-50 last paragraph, it might be that reductions in flow don't affect the 6-15 psu interval at all, and it's just a function of including the < 1 psu in the value in the average.

Table 8-21 contained percentile distributions for bottom areas less than 1, 6, and 15 psu, while Table 8-22 presented results for water volumes less than these same salinity values. These results were generated using the LAMFE model for baseline flows and a series of flow reductions, including the proposed 19% minimum flow reduction with a 120 cfs low-flow threshold. In response to this question, results were also generated for areas and volumes between 1 and 6 psu and between 6 and 15 psu for baseline flows and the proposed minimum flows (Tables R4 and R5).

Changes in these salinity intervals are very small compared to baseline conditions. In some cases, there is a small increase in a percentile value for the proposed minimum flow compared to baseline conditions. These should be viewed with caution, especially for the 6-15 psu values, as much of this salinity zone can move past the downstream model boundary at medium-high to high flows. Therefore, flow reductions can cause an apparent increase in the zone as it moves back into the geographic model domain. This can also occur, but less frequently, with the 1 to 6 psu zone. Regardless of model constraints, increased flows can sometimes actually cause reductions in a salinity zone as the zone may compress with increasing flow. These aspects of the salinity zone analysis were discussed on pages 8-48 and 8-49, where it was concluded to total area and volume values less than 1, 6, and 15 psu to be conservative.

Table R4. Percentile values of bottom areas with salinty values between 1 to 6 and 6 to 15 psu. Percentiles presented for baseline flows and flows reducted by the proposed minimum flows. Reductions in bottom areas expressed as percents of the baseline for each percentile value.

			Percentile (area)						
Salinty Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
1 to 6 psu	**Baseline**	**Hectares**	5.5	11.5	13.4	17.1	24.4	29.2	38.6
	19% 120 cfs low flow	**Hectares**	5.0	11.2	13.0	16.5	23.6	28.1	39.7
	Percent of baseline	**% of baseline**	91%	97%	97%	96%	97%	96%	103%

			Percentile (area)						
Salinty Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
6 to 15 psu	**Baseline**	**Hectares**	19.4	24.4	30.2	40.9	51.8	59.0	70.4
	19% 120 cfs low flow	**Hectares**	19.3	24.2	30.3	41.2	53.2	61.8	73.9
	Percent of baseline	**% of baseline**	99.6%	98.8%	100.3%	100.5%	102.7%	104.7%	105.0%

Table R5. Percentile values of water volumes with salinty values between 1 to 6 and 6 to 15 psu. Percentiles presented for baseline flows and flows reducted by the proposed minimum flows. Reductions in water volumes expressed as percent of the baseline for each percentile value.									
			Percentile (volume)						
Salinty Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
1 to 6 psu	**Baseline**	**m^3 x 10^3**	148	290	336	415	536	631	810
	19% 120 cfs low flow	**m^3 x 10^3**	149	291	334	411	530	628	820
	Percent of basline	**% of baseline**	100.6%	100.3%	99.5%	99.0%	98.8%	99.4%	101.3%
			Percentile (volume)						
Salinty Zone	**Flow**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
6 to 15 psu	**Baseline**	**m^3 x 10^3**	364	527	577	699	891	1019	1222
	19% 120 cfs low flow	**m^3 x 10^3**	385	537	591	711	937	1060	1302
	Percent of basline	**% of baseline**	105.8%	101.9%	102.4%	101.7%	105.2%	104.0%	106.5%

b. Similarly, can shoreline intervals (Table 8-23) be presented?

The results in Table 8-23 have been recomputed in Table R6 on the next page to show the distance intervals between the median positions of paired isohalines (e.g., 2 to 4 psu) and the amount of shoreline within those distance intervals. Values are presented for baseline flows and as percent changes in shoreline lengths resulting from a series of flow reductions, including the proposed minimum flows. In some cases, increases in the amount of shoreline between isohalines can result from withdrawals. This is presumably due to the greater upstream migration of the lower salinity isohaline relative to higher salinity isohaline, thus increasing the shoreline within the interval. Though this may seem like a net improvement, flow reductions still result in the upstream movement of each isohaline, thus exposing shoreline plants to a greater amount of salinity.

c. Why did the shoreline section include the dry season response, whereas other parts of the document only looked at change on an annual basis?

Shoreline plant communities are stationary features that do not shift in the river, as do fish populations, chlorophyll *a* concentrations and salinity distributions. For this latter set of ecological variables, impacts to flows are a concern over the entire flow regime as these variables shift within the tidal river. Tables with a range of percentile values were presented to show how changes in these variables were affected by withdrawals over the flow range of the river.

In contrast, critical isohalines are pushed downstream of salt-sensitive plant communities in the wet season (see discussion on page 8-58 of report). Consequently, shifts in isohaline positions in the wet season were not of concern as much as shifts in the dry season, when saline waters are found in the reaches of the river where low-salinity, brackish and freshwater plant communities occur. As discussed in Section 7.6.4, it was concluded that for the assessment to shoreline plant communities, the median position of selected isohalines would be examined for the entire year and for the critical spring dry-season (April 15-June 15).

Table R6 (Adapted from Table 8-23). Results for shoreline quantities between paired isohaline locations for baseline flows and seven flow reductions, including; (1) river kilometers between median values for paired isohaline locations; (2) Meters of toal shoreline between median values of paired isohaline locations, and (3) percent reductions of total shoreline between paired isohaline locations compared to baseline conditions.

Isohaline interval	River kilometers between median values of paired isohaline locations							
	baseline flows	19% minimum flow	Permitted	10% withdrawal	15% withdrawal	20% withdrawl	30% withdrawal	40% withdrawal
0.5 to 2 psu (km)	1.2	1.3	1.2	1.2	1.2	1.3	1.3	1.4
2 to 4 psu (km)	1.6	1.5	1.6	1.6	1.5	1.5	1.5	1.4
4 to 11 psu (km)	3.3	3.4	3.4	3.4	3.4	3.5	3.5	3.6
11 to 18 psu (km)	2.1	2.4	2.3	2.3	2.3	2.4	2.5	2.6

Isohaline interval	Meters of total shoreline between median values of paired isohaline locations							
	baseline flows	19% minimum flow	Permitted	10% withdrawal	15% withdrawal	20% withdrawl	30% withdrawal	40% withdrawal
0.5 to 2 psu (km)	2970	3789	3654	3655	3864	3454	3469	2968
2 to 4 psu (km)	5676	5150	5341	5527	5086	4221	4079	4186
4 to 11 psu (km)	9474	8413	8642	8520	8469	9880	9135	9626
11 to 18 psu (km)	12791	14271	14033	13764	13998	14271	15041	14519

Isohaline interval	Percent of total shoreline between paired isohaline locations compared to baseline conditions							
	baseline flows	19% minimum flow	Permitted	10% withdrawal	15% withdrawal	20% withdrawl	30% withdrawal	40% withdrawal
0.5 to 2 psu (km)	n/a	128%	123%	123%	130%	116%	117%	100%
2 to 4 psu (km)	n/a	91%	94%	97%	90%	74%	72%	74%
4 to 11 psu (km)	n/a	89%	91%	90%	89%	104%	96%	102%
11 to 18 psu (km)	n/a	112%	110%	108%	109%	112%	118%	114%

5. Salinity regressions

a. The last paragraph of Appendix 5A indicates that the models did not fit the observed data well. Were these regressions used in the MFL?

Incorrect material was put in Appendix 5A. An electronic copy of the revised appendix 5A was sent on CD via FEDEX and will be inserted into the final report. The whole-river regression was only used for descriptive purposes in Figures 5-10 and 5-11 to show box plots of longitudinal top and bottom salinity gradients for baseline flow conditions. The whole river regression model was not used to determine the MFL. The only salinity models that were used to determine the MFL were the LAMFE mechanistic model and the empirical isohaline location models.

b. How were withdrawals handled in Appendix 5B as compared to 5A and 5C? Text implies they were added back in in 5B but not elsewhere.

The text is unclear, but the regression equation on Appendix page 5B-3 shows that withdrawals from Tampa Bay Water were subtracted from the flow record. This was also done for all other empirical models described in Appendices 5A and 5C. This was necessary because these withdrawals occur downstream of the USGS streamflow gage, and are thus invisible in the flow records unless corrected for. Although these withdrawals only occurred for portion of 2003, correcting for them was necessary so that the flow data used to develop the empirical models reflected the actual flows that occurred. It should be noted that corrections for withdrawals by Mosaic Fertilizer were not necessary, since those withdrawals are included in the net reported flows from Lithia and Buckhorn Springs (Buckhorn is infrequently used for supply when the Lithia facility is down).

c. I found Appendix 5C very confusing. Are the predictions for average daily salinities? Were withdrawals considered (see above, Appendix 5B)? What was the period of record considered for the salinity and flow measurements used to develop these relationships? Which of these regressions were used in the MFL analysis?

The regressions for the SWFWMD and EPCHC stations are for instantaneous salinity values, since they were developed from single vertical profile salinity measurements recorded one time during each sampling day. However, average daily flows were used as the independent variable in the regressions. So, although the regressions were not based on average daily salinity measurements, the use of daily flow values produces predicted salinity values that are indicative of typical salinity values at each station on a given day for a set of preceding flow conditions.

The regressions for the USGS sites are for average daily salinity values and daily 5^{th} and 95^{th} percentile salinity values at those gages, which measure salinity every 15 minutes.

Withdrawals were handled as in Appendix 5B, in that withdrawals by Tampa Bay Water during 2003 were subtracted from the flow records to drive the actual inflow the estuary received.

The period of record used for the regressions corresponded to the period of salinity data collection at those sites, which was: 1974-2003 for the EPCHC station at US 41 and 1999-2003 for the EPCHC station at US 301; 1999 – 2002 for the SWFWMD stations; and 1999 – 2003 for the USGS gages.

The fixed station regressions were developed early in the MFL process and not used in the final MFL determination.

5C-4 2nd paragraph, is the critical flow just the 95th percentile flow, or is it the flow at which salinities greater than 0.5 were observed 95% of the time?

The sentence on page 5C-4 is confusing. A better explanation of the critical flow is on page 5C-6, which Dr. Alber refers to below. The sentence on lines 5-7 of the last paragraph on page 5C-6 states "Initially, these critical flow values were operationally defined for each station location, probe depth, and daily salinity metric as the 95th percentile of flow for a subset of flow values where the daily salinity metrics were greater than 0.5 ppt." The critical flow values for the EPCHC and SWFWMD stations were determined similarly, but using instantaneous salinity values rather than daily values.

5C-6 This issue is revisited/repeated for the USGS stations, where it looks like the critical flow values were tuned and so it's not exactly the same as the 95th percentile. However, Table 3 refers to the 95th percentile salinity. Table 8 provides information about the 5th percentile but the reason for doing that is not explained and it's not really discussed. Were these predictions used in the MFL?

As Dr. Alber suggests, the tuning of the critical flow values would cause them to not be the same as the 95th percentile flows used for the initial determination of the initial critical flow values. Table 3 refers to something else - the final critical flows used to predict the mean and 95th percentile salinity values at those gages.

The information in Table 8 included the regression coefficients to predict the daily 5th percentile salinity at each USGS gage. This was done to get a prediction of the near-minimum daily salinity that occurs at each gage as a function of inflow. None of the regressions for the USGS gages were used to determine the minimum flow.

5C-7 Method implies daily salinity was predicted as 0.5 if flows high. Why wasn't this done for the other stations?

This application of assigning a salinity of 0.5 psu above the critical flow was done for the other fixed station regressions (all USGS, SWFWMD, EPCHC stations**).**

5C-10 states the relationships were statistically significant but not true for last 2 relationships in Table 8.

The last two regressions in Table 8 are unusual, as they are for the prediction of near-minimum (5th percentile) daily salinity at the Bell Shoals gage, which very rarely experiences slightly brackish water. The SAS output for this regression confirms that even though a significant regression was obtained, the r^2 values were extremely low. Although this regression was reported in the Table, the District did not use it for any purpose.

Although referred to at the bottom of page 5C-11, the SAS output for the salinity regressions was mistakenly not included in the Appendices. The SAS output for the fixed station regressions is included on the CD that was sent via FEDEX to the panel.

2. Specific questions and comments

2-33 Is the GW used for phosphate mining linked to springs/surface runoff?

Groundwater use by the phosphate industry affected streamflow in the river more in the past than today. The trend analysis of flow presented in Chapter 2 and knowledge from the area indicates that considerable excess water left the mined lands prior to the 1980s. However, mining practices have changed dramatically, and the phosphate industry now uses less groundwater and retains water on their site more effectively. Also, there were no flow trends apparent for Lithia Springs after 1985, when fairly regular records for springflow began. It was beyond the scope of this minimum flows analysis to assess the net effect on mining in the basin, as the minimum flows were proposed based on the current physical characteristics of the basin. So, in short, the groundwater used for phosphate mining was not linked to springflow and surface runoff in the minimum flows analysis.

5-12 Fig. 5-13B looks like there are 2 seasons? (or times when more water coming in from Tampa Bay?)

Our interpretation is that in this segment in the river (kilometers 5-7), stratification increases dramatically when inflows increase above about 200 cfs, due to low salinity surface waters moving into this reach of the river.

5-19 Why was a 5-d flow average used for the LAMFE model here, and then a 3-d on p. 5-21? (and on p. 5-75, it's 3-d again for peak chlorophyll)

The 2D plots in Figures 5-21 are not plotted vs. flow, rather flows are listed to indicate the relative occurrence of low, medium, or high flow conditions. However, a consistent preceding flow term should have been used and the legends in Figure 5-21 will be changed to list three-day flows in the final report.

5-58 2nd paragraph, the uptake of DIN between 5 and 25 psu may be a reflection of where the water is/how long it's there rather than its salinity

Agreed, this will be reflected in the text of the final report.

5-71 Figure 5-66: if it's really days from the head of the estuary, why aren't these arrayed in order?

The median values for both chlorophyll *a* and residence time were taken from dates when chlorophyll *a* values were recorded within each one-kilometer segment. If the sampling were equal among zones on every sampling day, the plot of median residence times should increase consistently between segments progressing downstream. However, the sampling was somewhat unbalanced, in that the number of dates with chlorophyll observations differed between segments. Consequently, the array on the x axis did not fall in a perfectly consistent order, although they were not far off.

5-75 Is the reference line in Fig. 5-71 (at 120) for gaged or total flow?

The line was plotted using the flow term used for the minimum flow; freshwater inflow to the upper estuary (flow at Bell Shoals Road plus Buckhorn Springs). The figure title will be expanded for clarification.

6-53 2nd paragraph, how are "shorelines" distinct from "marsh and mangrove shorelines"?

The word "hardened" is missing - sentence should read "most numerous among marsh and mangrove shorelines, but were also abundant against hardened shorelines"

6-53 3rd paragraph, isn't it odd that species centered downstream more likely to move in response to inflow since less movement of isohalines in wider downstream areas?

This comment best pertains to page 6-56. The different degrees of movement of among species within different reaches of the river may be related to different life histories of those species. In particular, it appears that estuarine transients, which immigrate into the river as larvae or juveniles, tend to shift more than estuarine residents that spend their entire life cycles within the tidal river.

7-11 last paragraph, why were 11 and 18 isohalines evaluated if the fish analysis differentiated the communities at 6 and 15 psu?

The 11 psu isohaline was selected based on relationships of salinity to shoreline vegetation (along with the 2 and 4 psu isohalines, see last sentence on page 7-11). The 18 psu isohaline was selected to correspond to the upper limit of the mesohaline range in the Venice estuarine salinity classification system. The decision to select these isohalines for analysis was done before the Principal Components Analysis of benthic macroinvertebrate communities had been completed, which indicated breaks in benthic macroinvertebrate community structure at 6 and 15 psu. The LAMFE model was used to evaluate changes in these salinity zones for potential impacts to the benthos, in part because of the through manner in which the LAMFE model accounts for the bottom area of the river. Salinity relations were not used for the assessment of potential impacts to fish, as we concluded that relationships of inflow with abundance and distribution were more sensitive indicators of potential impacts to fish populations.

8-3 last paragraph, are there really significant relationships with inflow in 5 of 6 segments in 5-39? Very hard to see in figures, particularly km 6-9.

Regressions to predict DO in deep bottom waters are listed in Tables 5-1 and 5-2, with the significance of these tests listed in Appendices 5D and 5E. These regressions are for waters greater than or equal to 2 meters in depth, while the plots in Figure 5-39 are for bottom samples deeper than 1 meter. Despite the large scatter in these plots, there does appear to be significant relations between inflow and DO in several segments. The logistic regressions to predict DO < 2.5 mg/l in all bottom samples is discussed on page 5-44 (see Figure 5-44). This analysis, which was prepared for the Tampa Bay Water HBMP, found significant relationships between inflow and the probability of low DO in six segments of the river, but the slope of this relationship was comparatively flat in strata AR3, which is near kilometers 6-9, as pointed out in the question above.

8-4 2nd paragraph, used regressions developed in App. 5B to predict isohaline locations as a function of flow for DO analysis. Was this surface isohaline equations only? (if so, can't really use this to show stratification), The isohaline models were not used in the DO analysis. The comparison to the isohaline models on page 8-4 was simply to illustrate that saline waters move into the upper estuary at an increasing rate during low flows. Although only surface isohalines were used in the minimum flows analysis, models to predict isohaline locations corresponding to 2 meters depth were also developed. Potentially, comparison of the results of the surface and 2 meter models could be used to assess stratification, although other models (LAMFE or the empirical whole-river or fixed station models) might be better suited for this purpose.

8-4 3rd paragraph, should probably refer to Fig. 5-43 in relation to this discussion. Also, it looks like a slight decrease in occurrence of hypoxia in downstream segments at low flow (so an increase in DO), rather than a decrease in DO as stated here.

Figure 5-43 can be referenced in the final report, along with Figures 5-41 and 5-44, if desired. The term "positively correlated" in the second sentence is in error. Bottom DO concentrations are actually negatively correlated with flow in the most downstream segments, while the occurrence of hypoxia has a positive relationship (the proportion of DO < 2 mg/l increases with flow). That is what the author meant to suggest, and the last sentence in the paragraph refers to this opposite response of DO to low flows in the upper and lower parts of the tidal river.

8-5 2nd paragraph, I'm not sure I completely followed this argument. If the river is at 120 cfs, by adding in Buckhorn Springs you actually get to 132, so Tampa Bay Water could take 12 cfs out, whereas under the current regulations they are allowed to take 10% out of the river flow down to 124 (without considering Buckhorn Springs), so when the river is at 124 they can take 12.4 cfs. So the amount the limit is calculated on is higher because of the inclusion of Buckhorn Springs, but in the end the amount allowed is about the same? How is the spatial component of the regulation applied (i.e. you can't take more than 10% out anywhere?)

The example you refer to was posed only with regard to the effect of the low flow threshold, and did not consider the effect of an existing or proposed percent flow limits. Currently, Tampa Bay Water must cease withdrawals when flows at Bell Shoals Road (without Buckhorn Springs) are below 124 cfs. The proposed minimum flow has a low flow threshold of 120 cfs, including Buckhorn Springs. Stated another way, when flows at Bell Shoals are at 124 cfs per the existing permit, the flow term used for the proposed minimum flow will be at 136 cfs, thus allowing additional water use.

To compare the effects of the proposed rule with the existing regulations, including permits to Tampa Bay Water Permit and Mosaic Fertilizer, maximum allowable withdrawals are plotted vs. flow at Bell Shoals Road in Figure R9. For the sake of consistency, withdrawal quantities were calculated assuming a constant flow of 40 cfs from Lithia Springs and 13 cfs from Buckhorn Springs. Figure R9 shows that water users in the minimum flow scenario will be able to take some water at flows down to 100 cfs at Bell Shoals, compared to the 124 cfs cutoff that is now in effect. If adopted, all water users will have to comply with the red minimum flow line, and the constant withdrawals by Mosaic Fertilizer will have to cease at low flows to comply with the proposed low flow threshold. With regard to a spatial component of Tampa Bay Water's permit, they are allowed to take 10% of daily flow at their intake location, with is at the upstream end of the lower river. For the minimum flow rule, cumulative withdrawals by all water users, including those upstream, will not be able to reduce flows by more than 19% at this same location, and must comply with the 120 cfs low flow threshold. Although unlikely, any permits for new downstream water users would be regulated against flows at this same location.

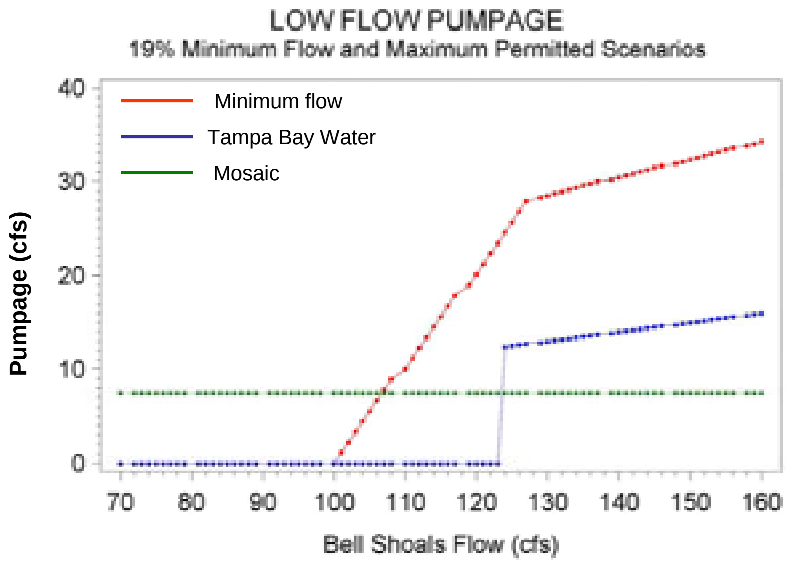


Figure R9. Maximum withdrawal quantities allowed by the proposed minimum flows and the water use permits issued to Tampa Bay Water and Mosaic Fertilizer vs. daily flow at Bell Shoals Road.

8-12 last paragraph, it's not clear it makes sense to use Fundulus, since the Matheson report points out they may decrease in abundance by moving onto the marsh rather than actually decreasing at particular flows.

Agreed, this species may move into marsh habitats at high water levels, thus affecting catch-per -unit effort. However, the fitted regression for *Fundulus seminolis* does not show a downturn at high flows, though the scatter plot indicates a slight tendency for some equally high abundances at intermediate flows (Figure 22 in Appendix 12, page 359 in Matheson et al). Though movement into marshes may affect the capture of this species during high flows, we believe the consistent positive relationship of abundance with inflows indicated by the regression is real, and indicative of the life history of this species, which is an estuarine resident that spends it entire life cycle in the tidal river and is not prone to displacement from the river at high flows.

8-17 Fig. 8-5, looks like total abundance converges for all but *Fundulus* on these CDF plots—so it's actually the same?

The CDF plots converge at the high percentiles, meaning the predicted peak abundances for the baseline and the various withdrawal scenarios don't differ at the higher percentiles. They do differ, at the low and mid percentiles. The reason this pattern does not occur for *Fundulus* for the reason described above - the linear regression for this species has a consistent positive relation between flow and abundance, thus the predicted baseline abundance values are always higher than the predicted values for the various withdrawal scenarios. The other species are described by quadratic regressions (Table 8-1), in which abundance takes a downturn at high flows. In these cases, the same peak abundance values are achieved for baseline and the flow reduction scenarios, as all the scenarios at some point hit the flow value at which peak abundance is achieved (see discussion at end of paragraph on page 8-16). This situation is why the section on reductions in abundance during dry periods (8.4.5, pages 8-30 to 8-36) was inserted into the report. For these types of species, reductions in abundance during prolonged dry periods can occur as a result of withdrawals, which may be masked by CDF plots that use data for the entire flow regime.

8-57 2nd paragraph, how does the Giovanelli model compare with the LAMFE predictions?

Though it is capable of predicting isohaline locations, the LAMFE model was not used for that purpose in the Alafia study. Instead, empirical isohalines models were developed, with the 0.5 psu isohaline models being most comparable to the Giovanelli (1981) regression model. The Giovanelli regression is listed below:

$$\text{ARSIL} = \frac{1.64 * (\text{ARTS})^{1.46}}{(\text{ARQ})^{0.44}}$$

Where: ARSIL = Daily mean location of the saltwater interface upstream of the US 41 bridge in miles;

ARTS = Daily mean tide stage plus 10 feet at U.S. 41, in feet above NGVD of 1929

ARQ = Daily mean discharge of the Alafia River at Lithia lagged 1.5 days, in cubic feet per second.

The equation by Giovanelli was for flows between 76 and 250 cfs at the USGS Alafia River at Lithia streamflow gage and did not include flows from Lithia or Buckhorn Springs. The saltwater interface was defined as the location where the average specific conductance value for top, middle and bottom waters was 1,000 µsiemens/cm, a value that is close to a calculated salinity value of 0.5 psu.

For the minimum flows project, separate regressions were used to predict the location of 0.5 psu salinity in surface waters and waters at 2 meters depth. For purposes of comparison in this response, the Giovanelli and minimum flows regressions were applied to observed flows (existing withdrawals left in) on days during which flows at the Alafia River at Lithia streamflow gage was between 76 and 250 cfs during the baseline period. Percentile values of the predicted locations of the 0.5 psu isohaline in surface and bottom waters and the locations of the saltwater interface (per Giovanelli) are listed in Table R7. The minimum flows regressions predict more upstream locations for 0.5 psu at 2 meters depth compared to the surface, which accurately reflects the shape of the salt wedge. In general, the minimum flows regressions produce similar results to the Giovanelli regression, which reflects a water column average value.

Table R7. Comparison of percentile values for the location of the saltwater interface (0.5 psu) predicted by the regressions of Giovanelli (1981) and the regressions for the minimum flows project for dates in the baseline period with flows between 76 and 250 cfs at the Alafia River at Lithia streamflow gage. All values predicted for observed conditions.

			Percentile (Km Location)						
Isohaline	**Regression**	**Units**	**5**	**15**	**25**	**50**	**75**	**85**	**95**
1000 usiemens/cm average	**Giovanelli**	**Kilometer**	9.0	9.5	10.0	11.0	12.3	12.9	13.6
0.5 psu surface	**Minimum Flows**	**Kilometer**	9.5	9.9	10.3	11.0	11.8	12.0	12.3
0.5 psu bottom	**Minimum Flows**	**Kilometer**	10.7	11.0	11.3	11.8	12.5	12.7	13.0

2B-3 Not enough info. provided to interpret this output: what do different abbreviations mean? Which equations were finally used? How were things grouped?

This Appendix will be clarified and re-submitted with the final report. Rainfall (inches/day) from the South Central rainfall station in the Alafia River watershed was used in the analysis. The regression parameters were defined as follows:

- srain_3 = rain on day t + rain on day (t-1) + … + rain on day (t-3)
- curain_1 = rain on day (t-1) raised to the third power
- lithia_flow = the gaged flow at the Alafia River at Lithia gage (cfs)
- srain_8 = rain on day t + rain on day (t-1) + … + rain on day (t-8)

The four groups were chosen as sub-sets of flows from ten sub-basins simulated by the HSPF model of Tara et al. (group 4 represented all 10 sub-basins). Although the regression equation for each group can be derived from the SAS output in Appendix 2B (pages 2B-3 to 2B-6), the final version of the report will have the equation for each group written out. The groups are defined as follows (see map on page 2B-2):

- Group 1 = sub-basins 1, 2, and 6
- Group 2 = sub-basins 1, 2, 6, 3, 5, and half of 7
- Group 3 = sub-basins 1, 2, 6, 3, 5, 7, and 4
- Group 4 = sub-basins 1 through 10

4A-15 No mention of high salinity predictions vs. data observed periodically at Riverview.

The periodic over-predictions of salinity at Riverview were most likely caused by inaccurate (under-estimated) ungaged flow estimates during these time periods. There could be also some localized phenomena at the Riverview station that causes the laterally averaged salinity during or right after a storm event to be higher than that at the measurement point which is generally not at the middle of the river. The periodic high salinity predictions at Riverview will be discussed in the final report.

4B-2 2nd paragraph, what percentile flows do these correspond to?

These flows were initially picked for testing purposes without considering percentile values. They correspond to low rates of flow as follows: (5 cfs – 0 percentile, 10 cfs – 1st percentile, 15 cfs - 2nd percentile, 20 cfs – 2nd percentile, 50 cfs - 13th percentile, and 100 cfs - 35th percentile).

4B-7 How was transit time defined for this model? It's customary to look at exponential decay, although any proportion can be used as long as it's specified (i.e. 50% removal). What was the average for the 3 days of release?

It was defined as the duration from the time point when a group of particles are released at Alafia River at Lithia streamflow gage to the time point when 50% of the particles reach the downstream boundary. The reason for releasing particles 3 times with 24 hours apart is to see if different release times (thus different tides at the beginning of the release) result in very different transit times (Chen - I called it transient time in the report because particles moves back-and-forth in the estuary before they exit the water body. I call the time for a particle to pass through a lake or stream transit time.) The answer is that the three transit times are almost identical. This is because the transit time is much longer than the tidal period.

4B-8 This would be much more informative if there were an actual number, rather than "10 days or less."

The actual numbers are 181.4, 161.2, 148.9, 141.4, 115.9, and 91.8 hours for 5, 10, 15, 20, 50, and 100 cfs.

3. Editorial suggestions/questions

3-3 Figure 3-2 is difficult to see – can it be enlarged?

Yes

3-5 Figure numbering is off, starting here with 3-2 (should be 3-3) and through rest of chapter

Will be fixed in final

3-6 References to figures off throughout.

Will be fixed in the final report.

3-14 last paragraph, "between kilometers 6.5" and where?

The phrase "below kilometer 6.5" means downstream of kilometer 6.5, can be re-written to "between the river mouth and kilometer 6.5".

3-15 is "between" supposed to be "differ"?

Yes, will be corrected.

4-1 last paragraph, The description of the flow at the three gages doesn't match the figure (4-2B). Are Bell Shoals and Riverview switched in the legend?

The legend is incorrect – Bell Shoals and Riverview are switched.

4-7 In Fig. 4-7, where are the diamonds signifying "95% removal modeled" Are they switched with the asterisks for "95% extrapolated modeled"?

The extrapolation had to be done only at very low flows, so the curves overlap over most of the flow regime. The diamonds for 95% removal modeled are covered up by the asterisks for the extrapolated curve. The diamond does show up at the lowest flow simulated, where the curves diverge.

4-8 3rd paragraph, is “1.4” supposed to be “1.5”? (looks like it in Fig. 4-7)

It should be 1.5 days in the text.

4-9 Legend to 4-6 should explain colors.

Will do in the final report.

5-28 Fig. 5-27 D is missing

Will be inserted in the final report.

5-57 4th paragraph, the fact that DIN concentrations were predicted based on dilution should be stated here, since it’s confusing until the 5th paragraph

The first sentence in the paragraph discusses the observed DIN values. Predicted DIN values are discussed beginning with the third sentence. Dr. Alber's suggestion about the effect of Buckhorn Springs has relevance to this paragraph. Paragraph and text can be revised for the final report.

5-59 last paragraph, there should be more interpretation of Fig. 5-57: looks like at fast flow, not much DIN builds up. As residence time increases, it’s long enough to translate inputs from upstream but too fast for phytoplankton to draw it down. At even slower flow, it’s taken up by phytoplankton.

Good points and the text will be expanded – nicely sums up what we found.

6-25 Description of statistical analysis says only results from adjacent groups are presented, but then group 2 is compared with group 4.

The reference to tests being conducted only between adjacent groups is in error will be removed.

6-30 1st paragraph, last sentence doesn’t match figure 6-20: dead *Mytilopsis* was found upstream of km 12, and both live and dead *Corbicula* were found there as well.

Sentence was erroneously reversed in reference to these two species, will be fixed in final report.

6-63 1st paragraph, what 2 variations of the plots were examined?

The text in this report (Janicki Environmental, 2004a) discusses how potential confounding effects of seasonal factors in fish life histories were to be partially accounted for or minimized. To accomplish this, two variations if bivariate plots of abundance vs. flow were examined. First, annual plots were produced to integrate variation over potentially confounding seasonal effects. Second, monthly plots were produced in which the dependent variables were standardized by month over the time series. The mean abundance value for each month across all years was subtracted from each monthly value, and each monthly value was divided by the standard deviation for the month across all years.

6.6.7 This section is not well-organized, making it difficult to follow the argument. It seems like the description on p. 6-46 should be put together with that of Fig. 6-28 (Also, no positive slopes are shown but that is discussed). 6-47 talks about three species but doesn't say which ones. The info. in the 1st real paragraph on p. 6-50 is repeated in the 1st paragraph on p. 6-53.

The text in section 6.6.7 pertains to abundance response to inflow, whereas Figure 6-28 is in the previous section which discussed distribution responses to inflow. The distribution responses all had negative slopes, as higher flows move the animals to lower kilometer values. Positive slopes for abundance are shown in Figure 6-29. As discussed on page 6-45, Peebles also found negative abundance slopes for some species but they were not of concern for the minimum flows analysis.

Regarding the comment for page 6-47, the species/life stages for which wash-out was observed were bay anchovy juveniles, and adults and juveniles of the *Americamysis almyra* (mysid). The text will be clarified in this regard.

The redundancy on pages 6-50 and 6-53 will be addressed in the final report.

6-56 3rd paragraph, a table showing the different lengths of flows used for the best r^2 values for each pseudospecies would be useful (or refer to table in Chapter 8?)

I suggest that reference be made to Appendix 8 in the Matheson et al report, which lists the r^2 values for the different flow lengths, and also the flow terms in the regressions with the best r^2 values for those pseudospecies that were selected for the minimum flows analysis in Chapter 8 (Table 8-14).

6-56 last paragraph, it would be useful to refer to table/graphs in Chapter 8 here so readers can see the 13 species in question.

Reference to Table 8-14 discussed above will cover this.

6-57 4th paragraph, year "200" needs to be fixed.

Will do.

6-60 last paragraph, refers to red drum but that's not plotted in Fig. 6-35D.

Wrong figure got inserted by mistake, graph for red drum, which shows the pattern discussed, will be inserted.

7-4 2nd paragraph should refer reader back to Table 2-9 for flow statistics

Will do.

7-9 1st paragraph, would have been nice to make the point that the invertebrates are important prey items earlier in the section.

This can be done in sections 7.6 or 7.6.1.

8-4 4th paragraph, should refer to Fig. 6-32? – although pink shrimp response not shown

Can also refer to chapter 8 where this is discussed in more detail and a plot for pink shrimp is shown (Figure 8-3A).

8-4 last paragraph, refer to Fig. 6-28.

Figure 6-28 pertains to distribution response, whereas the paragraph discusses abundance response. Figure 8-2D, which shows the inflow-abundance curve for Mnemiopsis, can be referenced instead. Alternately, the *Mnemiopsis* abundance curve with ln transformed values from Peebles' report could be added to Figure 6-29.

8-6 2nd paragraph, should this refer to Figure 6-27?

Yes, it should refer to Figure 6-27.

8-7 2nd paragraph, sections not numbered as "6.7.2.5"

Will be fixed in the final report, should refer to Sections 6.6.6, 6.6.7, 6.6.11, and 6.6.12.

8-10 2nd paragraph, section not labeled "6.7.2.5

Will be fixed as well to refer to Section 6.6.7

8-13 Both Figs. 8-2 and 8-3 would be more informative if observations were plotted.

Will do.

8-14 2nd paragraph, the logic behind comparing the percentiles against baseline is very confusing upon first reading. It is not immediately clear whether this discussion refers to flow percentiles or organisms, and the comparison of the percent change in a particular percentile (i.e. Table 8-3) is difficult to follow. Since this is an important point and sets up the rest of the chapter, it seems like it would be a good idea to walk the reader through it a little more slowly. For example, before you refer to Table 8-3 you could first describe the CDFs that show the abundance of mysid shrimp, etc. under baseline flows as compared to the various flow reductions, and put some lines on the graph to show the % reduction at particular percentiles. Then in later discussion of results, do not refer to the various percentiles as "flow percentiles" since that is confusing – for example p. 8-25 1st paragraph refers to flow percentiles to interpret mysid data, p. 8-30 describes Fig. 8-6 in terms of the greatest difference at low flows when in fact the graph only shows the percentiles.

The discussion will be reworked. CDF curves are introduced and referenced one page later, but these can be moved up as you suggest before the tables are discussed. The point about the relationships of flow and abundance percentiles discussion needs to be clarified, and there are passages in the text that can be improved. However, it is important to point out that for species that have linear regressions with flow, low abundance percentiles correspond with low flow percentiles, and high abundance percentiles correspond with high flows. For these species, the 15th percentile flow will correspond to the 15th percentile abundance. The latter part of the 2nd paragraph on page 8-14 refers to the relation between low and high flows and abundance percentiles for plankton taxa that have linear regressions.

To some extent, a similar relationship holds for red drum juveniles at low flows, since low abundance values also occur at low flows (see Figure 8-3C). The Section regarding the dry season response for taxa with quadratic regressions was inserted in part to discuss this type of response (Section 8.4.5) Based on the review comments, the text will be reworked in a number of places to make the differences and relations of flow and abundance percentiles more clear, and ensure that the proper tem is used so the reader does not have to make inferences about these relations. The author was a little too close to the results and assumed the readers were too.

8-15 Table 8-2 needs a size class column

Will insert that information.

8-16 1st paragraph is confusing. Last sentence could be, "this pattern occurs..during high flows. Flow reductions reduce the number of high flows, hence increasing abundance of plankton compared to baseline conditions."

The last sentence will be changed in keeping with what you suggest.

8-17 1st paragraph, first sentence should be "Tables for % reduction in abundance in comparison to baseline" to make it clearer.

Will do.

8-16 Refer to appropriate plots that match species as they're mentioned

Will do.

8-22 last line: shouldn't it be "might be greater during low flows and lower during high flows"?

That is correct, the word "low" was missing.

8-28 Isn't Table 8-9 the percent change as compared to those at baseline flows?

Yes, the figure titled will be expanded to reflect that.

8-30 3rd paragraph, insert “less than” before “the median value”

Will do.

8-31 shouldn’t figure legend refer to Table 8-1 and not 8-2?

That’s correct, will revise.

8-41 highlight lines in table where % change > 15%?

Will do

8-49 1st paragraph, need to make it clear that this was actually analyzed for different zones (i.e. < 1, < 6, and < 15). This is important because one might want to evaluate the differences in the different salinity zones identified by the PCA: if flows increase, that could decrease the 6-15 psu zone which is not necessarily desirable for the benthos.

Paragraph will be revised in keeping with this comment.

8-50 The presentation of the bottom area results, where you see the abundance curves first followed by the percentile analysis, makes a lot of sense. I think the plankton and fish data should also be presented in this order.

The plankton and seine and trawl discussions attempted to do this by each first showing regression curves for species with different types of response to freshwater inflow. A complete set of curves using the plots presented by Peebles and Matheson et al. could be included as an Appendix.

8-59 3rd paragraph, HDR is not identified in Chapter 3. Which analysis is this?
Fig. 8-13 the Series are not identified. Is this the same info. as Fig. 3-15?
Might also be useful to remind us that the 2 studies differed upstream—the HDR makes it look like a potential problem. If the distinction is that it’s wetland (vs. total shoreline) that should be pointed out.

The second paragraph on page 3-16 refers to the same shoreline work discussed in Chapter 8, but the text in Chapter 3 needs to mention that it was performed by HDR. This work and the corresponding data files were submitted as part of Tampa Bay Water's permit application for withdrawals from the river.

The data in Figure 8-13 are the same as Figure 3-15, but is shown in tenth kilometer lengths up to kilometer 13. The two scales are used because the figure in Chapter 3 was for general characterization, while the figure in Chapter 8 was in reference to fairly small scale changes in wetland/salinity exposure due to isohaline shifts.

The discussion of total shoreline and wetland shorelines on page 8-59 were both taken from the HDR data base. It was a matter of how the different types of shoreline in the data base were grouped and summed.

8-73 1st paragraph, change "as predicted 25th and 50th" to "but predicted 25th and 50th"; change"in all river segments except one" to "in all other segments"

Will do.

8-74 1st paragraph, insert "for the 12-15 km segment" at the end of the paragraph.

Will do.

8-87 Section 8.9 seems like it should have come earlier?

The point is well taken and section 8.9 could be moved up, but this is almost philosophical. Reductions in flows are important primarily in how they affect the ecological resources of the estuary. The minimum flows analysis was based on changes in ecological variables of concern for which we were able to develop quantitative, predictive relationships. So, we first demonstrated the degree that resources of concern are going to change as a result of potential flow reductions, and based on this analysis, proposed the minimum flow. Following that, the flow reduction analysis was presented as sort of a check. In other words, now that the minimum flows (including the low flow threshold) were based on effects to the river's resources, what is the net effect on freshwater inflows. The public can then be told these reductions average about 11 percent of the total inflow to the lower river. It seems to work as kind of a nice wrap up and I would like to leave section 8.9 where it is.

2A-7 Figure axes need labels

Will revise so predicted and observed axes are labeled properly.

2B-3 Can't read axis labels because of page numbers.

Will move page numbers to the side in this appendix.

4A-7 Since the salinities at Bell Shoals Rd. are so difficult to see in the figures, it would make sense to point out that one can usually not see the data and point to a section of the record where there was measurable salinity at this station.

It can be seen from Page 4A-46 – 4A-64 that there is no section of the record where there was appreciable salinity at Bell Shoals Road during the 4.6-year period, with the exception of a very brief period in late May and early June 2000, which can be referred to in the final report.

4A-16 What flows do table percentiles correspond to?

The 5th , 15th , 25th , 50th , 75th , and 90th percentile flows at Alafia River at Lithia stream flow gage are 36, 61, 86, 151, 305, and 575 cfs, respectively.

4A-86 Appendix E, would be nice to see calibration and validation separated out/marked off in figures. Also, "Riverview" misspelled in figure legends of top and middle panels throughout Appendices E and F.

The figures will be regenerated.

5B-3 last paragraph refers to plots, but none were included

These plots are provided on the CD FEDEXed to the panel and will be included in the final report.

Appendix 5C is poorly organized: the last paragraph on 5C-7 repeats from earlier text. The equation for SWFWMD and EPCHC stations on p. 5C-8 is exactly the same as that used for the USGS stations, but it's presented separately. Why not lump all of the methods, since they were so similar, then all of the results?

There is some redundancy in this section, but this was done intentionally because the regressions for SWFWMD and EPC stations are used to predict daily salinity at each location and depth while the regressions for the USGS stations predict the 5th, 50th, and 90th percentile daily salinities by location and depth. However, the text can be adjusted per the comments above.

Response to questions on Lower Alafia River Estuary Minimum Flows report submitted by Dr. Billy Johnson

Prepared by SWFWMD: November 14, 2007

Alifia MF Questions

1. Is the bathymetry in the lower Alifia fairly uniform across the river?

The Alafia has a typical riverine cross section, being shallow on the edges with a deep channel toward the middle of river. The deep barge turning basin downstream of kilometer 1 is an unusual feature. Though not uniform, the bathymetry of the Lower Alafia is generally simpler than that of most tidal rivers in the region, as there are only a few small islands and no real channel braids. See the bathymetric maps in Figure 3-2 of the report (page 3-3) and Figure 3 on page 4A-14 of the Appendices, the latter of which shows depth variation along the longitudinal axis of the river.

2. I believe the Bell Shoals gage is upstream of the shoals. Is that correct?

That is correct.

3. Was there any special treatment of the shoals in the LAMFE model?

No, but the measured elevation of the shoals was included in the LAMFE model. See Figure 3 on Page 4A-14 - the shoals are located at approximately x= kilometer 15.6. A special field trip was conducted to get improved bathymetric data for this location and incorporate that information in the LAMFE model.

4. Why extend the LAMFE model to the Lithia gage instead of stopping at the shoals and using the inflow at Bell Shoals that is used in all the regressions? What was the advantage?

There were several reasons:

(1) Because the shoals are several hundred meters downstream of the Bell Shoals USGS gage and the bathymetry in the area varies dramatically, water levels at the Bell Shoals gage are not the same as that at the shoals. As a result, measured water level data at the Bell Shoals gage can not be used as a boundary condition at the shoals.

(2) Because tidal water level fluctuations go beyond the Bell Shoals gage and the salt wedge can occasionally reach the Bell Shoals gage, it is not proper to use freshwater inflow as a boundary condition at either the Bell Shoals gage or the shoals.

(3) Flow data are actually measured at the Alafia River at Lithia gage, not the Bell Shoals gage.

(4) At the time this modeling study was conducted, we thought that extending the upstream boundary would generate results for the river segment between the shoals and the Lithia gage that could be used in the minimum flow study for the upper Alafia River.

5. What is the ratio of real time to computing time on what computer for the LAMFE model?

The time step used was 240 seconds. Model runs were done on a Pentium 4 PC with a single processor of 2.8GHz. For a 1680-day simulation, it took about 132 minutes. So the ratio of real time to computing time is about 18,327.

6. All the regressions for water quality / ecological variables had fairly low R^2 values, e.g., 0.2-0.3. Most of these variables are a function of freshwater inflow because of their dependence on salinity. Obviously salinity is a function of the inflow, but very much a function at times of large set ups / set downs in the Tampa Bay water surface due to winds over the Gulf (compare Figs 5.21d and 5.21e). Was there any analysis of the water surface elevation records so that values of the variables taken during such events might be discarded? Would this have improved the regressions?

In addition to empirical salinity models, least squares regressions were presented for the prediction of dissolved oxygen (DO) concentrations in waters > 2 meters deep, and logistic regressions were presented to predict the probability of hypoxia (DO < 2 mg/l), DO supersaturation, and chlorophyll *a* concentrations greater than 30 µg/l. The r^2 values for the regressions to predict DO concentrations were in the range of 0.48 to 0.72. McFadden's Rho^2 values were reported for the logistic regressions. McFadden's Rho^2 values are typically lower than r^2 values from least squares regression, with values in the range of 0.2 to 0.4 generally considered as satisfactory (Hensher and Johnson 1981, see literature cited in report). Least squares regressions were also presented for the prediction of fish distributions and abundance. These regressions frequently had r^2 values in the 0.2 to 0.3 range, although some were higher. Because of the many complex factors that can affect biological data, lower r^2 values for regressions with fish distribution and abundance are not surprising.

The District did prepare a data base for the vertical profile meter readings in which tide stage at the time of sampling was included as a variable. These meter readings (e.g., salinity, DO) included data that were collected the same time as the water quality data (e.g., chlorophyll). However, tide stage at the time of sampling was not merged into the water quality data base.

Inspection of the tide stage data for the vertical profile data base indicated there were no unusually high or low tides during the vertical profile and water quality studies. The table below lists percentile values for all the 15-minute tide stage measurements at the Gibsonton and Riverview USGS gages, plus percentiles of tide stage data measured during the vertical profiles sampling, which includes the water quality data. Based on this comparison, it seems the distribution of tides during the water quality sampling program was typical for the river, and there don't appear to be an excess of either high storm tides or unusual low tides in the data.

Salinity is a covariate of freshwater flow, so we did not include salinity in the regression models. Although tide stage could possibly affect some of the dependent variables in the regressions (possibly bottom DO, unlikely for DO supersaturation or surface chlorophyll *a)*, we did not think including tide stage at time of sampling would improve the fit of the models.

Selected percentile values of water levels at the USGS gages at Gibsonton and at Riverview for all 15 minute data measured at those sites and data measured when vertical profile samples were taken with water quality and biological samples during the years 1999 - 2003. All data as meters relative to NGVD 1929.					
at Gibsonton			**At Riverview**		
Percentile	All data	Profile samples	Percentile	All data	Profile samples
100	1.52	0.99	100	1.61	1.06
90	0.54	0.63	90	0.62	0.71
75	0.38	0.49	75	0.46	0.56
50	0.2	0.29	50	0.27	0.33
25	0	0.04	25	0.06	0.09
10	-0.18	-0.15	10	-0.13	-0.14
min	-0.86	-0.63	min	-0.74	-0.55

The vertical profile data base also included data for when biological data were collected in the lower river, including sampling by the ichthyoplankton and seine and trawl programs. These data are identified in this data set by an Agency variable. Review of those data does not indicate the occurrence of unusual tide events was a major factor. The data bases for the ichthyoplankton and seine and trawl catch compiled by USF and FWRI also included tide stage at time of sampling as measured variables. Tide stage data were included in the ichthyoplankton analysis to calculate the river volume at time of catch, but not used as an independent variable to predict abundance. Since the ichthyoplankton are collected mid-channel away from the shorelines, there are no effects of tides on catchability of those organisms.

In response to your question above, FWRI has communicated that rather than excluding rare tide events, it would be better to use a general linear model analysis similar to what they recently performed for the Little Manatee River. That approach attempts to account for noise sources in nekton data that are outside of the inflow effects (tidal stage, sampling depth, annual recruitment success, etc.) prior to conducting the inflow regressions. However, given the lack of unusual tides in the Alafia data set, the District suggests that this would not have a meaningful effect on the results or conclusions regarding the Alafia minimum flows.

7. The regressions for isohalines did not take into consideration the ungaged flow below Bell Shoals, but it is included in the LAMFE model. Is this the major reason there is no comparison of the regressions and the model? Is rainfall over the Alifia basin fairly uniform? If so, why not just do a ratio of areas and include the ungaged flow downstream of Bell Shoals in the isohaline regressions?

The ungaged flow issue was one we wrestled with, both from technical and practical perspectives. The ungaged flows are necessary to run the LAMFE model, as it requires the entire flow regime of the river in order to best simulate the physical and hydrological characteristics of the river. The ungaged flows, however, can sometimes involve considerable error, in part due to the limitations of the runoff models, but more the importantly the representativeness of the rainfall records used to drive the runoff models. Convectional storms, which dominate our summer rainy season, can be very localized with large differences in rainfall over short distances. This uncertainty in the actual rainfall over the ungaged area is a potential source of error.

Because of this potential error, we decided to ignore ungaged flow in the isohaline regression models and simply let ungaged flow contribute to the unexplained variation in those models. A watershed ratio method could be used to estimate ungaged flow, and for certain purposes in some watersheds it is a useful technique. However, for the regression models the ungaged flow would vary with the gaged flow, thus it should not explain any more of the variation. Also, the different watershed characteristics (e.g. increased urbanization) in the ungaged area might introduce error into flow estimates generated by the ungaged ratio method. A small watershed ratio (1.117) was used to estimate flows at Bell Shoals Road, but the watershed characteristics between that location and the upstream USGS streamflow gage are very similar.

Finally, application of the percent-of-flow method involves managing inflows to the lower river based on daily variations of flow. Since we do not have ungaged flows estimates on a short-term, real-time basis, we decided to base the minimum flow rule on the gaged flows that we measure daily, assuming that ungaged flows will largely vary with those flows.

8. On page 8-4, the report talks about how comb jelly can be very detrimental to the food supply and productivity of larval and juvenile fish. Your analysis showed substantial increases of comb jelly as the flow decreased. Yet, they didn't play a role in determining the withdrawal plan. I'm not a biologist so maybe I missed something, but why were they not considered?

The Executive Summary and the text on page 8-4 describes that the tendency of the comb jelly (*Mnemiopsis mccradyi*) to proliferate at low flows was one justification for implementation of a low-flow threshold. The predicted effect of the 120 cfs low-flow threshold in combination with a 19% flow reduction on *Mnemiopsis* abundance is predicted and discussed in that context on page 8-25.

9. You looked at some species during only dry periods along with the complete baseline data set. Should you have done the same with the red drum and mysid shrimp?

The analysis of dry period abundance was performed to emphasize that some species have strongly nonlinear responses to flow. For some species, regressions used quadratic formulae to predict their abundance, as abundance increased rapidly at low flows, peaked at mid-range flows, and decreased with high flows. This response seems understandable for some species that shift their distributions within and between the river and the bay as flows change, thus affecting their abundance in the river. As illustrated in Figure 8-13 (page 8-13), juvenile red drum demonstrated such a response and changes in their abundance specifically during dry periods were presented in Table 8-11 (page 8-32).

The regression for mysid shrimp abundance was a linear equation with natural log transformed variables. Application of percent-of-flow withdrawals to this type of regression results in a consistent reduction in abundance across the flow regime. This is shown in the percentile values in Tables 8-3 through 8-6 (pages 8-13 to 8-23). Percent reduction in mysids from baseline at low percentiles, which correspond to low flows, is the same as the percent reduction at high flows. Thus, there was no need to separately prepare cumulative frequency distributions for mysid shrimp during dry periods, for the form of the abundance/inflow relationship doesn't change, and the results in Tables 8-3 through 8-6 adequately reflect reductions in abundance in mysids during dry conditions.