Appendix E

Recommended Minimum Flows for the Little Manatee River Estuary DRAFT REPORT

Prepared for

Southwest Florida Water Management District

Pursuant to 373.042 F.S.

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Recommended Minimum Flows for the Little Manatee River Estuary, DRAFT REPORT

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Ecologic Evaluation Section
Resource Projects Department
Southwest Florida Water Management District
Brooksville, Florida 34604-6899

Author(s)
Janicki Environmental, Inc.

Conversions Table

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

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Acknowledgements

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Executive Summary

The Little Manatee River is one of the few rivers in Florida with a special designation by the Florida Department of Environmental Protection as an "Outstanding Florida Water". Flannery (1989) wrote that the Little Manatee River "probably best represents the natural ecological interactions of a river and its watershed within Tampa Bay". The shorelines are mostly unarmored, the main stem is sinuous and braided towards the mouth, and there are significant areas of emergent wetland vegetation and floodplain wetlands throughout the river. These features differentiate the Little Manatee River from other Tampa Bay tidal tributaries that have been armored and in many cases channelized. Despite these characteristics, the Little Manatee River watershed has undergone significant changes over the past several decades and has one of the highest rainfall to runoff ratios among Tampa Bay tributaries (Hood et al. 2011). In 2011, the Southwest Florida Water Management District (District) published a document (Hood et. al., 2011) detailing draft recommendations for a minimum flow (MFL) to protect the biological integrity of the freshwater segment of the Little Manatee River from significant harm. The recommended freshwater MFL was peer reviewed in a report to the District (Powell et al. 2012) and the MFL was subsequently reevaluated. The reevaluation led to a proposed minimum flow for the freshwater portion of the Little Manatee River including: a low flow cutoff of 35 cfs to protect wetted perimeter and fish passage; no more than a 13.5% reduction in flows above the low-flow cutoff is allowed anytime, and no more than a 12.8% and 11% reduction is allowed when flows are above their 60% and 80^{th} percentile values, respectively. These flow reductions are based on the gaged flow record at the USGS gage near Wimauma (02300500) which is also the demarcation point between the freshwater and estuarine segments of the Little Manatee River. The proposed minimum flows for the freshwater segment are now being finalized and are scheduled to be presented to the District Governing Board for consideration of approval in 2020 along with the proposed minimum flows for the estuary as described in this document.

The USGS gage near Wimauma (02300500) is the most downstream long term flow gage in the Little Manatee River and as such will serve as the gage of record (or compliance gage) for the Lower (estuarine) segment as well as the Upper (freshwater) segment. For the estuarine segment of the Little Manatee River, goals were identified to:

- Protect water quality from deviations that would result in significant harm to the ecosystem services these water quality attributes provide.
- Protect emergent wetland vegetative communities by maintaining the bottom area and volume of salinity isohalines in the estuary.
- Protect benthic macroinvertebrate communities by maintaining the bottom area of salinity isohalines in the estuary.
- Protect plankton communities using evidence-based regression relationships between plankton abundance and flows.
- Protect nekton communities using evidence-based regression relationships between nekton catch data and flows and salinity.

To establish the recommended minimum flows, freshwater inflow reduction scenarios were constructed by first developing a Baseline flow record reflective of expected conditions in the absence of anthropogenic effects. The flow reductions were then calculated by subtracting, in successive 10% increments from the Baseline record, between 10% and 40% of the available flow. This is the same approach used to evaluate the freshwater MFL. Predictive models were then used to evaluate changes in salinity, vegetative communities, benthos, zooplankton, and nekton (fish) as a function of the freshwater flow reduction scenarios. A 15% change in any of these resources of concern was identified as a prescriptive standard for identifying significant harm as has become standard practice for MFL development in District tidal rivers where more specific requirements are absent. A hydrodynamic model developed to predict salinity throughout the estuary (Huang and Liu (2007) was used to evaluate the changes in the area and volume of various salinity isohalines between 1 psu and 30 psu as a function of potential flow reduction scenarios. The effects of emergent wetland vegetative communities were evaluated based on the shift in salinity regimes that are thought to govern their long term location within the tidal river. Regressions of plankton abundance and flows were used to predict the flow reduction scenario that would result in a 15% reduction in abundance of the most sensitive plankton taxon evaluated. Nekton data were likewise evaluated using regression analysis. In addition, a habitat suitability index was developed to estimate potential reductions in the probability of occurrence of nekton taxa as a function of flow reductions while also accounting for other factors that affect the distribution of these taxa within the tidal river (e.g., shoreline habitat types). The effects of the flow reductions on all these attributes were evaluated as a global average, by year, by seasonal block, and by year and seasonal block.

The results of these assessments provided a weight of evidence that could be used to support the establishment of minimum flows for the Lower Little Manatee River. A 15 percent change in area or volume of salinity isohalines was not generally exceeded until the 30% flow reduction scenario and then only for the lowest salinity isohalines (i.e., 1psu to 7psu). The exception to this result was when areas and volumes for a particular salinity isohaline were very small under the Baseline condition. When areas and volumes are small under the Baseline condition, the flow reduction scenarios can result in small area of volume reductions resulting in large percent change from the Baseline condition. This occurred during the driest years and seasons. Because there was no low flow threshold (flows below which no reductions were implemented) established for the estuary at the time, the scenarios did not include one. However, the recommended minimum flows for the freshwater segment of the Little Manatee River which included a low flow threshold of 35 cfs was subsequently used as an additional scenario which ameliorated the issue for the dry periods described above. Based on the results of the plankton regression evaluations described by Peebles (2008), the most sensitive taxon to inflow changes is the juvenile yellowfin menhaden with a 12% reduction in abundance predicted with a 10% reduction in flow. This translates to a ca. 15% reduction in abundance with ca.12% reduction in flow. The final nekton (fish) abundance regressions include two important estuarine dependent taxa that both have local economic, as well as ecological, value. The results suggest that blue crab is the most sensitive of the taxon considered with a predicted ca. 9% reduction in relative abundance with a 10% reduction in flow which translates to a ca. 15% change in relative abundance with a ca. 16% reduction in flow. The fish habitat suitability model outcomes suggested that the results of the flow reduction scenarios would be dependent on the temporal scale of analysis and that while over the long term there would be little average effect on the area of favorable habitat, there were periods of time within the model simulation period where changes would be more significant. Outcomes of the habitat suitability modeling were quite similar to the salinity analysis outcomes with a less than 15% change predicted at flow reductions under 30% except during the driest years and seasons when a presumed low flow cutoff would eliminate the possibility of surface water withdrawals. Thereby, the importance of a low flow threshold in protecting abnormally low flows during specific seasonal blocks (e.g.. Block 1 in year 2000) is readily apparent and necessary for the protection of all of these resources of concern.

The District typically selects the most conservative results to implement the minimum flows to the system of interest. In this case, the results for juvenile yellowfin menhaden were most sensitive to changes in inflow based on the plankton regression results. The District considers the results presented to be the best estimates in line with the legal statue describing the use of best available information. When considering that there is uncertainty around these estimates, it is striking how similar the results are to the outcomes for the proposed MFL for the freshwater portion of the Little Manatee River. Given the similarities between the freshwater and estuarine MFL outcomes, and the fact that they use the same freshwater flow compliance gage, it seems intuitive to develop a single MFL that is protective of both the fresh and estuarine segments of the Little Manatee River. This report recommends that if all aspects of the recommended freshwater MFL are considered, the freshwater MFL would also be protective of the estuarine segment. This approach would protect the downstream resources, provide uniformity between the two segments, and allow for a consistent compliance assessment process.

1 PURPOSE AND BACKGROUND OF MINIMUM FLOWS

1.1 Overview

This document presents analysis and recommendations to the Southwest Florida Water Management District (District) in support of establishing minimum flows for the estuarine portion of the Little Manatee River, Tampa Bay, Florida. A related document for the freshwater portion of the Little Manatee River was developed in draft form (Hood et al., 2011), peer reviewed in 2012 (Powell et al., 2012) and subsequently revised in March of 2017. The Little Manatee River is one of the last remaining larger tidal river systems within the District without minimum flows adopted into Florida Administrative Code. The following sub-sections describe the legislative direction and appropriate administrative rules governing Florida's minimum flows process.

1.2 Legislative Direction

For streams and rivers, the development of instream flow legislation can be traced to recent work by fisheries biologists, dating back not much more than 40 years. Florida has had minimum flow and levels incorporated into its Water Resource Act since its enactment in 1972. However, it was not until 1997 that the role of minimum flows and levels were clearly defined by the state. A survey completed in 1986 (Reiser et al. 1989) indicated that at that time only 15 states had legislation explicitly recognizing that fish and other aquatic resources required a certain level of instream flow for their protection. Nine of the 15 states were western states "where the concept for and impetus behind the preservation of instream flows for fish and wildlife had its origins" (Reiser et al. 1989). Stalnaker et al. (1995) have summarized the minimum flows approach as one of standards development, stating that, "following the large reservoir and water development era of the mid-twentieth century in North America, resource agencies became concerned over the loss of many miles of riverine fish and wildlife resources in the arid western United States. Consequently, several western states began issuing rules for protecting existing stream resources from future depletions caused by accelerated water development. Many assessment methods appeared during the 1960s and early 1970s. These techniques were based on hydrologic analysis of the water supply and hydraulic considerations of critical stream channel segments, coupled with empirical observations of habitat quality and an understanding of riverine fish ecology. Application of these methods usually resulted in a single threshold or 'minimum' flow value for a specified stream reach."

The Southwest Florida Water Management District (District or SWFWMD), by virtue of its responsibility to permit the consumptive use of water and a legislative mandate to protect water resources from "significant harm", has been directed to establish minimum flows and levels for streams and rivers within its boundaries (Section 373.042, Florida Statutes). As currently defined by statute, "the minimum flow for a given watercourse shall be the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." Development or adoption of a minimum flow or level does not in itself protect a water body from significant harm. However, protection, recovery or regulatory compliance can be gauged and achieved once a standard has been established. The District's purpose in establishing minimum flows is to create a yardstick against which permitting and/or planning decisions regarding water withdrawals, either surface or groundwater, can be made. Should an amount of withdrawal requested cause “significant harm”, then a permit cannot be issued. If it is determined that a system is either not in compliance, or expected not to be in compliance during the next 20 years, as a result of withdrawals, then a recovery plan is developed and implemented.

1.2.1 State Statutes

According to state law, minimum flows and levels are to be established based upon the best available information (Section 373.042, F.S.), and shall be developed with consideration of “...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...” (Section 373.0421, F.S.). Because minimum flows are used for long-range planning and since the setting of minimum flows can potentially impact (restrict) the use and allocation of water, establishment of minimum flows will not go unnoticed or unchallenged. The science upon which a minimum flow is based, the assumptions made, and the policy used must, therefore, be clearly defined as each minimum flow is developed. It has been noted:

1.2.2 DEP Rules

According to the State Water Resources Implementation Rule (Chapter 62-40.473, Florida Administrative Code), “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.

1.2.3 Application of District Rules

Given the suite of legal directives above, the basic function of minimum flows remains to ensure that the hydrologic requirements of natural systems are met and not jeopardized by excessive water withdrawals. In turn, establishment of minimum flows 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 minimum flows play in natural resource protection and water supply management, the methods, data and analyses on which minimum flows are based should be comprehensive and technically sound. The Instream Flow Council (2002) noted that:

"*There is no universally accepted method or combination of methods that is appropriate for establishing instream flow regimes on all rivers or streams. Rather, the combination or adaptation of methods should be determined on a case-by-case basis; . . . In a sense, there are few bad methods – only improper applications of methods. In fact, most . . . assessment tools . . . can afford adequate instream flow protection for all of a river's needs when they are used in conjunction with other techniques in ways that provide reasonable answers to specific questions asked for individual rivers and river segments. Therefore, whether a particular method 'works' is not based on its acceptance by all parties but whether it is based on sound science, basic ecological principles, and documented logic that address a specific need*".

For this reason, the District has typically investigated multiple lines of evidence in support of establishing minimum flows and included peer-review to ensure conformity with both applicable legislative statutes and accepted scientific standards. As noted by Beecher (1990), “it is difficult [in most statutes] to either ascertain legislative intent or determine if a proposed instream flow regime would satisfy the legislative purpose”, but according to Beecher as cited by Stalnaker et al. (1995), an instream flow standard should include the following elements:

1) a goal (e.g., non-degradation or, for the District’s purpose, protection from “significant harm”);
2) identification of the resources of interest to be protected;
3) a unit of measure (e.g., flow in cubic feet per second, habitat in usable area, inundation to a specific elevation for a specified duration);
4) a benchmark period; and
5) a protection standard statistic.

In addition to Beecher's requirements, researchers (Seerley et al. 2006) at the University of Georgia Carl Vinson Institute of Government have identified the following seven guiding principles for instream flow protection:

1) Preserving whole functioning ecosystems rather than focusing on a single species.
2) Mimicking, to the greatest extent possible, the natural flow regime, including seasonal and inter-annual variability.
3) Expanding the spatial scope of instream flow studies beyond the river channel to include the riparian corridor and floodplain systems.

4) Conducting studies using an interdisciplinary approach.
5) Using reconnaissance information to guide choices from among a variety of tools and approaches for technical evaluations in particular river systems.
6) Practicing adaptive management, an approach for recommending adjustments to operational plans in the event that objectives are not achieved.
7) Involving stakeholders in the process.

In 2005, changes were made to the Florida Administrative Code that acknowledge the importance of retaining the hydrologic regime. Specifically, Chapter 62-40.473(2) of the State Water Resources Implementation Rule currently directs that "minimum flows and levels should be expressed as multiple flows or levels defining a minimum hydrologic regime". This change was intended to protect variation in water flows and levels that contributes to significant functions of ecosystems. An alternate approach which also maintains a flow regime is to develop minimum flows using a 'percent of flow approach' as discussed in Flannery et al. (2002) and has been incorporated into several SWFWMD surface water use permits and existing minimum flows in the SWFWMD.

1.3 District Approach for Establishing Minimum Flows

The District's approach for minimum flows development incorporates the five elements listed above by Beecher (1990) and more generally also incorporates the principles of Seerley et. al., (2006). These principals as defined by the District and applied to District minimum flows are as follows:

- The goal of a minimum flows determination is to protect the resource from significant harm due to withdrawals and was broadly defined in the enacting legislation as "*the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area*." What constitutes "significant harm" was not defined.
- Impacts on the water resources or ecology are evaluated based on an identified subset of site specific potential resources of interest but generally include: recreation in and on the water; fish and wildlife habitats and the passage of fish; estuarine resources; transfer of detrital material; maintenance of freshwater storage and supply; aesthetic and scenic attributes; filtration and absorption of nutrients and other pollutants; water quality, and navigation.
- The principal unit of measure used by the District for defining minimum flows is flow or discharge regime defined in cubic feet per second.
- Benchmark periods, if available, are generally defined as a period of record for the system under evaluation in which anthropogenic effects are presumed to be minimal or represent a natural, or “Benchmark” flow regime.
- The protection standard statistic is typically defined to include a low flow cutoff value and a proportion of the natural flow regime that would result in protection from significant harm to the system under study.

To justify adoption of a minimum flow for purposes of maintaining ecologic integrity, it is necessary to demonstrate, with site-specific information, the ecological effects associated with flow alterations and to also identify thresholds for determining whether these effects constitute significant harm. As described in Florida's legislative requirement to develop minimum flows, the minimum flow is designed to prevent "significant harm" to the state's rivers and streams. Not only must "significant harm" be defined so that it can be measured, it is also implicit that some deviation from the purely natural or existing long-term hydrologic regime may occur before significant harm occurs. The goal of a minimum flow would, therefore, not be to preserve a hydrologic regime without modification, but rather to establish the threshold(s) at which modifications to the regime begin to affect the aquatic resource and at what level significant harm occurs. If recent changes have already "significantly harmed" the resource, or are expected to do so in the next twenty years, it will be necessary to develop a recovery or prevention plan.

As minimum flows for rivers within the District have been adopted, the approaches used to establish the minimum flows have become more unified and those that have been passed the test of independent scientific review have been more commonly employed. Commonly accepted approaches now in use by the District include the "Percent of Flow" and "Building Block" approaches that define the minimum flows with respect to maintaining withdrawals as a proportion of the natural flow regime, and by identifying seasonality as an important attribute within which distinct criteria may be necessary, respectively. In addition, while earlier minimum flows reports contain considerable descriptive text not quantifiably used to establish the minimum flows, presently, the District prefers to limit the minimum flows reports to subjects/topics that are quantifiable and contribute directly to the establishment of the minimum flows.

The specific elements associated with the District approach to develop minimum flows are described in the sub-sections below.

1.3.1 Flows and Levels

Although somewhat semantic, there is a distinction between flows, levels and volumes that should be appreciated when considering minimum flows development. The term "flow" may most legitimately equate to water velocity; which is typically measured by a flow meter. A certain velocity of water may be required to physically move particles heavier than water; for example, periodic higher velocities will transport sand from upstream to downstream; higher velocities will move gravel; and still higher velocities will move rubble or even boulders. Flows may also serve as a cue for some organisms; for example, certain fish species search out areas of specific flow for reproduction and may move against flow or into areas of reduced or low flow to spawn. Certain macroinvertebrates drift or release from stream substrates in response to changes in flow. This release and drift among other things allows for colonization of downstream areas. One group of macroinvertebrates, the caddisflies, spin nets in the stream to catch organisms and detritus carried downstream, and their success in gathering/filtering prey is at least partially a function of flow. Other aquatic species have specific morphologies that allow them to inhabit and exploit specialized niches located in flowing water; their bodies may be flattened (dorsally-ventrally compressed) to allow them to live under rocks or in crevices; they may have special holdfast structures such as hooks or even secrete a glue that allows them to attach to submerged objects.

Discharge refers to the volume of water moving past a point per unit time, and depending on the size of the stream (cross-sectional area), similar volumes of water can be moved with quite large differences in the velocity. The volume of water moved through a stream can be particularly important to an estuary. It is the volume of freshwater that mixes with salt water that determines, to a large extent, what the salinity in a fixed area of an estuary will be. This is especially important for organisms that require a certain range of salinity. The volumes of fresh and marine water determine salinity, not the flow rate per se; therefore, volume rather than flow is the important variable to this biota. For the purpose of developing and evaluating minimum flows, the District identifies discharge in cubic feet per second for field-sampling sites and specific streamflow gaging stations.

In some cases, the water level or the elevation of the water above a certain point is the critical issue to dependent biota. For example, the wetland fringing a stream channel is dependent on a certain hydroperiod or seasonal pattern of inundation. On average, the associated wetland requires a certain level and frequency of inundation. Water level and the duration that it is maintained will determine to a large degree the types of vegetation that can occur in an area. Flow and volume are not the critical criteria that need to be met, but rather water surface elevation or level.

There is a distinction between volumes, levels and velocities that should be appreciated. Although levels can be related to flows and volumes in a given stream (stream gaging, in fact, often depends on the relationship between stream stage or level and discharge), the relationship varies between streams and as one progresses from upstream to downstream in the same system. Because relationships can generally be empirically determined between levels, flows and volumes, it is possible to speak in terms of, for example, minimum flows for a particular site (discharge in cubic feet per second); however, one needs to appreciate that individual species and many physical features may be most dependent on a given flow, level or volume or some combination of the three for their continued survival or occurrence. The resultant ecosystem is dependent on all three.

For analyses and reporting the District has transitioned to the North American Vertical Datum of 1988 (NAVD 88). The SWFWMD has transitioned away from NGVD29 for the following reasons:

- This datum was created using surveying technologies that were available in the early twentieth century. Its accuracy is limited when compared to the current state of the art in surveying and mapping.
- Nationally, many of the NGVD29 physical benchmarks have been destroyed or have invalid elevations because of ground subsidence, crustal deformation or glacial rebound.

- New surveying technologies such as global position systems (GPS) cannot effectively utilize NGVD29.

1.3.2 The Flow Regime

Fundamental to the approach used for development of minimum flows and levels is the realization that a flow regime is necessary to protect the ecology of the river system. The initial step in this process requires an understanding of historical and current flow conditions to determine if current flows reflect past conditions. If this is the case, the development of minimum flows and levels becomes a question of what can be allowed in terms of withdrawals before significant harm occurs.

Hill et al. (1991) identified four types of flows that should be considered when examining river flow requirements, including:

1) flood flows that determine the boundaries of and shape floodplain and valley features;
2) overbank flows that maintain riparian habitats;
3) in-channel flows that keep immediate stream banks and channels functioning; and
4) low flows that meet critical fish requirements.

As emphasized by Hill et al. (1991), minimum flow methodologies should involve more than a consideration of immediate fish needs or the absolute minimum required to sustain a particular species or population of animals, and should take into consideration “how streamflows affect channels, transport sediments, and influence vegetation.” Although, not always appreciated, it should also be noted, “that the full range of natural intra- and inter-annual variation of hydrologic regimes is necessary to [fully] sustain the native biodiversity” (Richter et al. 1996). Successful completion of the life-cycle of many aquatic species is dependent upon a range of flows, and alterations to the flow regime may negatively impact these organisms as a result of changes in physical, chemical and biological factors associated with particular flow conditions.

More recently, South African researchers, as cited by Postel and Richter (2003), listed eight general principles for managing river flows:

1) "A modified flow regime should mimic the natural one, so that the natural timing of different kinds of flows is preserved.
2) A river's natural perenniality or non-perenniality should be retained.
3) Most water should be harvested from a river during wet months; little should be taken during the dry months.
4) The seasonal pattern of higher baseflows in wet season should be retained.
5) Floods should be present during the natural wet season.
6) The duration of floods could be shortened, but within limits.
7) It is better to retain certain floods at full magnitude and to eliminate others entirely than to preserve all or most floods at diminished levels.
8) The first flood (or one of the first) of the wet season should be fully retained."

Common to this list and the flow requirements identified by Hill et al. (1991) is the recognition that in-stream flows and out of bank flows are important for ecosystem functioning, and that seasonal variability of flows should be maintained. Based on these concepts, the preconception that minimum flows (and levels) are a single value or the absolute minimum required to maintain ecologic health in most systems has been abandoned in recognition of the important ecologic and hydrologic functions of streams and rivers that are maintained by a range of flows. And while the term “minimum flows” is still used, the concept has evolved to one that recognizes the need to maintain a “minimum flow regime”. In Florida, for example, the St. Johns River Water Management District typically develops multiple flow requirements when establishing minimum flows and levels (Chapter 40-C8, F.A.C) and for the Wekiva River noted that, “[s]etting multiple minimum levels and flows, rather than a single minimum level and flow, recognizes that lotic [running water] systems are inherently dynamic” (Hupalo et al. 1994).

For freshwater rivers and streams, criteria associated with fish passage in the river channel, protection of instream flows for habitat suitability of benthic macroinvertebrates and fishes, and frequency and duration of floodplain inundation are routinely used. These analyses result in a specific discharge limit, in CFS, at which further reductions in flow would be considered significantly harmful and typically result in a percent reduction from a baseline flow condition to define the regulatory limits. For estuarine systems, salinity is a principal forcing function for tidal river biological processes controlling a host of biogeochemical processes related to phytoplankton availability, primary and secondary production, and the location of emergent wetland vegetation along the estuarine gradient of the tidal reach. Significant District resources have been expended in developing potential biological criteria used to support the establishment of minimum flows for tidal river reaches including scientific studies on oysters, benthic invertebrates, phytoplankton, zooplankton, and fishes. While no standard criteria have been accepted that could serve as threshold values for all District tidal river reaches, criteria have been developed on a case by case basis that have been used in combination to support the establishment of minimum flows for District tidal river reaches.

1.3.3 The Building Block Approach

The peer-review report on proposed minimum flows for the upper segment of the Peace River (Gore et al. 2002) identified a "building block" approach as "a way to more closely mirror original hydrologic and hydroperiodic conditions in the basin". Development of regulatory flow requirements using this type of approach typically involves description of the natural flow regime, identification of building blocks associated with flow needs for ecosystem specific functions, biological assemblages or populations, and assembly of the blocks to form a flow prescription (Postel and Richter 2003). As noted by the panelists comprising the Upper Peace River minimum flows review panel, "assumptions behind building block techniques are based upon simple ecological theory; that organisms and communities occupying that river have evolved and adapted their life cycles to flow conditions over a long period of pre-development history (Stanford et al. 1996). Thus, with limited biological knowledge of flow requirements, the best alternative is to recreate the hydrographic conditions under which communities have existed prior to disturbance of the flow regime." Although in most cases, the District does not expect to recreate pre-disturbance hydrographic conditions through minimum flows development and implementation, the building block approach is viewed as a reasonable means for ensuring the maintenance of similar, although dampened**,** natural hydrographic conditions.

Blocks are defined by analyzing the median daily flows for the period of record. Block 1 begins when the median daily flow drops below and stays below the 75% exceedance flow and continues until the beginning of Block 3. Block 3 begins when the median daily flow exceeds and stays above the 50% exceedance flow. Once the median daily flow falls below the 50% exceedance flow, Block 2 begins and continues until the beginning of Block 1. For the Little Manatee River, the dates separating the blocks are as follows:

- Block 1 – April 18th through June 22nd
- Block 2 – October 22nd through April 17th
- Block 3 – June 23rd through October 21st

The building block approach was used in the development of a recommended minimum flows for the freshwater portion of the Little Manatee River (Hood et al. 2011). However, in the latest reevaluation of the freshwater minimum flows (Janicki Environmental, 2017), the natural resource requirements for wetted perimeter, fish passage, instream habitat, and floodplain inundation were identified which lined up very closely with the building block approach. That is, because natural resources of concern have been identified that are reliant on different aspects of the hydrograph, the resource based flows generally mimic the building block approach. A comparison between the resource-based and building block approach demonstrate that the resource based flows align very well with the building block definitions. For the estuarine segment of the Little Manatee River, the natural resource requirements with principally limited to instream flows and therefore, the building block approach was retained for the assessment of how flow reductions would affect the natural resources of concern of the estuary including salinity regimes, benthos, plankton and nekton.

1.3.4 Benchmark Flows

The SWFWMD has adopted an approach for establishing benchmark flow periods that involves consideration of variation in climatic on river flow patterns. The approach is based in part on examination of variations in the Atlantic Multi-decadal Oscillation as described in other District reports (e.g. Kelly et. al. 2005a and b) and is now routinely used to develop minimum flows within the SWFWMD. Following assessment of historic and current flow regimes and the factors that have affected their development, the District develops protection standard statistics or criteria for preventing significant harm to the water resource. If there have been changes to the flow regime of a river over time, these changes must be evaluated to determine if significant harm has already occurred in the system. If significant harm has occurred, then a restoration plan may be required to achieve a minimum flow. In the case of the Little Manatee River, the

Benchmark Flows approach was evaluated and a "Baseline" flow record was established that best represented the expected flows in the absence of anthropogenic effects to the system. Analysis of rainfall records in the basin suggested little evidence historically wet and dry periods aligning with the Atlantic Multi-decadal Oscillation though there were certainly shorter wet and dry periods within the period of record. This is described in detail in Chapter 2.2 of this report.

1.4 Project History

A freshwater minimum flows report for the Little Manatee River was developed by the District in draft form in 2011 (Hood et al. 2011) and peer reviewed in 2012 (Powell et al. 2012). In 2016, Janicki Environmental, Inc. was contracted by the District to address peer review comments on the freshwater minimum flows document and provide additional analytical support through a re-evaluation of the proposed freshwater minimum flows for the Little Manatee River. A draft document describing that re-evaluation is currently in internal District review. District efforts to develop minimum flows for the estuarine section of the Little Manatee River were initiated in 2004. A hydrologic model (Intera 2006), a hydrodynamic model of the estuary (Huang and Liu 2007), analysis of the relationship between fish and flows (MacDonald et al. 2007), and analysis of the relationship between plankton and flows (Peebles 2008) have been conducted to evaluate the effects of freshwater flows on estuarine ecology. Janicki Environmental was contracted to compile existing information and perform additional analyses in support of recommending minimum flows for the estuarine portion of the Little Manatee River (this document).

1.5 Content of Remaining Chapters

The remaining chapters of this document include a description of:

- the watershed of the Little Manatee River including landuse, rainfall and streamflow characteristics as well as a review of recommended minimum flows for the freshwater section;
- the estuary of the Little Manatee River including its physical, water quality, and biological characteristics;
- the identified resources of concern and technical approach to identify the minimum flows;
- the specific criteria used to evaluate the minimum flows;
- the results of the minimum flows evaluation including outcomes of all analytical efforts, and
- the proposed minimum flows recommendations.

2 WATERSHED CHARACTERISTICS AND FRESHWATER MINIMUM FLOWS

This chapter includes a description of the Little Manatee River watershed including landuse, rainfall and streamflow characteristics, as well as a review of the technical approach used to establish the proposed minimum flows for the freshwater portion of the Little Manatee River (Hood et al. 2011). The Little Manatee River watershed was well described in Hood et al. (2011) and is reproduced in section 2.1 with permission for context with respect to the downstream estuary.

2.1 Background – Watershed Characteristics

The Little Manatee River originates in a swampy area east of Fort Lonesome, Florida in southeastern Hillsborough County and flows generally westward for about 36 miles toward its discharge point into Tampa Bay near Ruskin, Florida (Hood et al. 2011). The Little Manatee River watershed extends over the southern part of Hillsborough County and the northern portion of Manatee County (Figure 2-1). The watershed is bordered by the Alafia River watershed to the north, the Manatee River watershed to the south and to the east by the Peace River watershed (Hood et al. 2011). The Little Manatee drains approximately 224 square miles of land. The watershed incorporates the City of Palmetto and communities of Parrish, Ruskin, Sun City and Terra Ceia. Other features of interest include Lake Wimauma, Lake Parrish, the Little Manatee River State Recreation Area and the Cockroach Bay Aquatic Preserve.

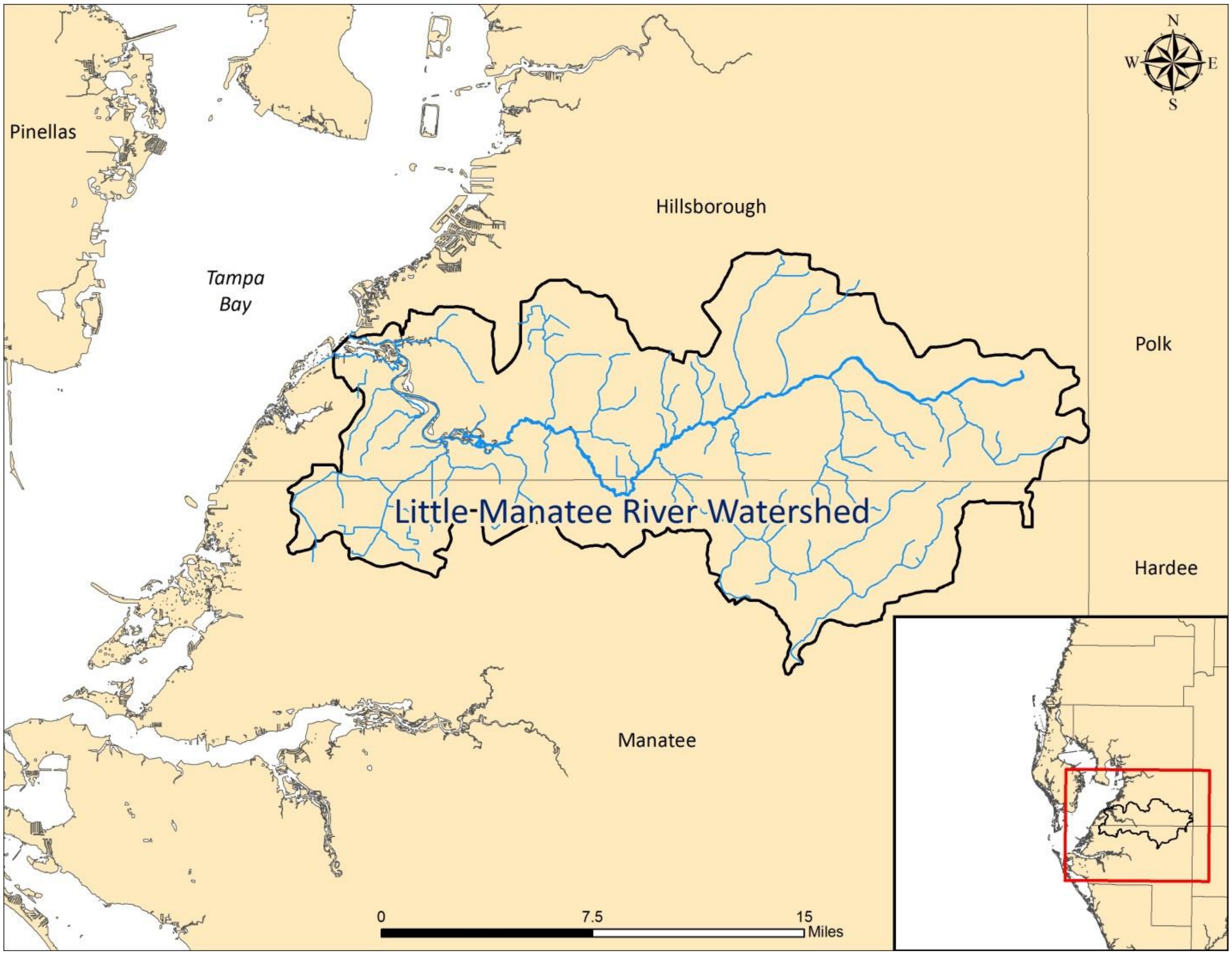

Figure 2-1. Location of the Little Manatee River (from Hood et. al., 2011).

In the Polk Upland province, near the town of Fort Lonesome, the river travels over the clay-rich Bone Valley Member of the Peace River formation. This is the lithologic unit planned for mining for phosphate minerals in the eastern part of the Little Manatee watershed. The river's banks in this region become less steep with many low relief floodplain or wetland areas surrounding the river. A portion of this area will have its physiography and associated surface water drainage systems modified by mining activities. Altered physiographic features in this region may include water-filled, former mine pits and large, diked clay-settling areas of various rectilinear configurations similar to those in the Alafia River watershed.

Primary soil groups in the Little Manatee River watershed include the Myakka-Urban land-St. Augustine and Estero-Wulfer-Kesson groups in the coastal areas. These associations are nearly level, poorly drained black soils commonly found in swamps, tidal marshes and river flood plains. Inland from these areas, the prevalent soil types are the EauGallie-Floridana, Myakka-Bassinger-Holopaw, Malabar-Wabasso-Bassinger, Myakka Immokalee-Pomello, Myakka Waveland Classic and Waveland-Pomello-Myakka associations. These groups include nearly level and poorly to moderately drained soils characteristic of flatwood areas.

The Little Manatee watershed is underlain by water-bearing limestones and dolomites of Eocene to Miocene age, covered by a 200-300 foot layer of unconsolidated sands and sandy clays of Pliocene, Pleistocene and Recent origin. The watershed lies within the southern groundwater basin and contains three distinct aquifer systems: the surficial, intermediate and Floridan. The surficial aquifer is unconfined and is composed of variable amounts of clean quartz to clayey sand. At the base of the surficial aquifer, there may be phosphate grains and clays present that have been reworked from the underlying phosphate-bearing Bone Valley Member. The underlying intermediate aquifer is made up of the permeable lithologies present in the Hawthorne Group including the lowermost limestone unit (Tampa Member). In the Little Manatee River watershed, the intermediate aquifer serves as a locally important potable water source for domestic wells.

The Little Manatee River watershed is approximately 224 square miles or 143,051 acres. From 1974 to 2004 there was a 400% increase in urban land use from 3,970 to 15,890 acres. Urban land use represented 11.1% of the land use in 2004. Even more apparent in the Little Manatee Watershed is the growth of the mining land use area. From 1974 to 2011 there have been 20,568 acres added to the mining land use and an additional 4,750 acres of reclaimed lands. This increase, primarily in the upper reaches of the watershed, has taken mining from approximately 0% of the watershed to over 12% of the watershed since 1974. The majority of lands now under mining and urban land use were previously classified as rangeland.

2.2 Rainfall

The National Center for Environmental Information warehouses rainfall data collected by the National Weather Service (NWS). Three long-term NWS rainfall gages exist within the Little Manatee River watershed and adjacent area: Hillsborough State Park, Parrish, and Plant City. Monthly total rainfall timeseries (inches) for these gages are presented in Figure 2-2. The line breaks in the plots represent missing data within the period of record for each gage. The Plant City rainfall gage record is relatively complete back to the early-1930s, with some missing monthly values during the 1970s, though there were several months within the period of record where no rainfall was recorded (i.e., reported as 0 inches of rainfall). The period of record for evaluation of the rainfall and hydrology for the original minimum flow report was defined as 1940 to 2009, but these data were updated through 2014, where available for our re-evaluation. The rainfall data were adequately characterized in the 2011 minimum flows report, and that characterization remains relevant to the updated data. Annual average rainfall in the watershed was approximately 54 inches. In a typical year, approximately 60 percent of the annual precipitation comes typically from convective rainfall (i.e., thunderstorms) during a four-month period from June through September along with periods of extremely heavy precipitation associated with the passage of tropical low pressure systems may occur during summer and early fall (i.e., June through November).

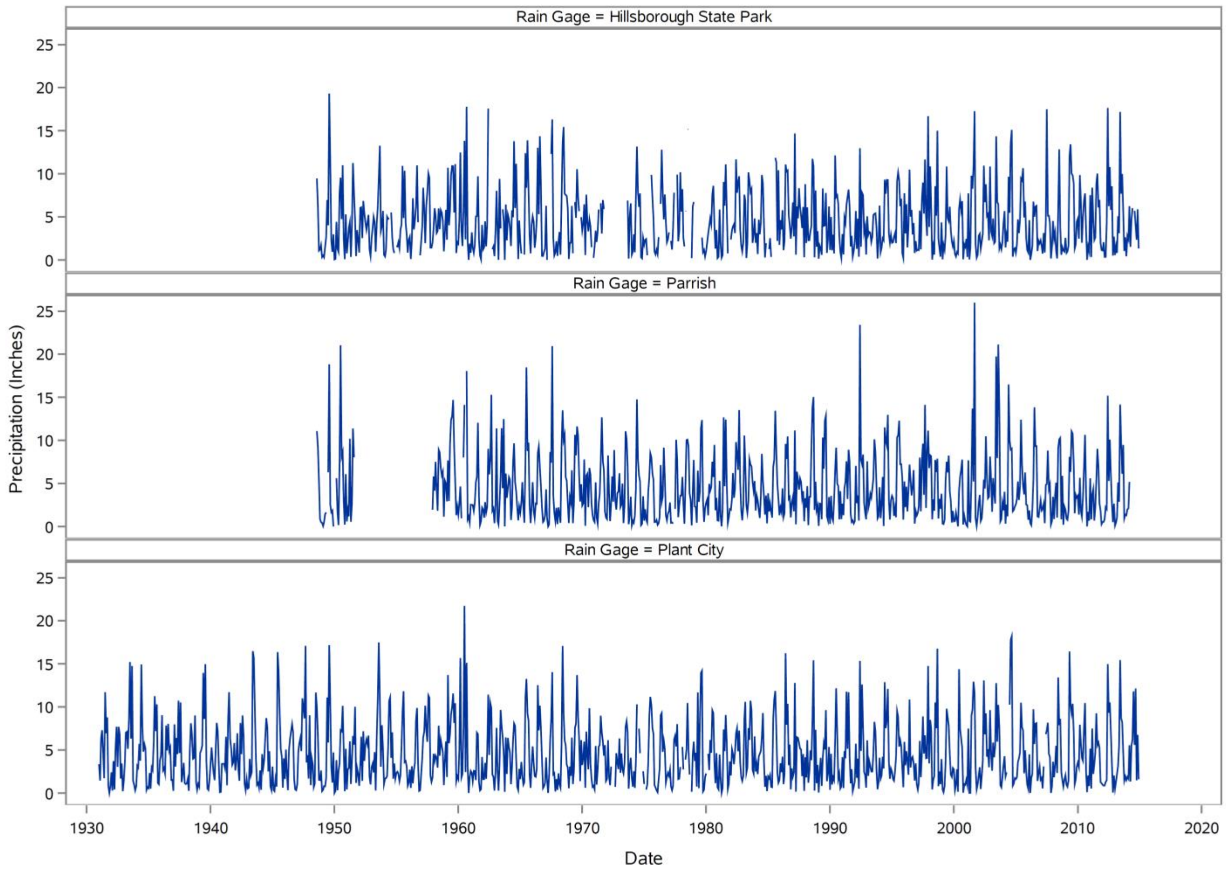

Figure 2-2. Rainfall timeseries for three National Weather Service gages in the vicinity of the Little Manatee River watershed.

Timeseries trend analysis was conducted on the rainfall timeseries for Plant City and Bradenton for the 2011 minimum flows report and no timeseries trends were observed over the period of record. This analysis was confirmed for the gages listed in Figure 2-2 as part of the 2017 re-evaluation, supporting the finding that there were no observed trends in rainfall over the period of record. The freshwater report also described several periods of above and below average rainfall over the period of record. A succinct manner of displaying this information is through the use of the Standardized Precipitation Index (SPI) (McKee et al. 1993) that standardizes rainfall to its long term expected values based on a defined period of record to characterize drought and surplus rainfall conditions. The SPI values can be integrated over various timescales to represent antecedent conditions. For example, the timeseries of the 12 month SPI values for the Parrish gage is presented in Figure 2-3. The plot is conceptually similar to a moving average except that each month's value is compared to a 12 month window of values ending in the same month over the entire period of record. For instance, for December 2000, the sum of the rainfall from January through December of 2000 is calculated and compared to all January-December sums across the period of record. The deviation from the expected condition is calculated and deviations are expressed based on the gamma distribution (Vincente –Serrano 2010). The Y axis in the plot therefore represents units of standard deviations and in this way the variability in rainfall relative to its expected values is plotted as a timeseries which allows comparisons across different gages with different expected rainfall conditions. Missing values were filled by imputing the average of the Hillsborough and Plant City gages as available. Values below zero indicate less than expected rainfall and values above zero represent periods of greater than expected rainfall. Droughts and surplus conditions can be categorized based on the following values (McKee et al. 1993):

- 2.0 +; extremely wet
- 1.5 to 1.99; very wet
- 1.0 to 1.49; moderately wet
- -.99 to .99; near normal
- -1.0 to -1.49; moderately dry
- -1.5 to -1.99; severely dry
- -2 and less; extremely dry

It is clear to see from the graph that the mid to late 1970's and the early 2000's were periods of rather severe drought while the late 1950's and early 1960's, and the mid 2000's were periods of well above average rainfall. The most recent time period suggests that the watershed recently recovered from another period of below average rainfall between 2010 and 2012.

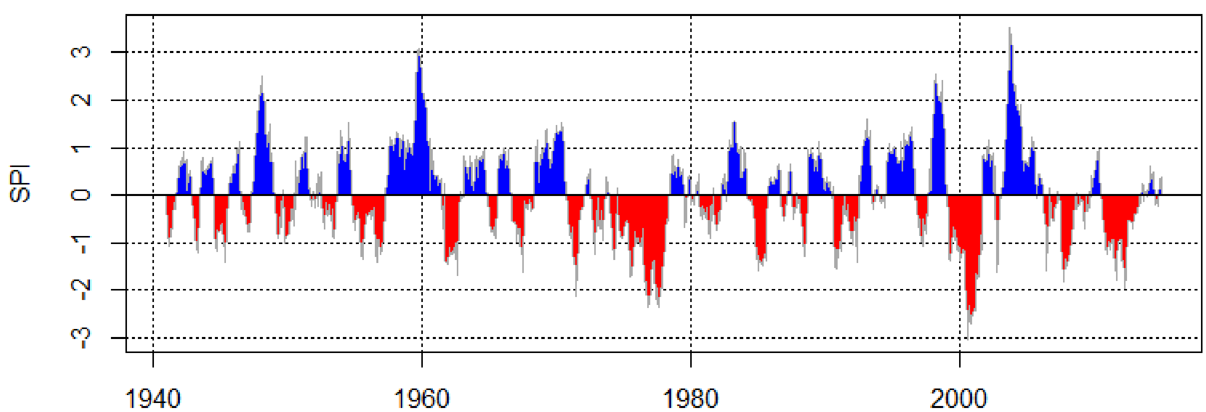

Figure 2-3. Twelve month Standardized Precipitation Index values for the Parrish gage based on data from 1940 to 2014.

2.3 Streamflow

Streamflow has been monitored by the U.S. Geological Survey (USGS) at three principal gages in the Little Manatee River. The most downstream gage (gage #1 in Figure 2-4) is located at the US Highway 301 bridge near Wimauma (USGS 02300500), which represents approximately 67% of the watershed. An active USGS streamflow gage in the upper reaches of the river, with records that date back to 1963, is the Little Manatee River near Ft. Lonesome (#2: USGS 02300100) which measures flow from approximately 15% of the watershed. An active gage on the South Fork of the river (#3: USGS 02300300) has been operation since October 2000. That gage was also operated during 1987-1989, with several other District sponsored gages (#'s 4, 5, 6) that were part of a study of the watershed that was conducted by the District and other agencies in the late 1980s (Flannery et al. 1991). The principal streamflow gage of record for the estuarine minimum flows is the USGS gage at Wimauma (USGS 02300500) since this is the most downstream gage on the river which measures freshwater flow. This gage is subsequently referred to in this document as the "Wimauma gage".

The average daily discharge for the Wimauma gage over the period 1940 to 2014 was 168 cubic feet per second (cfs) and the median value over the same period was 61 cfs indicating that the average is skewed by high flow events, with daily flows recorded up to a maximum of 11,100 cfs (Figure 2-5).

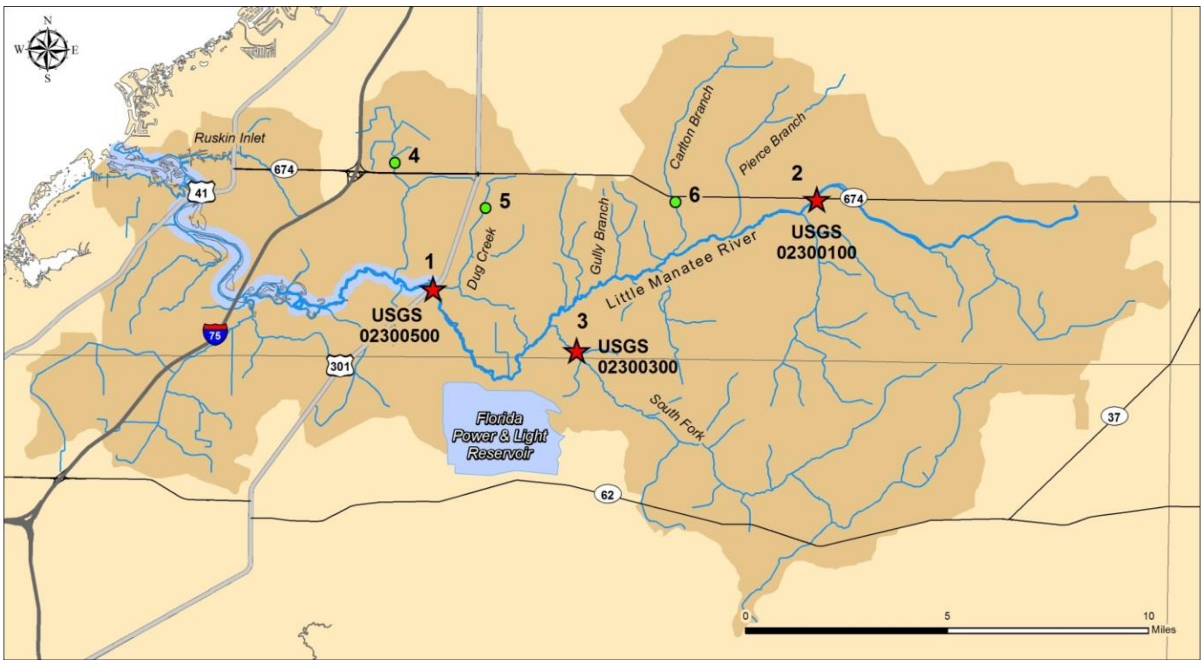

Figure 2-4. **Location of currently active (red stars) and previously operated (green circles) streamflow gages in the Little Manatee River watershed maintained by the USGS (replicated from Hood et. al., 2011).**

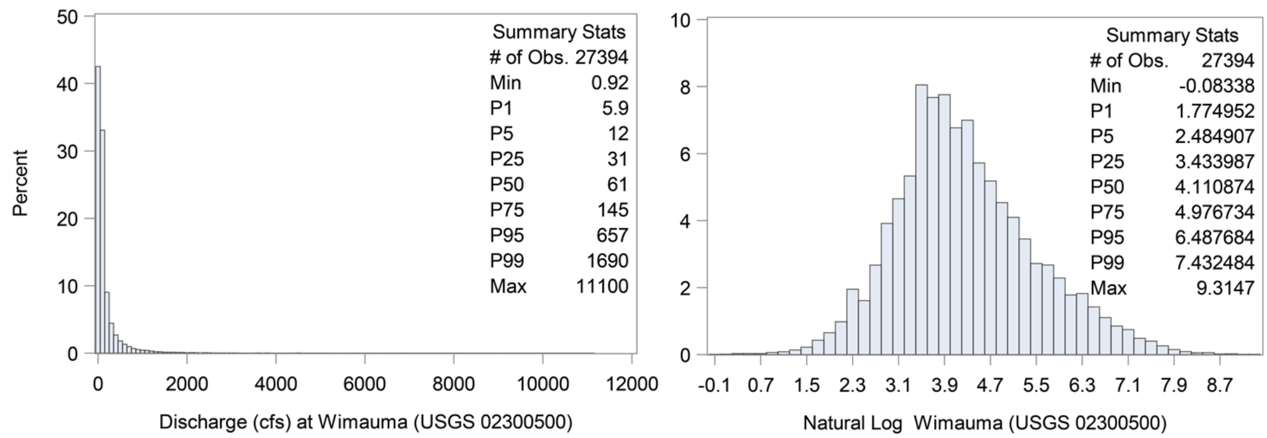

Figure 2-5. Frequency histogram and summary statistics for discharge at USGS 02300500 – Wimauma from 1940 through 2014 on natural (left) and natural log transformed (right) scale.

Hood et al. (2011) found that the runoff rate for the Little Manatee River watershed was higher than either the Hillsborough River (at USGS Station 0230300, Hillsborough River near Zephyrhills, FL) or Alafia River (at USGS Station 02301500, Alafia River at Lithia, FL) which represent similar portions of their respective watershed areas. This indicates that the Little Manatee River is a relatively flashy system even though much of its watershed is rural.

2.4 Land Use Changes

There are three principal anthropogenic influences to stream flows in the Little Manatee River: 1) changes in land-use characteristics over time, 2) groundwater extractions, and 3) surface water withdrawals. These factors are all well described in the 2011 minimum flows report. Briefly, the effects of increasing groundwater withdrawals on saltwater intrusion have been particularly acute in portions of the Little Manatee River watershed, and approximately half of the Little Manatee River watershed lies within the District-designated Most Impacted Area of the Southern Water Use Caution Area. As reported in Table 2-1 of the 2011 minimum flows report, while the acreage of citrus remained relatively constant over time, large increases were reported in the acreage and irrigation quantities for tomatoes and other vegetable (row) crops in the region. Irrigation practices for row crops, particularly the "flood field" irrigation practices of the late 1970s and 1980s, were thought to contribute significantly to land-surface runoff by increasing the water table, by using plastic underlayment that impedes infiltration, and by de-watering saturated fields to maintain constant water-table elevations.

The Land Use Land Cover dataset through 2011 (the most recent coverage) was acquired from the Southwest Florida Water Management District (SWFWMD 2012). These datasets include features categorized according to the Florida Land Use and Cover Classification System (FLUCCS). These features were photo-interpreted at 1:8,000 using 2010 1 – ft color infrared (CIR) digital aerial photographs and include the FLUCCS Land Use code, and vegetation indicators. Since the time landuse analysis was conducted for the original freshwater minimum flows report, the District has revised some of the land use classifications for the 2004 data resulting in a discrepancy between the values reported here and those reported in Hood et al., 2011. In addition, the landuse classification of wetlands and water in the 1970's landuse coverage may be unreliable. The landuse information for the watershed reported by Hood et al. (2011) updated through 2011 is provided in Table 2-1. A comparison between landuse in 1990 and 2011 is provided in Figure 2 6. One of the largest changes has been a steady decrease in rangelands within the watershed which have transitioned to other types of land use, including developed lands, agriculture, and mining. Irrespective, it is clear that there has been an increase in mined lands, developed urban lands, and agriculture over the time period. The "other agriculture" category contains "open/Public lands" and the recent increase in this acreage can be attributed to recent conservation efforts by Hillsborough County to purchase conservation lands within the watershed.

Table 2-1. Changes in land use classification acreage over time in the Little Manatee River watershed.

Land Use Type	Acreage by Year					
Year	**1974**	**1990**	**1999**	**2004**	**2007**	**2011**
Developed/Urban	3,970	11,354	13,517	16,161	18,519	21,356
Ag - Row Crop	13,204	10,897	15,383	12,952	12,717	10,410
Ag - Tree Crop		12,816	14,191	12,124	7,167	6,159
Other Agriculture	841	6,461	7,434	11,265	14,259	16,337
Forested Uplands	10,723	14,569	13,808	12,654	11,684	10,924
Wetlands	10,369	21,489	19,863	19,272	19,131	20,825
Mines	45	3,289	8,743	17,622	20,568	17,769
Reclaimed Mines	.	.	.	.	.	4,750
Water	681	4,997	5,175	5,236	5,436	5,609
Rangeland	102,299	57,659	44,938	35,810	33,614	28,956

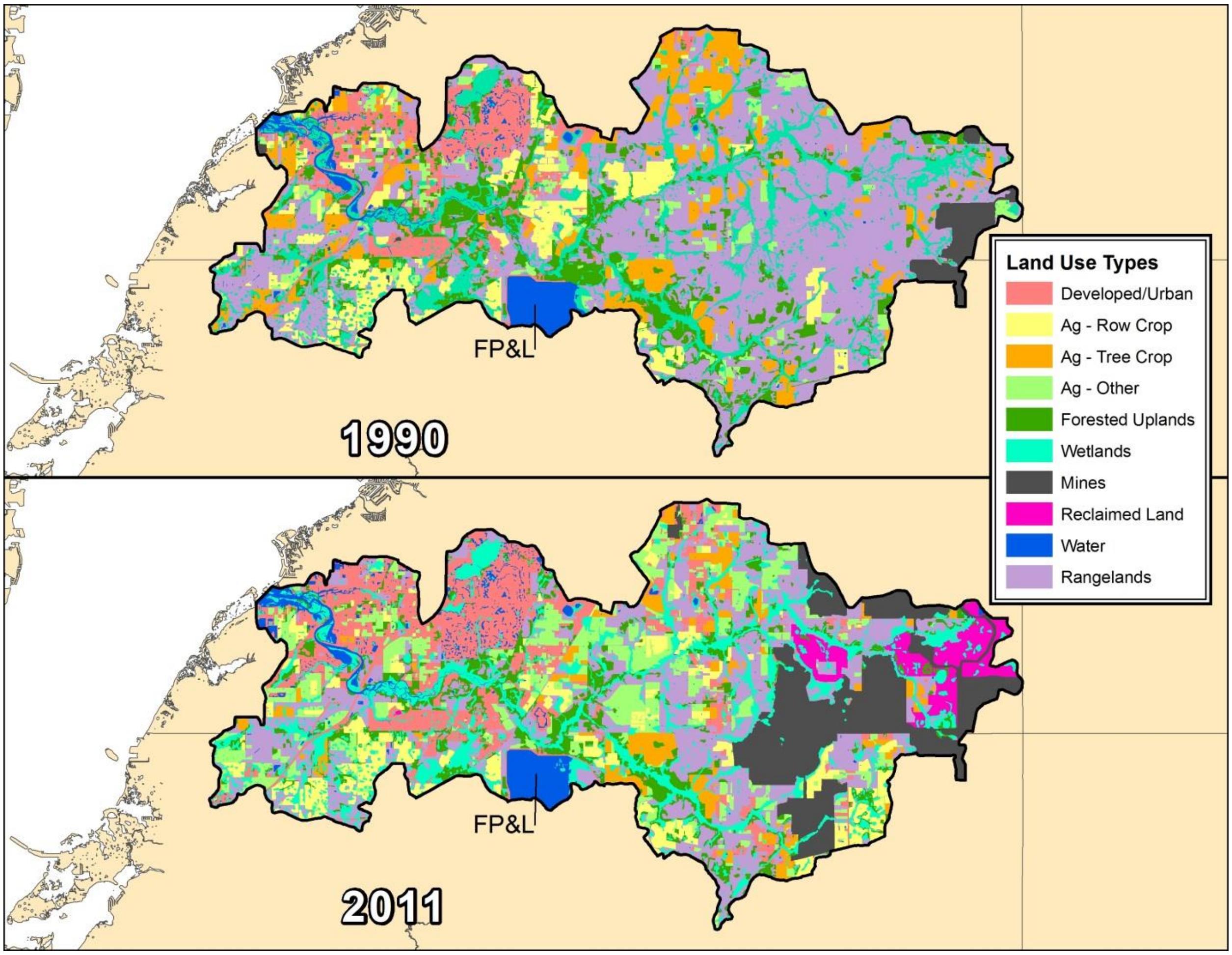

Figure 2-6. Changes in land use classification from 1990 to 2011 in the Little Manatee River watershed. The Florida Power and Light reservoir is labeled in the center of each map.

Developed and urban lands within the watershed have increased from 11,000 acres in 1990 to over 21,000 acres in the most recent land use survey. Mining lands increased until their peak in the 2007 land use survey. Some of the previously mined lands have recently transitioned to reclaimed mining lands. Agriculture in the Little Manatee River watershed peaked in 1999. Since 1999, the land used to for both row and tree crops has dropped significantly. Nearly 8,000 acres or 27% of the land which was used for tree and row crops in 1999 have been reclassified to "other open lands <rural>". This category is defined by SWFWMD as lands that:

- Include dead or deserted crops or tree crops;
- Usually portrays a rough, uneven, shrubby texture but still portrays the appearance of agricultural processes (straight borders, old field markings, old grove lines, etc.)

The classification is predominantly used for previously farmed lands that have since not been used for cultivation indicating that the Little Manatee River watershed is recently changing from a large agricultural area to one with less row and tree crops.

2.5 Surface Water Withdrawals and Discharges

There are thought to be three principal anthropogenic influences that have the potential to influence instream flows at the USGS gage (02300500) on the Little Manatee River near Wimauma. Florida Power and Light is permitted to 10% of river flow to supplement its cooling water pond when flows are above 40 cfs. However, the permit does allow for an emergency diversion schedule (EDS) to be applied when water levels in the cooling pond fall below 62 feet above mean sea level. According to the conditions of the site certification, FP&L must notify the director of the Resource Regulation at the District prior to implementing the EDS. Analysis by Hood et. al., (2011) suggested a range of FP&L withdrawals from 0 to 506 cfs, averaging approximately 9 cfs, as calculated on a daily basis. The Mosaic Company has a permitted surface water discharge, site D-001, that is located in the headwaters of the river on Alderman Creek. This outfall is managed under a permit issued by the Florida Department of Environmental Protection. The site is used to discharge stored surface water from mined lands during times of elevated rainfall amounts as reported by Hood et al. (2011). A time series plot of daily discharges as reported by Hood et. al. is provided in Figure 2-7. Daily discharge information is not currently available since 2009 but discharge records reported as monthly hydrologic loads through 2014 suggest that there have been only a few occurrences of significant discharges since 2009 (Figure 2-8). There was no attempt in the 2011 minimum flows report to account for potential effects of mining on historical flow trends or other characteristics of the streamflow data; however, it is clear that base-flow augmentation has occurred in the streamflow timeseries which must be accounted for when establishing the Baseline condition from which to identify protective flows for the Little Manatee River. Hood et al. described the effects of historical agricultural practices reliant on groundwater resources that have the potential to impact instream flows. Specifically, “flood field” irrigation practices associated with row crop agriculture was identified as a principal contributing factor to higher than expected instream flows in the 1980’s and 1990’s. Methods to adjust the historical timeseries of flows for anthropogenic streamflow augmentation was the subject of much research as described in section 4.2.7 of the original minimum flows report and the reevaluation of the freshwater minimum flows. The method accepted by the District for defining the Baseline flow timeseries representative of flows expected in the absence of anthropogenic effects is described in Chapter 5 of this report.

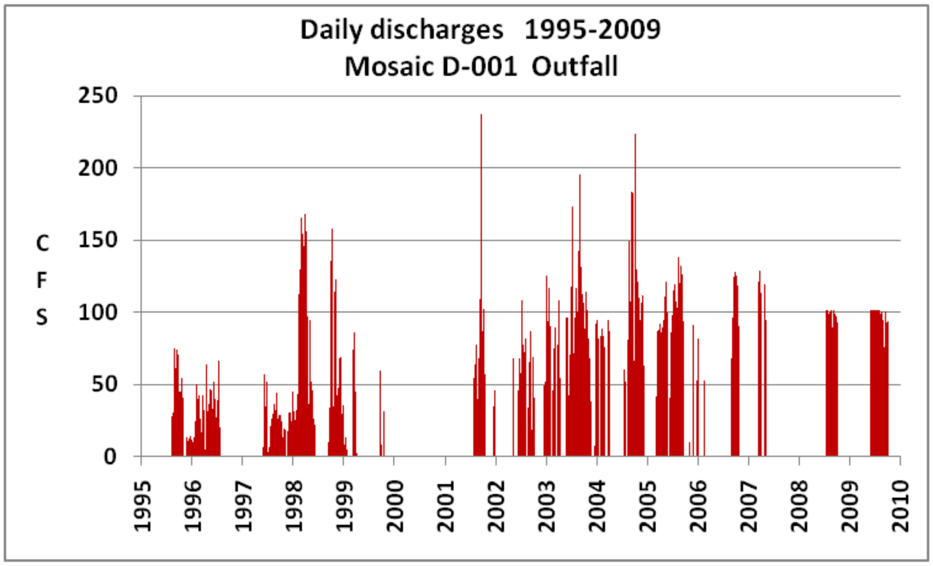

Figure 2-7. **Figure 4-16 from Hood et. al., 2011 displaying daily discharge values for the D-001 outfall through 2009.**

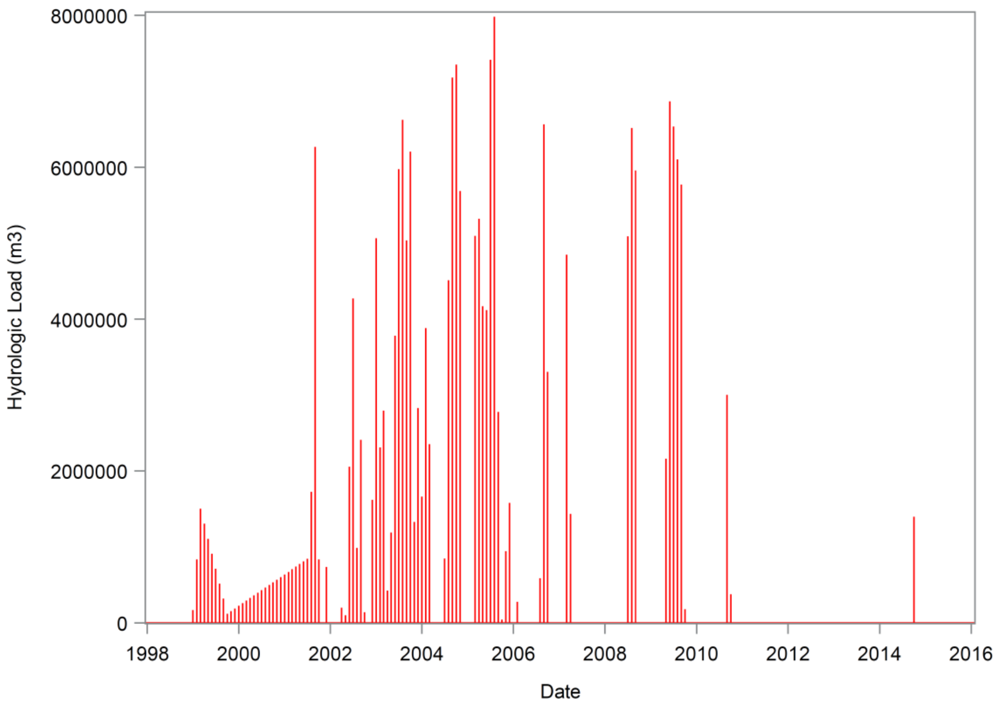

Figure 2-8. **Monthly hydrologic loads (1999-2014) for the D-001 outfall.**

2.6 Recommended Freshwater Minimum Flows

A reevaluation of the freshwater minimum flows for the Little Manatee River was recently completed and is under consideration for rulemaking as a protective standard for surface water withdrawals for the freshwater segment of the Little Manatee River. The recommended minimum flow for the freshwater portion of the river includes a low flow cutoff of 35 cfs based on evaluation of the water required to inundate the river channel in order to protect benthic invertebrates in the freshwater segment. Additional reach-specific criteria to allow fish passage to the upstream shoals in Reach 1 and 2 were also recommended if further consumptive use is permitted in the eastern portion of the watershed. In addition, no more than a 13.5% reduction in flows above the low flow cutoff is allowed anytime to protect instream habitat suitability for freshwater fish taxa, particularly the largemouth bass (*Microptera salmoides*). The floodplain inundation requirements became more restrictive criteria when floodplains were inundated (i.e., above the 60^{th} percentile of flow or 72 cfs). Above the 60^{th} percentile, a 12.8% reduction in flow would be allowed to protect the area and frequency of inundation of the floodplain with the exception of two specific reaches with higher elevated floodplains in Reach 2 and Reach 5. For these specific higher elevation floodplain wetland environments, a further restriction was applied when the flows were above the 80^{th} percentile (174 cfs) where an 11 % threshold becomes the most restrictive reduction standard.

The 13.5% reduction between 35 cfs and the 60^{th} percentile value (72 cfs) results in an allowable maximum take of approximately 10 cfs. This window for withdrawals equates to a frequency of approximately 30 percent in a typical year assuming the historic time-period is representative of future conditions. Above 72 cfs, the criterion developed to protect areas of floodplain inundation is implemented resulting in a 12.8% cap on consumptive use between 72 and 174 cfs. This results in a maximum withdrawal of 22 cfs when flows are between the 60^{th} to 80^{th} percentile of the baseline range. Above the 80% percentile (174 cfs), flow reductions are restricted to 11%. No cap on the magnitude of withdrawals is currently implemented as long as it does not exceed 11% of the daily flow; however, the District reserves the right to implement a “high flow cap” as part of any future water use permit.

3 ESTUARY CHARACTERISTICS AND WATER QUALITY

The Little Manatee River is the only tidal river in the Tampa Bay watershed designated as an "Outstanding Florida Water" (Florida Department of Environmental Protection, 2004) due largely to its relatively natural state with mostly unarmored shorelines, a sinuous river channel and highly braided areas with ample emergent wetland vegetation. Flannery (1989) wrote that the Little Manatee River "probably best represents the natural ecological interactions of a river and its watershed with Tampa Bay". These attributes differentiate the Little Manatee River from other Tampa Bay tidal tributaries. Despite these characteristics, the watershed has undergone significant changes related to anthropogenic activity over the past several decades. The following subsections describe in more detail the characteristics of the estuarine watershed including a physical description, changes in land use practices over time, characteristics of riparian buffer habitats, and the status and trends in salinity and water quality over time.

3.1 Physical Description

3.1.1 Estuarine Watershed

The entire Little Manatee watershed is 143,095 acres (224 square miles). The estuarine portion of the watershed is 47,633 acres (74.4 square miles) or 1/3rd of the entire watershed (Figure 3-1). The Wimauma gage delineates the estuarine and freshwater (or lower and upper) segments and is the gage of record (USGS 02300500) for establishing minimum flows for both segments. It should be noted that the estuarine segment contains a rather large section from Rkm 24 down to about Rkm 20 that is thought to be predominantly freshwater (i.e., tidal freshwater) during the majority of the year. The river runs generally east/west with the north side of the river in Hillsborough County and the south side mostly in Manatee County. The Hillsborough County side of the Little Manatee River is predominately urban/developed land while the Manatee County side of the river is more dominated by agricultural land use types. The estuarine basins contain 70% (14,952 acres) of all of the urban/developed land use for the entire river watershed (Table 3-1: Figure 3-2). The estuarine watershed currently has no mining activity in contrast to the freshwater portion of the watershed (Table 3-1). Most of the areas where urbanization occurred are areas that were developed in 1990 and have continued to increase (55%) until 2011. Agricultural land use types have diminished since 1990 with an 82% decrease in tree crops, a 19% decrease in row crops and a 132 increase on "other" agriculture that predominantly represents agriculture lands that are now fallow and inactive. The comparison between the 1990 and 2011 land use in the estuarine watershed is displayed spatially in Figure 3-3.

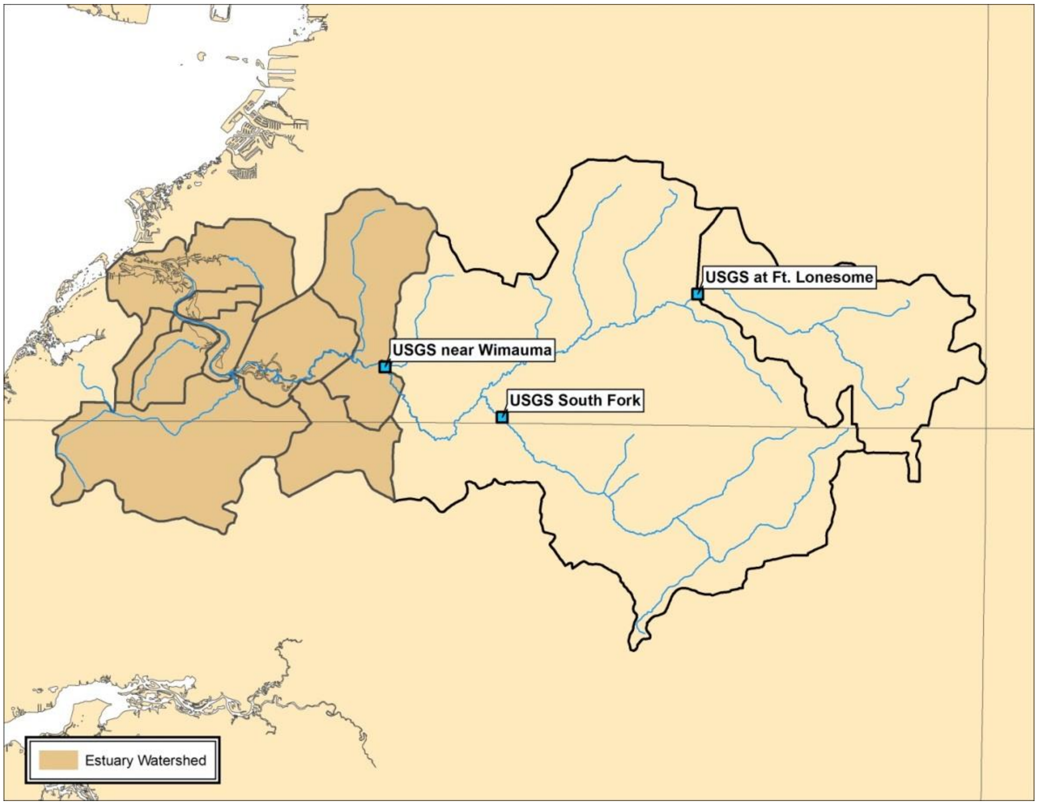

Figure 3-1. **The Little Manatee Watershed with the downstream estuarine portion shaded.**

Table 3-1. **Land use characterization for the Little Manatee River Estuarine basins and watershed.**

2011 Land Use Type	Acres in Estuary	Percent of Estuary	Total Acres in Watershed	Percent of Total Watershed
Developed/Urban	14,952	31%	21,356	70%
Ag - Row Crop	4,375	9%	10,410	42%
Ag - Tree Crop	623	1%	6,159	10%
Other Agriculture	5,124	11%	16,337	31%
Forested Uplands	3,867	8%	10,924	35%
Wetlands	8,193	17%	20,825	39%
Mines	0	0%	17,769	0%
Reclaimed Mines	29	0%	4,750	1%
Water	2,851	6%	5,609	51%
Rangeland	7,620	16%	28,956	26%
Total Acres	**47,634**		**143,095**	33%

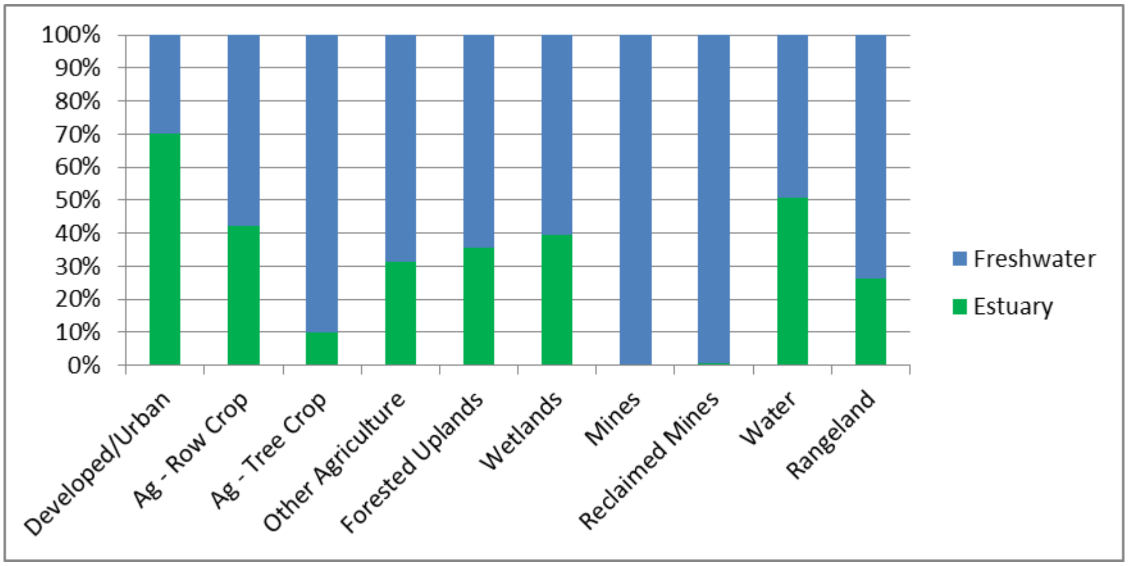

Figure 3-2. **Land use of the Little Manatee watershed comparing the relative percentage of each land use type in the freshwater and estuarine segment.**

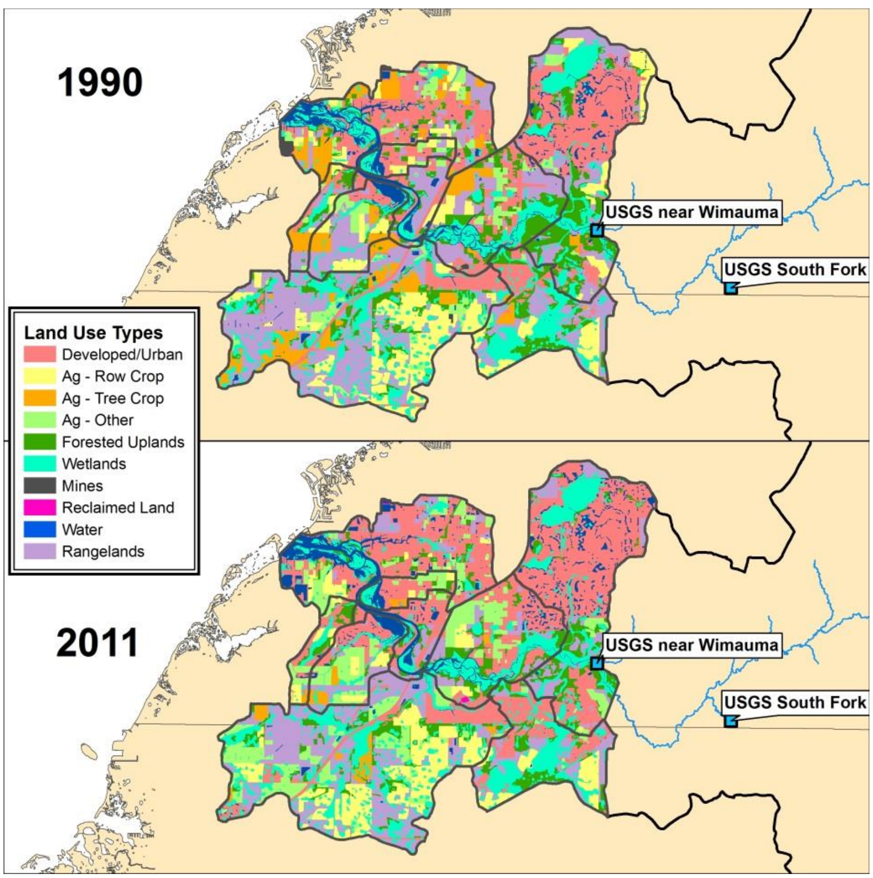

Figure 3-3. **Land Use changes for the Little Manatee estuarine watershed between 1990 and 2011 (SWFWMD).**

Table 3-2. Changes in estuarine land use types between 1990 and 2011.

Land Use Type	Acres of 1990 Land Use	Acres of 2011 Land Use	% Change
Developed/Urban	9,664	14,952	55%
Ag - Row Crop	5,394	4,375	-19%
Ag - Tree Crop	3,373	623	-82%
Other Agriculture	2,207	5,124	132%
Forested Uplands	5,299	3,867	-27%
Wetlands	8,125	8,193	1%
Mines	131	-	
Reclaimed Mines	-	29	
Water	2,200	2,851	30%
Rangeland	11,240	7,620	-32%

The distribution of major wetland features along the estuarine portion of the river (i.e., within the 100 meter buffer), along with the river kilometer system used in much of the analysis for the estuarine segment is provided in Figure 3-4.

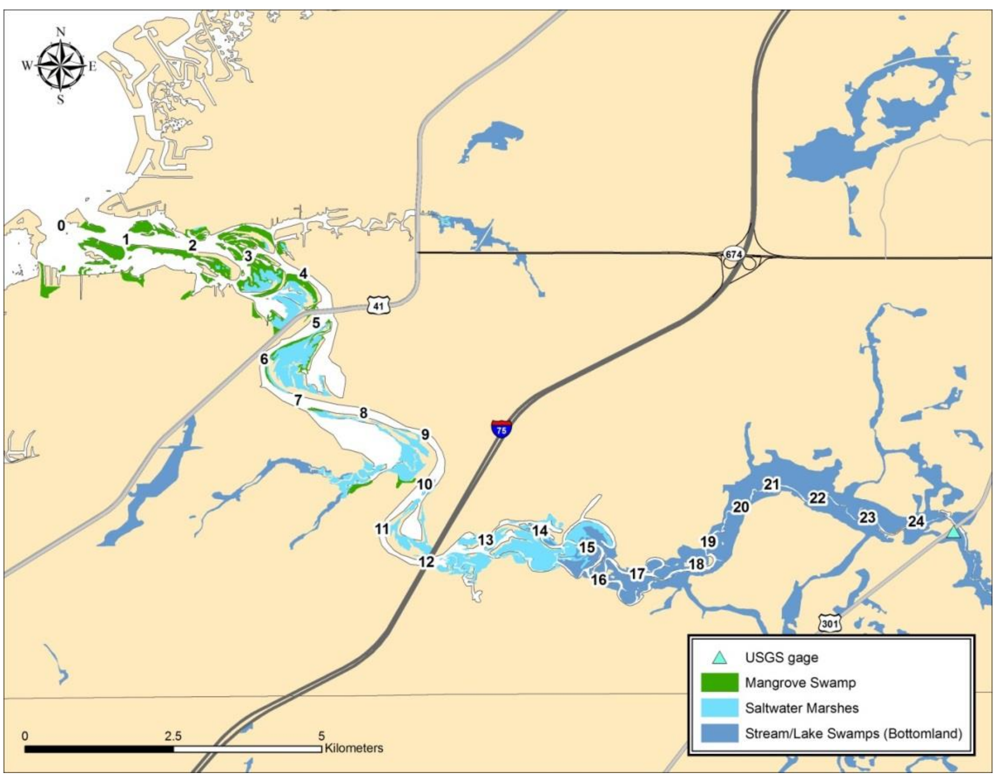

Figure 3-4. Distribution of major wetland features in the Little Manatee River Estuary. The numbers along the river represent the river kilometer system used for analysis.

3.1.2 Morphology and Structural Changes

The mouth of the Little Manatee River is approximately 0.8 miles wide (1.2 km) as it flows into Tampa Bay. The estuarine segment of the Little Manatee River has braided channels with shallow shoals, mangrove islands as well as several bayous off the main channel as you move upstream. And additional braided section of the river exists just upstream of Interstate 75 that continues upstream approximately 2.2 miles (3.5 km) until it becomes a single channel river. The river is typically shallow with most depths less than 4 meters though there were significant portions of the river between Tampa Bay and the Wimauma gage near US 301with depths greater than 4 meters (illustrated in green in Figure 3-5).

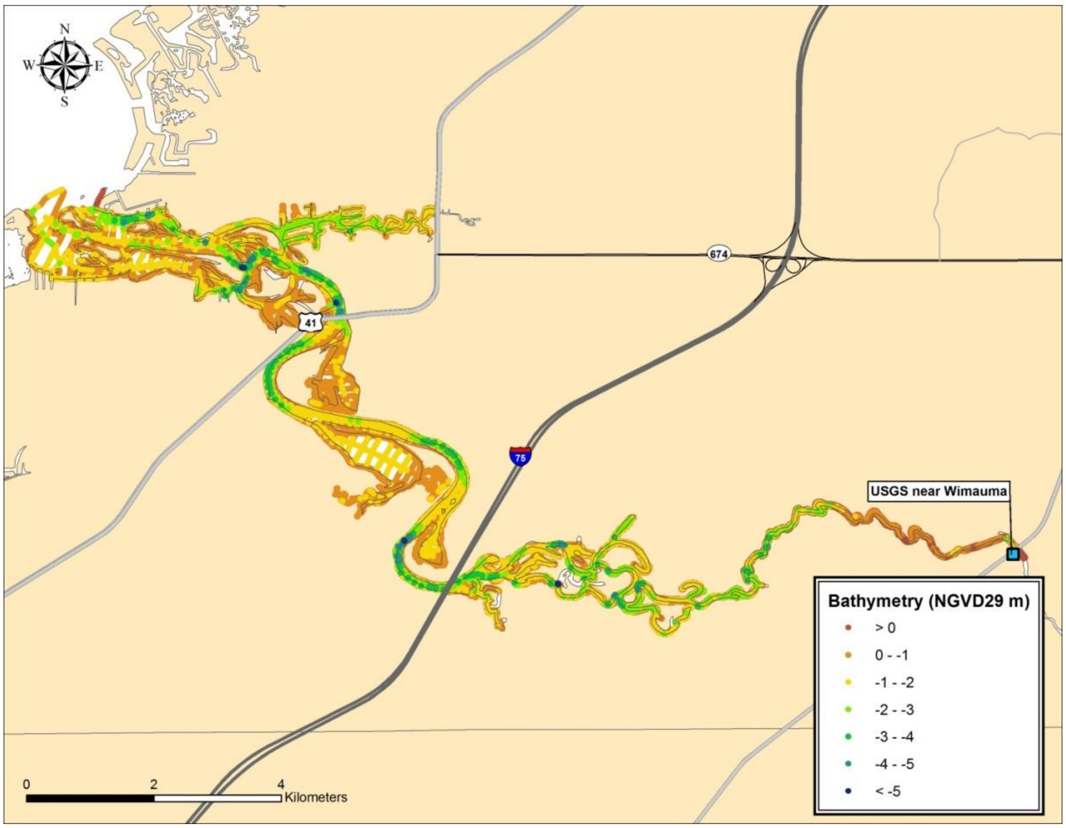

Figure 3-5. Bathymetry elevations of the Little Manatee River (USF, 2006).

3.1.3 Sediments and Bottom Types

Soils are important in determining how much runoff a given amount of rainfall will yield. Soils with high clay content or a shallow water table will generate more runoff than deep sandy soil. A soil's hydrologic group (U.S. Department of Agriculture, National Resource Conservation Service, 2009) is helpful in determining the runoff potential. Hydrologic soil groups (HSG) are separated into four categories: Group A, B, C, and D, though dual classifications exist. The soil type categories are based on intake and transmission of water during maximum yearly wetness conditions. It should be noted that the slope of the soil surface is not taken into consideration when assigning a soil to a hydrologic soil group. Specifics on each of the hydrologic soil types are described below.

Soils in Group A have low runoff potential when thoroughly wet because water is freely transmitted through the soil. Clay makes up less than 10 percent of the soil, while the rest of the 90 percent of the soil is composed of sand or gravel. Soils that are well aggregated, have low bulk densities, or soils that contain greater than 35 percent rock fragments that have loamy sand, sandy loam, loam or silt loam may also be placed in this group. When soils in Group B are moderately wet, they have moderately low runoff potential because water transmission through the soil is unimpeded. Typically, these soils are composed of 10 to 20 percent clay, and between 50 and 90 percent sand and also have loamy sand or sandy loam textures. Soils that are well aggregated, have low bulk densities, or soils that contain greater than 35 percent rock fragments that have loam, silt loam, silt, or sandy clay loam textures may also be placed in this group. Soils in Group C have a moderately high runoff potential when thoroughly wet because water transmission through the soil is somewhat restricted. Typically, these soils are composed of 20 to 40 percent clay, with less than 50 percent of the soil being composed of sand. Soils that are well aggregated, have low bulk densities, or contain greater than 35 percent of rock fragments that have clay, silty clay, or sandy clay textures may also be placed in this group. When soils in Group D are thoroughly wet, they have a high runoff potential because water movement through the soil is restricted or very restricted. Typically, these soils are composed of greater than 40 percent clay and less than 50 percent sand and have a clayey texture. In addition, all soils that have a depth reaching to a water impermeable layer less than 50 centimeters (20 inches) of the surface as well as soils with a water table within 60 centimeters (24 inches) of the surface are included in this group. Some soils that are classified as Group D are classified as such based solely on the presence of a water table within 60 centimeters (24 inches) or a water impermeable layer less than 50 centimeters (20 inches) of the surface, even if water is able to move freely through the soil. A dual hydrologic soil group may be assigned if these soils can be adequately drained. This assignment is based on the water table depth when drained and their saturated hydraulic conductivity. In a dual classification, the first letter refers to the drained condition and the second letter refers to the undrained condition. The dominate soil type for the estuarine watershed of the Little Manatee River is classified as A/D soils (

Table 3-3: Figure 3-6). The remaining soil types are split between C/D, A, and B/D with only 3 acres of type C soil. The areas that are not assigned a hydrologic soils group are due to them being submerged or not sampled by the NRCS.

Table 3-3. The area of each Hydrologic Soils group type in the Little Manatee River estuarine watershed (NRCS).

Hydrologic Soils Group	Acres
Not Assigned	3,179
A	4,267
A/D	31,803
B/D	1,793
C	3
C/D	6,592

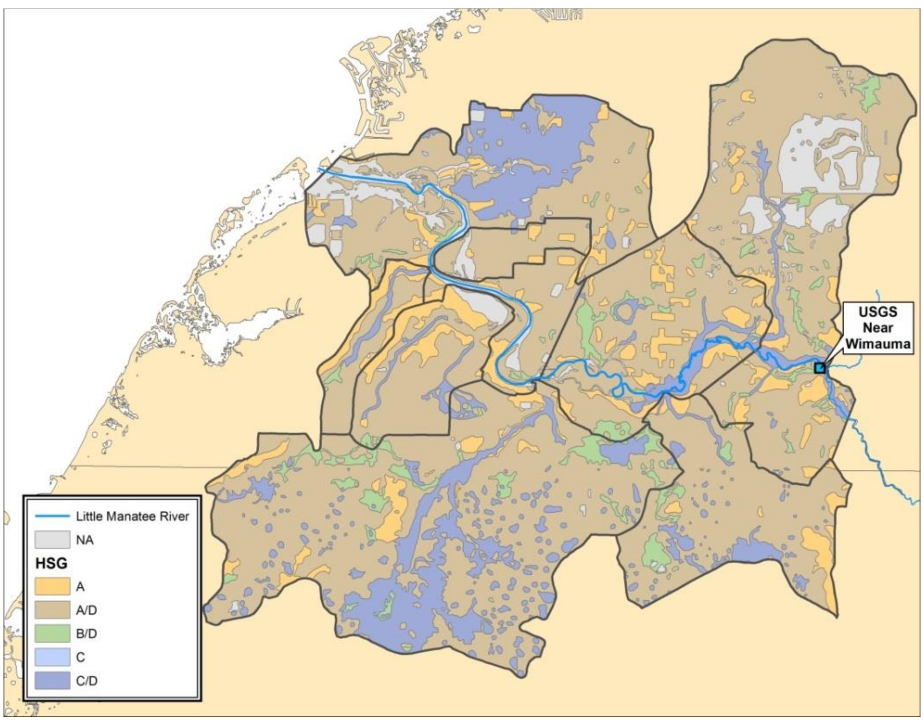

Figure 3-6. The hydrologic soils groups (HSG) in the estuarine portion of the Little Manatee River.

3.1.4 Estuarine Wetlands

The Southwest Florida Water Management District produced 2011 color infrared (CIR) digital aerial photographs photo-interpreted at 1:8,000 using the Florida Land Use and Cover Classification System (FLUCCS). These electronic layers were used to evaluate the extent of each wetland type in the estuarine portion of the Little Manatee River. Based on these data, the total wetland acreage in the Little Manatee River estuarine watershed accounts for 17% of the total estuarine watershed area. The upstream portion of the estuarine segment of the Little Manatee River is dominated by Bottom Land Hardwood Swamp (FLUCCS 1650) shifting to Saltwater Marshes (FLUCCS 6420) between Interstate 75 and US 41 and then transitioning to Mangrove Swamp (FLUCCS 6120) dominated wetlands below US41 (Figure 3-7). Figure 3-8 displays the percentage of wetland types within 100 meters of the Little Manatee River centerline. The relatively continuous extent of wetlands along the riparian buffer in the Little Manatee exemplifies its fairly natural state relative to other Tampa Bay tidal tributaries.

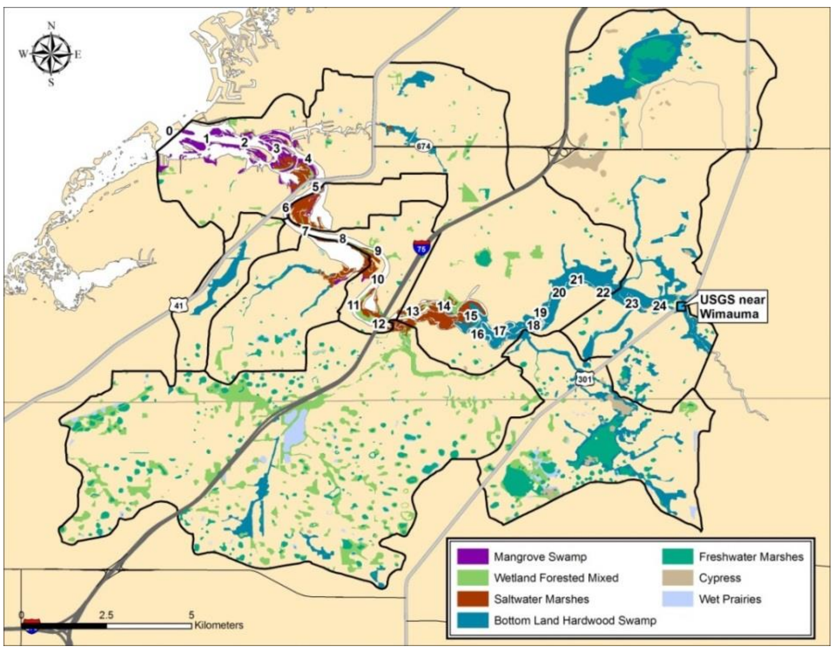

Figure 3-7. Wetlands within the Little Manatee Estuarine watershed.

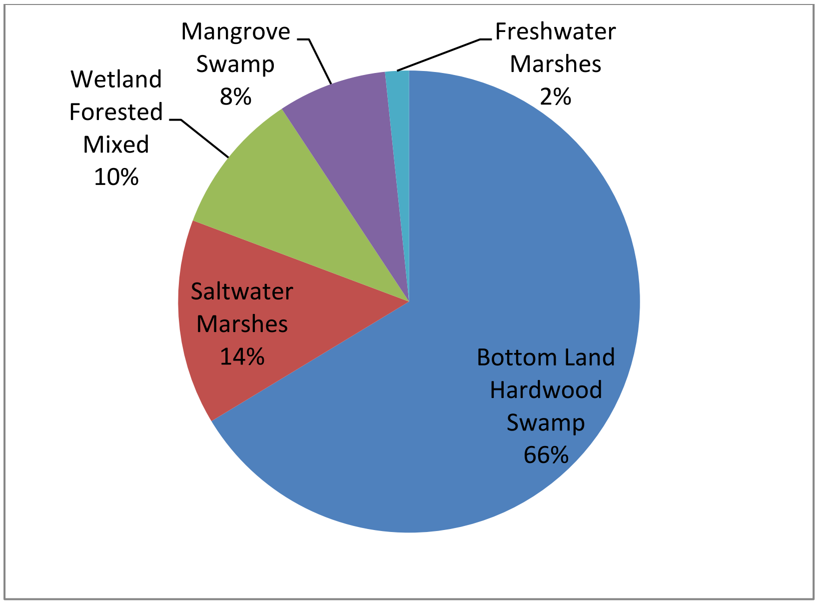

Figure 3-8. Wetland types within 100 meters of the Little Manatee River centerline in the estuarine watershed.

3.2 Salinity

Because an estuary is defined by mixing of marine and freshwater, salinity is typically the most important physical chemistry measurement used in evaluating the degree to which freshwater inflows are affecting the salinity content of the estuarine reaches of District tidal rivers. To that end, several studies have been conducted to determine the relationship between freshwater inflow and estuarine salinity in the Little Manatee River. One of the first known published studies describing the potential effects of freshwater withdrawals on estuarine resources of the Little Manatee River was a USGS report by Mario Fernandez Jr (1985) who examined the effects of a 50% surface water withdrawal scenario on the upstream migration of the freshwater-saltwater interface. The effects of withdrawals were estimated for two low flow recurrence intervals; a 90 day 2 year recurrence interval (i.e., 30.7 cfs) and a 90 day 20 year recurrence interval (i.e., 9.37 cfs). The author estimated a 0.6 and 0.2 mile upstream migration of the freshwater interface as a result of these scenarios. Since that time, several other studies have been conducted to more thoroughly estimate the effects of flows, including both ungagged and gaged flows, on salinity in the Little Manatee River estuary. These studies include a mechanistic hydrodynamic model (Huang and Liu 2007; Huang et al. 2010; Huang et al. 2011) and empirical regression analysis (HSW Engineering, Inc. 2008). The studies were performed specifically with respect to developing models that could be used to predict the effects of freshwater inflows, and surface water withdrawals, on salinity in the estuarine portion of the Little Manatee River in support of establishing minimum flows for the Little Manatee River estuary. These studies used similar datasets including 3 continuous recorder locations established and maintained by USGS near the downstream, middle and upstream end of the EFDC model domain. The locations were used to develop, calibrate and validate the models. In addition, available data from routine water quality monitoring conducted at fixed station locations by the Environmental Protection

Commission of Hillsborough County (EPC) as well as data collected as part of a probabilistic fisheries independent monitoring program were considered as part of the empirical regression analyses. The location of the continuous recorder gages and the EPC fixed station gages are displayed in Figure 3-9. Data collected from a fisheries independent monitoring program conducted by the Florida Fish and Wildlife Conservation Commission are displayed in Figure 3-10.

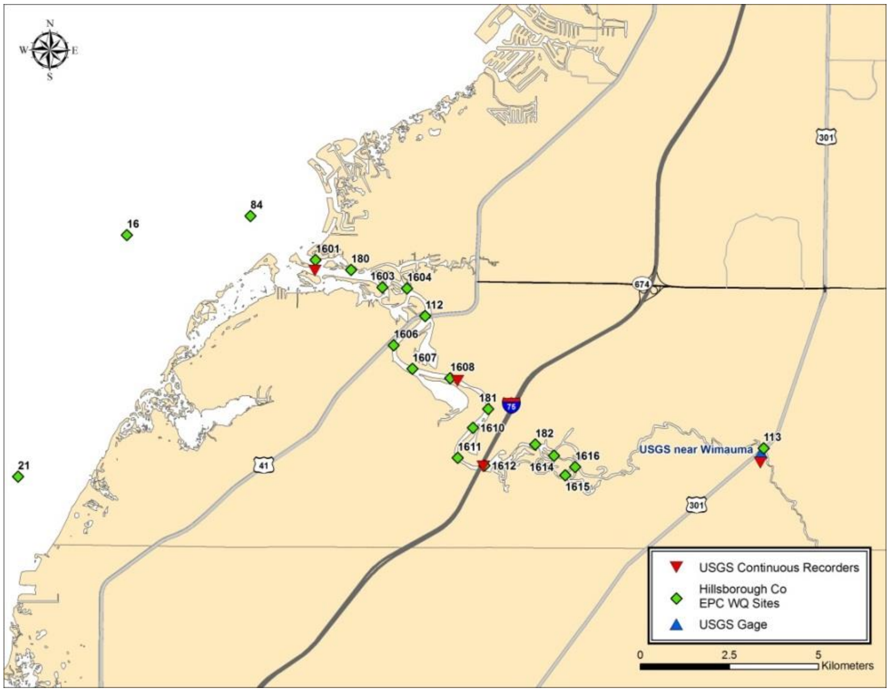

Figure 3-9. Location of USGS continuous recorders (red) and EPC fixed station water quality monitoring sites.

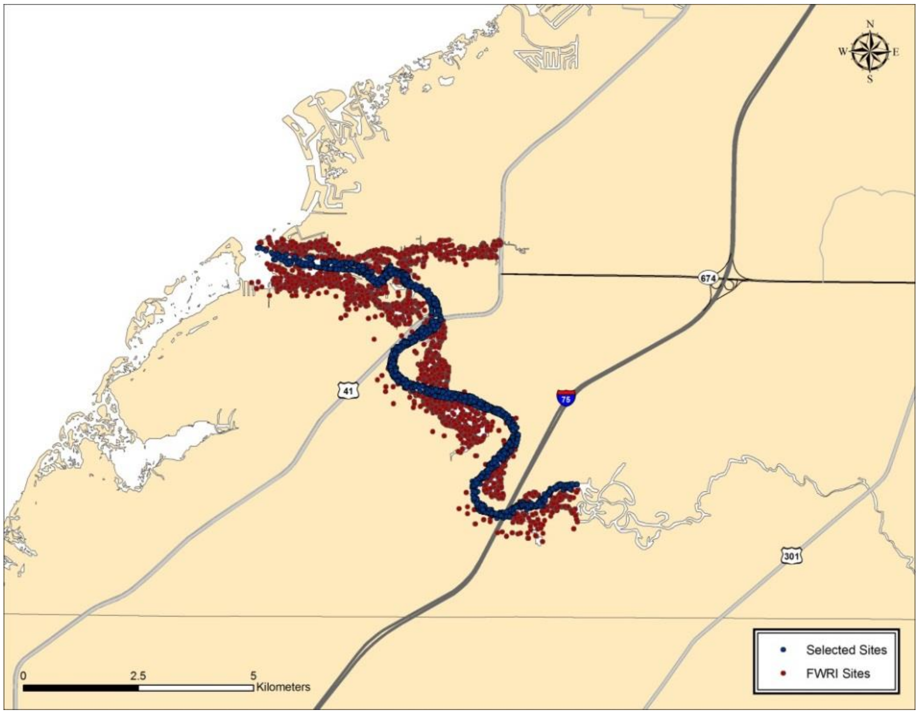

Figure 3-10. Location of fisheries independent monitoring program samples 1996-2014 with selected sites (blue) that were used to develop salinity regression models.

The sub-sections below describe the modeling efforts used to evaluate the effects of freshwater inflows on downstream estuarine salinity. The application of these models to establish the recommended minimum flows for Little Manatee River estuary is described in section 5-2.

3.2.1 Hydrodynamic Modeling of the Little Manatee River (Huang and Liu 2007)

Huang and Liu (2007) constructed a mechanistic Environmental Fluid Dynamics Code (EFDC) model (Hamrick 1996) in support of the establishment of minimum flows for the tidal reach of the Little Manatee River (i.e., below US Highway 301). The model was used to investigate the relationship between freshwater inflows and salinity distributions, simulate salinity transport processes, and estimate residence times in the Little Manatee River estuary as a function of freshwater inflow.

The Little Manatee River is a complex meandering system, and an orthogonal curvilinear grid system was developed to define the model boundary (Huang and Liu 2007: Figure 3-11). Three vertical layers were constructed to resolve vertical mixing in the shallow system. The District conducted a field data collection program to support model calibration and verification which included the placement of three continuous recorders at three stations in the tidal reach measuring water levels, salinity, and temperature (See Figure 3-9 above). Gaged freshwater inflows were obtained from the Wimauma gage located at the upstream end of the model domain. Ungaged flows from the watershed downstream of the gage were simulated by Intera

Aqua Terra Consultants (2006) using Hydrological Simulation Program – Fortran (HSPF). Additional Inputs to the runoff model included rainfall, land use, evapotranspiration, and infiltration to estimate runoff as well as tidal elevations.

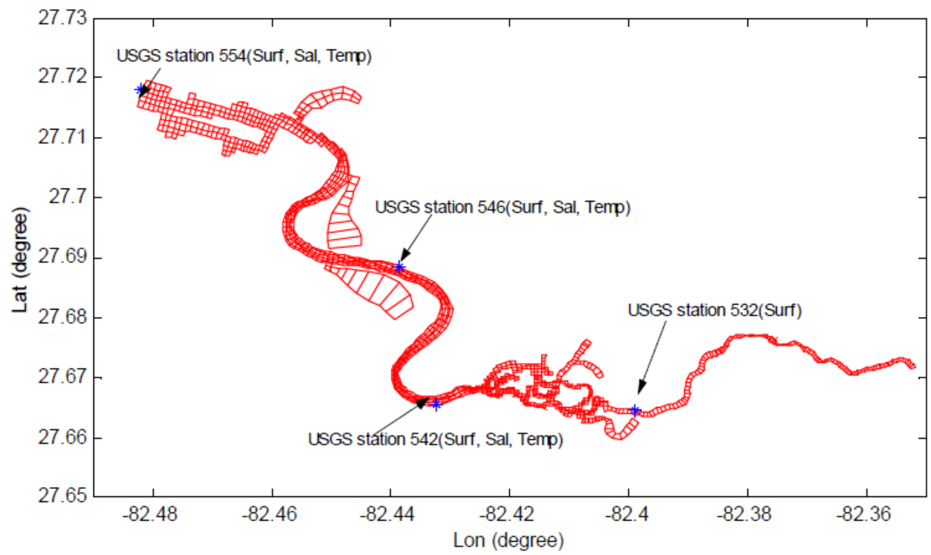

Figure 3-11. Model grid used by the EFDC model for the tidal reach of the Little Manatee River.

Continuous salinity recorder data from January-February, 2005 were used for model calibrations and from March-June 2005 for model verifications. Results of the model calibration using continuous hourly data indicated that the model predictions were in good agreement with observed data. Similarly, model verification yielded model predictions of water levels, salinity, and temperature that matched well with observations. The authors concluded that model fit over the verification time period adequately characterizes the hydrodynamic characteristics in the Little Manatee River. An example output of the model for February 9, 2005 for a high and low tide condition is provided in Figure 3-13. The flow at Wimauma on that date was 52 cfs at the Wimauma gage. The figure illustrates the rather dramatic difference in salinity that can occur at any point in the lower river as a function of tidal amplitude. At high tide, salinity in the main stem is generally higher than in the bayous and tributaries due to saline water intrusion. However, at low tide, salinity at the bayous is higher than that in the river main stem indicating that currents in the bayous are weaker than in the river main stem and relatively poor flushing occurs in the bayous.

After successful calibration, Huang and Liu then applied the model to simulate Estuarine Residence Time (ERT) and Pulse Residence Time (PRT) following the methodology in Miller and McPherson (1991). Miller and McPherson defined ERT as the time required for flushing all but a given fraction of the original water while PRT was described as the time to flush a pulse (slug) of water or a conservative constituent from the estuary. The District provided 17 flow values for model simulations to estimate ERT, spanning a range in gaged freshwater inflow from

6 to 1780 cfs. Simulation results for the lowest flow resulted in an estimated ERT of 53.3 days, while the highest flow resulted in an estimated ERT of 2.3 days. The best regression of the correlation between ERT and freshwater input was provided by a power law curve (Figure 3-13); however, in low flow conditions results from the regression equation tended to overestimate ERT. To model PRT, concentration was set to 1 in the most upstream volume element, and set to zero in all other elements and boundaries. As with ERT, the same 17 rates of freshwater inflow were examined to determine how quickly particles move through the estuary as a function of inflow. The time it took for 50% of the pulse released mass to pass by a specific location in the estuary along the center line was recorded as the PRT. Three locations along the center line were used for regression analysis between this 50% PRT and river flow (1 km, 7 km, and 15 km: Figure 3-14). The authors concluded that in general, the regression equations fit well with model prediction data but again, with low flow conditions, the difference between model predictions and regression results could be large.

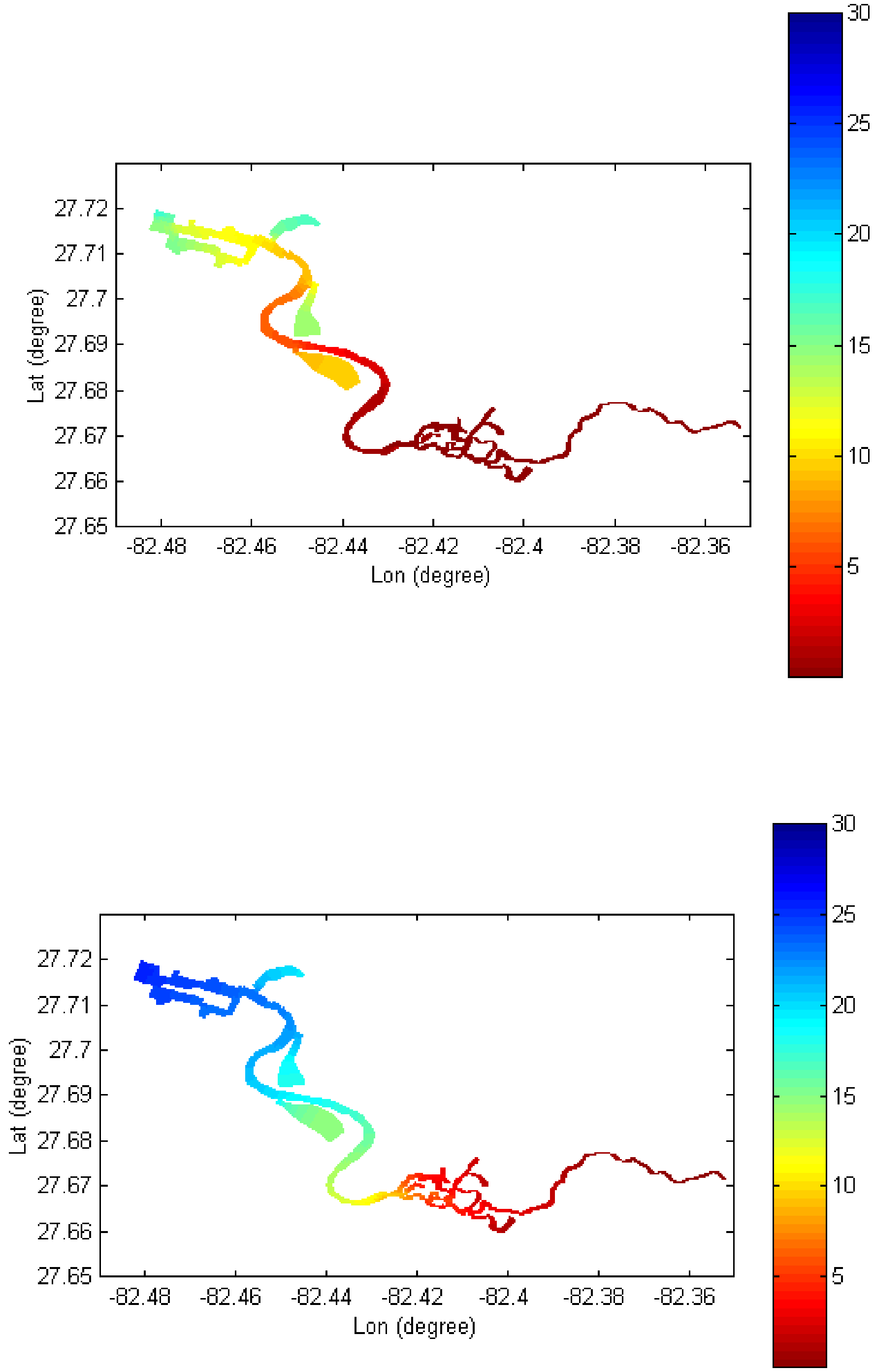

Figure 3-12. Salinity field at low tide (top) and high tide (bottom) on 2/9/2005 under river flow of 52 cfs.

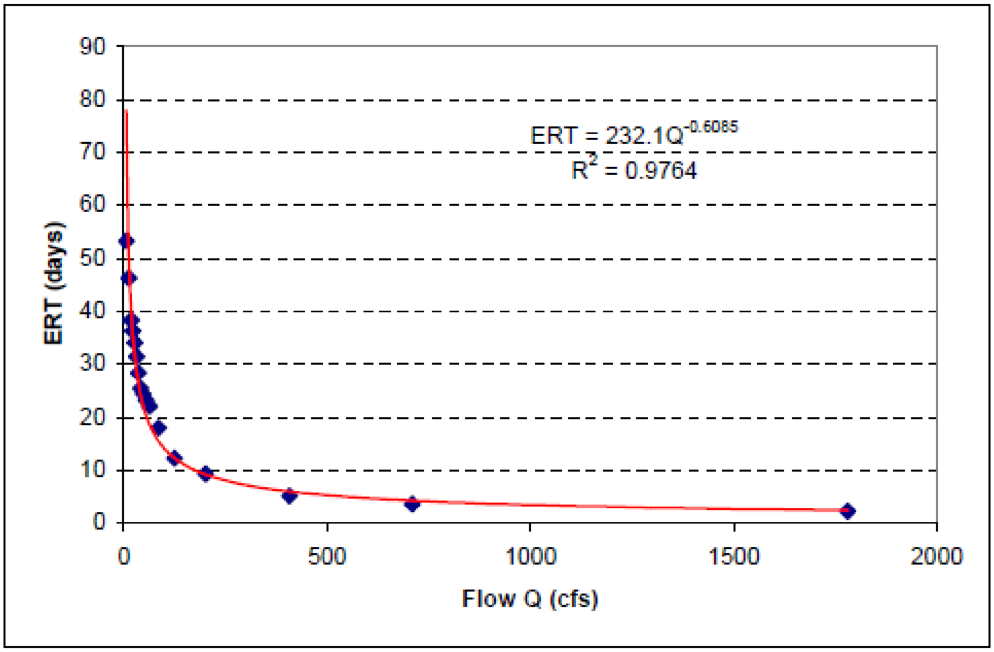

Figure 3-13. Estuarine Residence time as a function of gaged freshwater inflow.

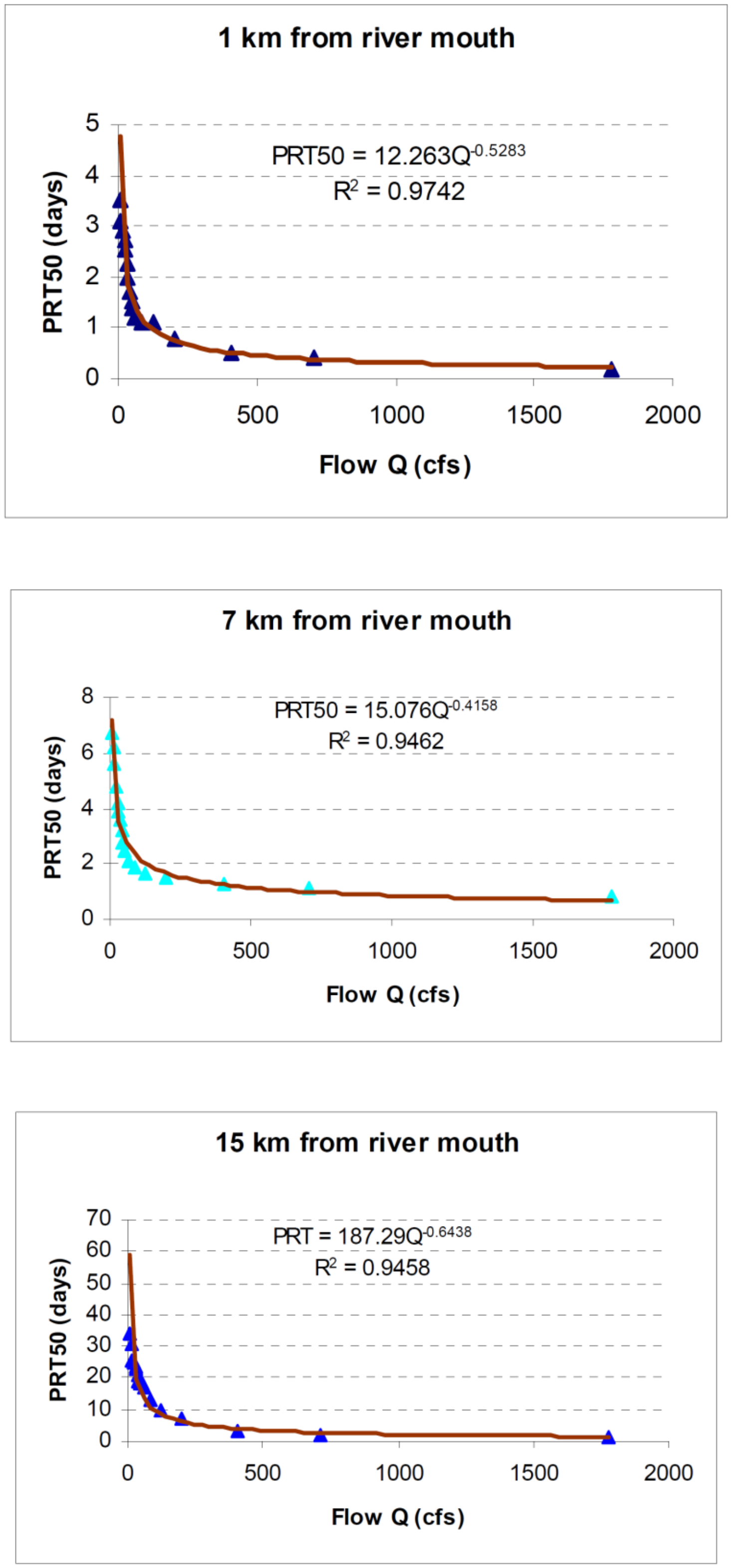

Figure 3-14. Pulse Residence Times as a function of flow for the 17 flow values evaluated.

The EFDC model for the Little Manatee River was subsequently described in a peer-reviewed journal publication (Huang et al. 2009) where the model was used to simulate water ages, essentially equivalent to pulse residence time as defined here. In the simulation, “water particles” were released at the upstream boundary of the model domain and the time it took for 50% of those particles to pass a given location in the tidal reach was defined as the “water age”. To separate the effects of river flow from tides, tidal effects on water ages were removed using a 24-h moving-average filter, resulting in tidally-averaged travel time (tidally-averaged water age) along the river main channel. The results for 17 flow values representing different flow conditions in the river are shown in Table 3-4. Note that the flow units are presented in cubic meters per second under high flow conditions, water ages are very low; large increases in water ages occur under low flow conditions.

Table 3-4. Tidally-averaged water age *T* at different locations along the main channel of the river under different constant inflow *Q* scenarios. From Huang et al 2009.

Scenario	Upstream gaged inflow (cfs)	Total inflow Q(cfs)	Water age *T* (days) at different distances from the river mouth (Rkm)									
			1	3	5	7	9	11	13	15	17	19
1	7	9	50.0	49.5	49.0	46.8	44.4	39.8	29.1	19.2	13.1	3.1
2	11	18	39.9	39.6	38.8	36.8	34.5	30.2	20.8	12.5	8.6	2.5
3	18	28	32.5	32.3	31.5	29.8	27.5	23.5	14.2	9.6	5.5	1.9
4	21	34	31.3	31.2	30.4	29.2	26.4	22.9	13.6	9.3	5.4	1.8
5	28	41	28.5	28.5	27.9	26.8	23.5	20.5	12.1	7.2	4.5	1.7
6	32	49	27.2	27.1	26.6	25.5	22.3	19.5	11.9	6.3	4.1	1.6
7	35	55	24.4	24.4	23.8	22.8	19.6	17.0	10.1	5.6	3.9	1.5
8	42	62	22.7	22.5	22.0	21.2	17.9	15.6	9.6	5.2	3.3	1.5
9	46	71	21.8	21.5	21.3	20.5	17.1	15.0	9.2	4.7	3.1	1.4
10	53	82	20.9	20.7	20.4	19.8	16.8	14.5	9.0	4.2	3.1	1.3
11	64	96	19.9	19.6	19.4	19.0	16.1	13.9	8.3	3.9	2.6	1.2
12	85	129	15.7	15.5	15.3	14.9	12.4	10.3	4.6	3.4	1.7	1.0
13	124	190	11.1	11.0	10.8	10.6	8.4	6.6	3.7	2.5	1.5	0.8
14	201	305	7.3	7.0	6.9	6.6	5.2	3.4	1.6	1.1	0.6	0.3
15	406	619	3.7	3.3	3.2	2.9	2.1	1.6	1.1	0.7	0.4	0.3
16	710	1078	2.0	1.8	1.6	1.3	1.1	1.0	0.5	0.5	0.3	0.2
17	1780	2707	1.2	1.0	0.7	0.6	0.6	0.4	0.3	0.2	0.2	0.1

* Note that flow values have been converted to cfs.

Huang et. al. 2011 followed their 2009 publication with a publication in 2011 to support the development of protective water resources management strategies for the Little Manatee River. The same EFDC model was applied to evaluate the effects of drought and surface water withdrawals on ERT. Model outputs were used to develop a predictive empirical equation to estimate the ERT and rate of change in ERT as a function of changes to river inflow. Again, ERT was defined as the time required to flush all but a certain fraction of the original water (or conservative constituent) that was initially distributed through the estuary. Ten percent of the original concentration was used as the cut off value to determine the residence time required to reduce the concentration of a conservative constituent in the estuary. Similar inflow scenarios from the previous work were again used for this study. The results showed that when flows were above around 20 m^3/s (i.e., 706 cfs), ERT increases almost linearly following a flow reduction; however, when inflows fall below 5 m^3/s (177 cfs), ERT begins to increase exponentially.

An equation was presented to estimate ERT from gaged, as opposed to total, inflow which was derived from the percentage ratio between ungagged flow and gaged flow. This allows the estimation of ERT based on gaged flows without the need to conduct rainfall runoff modeling to estimate ungagged inflows from watershed. The model was expressed as follows:

$$ERT = 26.517 Q_{gaged}^{-0.6083}$$

Where ERT is expressed in days and Q_{gaged} is the gaged flow at USGS 02300500-Wimauma. The ERT variation rate was defined in the study as the change in ERT per unit flow reduction. The derivative of the equation relating ERT to total inflow was used to obtain the equation showing the ERT variation rate. The ERT variation rate is almost negligible when flow was above 20 m^3/s while when flow fell below about 4 m3/s (141 cfs) further reduction of river flow led to substantial increases in ERT and ERT variation. Thus, it was proposed that the ERT and ERT variation rate at low flow conditions could be used as indicators to determine a critical flow range for management of inflows the system. The authors suggest that water-use restriction rules could be developed to avoid large reductions of river inflow when flows fall below a rate of 4 m^3/s. The authors suggest that the regressions may be useful to evaluate relationships between ERT and salinity, chlorophyll a, and dissolved oxygen in efforts to support the establishment of minimum flows for the Little Manatee River estuary; however, the authors also note that the regression equation may produce large errors in comparison to the numerical prediction when inflows are reduced to the values close to the minimum inflow of 0.260 m^3/s. At these lowest flows, tidal forces may play a more important role in estuarine mixing and transport. Thus, additional 3D hydrodynamic simulations may be needed to provide more accurate estimates of estuarine residence time for extreme low-flow conditions.

3.2.2 Empirical Salinity Modeling

Empirical salinity prediction models have been developed by HSW Engineering, Inc. to evaluate compliance with Florida Power and Light's permit requirements and to support the establishment of minimum flows for the Little Manatee River estuary (HSW 2008). HSW Engineering, Inc. performed salinity regression analysis that included development of isohaline regressions, fixed station salinity regressions and spatially distributed salinity regressions to predict the effects of surface water flows measured at the Wimauma gage on downstream salinity. While the empirical salinity models are steady state and do not account for time specific residual memory in the system that are an important aspect of the computations used in the EFDC model, they have the advantage of being able to predict salinity over long time periods without the extensive accumulation of inputs, including calculation of ungagged runoff values using other hydrologic models, and long computer run times that are required by the EFDC model. The EFDC model is very computationally intensive (i.e., a single four year run takes approximately 30 hours on today's computers). Since the District was concurrently pursuing the development of the EFDC model described above, the purpose of the empirical modeling effort was to provide an additional method of predicting salinity at various locations in the estuary as well as to have the ability to create salinity predictions over a long period of record. It is important to note that the EFDC model utilizes information from the previous time step to predict salinity in the next time step whereas the empirical regression models do not. While the EFDC model is considered the gold standard for evaluating the effects of flow reductions of estuary salinity content, the empirical salinity models can be useful to evaluate the predicted effects of salinity of salinity dependent biology in the system over a longer period of record than the current EFDC model runs. Again, The EFDC models are considered the gold standard for evaluating the effects of hypothetical flow reduction scenarios on estuarine salinity. The empirical salinity regressions were considered useful in support of the minimum flows for the purpose of extending daily salinity predictions beyond the EFDC model simulation period to evaluate biological responses (e.g., fish populations) to salinity changes evaluated under different flow reduction scenarios as described further in Chapters 5 and 6.

The HSW regressions used a combination of source data including both fixed station and probabilistic sampling. The HSW analysis utilized ordinary least squares (OLS) linear regression modeling. Explanatory variables for the multiple linear regression models included natural logarithm of 3-day moving average flow, tide at Ruskin, and bay salinity measured at EPC station 21 (see Figure 3-1 for location). The period of record for the regressions was 1976-2006.

Regressions predicting the location of a particular salinity isohalines included the 2-psu surface and average, 4-psu surface and average, 7-psu bottom and 15-psu bottom and average regressions. Adjusted R^2 values ranged from 0.57 for the bottom and water column average 15 psu isohaline to 0.81 for the water column average 2 psu isohaline model. Bay salinity was significant only for the 15 psu isohaline. The natural logarithm of 3-day moving average flow was significant in every model.

Fixed station regressions were performed at five fixed station locations, including three USGS locations (RKMs 0.8, 8.3, and 12.1) where 15-minute interval salinity and tide stage data were available and two additional channel segments. Explanatory variables included discharge (natural logarithm of 3-day or 6-day moving average flow), tide stage, and bay salinity at Ruskin. Adjusted R^2 values ranged from 0.60 to 0.80.

The spatially distributed (or whole river) salinity models included the combined 15-minute continuous recorder data at the 3 USGS sites as well as the profile meter data collected by EPC and others. Regression models were developed for surface, bottom, and water-column average salinity for the entire river section of interest using river kilometer, the natural logarithm of 3-day moving average flow, tide and bay salinity. Because strong serial correlation existed in the 15 minute data, a random replicable subset of 1% of the data was selected and included in the model development. Regression models using the vertical profile meter data alone, and in combination with the randomly selected USGS data, accounted for 73% to 82% of the salinity variability, respectively.

The authors recommended that the combined models would be most appropriate to be used for simultaneously estimating salinity at various locations in the estuary as a function of antecedent flows. The sampling frequency by source and river kilometer for the data used in developing the whole river salinity models is provided in Figure 3-15 where it is evident that the random subset of the USGS continuous recorder data dominated the number of observations. The EPC data were restricted to data between 2000 and 2006 with station names assigned as the river kilometer of the sample. Noticeably absent from these data were the long term EPC fixed station data for stations 112 (Rkm=4.8) and 113 (Rkm=23.4).

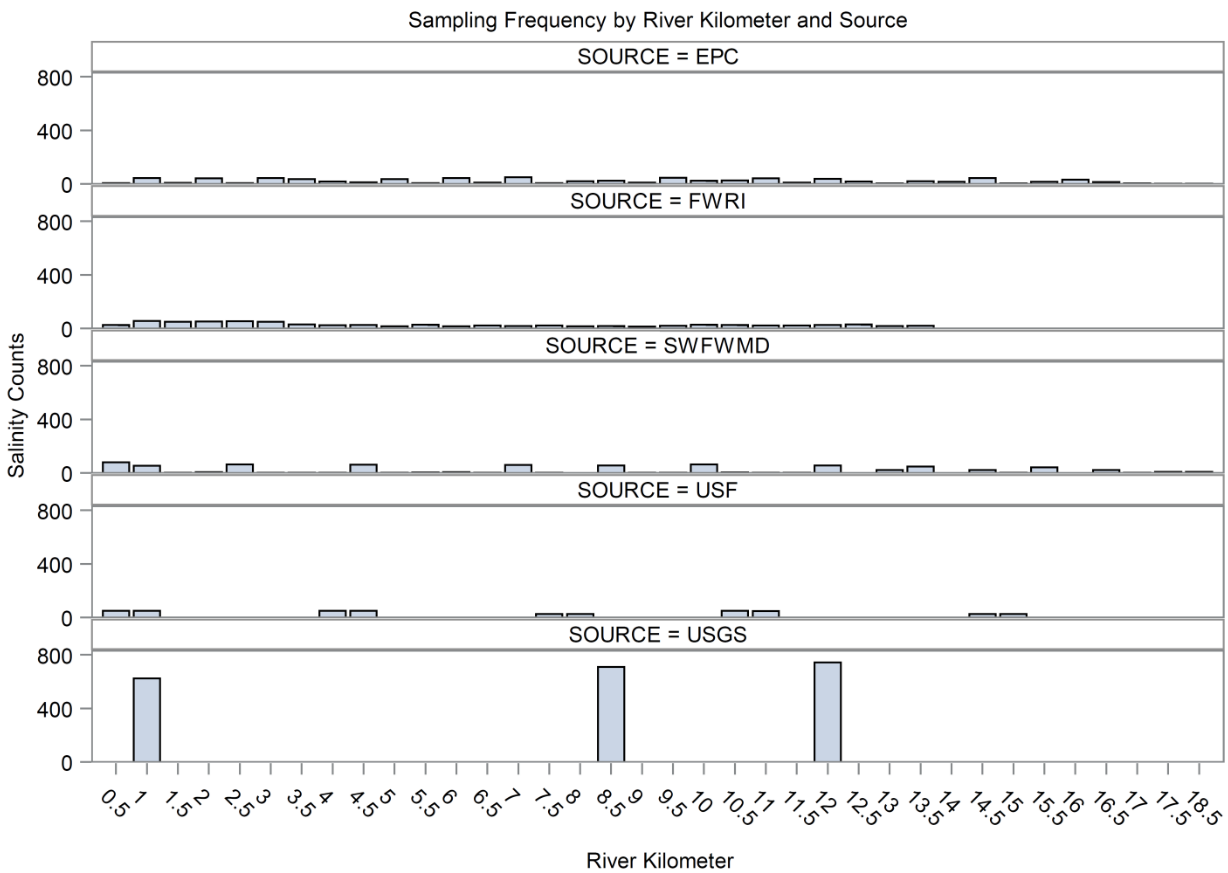

Figure 3-15. **Number of salinity observations for data used in HSW salinity regressions by source and river kilometer (binned in 0.5 kilometer increments).**

The HSW deliverables included SAS code and datasets so the regression analysis could be replicated and used to predict salinity as a function of future flow data; however, no model simulations were conducted to evaluate the effects of potential flow reduction scenarios. We replicated the whole river regression analysis and also developed alternative forms of these regressions to allow for predictions of salinity that can be used to evaluate the effects of flow reduction scenarios on habitat suitability for important estuarine biota over the full time period of biotic data collections. In particular, several forms of nonparametric regression were evaluated including Local (LOESS), Thin Plate Spline, and Adaptive Regression techniques (SAS Stat Users Guide 2014). The impetus for evaluating alternative forms of the regression was an attempt to improve predictive capacity at the tails of the distribution where modest overprediction was prevalent at low salinities (i.e., <10 ppt) and under-prediction more prevalent at higher salinities (i.e., > 20 ppt) (Figure 3-16). This suggests that non-linearity in the relationship between the 3-day lag average inflow, location in the river, and estuarine salinity may remain despite the natural log transformation of inflows. This outcome led to an effort to update the empirical salinity regression analysis to provide alternative methods for extending the daily prediction timeseries for modeling the potential effects of flow reduction scenarios. This effort does not necessarily diminish the utility of the HSW regressions as described in that report.

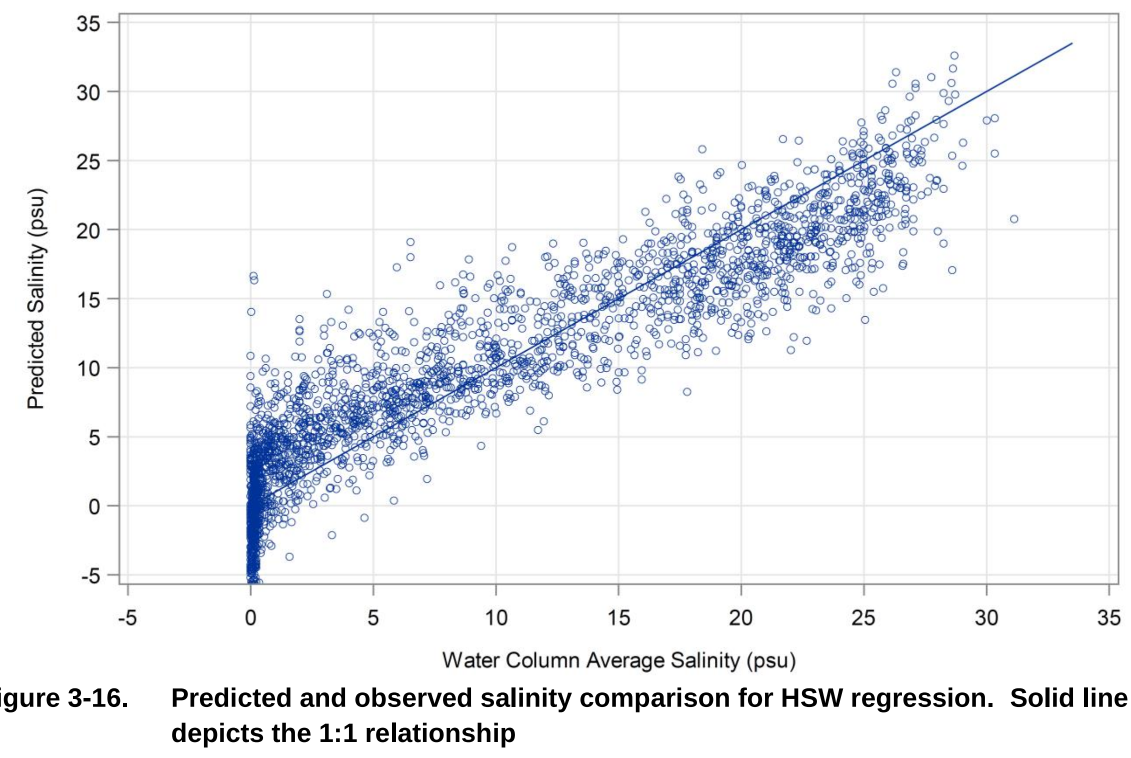

Figure 3-16. Predicted and observed salinity comparison for HSW regression. Solid line depicts the 1:1 relationship

LOESS regression is one of several novel statistical methods that build on classical methods such as linear and nonlinear least squares regression. LOESS combines much of the simplicity of linear least squares regression with the flexibility of nonlinear regression by fitting simple models to localized subsets of the data to build up a function that describes the deterministic part of the variation in the data (NIST/SEMATECH 2012*)*. Originally proposed by Cleveland (1979) and further developed by Cleveland and Devlin (1988), LOESS applies locally weighted polynomial regression to the data, using the observed explanatory data values near the point whose response is being estimated. The polynomial is fit using weighted least squares, giving more weight to points near the point whose response is being estimated and less weight to points further away.

Results comparing the three nonparametric methods described above resulted in the selection of the LOESS method to compare a nonlinear method against the linear regression described by HSW. Iteratively reweighted least squares methods and a low order polynomial were used to avoid over-fitting of the data and reduce the influence of outliers (SAS Institute 2014). In addition, the selection of the smoothing parameter relied on minimizing the Akaike Information Criteria with a routine to ensure that the model converged to the global minimum (AICC Global option in the SAS LOESS procedure: SAS institute, 2014) The "bay salinity" term used in the linear regression model was not used for the LOESS regression as it resulted in negative prediction values. A plot of the observed and predicted values of the LOESS fit is provided in Figure 3-17 where it is evident that 1) negative predictions rarely occur, 2) predictions are relatively unbiased between 10 and 25 psu and 3) over-prediction bias remains at salinities below 10 psu.

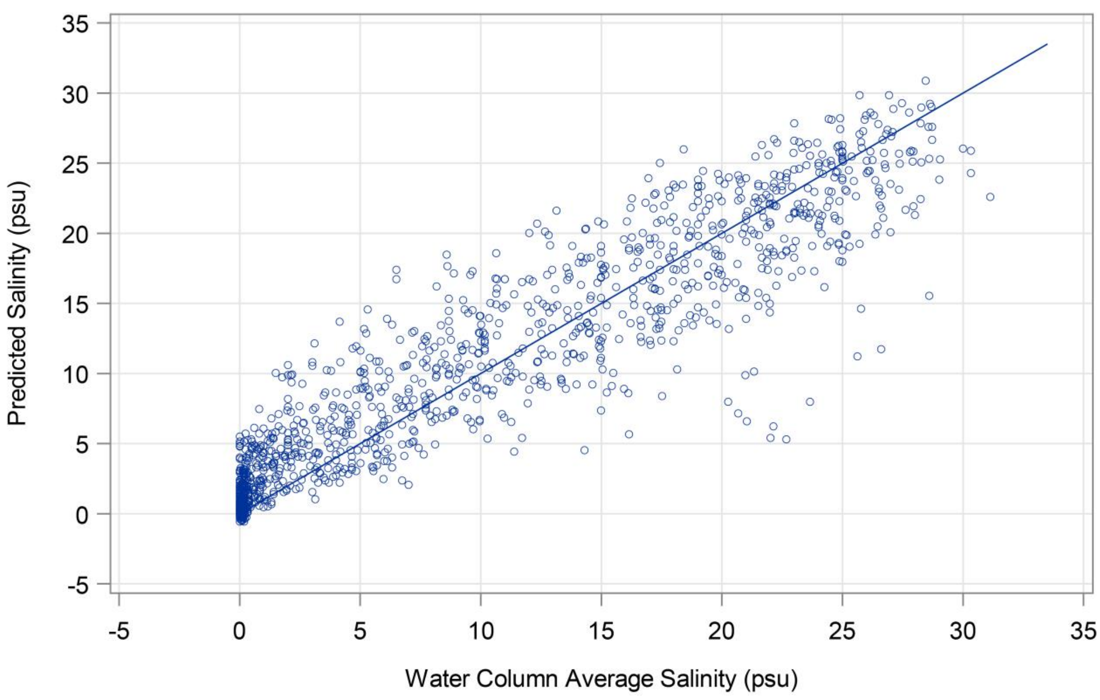

Figure 3-17. Observed and LOESS model predicted water column average salinity in the estuarine portion of the Little Manatee River. Solid line depicts the 1:1 relationship.

A contour plot comparing the average, and predicted average, water column salinity as a function of flow (natural log scale) and river kilometer is provided Figure 3-18. The contour lines represent salinity isohalines in 5 psu intervals. The data used in these regressions extend up to Rkm 18 and the contour plots suggest that the oligohaline area (i.e., the area between the 0 and 5 psu isohalines) may extend past Rkm 18 in both the data and the model predictions at flows below Ln 4.5 cfs (i.e., 90 cfs) which is approximately the 66th percentile value (exceeded 33 percent of the time).

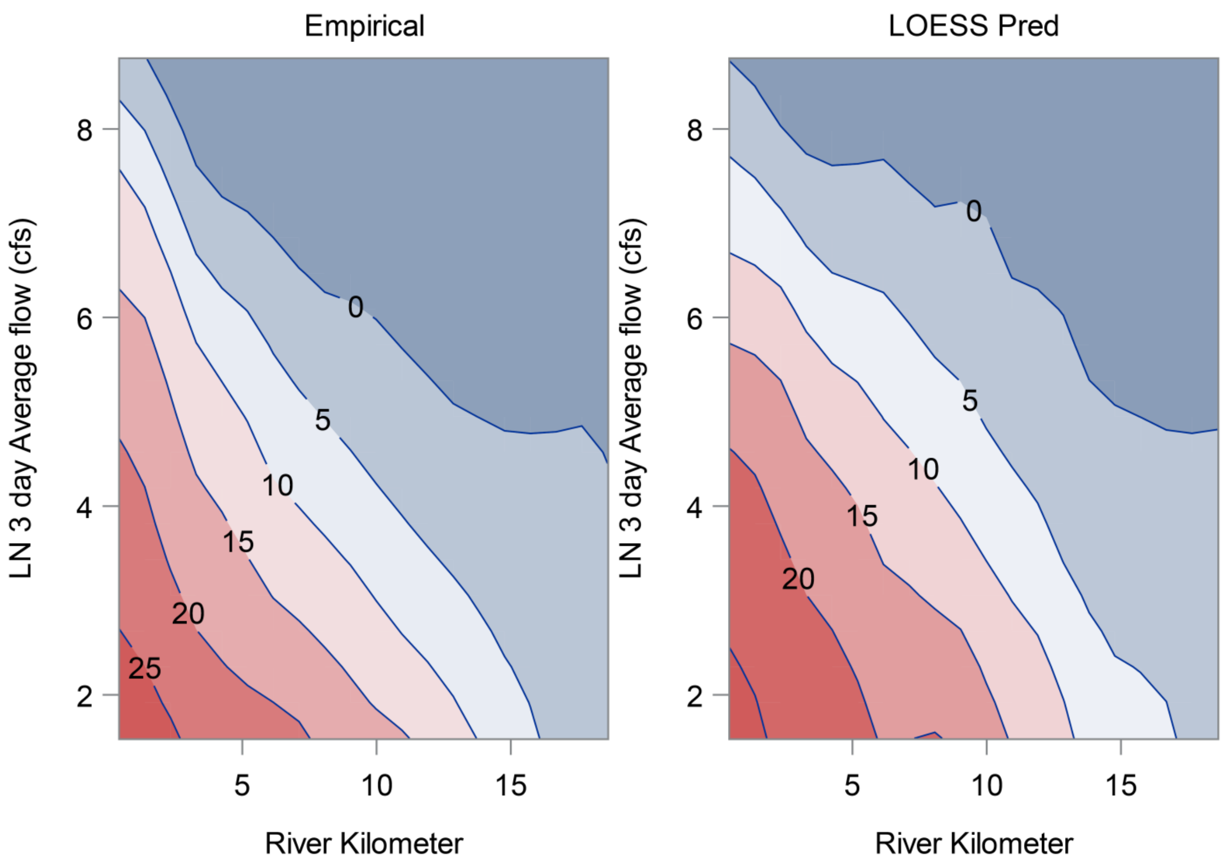

Figure 3-18. Comparison of the empirical data and LOESS model predictions for salinity throughout the lower 18 kilometers of the Little Manatee River as a function of flow and river kilometer.

3.2.2.1 Empirical Modeling Update

The salinity profile dataset used in the original empirical salinity modeling work was updated with data from FWRI and EPC through 2014 and 2016, respectively. In 2009, EPC added several fixed stations in the Little Manatee River where additional salinity sampling has been conducted between Rkm 0.8 and 16.4. These sites record physical chemistry data only and 91 observations have been recorded between January 2009 and July 2016. The upstream EPC station 113 was also added to the dataset to expand the inference space to river kilometer 23.4.

Given the availability and abundance of both probabilistic and fixed station data throughout river, the 3 USGS continuous recorder data were not considered for this update. An independent analysis showed that inclusion of these data increased the R^2 of the OLS regressions only by 3 percent from 0.81 to 0.84 but the sampling frequency, even using the 1% random subset, overwhelmed the total number of other samples collected. The sampling frequency included in this updated dataset is provided by river kilometer and source in Figure 3-19. The largest number of samples occurred for the long term EPC stations 112 (near Rkm 5) and 113 (near Rkm 23.5).

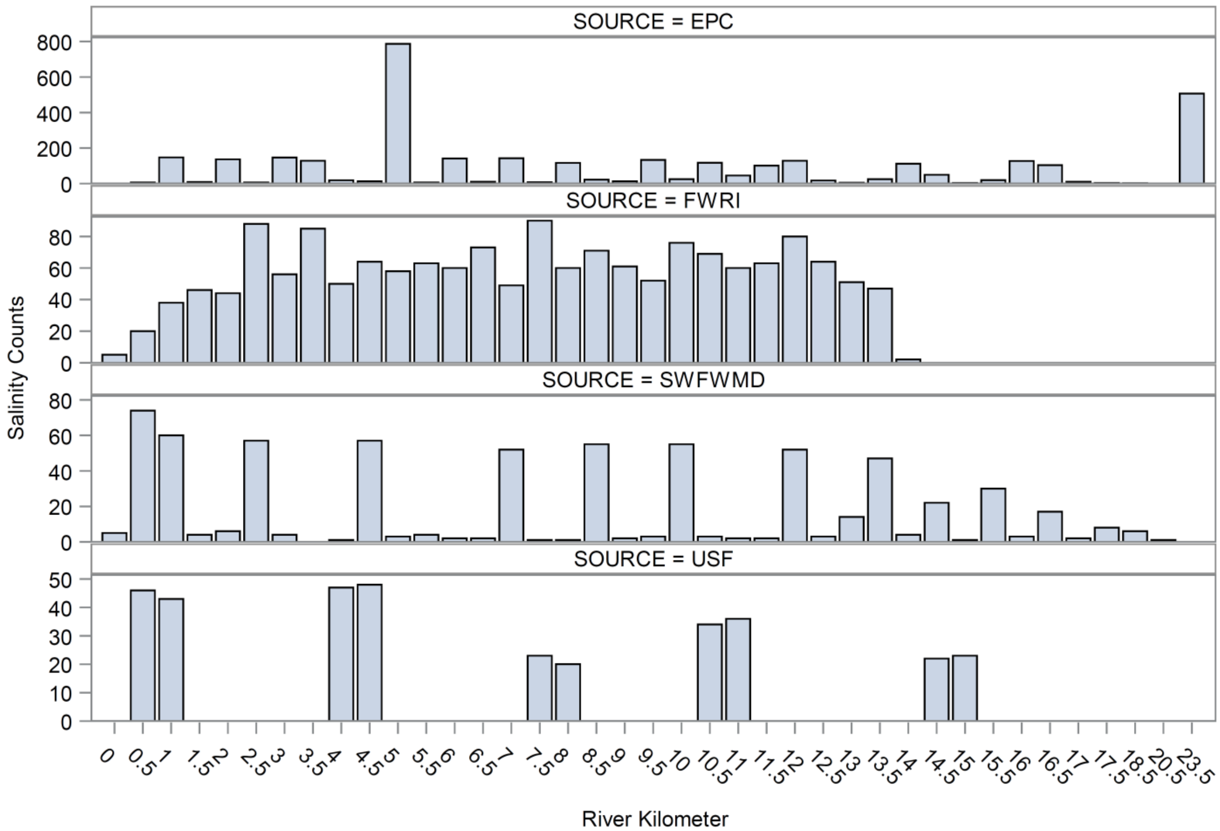

Figure 3-19. Number of salinity observations by source and river kilometer (binned in 0.5 kilometer increments) for period of record data available through July 2016. Note y axis scale is unique by row.

A contour plot of the updated empirical dataset is provided in Figure 3-20. The zero contour line in the plot on the left is somewhat misleading due to three observations of salinity above 5 psu at station 113, reported during the 1980's. These observations are reported along with the flow that occurred on the day of sampling in Table 3-5. While these values appear anomalous and occurred on only 3 of over 500 sampling events, it is not clear that they were misreported. However, the observations could reflect dates with high groundwater concentrations that resulted in high specific conductance readings. Assuming that salinity at station 113 was always zero results in the contour plot on the right in Figure 3-20 which then locates the freshwater interface near river kilometer 20 which generally corresponds well with the prediction of Fernandez (1985). Note that the locations expressed in Fernandez (1985) are expressed as river miles from approximately the same reference point (Shell Point).

Table 3-5. List of dates with potential anomalous salinity values recorded for station 113.

Date	Salinity (psu)	Time	Flow (cfs)
9/10/1980	5.1	10:10	142
10/15/1980	13.3	10:30	37
3/16/1988	14.7	13:24	194

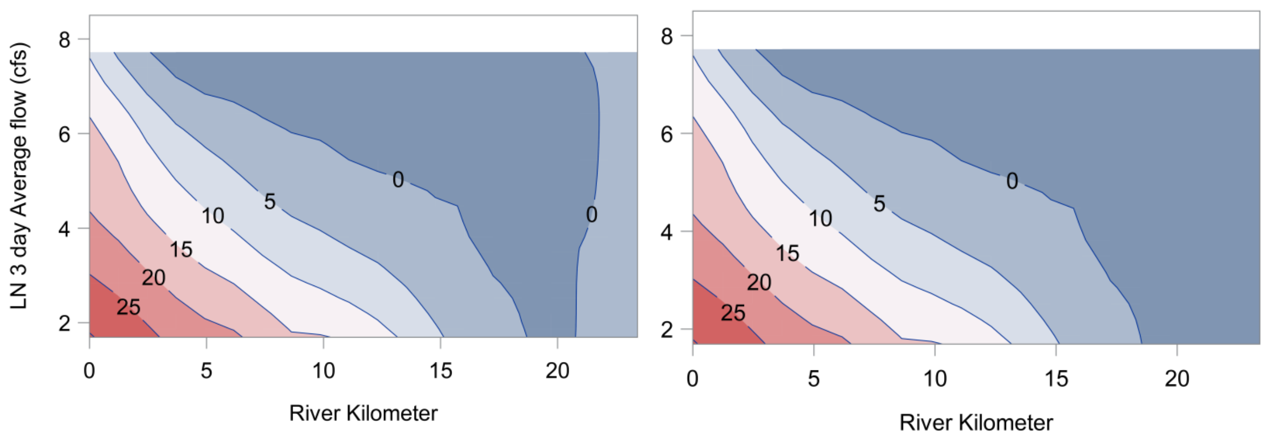

Figure 3-20. Contour plot of water column average salinity based on empirical data update with (left) and without (right) the three observations in Table 3-5.

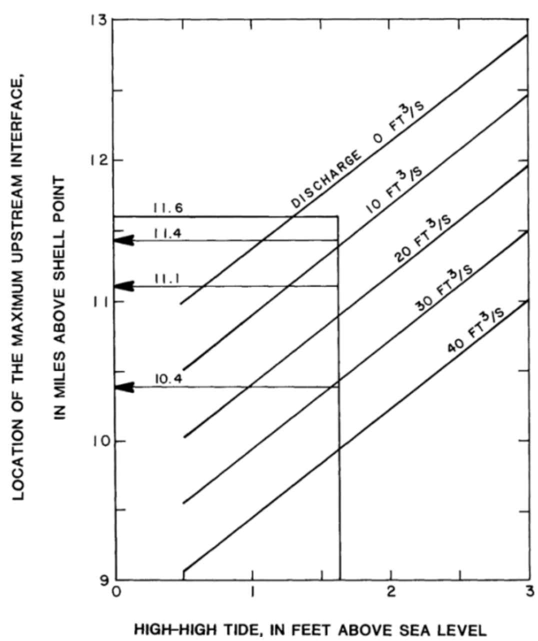

Figure 3-21. Estimated location of the freshwater interface as a function of tide and discharge from USGS02300500-Wimauma as reported in Figure 22 of Fernandez 1985. Note that location is described in river miles in this figure.

To assess the general empirical relationship between river flow and salinity throughout the estuary, the data were partitioned into 3 kilometer increments and the salinity data were plotted against the flow (i.e., 3 day average flow, natural log transformed) from USGS 02300500-Wimauma (Figure 3-22). One can see from the panel plots the general relationship between salinity and flow for each segment of the river as well as the variability in that relationship for different areas of the system. An OLS and LOESS regression model were again evaluated using the updated dataset. The high salinity values recorded at EPC station 113 were not removed from the analysis to maintain a conservative estimate of the location of the freshwater interface under low flow conditions. A three way interaction term was also included in the updated models to help capture the nonlinear relationship between location flow and salinity. The interaction term was described by the product of the 3 day average flow, river kilometer, and tide level at the time of sampling.

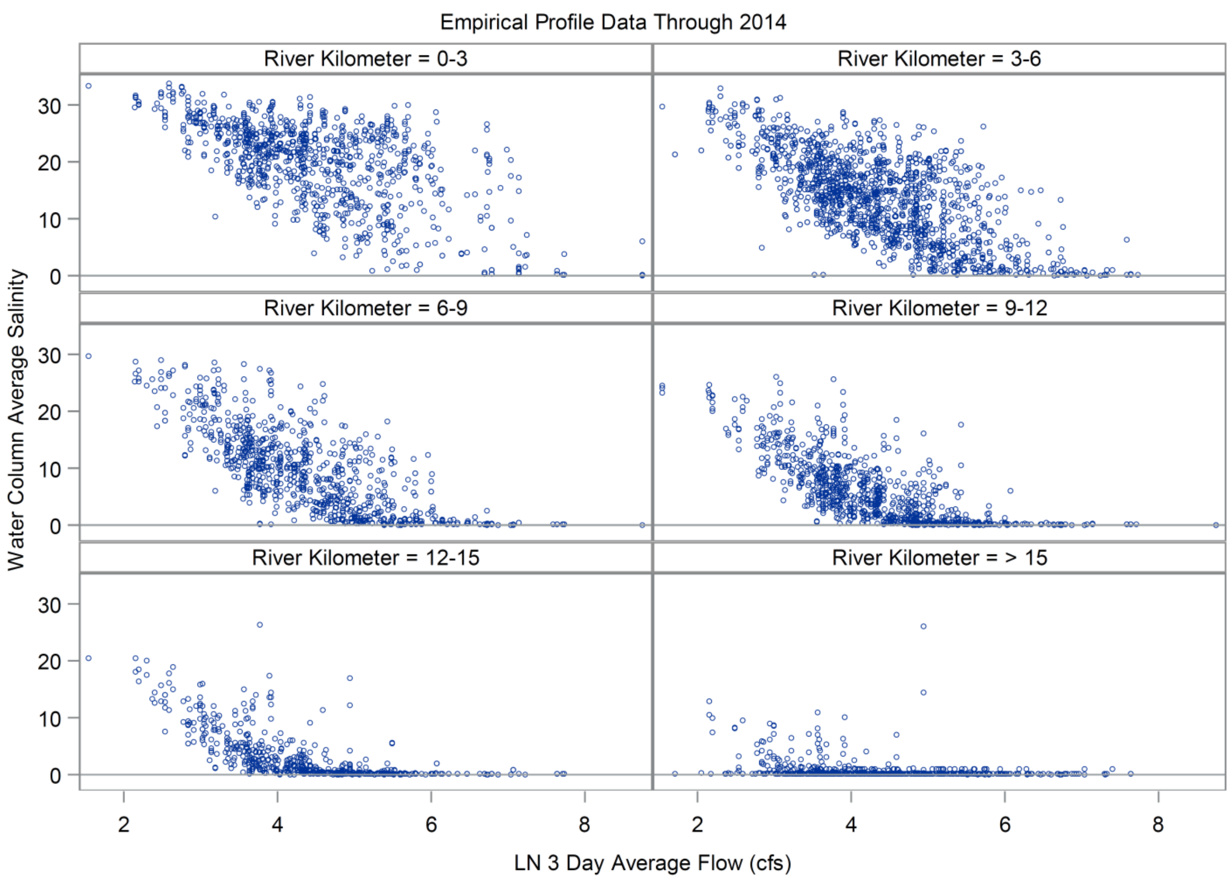

Figure 3-22. Empirical water column average salinity data as a function of natural log transformed flow at (USGS02300500-Wimauma) in 3 kilometer intervals from mouth of the Little Manatee River.

Ordinary least squares regression and LOESS regression were compared using the predicted and observed salinity plots as defined above and once again the LOESS model outperformed the OLS regressions when comparing the predicted and observed salinities (Figure 3-23).

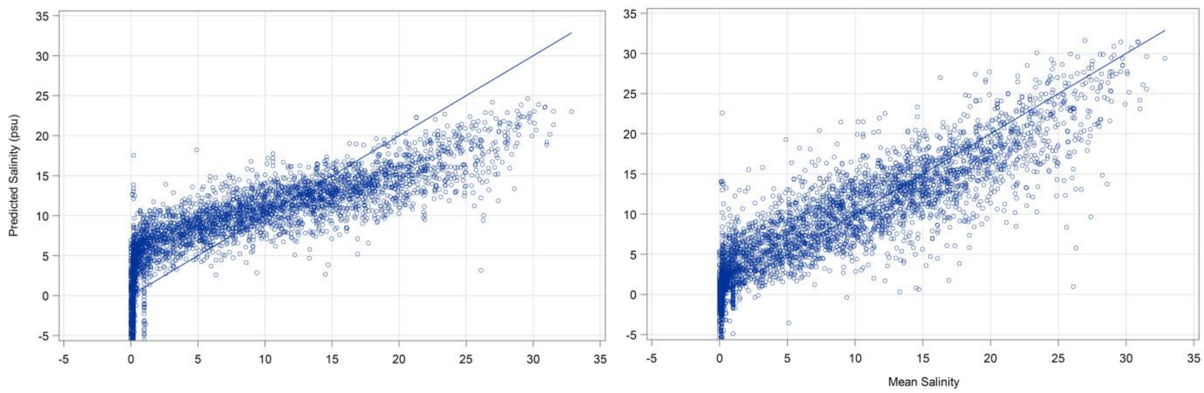

Figure 3-23. Predicted and observed plots for OLS regression (left) and LOESS regression (right) based on empirical data updated through 2014).

Predictions by the EFDC and LOESS models were then compared for the EFDC model time period, the results of which are provided along with the empirical data contour over the same time period in Figure 3-23. It should be noted that while the period of record was the same among these comparisons, the EFDC model provides daily predictions throughout the time period while the other two contour plots are based on dates when profile samples were collected. These model predictions will be further compared using daily estimates when evaluating the effects of the flow reduction scenarios on estuarine biota in the Little Manatee River estuary.

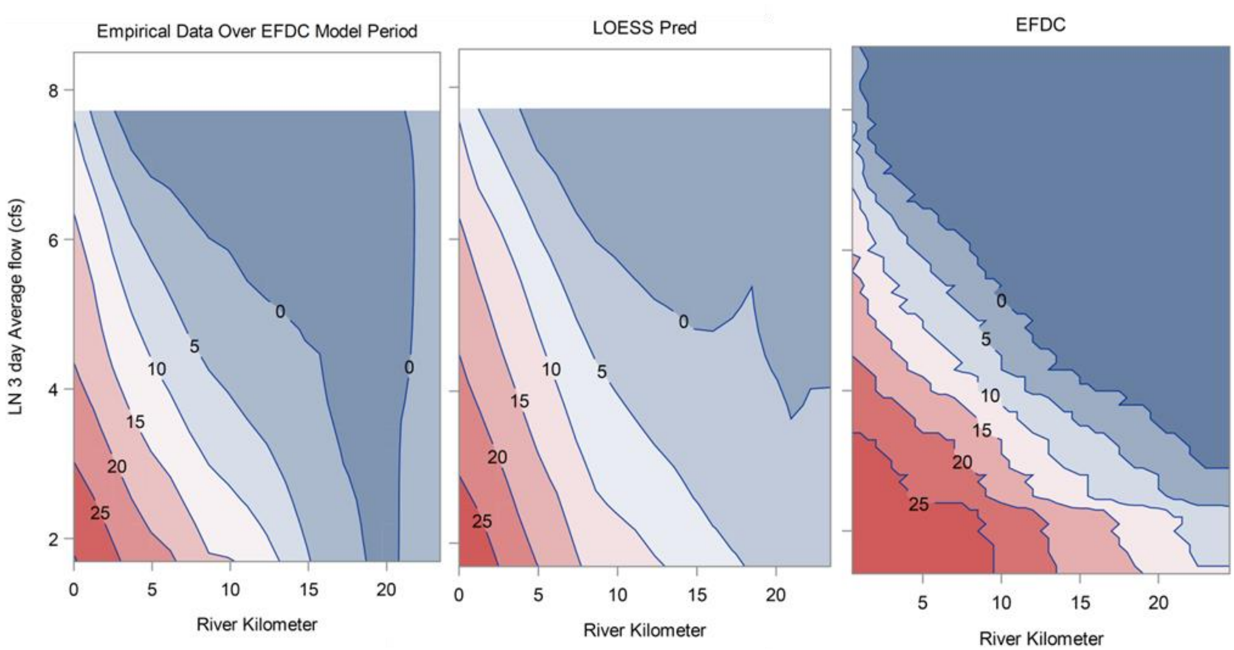

Figure 3-24. Contour plots of empirical data (left), LOESS regression predictions (middle), and EFDC model predictions (right) over the EFDC model time domain. Note that no flow values higher than 7.8 (log scale) were observed in combination with empirical synoptic data collections over the EFDC model period and therefore the white space at the top of the two graphs on the left.

3.3 Water Quality Characteristics

This section focuses on water quality data (other than salinity) collected in the estuarine portion of the Little Manatee River from the USGS gage at 301 to the mouth near Shell Point. Salinity was extensively covered in the previous section and is revisited in Chapter 5 of this report but is not further discussed in this section other than to describe the physical environment associated with the water quality sampling stations.

3.3.1 FDEP Water Quality Classifications and Standards

The Little Manatee River is designated by FDEP as an Outstanding Florida Waterbody, indicating its special significance as a tidal river in Florida. The tidal reaches of rivers in Florida remain evaluated based on a narrative standard. The narrative standard is stated under Rule 62-302.530(47)(b), F.A.C.: "*In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna*." Each water body also has a "Designated Use" in Florida statue. For Class III waters, including all southwest Florida tidal creeks, the designated use is defined as "*recreation and propagation and maintenance of a healthy, well-balanced population of fish and wildlife*" (Rule 62-302.400, F.A.C.). Impairment is determined by evaluating two principal water quality constituents: chlorophyll a concentrations and dissolved oxygen expressed as percent saturation. The threshold value for chlorophyll is expressed as an annual geometric average of 11 µg/l for estuaries and 20 µg/l for freshwater bodies. The dissolved oxygen criteria for marine waters are expressed as; a daily average shall not be below 42% saturation more than 10% of the time, and weekly and monthly averages of 51% and 56% respectively. The state accounts for areas that transition between salt and freshwaters such as the Little Manatee River depending on the conductivity/salinity at the time dissolved oxygen was measured. For example, if the dissolved oxygen of waterbody measured within a transitional zone as defined by FDEP, and that water's conductivity is below 4,580 umhos/cm or 2.7 PSU, then the applicable freshwater is applied. Conversely, the marine standard is applied if the conductivity exceeds that threshold. Again, based on the most recent assessment, the estuarine portion of the Little Manatee River is not listed as impaired, indicating a healthy and well balanced population of flora and fauna according to these standards. In addition, the FDEP classifies the Little Manatee River as a reference site based on its low Landscape Development Intensity index score though the watershed has recently undergone a rapid expansion in urban landuse in the estuarine portion of the watershed. Importantly, no portion of the Little Manatee River is currently listed as impaired for any parameter other than fecal coliform based on the latest Florida Department of Environmental Protection evaluation (April 2016).

3.3.2 Water Quality Status and Trends

The following subsections describe the general water quality status and trends over time for important water quality constituents measured in the estuarine portion of the Little Manatee River based on data collected by the Hillsborough County Environmental Protection Commission at 5 locations within the system. These 5 locations are provided in Figure 3-25.

Stations 112 and 113 are long term stations established in the 1970's while the other three gages were established in 2009.

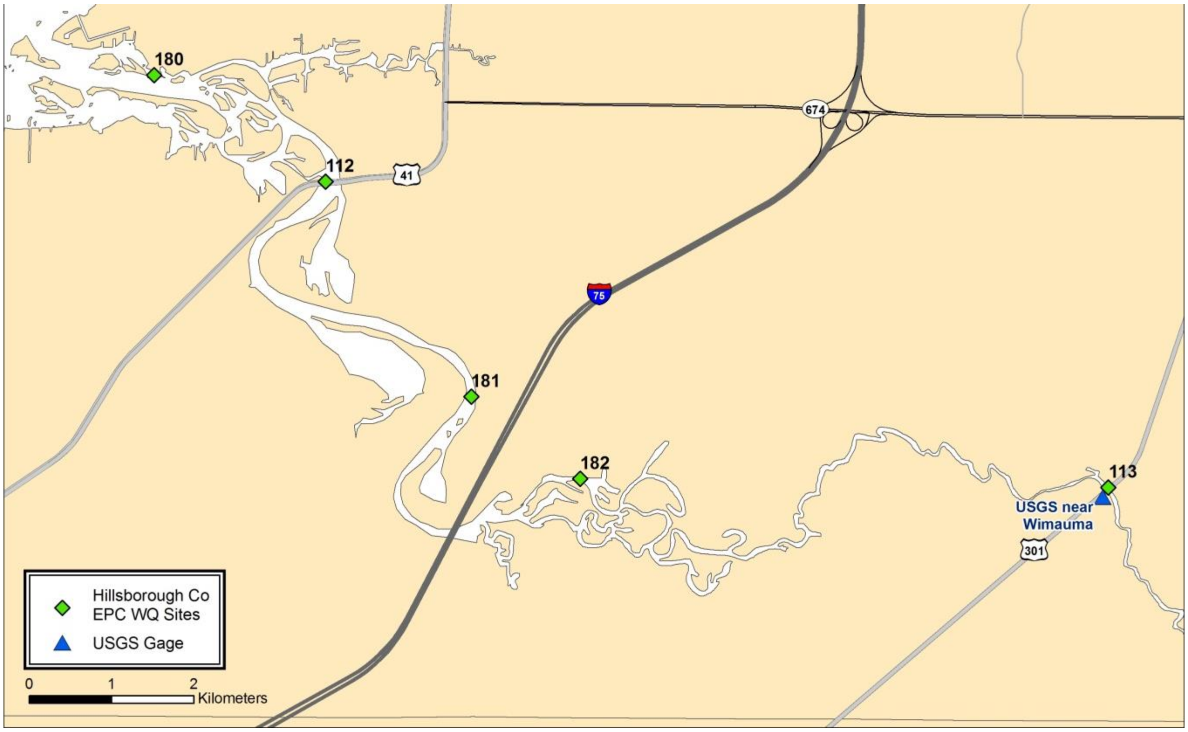

Figure 3-25. Hillsborough County Environmental Protection Commission fixed station locations in the lower Little Manatee River.

The 5 EPC fixed stations in Figure 3-25 above are well distributed throughout the Little Manatee River estuary. Station 113 is co-located with the USGS gage near Wimauma (02300500) at the most upstream head of the estuary and has a data record back to 1974. Station 112, located near the US41 bridge also has a data record back to 1974 while the other three stations were implemented in 2009.

A plot of the salinity distributions at these locations is provided in Figure 3-26 for reference to the typical physical chemistry of the water quality location. These data are based on a period of record when data were being recorded at all stations (i.e., 2009-2016). These data show the general distribution of the water quality sampling locations along the salinity gradient. The following subsections evaluate the status and trends in other important water quality constituents (other than salinity) using data collected by EPC.

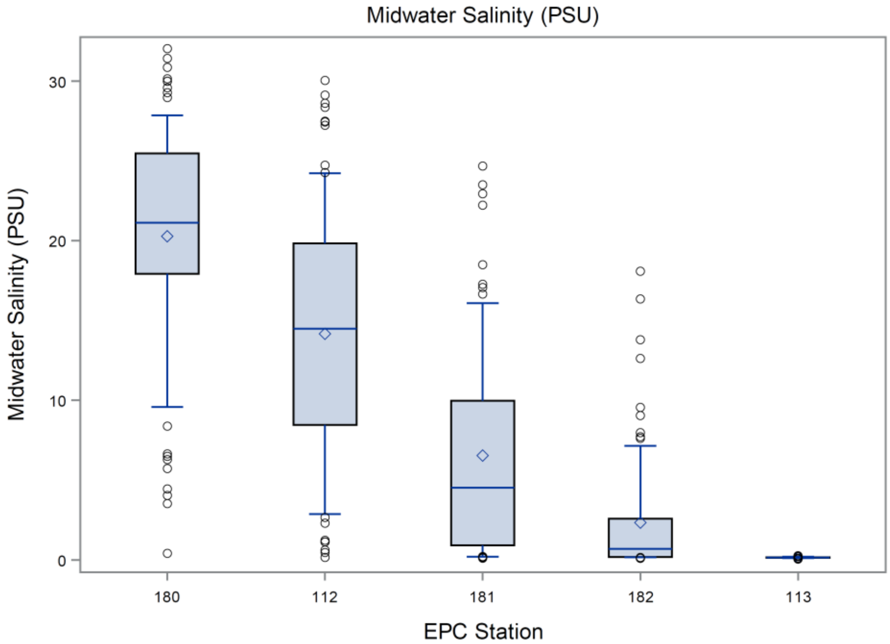

Figure 3-26. **Salinity distribution at various fixed station locations throughout the estuarine portion of the Little Manatee River.**

3.3.2.1 Chlorophyll *a* and Dissolved Oxygen

Given the importance of chlorophyll and dissolved oxygen concentrations as indicators of impairment for tidal rivers, these constituents are evaluated as primary indicators with respect to assessing their status and trends over time. The EPC has historically reported Chlorophyll a concentrations using estimates uncorrected for pheophytin and therefore the long term record for chlorophyll was based on these uncorrected values. The station-specific annual distribution of geometric average chlorophyll concentrations is provided in Figure 3-27. The stations in this plot are oriented from downstream (top) to upstream (bottom). A grey reference line denoting the 11 ug/l threshold is provided within each panel of the plot. The annual averages were generally below the 11 ug/l threshold values though stations 181 and 182, where salinity tended to be generally < 10 psu, the averages were more likely to exceed the threshold value. This is typical of the biogeochemistry of tidal rivers where initial mixing of fresh and estuarine waters creates a zone of productivity in the tidal river system.

Dissolved oxygen concentrations (expressed as percent saturation) have been reported since 2002 and tend to be above the 42% threshold for estuarine waters in all stations (Figure 3-28). The lower “whisker” on the boxplot represents the 10^{th} percentile value which in most years is above the 42% threshold at most stations. Distribution of long term dissolved oxygen measurements reported as concentration are provided in Figure 3-29 which show inter-annual variation in dissolved oxygen distributions over time. The distributions indicate that dissolved oxygen concentrations are typical of southwest Florida tidal rivers and that hypoxic conditions (i.e., concentrations less than 2 mg/l) are rare at these locations.

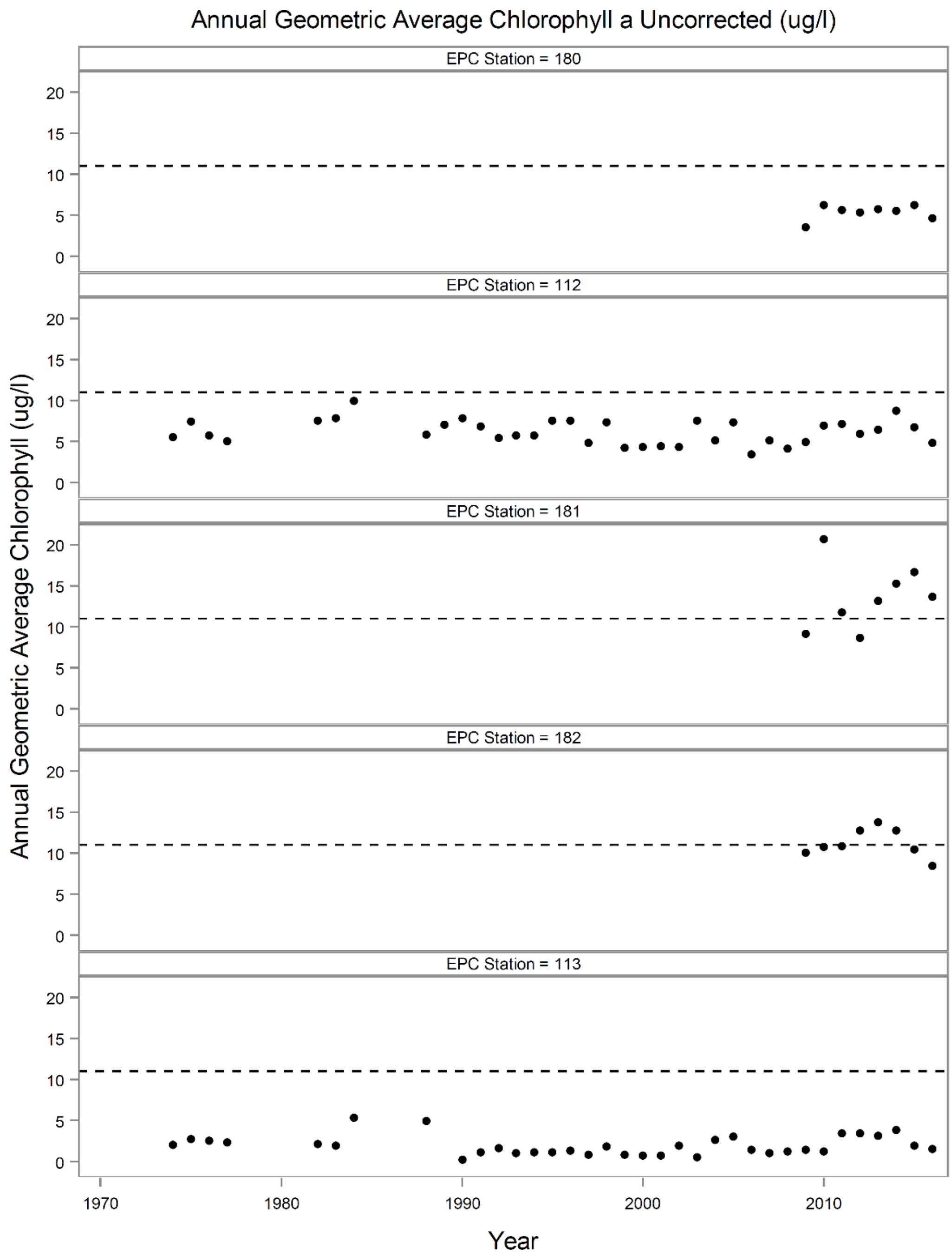

Figure 3-27. **Annual geometric average chlorophyll concentrations for period of record at each EPC station in the estuarine Little Manatee River. Broken horizontal reference line represents FDEP threshold criteria for evaluating impairment based on narrative standard.**

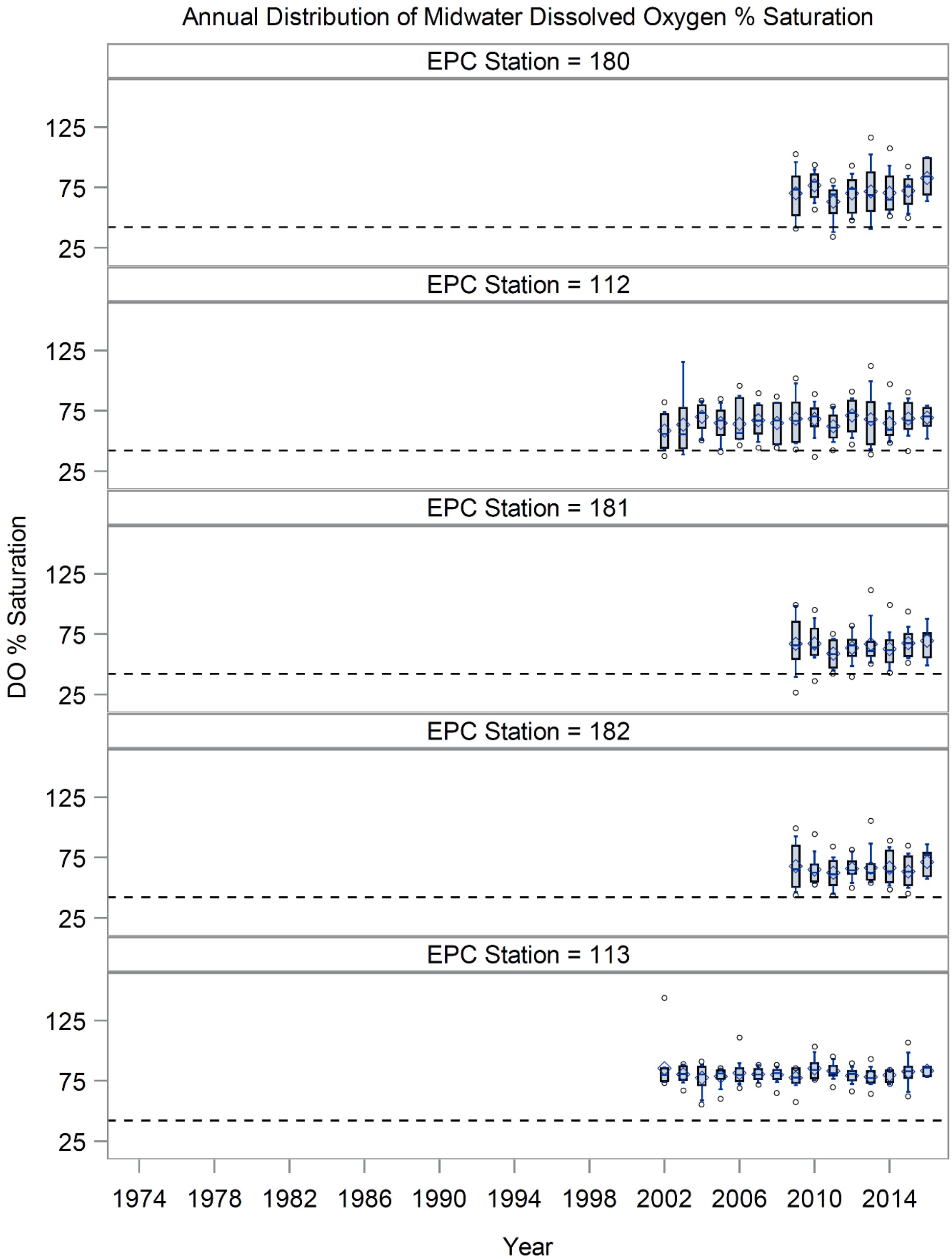

Figure 3-28. **Annual distribution of dissolved oxygen expressed as percent saturation. Broken horizontal reference line represents FDEP threshold criteria for evaluating impairment based on narrative standard.**

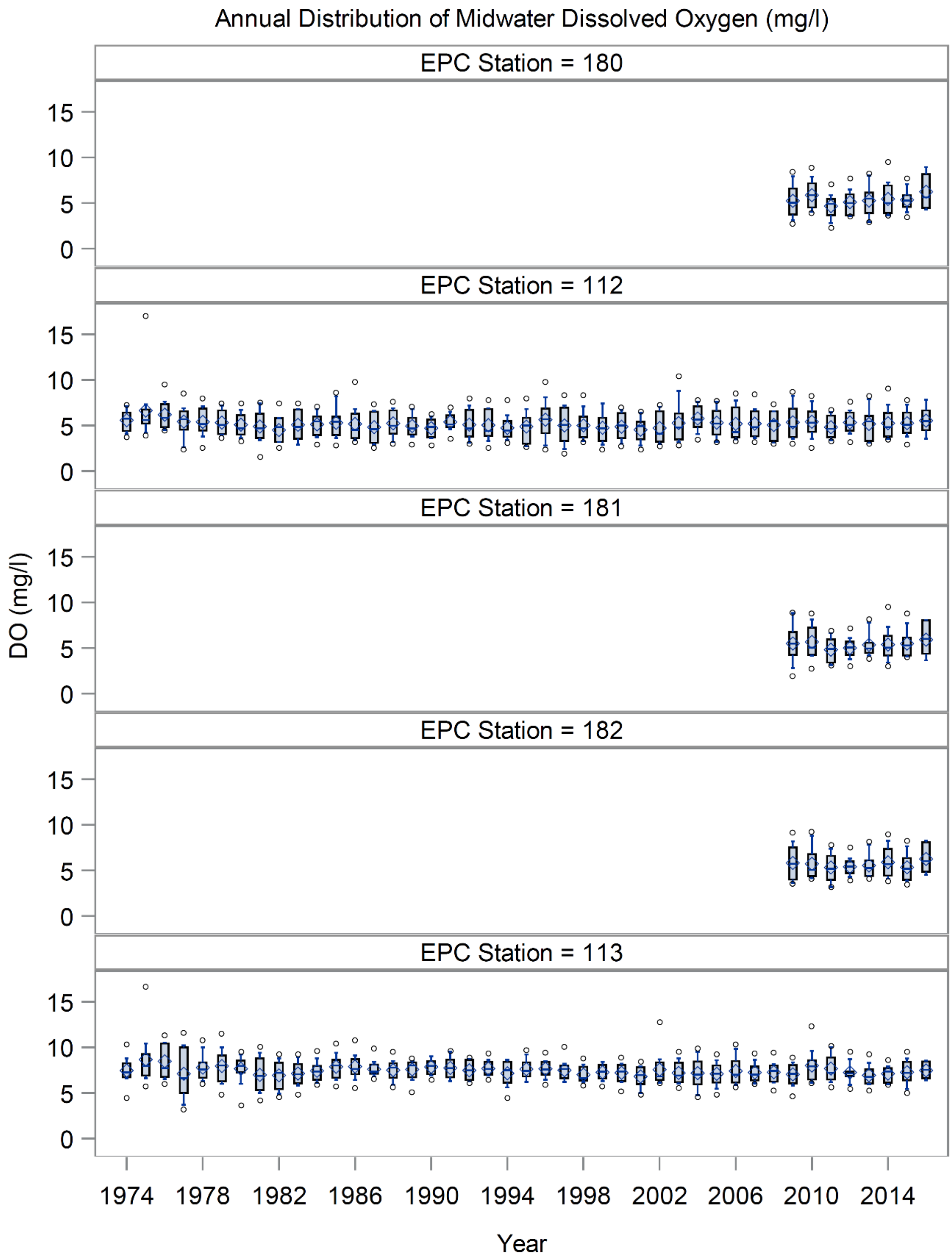

Figure 3-29 Annual distribution of midwater dissolved oxygen expressed as concentration.

Trends in water quality over time can be important information relevant to assessing the status and potential future condition of the waterbody relative to water quality standards. For the freshwater Little Manatee River minimum flows, Hood et al. (2011) evaluated trends in water quality using the Kendall Tau Trend Test (Hirsch and Slack 1984) based on data collected by USGS at the Wimauma gage. This nonparametric statistical method tests for a monotonic trend in the data over time but does not provide inference as to what may be causing any detected changes, only that a trend occurred. Hood et al. (2011) elected to partition out the effects of flow on water quality prior to evaluating the data for trend over time. A LOESS regression was used to predict the effects of flow on water quality and the residuals of that analysis were then used to evaluate the data for a trend over time (after accounting for any trend due to changes in flow over time). Note that USGS no longer collects water quality at this gage but the EPC station 113 is co-located there. Other District minimum flows reports in tidal rivers (e.g., Lower Hillsborough and Lower Alafia Rivers) did not specifically conduct trend analysis but rather examined the status of water quality constituents as a function of flow. To maintain continuity with the freshwater minimum flows, the Kendall Tau trend test was conducted on the water quality data collected by EPC both prior to, and after, accounting for the effects of flows. The results are presented in tables in the following subsections by station.

Results of trend tests for chlorophyll and dissolved oxygen are provided in Table 3-6. Most stations were stable over time for both constituents irrespective of the form of constituent (e.g., DO % saturation or concentration) or location in the water column. Chlorophyll at station 112 declined over the period of record after accounting for the effects of flow on chlorophyll at this station. An increasing trend in chlorophyll at station 113 appears to have resulted from an increase in the reported detection limit for the constituent after 2013 and is therefore considered a spurious result. It should also be noted that chlorophyll concentrations at station 113 were the lowest of any stations reporting chlorophyll.

Table 3-6. Results of Kendall Tau trend test for chlorophyll and dissolved oxygen for unadjusted and flow adjusted data.

Constituent	Station	Start Year	End Year	# of Samples	Trend Direction	Flow Adjusted Trend Direction
Chlorophyll a (ug/l)	112	1974	2016	365	No Trend	Decreasing
	113	1974	2016	241	Increasing*	Increasing*
	180	2009	2016	91	No Trend	No Trend
	181	2009	2016	91	No Trend	No Trend
	182	2009	2016	91	No Trend	No Trend
DO Sat Mid (%)	112	2002	2016	168	No Trend	No Trend
	113	2002	2016	172	No Trend	No Trend
	180	2009	2016	89	No Trend	No Trend
	181	2009	2016	91	No Trend	No Trend
	182	2009	2016	91	No Trend	No Trend

* Indicates potential spurious result due to apparent changes in method detection limit over time.

3.3.2.2 Nitrogen

Nitrogen is a principal nutrient that is fundamental to the success of native flora but can cause adverse effects in the form of phytoplankton blooms if it is found in excess. There are several forms of nitrogen measured by EPC including inorganic forms which are more labile and readily taken up by plants, and organic forms which principally result from decaying organic matter. Total nitrogen is generally computed as the sum of these organic and inorganic forms. That is, total nitrogen is the sum of organic nitrogen, ammonia and nitrate/nitrite. Most of these forms were either stable or decreasing (improving) over time based on EPC station trend results. The only exception was organic nitrogen at station 113 which was found to be increasing over time, and total nitrogen at station 112 after accounting for the effects of flow. While these results indicate the potential for increasing nutrient concentrations, the concentrations do not appear to be resulting in adverse effects to the system based on the results of the chlorophyll concentration analysis described above. Time series plots of total nitrogen and ammonia are provided in Figure 3-30 and Figure 3-31, respectively.

Table 3-7. Results of Kendall Tau trend test for nitrogen forms for unadjusted and flow adjusted data.

Constituent	Station	Start Year	End Year	# of Samples	Trend Direction	Flow Adjusted Trend Direction
Total Nitrogen (mg/l)	112	1981	2016	419	Decreasing	Decreasing
	113	1981	2016	421	No Trend	Increasing
	180	2009	2016	91	No Trend	No Trend
	181	2009	2016	91	No Trend	No Trend
	182	2009	2016	91	No Trend	No Trend
Ammonia (mg/l)	112	1974	2016	489	Decreasing	Decreasing
	113	1974	2016	487	Decreasing	Decreasing
	180	2009	2016	91	Decreasing	No Trend
	181	2009	2016	91	Decreasing	No Trend
	182	2009	2016	91	Decreasing	No Trend
Organic Nitrogen (mg/l)	112	1975	2016	474	No Trend	No Trend
	113	1975	2016	475	Increasing	Increasing
	180	2009	2016	91	No Trend	No Trend
	181	2009	2016	91	No Trend	No Trend
	182	2009	2016	91	No Trend	No Trend
Nitrates/Nitrites (mg/l)	112	1983	2016	401	Decreasing	No Trend
	113	1983	2016	400	Decreasing	No Trend
	180	2009	2016	91	No Trend	No Trend
	181	2009	2016	91	No Trend	No Trend
	182	2009	2016	91	No Trend	No Trend

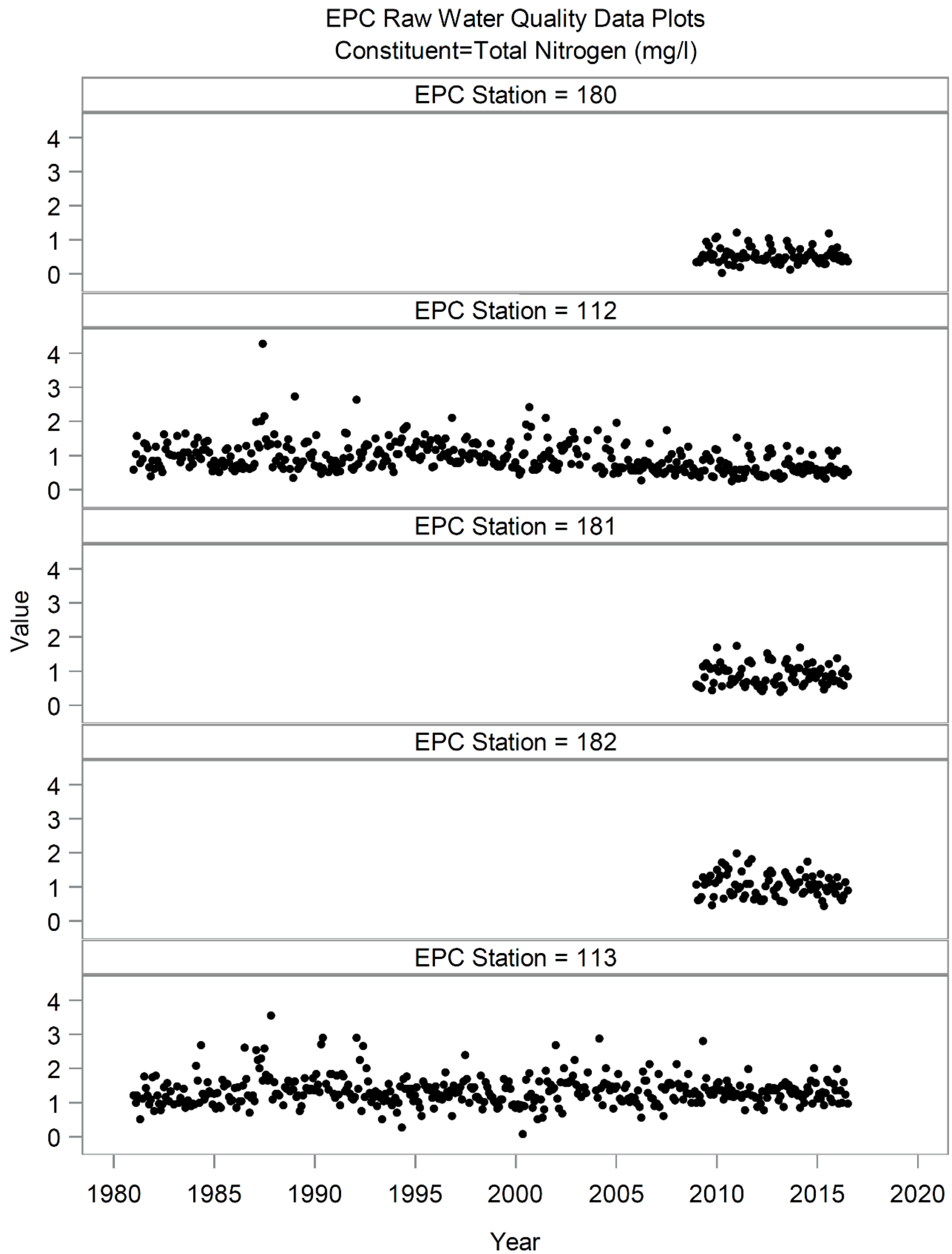

Figure 3-30. Timeseries plots of total nitrogen for each EPC station.

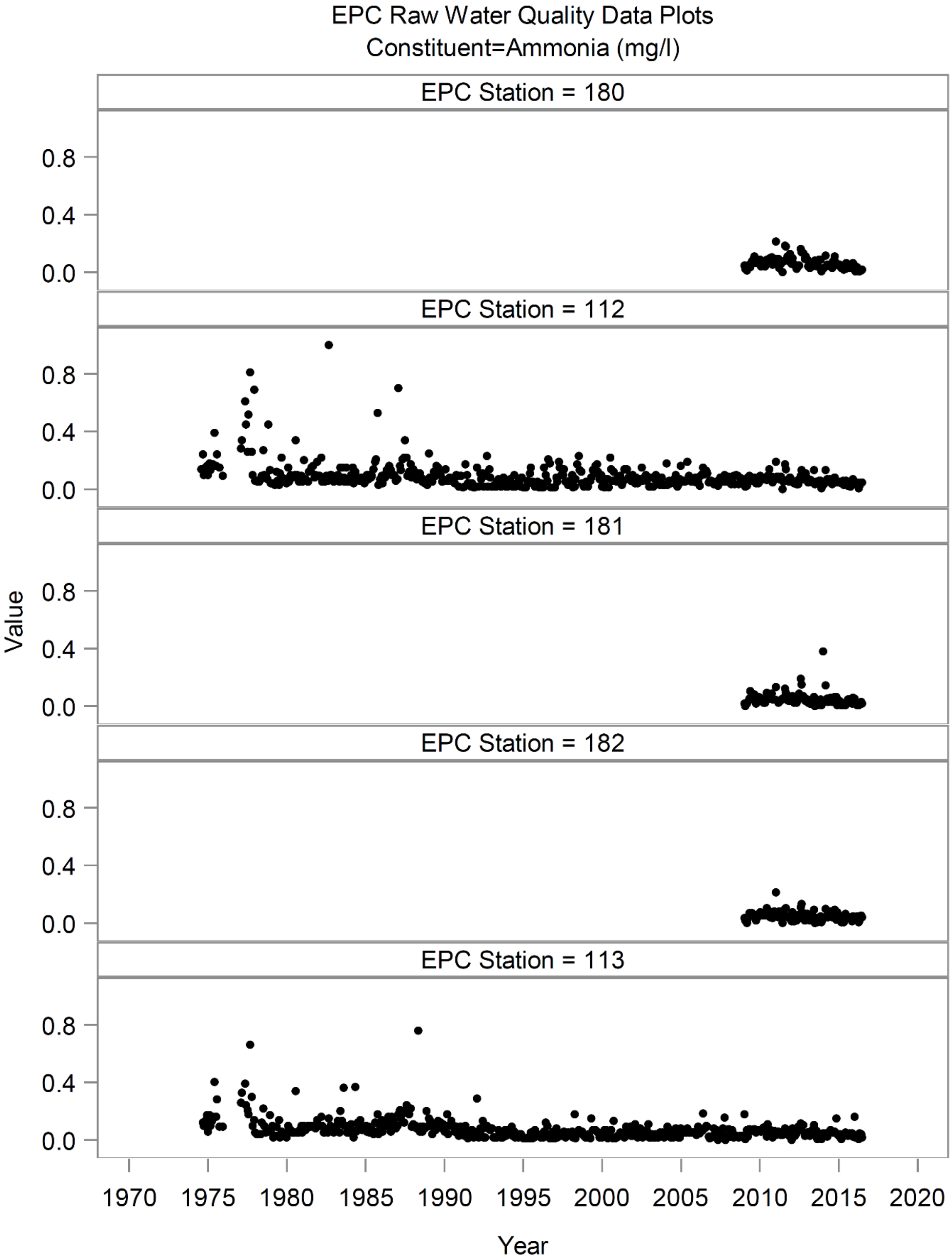

Figure 3-31. **Timeseries plots of ammonia for each EPC station.**

3.3.2.3 Phosphorus

Phosphorus (P) is an essential nutrient for plants that stimulates early growth. Although P is essential for plant growth, mismanagement can pose a threat to water quality. While the concentration of P is usually sufficiently low in fresh water to be the limiting nutrient, the Little Manatee River resides in the phosphorus rich "Bone Valley" geological formation and therefore, P is in plentiful supply. Nitrogen is the nutrient that typically limits phytoplankton in Tampa Bay and its tributaries (Fanning and Bell 1985, Vargo et al. 1991, Janicki and Wade 1996, as cited in Flannery et al 2008). Phosphorus is reported by EPC as both orthophosphate and total phosphorus. Results of trend test suggest phosphorus concentrations at many EPC stations were decreasing (i.e., improving) over time for both constituents. These results are confirmed by visual observation of the time series plots for total phosphorus (Figure 3-32).

Table 3-8. Results of Kendall Tau trend test for phosphorus forms for unadjusted and flow adjusted data.

Constituent	Station	Start Year	End Year	# of Samples	Trend Direction	Flow Adjusted Trend Direction
Total Phosphorus (mg/l)	112	1974	2016	509	Decreasing	Decreasing
	113	1974	2016	509	Decreasing	Decreasing
	180	2009	2016	91	No Trend	No Trend
	181	2009	2016	91	No Trend	No Trend
	182	2009	2016	91	No Trend	Decreasing
Ortho Phosphates (mg/l)	112	1974	2016	318	Decreasing	Decreasing
	113	1974	2016	331	Decreasing	Decreasing
	180	2009	2016	91	No Trend	Decreasing
	181	2009	2016	91	Decreasing	Decreasing
	182	2009	2016	91	No Trend	Decreasing

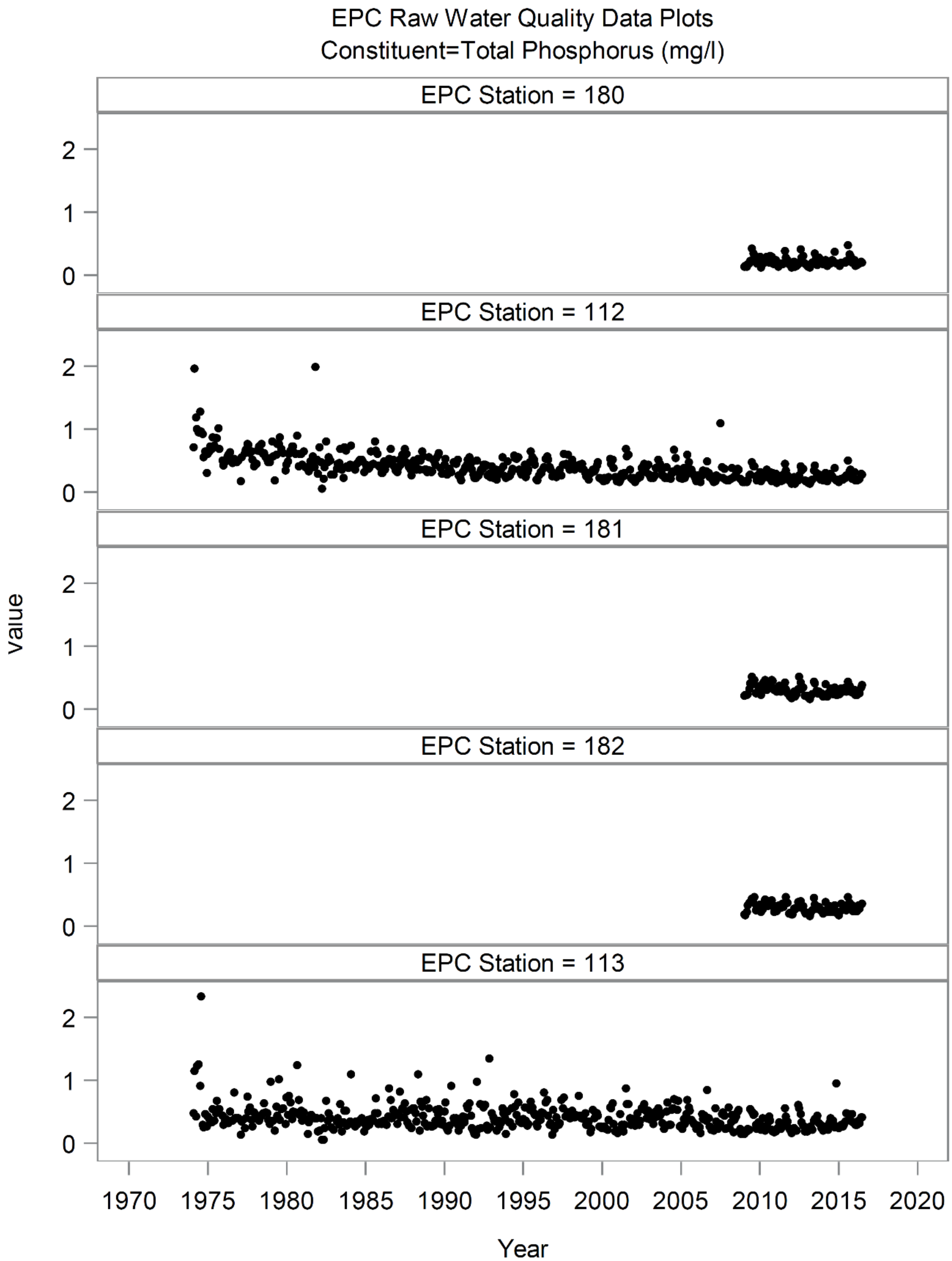

Figure 3-32. **Timeseries plots of total phosphorus for each EPC station.**

3.3.2.4 Chemical Constituents and Fecal Coliforms

Several other important water quality constituents were evaluated for this project including fecal coliforms, fluoride, pH, total suspended solids and turbidity. The results of trend analysis on these constituents suggest that these water quality parameters were either stable or decreasing (i.e., improving) over time throughout the estuarine portion of the system.

Table 3-9. Results of Kendall Tau trend test for other important water quality constituents for unadjusted and flow adjusted data.

Constituent	Station	Start Year	End Year	# of Samples	Trend Direction	Flow Adjusted Trend Direction
Fecal_Coliform (n/100ml)	112	1974	2016	505	Decreasing	Decreasing
	113	1974	2016	505	No Trend	No Trend
	180	2009	2016	91	No Trend	No Trend
	181	2009	2016	91	No Trend	No Trend
	182	2009	2016	91	No Trend	No Trend
Fluoride (mg/l)	112	1974	2016	495	Decreasing	Decreasing
	113	1974	2016	474	No Trend	No Trend
	180	2009	2016	91	Decreasing	Decreasing
	181	2009	2016	91	No Trend	Decreasing
	182	2009	2016	91	No Trend	No Trend
pH Mid	112	1974	2016	500	No Trend	No Trend
	113	1974	2016	502	No Trend	No Trend
	180	2009	2016	91	No Trend	No Trend
	181	2009	2016	91	No Trend	No Trend
	182	2009	2016	91	No Trend	No Trend
Total Suspended Solids (mg/l)	112	1974	2008	191	Decreasing	Decreasing
	113	1974	2008	378	No Trend	Decreasing
Turbidity (NTU)	112	1974	2016	509	Decreasing	Decreasing
	113	1974	2016	507	No Trend	Decreasing
	180	2009	2016	91	No Trend	Decreasing
	181	2009	2016	91	No Trend	No Trend
	182	2009	2016	91	No Trend	No Trend

4 BIOLOGICAL CHARACTERISTICS

This chapter describes the dominant biological characteristics of the Little Manatee River estuary and, If reported, the relationship between the biota and freshwater inflows. It is the District's aim to focus this document on describing attributes of the Little Manatee River estuary that can be used to directly inform the development of recommendations of minimum flows criteria. Therefore, this section is not intended to be a compendium of all scientific studies evaluating aspects of the estuarine biota utilizing the Little Manatee River estuary nor a treatise on the ecology of the system. This chapter does provide a summary of the relevant studies describing the dominant biotic habitats and populations that are principal resources of concern to be protected from significant harm due to surface water withdrawals. These biological communities do represent key ecological endpoints with high natural resource value that serve as important economic drivers and have high social value. These communities can generally be classified as exhibiting indirect effects of freshwater flows. That is, the biological response is modulated though some other direct response to flow, usually salinity which is routinely used as a proxy when identifying potential for significant harm to estuarine biota as a function of flow reductions. Despite this, where direct relationships between biota and flow were modeled and reported they were considered as potential candidates for evaluating the effects of flow reductions on these communities.

4.1 Shoreline and Emergent Vegetation

Mangroves and oyster bars are predominant features in the lower and middle reaches of the estuary with brackish marshes well developed in the upper estuary, especially north of Interstate 75 (Dames and Moore 1975; Fernandez 1985; Florida Marine Research Institute 1997). The District's 2011 electronic data on Florida Landuse and Land Classification Codes (FLUCCSCODE) was used to classify major wetland features in the Little Manatee River estuary. Mangrove shorelines dominate the shoreline west of the US41 bridge (Figure 4-1). Between US41 and interstate 75, the wetland vegetation transitions to saltwater marshes though mangrove communities remain interspersed alongside these marshes to I75. In fact, just above I75 there is a point of land on which patches of mangrove, juncus marsh, and leather fern all exist within a 500 meter area indicating that this area may represent a salinity regime tolerance boundary for several wetland community types with differing salinity optima.

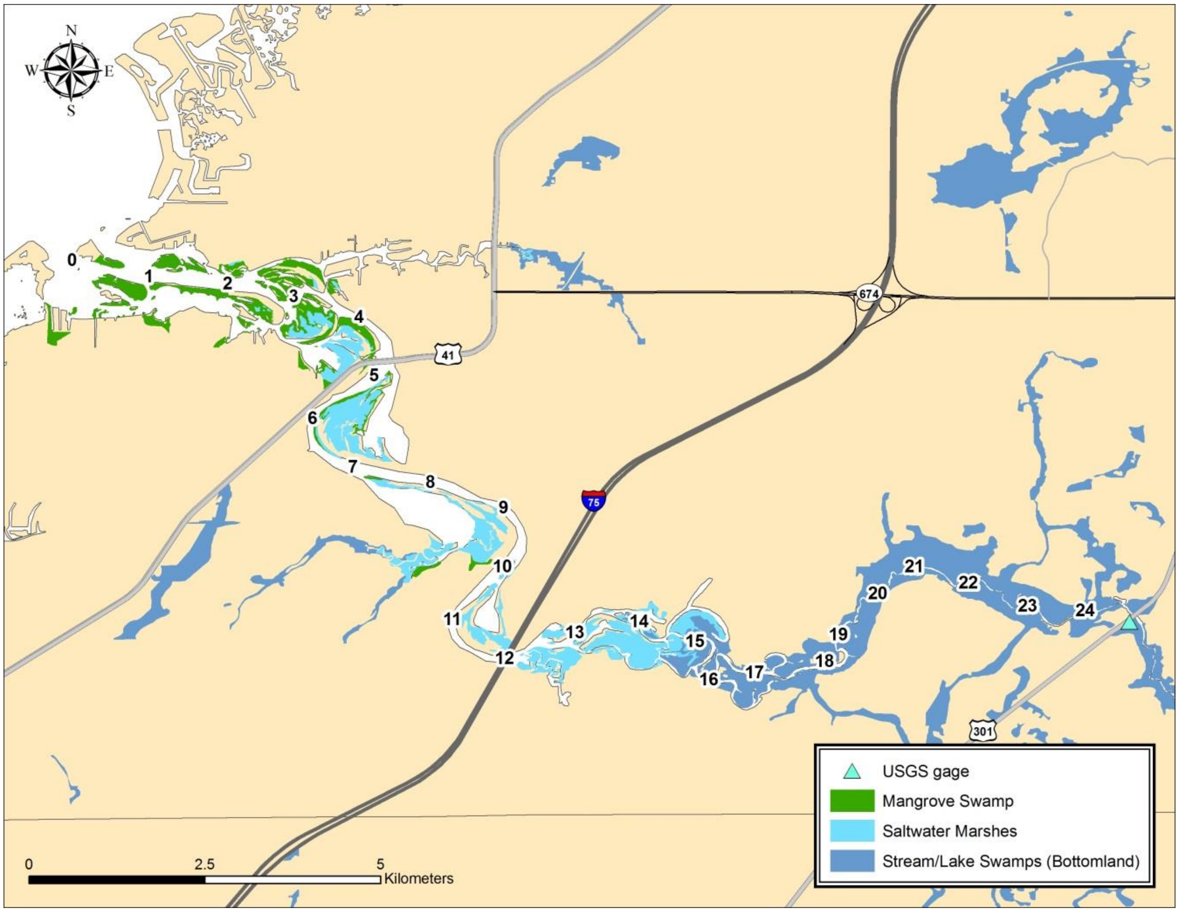

Figure 4-1. Distribution of major wetland features in the Little Manatee River Estuary. The numbers along the river represent the river kilometer system used for analysis.

Browder and Moore (1981) theorized that river flows locate areas of favorable salinities relative to important stationary habitat factors in tidal rivers. The overlap of these conditions, integrated over the nursery season, may impact growth and survival of juvenile organisms. Browder and Moore described this favorable overlap as the "Production Area" where fishery production would tend to be greatest within the estuary. While, this concept has been widely recognized and has been used to guide management decisions in frameworks such as the National Marine Fisheries Service's "Essential Fish Habitat" guidance to identify important areas for federally managed fish species, habitat affinities and site fidelities of estuarine dependent fish (and invertebrate) species utilizing physical habitats in estuaries remain poorly understood (Able 2005). Characterizing the dynamics between salinity preferences and physical habitat preferences for important fish taxa may help managers better understand how changes freshwater flows and resulting salinities correspond to environment requirements for fish populations utilizing tidal rivers. Estuarine taxa with high habitat affinities may be particularly susceptible to alteration of environmental conditions if their environmental preferences result in the choice between staying in a less favorable salinity and relocating with their salinity optimum to a less favorable physical habitat. Many research studies have been conducted in Tampa Bay tidal tributaries to support the development of environmental flow standards protective against significant harm due to surface water withdrawals as described in the following sub-sections of this chapter. Some have simply described attributes of community structure as a function of location within the tidal portion of the river, others have attempted to develop predictive models describing direct effects of flows on abundance and distribution, while others have incorporated ecological principals and included covariates to partition the effect of flow out of the myriad of others potential factors affecting the abundance and distribution of these communities in an open estuarine environment. The following sub-sections provide a summary of the methods, descriptive results, and inferential results as they pertain to establishing potential endpoints that can be used to support the establishment of the minimum flows for the Little Manatee River estuary.

4.2 Benthos

“Benthos” is a term used to describe organisms residing on or near the surface sediment layer such as aquatic insects, worms, snails, clams, and shrimp and has traditionally been used to describe benthic invertebrate communities in Tampa Bay studies. Benthic organisms are generally sessile, although some species may undergo migrations into the water column (*e.g*., amphipod crustaceans) or produce planktonic larvae (e.g*.,* polychaete worms) (Grabe and Janicki 2008). As a group, however, benthos are relatively sedentary and are considered to be effective integrators of a variety of environmental factors, including salinity (Boesch and Rosenberg, 1981; U.S.E.P.A., 1999). Unlike the more vagile nekton, most benthic invertebrates lack the mobility to escape large or rapid fluctuations in environmental conditions. Benthic organisms occupy a variety of niches with respect to energy transfer. The benthos process organic material as detritivores, suspension feeders, and deposit feeders, forming an essential link in the transfer of energy to secondary consumers including other benthic organisms, finfish, and avifauna (Grabe and Janicki 2008 and citations therein).

Several studies on benthic invertebrates have been conducted in the Little Manatee River including Dames and Moore (1975), HCEPC (2004), Grabe et al. (2004), Grabe et al. (2005). Janicki Environmental (2007). These data and reports were summarized by Grabe and Janicki (2008) in a report to the District with respect to their utility for supporting minimum flows thresholds protective against significant harm from freshwater flow reductions. A mollusk survey was also conducted specifically to characterize mollusk populations in preparation for setting minimum flows for the Little Manatee River estuary (Estevez 2006) though no predictive equations were defined that could be used to establish criteria for the protection of mollusks in the Little Manatee River.

4.2.1 Descriptive (adapted from Grabe and Janicki 2008)

Data on benthic assemblages in the Little Manatee River came from three programs. Two programs collected samples during the summer “wet” season only. These programs each employed a probabilistic design considering the Little Manatee River as a control site to evaluate the effects of freshwater withdrawals in the neighboring Alafia River. Samples were collected by the EPCHC as part of the Tampa Bay Benthic Monitoring Program between 1996-1998 and subsequently through 2003 by the Hillsborough Independent Monitoring Program. The absence of “dry” season benthic data led the District to support a one-time, spatially intensive survey of the benthos to provide a more robust dataset to aid in minimum flows development. Ninety-six samples were collected during late May-early June 2005 from the Little Manatee River mainstem and three bayous (Bolster, Hays, and Mill). Samples were collected from river kilometer (RKM) 0 (in line with Shell Point) to RKM 17. RKM “0” corresponds to the location of RKM 0 in Fernandez (1985). Ruskin Inlet and intertidal areas were excluded. Transects were established every 0.5 KM in the main stem of the river (Janicki Environmental, Inc. 2005). Two samples were collected at random locations within each 0.5 kilometer segment from RKM 0 to RKM 17. Eight samples were collected from Mills Bayou, 16 from Hayes Bayou, and four from Bolster Bayou. A total of 235 samples have been collected; 139 from EPCHC wet season surveys during 1996-2005 and 96 dry season samples collected for the District in 2005. The locations of all benthic samples collected from 1996-2005 are shown in Figure 4-2.

The EPCHC benthic samples were collected using a stainless steel Young grab sampler (0.04 m2). The 2005 survey for the District employed a 7.62 cm diameter hand core (area= 45.6 cm2) to sample the benthos. In practice, the samples were collected with a Young sampler and the core was removed from this larger sample. A cored subsample was removed from the Young sampler and retained for later analysis of the silt+clay content (%SC) of the sediment. Samples were sieved (500 μm mesh) to remove finer-grained particles of sediment and meiofauna. Samples were then fixed in a 10% solution of borax-buffered formalin and Rose Bengal stain. Water column measurements of temperature, dissolved oxygen, salinity/conductivity, and pH were made every meter below the water surface, from 0.1 m below the surface to 0.2 m above the bottom.

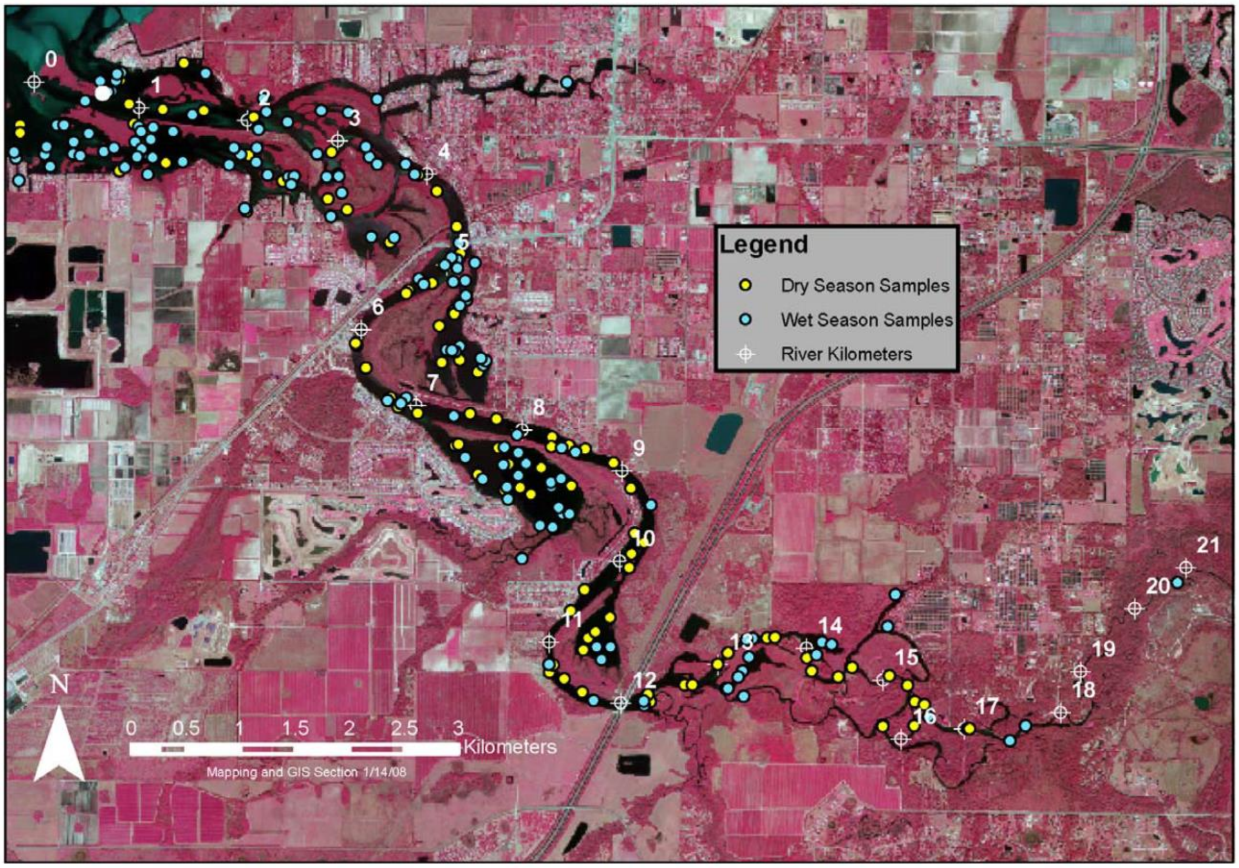

Figure 4-2. Location of benthic invertebrate samples collected between 1996-2005 in the Little Manatee River estuary.

Data analysis involved three general approaches: univariate summaries (dominant taxa, taxa richness, total abundance), linear and logistic regression to assess relationships between abundance or occurrence and inflows, and multivariate analyses exploring how the benthic assemblage was organized as a function of environmental parameters (e.g., salinity). Multiple environmental variables were included such as water temperature, salinity, dissolved oxygen, sample depth, temperature and cumulative flows over various time periods.

The report suggests that the Little Manatee River benthos was dominated by crustacean taxa, particularly the amphipods *Grandidierella bonnieroides* and *Apocorophium louisianum*. Dominant taxa were generally similar between wet and dry season surveys, although the rank orders differed. The number of taxa generally declined with upstream location irrespective of season though the abundance of benthic macroinvertebrates did not show any consistent longitudinal trend during either season. Descriptive analysis of the multivariate community structure, based upon samples stratified by river kilometer and season, suggested that during the wet season, the lowest two kilometers of the river supported a different faunal assemblage than the rest of the river which was generally similar in multivariate community structure. The dry season benthos showed evidence of a shift in assemblages at RKMs 6-8. Location in the river (RKM) was the single abiotic variable with the highest Spearman rank correlation coefficient to changes in multivariate community structure.

A number of taxa exhibited a shift in the preferred salinity, generally to a more saline habitat, from the wet season to the dry season indicating a tolerance for salinity changes relative to a dislocation from an existing habitat (Grabe and Janicki 2008). Principal components analysis identified changes in community structure associated with oligohaline (0-8 psu), mesohaline (8-19 psu) and polyhaline (19-28 psu) salinity classes. Interestingly, two taxa, *Grandidierella bonnierodes* and *Cyathura polita*, were found to be characteristic of both the oligohaline and polyhaline classes indicating a broad salinity distribution in which these organisms can be commonly found.

4.2.2 Relation to inflow

Generally, benthic macroinvertebrates are sedentary, lacking the mobility to escape large or rapid fluctuations in environmental conditions such as freshwater inflows. Flows affect the volume and velocity of the river, directly affecting benthos, and can physically wash benthic organisms out of the system. Flow also affects salinity, dissolved oxygen, sediments, and nutrient dynamics, and thus indirectly affect the abundance and distribution of benthos. In particular, in tidal rivers, salinity is typically negatively correlated with flow and can indirectly affect the distribution and abundance of individual species and the overall composition of the benthic community that have salinity preferences. The effect of salinity on benthic community structure also depends upon how the distributions of individual taxa vary with changes in salinity. Janicki Environmental (2007) employed a host of analytical tools to evaluate the relationship between benthos in southwest Florida tidal rivers and freshwater inflows. The analytical tools included linear regression, generalized linear models including univariate and multiple logistic regression, classification and regression trees, and artificial neural networks. An example of the univariate logistic regression outcomes for several dominant taxa is provided in Figure 4-3. The dominant taxa included representative amphipods (e.g., *Grandidierella bonnieroides* and *Ampelisca abdita*) that have been identified as being preferred prey items for estuarine dependent fishes (Peebles 2005) among other species. Logistic regression was used to assess salinity preferences for dominant taxa thought to be potential indicators for establishing benthos related flow thresholds to protect this resource of concern. The salinity optima (as defined by the top 75th percentile of their maximum probability of occurrence) for these species covered a range of tidal river salinity conditions and also showed that these taxa have a broad range of salinity conditions in which they typically occur with relatively high probability. Similar analysis was conducted by geographic location and season. The results demonstrate that, for many taxa (e.g., *Grandidierella bonnierodes:* Figure 4-4), the optimal habitat salinity range was wide, system dependent, and could range across the majority of the observed salinity conditions.

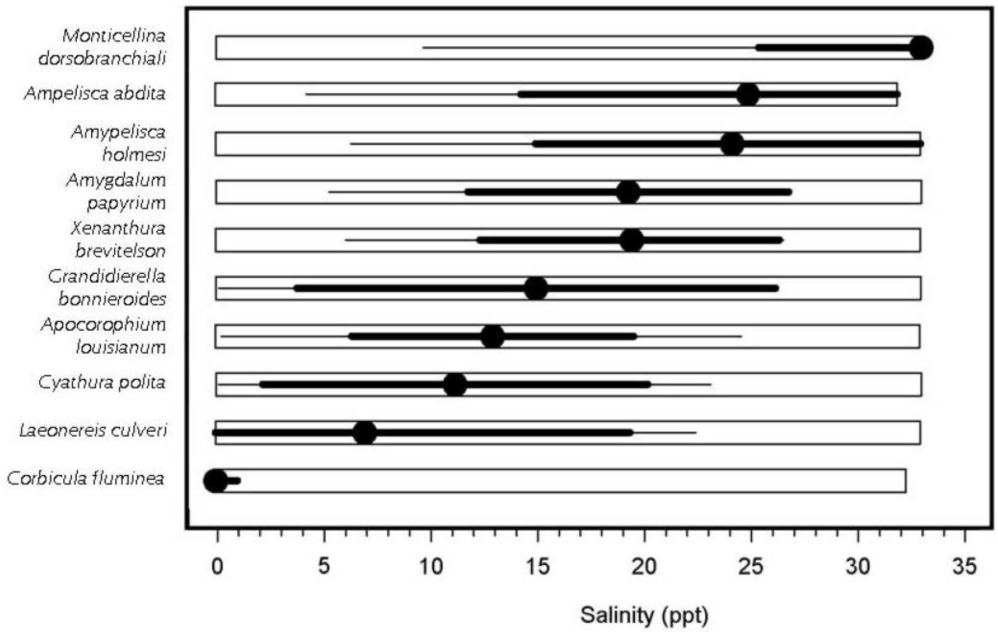

Figure 4-3. **Summary of salinity optimum (circle), optimal habitat range (i.e., 75% of optimum solid bar), 10th to 90th percentile probability of occurrence(thin line), and salinity model domain (open bar) for ten selected benthic taxa using pooled data from 12 southwest Florida tidal rivers (wet and dry seasons combined.**

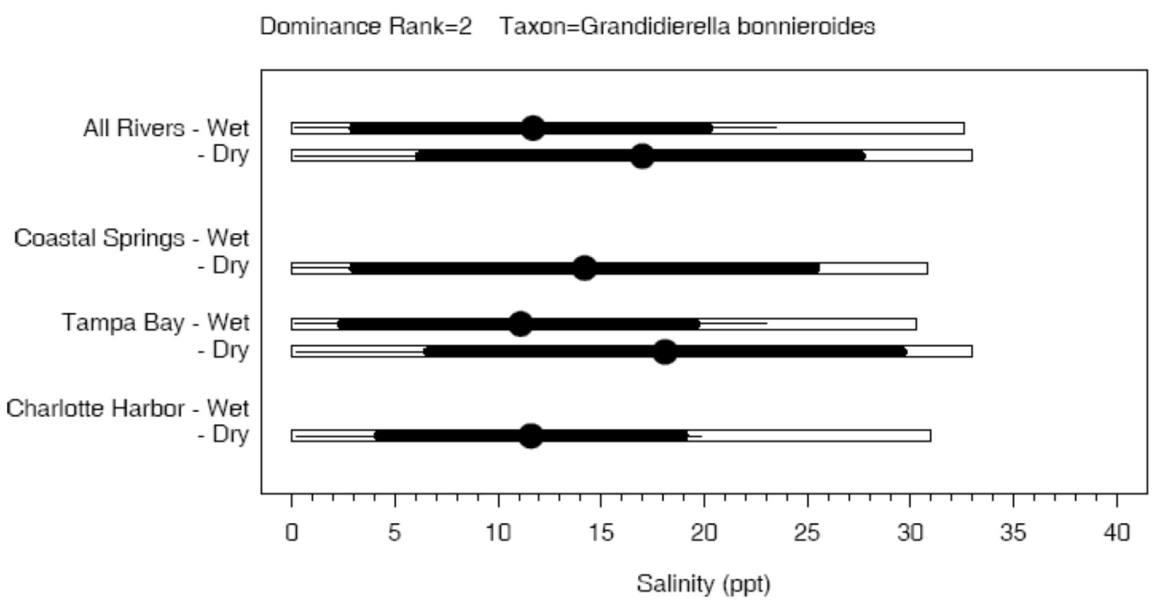

Figure 4-4. **Summary of salinity optimum (circle), optimal habitat range (i.e., 75% of optimum: solid bar), 10th to 90th percentile probability of occurrence(thin line), and salinity model domain (open bar) for *Grandidierella bonnierodes* by river group and seasons based on logistic regression analysis. The lack of a bar (Charlotte Harbor and Coastal Springs wet season) indicates the lack of a statistically significant relationship.**

Logistic regression was also used to estimate the probability of occurrence of the 50 "dominant" species by the four DO ranges: <2.5 mg/L: Six species, including four polychaete worms (*Prionospio perkinsi, Paraprionospio pinnata, Monticellina dorsobranchialis*, and *Stenoninereis martini*), the bivalve *Mytilopsis leucophaeata*, and the brachiopod *Glottidia pyramidata*, exhibited an optimum DO near 0 mg/L. The optimum dissolved oxygen for nine taxa, including *Edotea triloba, Apocorophium louisianum,* and *Mytilopsis leucophaeata,* fell within the 2.5 to 5.5 mg/L range. At least 18 taxa had DO optima within the 5.5 to 9.0 mg/L range during at least one season including *Grandidierella bonnieroides, Laeonereis culveri, Corbicula fluminea, Limnodrilus hoffmeisteri, Polymesoda carolinea, Chironomus* sp., and *Amygdalum papyrium*. The Little Manatee River is not a highly stratified system and has a low empirical probability of occurrence of a low dissolved oxygen event (i.e., < 2.0 mg/l) indicating that modeling these indirect effects on the biota using flow as an explanatory variable would not be fruitful in support of the minimum flows for the Little Manatee River estuary.

Multiple regression techniques that incorporate other factors (covariates) influencing probability of occurrence and abundance of these taxa (e.g., dissolved oxygen and sediment characteristics) suggested that once other factors are considered, the effect of salinity was only a weakly deterministic component of the model. For example, a multiple logistic regression model was developed for several important benthic taxa collected in the lower Alafia River (the river with the largest dataset available). Silt clay, dissolved oxygen, salinity and various lags and lag averages of flow were considered as potential explanatory variables. Only two of the seven taxa (*Ampelisca holmesi*, and *Paraprionospio pinnata*) had positive relationships with some lag antecedent flow condition indicating their potential as minimum flows indicators. However, neither of these models were of sufficient explanatory power to be useful in support of establishing minimum flows for the Little Manatee River estuary (i.e., $R^2 < 0.35$). Other analytical techniques including generalized linear models, principal components analysis, and neural network analysis suffered from the same limitations as described above: namely; 1) that these organisms are captured in less than half of the total number of samples thereby including many zero's in the dataset reducing statistical power of the models; 2) that the majority of the modeled relationships indicate a negative relationship with flow meaning that increased flows, decrease organism abundance, and 3) that the multiple explanatory variables are interrelated in a such a way that it is difficult to partition the effects of flow, or salinity, out of other factors affecting the distribution and abundance of these taxa.

Generally, the contribution of flow to explaining variation in probability of occurrence was small relative to other environmental factors. Kimmerer (2002) found that physical habitats that vary with flow play a more important role in upward trophic transfer than the direct effects of flow. The results of this study suggested that the measurable effects of flow on benthos were more related to environmental and physical characteristics than to the direct effects of flow but that fresh water inflow as an indirect effect is deterministic of the environmental factors regulating probability of occurrence. Grabe and Janicki (2008) concluded that while these biota are extremely important ecosystem attributes to be considered as part of the minimum flows process, they did not recommend any specific taxa or taxa group that could be directly used in support of establishing minimum flows for the Little Manatee River estuary. Given these considerations, we view the benthos as important ecological attributes that have salinity preferences and tolerances that can be used to inform salinity isohalines assessments under the assumption that changes in the area or volume of specific salinity isohalines will ultimately affect the distribution, probability of occurrence, and abundance of the benthos, including mollusks, adapted to that environment..

4.3 ZooPlankton

The predominant source of plankton data in Tampa Bay tidal tributaries was collected by Dr Ernst Peebles, professor at the University Of South Florida College of Marine Science along with his students and staff. Dr. Peebles has been integrally involved in studies aimed at developing environmental flow requirements for estuarine biota in southwest Florida tidal rivers including the development of the “percent of flow approach” which is now a standard method for defining minimum flows and consumptive water use in Southwest Florida tidal rivers (Flannery et. al. 2002). Peebles has performed District sponsored data collection and analysis in support of establishing minimum flows for all major District tidal rivers including the Hillsborough (MacDonald et al. 2005), Alafia River (Peebles et al. 2005), Tampa Bypass Canal (Peebles 2004), and Little Manatee River (Peebles and Flannery 1992: Peebles 2008). The focus of these studies has been on developing predictive tools to evaluate the impacts of freshwater flows on distribution and abundance of motile estuarine zooplankton (invertebrates and fishes) utilizing tidal river habitats in the context of process-based ecological theory. For the Little Manatee River, Peebles collected data between 1998 and 1990 and initially analyzed those data in a report to the District (Peebles and Flannery 1992). In 2008, Peebles applied new analytical methods and data presentations to the data in an update to the original data analysis (Peebles 2008). This latter report is the basis from which the zooplankton were evaluated with respect to the potential of zooplankton to serve as criteria in support of developing minimum flows thresholds protective against significant harm.

4.3.1 Descriptive (adapted from Peebles 2008)

Plankton net collections were made at fixed locations in the Little Manatee River estuary between January 1988 and January 1990 (Table 4-1.) A total of 960 samples were collected using a 505 micron mesh 3:1 conical plankton net equipped with a flow meter and a 1 liter plastic cod end jar (Peebles and Flannery 1992). The tows were conducted at night on an incoming tide at a speed of approximately 1.7m/s for 5 minutes with a mean filtration of 73 m^3. At each station, 4 tows were conducted: two oblique, one surface, and one bottom tow.

The small organisms collected at night by the plankton net represent a combination of the zooplankton and hyperbenthos communities. The faunal mixture present in the nighttime water column includes the planktonic eggs and larvae of fishes. Although fish eggs and larvae are the target catch, invertebrate plankton and hyperbenthos usually dominate the samples numerically.

The invertebrate catch largely consists of organisms that serve as important food for juvenile estuary-dependent and estuarine-resident fishes.

Table 4-1. Distribution of sampling effort (Peebles and Flannery 1992).

Location (km)	Collection Period	No. Collection Dates	No. Samples	Volume Filtered (m^3)		
				Oblique	Surface	Bottom
14.2	Jan88 – Jan89	24	96	3,633	1,799	1,710
10.3	Jan88 – Jan90	48	192	7,326	3,714	3,645
7.1	Jan88 – Jan89	24	96	3,805	1,906	1,801
3.8	Jan88 – Jan90	48	192	7,201	3,717	3,589
0.0	Jan88 – Jan90	48	192	6,887	3,510	3,411
-3.8	Jan88 – Jan90	48	192	6,288	2,842	2,642
Totals			**960**	**35,140**	**17,488**	**16,798**

Multiple data analysis updates were also performed as part of the re-evaluation of Peebles and Flannery (1992):

- **Freshwater Inflow** (F) was updated to be represented solely by streamflow at the USGS Little Manatee River near Wimauma gage (02300500).
- **Organism Weighted Salinity** (S_u; central salinity tendency for catch-per-unit-effort) was recalculated to reflect revisions to the database.
- **Organism Total Number** (N; total number of organisms in the tidal portion of the river) was calculated.
- **Center of Abundance** (km_u; central geographic tendency for CPUE) was calculated and was presumed to be an improvement over the previously reported A_{max} (location of the station with the highest CPUE during an individual collection effort) because it reflects CPUE trends along the entire transect and provides continuous, rather than discrete, results.
- **Organism Dispersion** was calculated as an interdecile range (IDR). In this application the IDR was defined as the length of the river in which the middle 80% of the catch was encountered. The IDR was regressed against observed km_u to determine whether organisms became more or less dispersed as they moved upstream and downstream in conjunction with changing inflow conditions.
- **Inflow Response Regressions**: Regression analysis was conducted for km_u on F and N on F. For these regressions, F was represented by same-day inflow and by mean inflows with lags up to 119 days.
- **Water Age at Capture** (T): kmu values and associated gaged inflow rates were entered into an equation derived from a forward-stepwise multiple regression to calculate resulting water ages which were then regressed against the mean inflow for the three days prior to collection.

- **Community-level Response** to Inflow was assessed via various multivariate analyses using PRIMER software.

4.3.2 Relation to Inflow

Based on the results of the listed analyses, several conclusions were made regarding shifts in distribution, abundance responses, and community heterogeneity which are summarized below.

- When freshwater inflow was reduced, the taxonomic composition along the sampling transects became more uniform, most notably at inflows <100 cfs. The lack of community heterogeneity during dry periods was attributed to the absence of freshwater taxa (cladocerans and freshwater clam larvae) and a generally greater upstream penetration of crab and shrimp larvae, mysids, larval gobies, and bay anchovy juveniles. Calanoid copepods, chaetognaths, polychaetes and percomorph fish eggs were important in distinguishing upper and lower estuary communities during high-inflow conditions. Decapod mysis (shrimp larvae) and bay anchovy juveniles were the most consistent discriminating taxa.

- Twenty-four taxa of fish and invertebrates exhibited distribution responses to freshwater inflow; the vast majority (n=22) were negative slopes indicating movement downstream as freshwater inflow increased. Slightly more than half (n=13) of the responses occurred within one week of a change in inflow. The IDR typically occurred along reaches of the river shorter than the sampled transect; thus, individual taxa tended to occupy discrete sections of tidal river as opposed to being widely dispersed throughout the length of the transect. Mysids, bay anchovy juveniles, and menhaden postflexion larvae were indicated to remain in relatively young water (<14 days elapsed since introduction at the estuary head) as they ranged back and forth through long reaches (11.2-17.1 km) in conjunction with changing inflows.

- Twenty-one significant relationships between abundance and inflow were reported; however, 16 of those were negative and therefore discounted by the author as potential minimum flows indicators because as flows decrease the predicted response is an increase in abundance. Taxa typically associated with higher salinities in the plume moved farther seaward into the open bay during high-inflow periods, causing a negative abundance correlation with inflow. For estuarine-dependent organisms known to congregate in estuarine nurseries in the interiors of rivers, there were 5 taxa that exhibited a positive relationship with flow (Table 4-2). This was observed for menhaden postflexion larvae, yellowfin menhaden juveniles, hogchoker juveniles, bay anchovy adults, and sand seatrout postflexion larvae. However, direct correlations between abundance and inflow were reported to be hampered by time lags. For hogchoker juveniles, the time lag of one day was too short to be related to adult reproduction or early life history survival and was instead theorized to be indicative of catchability responses caused by increased inflow. The remaining three taxa, however, had responses that were consistent with elevated adult spawning, improved survival during early life history, improved hydrodynamic transport from spawning ground to nursery, or improved delivery of olfactorants suspected of attracting young fishes to nursery habitats. The coefficients of determination (r^2 values) ranged from 41 to 61% and the report concluded these responses were potentially meaningful to inflow management.

Table 4-2. Abundance responses to mean freshwater inflow (Ln N vs. Ln F). Regression statistics include; linear regression slope (b), sample size (n), intercept (a), slope probability (p) and fit (r2, as %). DW identifies where serial correlation is possible (x indicates p<0.05 for Durbin-Watson statistic) and d is the number of daily inflow values used to calculate mean freshwater inflow. * denotes regressions applicable to final minimum flows analysis.

Taxon	Stage	Common name	n	a	b	p	r2	DW	d
Brevoortia spp.	postflexion larvae	menhaden	14	1.984	2.261	0.0133	41	x	34
**Brevoortia smithi*	juveniles	yellowfin menhaden	12	4.49	1.231	0.0032	60		30
Trinectes maculatus	juveniles	hogchoker	17	6.438	0.727	0.0189	32		1
**Anchoa mitchilli*	adults	bay anchovy	14	6.827	6.687	0.0051	49		36
Cynoscion arenarius	postflexion larvae	sand seatrout	10	8.258	0.666	0.0359	44	x	1

It is noted that while the distributional responses to changing inflows are an important ecological attribute, there is not a direct link between distributional responses and an observed adverse effect relating to the significant harm standard and therefore only the abundance regressions were applied to the analysis in support of establishing a minimum flow for the estuarine segment of the Little Manatee River.

The District has recently implemented acceptance criteria for employing biological regressions in support of minimum flows evaluations (Heyl et al. 2012). The acceptance criteria state that regressions must include a) a minimum 10 observations per variable, b) a positive linear or 'mid-flow maximum abundance' quadratic response, c) no significant serial correlation and d) an adjusted coefficient of determination (R^2) of at least 0.3. Based on these criteria the menhaden postflexion larvae regression does not meet the acceptance criteria due to the influence of serial autocorrelation potentially affecting the significance level (p value) associated with the regression. However, larger stage menhaden did not exhibit serial autocorrelation and were therefore considered along with the bay anchovy for minimum flows development. The outcomes of this assessment are detailed in section 5.2.3 of this report.

4.4 Nekton

Similar to the zooplankton studies that have been conducted in District tidal rivers with District support, the Florida Fish and Wildlife Conservation Commission (FWC) has been the predominant source of nekton (i.e., fish and motile macroinvertebrates) data in Tampa Bay tidal tributaries. Specifically, the FWC's Fisheries Independent Monitoring (FIM) program has been routinely collecting nekton data throughout Tampa Bay and in many of Tampa Bay's tidal tributaries since 1989. The program switched from a fixed station and seasonal monitoring design to a year-round probabilistic monitoring design in 1996. Since that time, several studies related to assessing the relationships between fish distribution and abundance and freshwater inflows have been conducted in support of establishing minimum flows. In Tampa Bay, these tributaries include the lower Alafia River (Matheson et al. 2005), lower Hillsborough River (MacDonald et. al., 2006), and Manatee River (Greenwood et al. 2007) among others. For the Little Manatee River, there was not a specific District sponsored data collection effort but the routine monitoring data collected in the Little Manatee River estuary, as well as a fixed station data collection effort between 1989 and 1991 were analyzed under contract to the District to explore the utility of those data to support minimum flows for the Little Manatee River estuary. That report (MacDonald et al. 2007) is the basis from which the fish relative abundance data were evaluated with respect to their potential to serve as criteria in support of developing minimum flows thresholds protective against significant harm. It should be noted that the term fish in this section refers to fishes and select macro invertebrate taxa collected in the gear types used by FIM including shrimp and crabs. Evaluation of fish habitat suitability is described in section 4.4.3. Much of the following two subsections was excepted directly from MacDonald et al 2007 with permission as the report was specifically produced to support the establishment of minimum flows for the Little Manatee River estuary.

4.4.1 Descriptive (summarized from MacDonald et al. 2007)

MacDonald et al. 2007 developed datasets including nekton catch information and antecedent flow conditions corresponding to the nekton sampling dates and analyzed those data to explore relationships between nekton distribution and abundance and freshwater inflows in support of the District's aim to establish minimum flows for the Little Manatee River estuary. Specifically, the multi-year datasets included information on the distribution and abundance of juvenile and small adult fishes as well as economically important macroinvertebrates (collectively referred to as nekton). Data collected with seines and trawls in nearshore and channel habitats of the Little Manatee River from two monitoring programs were examined: 1) stratified random sampling from 1996-2006 by the staff of FWC/FIM; and 2) fixed-station sampling conducted 1988-1991 by the predecessor agency to FWC/FWRI with funding from the Coastal Zone Management Program (CZM). Data on water temperature, salinity, pH and dissolved oxygen were collected in conjunction with seine and trawl sampling. The study had four main objectives:

1. To assess composition of the nekton community from 1988-1991 and 1996-2006;
2. To examine habitat use for selected economically important species;

3. To analyze movement and relative abundance of nekton populations in relation to magnitude of freshwater inflow;
4. To examine nekton community composition in relation to magnitude of freshwater inflow.

Sampling effort for the FIM study was stratified into two zones within the Little Manatee River (Figure 4-5), with four 21.3-m seine hauls and three 6.1-m otter trawl hauls collected per month per zone. Sampling for the CZM study consisted of approximately biweekly collections at fourteen fixed seine sites and ten fixed trawl sites at six locations along the tidal river (Figure 4-6).

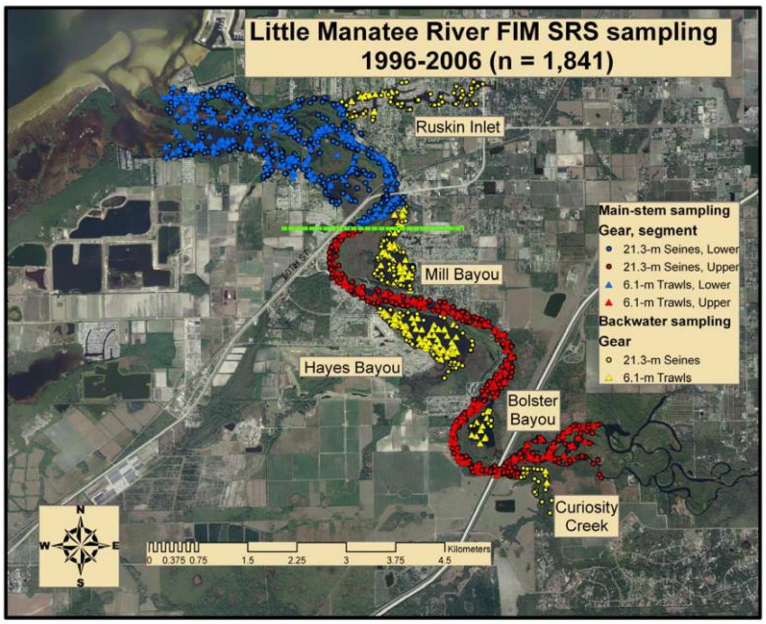

Figure 4-5. Fisheries-Independent Monitoring (FIM) program stratified-random-sampling (SRS) site locations in the Little Manatee River, January 1996–June 2006. The green line indicates the division between the upper and lower segments of the study area at river km 4.8. Copied with permission from Figure 1 of MacDonald et. al. 2007.

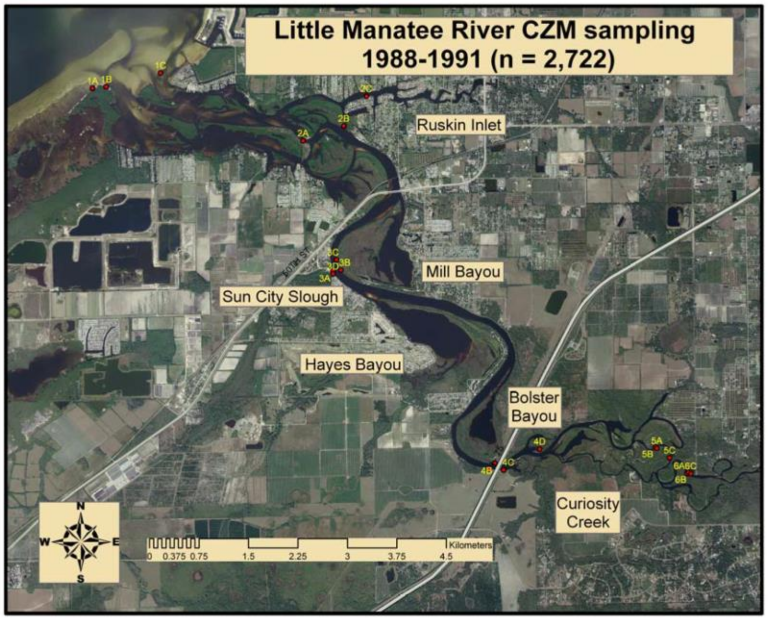

Figure 4-6. **Fixed-station sampling locations from the CZM study (January 1988–December 1991). Copied with permission from Figure 2 of MacDonald et al. 2007.**

A 21.3-m center-bag seine of 3.2-mm stretched mesh with leads spaced every 150 mm was deployed for shoreline collections in the FIM program. Water depths were limited to ≤ 1.8 m at the bag and ≤ 0.5 m at the shore (≤ 1.0 m for seawall shorelines). Trawl collections in the FIM sampling were made with a 6.1-m otter trawl with 38-mm stretched mesh body and 3.2-mm mesh liner. Usually, otter trawls were towed in a straight line, but this type of tow was limited to water depths between 1.8 and 7.6 m. In shallower areas, 1.0 to 1.8 m, where sufficient depth could not be found for a straight tow, the trawl was towed in an arc to minimize disturbance of the benthic environment by the boat. The trawl was towed for five minutes at an average speed of 0.6 ms-1, giving typical tow lengths of 180 m covering ~ 720 m2 (mean net opening = 4.0 m). Shoreline collections during CZM sampling were made with a 22.7-m bag seine (3.2-mm mesh). Seines were deployed from a boat and pulled onto shore. Catch data were standardized by area sampled, based on average haul distance at a given site. Trawl collections during CZM sampling were made with either a 3.6-m otter trawl (1988) or a 6.1-m otter trawl (1989–1991), both with 3.2-mm mesh liners. The trawls were towed for an average of five minutes (range 4-6 minutes) at approx. 0.5 ms-1. Tow duration and speed varied due to prevailing currents and obstructions. Trawl tow distances were only measured during 1989 through 1991 and averaged approximately 144 m (range 40-378 m). All the sampling gears used in the FIM and CZM studies tend to primarily collect small fish, either adults of small-bodied species or juveniles of larger taxa. Trawls tend to capture larger fish than seines (Nelson and Leffler 2001), and whether this is due to gear characteristics or preferred use of channel habitat by larger fish is uncertain. Sampling efficiency inevitably varies by species and size class (Rozas and Minello 1997), but it was assumed that reasonable consistency between samples collected with a given gear type existed. It was acknowledged that movement of various taxa (e.g., killifishes, Cyprinodontidae and Fundulidae) into emergent vegetation at high water levels occurs (Rozas and Minello, 1997) and could complicate interpretation of some results.

During the 1996-2006 FIM monitoring, seine (shoreline habitat) sample catch was dominated by bay anchovy at 65% of total abundance; just eight taxa formed over 80% of the total catch (bay anchovy, minidia silversides, eucinostomus mojarras, rainwater killifish, spot, tidewater mojarra, striped anchovy, and eastern mosquitofish). FIM trawls (channel habitat) were also dominated by bay anchovy, and when combined with hogchoker, eucinostomus mojarras, spot, pinfish, pink shrimp, and sand seatrout, these seven taxa formed over 90% of the total catch. Bay anchovies also dominated the 1988-1991 CZM seine and trawl collections. Taxon richness tended to be high during July-October, and low January-April. Peaks in juvenile abundance of offshore spawners, juvenile nearshore spawners, estuarine spawners and tidal-river residents occurred in different seasons, and it was thus concluded that the Little Manatee River estuary system provides important habitat for many taxa at all times of the year. The study period was marked by very variable flow conditions due to differences in annual rainfall patterns. The variable flows provided a variety of conditions for assessing effects of flow on nekton in the estuary.

Multivariate analysis of the 1996-2006 FIM data suggested that in the shoreline (seined) habitat, communities during high-flow years tended to be rather different from those in years with lower and more normal flows; for the channel (trawled) habitat, low-flow years were generally outliers compared to years with higher flow. Overall community variability increased with increasing flows in May-June in the shoreline habitat, but no clear spatial differences in community structure could be related to flow. A strong red tide event in 2005 is noted to have influenced community structure to a greater extent than any differences due to inflow changes. Results from the 1989-1991 CZM data multivariate analyses were similar and the best evidence for flow effects on community structure was provided when contrasts in flows were great. Very high flows in May-June of 1990 shifted community structure at several fixed stations to communities more characteristic of stations further upstream while unusually low flows in July-October 1989 had the opposite effect. Based on these results the report concluded that changes in flow had to be great to enable the detection of changes in the nekton community structure.

4.4.2 Relation to Inflow

Distribution responses of nekton to changes in freshwater inflow could only be investigated for the 1988-1991 CZM sampling because the FIM stratified-random survey (1988-1991) was not designed to represent the river's entire salinity gradient. Out of the 480 regressions between center of abundance (km_u) and inflow for seine data, 67 (14%) showed statistically significant responses to freshwater inflow; as well as 18 of the 60 (30%) pseudo-species combinations. Fifteen of the 18 pseudo-species moved upstream with decreases in freshwater inflow. For CZM trawl data, 21 of a total 160 regressions between km_u and inflow were statistically significant; 9 of 21 tested pseduo-species demonstrated responses to freshwater inflows, only one moved upstream with increasing inflow. The km_u-flow regressions that appeared the most biologically reasonable were blue crab (>100mm), menhaden (31 to 50mm and 51 to 100mm), striped anchovy (31 to 50mm and 51 to 100mm) and common snook (51 to 100mm) for the shoreline habitat (seines) and bay anchovy (31 to 50 mm), sand seatrout (≤30mm and 31 to 50mm) and spot for the channel habitat (trawls). However, the CZM sampling was done at fixed stations and it was recommended that results of distributional analyses should be treated with caution. Further, the distributional response does not have a direct link to significant harm and therefore is more of a descriptive approach to understanding the fish community response to changes in salinity which is examined later in this document using a different analytical approach.

Abundance responses to changes in freshwater inflow were evaluated using ordinary least squares (linear) regressions with FIM stratified-random sampling surveys conducted between 1996-2006. The form of the regression was either linear univariate or quadratic regression as a function of the (natural log transformed) median flow over the recruitment period for the taxon of interest. The response variable was the natural log average catch per unit effort (CPUE) for the recruitment period. Antecedent conditions were incorporated into the regressions through the evaluation of lag averages up to 360 days prior to sampling. The random distribution of samples allowed abundance estimates from the entire sampling area to be calculated, while fixed stations from the CZM study did not allow for abundance estimations between fixed station locations. Of the 2,899 regressions between mean CPUE and inflow calculated for seine nekton samples, 272 (6.7%) were statistically significant. Of the 41 seine pseduo-species, 31 (75.6%) showed a significant response to inflow; 2 of the 7 linear responses were positive such that CPUE decreased with decreasing flows. The remaining 24 were quadratic (non-linear) responses. Of the 1,150 regressions for trawl data, 79 (6.9%) were statistically significant. Ten of the 23 channel habitat (trawls) pseudo-species tested showed significant responses to freshwater inflow; seven quadratic and two linear responses, one of which was positive and the other negative. For the CPUE-flow regressions, the species with reasonable regressions were reported to include : blue crab (51 to 100mm and ≥100mm), striped anchovy (31 to 51mm), rainwater killifish (31 to 50mm), silver perch (31 to 50 mm), striped mullet (51 to 100mm) and common snook (51 to 100mm) from the shoreline habitat (seines) and blue crab (≥100mm) and pinfish (31 to 50mm) from the channel habitat (trawls). Relative abundance regressions with statistically significant results are provided in Table 4-3.

Again, the District acceptance criteria that include a) a minimum 10 observations per variable, b) a positive linear or ‘mid-flow maximum abundance’ quadratic response, c) no significant serial correlation and d) an adjusted r2 of at least 0.3 were applied (Heyl et al. 2012), were applied to the results and the final regressions used for evaluating the effects of freshwater inflows in support of establishing an minimum flows for the Little Manatee River estuary included blue crab collected in both seines and trawls and striped mullet in seines Table 4-4.

Table 4-3. Abundance regression results for estuarine taxa utilizing the Little Manatee River estuary.

Scientific Name	***Common Name***	***Gear***	***Size***	***df***	***Intercept***	***Linear coef.***	***Linear P***	***Quad. coef.***	***Quad. P***	r^2	adj r^2	***DW***	***D***
Anchoa mitchilli	Bay anchovy	Seine	0 to 30	8	16.9917	-6.7626	0.0473	0.7679	0.0417	0.4767	0.3459	x	180
Callinectes sapidus	Blue crab	Trawl	100 to 999	9	-0.5657	0.2400	0.0025	.	.	0.6563	0.6181		60
Callinectes sapidus	Blue crab	Seine	51 to 100	9	-0.0453	0.0184	0.0290	.	.	0.4280	0.3644		360
Callinectes sapidus	Blue crab	Seine	100 to 999	9	-0.0207	0.0095	0.0495	.	.	0.3636	0.2929	x	90
Callinectes sapidus	Blue crab	Seine	0 to 30	7	8.6885	-3.6445	0.0173	0.3872	0.0177	0.5803	0.4604		120
Microgobius gulosus	Clown goby	Seine	0 to 30	8	-5.4405	2.7016	0.0422	-0.3000	0.0390	0.4420	0.3025	x	30
Centropomus undecimalis	Common snook	Seine	51 to 100	7	-11.7670	5.6199	0.0106	-0.6492	0.0108	0.6309	0.5255	x	240
Centropomus undecimalis	Common snook	Seine	31 to 50	7	-8.8704	4.2983	0.0123	-0.5040	0.0121	0.6178	0.5086	x	210
Centropomus undecimalis	Common snook	Seine	100 to 999	7	7.2034	-3.3198	0.0221	0.3879	0.0217	0.5538	0.4263		330r
Gambusia holbrooki	Eastern mosquito fish	Seine	0 to 30	8	-37.3182	18.0394	0.0281	-2.1311	0.0276	0.4780	0.3475	x	360r
Gambusia holbrooki	Eastern mosquito fish	Seine	31 to 50	8	5.9626	-2.6043	0.0114	0.2902	0.0106	0.5894	0.4868		180
Trinectes maculatus	Hogchoker	Trawl	31 to 50	8	-3.7709	2.1328	0.0454	-0.2534	0.0366	0.5684	0.4605	x	150
Oligoplites saurus	Leatherjacket	Seine	31 to 50	8	-1.8426	1.2230	0.0367	-0.1643	0.0386	0.4438	0.3047		60
Oligoplites saurus	Leatherjacket	Seine	0 to 30	9	1.3634	-0.2124	0.0181	.	.	0.4802	0.4224		120r
Brevoortia spp.	Menhaden	Seine	51 to 100	8	7.7193	-3.6098	0.0152	0.4213	0.0147	0.5500	0.4375	x	180r
Brevoortia spp.	Menhaden	Seine	31 to 50	8	11.3720	-5.2689	0.0082	0.6128	0.0076	0.6172	0.5215		210
Brevoortia spp.	Menhaden	Seine	0 to 30	8	11.7307	-5.7870	0.0005	0.7087	0.0003	0.8694	0.8367	x	90r
Gobiosoma bosc	Naked goby	Seine	20 to 50	8	13.2878	-6.3688	0.0176	0.7804	0.0145	0.6564	0.5706	x	330
Lagodon rhomboides	Pinfish	Trawl	51 to 100	8	-3.3372	1.6772	0.0066	-0.2000	0.0058	0.6613	0.5766		360
Lagodon rhomboides	Pinfish	Trawl	31 to 50	9	1.9326	-0.3888	0.0003	.	.	0.7869	0.7632		330
Lagodon rhomboides	Pinfish	Trawl	0 to 30	8	37.8322	-16.5856	0.0205	1.8379	0.0280	0.7435	0.6793		300r
Lagodon rhomboides	Pinfish	Seine	0 to 30	8	39.0698	-18.2744	0.0160	2.1679	0.0156	0.5410	0.4262	x	270r
Farfantepenaeus duorarum	Pink shrimp	Trawl	0 to 30	8	7.5067	-3.2264	0.0402	0.3754	0.0429	0.4439	0.3048	x	120
Lucania parva	Rainwater killifish	Seine	0 to 30	8	-38.9393	19.4776	0.0011	-2.3452	0.0009	0.8347	0.7934	x	270r
Lucania parva	Rainwater killifish	Seine	31 to 50	8	1.1283	-0.1743	0.0338	.	.	0.4498	0.3810	x	30
Poecilia latipinna	Sailfin molly	Seine	31 to 50	8	-17.1693	8.2479	0.0378	-0.9712	0.0376	0.4366	0.2957	x	360r
Poecilia latipinna	Sailfin molly	Seine	51 to 100	8	-4.5588	2.2188	0.0054	-0.2619	0.0051	0.6609	0.5762		0r
Poecilia latipinna	Sailfin molly	Seine	0 to 30	8	8.3852	-3.5302	0.0387	0.3755	0.0436	0.4777	0.3471		180

Scientific Name	***Common Name***	***Gear***	***Size***	***df***	***Intercept***	***Linear coef.***	***Linear P***	***Quad. coef.***	***Quad. P***	***r^2***	***adj r^2***	***DW***	***D***
Cynoscion arenarius	Sand seatrout	Seine	0 to 30	8	1.3979	-0.6463	0.0175	0.0760	0.0141	0.6095	0.5118	x	150
Cynoscion arenarius	Sand seatrout	Seine	31 to 50	8	2.9767	-1.3925	0.0043	0.1602	0.0042	0.6619	0.5774		210
Cynoscion arenarius	Sand seatrout	Trawl	31 to 50	8	11.0289	-4.8178	0.0059	0.5381	0.0062	0.6368	0.5460	x	300
Cynoscion arenarius	Sand seatrout	Trawl	0 to 30	8	15.3721	-6.6897	0.0083	0.7496	0.0097	0.6573	0.5716	x	360
Eucinostomus gula	Silver jenny	Seine	40 to 999	8	-16.5592	8.2139	0.0280	-0.9838	0.0241	0.6244	0.5305	x	240r
Bairdiella chrysoura	Silver perch	Seine	31 to 50	9	0.8670	-0.1583	0.0156	.	.	0.4956	0.4396	x	0r
Leiostomus xanthurus	Spot	Trawl	51 to 100	8	3.2560	-1.4593	0.0194	0.1663	0.0214	0.5573	0.4467		30r
Leiostomus xanthurus	Spot	Seine	0 to 30	8	19.7447	-9.0487	0.0220	1.0535	0.0162	0.6421	0.5526	x	30
Leiostomus xanthurus	Spot	Trawl	0 to 30	8	23.7674	-10.5083	0.0102	1.1595	0.0095	0.5941	0.4926		30
Anchoa hepsetus	Striped anchovy	Seine	31 to 50	9	3.5409	-0.6964	0.0045	.	.	0.6116	0.5685	x	300
Anchoa hepsetus	Striped anchovy	Seine	0 to 30	8	12.2622	-5.0158	0.0065	0.5126	0.0100	0.7928	0.7410		270
Mugil cephalus	Striped mullet	Seine	51 to 100	9	-0.1807	0.0918	0.0034	.	.	0.6324	0.5916		150
Mugil cephalus	Striped mullet	Seine	31 to 50	8	7.0739	-3.4871	0.0255	0.4423	0.0206	0.5767	0.4708		30r

Table 4-4. Final fish regressions after applying District criteria.

Scientific Name	***Common Name***	***Gear***	***Size (mm)***	***Months***	***Response***	***df***	***Intercept***	***Linear coef.***	***Linear P***	***Quad. coef.***	***Quad P***	***r^2***	***adj r^2***	***DW***	***Days***
Callinectes sapidus	Blue crab	Trawl	100 to 999	Jan. to Dec.	linear	9	-0.5657	0.2400	0.0025	.	.	0.6563	0.6181		60
Mugil cephalus	Striped mullet	Seine	51 to 100	May to Jul.	linear	9	-0.1807	0.0918	0.0034	.	.	0.6324	0.5916		150
Callinectes sapidus	Blue crab	Seine	51 to 100	Jan. to Dec.	linear	9	-0.0453	0.0184	0.0290	.	.	0.4280	0.3644		360

4.4.3 Environmental Favorability Functions

Given the importance of estuarine fishes as a biological response endpoint, the District sponsored additional analyses to supplement the existing information in an attempt to develop a habitat suitability index using the fisheries data. The District, as part of this contract, pursued the development of a habitat suitability index for estuarine dependent fishes using fish occurrence (i.e., presence/absence) instead of relative abundance as a biological response to changes in salinity instead of attempting to model the effects of flow as a direct effect. The benefits of this modeling effort include the ability to account for other factors affecting the probability of occurrence of these taxa including potential shoreline habitat preferences. The objective of this work was to develop a model to predict the relative favorability of different flow regimes for fish species of interest utilizing mid and lower salinity habitats in the estuarine segment of the Little Manatee River.

The Environmental Favorability Function (EFF) has been used extensively in conservation biogeography to evaluate the potential spatial distribution of species conservation areas (Real et al. 2006), compare distribution among species with different empirical prevalence (Real et al. 2009), and assess environmental factors determining favorability of particular habitat within conservation areas (Acevedo et al. 2010a; Acevedo et al. 2010b). The EFF has also recently been used in the Tampa Bay area to evaluate the effects of flows on fish occurrence in the lower Alafia River (Wessel 2011) and to evaluate the effects of management scenarios controlling physical chemistry and habitat parameters on fish occurrence in Old Tampa Bay (Janicki Environmental 2014). The EFF is based on logistic regression and was implemented using the Logistic Procedure in SAS (SAS Institute, 2014). The probability of occurrence (P(y=1|x)) of a particular taxon was estimated as a function of environmental variables including salinity recorded at the time of capture and habitat classifications describing the shoreline characteristics against which the seine was pulled. The logistic regression equation was defined as:

$$y_{ijk} = Ln\left[\frac{P}{1-P}\right] = \alpha + \beta_1 X_1 + \beta_2 X_1^2 + \beta_j X_j + \beta_k X_k + \beta j_k X j_k$$

Where:

y =logit estimate (log odds)

Ln=Natural log

P = Probability of occurrence

α =Intercept

$\beta_{1 \ldots k}$ =Regression coefficients

X_1=Salinity(ppt)

X_j=Season (w-s)

X_k = Shore habitat (1-3)

X_{jk} = Shore*Season interaction

A quadratic term was imposed to capture salinity preferences in the mesohaline to polyhaline range (i.e., 10-25ppt). The effect of shoreline habitat was initially modeled as a 6 level categorical variable including Mangroves, Emergent Vegetation, Terrestrial Grasses, Structure (seawalls, docks, etc.), None (bare sand), and Trees using the effect coding scheme such that the model coefficients of each habitat category represent deviations from the average condition with "Trees" coded as the reference category. For the refined model the habitat levels were collapsed to categories representing dominant habitat types in the Little Manatee River (i.e., Mangroves, Emergent Vegetation (marshes), Structure, and Freshwater habitats ("Freshwater") with trees, terrestrial grasses, and bare sand levels grouped into a single reference category. A plot of the dominant shore types associated with the FIM samples is provided in Figure 4-7.

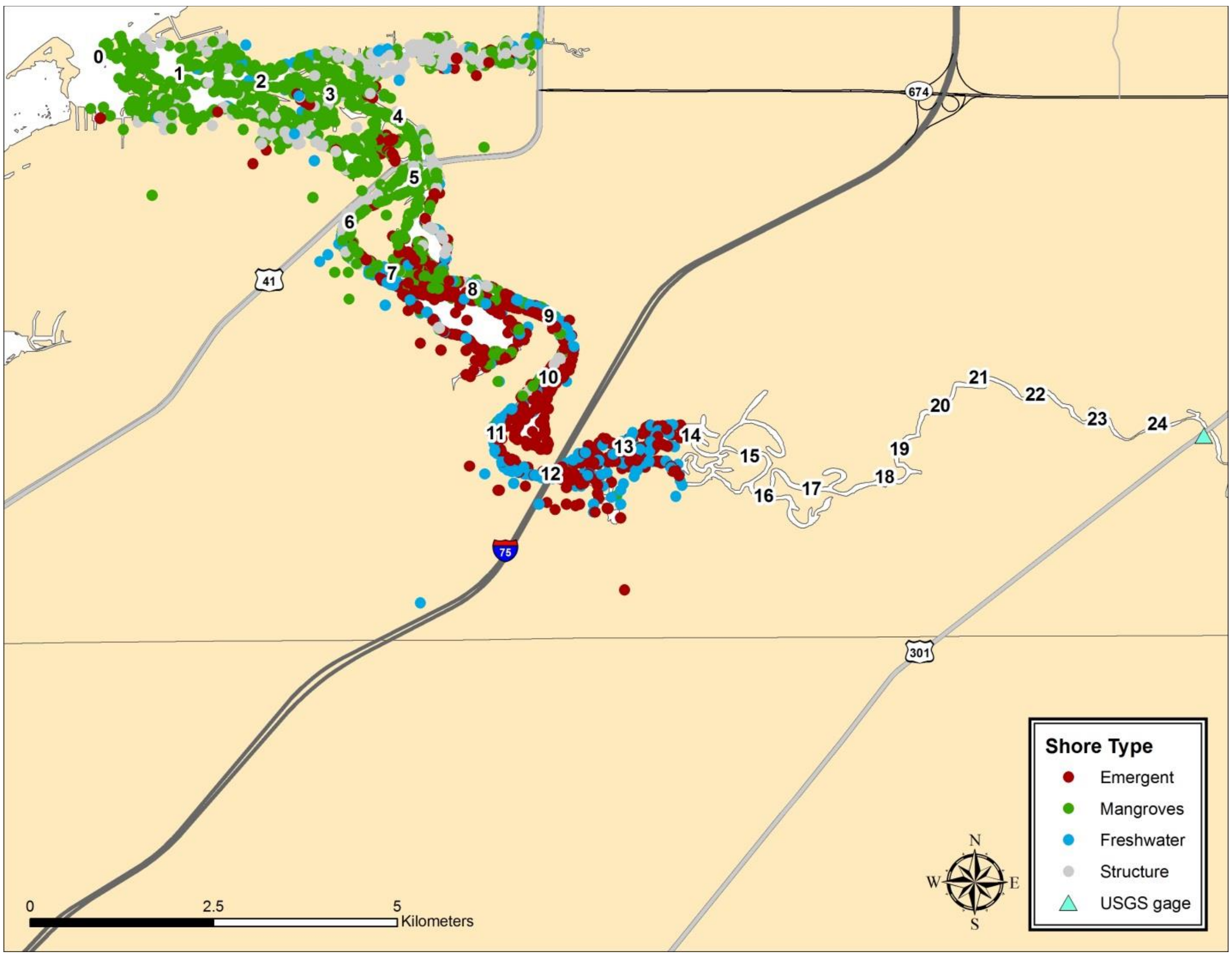

Figure 4-7. Dominant shore types associated with nekton sampling in the Little Manatee River.

A seasonal term and season shore type interaction term were considered in the model to account for species-specific recruitment and habitat utilization of the lower river. The seasonal term was binary and delineated by warm (April-October) and cool (November-March) periods in southwest Florida that also correspond with typical recruitment periods for many estuarine dependent nekton taxa. The logistic model is a linear (additive) model using a link function to relate the explanatory components to the response. To transform the predicted logit estimate into an estimate of the probability of occurrence requires the transformation of the logit estimate to a probability via the equation:

$$P(y = 1 | x) = \frac{\exp^{y}}{1 + \exp^{y}}$$

The taxa considered for CPUE regressions by MacDonald et al. (2007) were also considered as potential candidates for EFF development. The logistic regression models were implemented using Proc Logistic and the Firth option in the model statement (SAS Institute 2014) which specifies Fishers scoring optimization. The Firth option is a bias reduction technique used when data may be imbalanced such as when the one habitat type was sampled disproportionately across the study area or when the data are heavily zero inflated. To evaluate the logistic regression model performance, the Wald Chi Square Test for significance was used to test the global hypothesis, the concordance statistic was used to evaluate predictive performance, the Hosmer and Lemeshow test was used to test for goodness of fit of the predictions based on observed and expected outcomes, and the likelihood ratio test was used to compare potential models within the same model structure (SAS Institute 2014).

Taxa with significant response in terms of probability of occurrence to either the linear or quadratic component of salinity ($\alpha = 0.10$) are presented in Table 4-5. All months were retained for this analysis and a seasonal intercept was used to account for recruitment. No "pseudo-species" (i.e., size classes) were considered. Only those taxa with negative responses to salinity were considered in support of establishing minimum flows for the Little Manatee River. That is, the taxa should have a higher probability of occurrence at lower or mid-range salinities in order to be considered as being sensitive to changes in inflow for the purposes of informing the minimum flows criteria. Three taxa (*Lepomis macrochirus*, *Lepomis microlophus*, *Micropterus salmoides*) were captured in less than 5% of the samples and are not commonly thought of as estuarine taxa and therefore were also excluded from further analysis. Taxa considered for analysis are presented in Table 4-5 with an asterisk indicating those taxa used in the final assessment in support of establishing minimum flows for the Lower Little Manatee River. Detailed results of the logistic regression modeling effort can be found in Appendix A.

Table 4-5. **Logistic regression results for fish taxa with statistically significant ($\alpha = 0.10$) responses to salinity. Numbers in parentheses associated with taxon names represent number of occurrences out of 2689 samples.**

Scientific Name	Intercept	Linear coefficient	Linear p value	Quadratic coefficient	Quadratic p value	Habitat p value	Concordance statistic
Anchoa mitchilli (1102)	-0.556	0.036	0.019	-0.001	0.031	0.000	57.7
*Archosargus probatocephalus (416)	-1.854	-0.056	0.007	0.002	0.005	0.006	64.4
Brevoortia spp. (118)	-4.075	0.159	0.000	-0.005	0.000	0.001	73.5
Callinectes sapidus (506)	-1.335	0.010	0.638	-0.002	0.050	0.000	69.4
*Centropomus undecimalis (739)	-0.590	-0.023	0.211	-0.001	0.047	0.000	68
Eucinostomus harengulus (1372)	-0.255	0.048	0.001	-0.001	0.021	0.000	57.3
*Eugerres plumieri (502)	-0.899	-0.052	0.013	-0.001	0.257	0.353	71.1
Farfantepenaeus duorarum (914)	-1.596	0.119	0.000	-0.004	0.000	0.001	61.7
Fundulus grandis (188)	-3.108	0.134	0.000	-0.005	0.000	0.000	64.1
Gambusia holbrooki (270)	-0.833	-0.198	0.000	0.000	0.971	0.000	88.5
*Gobiosoma bosc (644)	-0.671	-0.076	0.000	0.002	0.018	0.160	61.2
*Gobiosoma spp. (518)	-0.660	-0.115	0.000	0.002	0.002	0.010	67
Lagodon rhomboids (1038)	-0.724	0.026	0.093	0.000	0.562	0.000	57.1
Leiostomus xanthurus (688)	-1.561	0.081	0.000	-0.002	0.000	0.000	58.3
Lepomis macrochirus (48)	-2.587	-0.433	0.000	0.009	0.106	0.077	92
Lepomis microlophus (21)	-3.049	-0.679	0.000	0.021	0.000	0.100	93
*Lucania parva (654)	-0.378	-0.103	0.000	0.002	0.000	0.000	70.7
Lutjanus griseus (185)	-3.209	0.058	0.081	-0.002	0.071	0.005	61.7
Menidia spp. (1618)	0.541	0.044	0.005	-0.003	0.000	0.000	64.6
*Microgobius gulosus (1018)	0.027	-0.076	0.000	0.001	0.008	0.011	64.7
Micropterus salmoides (20)	-3.582	-0.383	0.001	0.009	0.037	0.583	91.4
Mugil cephalus (333)	-2.084	0.069	0.006	-0.003	0.002	0.000	61.1
Oligoplites saurus (347)	-2.776	0.112	0.000	-0.004	0.000	0.212	75.8
*Poecilia latipinna (273)	-1.493	-0.108	0.000	0.003	0.015	0.000	71.6
Sciaenops ocellatus (633)	-1.382	0.020	0.365	-0.002	0.007	0.000	77.7
Strongylura notata (164)	-4.780	0.133	0.001	-0.002	0.034	0.038	80.6
*Trinectes maculatus (920)	0.250	-0.062	0.001	0.000	0.758	0.000	75.8

Real et al. (2006) proposed a modification of the output of the logistic regression equation to compensate for the differences from a prevalence of 0.5 by adjusting the intercept term by the log odds of the empirical occurrence of the taxa being modeled for each of the categorical combinations. The adjustment was defined as:

$$y' = y - Ln\left[\frac{n_{1s}}{n_{0s}}\right]$$

Where:

n_{1s}=# of presences per categorical effect

n_{0s}=# of absences per categorical effect

This is the logit of the favorability model described by Real et al. (2006). Exponentiation of the logit of the favorability yields the EFF. Since the EFF standardizes the outcomes to their overall average log odds of occurrence (in this case for each season and shore type), a cut-point value of 0.5 was used to assign Favorable (i.e., values greater the overall average) and Unfavorable (values less than the overall average) predictions for each species using the EFDC and LOESS model salinity predictions. Habitat categories were assigned to model predictions based on the principal wetland habitat types in the river as depicted in Figure 4-1 and linked to the EFDC model grid (for the EFDC model predictions) and the river kilometer system (for the LOESS model predictions). For the EFDC model, a salinity prediction was generated for each date and each grid cell in the simulation timeseries (2001- 2004). For the LOESS model, a salinity prediction was generated for each date and each 0.1 Rkm increment in the LOESS model timeseries (i.e., 1996-2014). These predicted salinity values were then used as input into the logistic regression model along with the assigned habitat and season categories for each location and date in the timeseries. The results of application of the EFF models to the flow reduction scenarios are provided in Chapter 5 of this report. An example application to the flow reduction scenarios for *Eugerres plumieri* (Mojarra) on December 6, 2003 is provided in Figure 4-8. The figure compares the predictions of favorable habitat using the EFDC model salinity predictions (left) and the LOESS model salinity prediction (right) for the same date. Notice how the downstream end of the favorable habitat is truncated as a function of the flow reduction scenarios indicating that favorable downstream habitat is lost as a function of increasing salinity in the downstream segment of the river as a function of flow reductions.

Mojarra
12/6/03

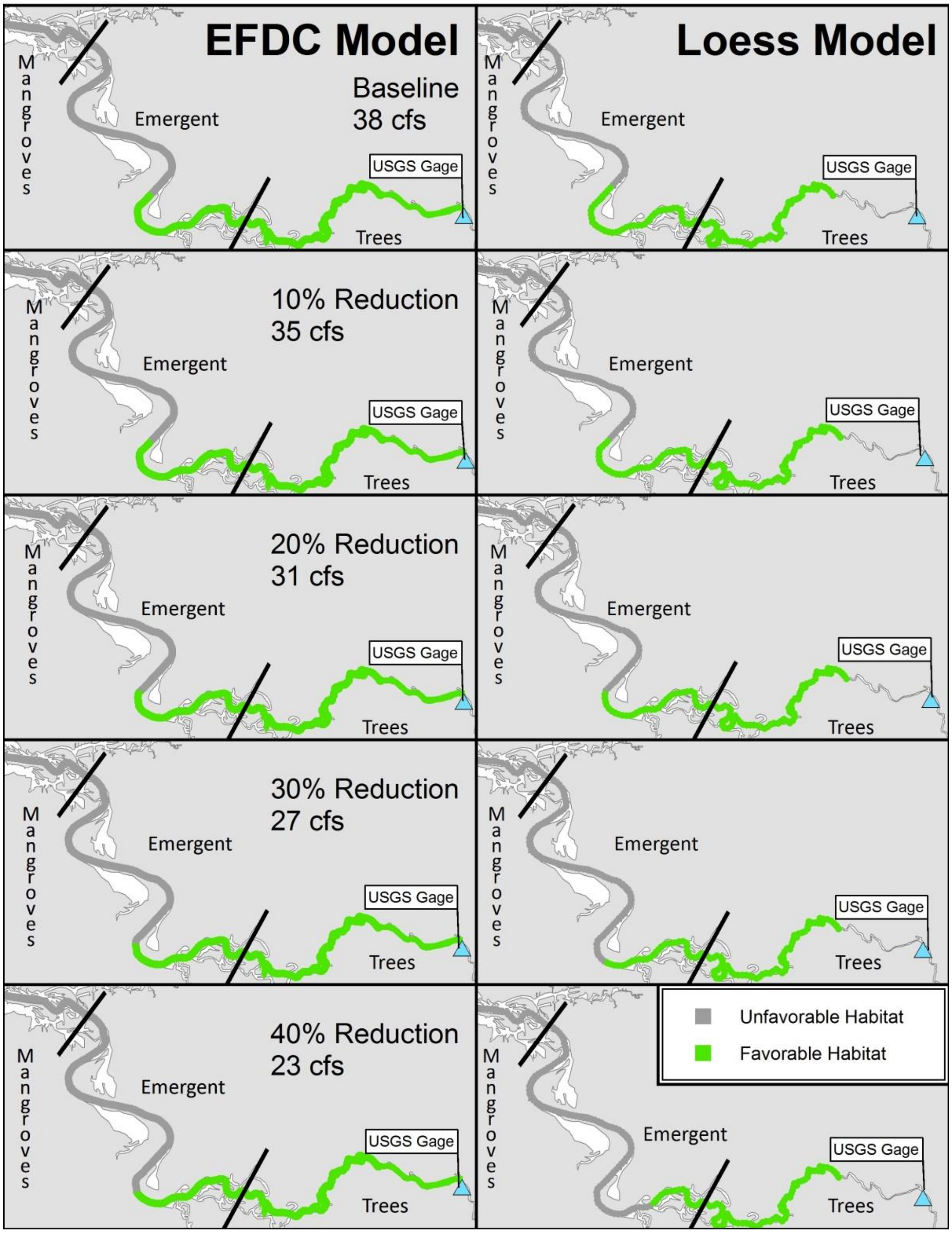

Figure 4-8. Favorable habitat predictions for Mojarra (*Eugerre plumieri*) on December 6 2003 based on EFDC and LOESS model salinity predictions and logistic regression equation converted to the EFF.

4.5 Manatee

4.5.1 Descriptive

The Florida manatee (*Trichechus manatus latirostris*) is a marine mammal subspecies of the West Indian manatee and is found only in the southeastern United States. Manatees are poor thermal regulators with relatively low metabolic rates (Rouhani et al. 2006) and are generally vulnerable to exposure to temperatures below 20ºC (68ºF). Manatees tend to congregate in warm water natural springs or in the cooling water discharge of power plants scattered along the coast of Florida. Evidence suggests that the location and use of warm-water refuges is a response that calves learn from their mothers and thus the potential loss of a refuge can affect generations of manatees (Worthy 2005). There is no known thermal refuge for manatee in the Little Manatee River though manatee have been observed utilizing the estuarine portion of the system. The Tampa Electric Company operates a power plant in Apollo Beach which is in close proximity to the Little Manatee River. This power plant has a significant warm water discharge that is heavily utilized by manatee during periods of cooler water temperatures. Based on these observations and a general lack of data from which to evaluate criteria protective of manatee in the Little Manatee River, no criteria were developed to evaluate the effects of flow reductions on this species in the Little Manatee River estuary.

5 GOALS, RESOURCES OF CONCERN, AND TECHNICAL ASSESSMENTS

The goal of a minimum flows determination is to protect the resource from significant harm due to withdrawals. This goal was broadly defined in the enacting legislation as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." What constitutes "significant harm" was not defined. In the absence of specific stressor-response threshold values identifying significant harm, a 15% reduction in a beneficial attribute of a resource of concern has been identified as a prescriptive standard by which significant harm has been defined. This 15% threshold has been used and supported in the development of the majority of minimum flows developed for Southwest Florida Water Management District which have been peer reviewed and subsequently adopted into Florida Administrative Code. The identification of the threshold values relies on a “percent of flow” approach in which predictive equations or mechanistic models are used in an iterative fashion to evaluate the effects of daily flow reduction scenarios of various increasing percentages of flow until the response threshold is achieved. Richter et al. (2011) suggested that, in the absence of detailed scientific investigation, a presumptive standard could be accepted that included a range of flow reductions with increasing risk of ecological harm. The following set of standards was proposed, again with the caveat that these standards do not replace evidence-based establishments of threshold values for the particular system under study:

- A high level of ecological protection will be provided when daily flow alterations are no greater than 10%; a high level of protection means that the natural structure and function of the riverine ecosystem will be maintained with minimal changes.
- A moderate level of protection is provided when flows are altered by 11 –20%; a moderate level of protection means that there may be measurable changes in structure and minimal changes in ecosystem functions.
- Alterations greater than 20% will likely result in moderate to major changes in natural structure and ecosystem functions, with greater risk associated with greater levels of alteration in daily flows.

Richter et al. (2011) also noted that allowable depletions of freshwater flows to estuaries tend to be larger than for non-tidal systems. However, results of detailed scientific investigations have yielded a range of threshold values between 8% to over 30% which, in many cases, are seasonally dependent. While these criteria were developed based on the results of a meta-analysis using published, detailed scientific investigations of the effects of surface water withdrawals on tidal and non-tidal riverine systems including results of the District’s own minimum flows, the Districts minimum flows program only uses these presumptive standards as a reference from which to include in a weight of evidence approach along with detailed scientific investigation.

The following sub-sections describe the resources of concern, the flow reduction scenarios, and application of the predictive models used in an evidence based attempt to assess the relationship between inflows and estuarine responses that support establishing the minimum flows for the estuarine portion of the Little Manatee River.

5.1 Resources of Concern

The resources addressed by the District's minimum flows analyses include the surface waters and biological communities associated with the river system, including the river channel and its floodplain. As noted in Hood et al. 2011, the Little Manatee River system is physiographically complex with a meandering channel and associated floodplain wetlands. This hydrologic and physical setting provides habitat for a diverse array of plant and animal populations. Because "[a]quatic species have evolved life history strategies primarily in direct response to the natural flow regimes" (Bunn and Arthington 2002), a primary objective of minimum flows and levels analysis is to provide for the hydrologic requirements of biological communities associated with the river system (Hood et al. 2011). Human uses of the natural resources are also an important consideration for the establishment of minimum flows criteria. Such uses include fishing, swimming, wildlife observation, aesthetic enjoyment, and boating.

As described in Flannery et al. (2008), 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. 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. Typically, the metrics applied to minimum flows assessments in estuarine are less well related to specific habitat requirements such as the wetted perimeter, fish passage, or floodplain inundation assessments used as a standard part of minimum flows evaluations in freshwater systems or freshwater portions of tidal tributaries such as the upper Little Manatee River. Despite this attribute, the approach to both freshwater and estuarine river minimum flows criteria development 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. 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 (Flannery et al. 2008).

For the estuarine portion of the Little Manatee River, the resources of concern and ecological indicators are defined below:

- Maintain the distributions of salinity, dissolved oxygen and chlorophyll at current levels
- Protect emergent wetland vegetative communities by limiting changes in the bottom area and volume of salinity isohaline as a function of hypothetical flow reduction scenarios.
- Protect benthic macroinvertebrate communities by limiting changes in the bottom area and volume of biologically relevant salinity isohalines as a function of hypothetical flow reduction scenarios using EFDC model predictions.
- Protect plankton communities by limiting reduction in predicted abundance based on direct relationships between abundance and flows.
- Protect nekton communities by limiting reduction in nekton relative abundance habitat suitability based on regression relationships predicting relative abundance and occurrence as a function of flow (or salinity).

5.1.1 Flow Reduction Scenarios

The flow reduction scenarios used for the estuarine segment of the Little Manatee River are the same as those used for the freshwater segment and are based on a “Reduction from Baseline” approach in which a percentage of the Baseline flow record was removed on a daily basis. The baseline flow record was based on the observed long term USGS gage near Wimauma (USGS 02300500) with corrections to account for historical withdrawals as well as augmentation to the baseflow of the Little Manatee River via historical agricultural practices. Derivation of the “Baseline” flows was necessary because anthropogenic impacts have affected the observed streamflow record. Both surface water withdrawals and increased runoff due to historical anthropogenic landuse practices have impacted the observed record. The Baseline flow record was described thoroughly in the most recent reevaluation of the Little Manatee River freshwater minimum flows report (Janicki Environmental, Inc. 2017) but is summarized in the following paragraphs due to its importance in application to developing the recommended minimum flows for the estuarine segment.

Hood et. al. (2011) described historical increases in groundwater use due to an estimated ten-fold increase in row crop agriculture between 1974 and 2004 with tomatoes being the primary crop but strawberries, cucumbers, melons, and other crops grown as well. Similar increases in agricultural land use between the 1970’s and 2000 have also been reported as part of establishing minimum flows for the Peace and Myakka Rivers (Kelly et al. 2005a, Kelly et al. 2005b). For the revised freshwater minimum flows report, statistical analysis was conducted to a method for estimating the quantity attributable to excess flows due to anthropogenic influence. Indices based on long term average rainfall and streamflow were used in a linear regression to predict the relationship between antecedent rainfall and flows prior to 1977. The residuals of the developed relationship were then used to estimate the bias post 1977 which was attributed to anthropogenic effects. The residuals of the simple linear regression of flows and rainfall indices are plotted as a timeseries in Figure 5-1. The residuals are calculated as the result of subtracting the observed values from the predicted values. Therefore, a negative residual indicates that there is more streamflow than expected based on the predicted relationship. After 1977 there is a noticeable shift in the residuals suggesting systematic bias due to excess flow compared to that expected based on the regression for the pre -1977 period. This systematic bias in the residuals was attributed to anthropogenic influences on streamflow. There is also a noticeable trend in the residuals back towards zero after 2000 which corresponds to the updated landuse information showing increases in conservation lands and decreases in active agricultural lands in the watershed. In addition, the Little Manatee River has been a focus area for implementation of agricultural best management practices which are aimed at increasing irrigation efficiency and water reuse.

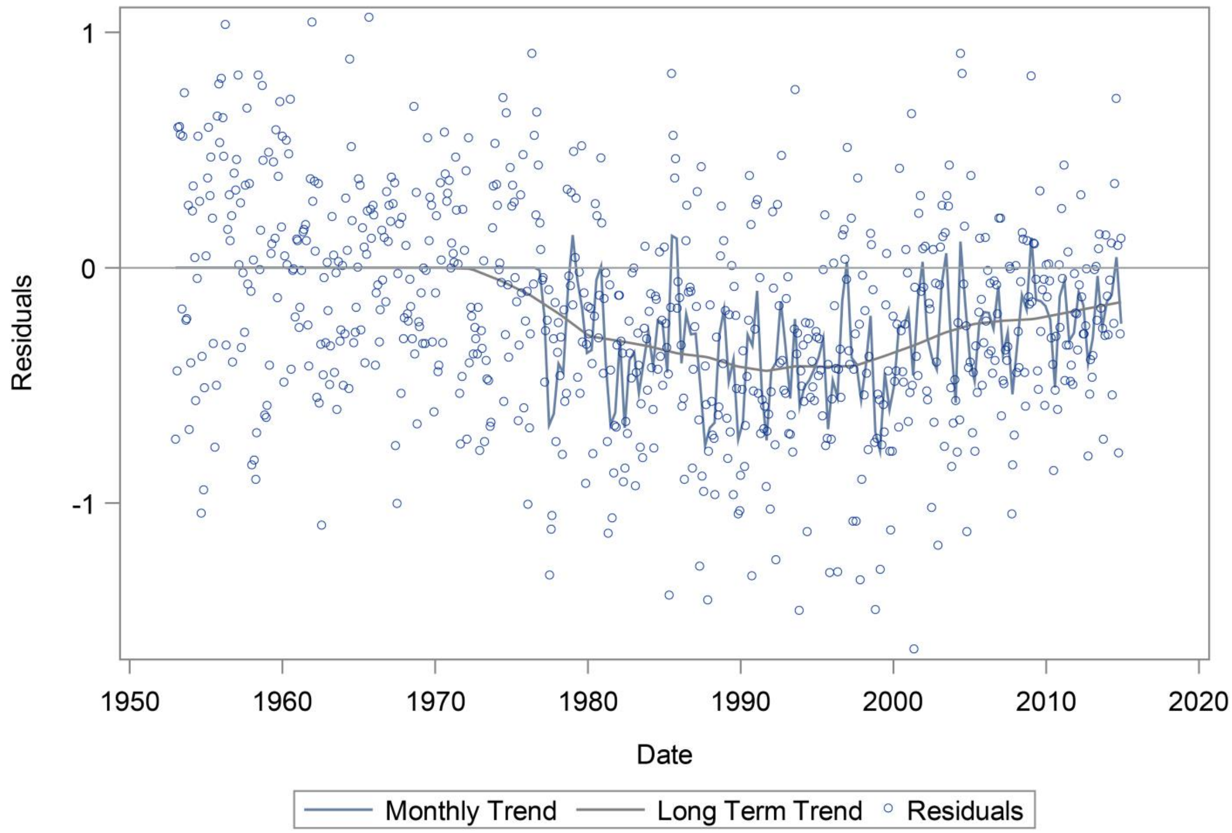

Figure 5-1. Timeseries of residuals (i.e. predicted-observed) with LOESS curve of monthly and long term trend in residuals post 1976. Residuals are in units of standard deviations from long term average conditions.

The trend lines in this plot represent the best estimate of the average anthropogenic effect over time. LOESS regression (PROC LOESS: SAS V9.4) of the residuals was used to derive a correction to adjust out the anthropogenic effects to streamflow using the same logic presented in Hood et. al., 2011. The difference from zero for each monthly LOESS estimate was calculated and back transformed to represent a monthly deviation in cfs increments that was then applied to the daily flow record. The intra-annual distribution of estimated excess flows was calculated and plotted (Figure 5-2) along with the results of MIKE-SHE modeling in the Myakka River to assess the same phenomenon (Flannery et al. 2011). The results of the correction described above for the Little Manatee River are strikingly similar to that described by the MIKE

SHE model in terms of both timing and magnitude with higher excess flows predicted during the summer wet season in both models.

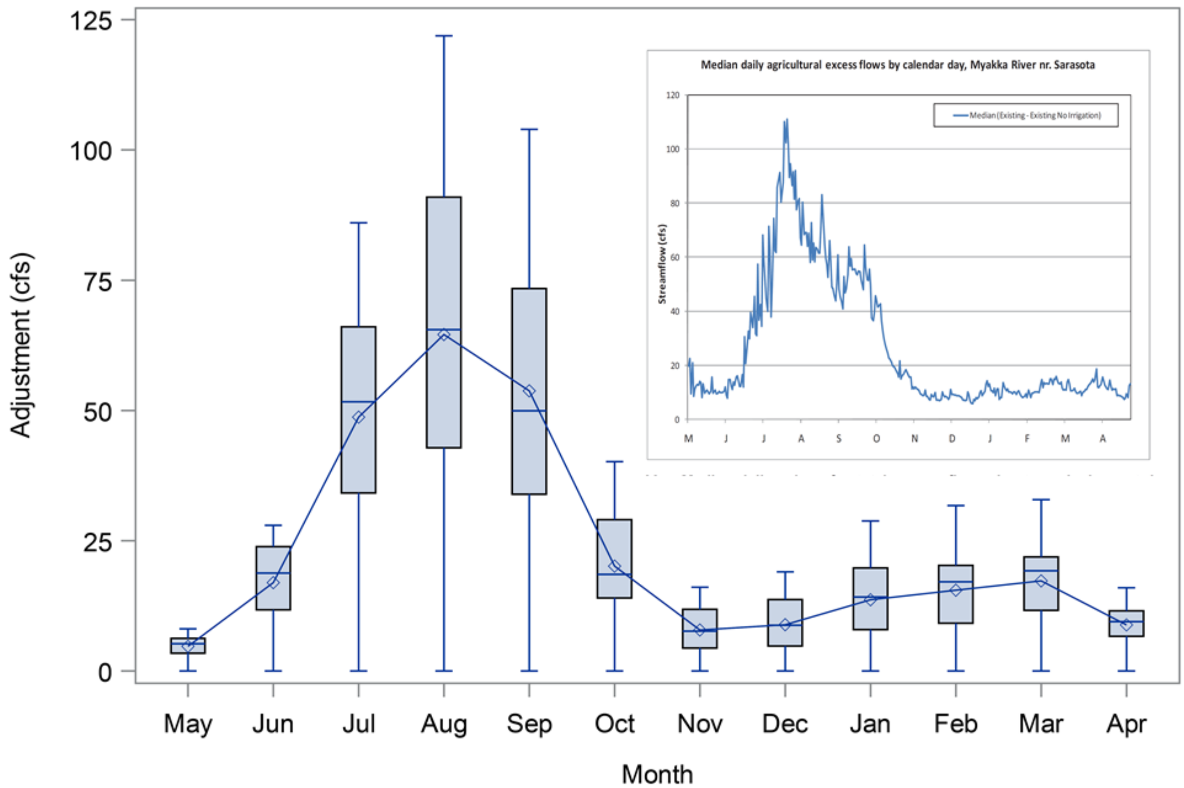

Figure 5-2. Distribution of residuals post 1977 indicating the potential differences due to agricultural flows.

The estimated excess flows reflect average expectations and event-specific variability in excess flows due to historical agricultural practices or discharges from mining activities. The long term trend in LOESS predictions of the residuals suggest that these historical excess flows have been trending towards zero since 2000. The District's Farms program has implemented programs to improve irrigation efficiencies in the watershed, mining practices have improved reuse of process water, and Hillsborough County has been active in acquiring conservation lands that were previous in agricultural or ranchlands. Therefore, the adjustment for excess flows was used to define a "Baseline" flow condition to evaluate the effects of flow reduction scenarios against an estimated flow assumed to be relatively unaffected by anthropogenic activity. The estimated excess flows were removed from the observed Wimuama gage flow record reported by USGS and then the surface water withdrawal record was added back to the record to create the "Baseline" condition.

Once the Baseline flow record was established, the flow reduction scenarios were derived by reducing the daily flow record by 40% in 10% increments resulting in 5 scenarios including the

Baseline. Note that a low flow threshold (point at further withdrawals are not allowed) was not included in the flow reduction scenarios. The importance of the low flow threshold is discussed in later sections, however, because a low flow threshold had not been identified at the time the flow reduction scenarios were generated, it was not included in the scenarios at the Districts request. A cumulative distribution plot of each of the various flow reduction scenarios relative to the Observed and Baseline flow records is provided in Figure 5-3. The “Reconstructed” scenario is only provided for reference as to what the flow distribution would have been without withdrawals by FP&L and was not otherwise considered in the context of establishing minimum flows for the estuarine portion of the Little Manatee River.

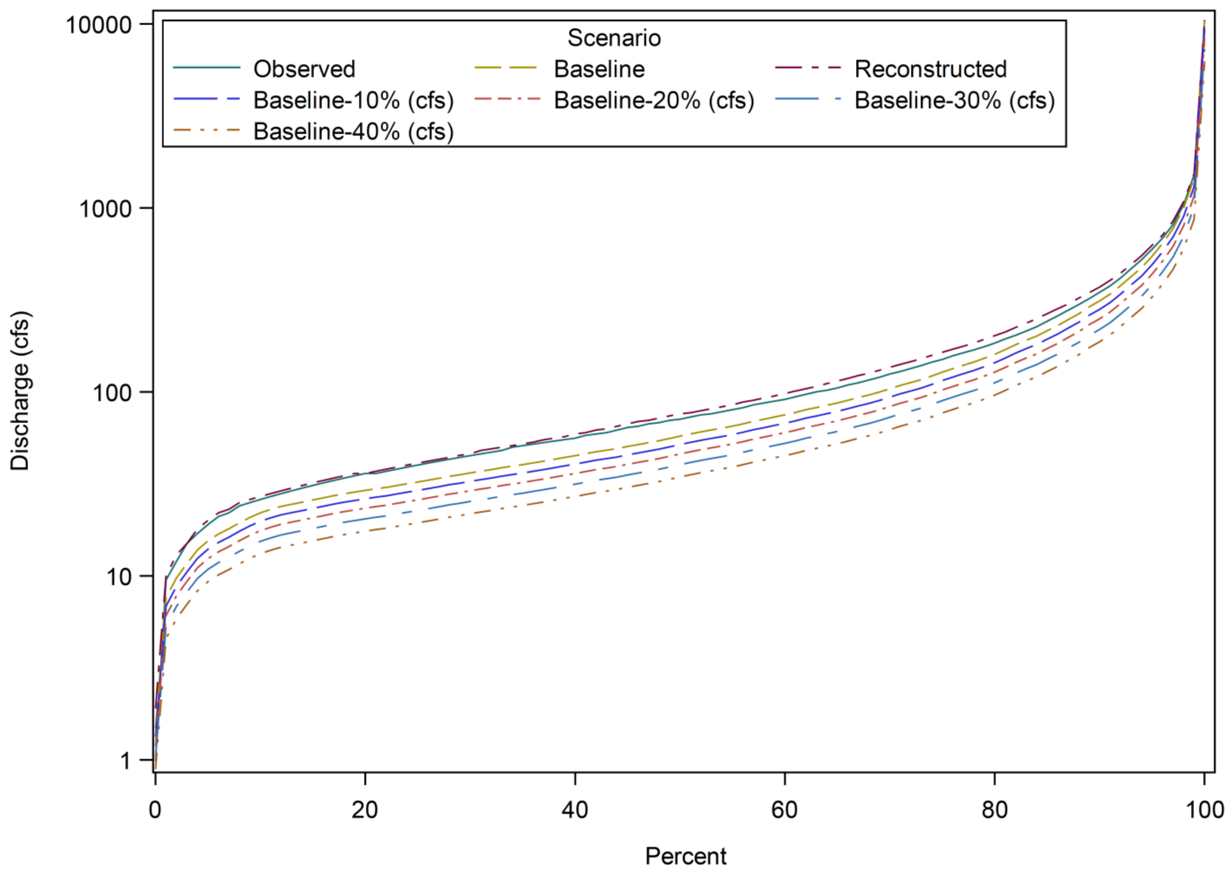

Figure 5-3. **Cumulative distribution plots of Baseline, Reconstructed, and each of the flow reduction scenarios between 10 and 40%.**

Once the flow reduction scenarios were defined, the models developed to evaluate the resources of concern were applied to the flow reduction scenarios. These results of this evaluation are described in the following sections.

5.2 Model Applications

The following sub-sections describe the application of the mechanistic and statistical models to evaluate the effects of reductions in freshwater inflow to the Little Manatee River estuary on physical and biological processes representing the important resources of concern with respect to establishing a minimum flow for the Little Manatee River estuary. The analysis of changes in salinity as a function of freshwater inflow is a primary evaluation in the determinant of the recommended minimum flow for the Little Manatee River estuary in part because of the influence of salinity on several other resources of concern including:

- Benthos – the 7, 8, and 18 psu isohalines are indicative of an identified community specific oligohaline and polyhaline zones for the Little Manatee River.

- Wetland vegetative communities – While no discrete numeric thresholds were established to protect vegetative communities, limiting changes in the bottom area and volume of salinity isohalines to no more than 15% is accepted as a protective limit for vegetative communities along the riparian buffer.

- Plankton – The plankton regressions were developed using freshwater flow as a direct effect on abundance and location though salinity is a known controlling factor directly related to flow that is likely more biologically relevant than the physical effects of flow.

- Nekton- analysis of the nekton data included predictive equations relating abundance to flow, and occurrence to salinity.

The water quality in the Little Manatee River met all water quality standards and was either stable over time or improving. After descriptive assessment of the relationship between water quality and flow it was decided that there were not predictive relationships worth perusing that would inform criteria for developing a threshold based on water quality. The descriptive plots of water quality and flow for flows less than 500 cfs are provided in Appendix D. The effect of flow reductions on each of these other attributes is described in the following sub-sections.

5.2.1 EFDC Model Application

The EFDC model runs were conducted for a period of January 2000 through June 2005. December 1999 was used as a spin up period for model development but was eliminated from all calculations evaluating the flow reduction scenarios. The model output was formatted in three ways:

- The daily average bottom area and volume for each salinity isohaline between 1 and 30 was generated for each date in the timeseries.
- The salinity at 5 fixed station locations was output at 48 minute intervals.
- The salinity for every grid cell and layer was output at 10 minute intervals.

The primary output used for evaluating the effects of the flow reduction scenarios on estuarine salinity was the daily average isohaline bottom area and volume datasets. Each isohaline between 1 and 30 psu was evaluated for each flow reduction scenario by year and block by comparing the average area and volume against the average Baseline area and volume over the same temporal scale. Only full years (i.e., 2000-2004) were used for analysis. The blocks used for this analysis correspond to the blocks defined by the “Building Block” approach described in Chapter 1. That is:

- Block 1 – April 18th through June 22nd
- Block 2 – October 22nd through April 17th
- Block 3 – June 23rd through October 21st

The results of the flow reduction scenarios were isohaline dependent with the lowest isohalines being most sensitive to flow reductions which is logical since the lowest isohalines tend to occupy the least amount of bottom area on average over the model domain. The results were also dependent on the temporal scale used for averaging. For example, when evaluating the results of percent reductions on isohaline area for individual years across blocks, the 15% threshold was not exceeded until the 30% reduction scenario and then only for the lowest isohalines in two of the 5 years of simulation (i.e., 2000 and 2001) (Figure 5-4). These years were exceptionally dry periods in the long term rainfall record. The lowest isohalines were only exceeded for the 40% flow reduction scenario in the remaining years (including 2002 not shown for brevity). When evaluating the effects of the flow reduction scenarios by block across years, the results are similar to the results for individual years across blocks where the 15% threshold was only exceeded for the lowest salinities at flow reductions approaching 30% (Figure 5-5). However, when averaging by block and year, it was clear that in the driest years (2000 and 2002) and driest season of the year (Block 1), the lowest isohalines were more sensitive to flow reductions with a 10 percent flow reduction resulting in up to a 90% reduction in the area of salinities less than 1 psu and all isohalines less than 9 psu showing a greater than 15% change of the 10% reduction scenario (Figure 5-6). This was due to the area of the lower salinity isohalines being minimizes during low flow conditions resulting in larger changes when expressed as a percentage of the baseline area. In fact, there were cases where a particular flow reduction scenario resulted in a predicted bottom area of zero for an isohaline, resulting in a 100% difference predicted due to the flow reduction. The results using isohaline volume were nearly identical to those using bottom area. Plots summarizing the results of flow reductions on volumes as well as plots of isohaline area and volume versus flow are provided in Appendix B.

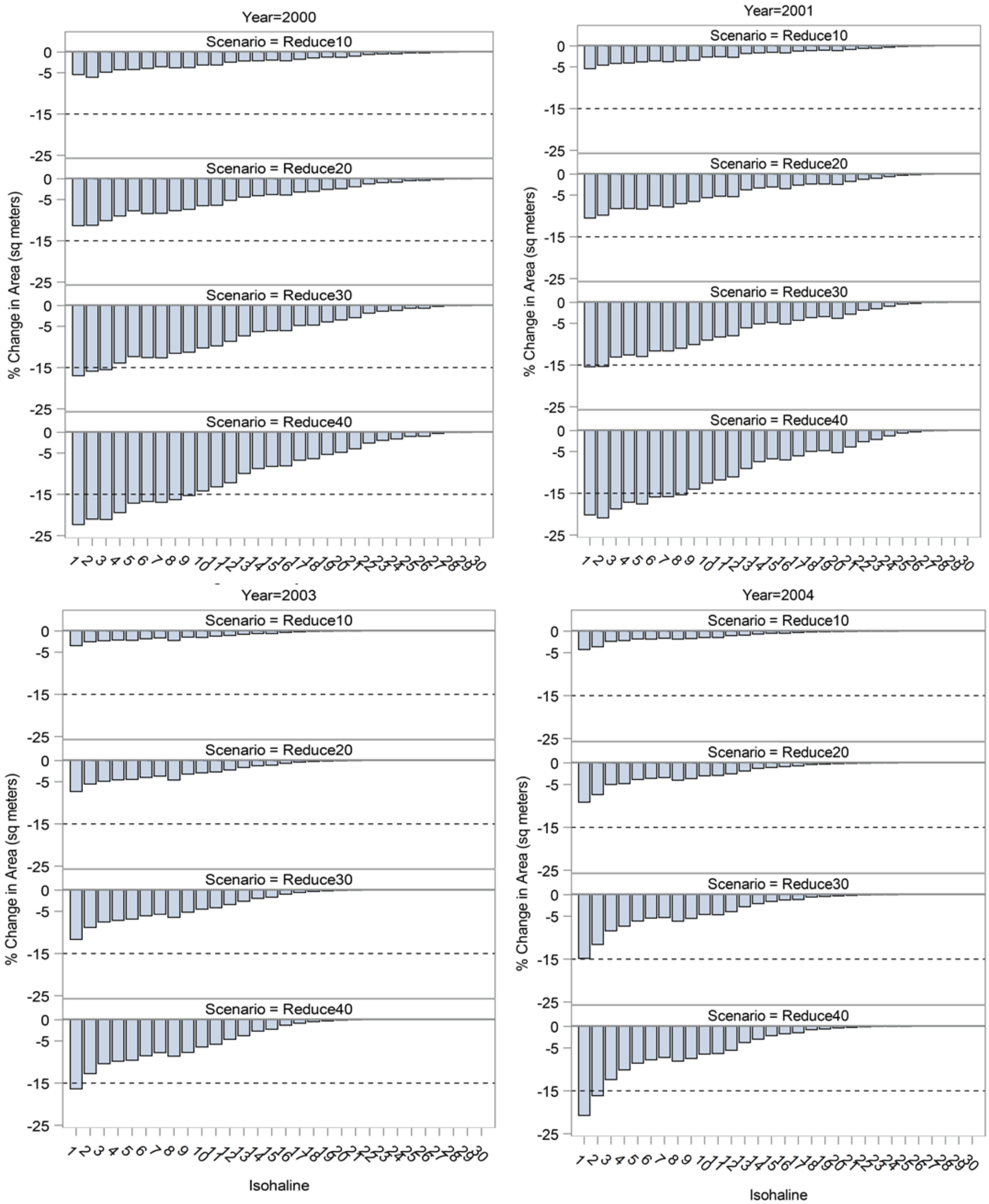

Figure 5-4. **Percent change (y axis) in bottom area (square meters) of salinity isohalines less than 1 through (less than) 30 (x axis) BY YEAR. Broken reference line represents 15% threshold used to identify potential for significant harm.**

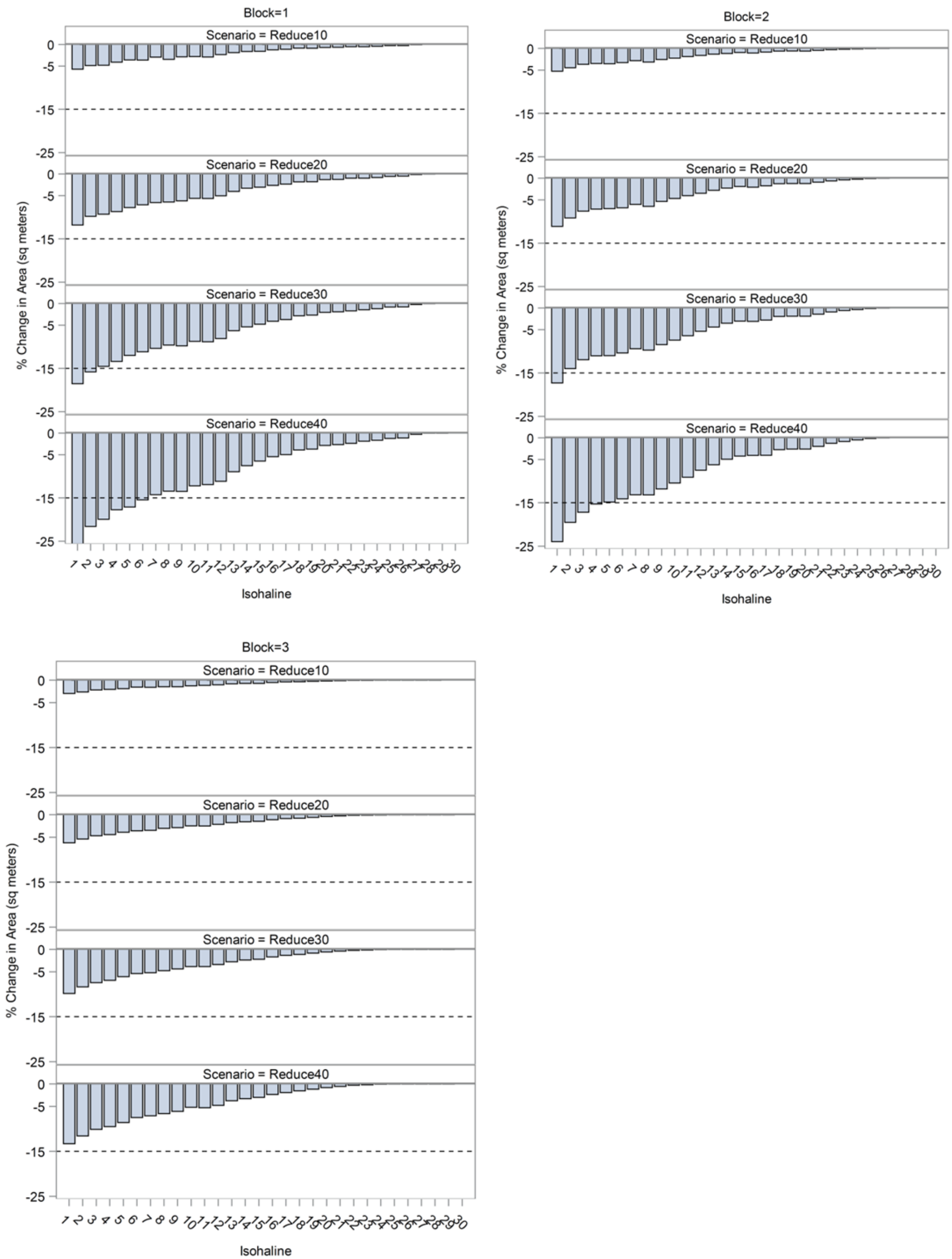

Figure 5-5. Percent change (y axis) in bottom area (square meters) for salinity isohalines less than 1 through 30 (x axis) BY BLOCK. Broken reference line represents 15% threshold used to identify potential for significant harm.

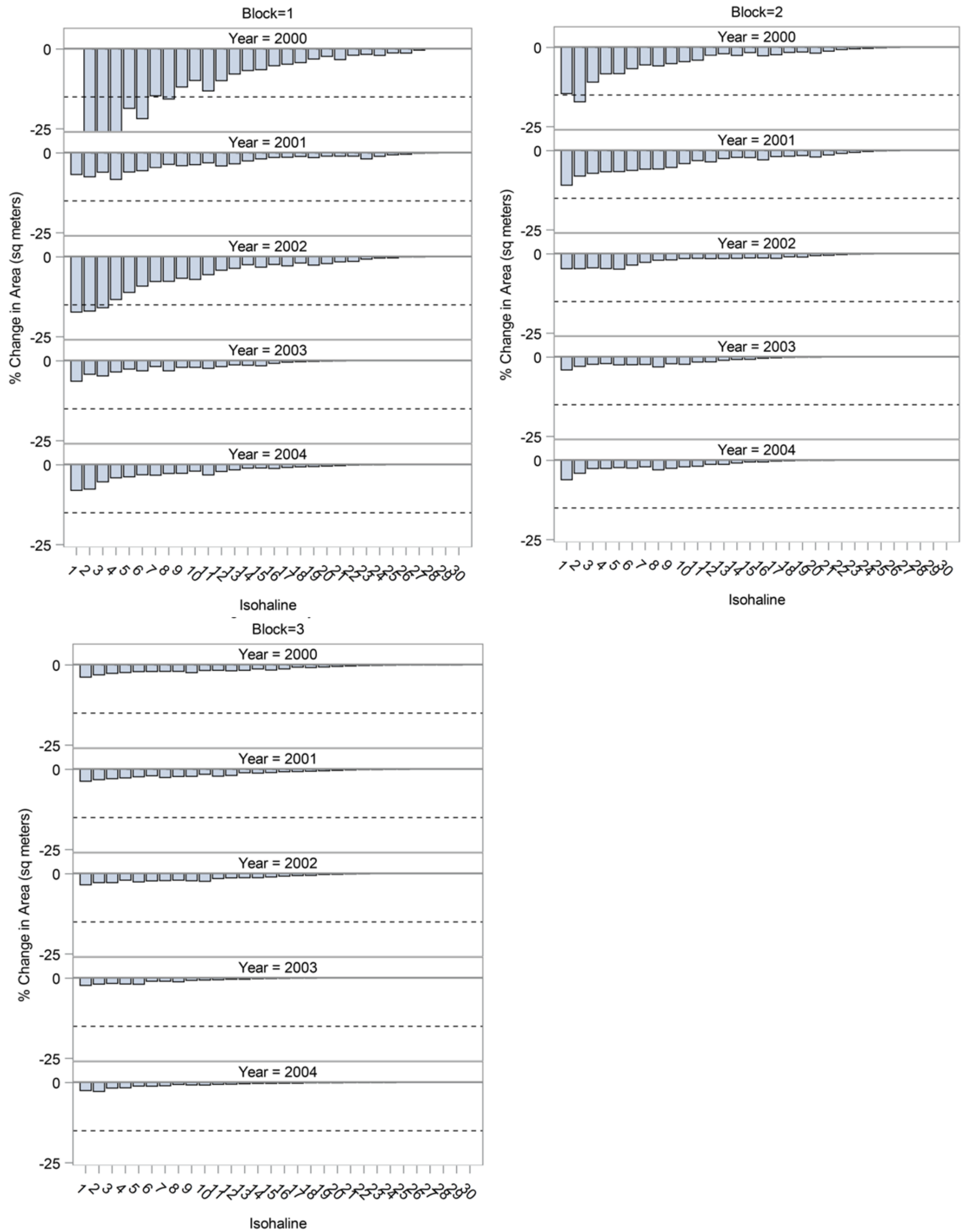

Figure 5-6. **Percent change (y axis) in bottom area (square meters) for salinity isohalines less than 1 through 30 (x axis) BY YEAR AND BLOCK for the 10% reduction scenario only. Broken reference line represents 15% threshold used to identify potential for significant harm.**

A depiction of the salinity distribution for certain extreme low flow days during the observed period of record is provided in Figure 5-7 for context. These salinity predictions depend on more than simply the flow at the USGS gage near Wimauma but provide an example of the expected salinity distributions for the various isohalines under similarly low flow conditions (i.e., < 25th percentile). These plots are instructive and suggest that under extremely dry conditions (as was spring of 2000) somewhere near 20 cfs would be required to have a freshwater (i.e., salinity less than 2 psu) zone in the upper portion of the model domain just below US301. This means that the bottom area and volume of the isohalines (e.g., <1) are zero or near under these extreme low flow conditions. This results in large percent changes in area or volume even with relatively small changes in flows as described by the flow reduction scenarios. Notably, including a low flow cutoff (below which no flow reduction would occur) would likely change the results of this evaluation for these low flow conditions.

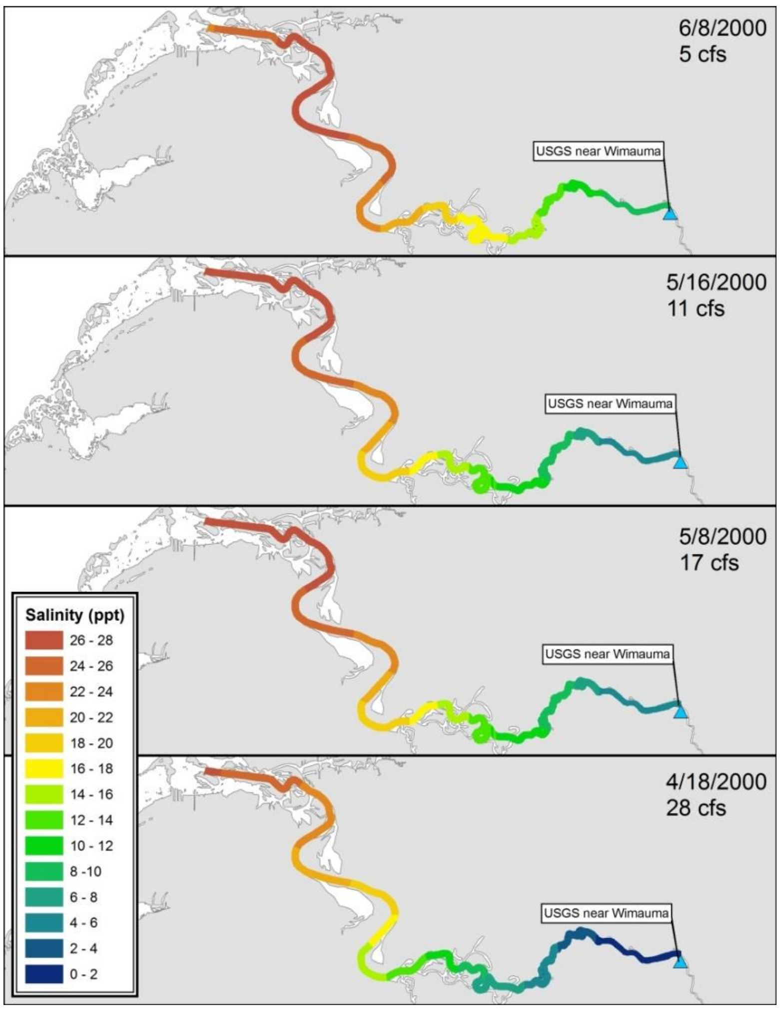

Figure 5-7. Daily and water column average salinity contours as a function of flow for a series of low flow events in 2000.

5.2.2 Salinity Regression Application

An extensive comparison of the empirical salinity model and the EFDC model was described in section 3.2.2 of this report. The empirical salinity models were not developed to evaluate the effects of flow reductions on salinity directly because the EFDC model is considered the gold standard for that evaluation. Rather, the purpose of the empirical salinity regressions was to provide a representative prediction timeseries for each date in the long-term period of record that overlapped the period of record for routine fisheries independent monitoring in the Little Manatee River estuary described in section 4.4. The application of the empirical salinity regressions for evaluating the effects of flow reductions on fish habitat suitability are described in section 5.2.3.3 below.

5.2.3 Biological Regression Applications

5.2.3.1 Plankton

Twenty-one significant relationships between abundance and inflow were reported, 16 of which were negative. Peebles (2008) suggested that taxa typically associated with higher salinities moved farther seaward into the open bay during high-inflow periods, causing a negative abundance correlation with inflow. For estuarine-dependent organisms known to congregate in estuarine nurseries in the interiors of rivers, there was an increase in total abundance when inflows were elevated. This was observed for menhaden postflexion larvae, yellowfin menhaden juveniles, hogchoker juveniles, bay anchovy adults, and sand seatrout postflexion larvae. However, direct correlations between abundance and inflow were hampered by time lags. For hogchoker juveniles, the time lag of one day was too short to be related to adult reproduction or early life history survival and was instead indicative of catchability responses caused by increased inflow. The remaining three taxa, however, had responses that were consistent with elevated adult spawning, improved survival during early life history, improved hydrodynamic transport from spawning ground to nursery, or improved delivery of olfactorants suspected of attracting young fishes to nursery habitats. The coefficients of determination (r^2 values) ranged from 41 to 61% and Peebles et al. (2008) concluded these responses were potentially meaningful to inflow management. Based on application of District regression acceptance criteria described in section 4.3.2 (Heyl et al. 2012), juvenile Yellowfin Menhaden and Bay anchovy were considered as final plankton indicators for minimum flows development. The regressions were applied for these two taxa to the flow reduction scenarios used to evaluate the potential for significant harm. The percent change in abundance was calculated as the difference in average abundance over the period of record for each scenario compared to the Baseline scenario and expressed as a percentage reduction from Baseline. The results of this analysis are provided in Table 5-1. Based on these results, the most sensitive taxon is the yellowfin menhaden with a 12% reduction in abundance predicted with a 10% reduction in flow. Using linear interpolation between the results for the 10^{th} and 20^{th} percentile flow reductions, the results translate to a ca. 15% reduction in abundance (the threshold for identifying significant harm) with ca.12% reduction in flow.

Table 5-1. **Results of minimum flows evaluation for final plankton taxa regressions showing percentage change in abundance as a function of the flow reduction scenarios.**

Taxon	10% Reduction	20% Reduction	30 % Reduction	40 % Reduction
Bay Anchovy	-6.9825126	-14.2127	-21.7323	-29.5972
Yellowfin Menhaden	-12.164004	-24.0192	-35.5362	-46.6783

5.2.3.2 Nekton Regressions

For the plankton regressions, the regressions were based on a log-log relationship and the predicted change in abundance (or relative abundance in the case of nekton) is a constant percentage as a function of the percent change in flow, irrespective of the magnitude of flow. This type of equation defined the “elasticity” principal in econometrics (Johnston and DiNardo 1997) and means that it does not matter what time period is evaluated or which seasonal block is evaluated, the outcome will be a constant percentage based on the percent flow reduction approach with no low-flow threshold. Therefore, it was not necessary to evaluate the reductions as a function of seasonal block or inter-annual differences. However, the addition of the constant in the fish regressions Ln (cpue+1) effected this relationship for the nekton regressions and it was necessary to evaluate the regressions against the time series of flow reduction scenarios.

The final nekton abundance regressions included two important estuarine dependent taxa that both have local economic, as well as ecological, value. Results of the percent flow reductions suggest that blue crab are most sensitive of the taxa considered with a predicted ca. 9% reduction in relative abundance with a 10% reduction in flow which translates to a ca. 15% change in relative abundance with a ca. 16% reduction in flow.

Table 5-2. **Results of minimum flows evaluation for final fish taxa regressions showing percentage change in relative abundance as a function of the flow reduction scenarios.**

Taxon	Gear	10% Reduction	20% Reduction	30% Reduction	40% Reduction
Blue Crab	Seine	-7.178	-15.186	-24.244	-34.673
Blue Crab	Trawl	-8.872	-18.528	-29.149	-40.995
Striped Mullet	Seine	-6.075	-12.798	-20.332	-28.915

The nekton habitat suitability models developed using the EFF function is also dependent on the magnitude of flow as expressed by the changes in predicted salinity. The results of the EFF application to the flow reduction scenarios are provided in the following section.

5.2.3.3 Nekton Habitat Suitability

As described in section 4.4.3, the habitat suitability model was used as an additional weight of evidence to evaluate the effects of flow reductions on suitability for fish utilization of the Lower Little Manatee River. The results were evaluated in two ways; using the EFDC model salinity predictions for each, cell, date, and flow reduction scenario for the time period of 2000-2005, and using the empirical salinity model predictions over the entire timeseries of nekton data collection. Those cells where the EFF prediction was above 0.5 was assigned as Favorable and otherwise Unfavorable. The area of the cells where the EFF model predicted as Favorable was then summed for each day in the period of record. The average area for each of the flow reduction scenarios was then calculated for the Baseline condition as well as each of the 4 flow reduction scenarios by block, year and block and year combinations. The differences relative to the Baseline condition for each model scenario was calculated for each year across seasonal blocks, across years, by seasonal block, and for each year and seasonal block.

The results for the EFDC model (regarded as the gold standard for evaluating salinity in this report) suggests that the reduction in favorable habitat area was limited to less than 10% of Baseline for all taxa considered for any year across seasonal blocks when flow reductions were less than 20% (Table 5-3). The taxa with the most significant responses were typical tidal river resident species that tend to inhabit lower salinity portions of tidal rivers in Florida including Sailfin Molly (*Poecilia latipinna*), small gobies less than 20mm (*Gobiosoma spp*.), Striped Mojarra (*Eugerres plumieri),* and Rainwater killifish (*Lucania parva*). Results were similar when evaluating changes by seasonal block across years (
Table **5-4**).

Table 5-3. Results of EFF model evaluation for EFDC model salinity predictions across seasonal blocks by year. Table is sorted with the largest predicted change on top and only taxa with greater than a 10% change under any scenario are shown.

Taxon	Year	10% Reduction	20% Reduction	30 % Reduction	40 % Reduction
Sailfin Molly	2000	-4.0	-7.9	-12.0	-16.2
Small Gobies <20mm	2000	-3.8	-8.0	-11.8	-16.1
Striped Mojarra	2000	-3.6	-7.5	-11.6	-16.0
Rainwater Killifish	2000	-3.5	-7.7	-11.6	-15.9
Sailfin Molly	2001	-3.3	-7.4	-11.6	-15.9
Code Goby	2000	-3.6	-7.7	-11.7	-15.8
Naked goby	2000	-3.4	-7.5	-11.5	-15.6
Rainwater Killifish	2001	-3.3	-6.9	-11.1	-15.5
Small Gobies <20mm	2001	-3.2	-6.9	-10.7	-15.4
Mosquitofish	2000	-3.5	-6.8	-11.1	-15.2
Mosquitofish	2001	-3.5	-6.7	-11.1	-15.0
Naked goby	2001	-3.3	-6.8	-10.7	-15.0
Code Goby	2001	-3.2	-6.8	-10.6	-14.9
Hogchoker	2000	-3.0	-6.4	-10.0	-14.2
Common Snook	2000	-2.9	-6.3	-9.9	-13.8
Striped Mojarra	2001	-2.6	-5.9	-8.9	-12.8
Sailfin Molly	2002	-2.1	-4.7	-7.6	-11.6
Hogchoker	2001	-2.6	-4.8	-7.8	-11.4

Table 5-4. Results of EFF model evaluation using the EFDC model salinity predictions across years by seasonal block. The table is sorted with the taxon with the largest predicted change on top and only taxa with greater than a 10% change under any scenario are shown.

Taxon	Block	10% Reduction	20% Reduction	30 % Reduction	40 % Reduction
Sailfin Molly	1	-3.3	-7.2	-11.1	-15.7
Mosquitofish	1	-3.6	-7.1	-11.1	-15.5
Rainwater Killifish	1	-3.6	-7.0	-11.1	-15.3
Small Gobies <20mm	1	-3.5	-7.0	-10.7	-15.0
Naked Goby	1	-3.3	-7.0	-10.7	-14.8
Code Goby	1	-3.2	-7.0	-10.6	-14.5
Striped Mojarra	1	-2.8	-5.8	-9.0	-12.5
Hogchoker	1	-2.4	-5.5	-8.4	-11.8
Common Snook	1	-2.3	-5.2	-8.3	-11.3
Sailfin Molly	2	-2.4	-5.1	-7.9	-11.2
Small Gobies <20mm	2	-2.3	-5.0	-7.7	-10.9
Rainwater Killifish	2	-2.2	-4.8	-7.6	-10.7
Code Goby	2	-2.2	-4.7	-7.5	-10.4
Naked Goby	2	-2.2	-4.7	-7.4	-10.4
Mosquitofish	2	-2.3	-4.6	-7.4	-10.1
Striped Mojarra	2	-2.4	-4.8	-7.1	-10.0

However, when comparing the flow reduction scenarios by block and year, the EFF model suggested that there are specific combinations of conditions that can result in a significant reduction in favorable habitat for these taxa even under the lowest flow reduction scenario (i.e., 10% reduction). These periods occurred in the driest years and blocks (**Error! Not a valid bookmark self-reference.**). The results of the block-within-year assessment suggest that a greater than 15% reduction in favorable habitat may occur during the driest portions of some dry years (e.g., year 2000) even under the smallest flow reduction scenario evaluated (i.e., 10% reduction).

The results using the longer period of record and the LOESS model salinity predictions were very similar to those described above for the EFDC model and are provided in Appendix D. It is imperative to recall that the EFDC model evaluations did not include a low flow cutoff for this assessment. In fact, flows in Block 1 of 2000 were never above the low flow cutoff recommended for the freshwater minimum flows (i.e., 35 cfs). To evaluate the effects of the low flow cutoff, the EFF analysis was conducted using the LOESS regression model where a low flow cutoff could more readily be added as an additional scenario to evaluate. The recommended prescription (minimum flows) flow for the freshwater segment of the Little Manatee River was used for this evaluation. The minimum flows flow included a low flow cutoff of 35 cfs, below which no withdrawal was allowed. Above 35 cfs, a 13.5% reduction was imposed up to the 60th percentile of flow (72 cfs). Between the 60th and 80th percentile of flow (174 cfs), a 12.8% reduction was imposed and above the 80th percentile, an 11% reduction was imposed.

Table 5-5. Results of EFF model evaluation using the EFDC model salinity predictions by year and seasonal block. The table is sorted with the taxon with the largest predicted change on top and only taxa with greater than a 15% change under the 20% scenario are shown.

Taxon	Block	Year	10% Reduction	20% Reduction	30 % Reduction	40 % Reduction
Sailfin Molly	1	2000	-17.9	-38.8	-56.4	-75.4
Mosquitofish	1	2000	-17.8	-34.3	-54.0	-68.9
Rainwater Killifish	1	2000	-17.9	-34.2	-54.1	-68.5
Small Gobies <20mm	1	2000	-18.4	-34.2	-51.1	-67.4
Naked Goby	1	2000	-18.8	-34.9	-49.9	-66.2
Code Goby	1	2000	-21.5	-36.2	-49.8	-66.2
Striped Mojarra	1	2000	-15.6	-28.9	-46.5	-58.6
Hogchoker	1	2000	-11.4	-24.6	-38.2	-51.4
Common Snook	1	2000	-11.4	-23.8	-37.3	-49.9
Sailfin Molly	1	2002	-7.0	-15.5	-26.5	-41.2
Rainwater Killifish	1	2002	-8.2	-15.8	-24.4	-37.6
Mosquitofish	1	2002	-8.2	-15.7	-24.1	-37.3
Small Gobies <20mm	1	2002	-8.0	-15.5	-23.9	-34.0

The results of the recommended minimum flows flow scenario as applied to the nekton data using the EFF model suggest that the recommended freshwater minimum flows would be fully protective of the nekton habitat for any season or block within the period of record evaluated (Table 5-6). No reduction would occur in Block 1 of 2000 because no flow reduction would be allowed. The reductions in Block 2 of 2000 and Block 1 of 2001 were the most sensitive to the Prescription flow scenario but were much less than even the 10% flow reduction scenario without a low flow threshold over the same time period illustrating the protective effects of the low flow cutoff in minimizing significant harm during low flow periods. This is further discussed in the minimum flows synthesis chapter (Chapter 6) of this report.

Table 5-6. Results of EFF model evaluation using the recommended freshwater minimum flows and evaluated using the LOESS model salinity predictions for each year and seasonal block.

Taxon	Block	Year	10% Reduction	20% Reduction	Recommended Freshwater minimum flows
Poecilia latipinna	2	2000	-17.2	-33.6	-9.1
Poecilia latipinna	1	2001	-16.9	-33.0	-2.5
Lucania parva	1	2001	-17.1	-32.8	-3.2
Gambusia holbrooki	1	2001	-16.5	-32.6	-2.7
Gobiosoma spp.	1	2001	-18.5	-32.5	-4.1
Lucania parva	2	2000	-15.1	-32.2	-7.8
Poecilia latipinna	2	2000	-15.2	-32.0	-7.7
Poecilia latipinna	1	2001	-16.6	-31.7	-1.1
Gobiosoma spp.	1	2001	-14.9	-31.4	-1.0
Gambusia holbrooki	1	2001	-15.7	-30.4	-1.1
Gobiosoma spp.	2	2000	-14.9	-30.2	-6.9
Gobiosoma bosc	2	2000	-15.8	-30.1	-9.0
Poecilia latipinna	2	2000	-14.6	-28.3	-4.6

6 MINIMUM FLOWS EVALUATION RESULTS SYNTHESIS

Alber (2002) proposed a conceptual model that describes the role of scientists, citizens, politicians and resource managers in the management of freshwater inflow into estuaries. As Alber and others recognized, the management of freshwater inflows to estuaries relies on a wealth of information beyond the scope of any one tool. The analytical tool(s) must be combined with expert knowledge of the biology of the organism(s) under study. Riverine system dynamics, including surface and ground water modeling, and the influences of nutrient loadings into the system must also be considered. Finally, socio-economic impacts must be evaluated in order to provide informed assessments regarding the potential impacts of freshwater reductions to the health of the surrounding resource.

Flannery et al. (2002) described a framework of important considerations for managing unimpounded rivers in Southwest Florida designed to maintain the physical structure and ecological characteristics of the river under study. This approach relies on empirical information from hydrobiological monitoring as well as simulation based modeling approaches to assess the effects of freshwater reductions on ecosystem integrity. Primary and secondary production was recognized as potentially important management criteria. In this report, we have examined the effects of hypothetical flow reductions on multiple attributes of ecosystem integrity to estimate the limit to which surface water withdrawals could be abstracted before causing significant harm to the estuarine resources of the Little Manatee River as required by state law. The subsections below provide concise summaries for each of the resources of concern that were evaluated for this analysis.

6.1 Salinity Isohalines

The change in bottom area and volume of salinity isohalines did not generally exceed the 15% threshold until the 30% flow reduction scenario and then only for the lowest salinity isohalines examined. However, it was clear that when the salinity isohaline bottom areas and volumes were small under the Baseline condition, the percent change as a function of flow was larger and in extreme cases such as the driest year and season in the simulation (2000; Block 1), the 15% change threshold would be exceeded under even the most conservative flow reduction scenario examined. It is critical to understand that these flow reduction scenarios did not include a low flow cutoff which likely impacted this outcome. The majority of estuarine District minimum flows include a low-flow cutoff and it is worth considering an additional set of EFDC model runs that include a low flow cutoff value once a low flow cutoff is established in order to determine and account for the potential effects of relatively small quantity withdrawals at very low flows on the lowest salinity isohalines.

6.2 Biological Interactions Between Flow and Salinity

The results of the assessment of biological responses to changes in inflows relied mostly on evaluation of plankton and nekton data as the benthic macroinvertebrate and mollusk surveys resulted in primarily a descriptive characterization of the community structure. The sub-sections below describe the outcomes of the minimum flows evaluation for these resources of concern.

6.2.1 Plankton Abundance Outcomes

Based on the results of the plankton regression evaluations, the most sensitive taxon to inflow changes is the juvenile yellowfin menhaden with a 12% reduction in abundance predicted with a 10% reduction in flow. This translates to a ca. 15% reduction in abundance (the threshold for identifying significant harm) with ca.12% reduction in flow.

6.2.2 Nekton Relative Abundance Outcomes

The final fish abundance regressions include two important estuarine dependent taxa that both have local economic, as well as ecological, value. The results suggest that blue crab are the most sensitive of the taxa considered with a predicted ca. 9% reduction in relative abundance with a 10% reduction in flow which translates to a ca. 15% change in relative abundance with a ca. 16% reduction in flow.

6.2.3 Nekton Environmental Favorability Outcomes

The habitat suitability model outcomes suggested that the results of the flow reduction scenarios would be dependent on the temporal scale of analysis but did not generally approach a 15% reduction until the 30% flow reduction scenario when evaluated by year across blocks or by block across years. There were periods of time within the model simulation period where changes were predicted to be more significant if flow reductions were allowed during the driest seasons and years (e.g., 2000 Block 1). However, as with the results for the EFDC model (on which the salinity predictions were based), the importance of a low flow cutoff value included in the EFDC model runs was a critical consideration in this outcome. Analysis using the LOESS model salinity predictions suggested that the inclusion of a low flow cutoff such as that recommended by the freshwater minimum flows would be protective of changes in favorable habitat for all species under this scenario.

6.2.4 Manatee

There was insufficient information to establish manatee based criterion in the Little Manatee River.

7 – MINIMUM FLOWS RECOMMENDATIONS

7.1 Recommended Minimum Flows

The list of results for the individual resources of concern is provided in Table 7-1.

Table 7-1. List of results for individual resources of concern evaluated for the Little Manatee River estuary.

Analysis Name	Measure/Goal	Block	Maximum Allowable Flow Reduction
Salinity Isohaline	Prevent significant departure of salinity regime	Block 1 and 2	30%
Plankton	Maintain abundance of Yellowfin Menhaden	All	12%
Nekton	Maintain abundance of Blue Crab	All	16%
Nekton	Maintain Favorable habitat during dry season	All	Low Flow cutoff required to be protective during driest seasons and years

The most conservative of these results is that of the yellowfin menhaden based on the plankton regression results. As stated previously, the EFDC flow reduction scenarios were run without a low flow cutoff and therefore may tend to overstate the effects of flow reductions during low flow conditions. Because a low flow cutoff is recommended for the freshwater section of the Little Manatee River, it seems intuitive that the Little Manatee River estuary will be subjected to a low flow cutoff as well. It is also important to consider that the results presented provide the best estimate of the effects of potential flow reductions but that each of the models used in the development of the estimates has some uncertainty associated with the predictions. Quantifying model uncertainty as it is propagated throughout the analysis is a very challenging task and is beyond the scope of this effort. The District considers the results presented in this document to the best estimates in line with the legal statue describing the use of best available information to establish minimum flows. When considering that there is uncertainty around these estimates it is striking how similar the outcomes for the estuary are to the outcomes for the proposed minimum flows for the freshwater portion of the Little Manatee River which is briefly described below.

A summary of the recommended minimum flow for the freshwater section of the Little Manatee River is provided in Table 7-2 for reference. The recommended minimum flow for the freshwater portion of the minimum flows is a low flow cutoff value of 35 cfs to protect wetted perimeter and fish passage with additional reach specific criteria to protect upstream shoals in Reach 1 and 2 if further consumptive use is permitted in the eastern portion of the watershed. In addition, no more than a 13.5% reduction in flows above the low flow cutoff is allowed anytime and no more than a 12.8% and 11% reduction is allowed when flows are above their 60% and 80^{th} percentile values, respectively.

Table 7-2. Table of results minimum flows evaluation of freshwater resources of concern.

Analysis Name	**Measure/Goal**	**Block**	**Criterion Values**
Fish Passage	Maintain depth of 0.6 ft. at shoals at historical inundation frequency	All	Reach 1= 15 cfs, Reach 2= 27 cfs Wimauma = 35 cfs
Wetted Perimeter	Maximize inundation of stream bottom for benthic invertebrates	All	31 cfs
SEFA	Avoid > 15% reduction in habitat for various instream species	All	No more than 13.5%
Floodplain	Avoid > 15% reduction of floodplain inundation frequency and areal extent	Flow greater than 60^{th} and 80^{th} percentile	No more than 12.8% when flows are above 60^{th} percentile (i.e.,72 cfs) and 11% when flows are above the 80th percentile (174 cfs).

Notice that the prescription flow with a 35 cfs low flow cutoff will still result in a increase in the freqecy of flows below 35 cfs of approximately 7% (Figure 7-1) however, withdrawals could be scaled such that they never aused the flow to fall below the 35 cfs low flows cutoff.

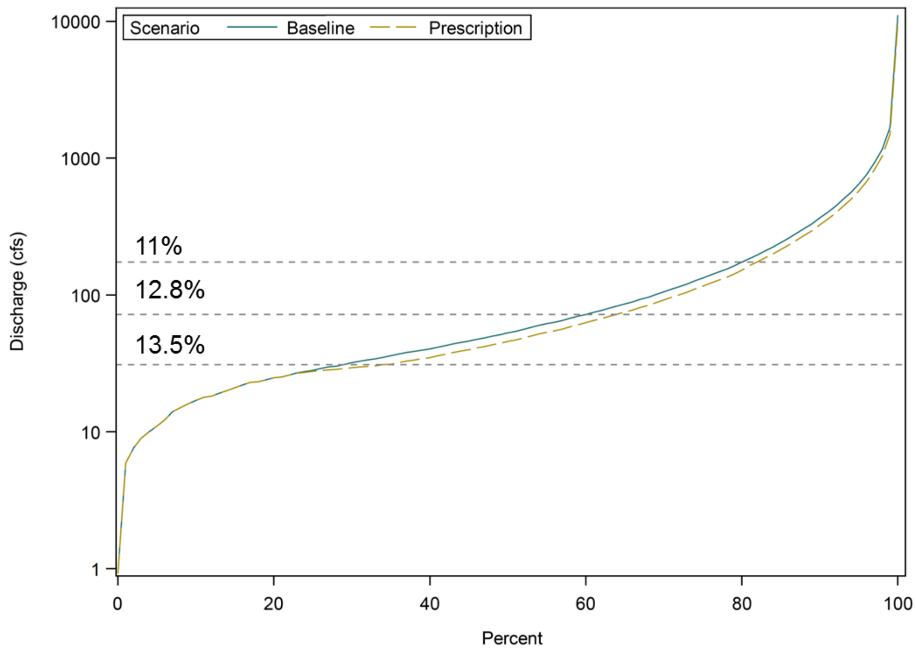

Figure 7-1. **Baseline and Prescription flow distribution with allowable consumptive use located on the hydrograph.**

Given the similarities between the freshwater and estuarine minimum flows outcomes, and the fact that they use the same compliance gage, it seems intuitive to develop a single minimum flows that is protective of both the fresh and estuarine segments of the Little Manatee River. This report recommends that if all aspects of the recommended freshwater minimum flows are adopted, the freshwater minimum flows would also be protective of the estuarine segment. This approach would protect the downstream resources, provide uniformity between the two segments of the river and allow for a consistent compliance assessment process. The median flows under the Baseline and Prescription (minimum flows) scenario for the proposed freshwater minimum flows are provided in Figure 7-2. It is evident from the figure that that the low flow cutoff would limit withdrawals during the dry season during the drier years which would be protective of favorable habitat for all species considered. The freshwater minimum flows are 1.5% higher than the threshold value identified using the plankton regressions; however, the low flow cutoff was not applied to the estuarine flow management scenarios. Including a low flow cutoff would likely result in an additional allowance for the plankton results between the Baseline and 15% trigger for identifying significant harm. The blue crab would also be fully protected from significant harm due to fresh water withdrawals under the freshwater minimum flows and the freshwater minimum flows was shown to be protective of favorable habitat for nekton using the LOESS EFF analysis.

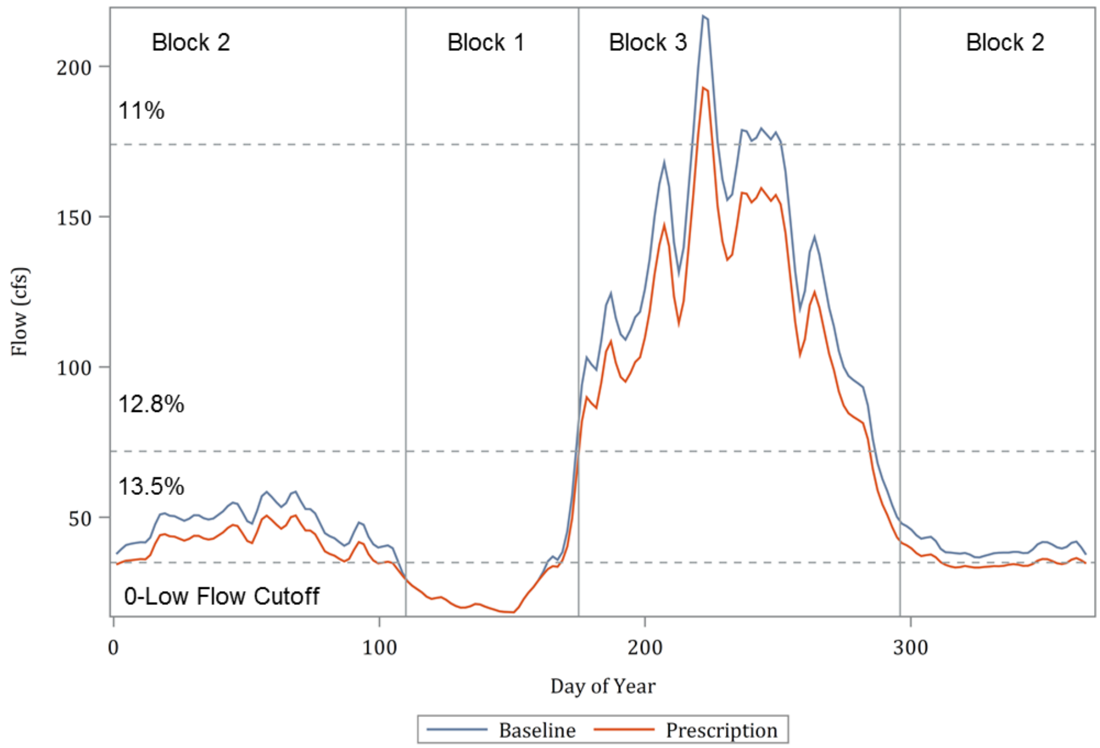

Figure 7-2. Median flows under Baseline and Prescription scenario for each day of the year illustrating seasonal distribution of expected maximum difference in flows allowed under minimum flows.

7.2 Additional EFDC Model Runs

Additional model runs were requested by the District after completion of a draft version of this document to address two principal concerns; evaluating the effects of the recommended Prescription flow for the Upper Little Manatee River on changes in the salinity isohaline position, and evaluate the effects of three sea level rise scenarios (low, average, and high projections) provided by the District on the Baseline and Prescription flow isohaline positions. As with the previous analysis of the EFDC model results described in section 5.2.1., the evaluations were constructed in three ways, comparing the average difference in area and volume of each salinity isohaline by year across block, by block across year, and by year and block. December of 1999 was removed from analysis and only full years were evaluated for the annual comparisons.

The results of the evaluations suggest that the Prescription flow described above would result in less than a 10% reduction in the area of any salinity isohaline for any block (averaged across years) or year (averaged across block). Only when evaluating the effect of the Prescription flow by year and block did any isohaline exceed a 15 percent change. A single isohaline (the 2 ppt isohaline) had a greater than a 15% change in Block 1 (the dry season) of year 2000 and 2002 due entirely to the fact that the 2 ppt isohaline was very small under the Baseline condition. If fact, in 2000 there was zero area of salinity less than 1 ppt under the Baseline condition according to the EFDC model, indicating that the model domain was predicted to contain no freshwater.

The sea level rise scenarios did not have a pronounced effect on salinity isohaline position except for conditions as noted above when the low salinity isohaline areas were extremely small under the baseline condition. The greatest change when evaluated either across years or across block occurred when the “High” sea level rise scenario was added to the Prescription flow timeseries. These results indicated that the “High” scenario posed the greatest risk to posing significant harm to the area and volume of salinity habitat in the estuarine portion of the Little Manatee River as defined by the area west of US 301 but the more moderate estimates of sea level rise would, when evaluating on long term average conditions, result in a 15% change in area or volume. The details of this evaluation are presented in Appendix E.

The next chapter describes recommended future efforts that will improve the knowledge base for better natural resource management with respect to evaluating the effects of fresh water withdrawals on the Little Manatee River estuary.

8 – FUTURE EFFORTS

The recommendation of a minimum flow for the Little Manatee River estuary does not imply that the system is fully understood or that future scientific information would not inform refinements to the minimum flow over time. There are significant empirical data gaps for estuarine biota in the upstream portion of the estuary (i.e., Rkm18 through 24: Figure 8-1).

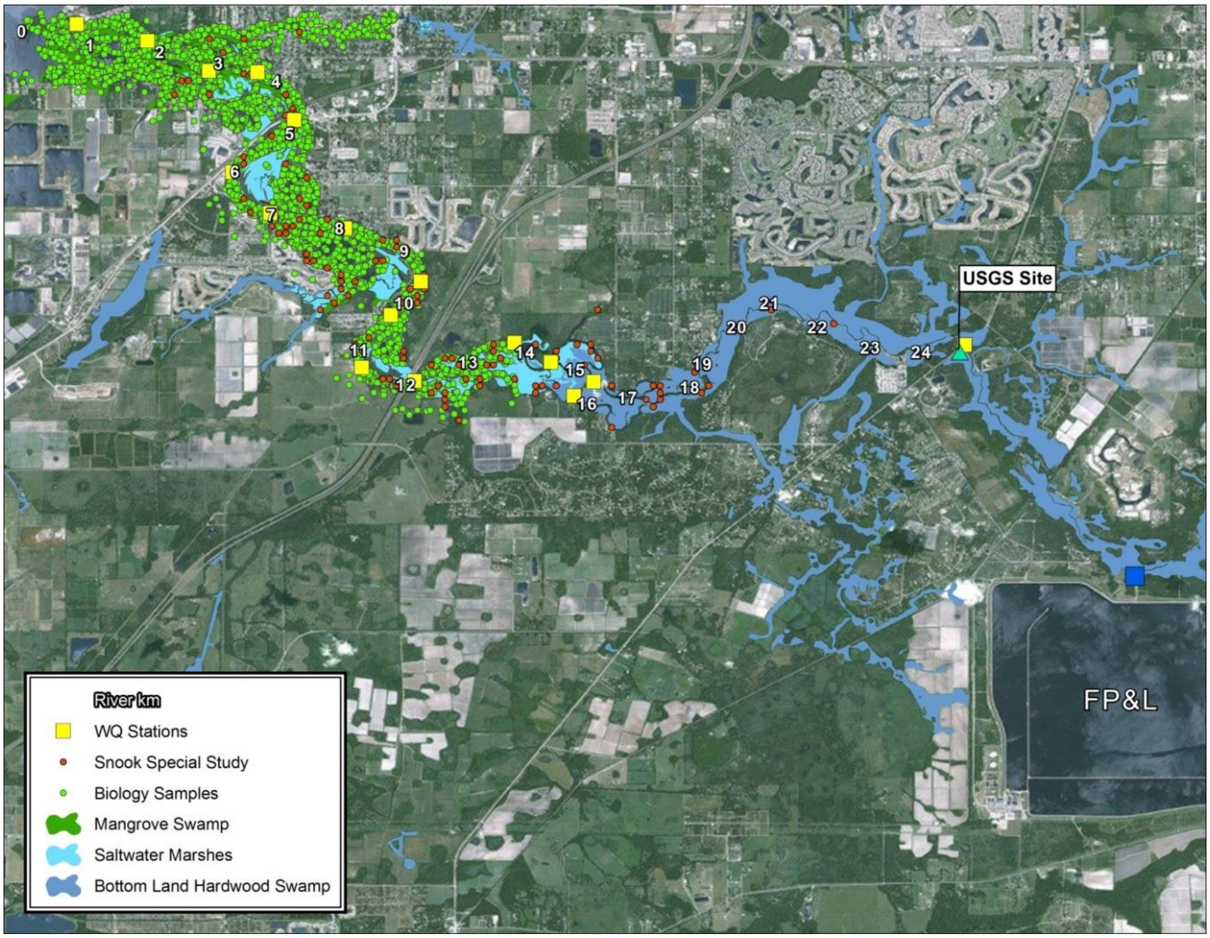

Figure 8-1. Location of samples throughout the lower Little Manatee River.

A field visit on May 11th 2018 was conducted to investigate the presence of "rock outcroppings" in the upstream portion of the Lower Little Manatee River (reported by Fernandez 1985 as between river mile 13 and 14 using Shell Point as a reference). Fernandez proposed that these areas could serve to limit tidal intrusion upstream which would be an important consideration in developing a minimum flow for the Lower Little Manatee River. This location generally corresponds to an area just east of Little Manatee River State Park boat launch. A kayak was launched at the State Park and paddled upstream to US 301. Flow at the Wimauma gage was

35 cfs, precisely corresponding to the proposed low flow cutoff for the Upper Little Manatee River. Plots of cumulative precipitation and flow at the Wimauma gage are presented in Figure 1 for reference. This area of the river is characterized by a series of shoals without a defined thalweg followed by pools of deeper water. The bottom was silty-sand throughout this stretch of the river and the shoals were approximately 0.6 feet deep across the shoal at the flow of 35 cfs. However, there were no defined or exposed rock outcroppings observed or discovered by penetrating the river bottom with the kayak paddle. It is possible that the rock outcroppings have been buried in sediment over time or possibly even eroded but there was no evidence that these rock outcroppings currently exist within the river channel and the park rangers were likewise unaware of rock outcroppings in the area. Despite this, the shoal areas would likely serve as somewhat of an impediment to tidal intrusion under very low flow conditions. All areas of this section of the river were passable with a small kayak at 35 cfs. As an aside, several small schools of mullet (mugil spp.) were observed along with a single needlefish (Strongylura spp.) indicating that estuarine species do utilize this section of the river despite that the area was observed to be tidal freshwater.

It is unknown the extent to which this portion of the system is used by estuarine fish taxa including important gamefish species such as the Common Snook which are known to overwinter in freshwater portions of tidal systems but need sufficient hydrologic depth to move upstream (Blewett et al. 2009). A small but deep pool of at the FP&L intake may be an attractive area for snook to overwinter but there are no known studies evaluating the utilization of this upper portion of the river or the pool. In addition, there is ample freshwater floodplain vegetation that was outside the domain of the hydraulic and hydrologic models used to evaluate the freshwater portion of the Little Manatee River. There are a few transects downstream of US 301 in the existing models but not enough to characterize the floodplain inundation frequency and effects of flow reductions on those frequencies as was done for the freshwater minimum flows. Existing efforts to monitor for snook in downstream portions of the river by FWC (Alexis Trotter FWC, personal communication) could be extended upstream, and existing hydrologic models such as the SWMM or HECRAS models could be extended downstream to pursue these areas of research in the portion of the system between river kilometer 18 and the pool at FP&L. These studies would provide valuable information to inform future assessments of the relationship between freshwater inflows to the Little Manatee River estuary and the oligohaline and tidal freshwater reaches of the estuary that are currently less than fully understood. In the interim, this report has detailed outcomes of scientific investigations aimed at providing natural resource protection against surface water withdrawals that would result in significant harm to estuarine resources in the Little Manatee River estuary.

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10 - APPENDICES (TYPICALLY BOUND SEPARATELY)

10.1 TECHNICAL APPENDICES

10.2 PEER REVIEW REPORT

10.3 STAFF RESPONSE TO PEER REVIEW REPORT

10.4 PUBLIC COMMENTS