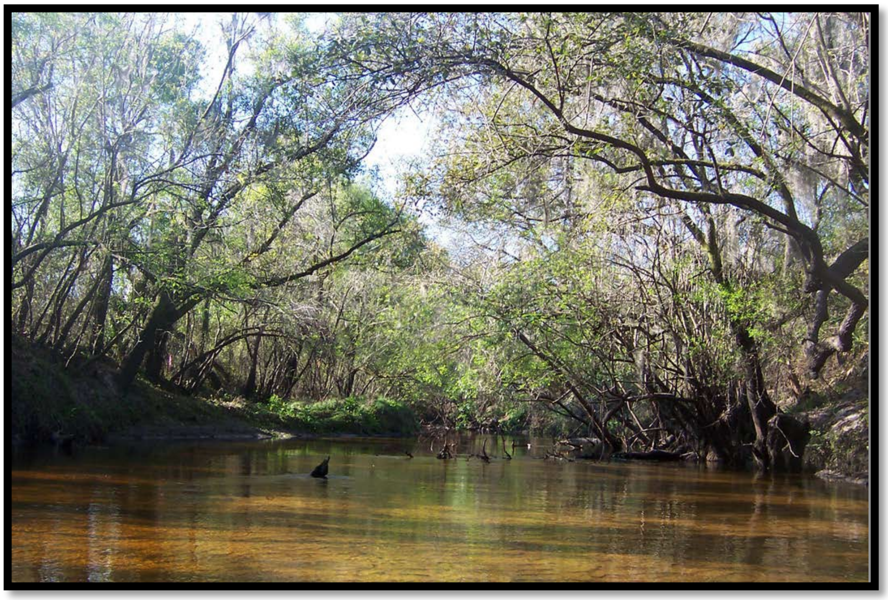
Recommended Minimum Flows for the Little Manatee River
Final Draft Report



November 2023

Southwest Florida Water Management District

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EXECUTIVE SUMMARY

The Southwest Florida Water Management District (District) is directed by the Florida Legislature to establish minimum flows for flowing watercourses within its boundary. Minimum flows are defined in Section 373.042(1) of the Florida Statutes as “the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.” For minimum flows development, each water management district of the state or the Florida Department of Environmental Protection identify specific metrics or criteria that can be associated with significant harm. Once adopted into the District’s Water Levels and Rates of Flow Rules within the Florida Administrative Code, minimum flows can be used for water supply planning, water use permitting, and environmental resource regulation.

This report summarizes minimum flows developed for the Little Manatee River, including both the freshwater and estuarine portions of the river. Analyses used to develop minimum flows for the freshwater portion or Upper Little Manatee River focused on the river from its headwaters near Fort Lonesome in southeastern Hillsborough County to the US Highway 301 bridge, where the US Geological Survey (USGS) Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage is located. Analyses supporting minimum flows development for the estuarine portion of the river or Lower Little Manatee River, focused on the portion of the river downstream of the US Highway 301 bridge to Tampa Bay. However, because freshwater and tidal, low-salinity conditions occur approximately 3-4 miles (5-7 km) downstream of the US Highway 301 bridge, the Hillsborough County Environmental Protection Commission’s Water Quality Monitoring Station No. 1616, which is located downstream from the bridge, was used to define the boundary between the Upper Little Manatee River and Lower Little Manatee River for minimum flows purposes.

The Little Manatee River is one of the most pristine blackwater rivers in Southwest Florida. The watershed of the river is located in southern Hillsborough County and the northern portion of Manatee County; it includes the communities of Parrish, Ruskin, Sun City Center, and Wimauma. The Little Manatee River flows west about 40 miles (64 km) from its headwaters east of Fort Lonesome before emptying into Tampa Bay near Ruskin.

The recommended minimum flows for the Upper and Lower Little Manatee River were developed using the best information available, as required by Florida Statutes, and were based on all relevant environmental values identified in the Florida Water Resource Implementation Rule for consideration when establishing minimum flows. The District’s approach for developing minimum flows is habitat-based, and because the Little Manatee River includes a great variety of aquatic and wetland habitats that support diverse biological communities, key ecological resources were identified for minimum flows development consideration. The resource management goals that were the focus of the technical analyses for the development of minimum flows for the Little Manatee River included the following:

- Determination of a low-flow threshold to provide protection for ecological resources and recreational use of the Little Manatee River during critical low-flow periods.
- Maintenance of seasonal hydrologic connections between the Upper Little Manatee River channel and floodplain to ensure the persistence of floodplain structure and function.
- Maintenance of available instream habitat for fish and benthic macroinvertebrates in the Upper Little Manatee River.

- Maintenance of biologically relevant salinities over a range of flow conditions that protect the distribution of plankton, benthic macroinvertebrates, fish, and shoreline vegetation communities in the Lower Little Manatee River.
- Maintenance of favorable estuarine habitat for nekton in the Lower Little Manatee River.

Flow-based blocks, which are defined below, were developed for the Upper Little Manatee River based on responses of some of the river's resource management goals to the long-term flow record at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage from April 1, 1939 through December 31, 2021. An evaluation demonstrated that the same flow-based blocks were reasonable and appropriate for use in the Lower Little Manatee River.

Block 1 – Flows less than or equal to 29 cubic feet per second (cfs)
Block 2 – Flows greater than 29 cfs to less than or equal to 96 cfs
Block 3 – Flows greater than 96 cfs
3a – Flows greater than 96 cfs and less than or equal to 224 cfs (low floodplain)
3b – Flows greater than 224 cfs (high floodplain)

The criteria used for minimum flows development in the Little Manatee River addressed maintenance of 85 percent of the most sensitive criterion associated with the resource management goals through the use of flow-based blocks. In addition, a low-flow threshold was applied to Block 1 to ensure fish passage, habitat protection, and flow continuity associated with various environmental and human-use values. Finally, assessments were conducted to ensure all relevant environmental values that must be considered when establishing minimum flows would be protected by the minimum flows proposed for the Little Manatee River.

For both the Upper and Lower Little Manatee River, the recommended minimum flows for Block 1 provide protection for ecological resources and recreational use during critical low-flow periods through the application of a low-flow threshold. Proposed Upper Little Manatee River minimum flows for Block 2 are based on maintaining available instream habitat and are based on maintaining floodplain inundation for Block 3. The most sensitive criterion for the Lower Little Manatee River minimum flows development for Blocks 2 and 3 was the maintenance of favorable estuarine fish habitat, and the recommended minimum flows were established based on preserving 85 percent of the favorable estuarine fish habitat. The recommended minimum flows for the Upper and Lower Little Manatee River are based on average daily flows for the previous day at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage adjusted for upstream withdrawals, and are summarized in the tables that follow.

The recommended minimum flows for the Little Manatee River are protective of all relevant environmental values identified for consideration in the Water Resource Implementation Rule when establishing minimum flows. They are currently being met and are also expected to be met over the next 20 years. Therefore, development of a recovery or specific prevention strategy is not necessary.

An adaptive management approach will be used by the District to monitor and assess the status of minimum flows established for the Little Manatee River. Changes in the Little Manatee River watershed related to numerous factors, including climate change, could potentially affect flow characteristics, and additional information relevant to minimum flows development may become available. The District is committed to periodic re-evaluation and, if necessary, revision of minimum flows established for the Little Manatee River.

Upper Little Manatee River			
Flow-Based Block	**If Previous Day's Flow, Adjusted for Upstream Withdrawals, is:**	**Minimum Flow is:**	**Potential Allowable Flow Reduction is:**
1	≤29 cfs	Flow on the Previous Day	0 cfs
2	>29 cfs and ≤96 cfs	29 cfs or 88 Percent of Flow on the Previous Day, Whichever is Greater	12 Percent of Flow on the Previous Day
3a	>96 cfs and ≤224 cfs	85 cfs or 87 Percent of Flow on the Previous Day, Whichever is Greater	13 Percent of Flow on the Previous Day
3b	>224 cfs	90 Percent of Flow on the Previous Day	10 Percent of Flow on the Previous Day

Lower Little Manatee River			
Flow-Based Block	**If Previous Day's Flow, Adjusted for Upstream Withdrawals, is:**	**Minimum Flow is:**	**Potential Allowable Flow Reduction is:**
1	≤29 cfs	Flow on the Previous Day	0 cfs
2	>29 cfs and ≤96 cfs	29 cfs or 87 Percent of Flow on the Previous Day, Whichever is Greater	13 Percent of Flow on the Previous Day
3	>96 cfs	84 cfs or 68 Percent of Flow on the Previous Day, Whichever is Greater	32 Percent of Flow on the Previous Day

CHAPTER 1 - INTRODUCTION

This report describes the development of minimum flows for the Little Manatee River, which were formulated by the Southwest Florida Water Management District (District) using the best available information. In this introduction, we describe the history of minimum flows development for the Little Manatee River, as well as legal directives and approaches used by the District to develop minimum flows.

1.1 Minimum Flows Development History

The need for development of minimum flows for the Little Manatee River was identified in the District's initial minimum flows and levels priority list and schedule that was developed in response to relevant statutory directives enacted in the late 1990s. Since that time, the District has independently and cooperatively supported data collection and analysis efforts that could be used for minimum flows development.

In November 2011, the District published a draft report containing recommended minimum flows for the upper or freshwater portion of the Little Manatee River for consideration for peer review (Hood et al. 2011 in Appendix A). Analyses used to develop minimum flows for the Upper Little Manatee River focused on the river from its headwaters near Fort Lonesome in southeastern Hillsborough County to the US Highway 301 bridge, where the US Geological Survey (USGS) Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage is located (Figure 1-1). The draft report was reviewed by a panel of independent scientists from late 2011 through early 2012. The panel recommended that the District's technical evaluation of the proposed minimum flows for the Upper Little Manatee River could be improved through the use of additional scientific methods, analyses, data integrations, and interpretations (Powell et al. 2012 in Appendix B); specific comments by the peer review panel and how they were addressed are mentioned in the appropriate chapters and sections throughout this report.

The District contracted with Janicki Environmental, Inc. (JEI), through Greenman-Pedersen, Inc. (GPI), from 2016 through 2018 to conduct an initial re-evaluation of the draft recommended minimum flows for the Upper Little Manatee River to address the peer review panel comments and complete additional analyses (JEI 2018a in Appendix C). From late 2019 through early 2021, the District conducted a second re-evaluation of the recommended minimum flows for the Upper Little Manatee River. This re-evaluation included additional data collection and analyses, as well as contracting with JEI, through Jacobs Engineering Group, Inc. (Jacobs), to update the analyses conducted from 2016 through 2018 and conduct additional evaluations (Jacobs and JEI 2020, 2021a, 2021b, 2021c, 2021d). With the exception of Jacob and JEI (2020), which is included in Appendix D, no information from the documents referenced above was used to develop the upper river minimum flows. Note that the recommended minimum flows for the Upper Little Manatee River are based on the methods and results included in this report since the best information that is currently available was used to develop the minimum flows.

The analyses supporting minimum flows development for the estuarine portion of the Little Manatee River focused on the portion of the river downstream of the US Highway 301 bridge to Tampa Bay (Figure 1-1). Fluctuating diurnal and semidiurnal tides influence the District efforts to develop minimum flows for the Lower Little Manatee River have been ongoing for a number of years. From 2016 through 2018, the District contracted with JEI, through GPI, to compile existing information, conduct additional analyses, and develop draft minimum flows for the Lower Little Manatee River (JEI 2018b in Appendix E). The District contracted with JEI, through Jacobs, to conduct a re-evaluation of the draft recommended minimum flows for the Lower Little Manatee River from late 2019 through early 2021, which included updating the analyses that were conducted from 2016 through 2018 (Jacobs and JEI 2020, 2021a, 2021b, 2021c, 2021d). Similar to the upper river, with the exception of Jacob and JEI (2020), which is included in Appendix D, no information from the documents referenced above was used to develop the lower river minimum flows. As with the upper river, the recommended minimum flows for the Lower Little Manatee River are based on the methods and results included in this report using the best information that is currently available.

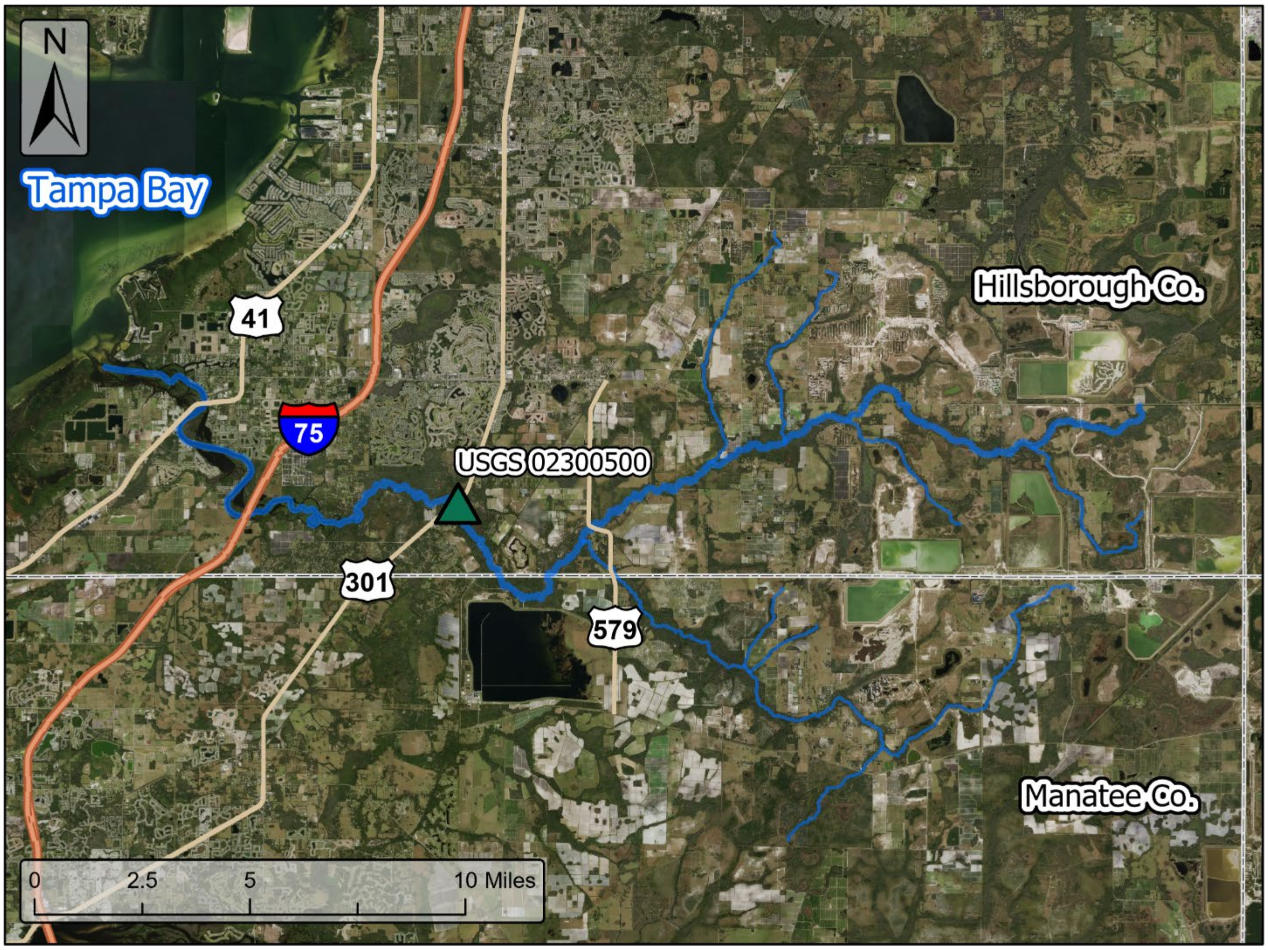

Figure 1-1. Location of the Little Manatee River. Note that USGS 02300500 is the US Geological Survey Little Manatee River at US 301 near Wimauma, FL gage.

The District published a draft report containing the recommended minimum flows for both the Upper and Lower Little Manatee River in September 2021. The report was reviewed by a panel of independent scientists in October and November 2021. Because their comments were extensive (Appendix F), the peer review period was extended to allow time for the District to conduct the additional work required to respond to the comments. This work included contracting with JEI, both solely and through GPI, for some of the tasks. The District's responses to the comments of the peer review panel can be found in Appendix G. This report includes the work conducted to address the peer review panel's comments and to develop minimum flows for the Upper and Lower Little

Manatee River. The peer review panel's final report is included in Appendix H and indicates that all of their comments have been addressed and they are supportive of the work included in this report.

Comments received from stakeholders and the public from October 2021 to date are included in Appendix I. These comments were considered when making improvements and revisions to the methods used to develop the proposed minimum flows described in this report.

A summary of the public workshop that was held in September 2023 is included in Appendix J. The comments received during the workshop are also provided in the appendix and were supportive of the work included in this report.

1.2 Legal Directives and Use of Minimum Flows

This section describes the legal directives and approaches the District uses to develop minimum flows for flowing systems, such as the Little Manatee River.

1.2.1 Relevant Statutes and Rules

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

1. Section 373.042 of the Florida Water Resources Act of 1972 (Chapter 373, F.S.) directs the Florida Department of Environmental Protection (DEP) or the District to establish minimum flows for all flowing surface watercourses in the area. This section states that "the minimum flow (and minimum water level) shall be calculated by the department and the governing board using the best information available." This statute also requires development of a priority list and schedule for the establishment of minimum flows (and minimum water levels), which is annually updated and approved by the District Governing Board and DEP. Section 373.042 also allows for the establishment of an independent scientific peer review panel and use of a final report prepared by the peer review panel when establishing minimum flows (and minimum water levels).
2. Section 373.042(1), F.S., allows for considerations and exclusions concerning minimum flows (and levels) establishment, including changes and structural alterations to watersheds, surface waters, and aquifers and their effects. This section also determines that recovery and prevention strategies must be put in place if the system is not currently meeting or is projected to not meet the applicable minimum flows within the next 20 years. In addition, the periodic, and as-needed, revision of established minimum flows is required.
3. Rule 62-40.473 of the Florida Water Resource Implementation Rule [Chapter 62-40, Florida Administrative Code (F.A.C.)] provides goals, objectives, and guidance regarding the prioritization, establishment, and peer review of minimum flows; their use in other regulatory

activities; and requirements for recovery or prevention strategies. This rule identifies the ten environmental values described in Section 1.2.2 below that are to be considered when establishing minimum flows. In recognition of the fact that flows naturally vary, this rule also states that minimum flows should be expressed as multiple flows defining a minimum hydrological regime to the extent practical and necessary.

4. Chapter 40D-8, F.A.C., the District's Water Levels and Rates of Flow Rule, describes the minimum flows and levels established within the District.
5. Chapter 40D-80, F.A.C., the District's Recovery and Prevention Strategies for Minimum Flows and Levels Rule, sets forth the regulatory portions of the recovery or prevention strategies to achieve or protect, as applicable, the minimum flows and levels established by the District.
6. Rules 62-41.300 through 62-41.305 within the DEP's Chapter 62-41, F.A.C., Regulation of the Consumptive Use of Water Rule, include regional requirements associated with establishment and regulatory use of minimum flows (and minimum levels) and other regulatory activities within the Central Florida Water Initiative (CFWI) Planning Area. Defined in Section 373.0465(2)(a), F.S., the CFWI Planning Area is a region within Central Florida where the boundaries of the St. Johns River Water Management District, the South Florida Water Management District, and the Southwest Florida Water Management District abut, and enhanced coordination efforts have been deemed necessary for effective water resource management.

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

Additional information pertaining to the establishment and implementation of minimum flows and other related issues is available from the District's Minimum Flows and Levels Program web page at https://www.swfwmd.state.fl.us/projects/mfls.

1.2.2 Environmental Values

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

- 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;
- Sediment loads;
- Water quality; and
- Navigation."

The ways in which these environmental values are protected by the methods and results used to develop the minimum flows for the Little Manatee River are provided in Section 6.7.

1.3 Development of Minimum Flows

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

- Alterations to hydrology will have consequences for the environmental values listed in Rule 62-40.473, F.A.C., and Section 1.2.2 of this report.
- Relationships between some of the altered environmental values can be quantified and used to develop significant harm thresholds or criteria that are useful for establishing minimum flows and minimum water levels.
- Alternative hydrologic regimes may exist that differ from non-withdrawal impacted conditions but are sufficient to protect water resources and the ecology of these resources from significant harm.

Support for these assumptions is provided by a large body of published scientific work addressing relationships between hydrology, ecology, and human-use values associated with water resources (Poff et al. 1997, Postel and Richter 2003, Wantzen et al. 2008, Poff and Zimmerman 2010). This information has been used by the District and other water management districts in Florida to identify significant harm thresholds or criteria supporting development of minimum flows and levels for over 400 water bodies (DEP 2021a), as summarized in numerous publications associated with these efforts (SFWMD 2000, 2006, Flannery et al. 2002, SRWMD 2004, 2005, Neubauer et al. 2008, Mace 2009).

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

1.3.1 Flow Definitions and Concepts

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

- Flow or streamflow refers to discharge, which is the volume of water that flows past a point for some unit of time. For minimum flows purposes, flow is typically expressed in cubic feet per second (cfs).
- Long term is defined in Rule 40D-8.021, F.A.C., as an evaluation period for establishing minimum flows that spans the range of hydrologic conditions which can be expected to occur based upon historical records.
- Reported flows are directly measured or estimated by a relationship developed using measured flows and water depth or velocity. Examples include measured and estimated flows reported by the US Geological Survey (USGS) and those included in the District's databases. Most reported flows are actually estimated using velocity and water depth measurements or regressions (Index/Velocity rating curves) or other methods developed from field measurements. Reported flows are alternatively referred to as *observed* or *gaged* flows.
- Modeled flows are flows that are derived using a variety of modeling approaches. Examples include flows predicted using numerical groundwater flow models, flows predicted with statistical models derived from either observed or other modeled hydrologic data, and impacted flows adjusted for withdrawal-related flow increases or decreases.
- Impacted flows are flows that include withdrawal-related impacts. Impacted flows can be *reported flows*, and they can also be *modeled flows*.
- Baseline flows are flows that have occurred or are expected to occur in the absence of withdrawal impacts. Baseline flows may be *reported flows* if the flow records are from a period prior to any withdrawal impacts. More typically, baseline flows are *modeled flows*. Baseline flows are alternatively referred to as *natural*, *adjusted, unimpacted*, *unimpaired*, or *historic* flows.
- Minimum flow is defined by the Florida Water Resources Act of 1972 as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area."
- A flow regime is a hydrologic regime characterized by the quantity, timing, and variation of flows in a river. Rule 62-40.473, F.A.C., dictates that "minimum flows and levels should be expressed as multiple flows or levels defining a minimum hydrologic regime, to the extent practical and necessary, to establish the limit beyond which further withdrawals would be significantly harmful to the water resources or the ecology of the area as provided in Section 373.042(1), F.S."

1.3.2 Baseline Flow Conditions

The District's use of significant harm criteria for minimum flows development is predicated upon identification of a baseline flow record or records that characterize environmental conditions expected in the absence of withdrawals. For river segments or entire rivers where flows are currently or historically have not been affected by water withdrawals, reported flows for the period without withdrawal effects or for the entire period of record can be used as baseline flows. However, reported flows are typically impacted flows that incorporate withdrawal effects, or are available for a limited period, and baseline flows must be estimated using hydrological and/or groundwater models. Development of the baseline flow record for the Little Manatee River is discussed in Section 5.2.

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

1.3.3 Building-Block Approach

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

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

For some baseflow- or groundwater-dominated systems, such as short, coastal rivers or spring runs, where discharge from spring vents accounts for much of the flow, use of a seasonal, building-block approach may not be necessary. In addition, association of blocks with specific flow ranges, which typically, but not always, correspond with seasonal periods, may be appropriate for establishing minimum flows for some systems.

In the past, the building-block approach for characterizing flow regimes was based on fixed dates. However, the fixed-date approach for block definition is not currently considered appropriate for representing seasonal flow regimes for the system in years when annual flows remain low or high relative to the historical flow regime. To address this issue, the District has recently started using flow-based blocks that correspond with typical, seasonal periods of low, medium, and high flows to develop minimum flows. For example, this approach was successfully used for the recent re-evaluation of minimum flows for the Lower Peace River (Ghile et al. 2021) and was strongly supported by findings of the independent peer review panel that contributed to that effort (Bedinger et al. 2020). As described in Section 5.1 of this report, flow-based blocks were used for the development of proposed minimum flows for the Little Manatee River.

1.3.4 Low-Flow Threshold

Criteria used to establish low-flow thresholds in freshwater rivers include fish passage depths or potential changes in wetted perimeter (i.e., the width of the stream bottom and banks in contact with water for a stream channel cross section). In estuarine river segments, low-flow thresholds have been established to address various water quality concerns, including those associated with salinities (Ghile et al. 2021) and concentrations of chlorophyll and dissolved oxygen (Flannery et al. 2008). A low-flow threshold associated with maintaining adequate freshwater flows to protect numerous environmental values is proposed for both the Upper and Lower Little Manatee River and was applied to the proposed minimum flows for Block 1.

1.3.5 Significant Harm and 15 Percent Change Criteria

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

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

For criteria selection and use, the District uses natural breakpoints, inflections, or thresholds, when available. For example, in perennially flowing freshwater systems, a water depth of 0.6 ft (0.18 m) is used to establish a minimum low-flow threshold for promoting fish passage and flow continuity. Another threshold-based criterion used for flowing freshwater systems is the lowest wetted perimeter inflection point (LWPIP), where inflections in curves relating flow and wetted perimeter are used to determine threshold flows for significant harm.

When natural breakpoints, inflections, or thresholds are not available, the District has used a 15 percent habitat- or resource-reduction standard as a criterion for significant harm. The basis for the management decision to equate a 15 percent change to significant harm lies, in part, with a recommendation put forth by the independent peer review panel that considered the District's proposed minimum flows for the Upper Peace River (SWFWMD 2002). In their report, the panel noted that "in general, instream flow analysts consider a loss of more than 15 percent habitat, as compared to undisturbed or current conditions, to be a significant impact on that population or assemblage" (Gore et al. 2002). The panel's assertion was based on consideration of environmental flow studies employing the Physical Habitat Simulation (PHABSIM) system for analyzing flow, water depth, and substrate preferences that define instream habitat availability for aquatic species. Since then, more than 20 peer review panels have evaluated the District's use of the 15 percent standard for significant harm. Although many have questioned its use, none have identified a more appropriate industry standard or best practice for environmental flows management.

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

Gleeson and Richter (2017) suggested that "high levels of ecological protection will be provided if groundwater pumping decreases monthly natural baseflow by less than 10 percent through time."

Presumptive flow-based criteria, such as these, assume that resources are protected when more detailed relationships between flow and resources of interest are not available. Habitat- or resource-based presumptions of harm are based on data and analyses linking incremental reductions in flow to reductions in resources or habitats. As such, the 15 percent habitat- or resource-based standard makes more use of the best information available than a presumptive, flow-based criterion would. In the absence of natural breakpoints, inflections, or thresholds, the 15 percent presumptive habitat- or resource-based standard for significant harm represents the District's best use of the best available information.

1.3.6 Percent-of-Flow Method

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

The District was among the first to use the percent-of-flow method, as early as the late 1980s/early 1990s for the Lower Peace River (Flannery et al. 2002) and has successfully used a percent-of-flow method, often in combination with a low-flow threshold, to establish minimum flows for numerous flowing systems. These systems include the Upper and Lower Alafia River, Upper and Lower Anclote River, Blind Spring, Upper Braden River, Chassahowitzka River/Chassahowitzka Spring Group, Crystal River/Kings Bay Spring Group, Dona Bay/Shakett Creek System, Gum Slough Spring Run, Homosassa River/Homosassa Spring Group, Upper Hillsborough River, Upper and Lower Myakka River, Middle and Lower Peace River, Upper and Lower Pithlachascotee River, Rainbow River/Rainbow Spring Group, Lower Shell Creek, and the Weeki Wachee River/Weeki Wachee Spring Group.

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

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

1.3.7 Adaptive Management

Adaptive management is a standard approach for reducing the inherent uncertainty associated with natural resource management (Williams and Brown 2014) and is recommended by the US Department of the Interior for decision-making in the face of uncertainty about management impacts (Williams et al. 2009). Adaptive management is a systematic, iterative approach to meeting management objectives in the face of uncertainty through continued monitoring and refinement of management actions based on consideration of alternatives and stakeholder input (Herrick et al. 2019a).

An adaptive management approach will be used by the District to implement minimum flows established for the Little Manatee River. This approach will require ongoing monitoring, assessment, and as necessary, periodic re-evaluation of the minimum flows.

1.4 Vertical Datums

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

1.5 Units of Measurement

In this report, for various reasons, both US Customary Units, developed from English units, and the International System of Units (SI), the modern form of the metric system, are used. Minimum flows that are adopted by the District into rule are codified using US Customary Units, and those units are also used in various modeling methodologies and software. Some of the scientific studies and data collection efforts which support the recommended minimum flows for the Little Manatee River reported their results in SI units. Where appropriate, values in both units or conversion factors are provided.

CHAPTER 2 - PHYSICAL AND HYDROLOGIC SETTING AND DESCRIPTION OF THE LITTLE MANATEE RIVER SYSTEM

This chapter provides a description of the Little Manatee River, its watershed, and the surrounding area. It includes information on land use, geology, hydrology, rainfall, water use, and river flow. As part of the development of minimum flows, the District evaluates hydrologic changes in the vicinity of the system and determines the impact on flow from existing withdrawals.

2.1 Description of Little Manatee River Watershed

The Little Manatee River is one of the most pristine blackwater rivers in Southwest Florida and is the only tidal river in the Tampa Bay watershed designated as an Outstanding Florida Water (OFW) by the DEP due largely to its relatively natural state with mostly unarmored shorelines, a sinuous river channel, and highly braided areas with ample emergent wetland vegetation (Parsons, Inc. 2009). The Little Manatee River likely best represents the natural ecologic interactions of a river and its watershed with Tampa Bay, when considering all of the bay's various tributaries (Flannery 1989). Since it is one of the most pristine blackwater rivers in the state, federal legislation was introduced in 2020 to designate the Little Manatee River as a National Scenic River and add it to the National Park Service's Wild and Scenic River System; however, the bill was not voted on (Tampa Bay Times, October 18, 2020).

The watershed of the Little Manatee River is 224 square miles (579 square km) (SWFWMD 2021a); it extends from eastern Tampa Bay to the southeastern corner of Hillsborough County and includes the northern portion of Manatee County (Figure 2-1). Discharge for the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage averaged 168 cfs or 110 million gallons per day (mgd) from October 1939 through December 2021. The watershed includes the communities of Parrish, Ruskin, Sun City Center, and Wimauma.

The river flows west about 40 miles (64 km) from its headwaters in a swampy area east of Fort Lonesome in southeastern Hillsborough County before emptying into Tampa Bay near Ruskin (Figure 2-2). At the headwaters near Fort Lonesome, the river channel flows down a relatively steep gradient that eventually flattens out in the middle and lower reaches. The Little Manatee River has numerous named tributaries; the South Fork, located almost entirely in Northeast Manatee County, is the largest, followed by the North Fork. The main channel of the Little Manatee River begins at the confluence of the North and South Fork tributaries about 22 miles (35 km) upstream of the river mouth (PBS&J 2008 in Appendix K). The North Fork, however, is often referred to and considered an extension of the Little Manatee River, while the South Fork is considered a separate tributary. Additional tributaries include Dug, Cypress, and Carlton Branch Creeks (Figure 2-3).

Natural lakes within the Little Manatee River watershed include Lake Wimauma and Carlton Lake. Lake Parrish is a man-made reservoir covering 4,000 acres (1,600 hectares), constructed just downstream from where the South Fork joins the Little Manatee River (Figure 2-3). Lake Parrish is used primarily for cooling water for a large Florida Power & Light (FP&L) Company power plant. The watershed also contains numerous intermittent, shallow ponds.

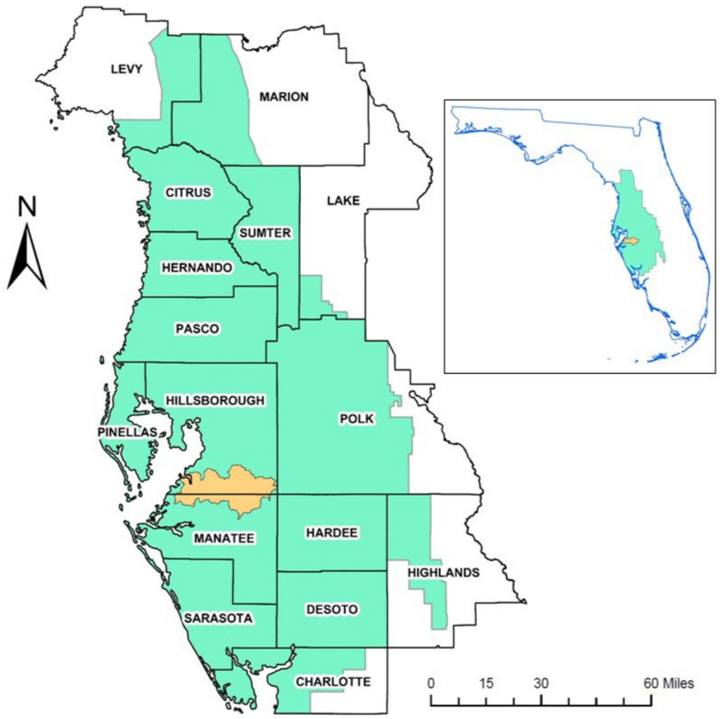

Figure 2-1. Location of the Little Manatee River watershed (orange) within the Southwest Florida Water Management District (green).

Figure 2-2. Location of the Little Manatee River within the Tampa Bay Area.

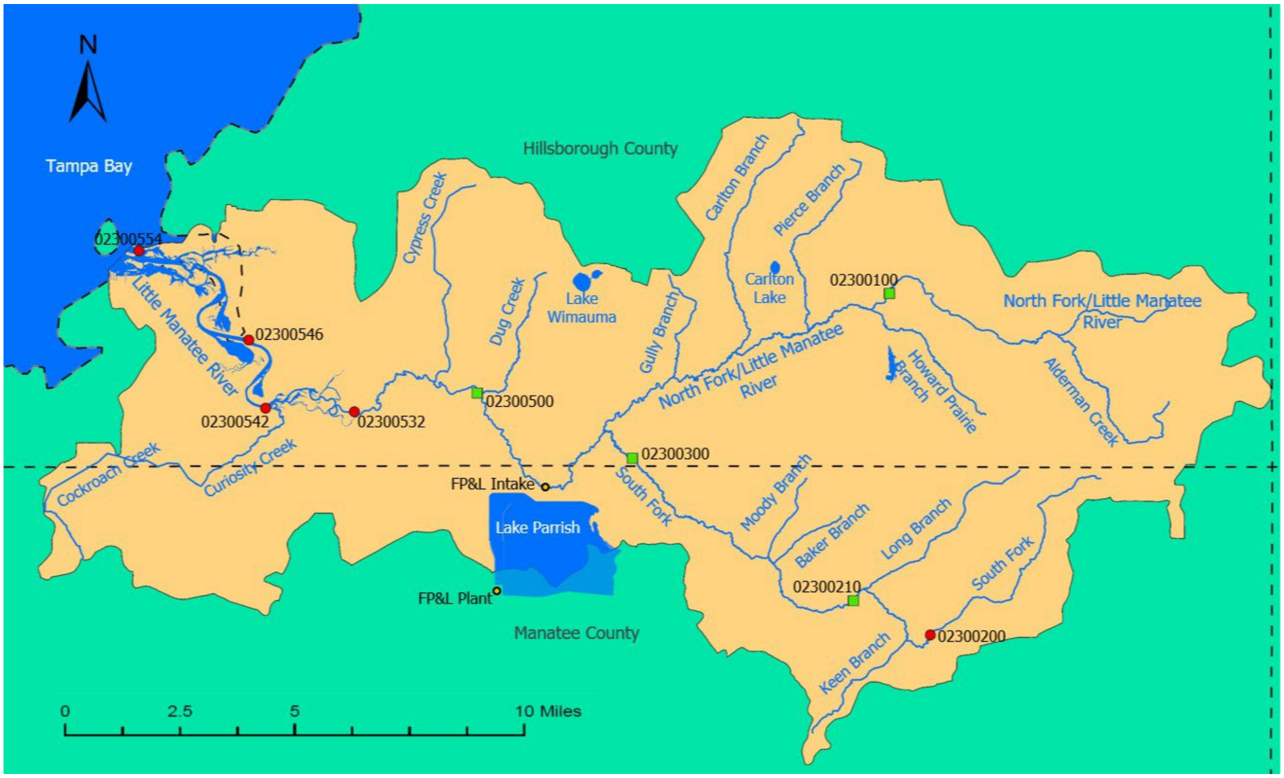

Figure 2-3. The location of the Little River Manatee River, selected tributaries, and lakes within its watershed. Active (green squares) and inactive (red circles) US Geological Survey gages are shown, including Little Manatee River at Shell Point (No. 02300554), Little Manatee River at Ruskin, FL (No. 02300546), Little Manatee River at I-75 near Ruskin, FL (No. 02300542), Little Manatee River near Ruskin, FL (No. 02300532), Little Manatee River at US 301 near Wimauma, FL (No. 02300500), South Fork Little Manatee River near Wimauma, FL (No. 02300300), South Fork Little Manatee River near Parrish, FL (No. 02300210), Little Manatee River near Ft. Lonesome, FL (No. 02300100), and South Fork Little Manatee River near Duette, FL (No. 02300200). County boundaries are delineated by dashed black lines. Florida Power and Light (FP&L) plant and intake locations are indicated with yellow circles.

Analyses used to develop minimum flows for the upper (freshwater) portion of the Little Manatee River focused on the river from its headwaters near Fort Lonesome to the US Highway 301 bridge crossing, where the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage is located (Figure 1-1). The analyses supporting minimum flows development for the estuarine portion of the Little Manatee River focused on the river downstream from the gage to the mouth of the river at Tampa Bay (Figure 1-1). A tidal freshwater zone extends about 3-4 miles (5-7 km) below the US Highway 301 bridge crossing (Peebles and Flannery 1992). Fluctuating diurnal and semidiurnal tides influence the river to a point about 0.6 mile (1 km) upstream of the US 301 bridge crossing (Fernandez 1985), but tidal water level fluctuations at the bridge are small. The river channel ranges in width from approximately 3,900 ft (1,200 m) at the mouth of the river to 390 ft (120 m) at US Highway 41 and narrows to 40 to 150 ft (12 to 46 m) at the US Highway 301 bridge.

Throughout the tidal reach of the Little Manatee River, a mixture of diurnal and semidiurnal tidal signals can be observed. At a tidal benchmark near the US Highway 41 bridge crossing, tidal harmonic constituents are mainly M2 (lunar semidiurnal, period of 12.42 hours), S2 (solar semidiurnal, period of 12 hours), K1 (lunar diurnal, period of 23.93 hours), and O1 (lunar diurnal, period of 25.82 hours), with their amplitudes being estimated by the National Oceanic and

Atmospheric Administration to be 0.41, 0.15, 0.5, and 0.44 ft (0.12, 0.05, 0.15, and 0.13 m), respectively. Like other estuaries within the District, tides in the Little Manatee River have a range that is much smaller than 6.56 ft (2 m) and can be classified as microtidal. For example, at the US Highway 41 bridge, tides have a mean range of 1.54 ft (0.47 m) and a great diurnal range of only 1.99 ft (0.61 m) (https://tidesandcurrents.noaa.gov/stationhome.html?id=8726436#info).

Compared to other rivers in the region, flow within the Little Manatee River watershed has a relatively high mean runoff rate normalized by contributing area. The mean annual streamflow flux increases in the downstream direction. Daily flow hydrographs exhibit spiky behavior, indicating relatively low surface storage available to attenuate surface runoff (Geurink and Basso 2013). The depth to water table is moderate (3-6 ft or 1-2 m) except along streams, where it is shallow. The drainage system is connected to a thin surficial sand aquifer that is well-confined at its base by a thick Hawthorn Group clay, which hydraulically isolates it from the underlying Upper Floridan aquifer (UFA).

Approximately 99 percent of the soils within the Little Manatee River watershed have been classified in the US Department of Agriculture Soil Survey Geographic Database according to their estimates of runoff potential (Figure 2-4). The majority (53 percent) of soils are Type A/D, indicating that drained areas have a high infiltration with low runoff potential and undrained areas have a very slow infiltration rate with high runoff potential (SWFWMD 2018). Type A soils (high infiltration rate/low runoff potential) account for 19 percent of the soils and are more prevalent in the eastern portion of the watershed. Moderate (Type B/D) and slow (Type C/D) infiltration soils each comprise 12 percent of the watershed. The 4 percent of the watershed described as “Null” hydrologic groups are summarized as water (81 percent), urban land (19 percent), and gypsum land (<1 percent). Mining and reclamation activities may affect runoff potential of natural soils in the eastern portion of the watershed (Figure 2-4).

The Little Manatee River flows through several protected areas. It flows for 4.5 miles (7.2 km) through 11 unique natural communities within the approximately 2,500-acre (1,012-hectare) Little Manatee River State Park, which is located along the river west of US Highway 301. From US Highway 301 to Tampa Bay, the river flows through Cockroach Bay Aquatic Preserve (DEP 2017). The emphasis on the conservation of important ecosystem habitat led to the establishment of the preserve in 1976, and it protects 4,800 acres (1,943 hectares) of public resources. The southern boundary of the aquatic preserve is along the Hillsborough/Manatee County line, while the northern boundary extends eastward into the mouth of the Little Manatee River just south of Shell Point. The location of Cockroach Bay Aquatic Preserve in Florida’s densely developed Tampa Bay watershed makes it especially important from both a natural resource and a human use perspective (DEP 2017). Large areas of seagrass and mangrove within the aquatic preserve provide habitat, feeding grounds, and nurseries for listed species and many commercial and recreational fish species. The seagrasses and mangroves also help remove nutrients from bay water in the absence of similar resources lost in the more urban areas of the bay.

As compared with other areas draining to Tampa Bay, the Little Manatee River watershed is largely undeveloped, particularly the eastern portion. In the western quarter, near the coast, urban development is prevalent in a north-south band and in areas near the major north-south transportation corridors (i.e., US Highway 41, Interstate 75, and US Highway 301). Small urban areas, such as Sun City, Ruskin, Palmetto, Parrish, and Wimauma, are supported by local agriculture. In the eastern half of the watershed, the phosphate industry owns large parcels that either have been mined, are being mined, or are proposed to be mined in the future (Figure 2-4). Areas of phosphate mining include the headwaters region of the Little Manatee River along the North Fork and the vicinity of the South Fork in Manatee County. The remainder of the watershed contains large expanses of undeveloped swamps and uplands. These lands are the most prevalent along the riverine corridors, including the North and South Forks up to the headwaters.

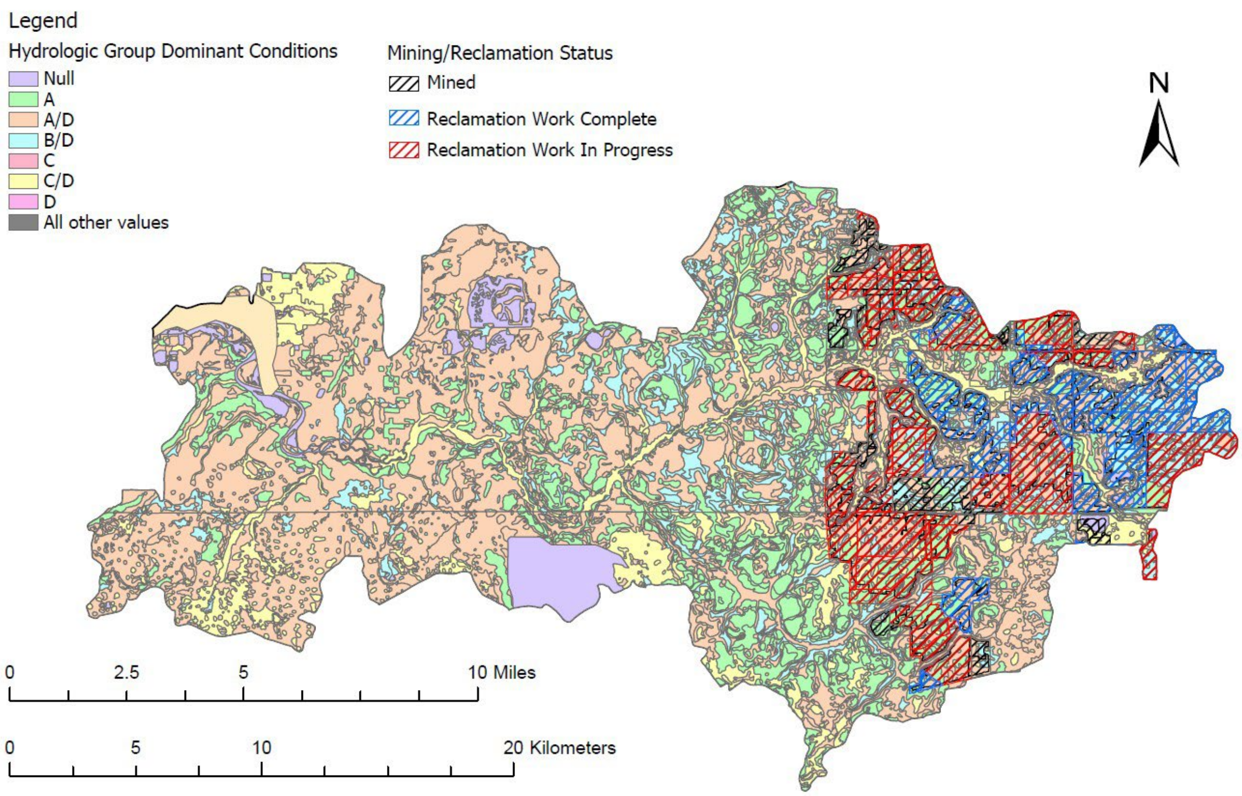

Figure 2-4. Hydrologic group dominant conditions for soils in the Little Manatee River watershed (SWFWMD 2018), phosphate mined units (DEP 2021b), and reclaimed mined land (DEP 2021c). Soil groups are defined as follows: A = high infiltration rate/low runoff, B = moderate infiltration rate, C = slow infiltration rate, D = very slow infiltration rate/high runoff potential. If a soil is assigned to a dual hydrologic group, the first letter is for drained area and the second for undrained. Null soils include water, urban land, and gypsum land.

2.2 Current and Past Land Use

This section describes land use within the Little Manatee River watershed, including changes that have occurred in the watershed from 1974 through 2020 using the Florida Land Use, Cover and Forms Classification System (FLUCCS) (Anderson et al. 1976, SWFWMD 2003a, 2003b, 2007, 2011, 2019, 2021a). The FLUCCS was created to provide a uniform land classification system that would satisfy a wide variety of users: from the national planning scale, down to use by local and regional agencies (FDOT 1999). Land-use/cover data is derived from local aerial imagery through various methods of post-processing. The FLUCCS is designed with land-use/cover information existing in four hierarchical levels of increasing specificity. Level 1 is the most general and includes eight land-use descriptions (Urban & Built-Up, Agriculture, Rangeland, Upland Forest, Water, Wetlands, Barren, and Transportation/Communication/Utilities), while Level 4 includes over 100 specific land uses and habitat types (e.g., Mixed Wetland Hardwoods or Residential – Low Density)

(FDOT 1999). For evaluation of the Little Manatee River watershed, the eight Level 1 classifications were used to compare land-use changes at the regional (watershed) scale over time. When appropriate, Level 2, 3, and 4 land-use descriptors were used to further investigate meaningful trends over time.

The 1974 information represents land use and cover generated with the USGS's early framework for a national land-use/cover coding system, which utilized eight descriptors of land use (Anderson et al. 1976, Figure 2-5). This early USGS framework contributed to the creation of the FLUCCS, and the original eight classifications were maintained as the FLUCCS's Level 1 land-use/cover descriptors. The 1990, 1999, 2004, 2011, 2017, and 2020 maps represent FLUCCS information created by the District (Figures 2-6 through 2-11). The FLUCCS information since 1990 is more detailed than the 1974 USGS information due to finer resolution of the mapping units and the application of the hierarchal system of increasing specificity. Therefore, some of the changes in land-use/cover between the USGS- and FLUCCS-derived maps are likely the result of differences in methodologies rather than actual land-use changes. For example, the apparent two-fold increase in wetlands from 1974 to 1990 is a relic of the coding and mapping procedures used; wetlands did not increase two-fold during this time. Nonetheless, including the 1974 USGS information is useful.

Per the most current (2020) FLUCCS information (Figure 2-11), 35 percent of the Little Manatee River watershed (50,480 acres or 20,429 hectares) is designated Level 1 Urban and Built-Up land use, which includes Residential (low-/med-/high-density), Commercial & Services, Industrial, Extractive Mines/Reclaimed Lands, Institutions, Recreational Areas, and Undeveloped Open Land. The Level 1 Urban and Built-Up lands are concentrated primarily to the west and eastern regions of the watershed. Included in the Level 1 Urban and Built-Up category is the Level 3 Extractive category. To allow a more meaningful description of land uses within the watershed, Level 3 Extractive lands are presented independently of the Level 1 Non-Extractive Urban and Built-Up category (Figures 2-5 through 2-11). Of all the Level 1 Urban and Built-Up lands within the watershed, 43 percent are Non-Extractive (21,463 acres or 8,686 hectares), which includes all uses under the Level 1 Urban and Built-Up category except Level 3 Extractive (Figure 2-11). Fifty-seven percent of the Level 1 Urban and Built-Up lands within the watershed have Extractive land uses (29,017 acres or 11,743 hectares), which are almost entirely related to phosphate mining operations. Level 1 Non-Extractive Urban and Built-Up lands are concentrated in the western region of the watershed, where Ruskin and Sun City Center exist as population hotspots of residential and commercial service land uses.

Thirty-one percent of the watershed (44,403 acres or 17,969 hectares) is designated as Level 1 Agriculture land use, which includes Crop/Pastureland, Nurseries, Farms, and Vineyards (Figure 2-11). The agricultural lands are widespread through the central area, as well as in the southwestern extent of the watershed. Fourteen percent of the watershed (20,469 acres or 8,284 hectares) is designated Level 1 Wetlands, which bound much of the river mainstem and its many tributaries. Seven percent is Level 1 Upland Forests (10,468 acres or 4,236 hectares), which primarily bounds the river's wetlands in more undisturbed areas. Four percent is Level 1 Water (6,034 acres or 2,442 hectares), and 5 percent is Level 1 Rangeland (7,824 acres or 3,166 hectares), which includes important Scrub- and Prairie-like habitats that are predominantly housed in a network of State Parks, preserves, and other managed wildlife areas.

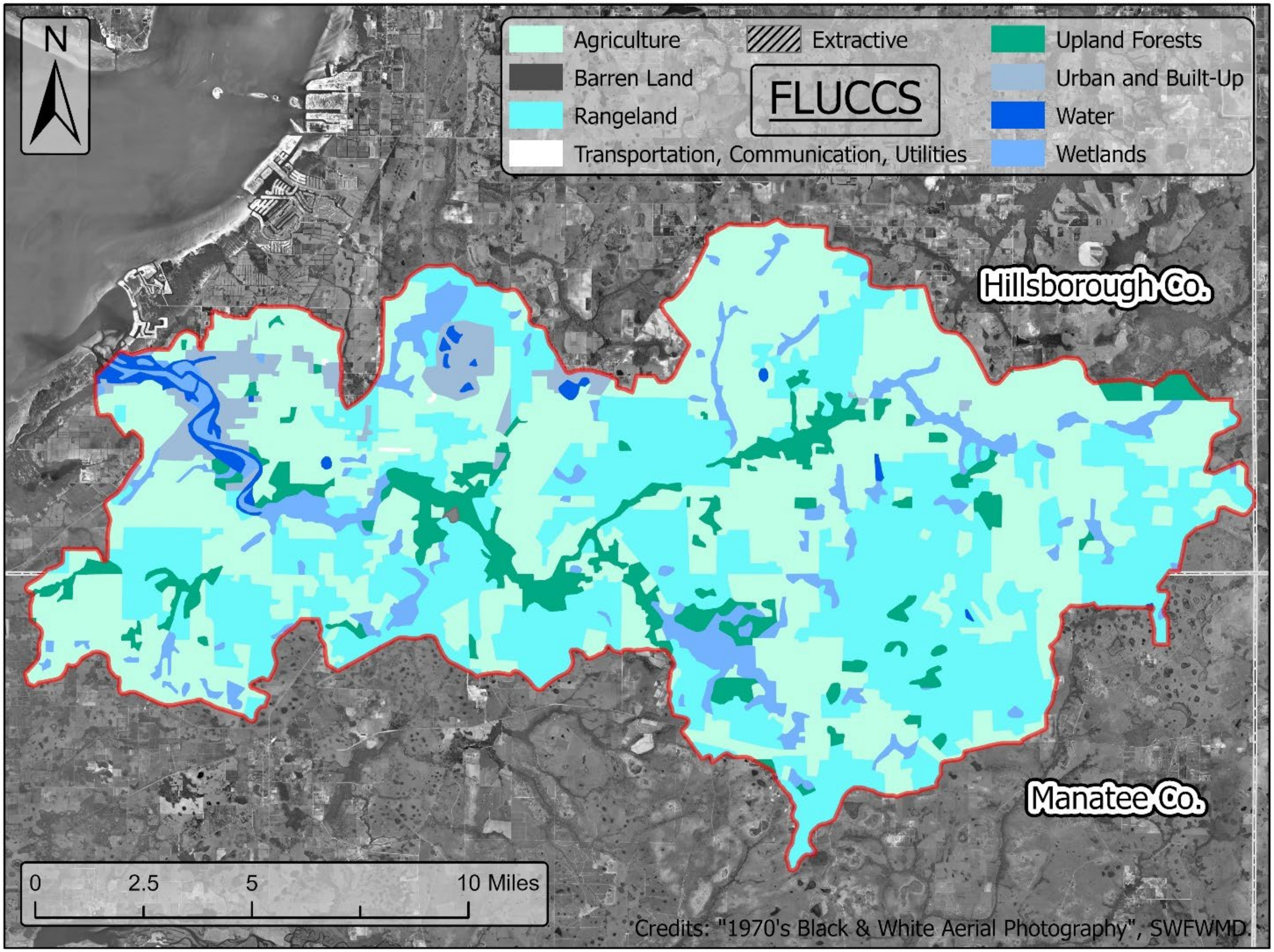

Figure 2-5. The 1974 Florida Land Use, Cover and Forms Classification System of the Little Manatee River watershed (Anderson et al. 1976).

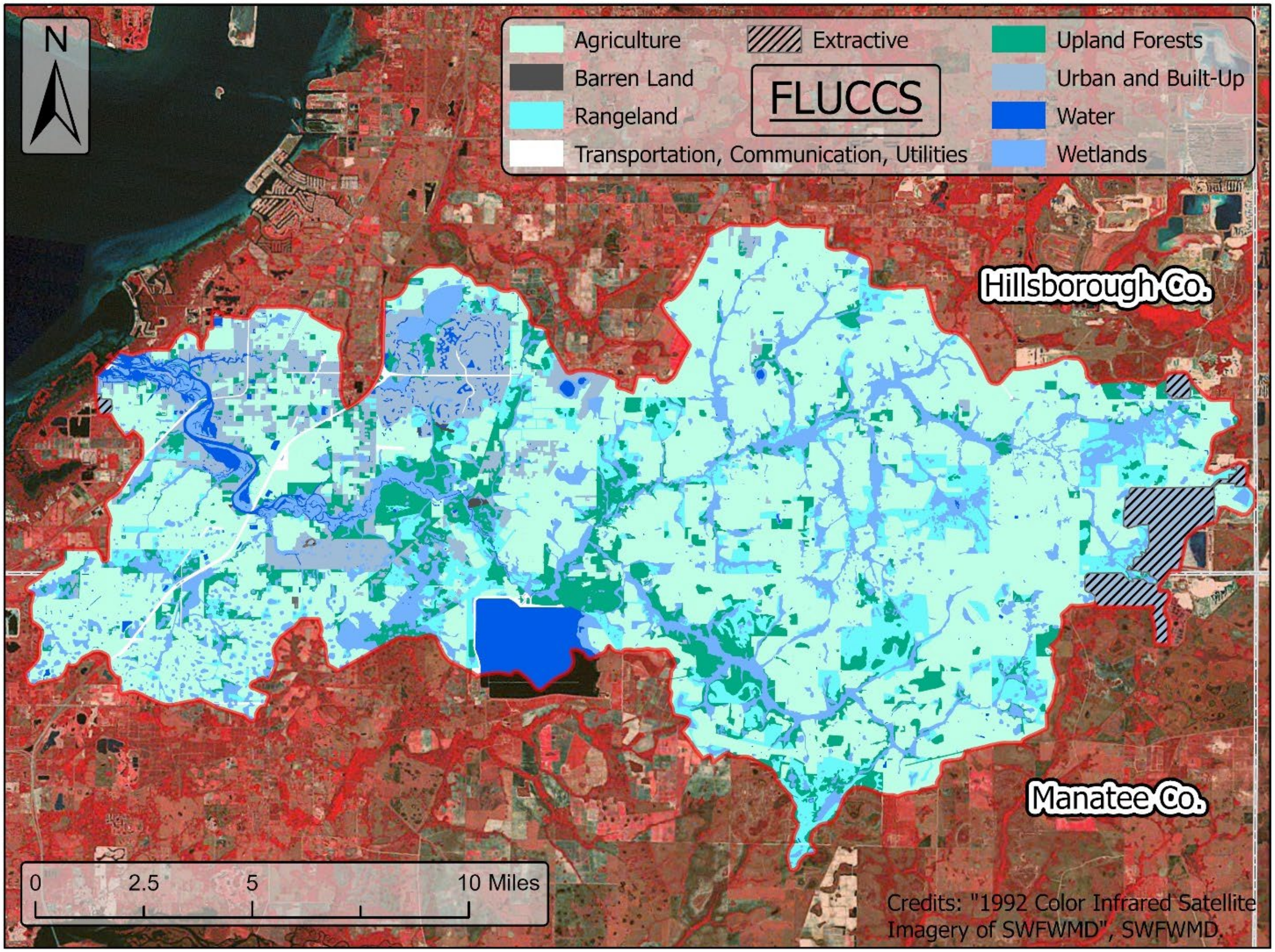

Figure 2-6. The 1990 Florida Land Use, Cover and Forms Classification System (Level I, with the exception of Level 3 Extractive) of the Little Manatee River watershed (SWFWMD 2003a).

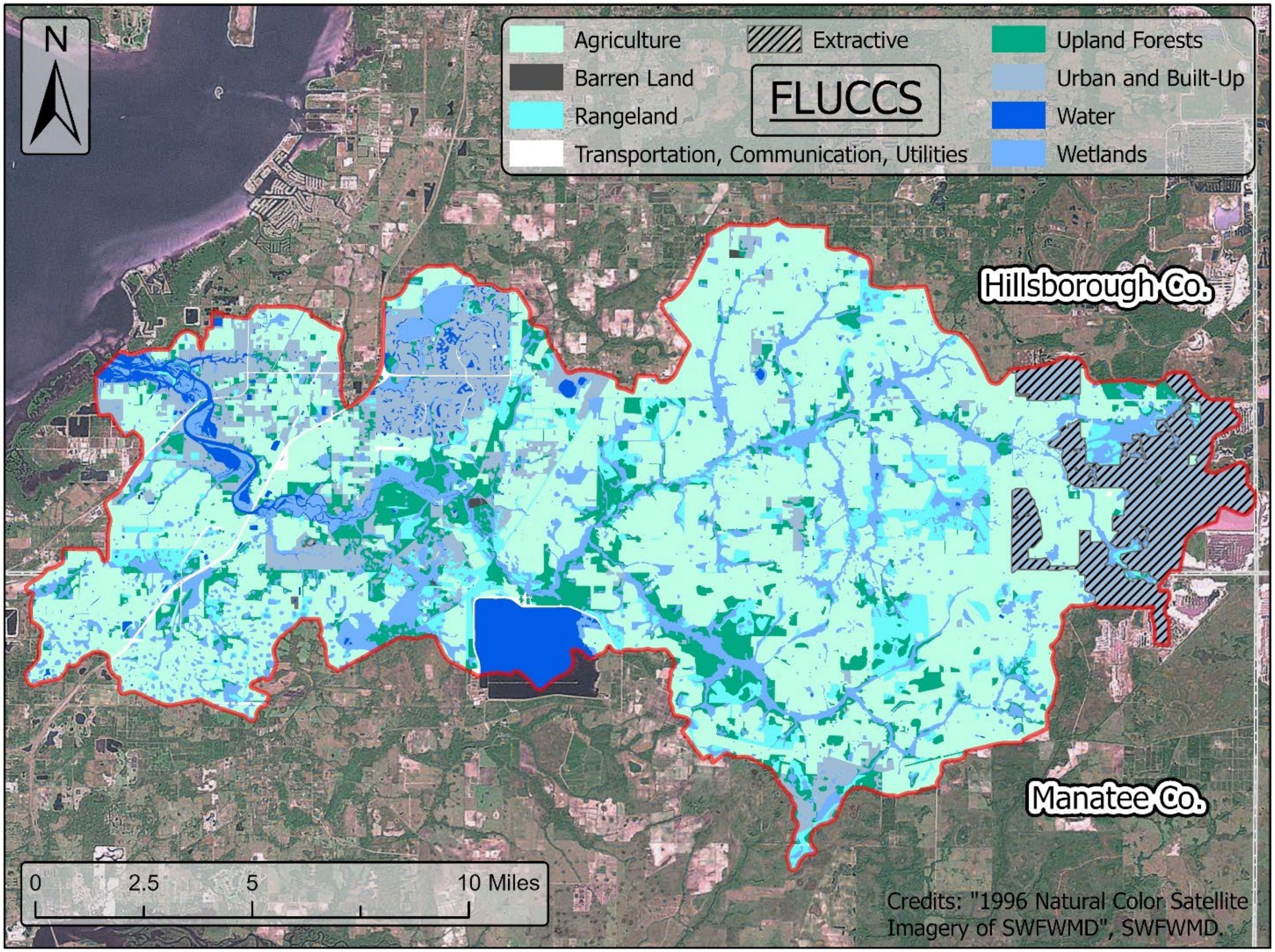

Figure 2-7. The 1999 Florida Land Use, Cover and Forms Classification System (Level I, with the exception of Level 3 Extractive) of the Little Manatee River watershed (SWFWMD 2003b).

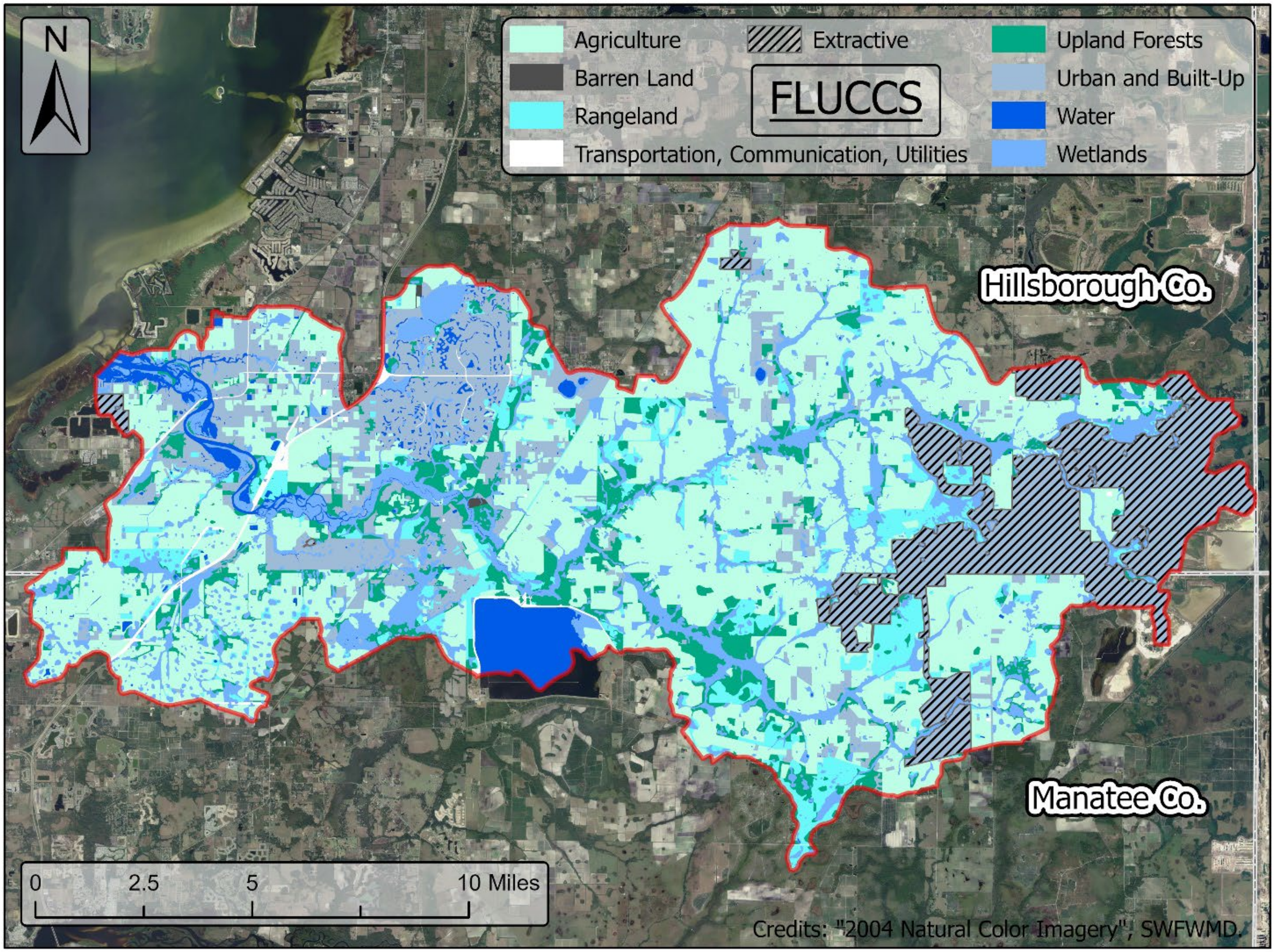

Figure 2-8. The 2004 Florida Land Use, Cover and Forms Classification System (Level I, with the exception of Level 3 Extractive) of the Little Manatee River watershed (SWFWMD 2007).

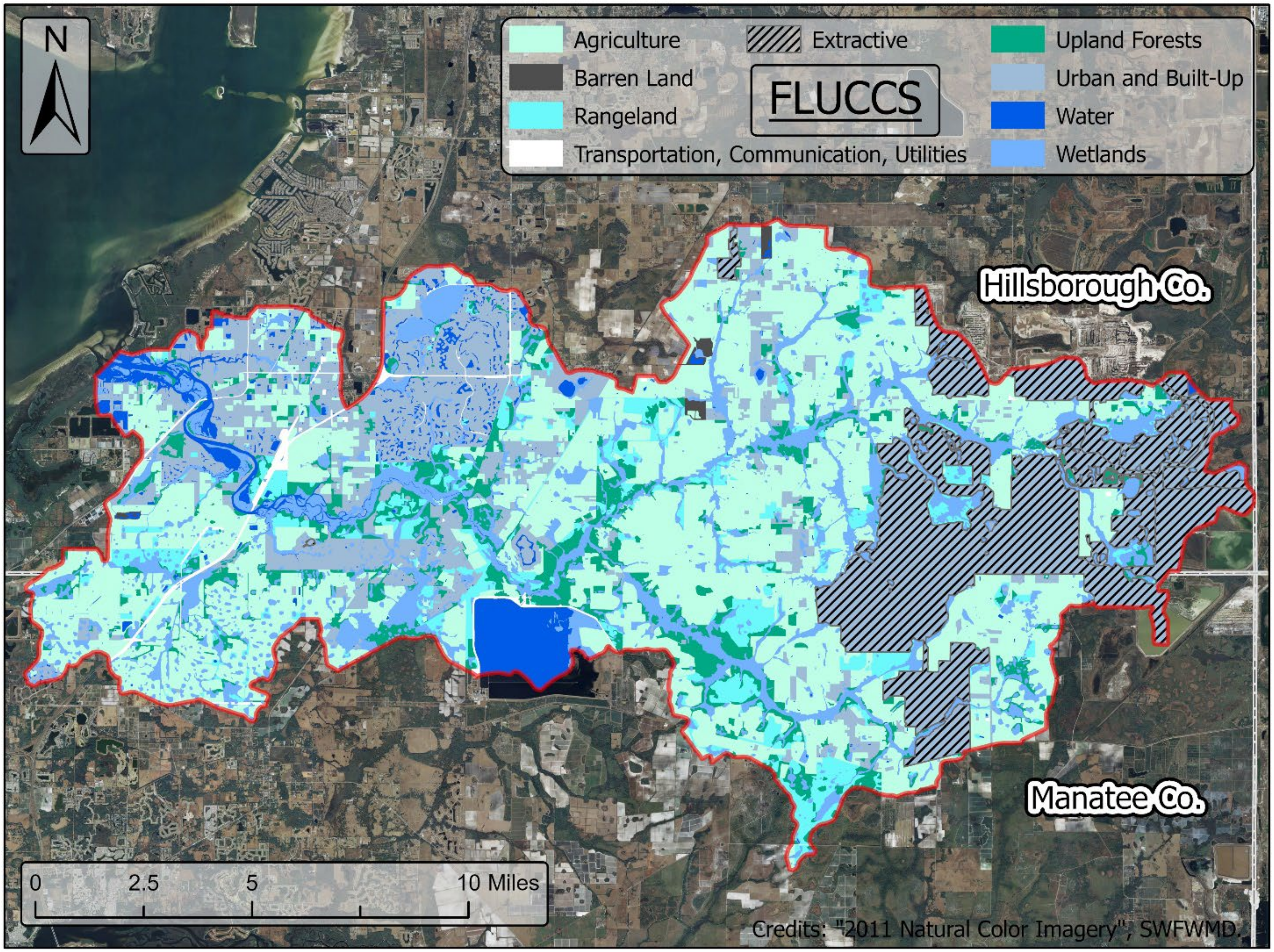

Figure 2-9. The 2011 Florida Land Use, Cover and Forms Classification System (Level I, with the exception of Level 3 Extractive) of the Little Manatee River watershed (SWFWMD 2011).

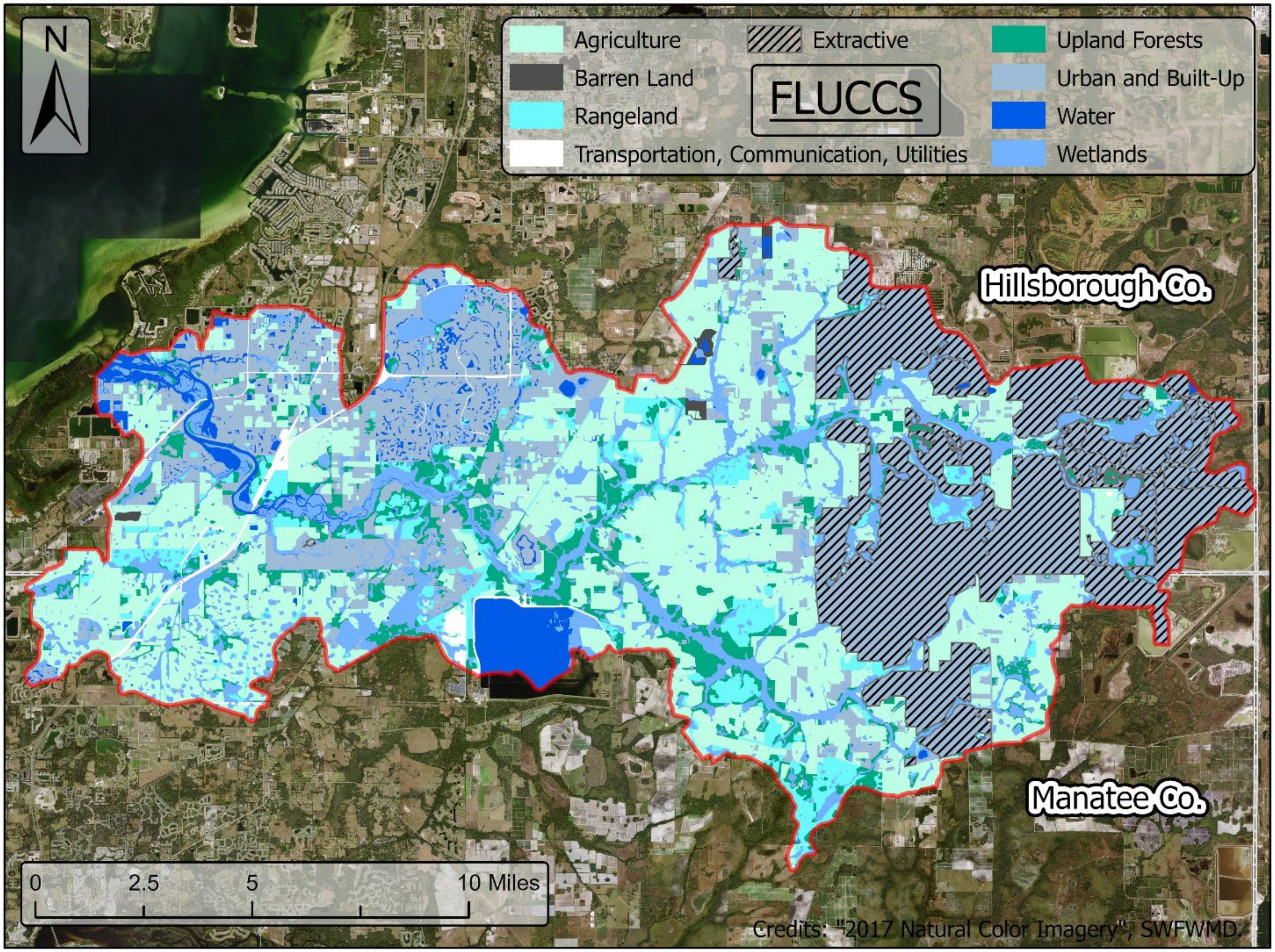

Figure 2-10. The 2017 Florida Land Use, Cover and Forms Classification System (Level I, with the exception of Level 3 Extractive) of the Little Manatee River watershed (SWFWMD 2019).

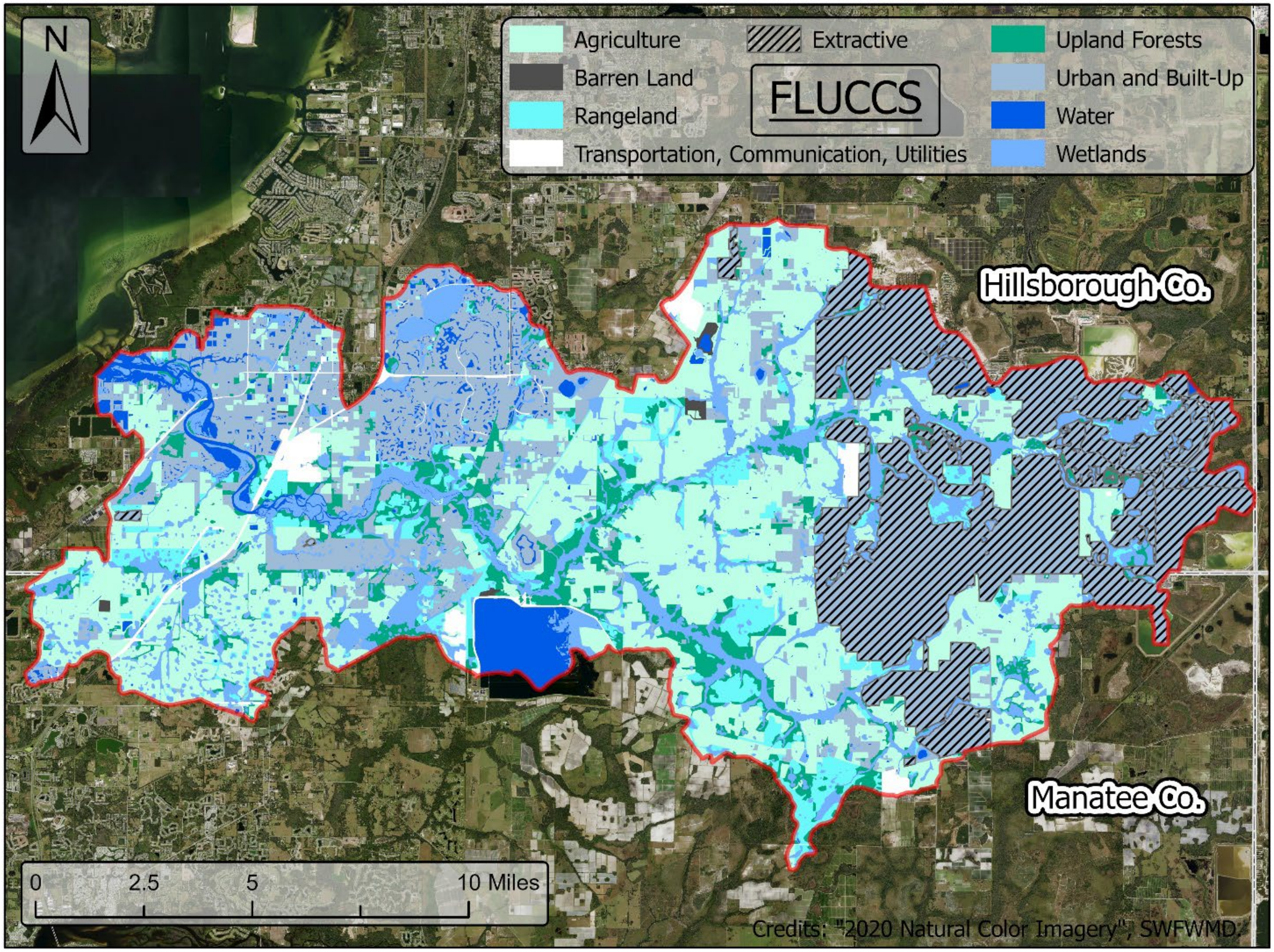

Figure 2-11. The 2020 Florida Land Use, Cover and Forms Classification System (Level I, with the exception of Level 3 Extractive) of the Little Manatee River watershed (SWFWMD 2021a).

Between 1974 and 1990, 35,690 acres (14,443 hectares) of Rangeland were converted to other uses: primarily Urban and Built-Up (8,948 acres or 3,621 hectares) and Agriculture (7,266 acres or 2,940 hectares) (Table 2-1 and Figures 2-5 and 2-6). Since 1990, Rangeland coverage has continued to decrease another 5,777 acres (2,338 hectares), in support of Urban and Built-Up increases (Table 2-1 and Figures 2-7 through 2-10). In 1974, there were no Urban and Built-Up lands in the eastern region of the watershed. Per the comparison between the 1974 data (Anderson et al. 1976) and the 1990 FLUCCS data, wetlands seemingly gained 11,123 acres (4,501 hectares), but this is a relic of the resolution at which the 1974 data was coded. Within Anderson et al.'s data (1976), wetlands were not coded along most of the riverbanks, like they have been since 1990.

Table 2-1. Land-use changes (acres) from 1974 through 2020 in the Little Manatee River watershed. Green shading represents increases in acres from the previous assessment period, while red represents decreases. All FLUCCS Codes are Level 1, except for Extractive (Mining Lands), which is Level 3 to provide details on the expansion of Mining Lands in the watershed over time. (Data from Anderson et al. 1976, SWFWMD 2003a, 2003b, 2007, 2011, 2019, 2021a).

FLUCCS Code	1974	1990	1999	2004	2011	2017	2020
Agriculture	66,513	73,779	71,934	60,711	53,621	47,381	44,403
Barren Land	0	84	90	69	368	393	321
Rangeland	49,291	13,601	10,036	8,885	8,241	7,698	7,824
Transportation, Communications, Utilities	76	1,200	1,196	1,279	1,426	1,695	3,106
Upland Forests	10,722	14,574	13,812	11,926	10,924	10,648	10,468
Urban and Built-Up (Non-Extractive)	4,427	10,085	12,234	16,887	19,563	20,493	21,463
Extractive	45	3,290	8,746	17,692	22,519	28,672	29,017
Water	1,658	4,986	5,177	5,228	5,609	5,825	6,034
Wetlands	10,372	21,496	19,868	20,418	20,825	20,301	20,469

Since 1990, Agricultural lands have decreased 29,376 acres (11,888 hectares) or 40 percent. A strong majority of these decreases have occurred in the eastern extent of the watershed, where Level 3 Extractive lands have increased from 3,290 acres (1,331 hectares) in 1990 to 29,017 acres (10,411 hectares) in 2020, a 9-fold increase (Table 2-1). Urban and Built-Up lands have more slowly increased in the western region of the watershed, mostly in Ruskin, where development has proliferated throughout the surrounding previously agricultural areas. The inverse relationship between Level 1 Agriculture lands against Level 3 Extractive and Level 1 Non-Extractive Urban and Built-Up lands is apparent in Figure 2-12. The extent of Level 1 Wetlands has experienced less change than other categories since 1990, decreasing from 21,496 acres (8,699 hectares) to 20,469 acres (8,283 hectares) (Table 2-1). Level 1 Upland Forests have decreased from 14,574 acres (5,898 hectares) to 10,468 acres (4,236 hectares) since 1990. The extent of Level 1 Water has remained mostly stable since 1990, increasing from 4,986 acres (2,018 hectares) to 6,034 acres (2,442 hectares). Level 1 Transportation, Communications, and Utilities experienced slower growth from 1990 (1,200 acres or 486 hectares) to 2017 (1,695 acres or 686 hectares), and then nearly doubled in extent between 2017 and 2020 (3,106 acres or 1,257 hectares).

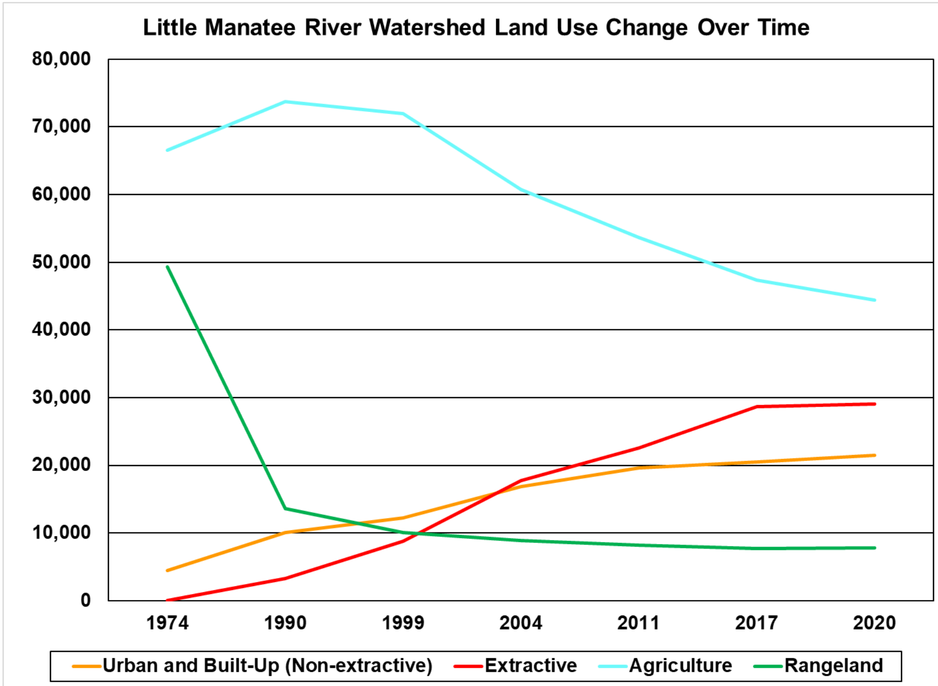

Figure 2-12. Land-use changes over time (1974 – 2020) in the Little Manatee River watershed. Data from: Anderson et al. 1976, SWFWMD 2003a, 2003b, 2007, 2011, 2019, 2021a.

The industry of phosphate mining has significantly changed the land-use composition of the Little Manatee River watershed since its local initiation in the late 1970s. Currently, the Mosaic Company operates every mandatory phosphate mine in the watershed and is the largest single landowner of mined lands. The Mosaic Company owns more than 36,960 acres (14,957 hectares) or 26 percent of the land within the watershed (Figure 2-13). Of these land holdings, 5,473 acres (2,213 hectares) are undisturbed and primarily exist as buffers between public waterways and mining operations. The Mosaic Company operates, has operated, or may operate phosphate mining activity on 31,487 acres (12,742 hectares), or 22 percent of land within the watershed. Of these lands, mining is in progress on 16,856 acres (6,821 hectares) or 12 percent of the watershed (Figures 2-13 and 2-14). Mining has concluded, and the lands have been reclaimed, on 9,336 acres (3,778 hectares), and future mining may occur on 5,295 acres (2,143 hectares) (Figures 2-13 and 2-14).

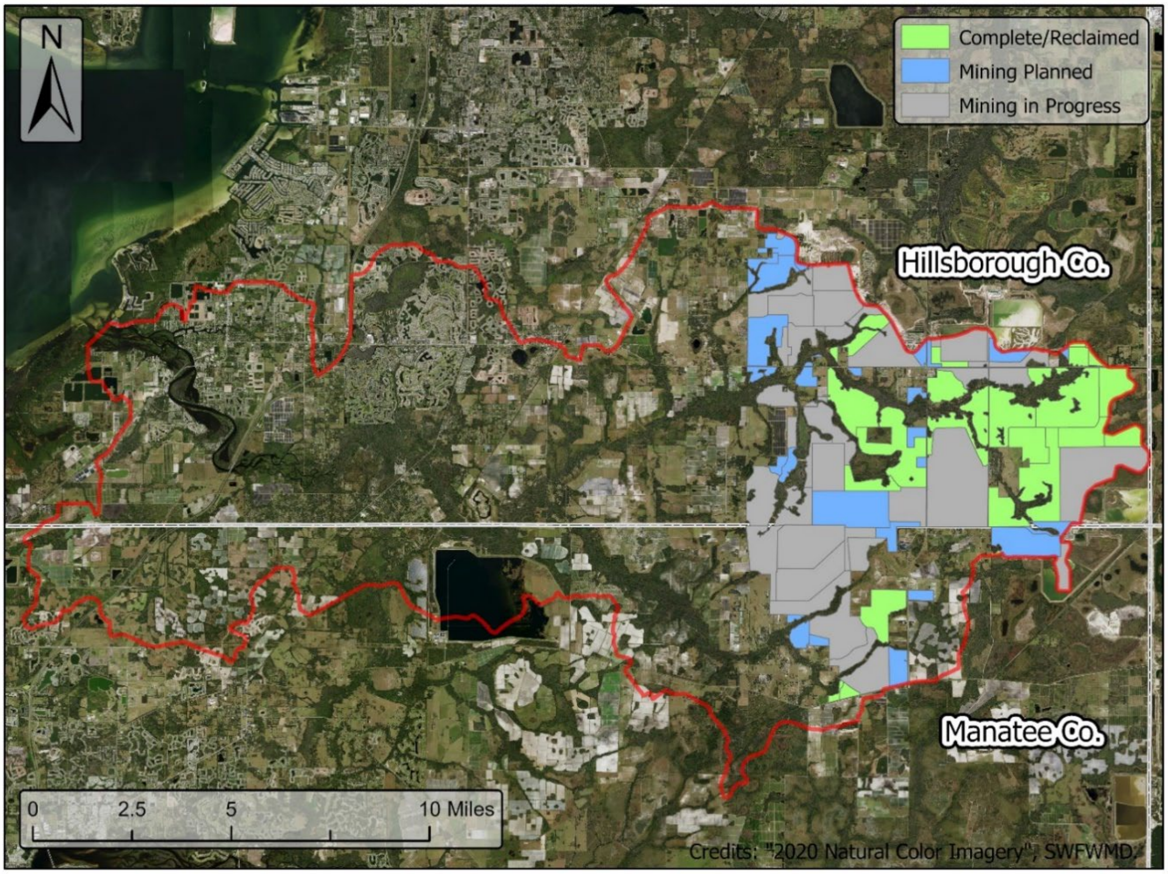

Figure 2-13. Locations of Mandatory Phosphate Mining Units by reclamation status within the Little Manatee River watershed (FDEP 2021b, 2021c).

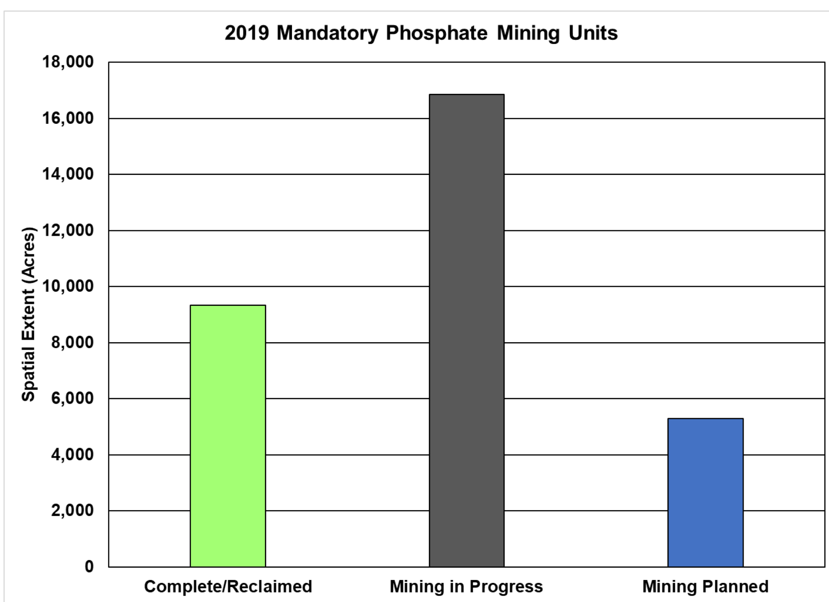

Figure 2-14. Acres of Mandatory Phosphate Mining Units by reclamation status within the Little Manatee River watershed (FDEP 2021b, 2021c).

The Landscape Development Intensity Index (LDI) uses land use and cover data to calculate levels of human disturbance on aquatic systems by multiplying areas of a particular land use and cover classification by an LDI energy coefficient. The energy coefficients consider the amount of non-renewable energy used per unit area, including the consumption of electricity, fuels, fertilizers, pesticides, public water supply, and water used for irrigation (Brown and Vivas 2005). To calculate the LDI for the Little Manatee River, a buffer of 100 m was applied around both the main channel of the river and major tributaries (Figure 2-3). Land use and cover data for the buffered area were obtained from the 2020 Level III FLUCCS (SWFWMD 2021a). Where FLUCCS categories did not exactly match those described by Brown and Vivas 2005 and DEP 2012a, a best approximation was made by either averaging LDI coefficients for similarly classified land-use areas, or by assigning the value associated with the most intensive probable use. The LDI for the main channel of the Little Manatee River was calculated as 1.39. When all major tributaries were included, the calculated LDI was 1.90. Both values indicate a minimally disturbed watershed, consisting primarily of natural lands (Brown and Vivas 2005, DEP 2012a).

2.3 Climate and Rainfall

The Little Manatee River watershed lies within a humid, subtropical zone that is influenced by its proximity to the Gulf of Mexico. Subtropical zones are characterized by hot, humid summers and mild to cool winters. The temperature of the Gulf waters moderates the air temperatures in the area. The average mean daily temperature is approximately 70°F (21°C). Mean summer temperatures are in the low 80s (°F), and the mean winter temperatures are in the upper 50s (°F).

Average rainfall is approximately 53 inches (135 cm) per year but varies widely from season to season and year to year. About 60 percent of the annual rainfall occurs during the summer rainy season months of June through September when convective thunderstorms are common due to daytime heating and afternoon sea breezes. In addition, summer and fall rainfall can be enhanced by tropical cyclone activity from June through November. The dry season extends from mid-October through mid-June, with the lowest average rainfall in November (Figure 2-15). Winter rainfall slightly increases during January through March due to passing of cold fronts that bring rain in advance of high pressure by dry air (Kelly 2004, Hood et al. 2011 in Appendix A). Winter rainfall tends to be more evenly distributed, since rainfall generally results from large frontal systems as cold air masses from the north move south through the area (Kelly and Gore 2008).

An analysis of mean decadal rainfall and 20-year moving average rainfall accumulated for the Little Manatee River watershed by the District hydrologic data group from 1915 through 2021 shows an increasing trend up until 1970, followed by a declining trend until about the year 1995, and then an increasing trend through 2010 (Figures 2-16 and 2-17). This is consistent with multi-decadal cycles associated with the Atlantic Multidecadal Oscillation (AMO) (Enfield et al. 2001, Kelly and Gore 2008, Cameron et al. 2018). The 20-year average was below the 50th percentile (P50) for most of the 20-year averages from 1980 through 2005. Recent 20-year periods have increased with moving averages near the 50th percentile. The annual rainfall departure since 1930 shows a similar pattern, with the majority of years above average during the warm AMO period and most of the years below average during the cool period from 1970-1995 (Figure 2-18). The one exception is the 2010-2021 period when eight of 12 years were below average.

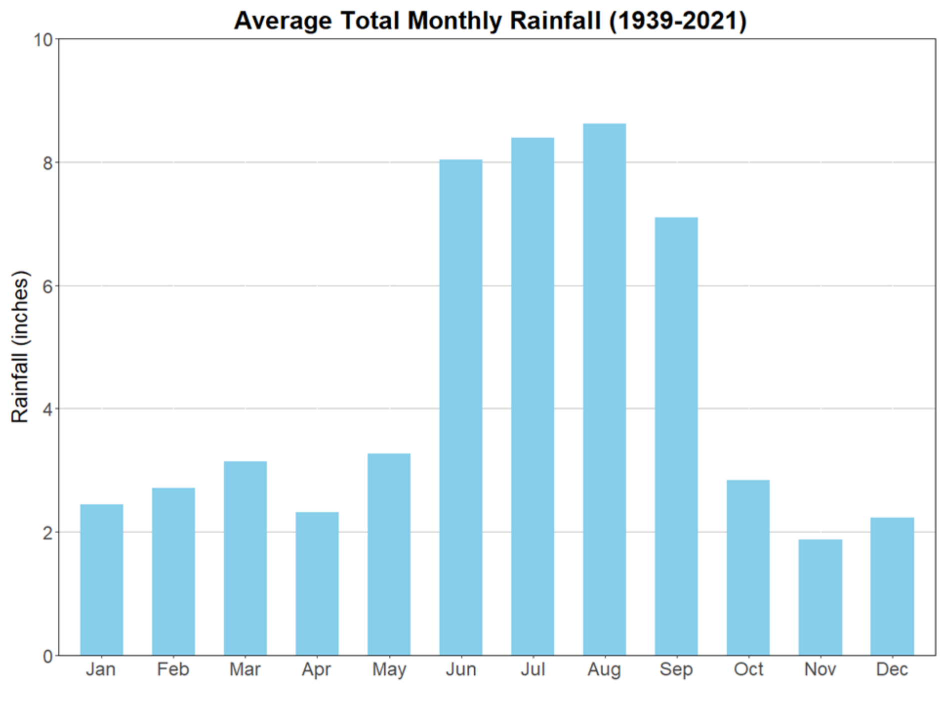

Figure 2-15. Average total monthly rainfall for Little Mantee River watershed from 1939 through 2021 (Source: https://www.swfwmd.state.fl.us/resources/data-maps/rainfall-summary-data-region).

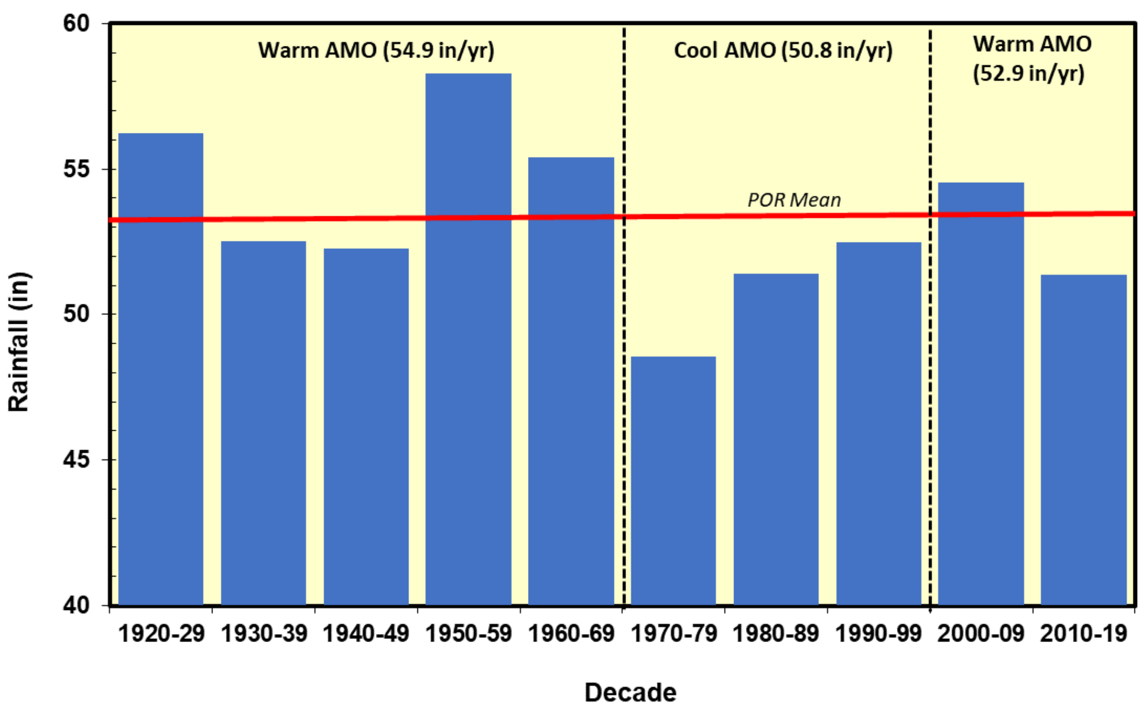

Figure 2-16. Mean decadal rainfall and Atlantic Multidecadal Oscillation (AMO) periods within the Little Manatee River watershed from 1920 through 2019 (Source: https://www.swfwmd.state.fl.us/resources/data-maps/rainfall-summary-data-region).

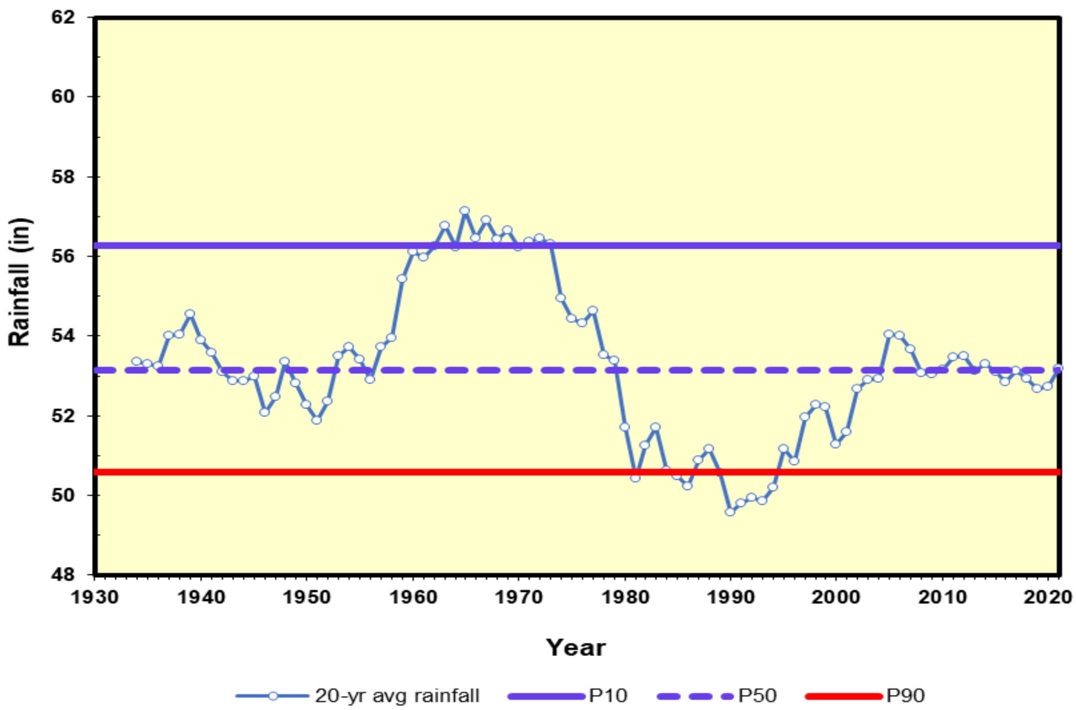

Figure 2-17. Twenty-year moving average and 10th, 50th, and 90th exceedance percentiles (P10, P50, and P90, respectively) of annual rainfall within the Little Manatee River watershed from 1915 through 2021 (Source: https://www.swfwmd.state.fl.us/ resources/data-maps/rainfall-summary-data-region).

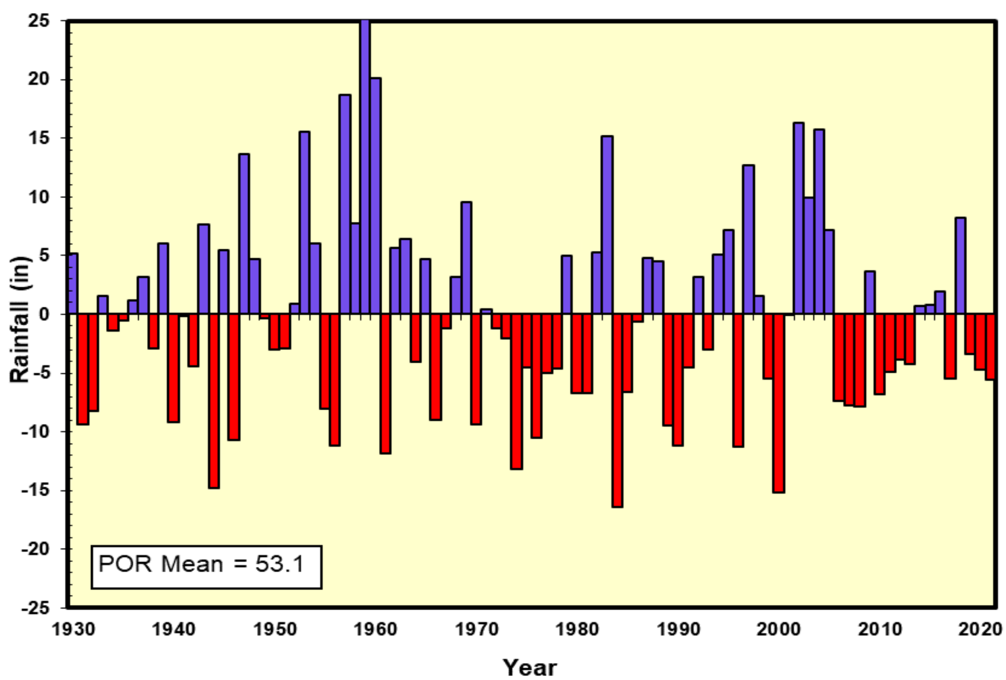

Figure 2-18. Annual departure in rainfall from the period of record (POR) mean within the Little Manatee River watershed from 1930 through 2021 (Source: https://www.swfwmd.state.fl.us/resources/data-maps/rainfall-summary-data-region).

2.4 Hydrogeologic System

The hydrogeology of the District can generally be divided into three broad regions that correspond to major groundwater basins within the UFA (Figure 2-19). Within the District, from north to south, are the Northern West-Central Florida Groundwater Basin (NWCFGWB), the Central West-Central Florida Groundwater Basin (CWCFGWB), and the Southern West-Central Florida Groundwater Basin (SWCFGWB). In general, the UFA is mostly unconfined in the NWCFGWB, semi-confined in the CWCFGWB, and well-confined in the SWCFGWB, as the intermediate confining unit (ICU) thickens from north to south.

The hydrogeologic framework within the Little Manatee River watershed area includes a thin unconfined surficial aquifer (SA), thick ICU, and a thick carbonate UFA. At land surface and extending several tens of feet deep are generally fine-grained quartz sands that grade into clayey sands just above the contact with the ICU. A thick clay layer varying in total thickness from 200 to 300 ft (60 to 90 m) forms the ICU and overlies the limestone units of the UFA (Figures 2-20 and 2-21). Imbedded within the ICU may be isolated thin permeable zones of limestone, shell, gravel, or sand that form local aquifers – used mainly for household water use. These thin permeable zones are referred to as the intermediate aquifer (PZ 2) (Basso and Hood 2005). Because of this geology, the UFA is well-confined over southern Hillsborough and northern Manatee Counties. This geology results in little to no hydraulic connection between the surficial sand aquifer and the underlying UFA – where groundwater withdrawals have largely reduced the potentiometric surface on average 30 to 50 ft (9 to 12 m) in South-Central Hillsborough and Central Manatee Counties since the early 1930s.

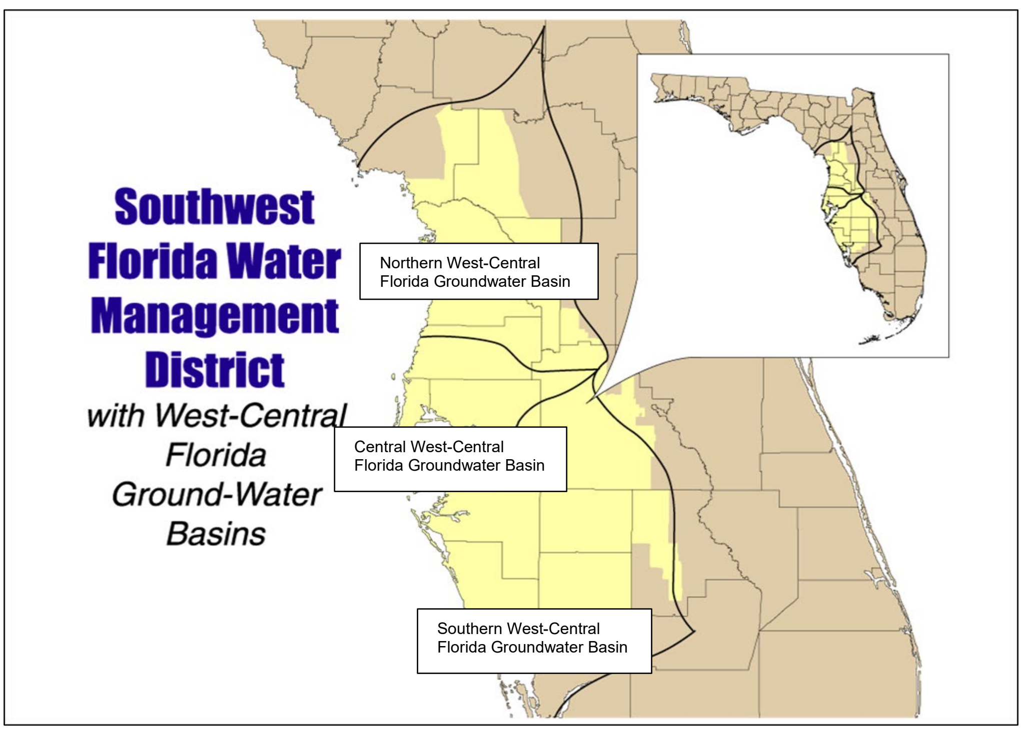

Figure 2-19. Location of regional groundwater basins within the Southwest Florida Water Management District.

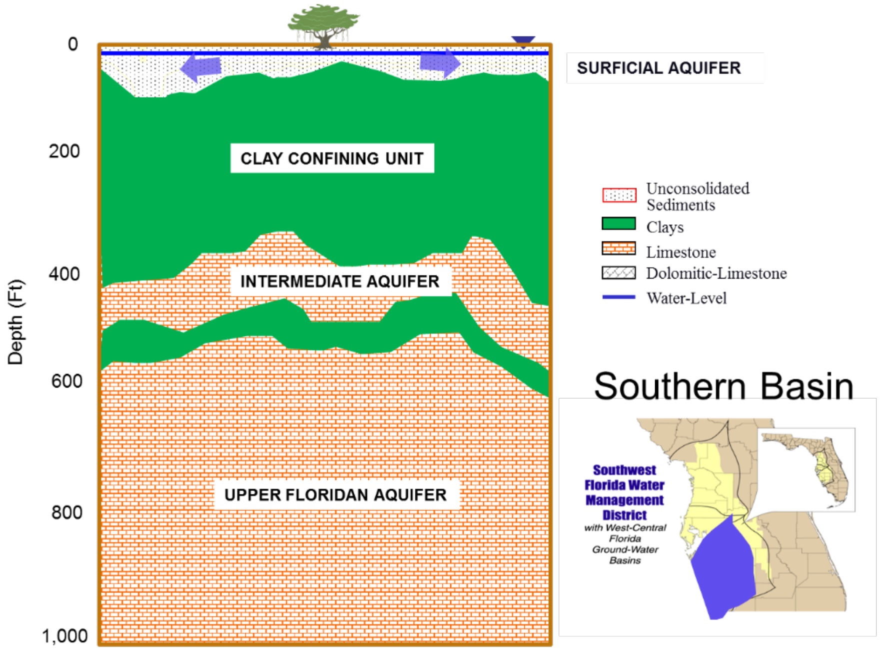

Figure 2-20. Generalized hydrogeologic column within the western and central portion of the Southern West-Central Florida Groundwater Basin. Note that the purple area on inset map corresponds to the area represented by this column.

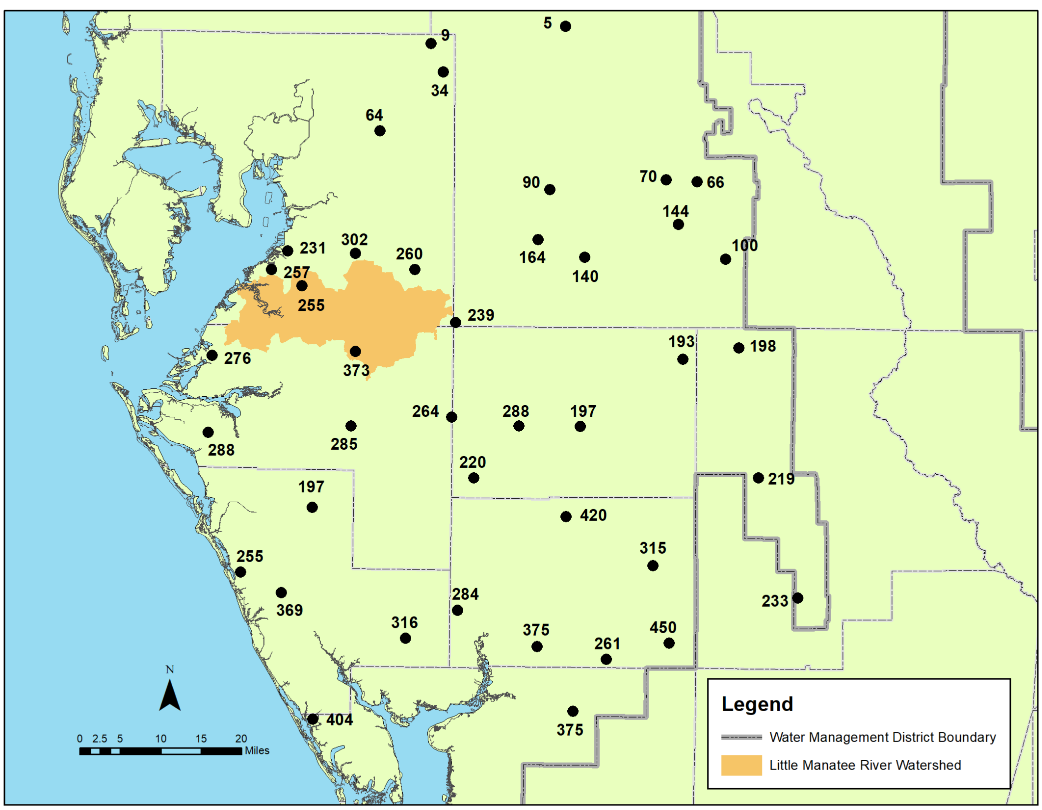

Figure 2-21. Total clay thickness (ft) between the base of the surficial aquifer and top of the Upper Floridan aquifer based on District Regional Observation and Monitor-Well Program site reports.

As a result of the reduced potentiometric surface, the Southern Water Use Caution Area (SWUCA) was established in 1992, which encompasses an area of approximately 5,100 square miles (13,209 square km), including all or part of eight counties in the southern portion of the District (Marchand et al. 2018), as well as the Little Manatee River watershed (Figure 2-22). Historical increases in groundwater use occurred between 1974 and 2004 due to an estimated ten-fold increase in row-crop agriculture, including the cultivation of tomatoes, strawberries, cucumbers, and melons. The SWUCA Recovery Strategy was adopted in 2006 to address declines in aquifer levels, exceeding 50 ft (15.2 m) in some areas, from groundwater withdrawals. These declines have contributed to saltwater intrusion along the coast, reduced flows in the Upper Peace River, and lower lake levels in Polk and Highlands Counties. Additionally, an area of about 708 square miles (1,834 square km) located along the coast of southern Hillsborough, Manatee, and northwestern Sarasota counties, where the concern for saltwater intrusion was greatest, was designated as the Most Impacted Area (MIA) (Figure 2-23).

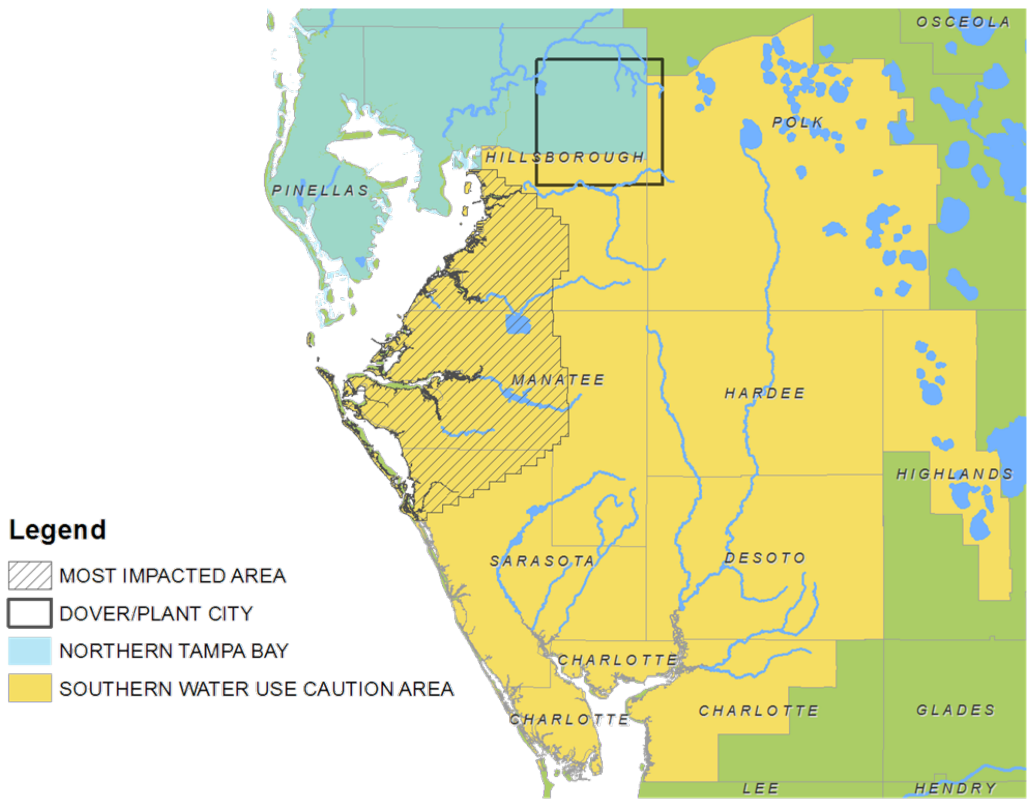

Figure 2-22. Location of the Southern Water Use Caution Area and Most Impacted Area.

While large water level declines have occurred in the UFA due to groundwater extraction, there is no evidence to suggest any significant connection or impact to the near surface wetlands, lakes, streams, or the SA in the well-confined parts of the SWUCA. Vertical hydraulic head differences between aquifers and similar response in water levels can infer the relative degree of the hydraulic connection between the units. As part of the Regional Observation and Monitor-well Program (ROMP), the District has installed cluster wells, which monitor discrete vertical horizons in each aquifer system, at several locations in the Little Manatee River watershed area (Figure 2-23). Water levels at three representative sites, ROMP Sites 39, 49, and 50, are shown in Figures 2-24, 2-25 and 2-26. Based upon review of the hydrographs, large vertical head differences between the SA and the UFA and independent response in water level fluctuations between aquifers indicate relatively low hydraulic connection and tight confinement separating the systems.

Vertical hydraulic head difference from nested monitor well pairs in the SA and UFA is often used as a qualitative guide of relative confinement of the UFA by the ICU. In areas of less than a foot (0.3 m) of difference, the UFA is mostly unconfined. Where vertical head difference is more than 1 ft (0.3 m) but less than 20 ft (6 m), the UFA is semi-confined. Where the vertical head difference is greater than 20 ft (6 m), the UFA is typically well-confined (Basso 2019). These qualitative criteria generally hold true except in transition areas between downward and upward head potentials in coastal regions of the UFA, where there is an upward vertical head gradient from the UFA. In these coastal areas, the thickness of the ICU determines the degree of confinement. Other qualitative factors used in determining the relative degree of confinement of the ICU include sinkhole density and the degree of natural surface water drainage patterns. Highly dendritic networks of surface water drainage imply a tight ICU, as well as areas with little to no sinkhole development. These are both characteristics of the Little Manatee River watershed.

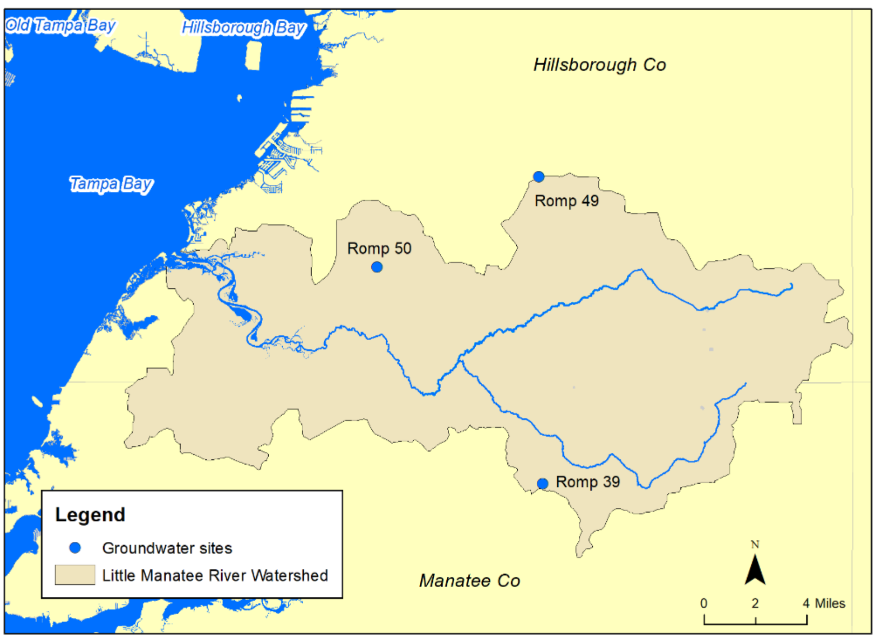

Figure 2-23. Location of District monitor well sites ROMP 39, ROMP 49, and ROMP 50 within or near the Little Manatee River watershed. ROMP = Regional Observation and Monitor-well Program.

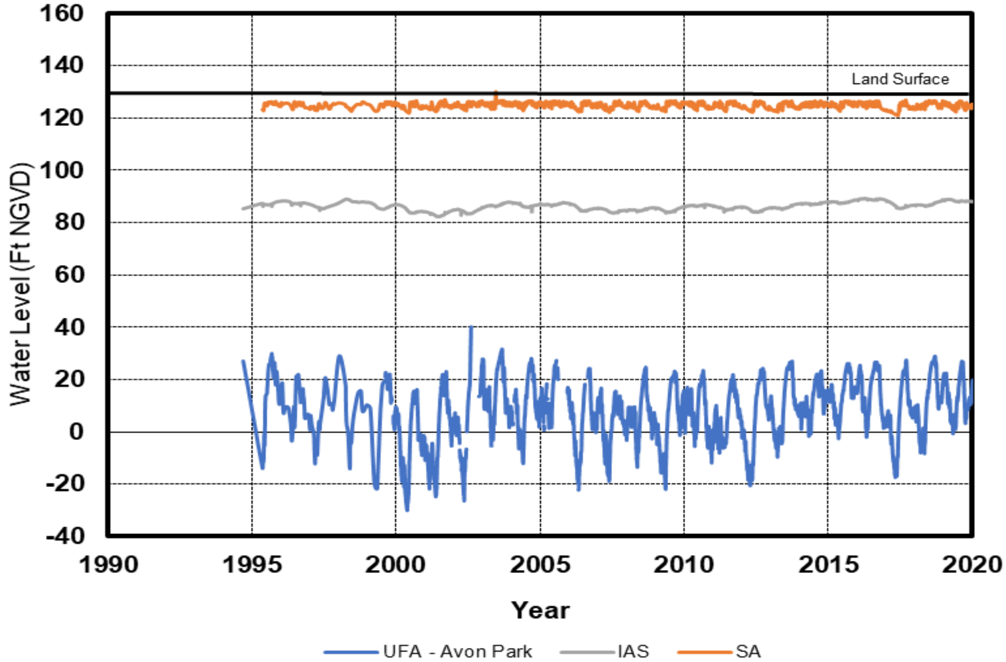

Figure 2-24. Water levels (in ft) from monitor wells installed into the surficial aquifer (SA), intermediate aquifer (IAS), and Upper Floridan aquifer (UFA-Avon Park) at the District Regional Observation and Monitor-well Program Site 39. Note 1 ft = 0.3 m.

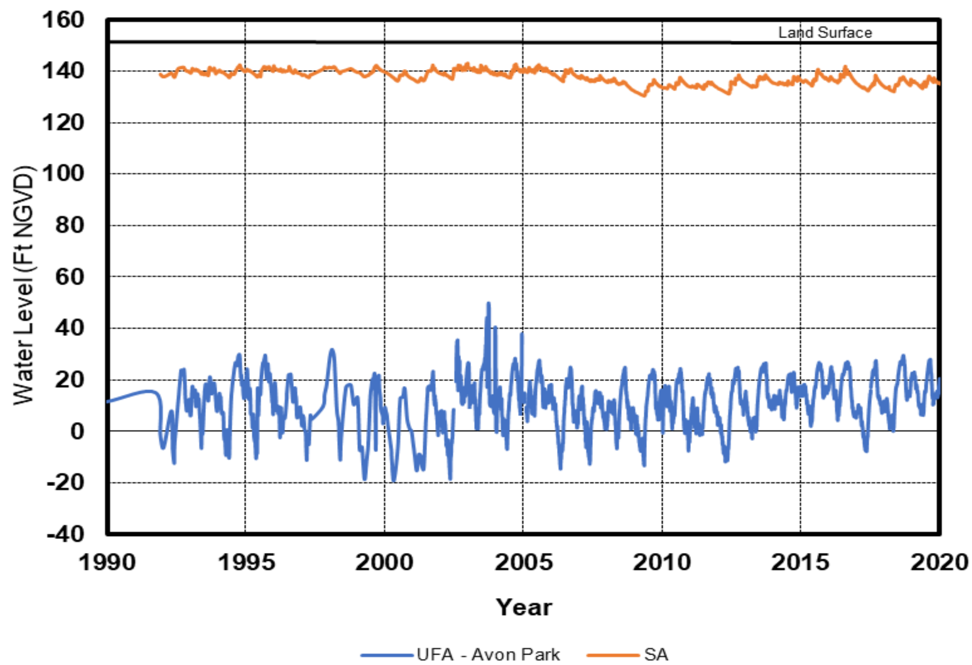

Figure 2-25. Water levels (in ft) from monitor wells installed into the surficial aquifer (SA) and Upper Floridan aquifer (UFA-Avon Park) at the District Regional Observation and Monitor-well Program Site 49. Note 1 ft = 0.3 m.

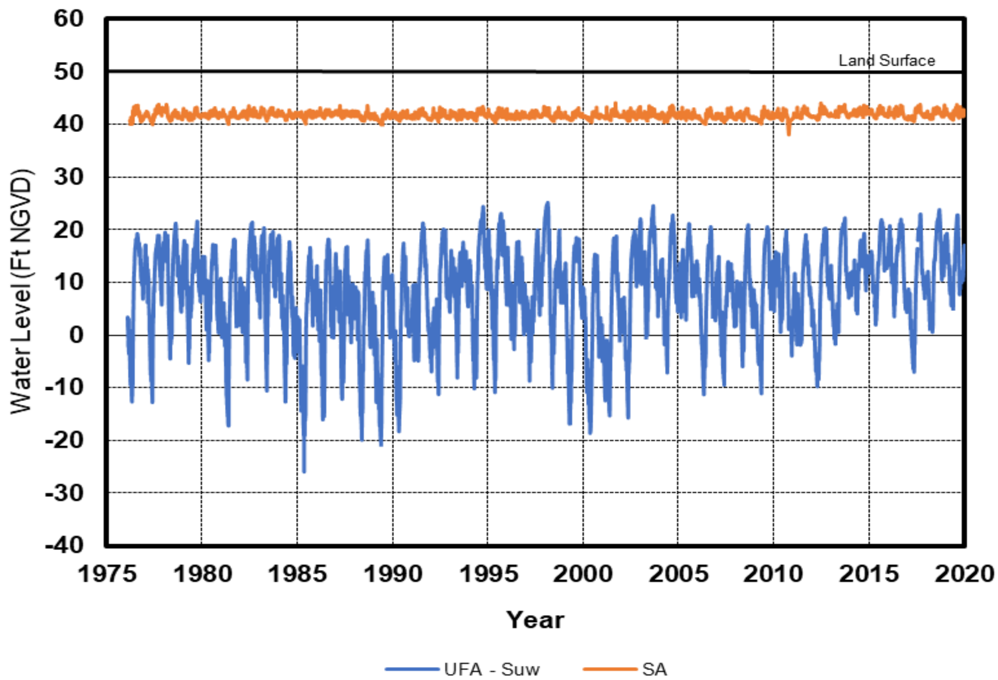

Figure 2-26. Water levels (in ft) from monitor wells (in ft) installed into the surficial aquifer (SA) and Upper Floridan aquifer (UFA-Suw) at the District Regional Observation and Monitor-well Program Site 50. Note 1 ft = 0.3 m.

The long-term head difference (greater than 5 years of record) between the SA and UFA is shown from District nested well sites in Figure 2-27. Nested wells within or near the Little Manatee River watershed show vertical head differences ranging from 33 to 128 ft (10 to 39 m) except near the coastal transition zone, where an upward head potential exists. This indicates a well-confined UFA in this area.

The geologic units that form the freshwater portion of the UFA, in descending order, include the Oligocene Age Suwannee Limestone, Upper Eocene Age Ocala Limestone and the Middle Eocene Age Avon Park Formation (Table 2-2). In the Little Manatee River watershed, the Suwannee Limestone forms the top of the UFA. The entire carbonate sequence of the UFA thickens and dips toward the south and southwest. The average thickness of the UFA ranges from 1,000 ft (305 m) in Central Hillsborough County to 1,500 ft (457 m) in Central Charlotte County (Miller 1986).

The base of the UFA generally occurs at the first, persistent sequence of evaporitic minerals, such as gypsum or anhydrite, that occur as nodules or discontinuous thin layers in the carbonate matrix. This low permeability unit is regionally extensive and is generally referred to as Middle Confining Unit (MCU) 2 (Miller 1986). The MCU 2 unit essentially forms the base of the freshwater flow system in this portion of West-Central Florida.

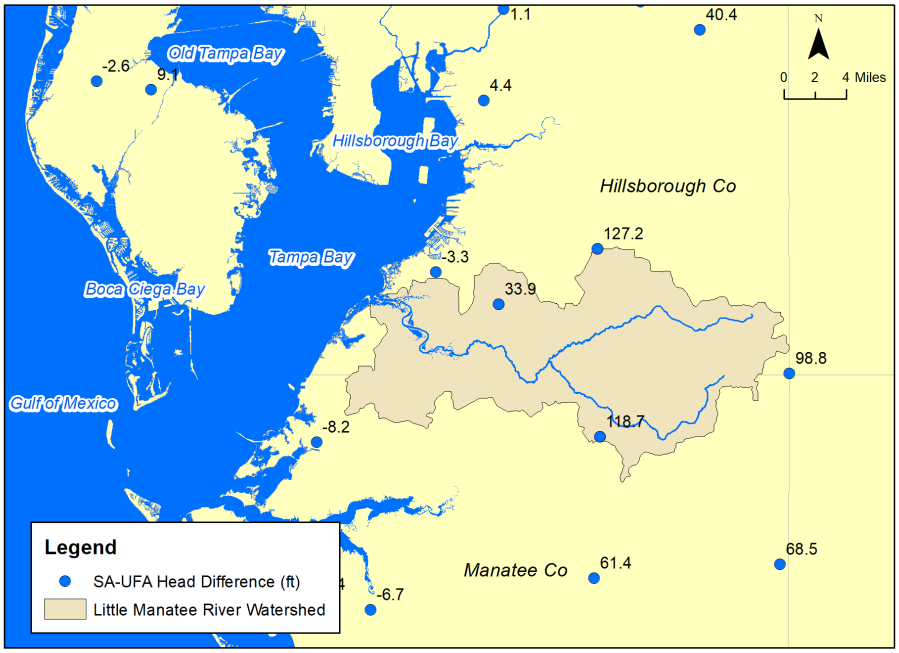

Figure 2-27. Long-term average vertical head difference (>5 years in ft) between the surficial aquifer (SA) and Upper Floridan aquifer (UFA) from District nested monitor wells within or near the Little Manatee River watershed. Note negative values indicate an upward potential from the UFA to SA and 1 ft = 0.3 m.

2.5 Little Manatee River Flow History

Historically, surface water from agricultural operations augmented stream flow within the Little Manatee River watershed largely due to spring and fall vegetable farming (Flannery et al. 1991). These excess flows were attributed to historical flood-field irrigation practices, in which ridges and furrows were constructed and fields flooded to control water table depths. Bed preparation, crop establishment, and freeze protection were the most intensive water uses for typical flood field row crops (strawberries and tomatoes) in the watershed. Bed preparation, which generally started in July, included the building of ridges and furrows and installation of plastic underlayment, requiring the saturation of sandy soils typical of the Little Manatee River watershed. Together, the artificially-raised water tables and the plastic underlayment in fallow fields increased summer surface runoff, despite summer being a relatively unproductive time for row-crop agriculture, with strawberry and tomato harvest lasting until April and June, respectively.

Since the implementation of rules within the SWUCA in recent years, the efficiency of agricultural water use has been improved through use of Best Management Practices (BMPs), including the conversion of irrigation systems to more efficient technologies (e.g., from seepage irrigation to drip irrigation) and the use of weather stations, soil moisture sensors, and evapotranspiration (ET) sensors (Hood et al. 2011 in Appendix A). In addition, BMPs to reduce the amount of groundwater used and the amount of surface water discharged, such as the construction of surface water reservoirs to capture stormwater and tailwater for reuse and rainwater harvesting in greenhouse nurseries, have been implemented. As described in Section 5.2, surface water from agricultural operations has been identified as a principal source of excess flows to the Upper Little Manatee

Table 2-2. Hydrogeology of the southern Hillsborough/northern Manatee County area (modified from Miller 1986, Barr 1996, Sacks and Tihansky 1996).

<table>
<tr><th>Series</th><th colspan="2">Stratigraphic Unit</th><th colspan="2">Hydrogeologic Unit</th><th>Lithology</th></tr>
<tr><td>Holocene to Pliocene</td><td colspan="2">Undifferentiated Surficial Deposits</td><td>Surficial Aquifer</td><td>Surficial Aquifer</td><td>Sand, silty sand, clayey sand, peat, and shell</td></tr>
<tr><td rowspan="6">Miocene</td><td rowspan="6">Hawthorn Group</td><td rowspan="2">Peace River Formation</td><td>Confining Unit</td><td rowspan="7">Intermediate Aquifer System</td><td rowspan="4">Predominantly phosphatic clay, gray to green to brown, plastic, ductile, minor sand, phosphatic gravel, residual limestone and dolostone</td></tr>
<tr><td rowspan="2">PZ 2</td></tr>
<tr><td rowspan="2">Arcadia Formation</td></tr>
<tr><td>Confining Unit</td></tr>
<tr><td rowspan="2">Tampa or Nocatee Member</td><td>PZ 3</td><td rowspan="3">Limestone, gray to tan, sandy, soft, clayey, minor sand, phosphatic; chert found locally</td></tr>
<tr><td rowspan="2">Confining Unit</td></tr>
<tr><td rowspan="2">Oligocene</td><td></td><td></td></tr>
<tr><td colspan="2">Suwannee Limestone</td><td>Upper Permeable Zone</td><td rowspan="3">Upper Floridan Aquifer</td><td>Limestone, cream to tan, sandy, vuggy, fossiliferous</td></tr>
<tr><td rowspan="3">Eocene</td><td colspan="2">Ocala Limestone</td><td>Semi-Confining Unit</td><td>Limestone, white to tan, friable to micritic, fine-grained, soft, abundant foraminifera</td></tr>
<tr><td colspan="2" rowspan="2">Avon Park Formation</td><td>Lower Permeable Zone</td><td>Limestone and dolomite; limestone is tan, recrystallized; dolomite is brown, fractured, sucrosic, hard; peat found locally at top; interstitial gypsum in lower part</td></tr>
<tr><td colspan="2">Middle Confining Unit II</td><td></td></tr>
</table>

River beginning in 1978, and these flows began trending toward zero after 2000 because of decreases in active agricultural lands and implementation of agricultural BMPs in the watershed.

Flow has been measured by the USGS at various gages within the Little Manatee River watershed for many years (Figure 2-3). They include the Little Manatee River near Ft Lonesome, FL (No.

02300100), South Fork Little Manatee River near Wimauma, FL (No. 02300300), Little Manatee River at US 301 near Wimauma, FL (No. 02300500), Little Manatee River at Ruskin, FL (No. 02300546), and Little Manatee River at Shell Point near Ruskin, FL (No. 02300554). The farthest downstream sites near Ruskin are tidally influenced. The Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage provides the longest history of freshwater river flow, with data collection at the site initiated in 1939.

A cumulative distribution curve of daily gaged flows from 1939 through 2021 at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage is shown in Figure 2-27. The median flow of the river (63 cfs) is only 37 percent of the mean value (169.3 cfs), demonstrating that the mean is influenced by periodic high flows and the median is more representative of typical flow rates in the river. The highest recorded daily flow rate was 11,100 cfs in September 1960 during Hurricane Donna, while the lowest daily flow of 0.9 cfs was recorded in December 1976.

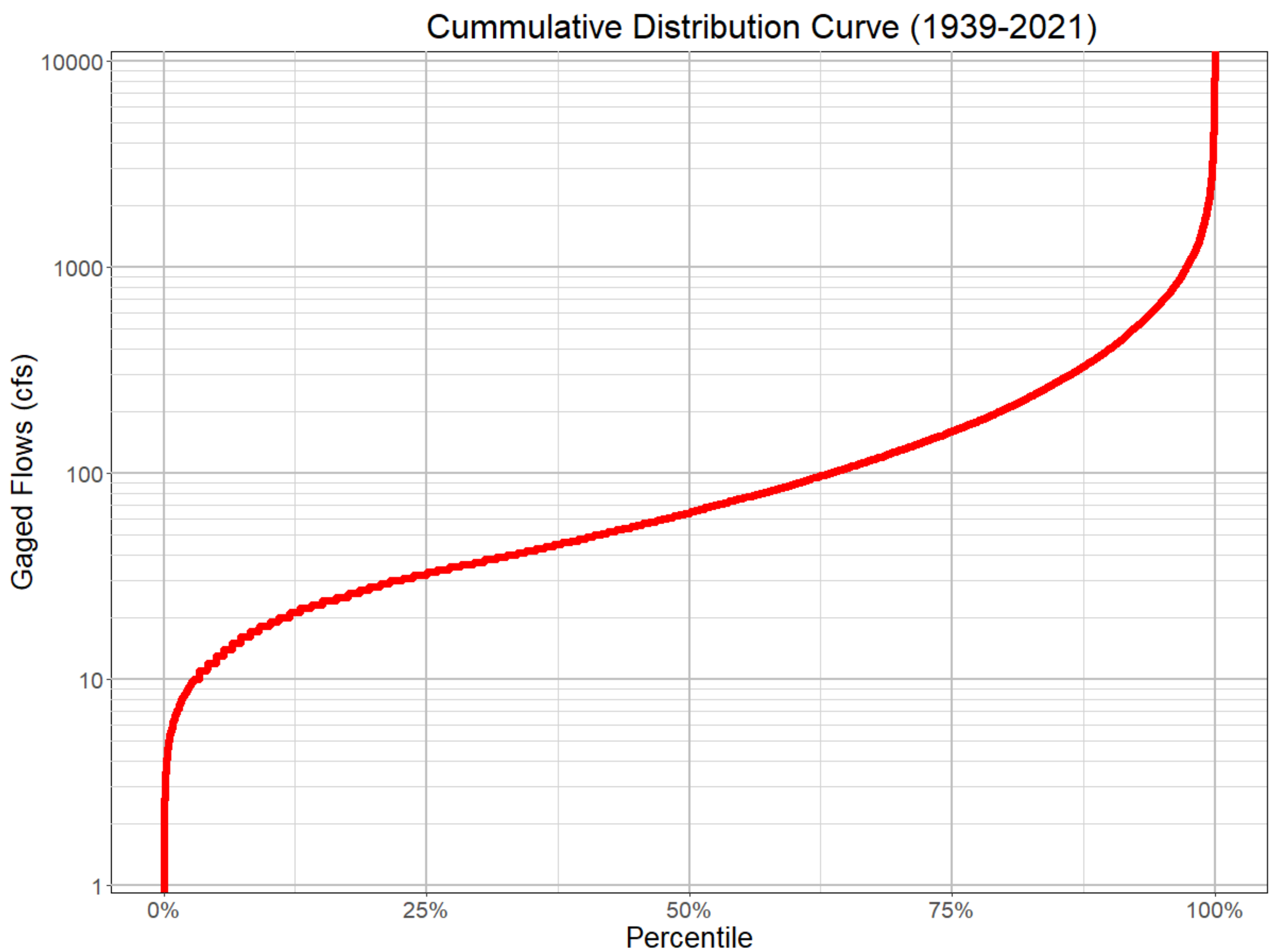

Figure 2-27. A cumulative distribution curve of daily flows at the at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage from 1939 through 2021.

The distribution of average monthly flows (Figure 2-28) for the river is similar to the distribution of monthly rainfall in the watershed (Figure 2-15), with a summer wet season that follows a dry season that extends from October to May. However, the relative difference between minimum and maximum monthly streamflow values is greater than for monthly rainfall. Streamflow reaches its lowest levels relative to rainfall in May, when evapotranspiration rates are high, groundwater levels are low, and there is considerable surface water storage available in depressions and wetlands. In contrast, streamflow is relatively high compared to rainfall in the late summer when soils are more saturated, groundwater levels are high, and there is less available surface water storage. As a result, streamflow has delayed and more pronounced seasonal variations than rainfall.

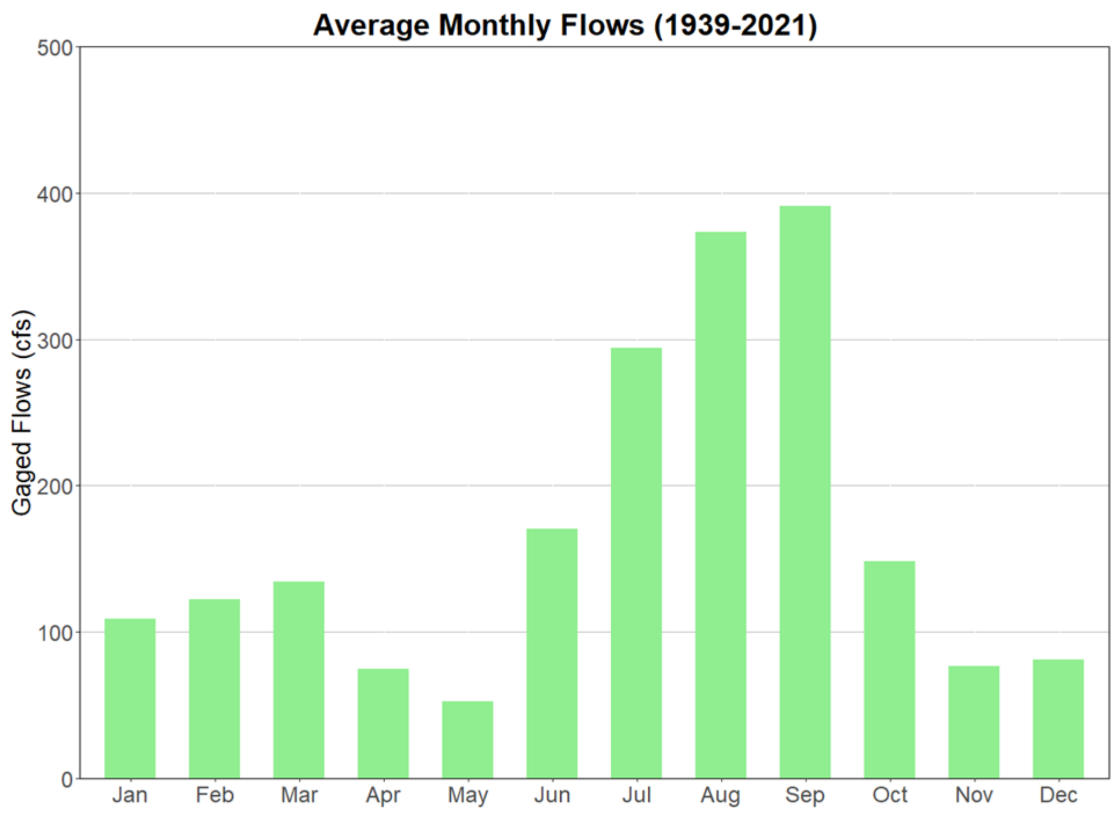

Figure 2-28. Average monthly rates of flow measured at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage from 1939 through 2021.

The annual and monthly flow history with a 6th-order polynomial fit to the data for the Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage for the period of record is shown in Figures 2-29 and 2-30. There appears to be no significant long-term trend to the flow data based on the polynomial fit. Spring dry season (April through June) and wet season (June through September) monthly average flows are show in Figures 2-31 and 2-32. There appears to be a slight increasing trend in dry-season flows and no significant long-term trend to the wet-season flows.

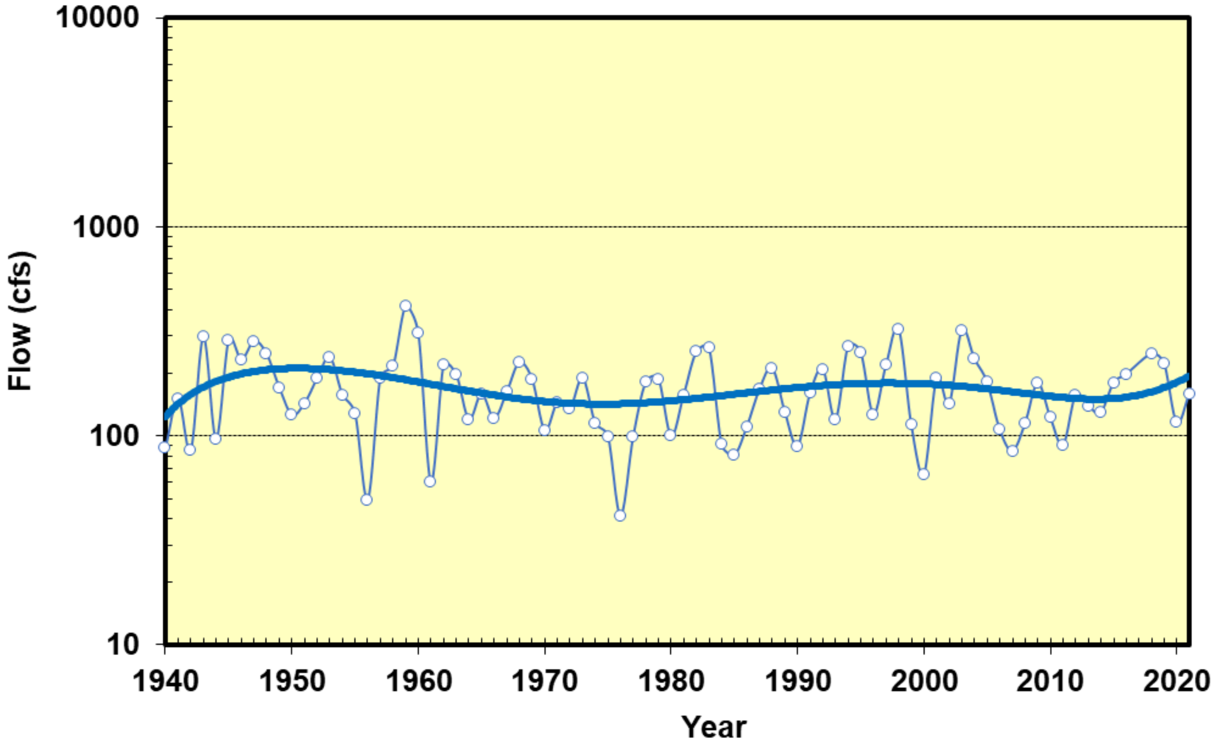

Figure 2-29. Annual average flow history at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage from 1940-2021 with a 6th-order polynomial trend line.

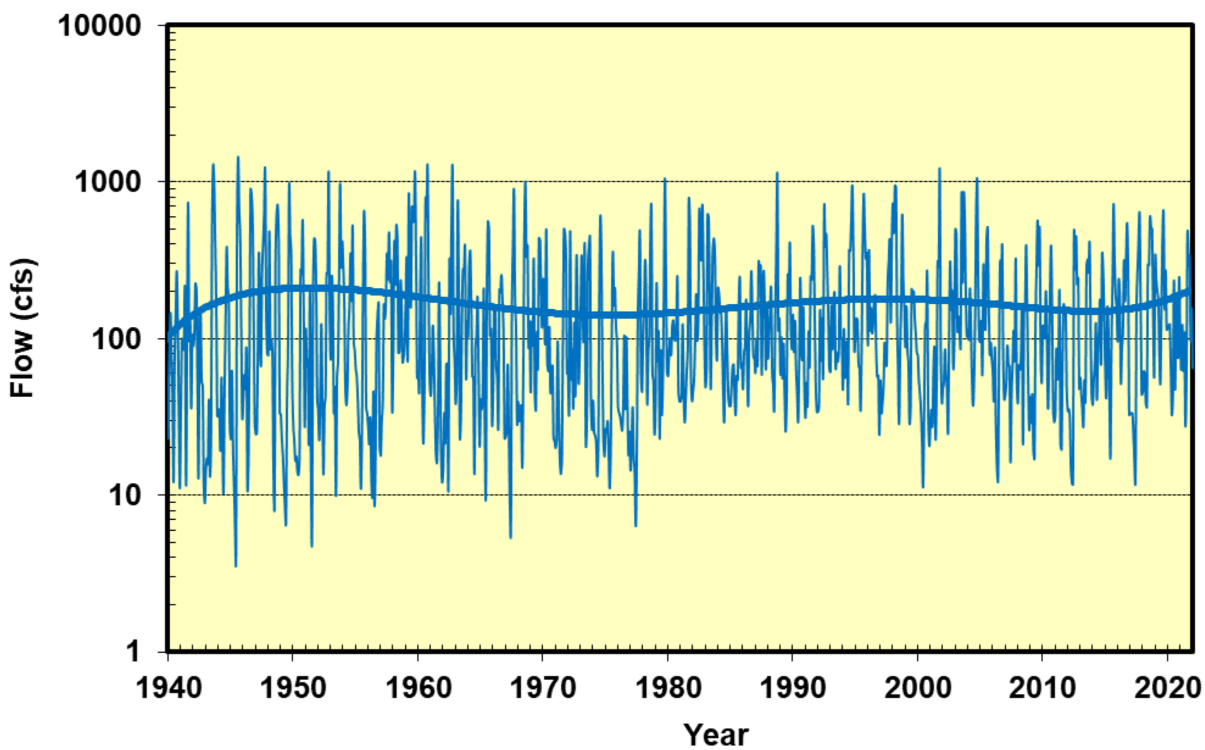

Figure 2-30. Monthly average flow history at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage from 1940-2021 with a 6th-order polynomial trend line.

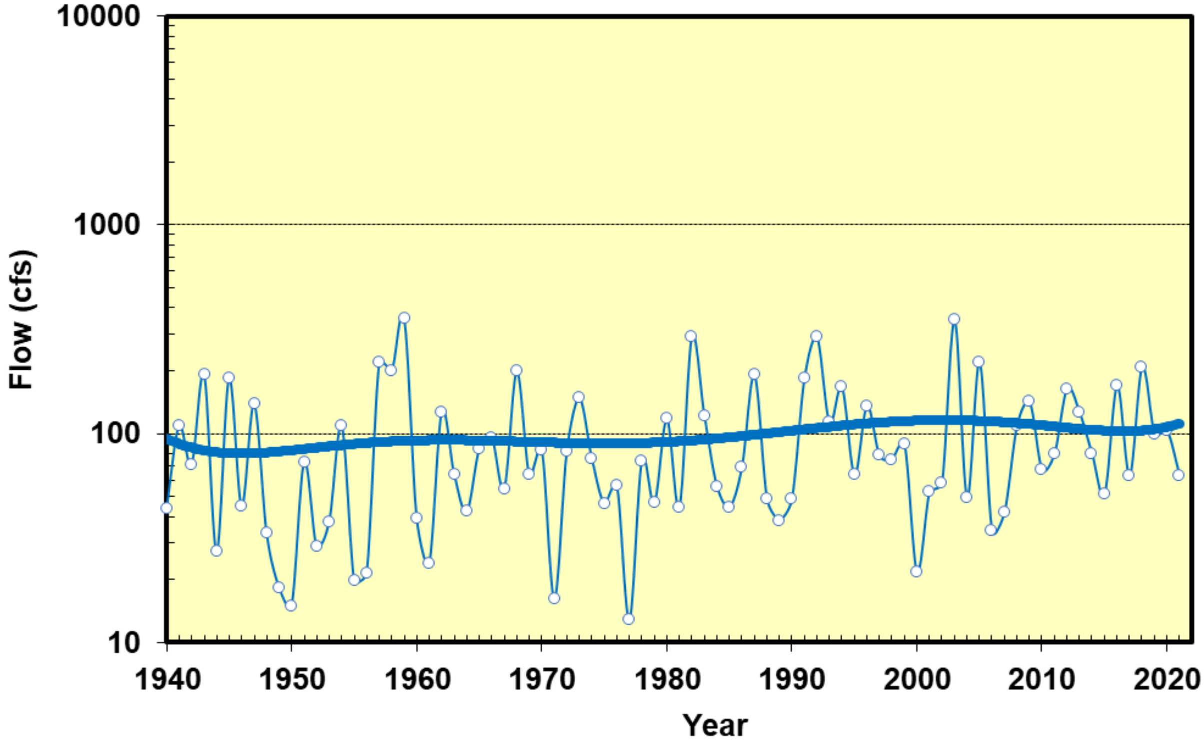

Figure 2-31. Spring dry season (April-June) average flow history at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage from 1940-2021 with a 6th-order polynomial trend line.

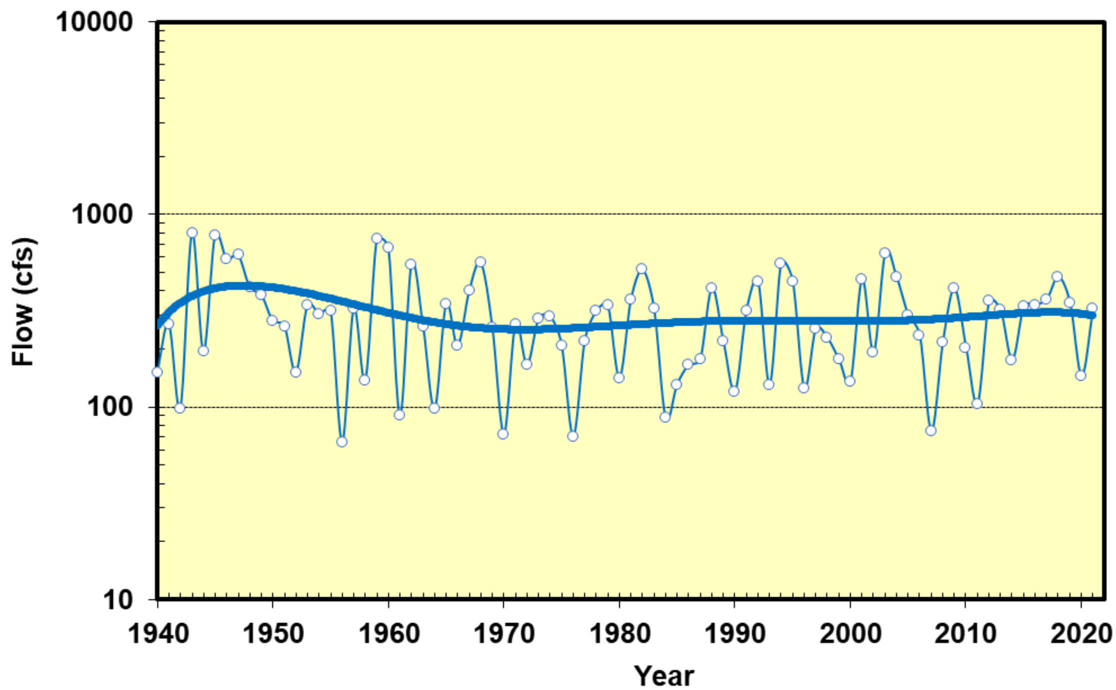

Figure 2-32. Wet season (June-September) average flow history at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage from 1940-2021 with a 6th-order polynomial trend line.

To confirm this understanding, the recently completed East Central Florida Transient Expanded (ECFTX) model (CFWI HAT 2020) was run to determine the head and baseflow changes associated with average 2010-2014 pumping within the model domain. The model domain covers an area ranging from Daytona Beach (to the north) to the Charlotte-Desoto County line (to the south). It spans from the Gulf of Mexico to the Atlantic Ocean (Figure 2-33). The model grid is aligned in a north-to-south direction and has 603 rows and 704 columns with a uniform grid spacing of 1,250 ft (381 m). It includes an area of approximately 23,800 square miles (61,642 square km).

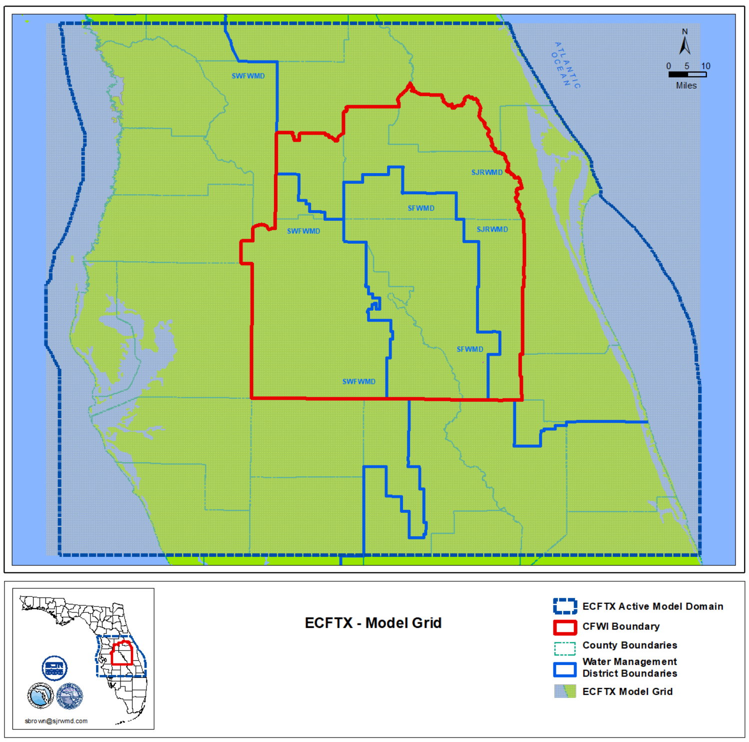

Figure 2-33. Model grid for the East Central Florida Transient Expanded (ECFTX) model domain (from CFWI HAT 2020).

Vertically, the ECFTX model includes eleven hydrostratigraphic layers, and each is treated as a separate layer in the model (Figure 2-34). In descending order, they are: (1) the SA, (2) the Intermediate Aquifer System/Confining Unit (IAS/ICU), (3) the UFA – upper permeable zone (UFA-upper), (4) the Ocala-Avon Park low permeability zone (OCAPlpz), (5) the Avon Park high-permeability zone (APhpz), (6) MCU_I, the first component of the Middle Confining Unit, (7) the overlap unit of the Lower Floridan aquifer (LFA) (second component, where MCU_I and MCU_II overlap without touching), (8) MCU_II, the third component of the MCU, (9) the upper permeable zone (the first subdivision of the LFA called the LFA-upper), (10) the low permeability glauconitic marker unit (second subdivision of the LFA called GLAUClpu), and (11) the LFA – basal permeable zone (LFA-basal).

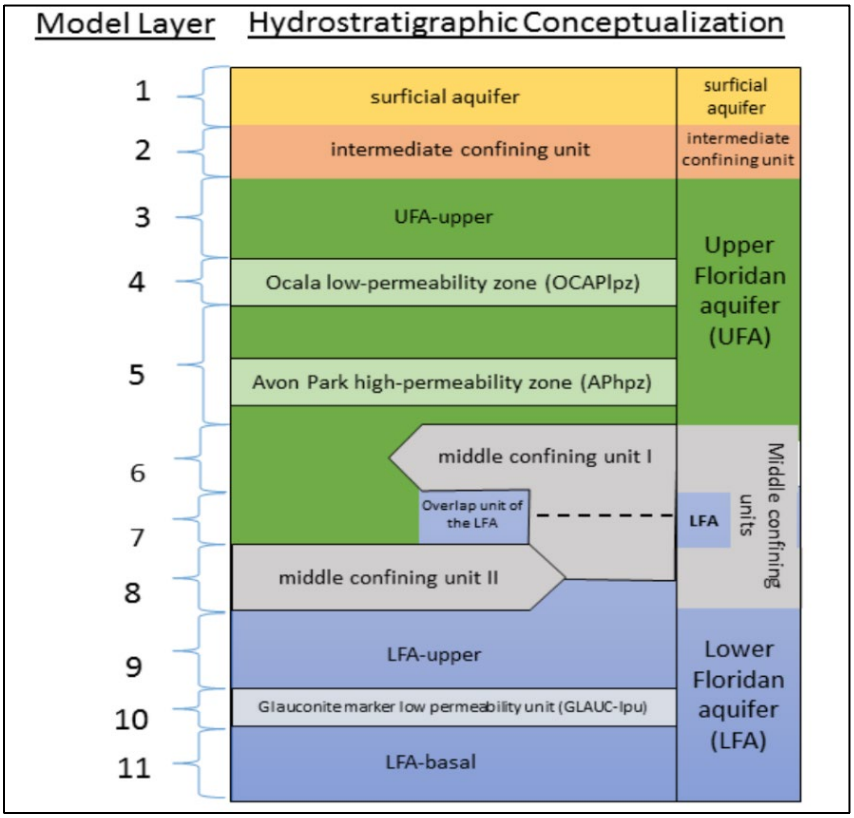

Figure 2-34. Vertical discretization of the ECFTX model (from CFWI HAT 2020).

The ECFTX model is a transient model using monthly stress periods that was calibrated from 2004-2012 and verified from 2013-2014. A 2003 steady-state model was run to establish starting conditions for the transient simulation. Calibration targets for the entire ECFTX model domain required a mean error of less than one foot (0.3 m) for all wells in the SA, UFA, and LFA, a root mean squared error of less than 5 ft (1.5 m) from all wells within each aquifer, and a mean absolute error within 5 percent of the total head elevation range for each aquifer. For the CFWI area, 50 percent of the wells were required to have a mean absolute error of less than 2.5 ft (0.76 m), and 80 percent of the wells were required to have a mean absolute error of less than 5 ft (1.5 m). Total modeled springflow had to be within 10 percent of the estimated/measured mean springflow and simulated mean springflow for each 1st and 2nd magnitude spring, and continuous observations had to be within 10 percent of mean average observed flow over the calibration period.

Head and springflow calibration targets were achieved for the CFWI planning area and ECFTX model domain. For the calibration period from 2004-2012, mean simulated springflow in the model from all 158 springs was 2,082 cfs, while observed (estimated and measured) springflow was 2,158 cfs, resulting in a mean error of -3.5 percent. The ECFTX model was successfully peer reviewed by Dr. Mark Stewart, Dr. Lou Motz, and Pete Andersen from Tetra Tech, Inc. over the duration of model construction and calibration (Andersen et al. 2020).

The pumping scenario consisted of reducing model-wide pumping by 50 percent from 2003-2014 and noting changes in head and baseflow associated with this reduction compared to the existing pumping during the same time period. The changes were multiplied by two to estimate changes associated with current pumping conditions from a non-pumping condition. The change was processed to show average five-year change from 2010-2014 to reflect more recent pumping history.

Estimated SA water level change from a pre-pumping to average 2010-2014 pumping condition is shown in Figure 2-35. Most of the predicted SA water level changes showed an increase due to agricultural return water applied within the SA from UFA withdrawals. Increases ranged from 0.25-1 ft (0.08-0.3 m), with localized areas greater than 1 ft (0.3 m). Predicted lowering of the SA water levels was relatively minor, generally less than 0.1 ft (0.03 m). These results are consistent with a thick ICU and tightly confined UFA in the area. Baseflow changes, which are the SA groundwater contribution to flow at the Little Manatee River, were predicted to increase 11.6 percent for the Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage from a non-pumping to average 2010-2014 withdrawal condition. This result is consistent with increased water table elevations associated with agricultural irrigation and the trend of increasing dry season flow as measured at the USGS gage over the period of record.

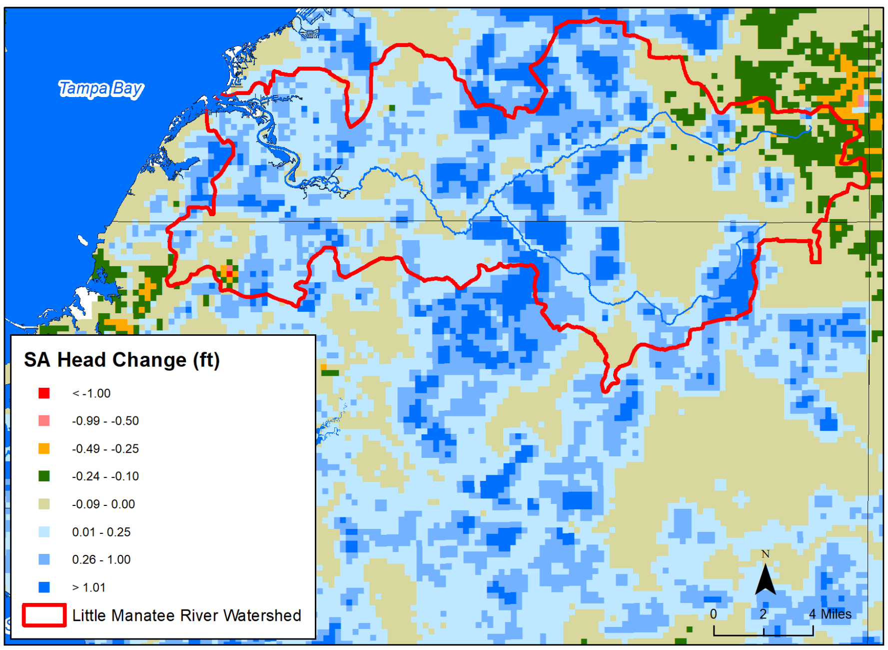

Figure 2-35. Surficial aquifer (SA) water level change from zero pumping to 2010-2014 average pumping conditions as predicted by the East Central Florida Transient Expanded (ECFTX) model. Note: Positive (blue) indicates an increase from a non-pumping condition and 1 ft = 0.3048 m (from CFWI HAT 2020).

The flow changes associated with the Little Manatee River are due to its connection to the SA. Surface water runoff from rainfall and increased baseflow due to agricultural irrigation (water table increases from irrigation and irrigation runoff) directly contribute to flow changes through time. There are no significant groundwater withdrawal impacts that result in reductions to river flow, since the system is well-confined from the SA to the underlying UFA where nearly all groundwater use occurs. Due to this situation, the minimum flow criteria will apply only to any existing or future surface water withdrawals from the river.

2.6 Surface Water Withdrawals

The FP&L Company, which operates an electrical power generation plant just south of the main river channel in Manatee County, withdraws surface water from the Little Manatee River (Figure 2-3). The FP&L Manatee Plant is the only water user in the watershed that withdraws surface water from the Little Manatee River or its tributaries.

The FP&L Manatee Plant is located near the southwest corner of the cooling pond or Lake Parrish shown in Figure 2-3. It has three units, and Unit 1 began operation in 1976. Units 1 and 2 use either natural gas or residual oil as the source for power generation. Unit 3 was approved in 2003 under the Power Plant Siting Act by the Florida Governor and Cabinet and uses natural gas as the fuel source for power generation. Cooling, general service, and process water for the power plant is stored in Lake Parrish, which was constructed in the early 1970s. Three sides of Lake Parrish have above-grade earthen dikes, while the natural ground elevation is sufficiently high to contain the water on the eastern shore. Since water losses from Lake Parrish as a result of evaporation and downward groundwater seepage are not fully replaced by rainfall during most years, make-up water for the cooling pond is provided by withdrawals from the Little Manatee River.

An intake facility is located on the south bank of the river, where pumps are used to withdraw water. The initial regulatory schedule that determined allowable withdrawals from the river was established in a permit agreement established between FP&L and the District in 1973. That schedule established three seasonal low-flow thresholds below which withdrawals could not reduce river flows: 40 cfs from October through July, 112 cfs for August, and 97 cfs for September.

As part of the recertification of the power plant in 2004, which included the addition of natural gas fuel, the schedule for river withdrawals was substantially revised in order to minimize potential impacts to the Little Manatee River. Under the current Water Use Permit (WUP), No. 5302.002, FP&L's withdrawals are restricted to 10 percent of river flow at the intake site, with a 40 cfs low-flow threshold applied year-round. The withdrawal schedule allows for an emergency diversion schedule (EDS) to be applied when water levels in the cooling pond fall below 62 ft NGVD and until they reach 63 feet NGVD, subject to meeting the low-flow threshold of 40 cfs. The WUP states that once minimum flows for the Little Manatee River are adopted by the District, the diversion schedules included in the permit and site certification shall be modified to be consistent with the adopted minimum flows. The withdrawal rates permitted by FP&L are based on a stream gage maintained by FP&L located about 3 miles (5 km) upstream from the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage, but the difference in drainage areas is fairly small.

The daily surface water withdrawals from the Little Manatee River by FP&L from 1976 through 2021 are summarized in Figure 2-36. Note that these withdrawals were included when developing the baseline flow record (see Section 5.2).

From 1976 through 1989, there was no withdrawal 69 percent of the time. Withdrawals ranged from 0.1 to 266.3 cfs, and the average withdrawal by FP&L was 34.5 cfs. The highest withdrawals (181.5-266.3 cfs) occurred during four days in December 1976 in association with filling Lake Parrish (Figure 2-36).

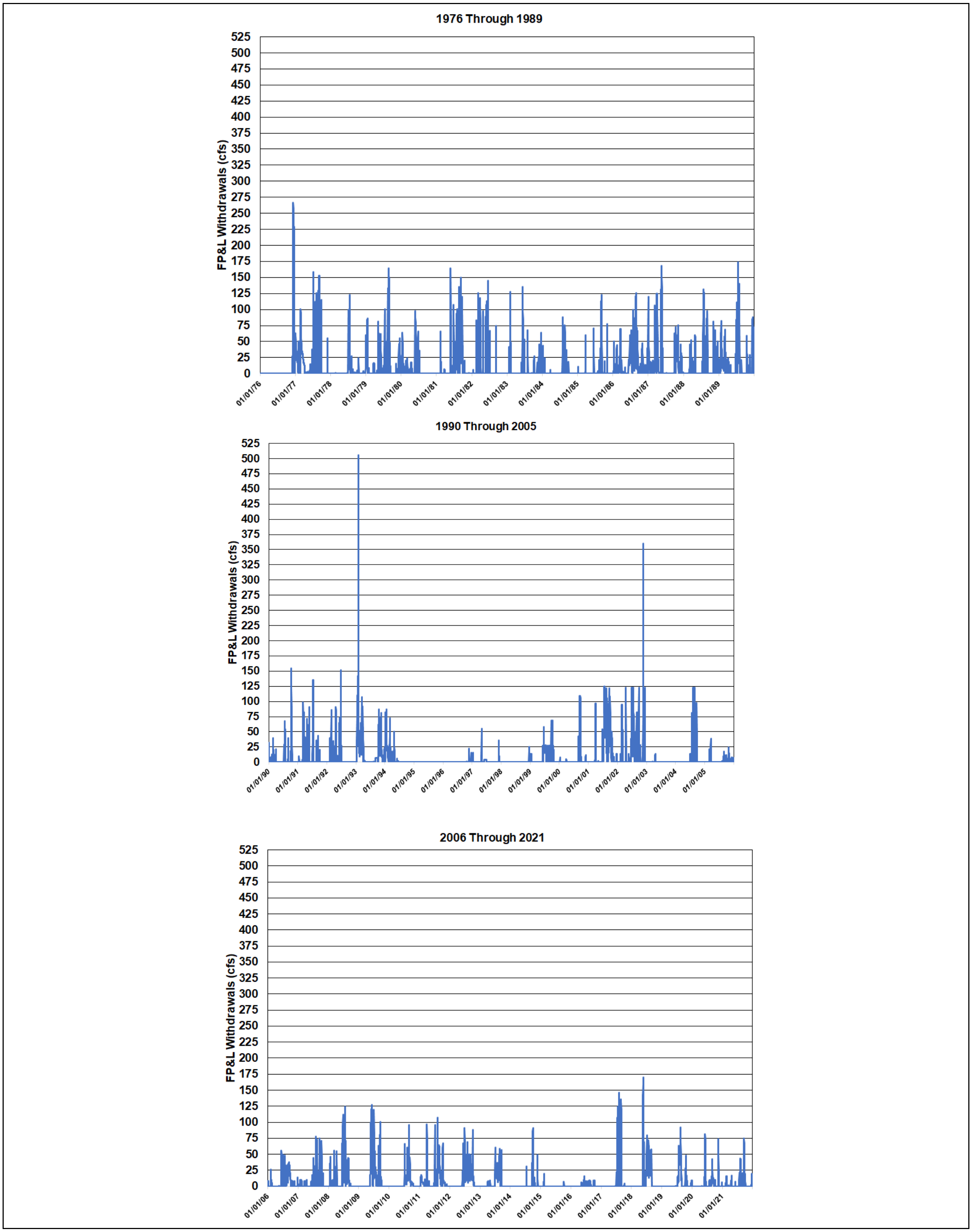

Figure 2-36. Daily surface water withdrawals by the FP&L Company from the Little Manatee River from 1976 through 2021. Top graph: 1976-1989, middle graph: 1990-2005, lower graph: 2006-2021.

There were no withdrawals from the Little Manatee River by FP&L 79 percent of the time from 1990 through 2005. The highest withdrawals occurred during this time period, with withdrawals of 360 cfs occurring on three days in November 2002 and the highest withdrawal to date, 505.6 cfs, occurring on February 1, 1993 (Figure 2-36). During this time period, the average withdrawal was 34.2 cfs.

On average, the withdrawals by FP&L from the Little Manatee River have been declining over time. The average withdrawal by FP&L from 2006 through 2021 was 24.2 cfs, and withdrawals ranged from 0.1 to 170.4 cfs. There were no withdrawals from the river 73 percent of the time during this period.

2.7 Surface Water Discharges

The Mosaic Company has three permitted surface water discharges from the Four Corners Mine. Two of these permitted discharges outfall into tributaries that flow into the Little Manatee River (Figure 2-37). These outfall sites are managed under DEP Permit Number FL0036412 on a five-year recurring application basis. The permit, under the provisions of Chapter 403, F.S., as well as applicable rules of the F.A.C., constitutes authorization to discharge to waters of the state under the National Pollutant Discharge Elimination System (NPDES).

The Mosaic Company operates the Four Corners Mine, a 47,361-acre (19,166-hectare) phosphate mine and beneficiation plant in Hillsborough, Polk, Manatee, and Hardee Counties. The mined ore is pumped as a slurry to the beneficiation plant, where sand and clays are separated from the phosphate rock by washing, screening, and double flotation. Water that is decanted from on-site clay settling areas is passed into the mine's recirculation ditch system for reuse. The treatment of mine recirculation water primarily involves the settling of solids, but additional treatment methods are available, if necessitated, by reported pollutant exceedances.

When rainfall contributions exceed the mine's available surface water storage capacity, discharges are made from Site D-001 into the headwaters of Alderman Creek (Little Manatee River tributary), Site D-002 into the headwaters of Payne Creek (Peace River tributary), and Site D-003 into the headwaters of Howard Prairie Branch (Little Manatee River tributary). For the purposes of this report, information regarding Site D-002 is not included. Monthly reporting on flows and water quality from the discharges at these structures is required by DEP Permit Number FL0036412 and can be queried on Oculus, the DEP's online repository for permit-related data.

Surface water discharge Site D-001 became operational in 1989 and is an outfall structure consisting of a V-notch weir. Over the period of record, the average monthly discharge is 11.35 mgd (Figure 2-38). An outfall structure consisting of a compound rectangular steel weir, Site D-003 became operational in 2014. The average monthly discharge from Site D-003 over the period of record is 3.19 mgd (Figure 2-39).

Surface water discharges at both sites are variable and typically highest during the wet season months from July through September (Figures 2-38 and 2-39). Discharges from Site D-001 remained relatively low, typically less than 20 mgd, from 1989 until 1998, when 80 mgd was discharged in May. There was no discharge of surface water from this outfall into Alderman Creek from December 1999 through August 2001. From September 2001 through October 2009, when there was a discharge, it averaged 30 mgd, and the highest discharge to date of 87 mgd occurred

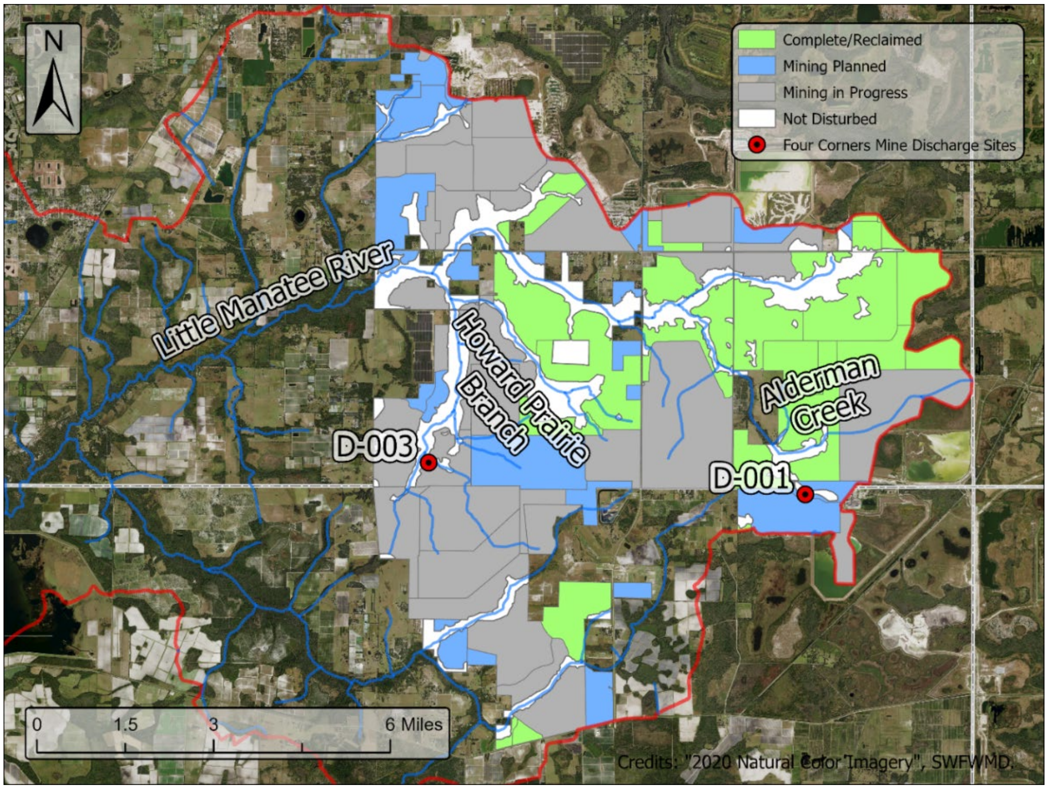

Figure 2-37. Locations of The Mosaic Company's permitted surface water discharges into Little Manatee River tributaries overlain on Mandatory Phosphate Mining Units (FDEP 2021b, 2021c).

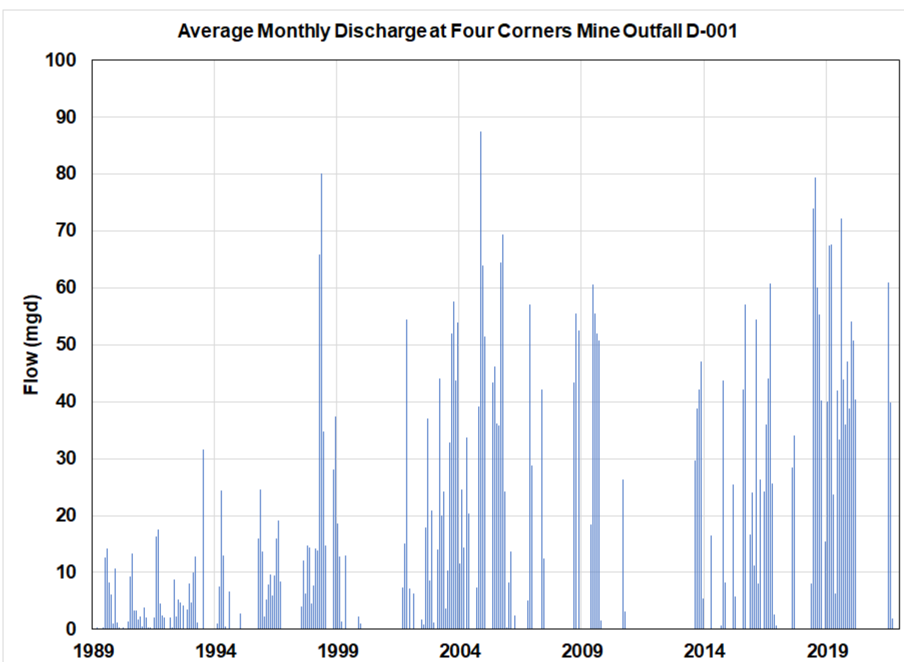

Figure 2-38. The average monthly surface water discharge (mgd) from the Four Corners Mine Outfall Site D-001 to the headwaters of Alderman Creek from 1989 through 2021.

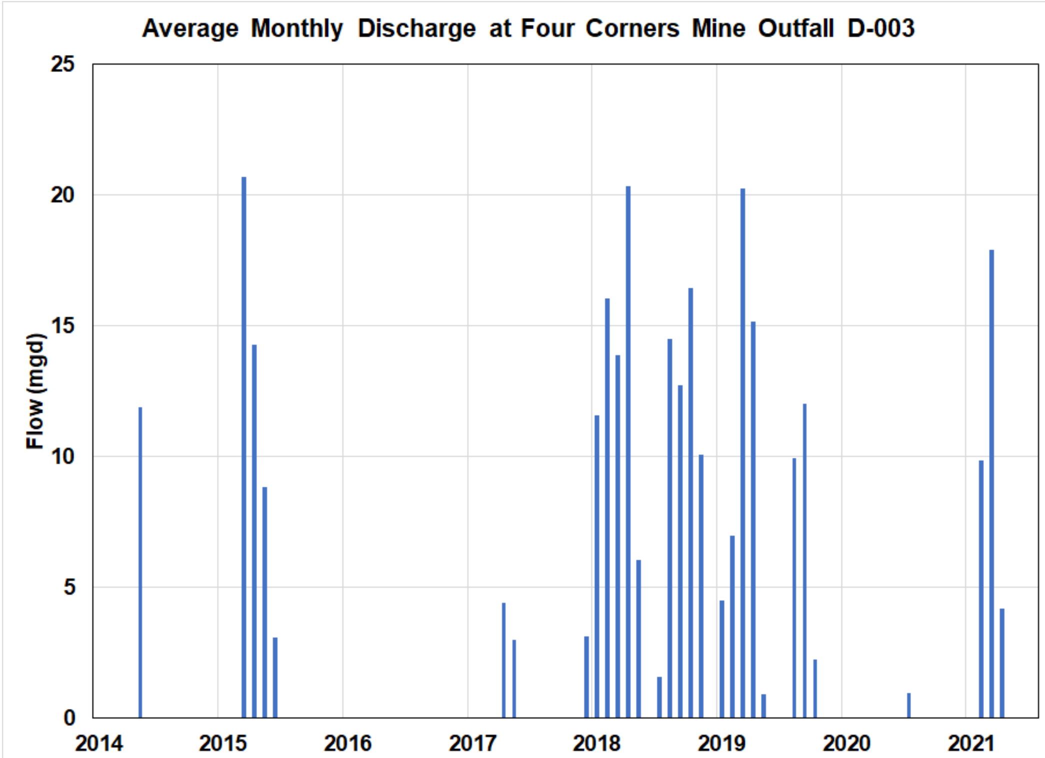

Figure 2-39. The average monthly surface water discharge (mgd) from the Four Corners Mine Outfall Site D-003 to the headwaters of Howard Prairie Branch from 2014 through 2021.

in November 2004 (Figure 2-38). From November 2009 through July 2013, there was little to no discharge from Site D-001. Since August 2013 through March 2020, when there was a discharge of water into Alderman Creek, it averaged 35 mgd. With few exceptions, there was no discharge from Site D-001 from April 2020 through December 2021 (Figure 2-38).

The discharges of surface water from Site D-003 into Howard Prairie Branch have been infrequent and have rarely exceeded 20 mgd (Figure 2-39). The highest discharge of water from Site D-003, almost 21 mgd, occurred in August 2015.

As described in Section 2.2, the acreage of mined lands has increased in the Little Manatee River watershed over time, and the discharge of water from Site D-001 appears to be on an increasing trend since 1989 (Figure 2-38). Because the discharge from Sites D-001 and D-003 sites does not always occur and when it does, it is variable (DEP 2012b), it was not considered when developing the baseline flow record for the Little Manatee River. In addition, because the data are not available as daily values, including the additional flow from Sites D-001 and D-003 into the baseline flow record would be difficult. It is also unknown how the discharges of surface water into the headwaters of both Alderman Creek and Howard Prairie Branch affect the flow at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage, which was used to develop the baseline flow record (see Section 5.2). However, the excess flows from agricultural return water are included in the baseline flow record and most likely include the discharge of surface water from these sites, and not specifically including the discharge data from Sites D-001 and D-003 provides for the development of more protective minimum flows.

CHAPTER 3 - WATER QUALITY CHARACTERISTICS AND RELATIONSHIPS WITH FLOW

This chapter includes an overview of the status and trends for water quality parameters of concern for the Little Manatee River. Exploratory evaluations of water quality and flow relationships are also presented. In addition to the information included in this chapter, detailed supplementary information is included in Jacobs and JEI (2020) in Appendix D. For those parameters that have adopted water quality standards, the standards are included in many of the plots and analyses in this chapter and in Jacobs and JEI (2020) in Appendix D. The inclusion of adopted water quality standards is for informational purposes only and is not intended to be a determination of impairment.

3.1 Introduction

Water quality is one of ten Environmental Values defined in the Florida Water Resource Implementation Rule (Chapter 62-40, F.A.C.) to be considered when establishing minimum flows. Under Rule 62-302.200, F.A.C., Florida's surface water quality standards consist of four components: 1) the designated use or classification of each water body; 2) the surface water quality criteria (numeric and narrative) for each water body, which are established to protect its designated use; 3) the anti-degradation policy; and 4) moderating provisions, such as mixing zones. Each surface water body in Florida is classified according to its present and future most beneficial use, referred to as its designated use, with class-specific water quality criteria for select physical and chemical parameters, which are established to protect the water body's designated use (Chapter 62-302, F.A.C.).

3.1.1 Water Quality Classification

The Little Manatee River is designated by the DEP as an OFW, which is a water designated worthy of special protection because of its natural attributes. This special designation is applied to certain waters and is intended to protect existing water quality. Discharges regulated through a permitting program that are proposed within an OFW must not lower background ambient water quality. Permits for indirect discharges that would significantly degrade a nearby water body designated as an OFW may not be issued. In addition, activities or discharges within an OFW, or which significantly degrade an OFW, must meet a more stringent public interest test. Each water body has a designated use in Florida statutes, and the Little Manatee River is designated as a Class III water, which 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.).

3.1.2 Impaired Waters Rule

Section 303(d) of the Federal Clean Water Act (CWA) requires each state to identify and list Impaired Waters, where applicable water quality criteria are not being met. To meet the reporting requirements of the CWA, the State of Florida publishes the Integrated Water Quality Assessment for Florida. Assessments are made based on specific segments that are each assigned a specific Water Body Identification (WBID). The Little Manatee River watershed includes 28 WBIDs (Figure 3-1). As of November 2022, no mainstem portion of the Little Manatee River (e.g., WBIDs

1742A1, 1742B, 1742C1, and 1790) is currently listed as Impaired for any parameter other than for *Escherichia* (*E.*) *coli* or Enterococci bacteria (https://floridadep.gov/dear/watershed-assessment-section/documents/comprehensive-verified-list). Numerous tributaries of the river are listed as Impaired for fecal coliform, *E. coli*, or Enterococci bacteria.

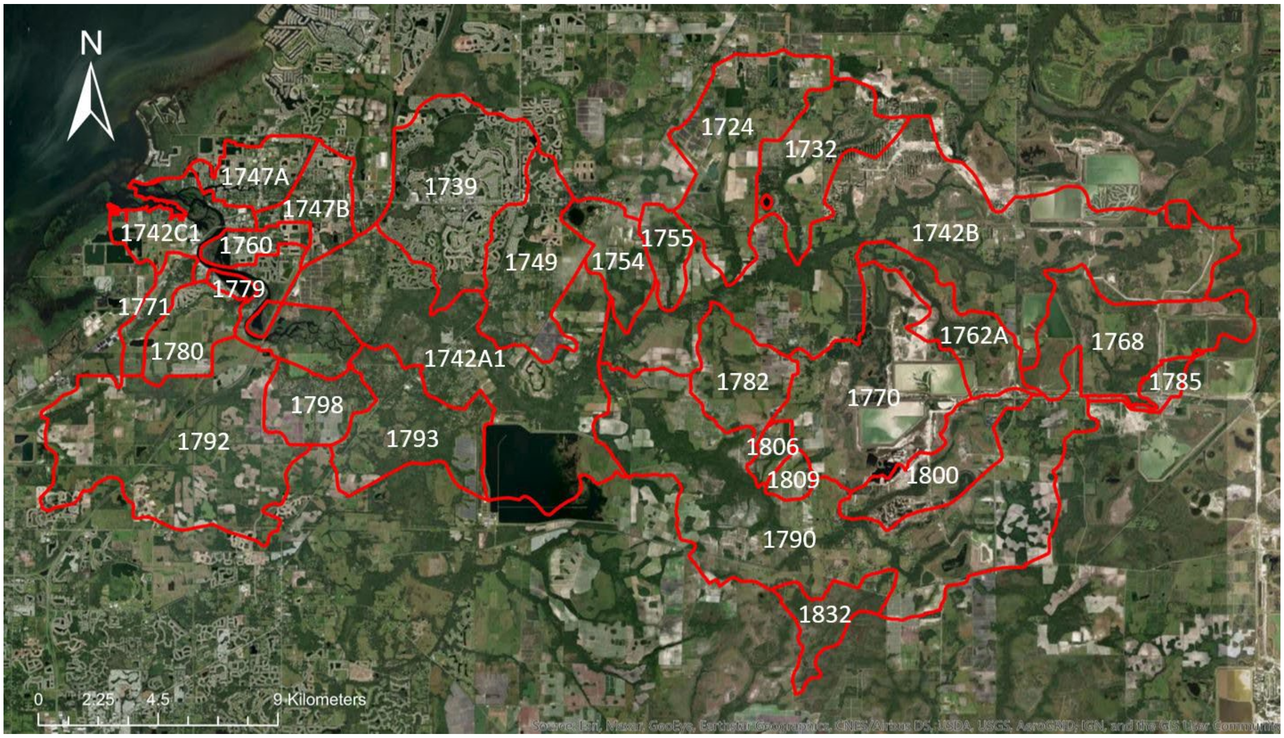

Figure 3-1. Location of Water Body Identifications (WBIDs, red boundaries) within the Little Manatee River Watershed (from SWFWMD 2021c).

3.1.3 Total Maximum Daily Loads

Section 303(d) of the CWA requires states to submit a list of surface waters that do not meet applicable water quality standards (Impaired Waters) to the US Environmental Protection Agency (EPA) and to establish a total maximum daily load (TMDL) for each pollutant causing the impairment. A TMDL is the amount of a certain pollutant that a receiving water body can assimilate without causing violation of a pollutant-specific water quality standard. All TMDLs are site-specific criteria and apply to identified WBIDs. Exceeding a TMDL value constitutes exceeding the criteria for the identified WBID. A TMDL must be developed for WBIDs placed on DEP's Verified List of Impaired Waters. Once a TMDL has been adopted, the WBID for which the TMDL applies is then removed or “delisted” from the Verified List of Impaired Waters. Delisting a WBID does not imply that the WBID is no longer impaired.

A TMDL for fecal coliform was prepared by the DEP in 2009 for the Little Manatee River (WBID 1742A) and South Fork of the Little Manatee River (WBID 1790) (Bridger and Tyler 2009). A state-wide TMDL for mercury has also been developed (DEP 2013), and the Little Manatee River is under a fish consumption advisory for mercury for Bluegill Sunfish (*Lepomis macrochirus*), Largemouth Bass (*Micropterus salmoides*), Redear Sunfish (*Lepomis microlophus*), and Spotted Sunfish (*Lepomis punctatus*) (www.dchpexternalapps.doh.state.fl.us/fishadvisory/).

3.2 Methods for Water Quality Analysis

For characterization of water quality in the Little Manatee River, the Hillsborough County Environmental Protection Commission (EPC) and Impaired Waters Rule (IWR) databases were queried to identify routine water quality monitoring sites. In accordance with minimum sampling requirements presented by Reckhow et al. (1993), sites were included in our analysis if they contained at least five years of data, 60 observations within their period of record, and if the results of recent data collection efforts were available.

Trends in water quality over time can provide important information relevant to assessing the current status and potential future condition of a water body, relative to water quality standards. The Seasonal Kendall Tau trend test (Hirsch and Slack 1984) is a nonparametric statistical method that screens for monotonic trends in data over time but does not provide inferences as to what may be causing detectable changes. Similar to methods employed by Hood et al. (2011 in Appendix A), the effects of flow on water quality were removed prior to evaluating data for trends over time.

To further evaluate relationships between water quality and flow, linear regression was performed on natural log transformed flow and water quality parameter data. Linear regression is a common statistical method for relating predictor variables to response variables under strict assumptions. A seasonal classification term was added to the model to evaluate how different months may affect the response between flows and water quality parameters. Importantly, even when linear regressions suggest significant relationships, this does not imply causation. While Seasonal Kendall Tau trend tests and linear regressions were performed for all qualifying water quality constituents in both the Upper and Lower Little Manatee River, ecological and environmental properties of freshwater and estuarine systems and land-use changes throughout the watershed guide the presentation of relevant results in this chapter.

3.3 Upper River Water Quality

Four stations were included in the water quality analysis for the Upper Little Manatee River. They include EPC Stations 129 and 140, and Manatee County Stations D1 and D3 (Table 3-1, Figure 3-2).

3.3.1 Chlorophyll *a* and Dissolved Oxygen

Chlorophyll and dissolved oxygen concentrations are important indicators of impairment in flowing systems. While there are many types of chlorophyll, chlorophyll *a* is commonly assessed for aquatic ecosystem studies. The EPC has historically reported chlorophyll *a* concentrations using estimates uncorrected for pheophytin; therefore, the long-term record for chlorophyll was based on these uncorrected values. The annual geometric means for uncorrected chlorophyll *a* were consistently well below the 20 µg/L DEP threshold for freshwater streams (per 62-303.651 (4), F.A.C.; Figure 3-3). Only corrected chlorophyll *a* values were reported for Stations D1 and D3, in which phaeophytin, a natural chlorophyll *a* degradation product with light absorption at the same spectrum as chlorophyll a, is removed. Therefore, the annual geometric mean for corrected chlorophyll *a* was also compared for all four stations analyzed in the upper river (Figure 3-4), with comparable results, suggesting no significant issues with algal blooms in this river segment. No temporal trends for chlorophyll *a* were observed in this section of the river. A negative relationship was observed between chlorophyll *a* and flow at Stations 129 and 140 (Table 3-2).

Table 3-1. Routine water quality sampling stations above US Highway 301 in the Upper Little Manatee River (from Jacobs and JEI 2020 in Appendix D).

Site Identification No.	Latitude	Longitude	WBID	First Sample	Most Recent Sample
129	27.70468	-82.1978	1742B	Jan. 1999	Jan. 2020
140	27.66283	-82.301	1742B	Jan. 1999	Jan. 2020
D1	27.64859	-82.2944	1790	Jan. 2000	Dec. 2017
D3	27.60194	-82.2111	1790	Feb. 2000	Dec. 2017

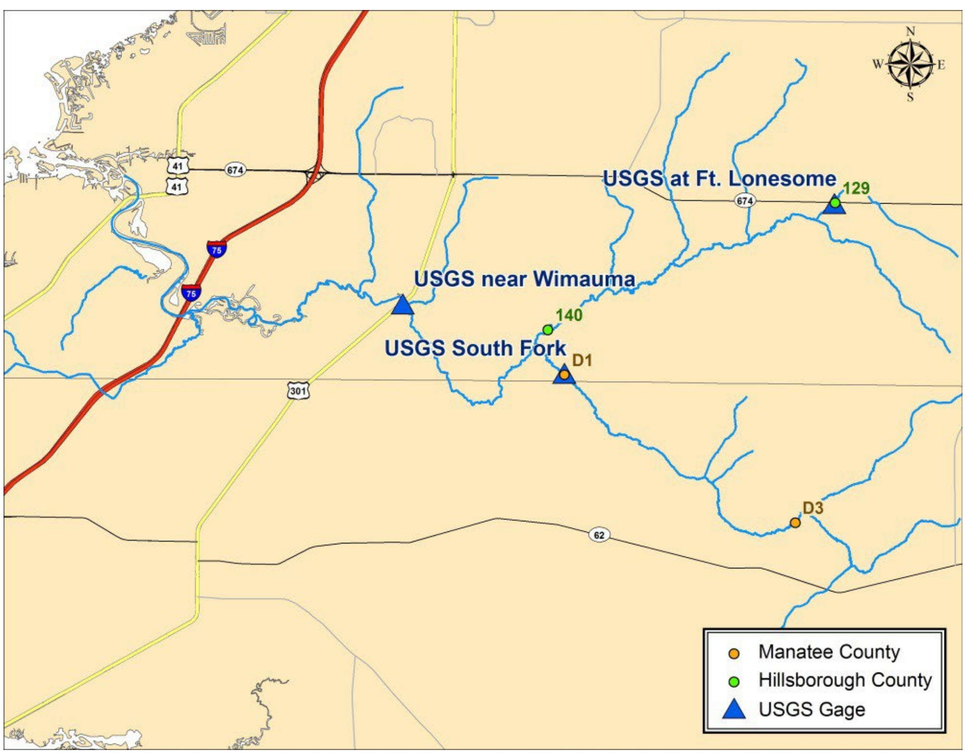

Figure 3-2. Location of active, long-term water quality monitoring sites and US Geological Survey (USGS) stream flow gaging stations selected for analysis of water quality in the Upper Little Manatee River (from Jacobs and JEI 2020 in Appendix D).

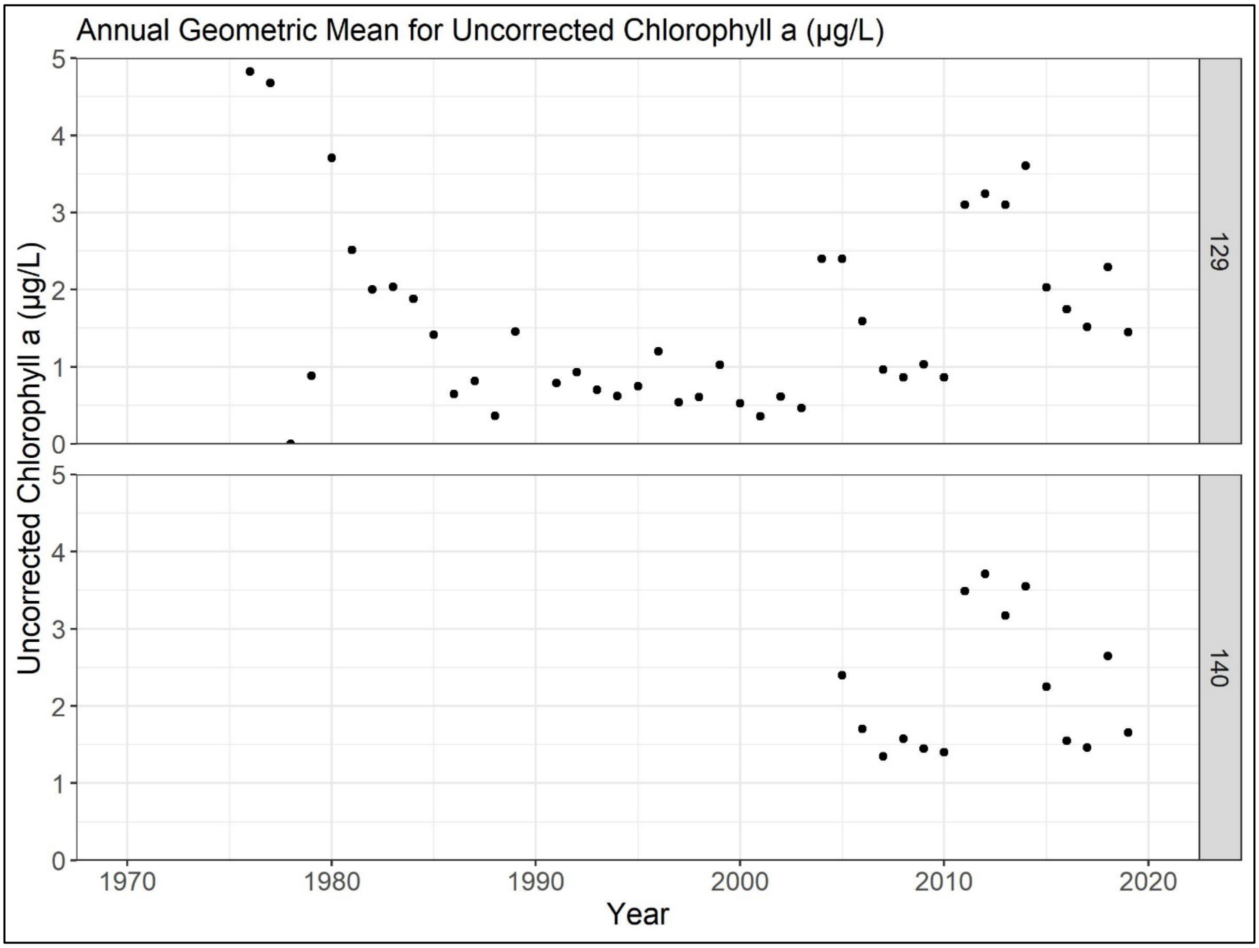

Figure 3-3. Annual geometric mean uncorrected chlorophyll *a* concentrations (µg/L) for the period of record at Hillsborough County Environmental Protection Commission Stations 129 and 140 in the Upper Little Manatee River.

Mid-water dissolved oxygen levels have been reported by the EPC and DEP as both concentrations and as percent saturation. The latter gives an approximation for the amount of oxygen the water can hold, as a function of temperature and, in estuarine systems, salinity. An increasing trend in flow-adjusted dissolved oxygen percent saturation was observed at both Stations 129 and D1, generally suggesting improvement of the system (Tables 3-2 and 3-3). When data at Station D3 were flow adjusted, the Seasonal Kendall Tau trend went from decreasing to no change (Table 3-2). Annual distributions of long-term dissolved oxygen since 1976 for Station 129, 1982 for Station 140, and shorter records since 2000 for Stations D1 and D3 are provided in Figure 3-4. Occurrence of mid-water hypoxic conditions (less than 2 mg/L) were extremely rare, occurring once at Station 129 in 1977. While not considered for statistics, 127 bottom dissolved oxygen samples were also taken in this river section by the EPC. None of these samples were below the hypoxic threshold of 2 mg/L. Annual distributions of dissolved oxygen percent saturation data indicate typical values well above the DEP threshold of 42 percent for Class II water bodies (per 602-302.533, F.A.C.; Figure 3-5). A negative relationship between flow and dissolved oxygen saturation was observed at Stations 129, 140, and D1 (Tables 3-2 and 3-3).

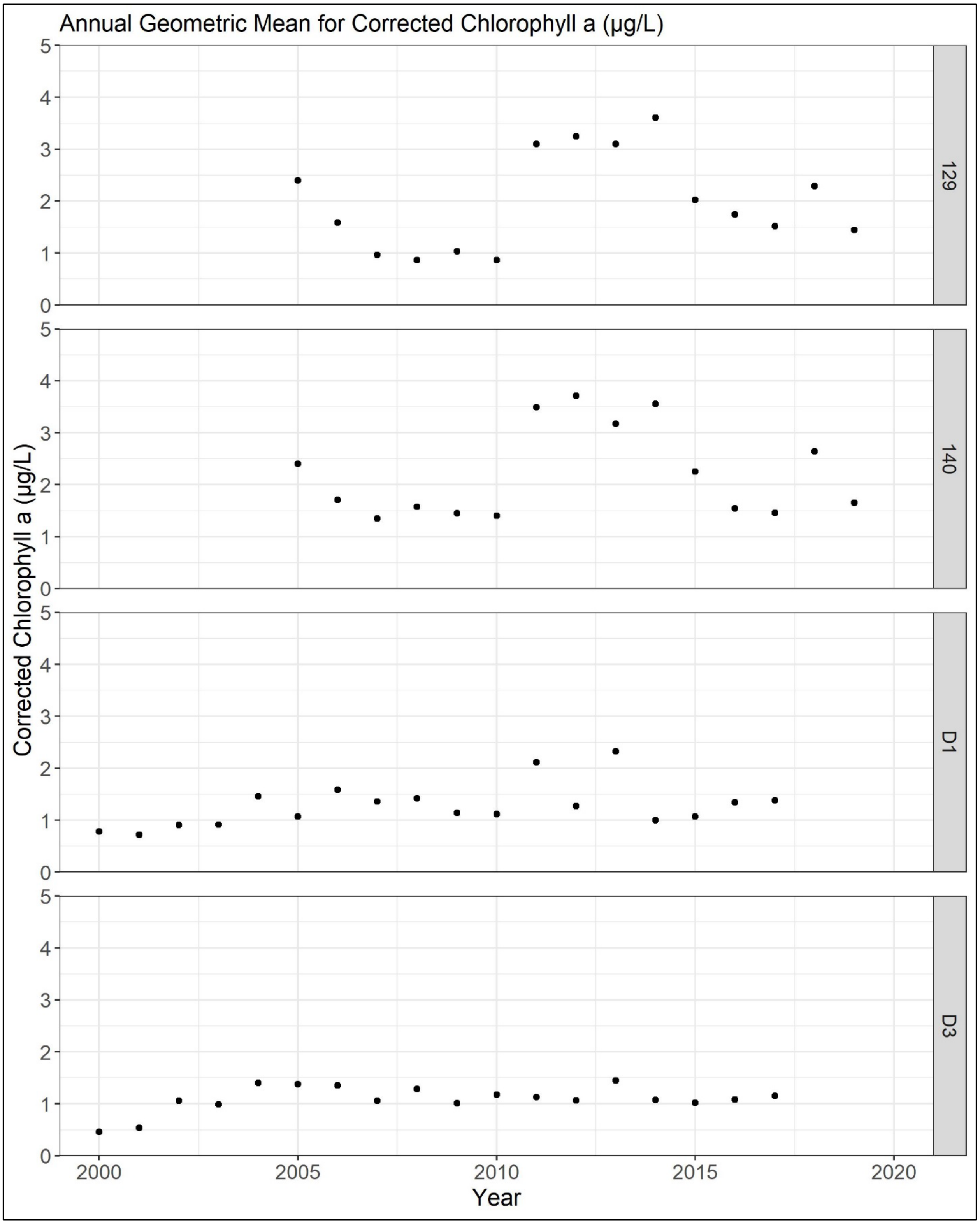

Figure 3-4. Annual geometric mean corrected chlorophyll a concentrations (µg/L) for the period of record at Hillsborough County Environmental Protection Commission Stations 129 and 140 and Manatee County Stations D1 and D3 in the Upper Little Manatee River.

Table 3-2. Results of Seasonal Kendall Tau trend tests with time for Stations 129 and 140 in the Upper Little Manatee River (from Jacobs and JEI 2020 in Appendix D). A zero value indicates a lack of statistical significance for the regression flow term, -1 indicates a statistically significant inverse relationship between the parameter and flow, and 1 indicates a statistically significant increasing relationship between the parameter and flow.

Water Quality Parameter	Station	Start Year	End Year	# of Samples	Temporal Trend Direction		Regression Results
					Trend	Flow Adjusted Trend	
Chlorophyll *a* (µg/L)	129	1976	2019	381	No Trend	No Trend	-1
	140	1981	2019	333	No Trend	No Trend	-1
Dissolved Oxygen (percent Saturation)	129	2002	2019	211	Increasing	Increasing	-1
	140	2002	2019	212	Decreasing	No Trend	-1
Total Nitrogen (mg/L)	129	1981	2019	455	No Trend	No Trend	1
	140	1981	2019	447	No Trend	No Trend	0
Ammonia (mg/L)	129	1976	2019	509	Decreasing	Decreasing	-1
	140	1981	2019	452	Decreasing	Decreasing	0
Organic Nitrogen (mg/L)	129	1977	2019	497	Increasing	Increasing	1
	140	1981	2019	446	Increasing	Increasing	1
Nitrate/Nitrite (mg/L)	129	1983	2019	436	No Trend	No Trend	-1
	140	1983	2019	439	Decreasing	Decreasing	-1
Total Phosphorus (mg/L)	129	1976	2019	511	Decreasing	Decreasing	1
	140	1981	2019	454	Decreasing	Decreasing	1
Ortho-Phosphate (mg/L)	129	1976	2019	357	Decreasing	Decreasing	1
	140	1981	2019	351	Decreasing	Decreasing	1
Fecal Coliform (n/100 mL)	129	1976	2016	474	No Trend	No Trend	1
	140	1981	2016	418	No Trend	No Trend	1
Fluoride (mg/L)	129	1976	2019	501	Increasing	Increasing	1
	140	1981	2019	450	No Trend	No Trend	1
pH (SU)	129	1976	2019	507	Increasing	Increasing	-1
	140	1981	2019	448	Increasing	Increasing	-1
Total Suspended Solids (mg/L)	129	1976	2008	355	No Trend	No Trend	0
	140	1981	2008	300	Decreasing	Decreasing	1
Turbidity (NTU)	129	1976	2019	509	Decreasing	Decreasing	1
	140	1981	2019	450	Decreasing	Decreasing	1

Table 3-3. Results of Seasonal Kendall Tau trend tests with time with flow for Manatee County Stations D1 and D3 in the South Fork of the Upper Little Manatee River (from Jacobs and JEI 2020 in Appendix D). A zero value indicates a lack of statistical significance for the regression flow term, -1 indicates a statistically significant inverse relationship between the parameter and flow, and 1 indicates a statistically significant increasing relationship between the parameter and flow.

Water Quality Parameter	Station	Start Year	End Year	# of Samples	Seasonal Kendall Tau Test Result for Trend with Time		Regression Results
					Trend	Flow Adjusted Trend	
BOD 5-Day (mg/L)	D1	2000	2017	89	Increasing	Increasing	0
	D3	2000	2017	92	Increasing	Increasing	0
Color (PCU)	D1	2000	2017	199	Decreasing	No Trend	1
	D3	2000	2017	206	No Trend	No Trend	1
Chlorophyll *a* (µg/L)	D1	2000	2017	190	No Trend	No Trend	0
	D3	2000	2017	198	No Trend	No Trend	0
Dissolved Oxygen (mg/L)	D1	2000	2017	200	No Trend	Increasing	-1
	D3	2000	2017	204	Increasing	No Trend	0
Dissolved Oxygen (percent Saturation)	D1	2000	2017	197	Increasing	Increasing	0
	D3	2000	2017	201	Increasing	Increasing	0
Fluoride (mg/L)	D1	2000	2017	136	No Trend	No Trend	-1
	D3	2000	2017	137	No Trend	No Trend	-1
Nitrate (mg/L)	D1	2000	2017	153	Increasing	Increasing	-1
	D3	2000	2017	155	Decreasing	No Trend	0
Total Kjeldahl Nitrogen (mg/L)	D1	2000	2017	173	No Trend	No Trend	1
	D3	2000	2017	183	Increasing	No Trend	1
Total Nitrogen (mg/L)	D1	2000	2017	188	Increasing	Increasing	0
	D3	2000	2017	195	No Trend	Increasing	1
Nitrate/Nitrite (mg/L)	D1	2000	2017	188	Increasing	Increasing	-1
	D3	2000	2017	196	No Trend	No Trend	0
pH (SU)	D1	2000	2017	200	Decreasing	Decreasing	1
	D3	2000	2017	206	Decreasing	Decreasing	0
	D1	2000	2017	173	Decreasing	No Trend	1

Ortho-Phosphate (mg/L)	D3	2000	2017	179	No Trend	No Trend	0
Total Phosphorus (mg/L)	D1	2000	2017	189	Decreasing	No Trend	0
	D3	2000	2017	193	No Trend	No Trend	0
Salinity (psu)	D1	2000	2017	197	No Trend	No Trend	-1
	D3	2000	2017	202	No Trend	No Trend	-1
Specific Conductance (µmhos/cm)	D1	2000	2017	198	No Trend	No Trend	0
	D3	2000	2017	204	No Trend	No Trend	0
Temperature (°C)	D1	2000	2017	197	No Trend	No Trend	0
	D3	2000	2017	203	No Trend	No Trend	0
Total Ammonia (mg/L)	D1	2000	2017	184	No Trend	No Trend	1
	D3	2000	2017	190	No Trend	No Trend	1
Total Suspended Solids (mg/L)	D1	2000	2017	191	No Trend	No Trend	1
	D3	2000	2017	200	No Trend	No Trend	1
Turbidity (NTU)	D1	2000	2017	199	No Trend	No Trend	0
	D3	2000	2017	206	No Trend	No Trend	-1
Un-ionized Ammonia (mg/L)	D1	2000	2017	179	No Trend	No Trend	-1
	D3	2000	2017	185	No Trend	No Trend	-1

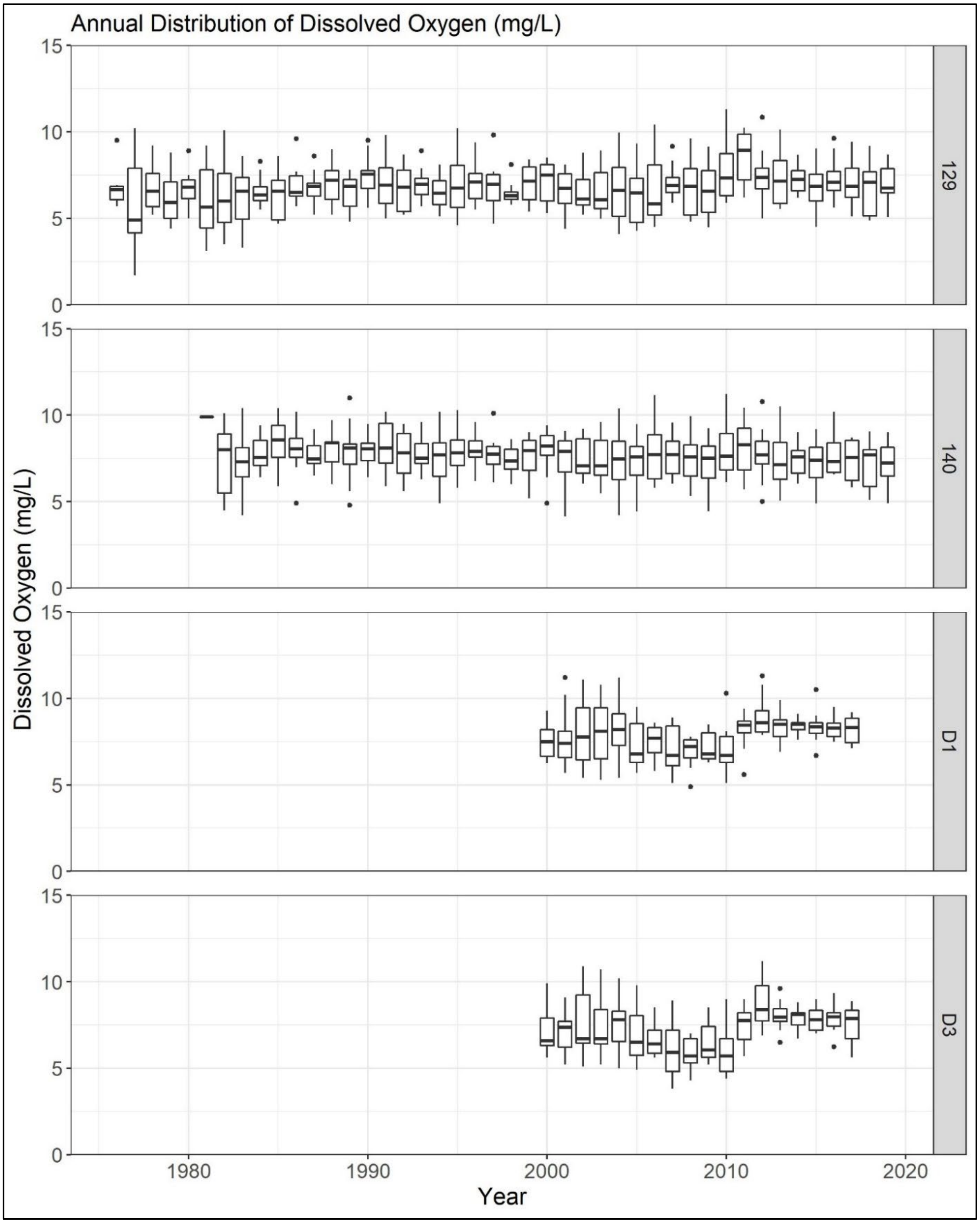

Figure 3-4. Annual distribution of mid-water dissolved oxygen concentrations (mg/L) at two Hillsborough County Environmental Protection Commission stations (129 and 140) and two Manatee County stations (D1 and D3). Boxed values include the 25th to the 75th percentiles with the centerline reflecting the 50th percentile value. Outliers are indicated by dots, representing values outside of the 1.5*Interquartile Range.

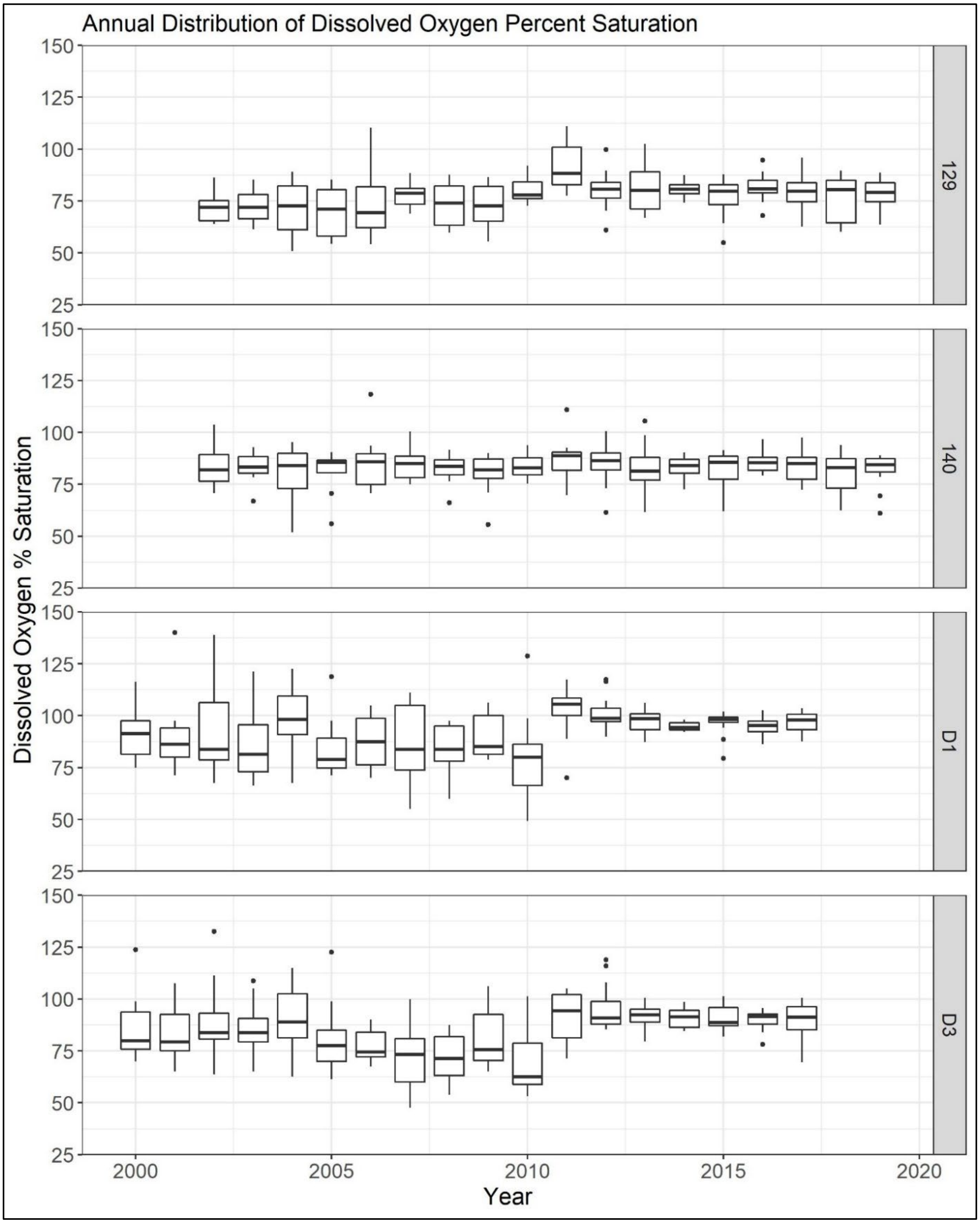

Figure 3-5. Annual distribution of mid-water dissolved oxygen percent saturation at two Hillsborough County Environmental Protection Commission stations (129 and 140) and two Manatee County stations (D1 and D3). Boxed values include the 25th to the 75th percentiles with the centerline reflecting the 50th percentile value. Outliers are indicated by dots, representing values outside of the 1.5*Interquartile Range.

3.3.2 Nitrogen

Nitrogen is a principal plant nutrient that has been identified as limiting phytoplankton in Tampa Bay and its tributaries; at excess concentrations, nitrogen can be associated with phytoplankton blooms (Fanning and Bell 1985, Vargo et al. 1991, Janicki and Wade 1996). Several forms of nitrogen have been measured at the EPC and Manatee County stations in the Upper Little Manatee River. They include inorganic forms, such as ammonia and nitrate/nitrite, which are more labile and readily taken up by plants, and organic forms, which principally result from decaying plant matter. Total nitrogen is generally computed as the sum of these organic and inorganic forms.

Seasonal Kendall Tau trend tests indicated increasing trends in organic nitrogen at Stations 129 and 140, and regression results yielded a positive relationship to flow (Table 3-2, Figure 3-6). Other forms of nitrogen, including total nitrogen, ammonia, and nitrates/nitrate, had either no temporal trend or a decreasing temporal trend at Stations 129 and 140 (Table 3-2). Both Manatee County stations on the South Fork of the Little Manatee River displayed increasing trends for flow-adjusted total nitrogen (Table 3-2, Figure 3-7). Station D1 also had increasing flow-adjusted trends for nitrate and nitrate-nitrite by Seasonal Kendall Tau trend tests (Table 3-3).

A previous evaluation of long-term monitoring data in the Little Manatee River indicated increasing nutrient enrichment and mineralization of the system with significant increases in nitrate-nitrite, pH, and turbidity since the 1970s (Flannery et al. 1991). This was attributed to land-use changes in the watershed, particularly from additional groundwater pumping and irrigation runoff. While the trend of increasing forms of nitrogen are still evident at select stations in the Upper Little Manatee River, irrigation efficiencies through adoption of BMPs have led to a decline in excess flows from agricultural lands since 2000 (JEI 2018a in Appendix C). Increasing trends in select nitrogen forms at individual stations do not appear to be resulting in adverse effects to the system, based upon the results of the chlorophyll concentrations described in Section 3.3.1.

3.3.3 Phosphorus

Phosphorus is an essential nutrient for plants that stimulates early growth but can lead to water quality degradation at high concentrations. While the concentration of phosphorus is usually low enough in freshwater to be a limiting nutrient for photosynthetic biota, the Little Manatee River resides in the phosphorus-rich “Bone Valley” geologic formation, where phosphorus is in plentiful supply.

Phosphorus concentrations are reported by both EPC and Manatee County as orthophosphate and total phosphorus. Trend tests suggest decreasing phosphorus concentrations at EPC Stations 129 and 140 in the North Fork of the Upper Manatee River (Table 3-2, Figure 3-8), suggesting improving water quality, and no trend in flow-adjusted phosphorus data at Manatee County Stations D1 and D3 in the South Fork, although the trend was decreasing prior to flow adjustment (Table 3-3).

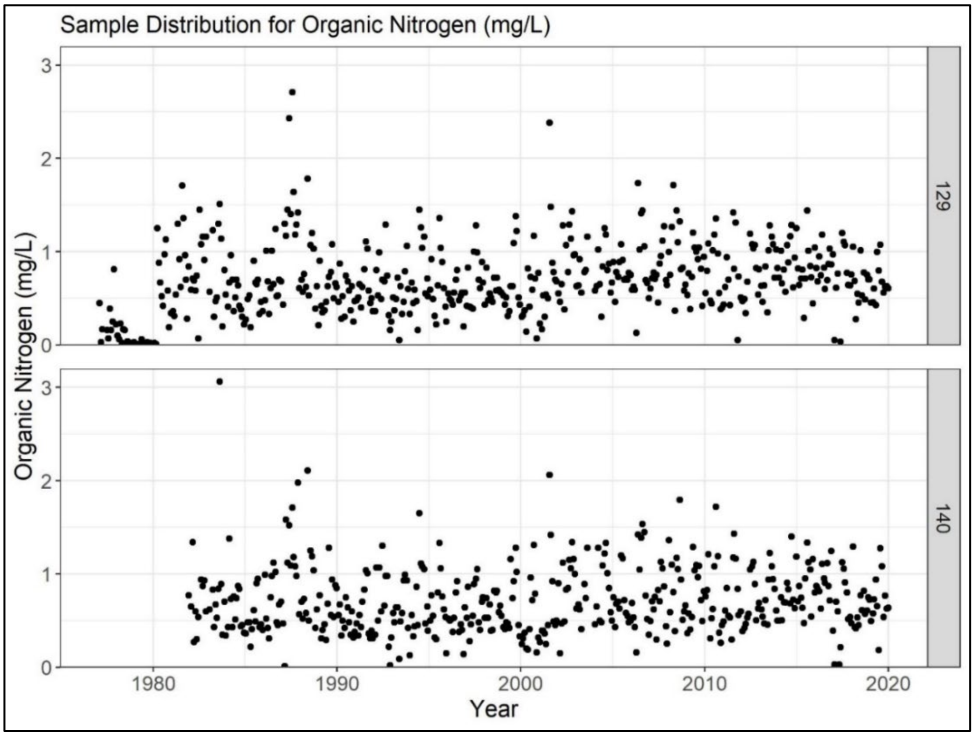

Figure 3-6. Time series of organic nitrogen concentrations (mg/L) for Hillsborough County Environmental Protection Commission Stations 129 and 140 in the Upper Little Manatee River.

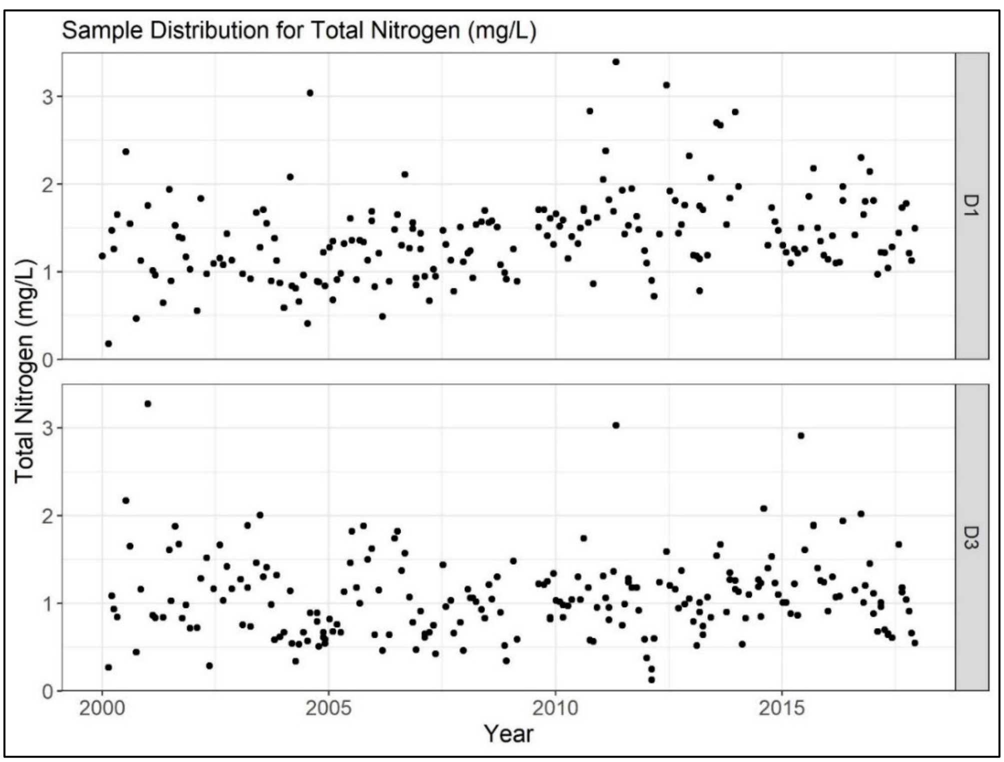

Figure 3-7. Time series of total nitrogen concentrations (mg/L) for Manatee County Stations D1 and D3 in the Upper Little Manatee River.

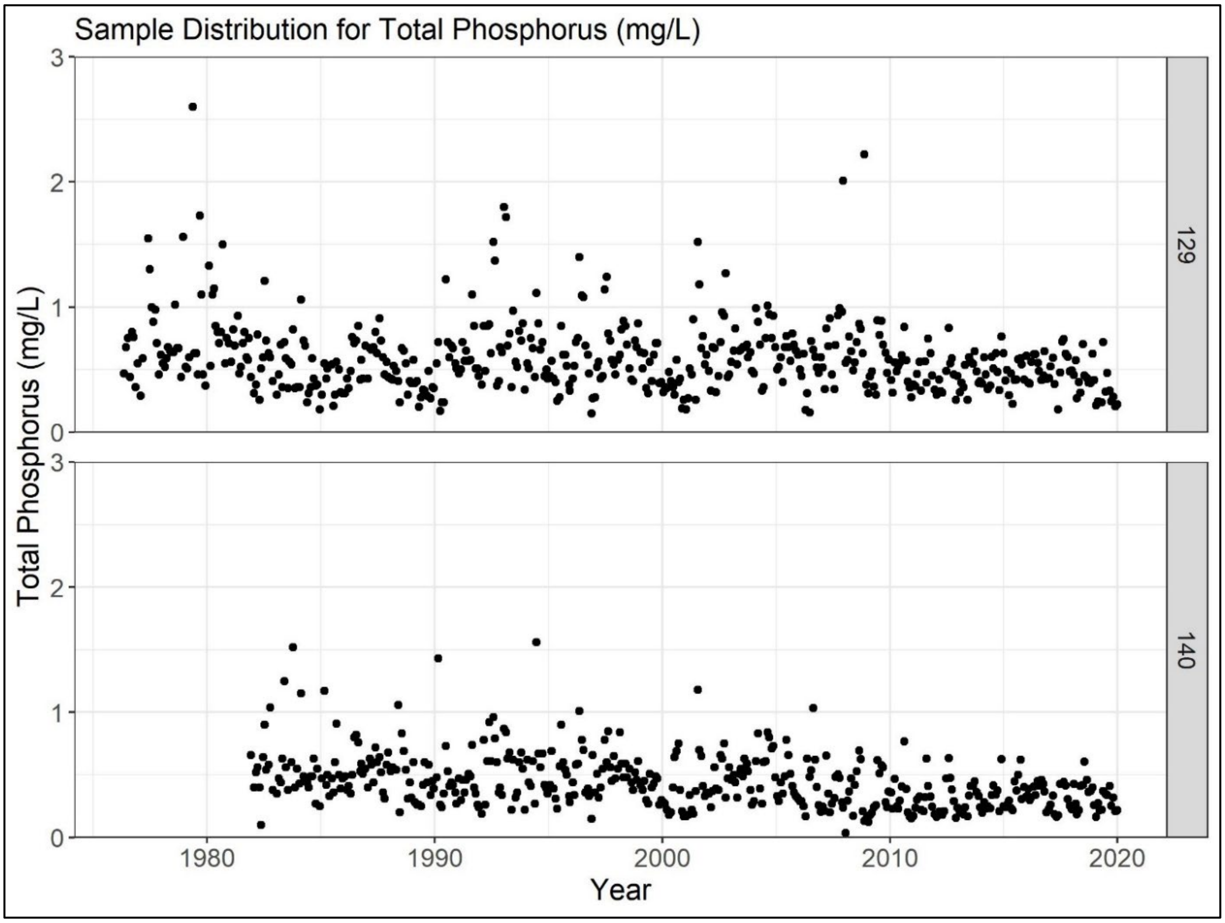

Figure 3-8. Time series of total phosphorus concentrations (mg/L) for Hillsborough County Environmental Protection Commission Stations 129 and 140 in the Upper Little Manatee River.

3.3.4 Other Water Quality Parameters

Of the significant Seasonal Kendall Tau trend tests at the EPC and Manatee County stations, many parameters indicated improving conditions over time (e.g., decreasing concentrations of nutrients, decreasing turbidity). Exceptions include increasing trends in organic nitrogen concentrations at Stations 129 and 140 (described in Section 3.3.2), an increase in pH at both stations (Table 3-2, Figure 3-9), and an increasing trend in fluoride at Station 129 (Table 3-2, Figure 3-10). Regression analysis indicated a negative relationship between pH and flow at both stations and a positive relationship between fluoride and flow at Station 129.

As discussed in Section 3.3.2, groundwater pumping and irrigation runoff may influence pH levels in the Little Manatee River watershed. This was also the postulated cause for increasing river pH in Horse Creek, located nearby in Hardee and Desoto Counties (ATM and JEI 2021). Expansive phosphate mining and land reclamation activity in the Upper Little Manatee watershed may also impact these water quality parameters. During periods of high runoff or discharge, released waters from mining activities can decrease the pH of rivers and increase fluoride and phosphate concentrations (Toler 1967, Kelly et al. 2005a). In the Alafia River, changes to mining practices in the 1970s led to a dramatic reduction in both fluoride and phosphate loadings (Kelly et al. 2005b).

The impacts of extractive activities on pH and fluoride levels in the Upper Little Manatee River are unclear, as phosphorus levels have not increased concomitantly as one may expect from evaluations of other systems impacted by mining (Section 3.3.3). Details of additional water quality parameter analyses may be found in Jacobs and JEI (2020 in Appendix D).

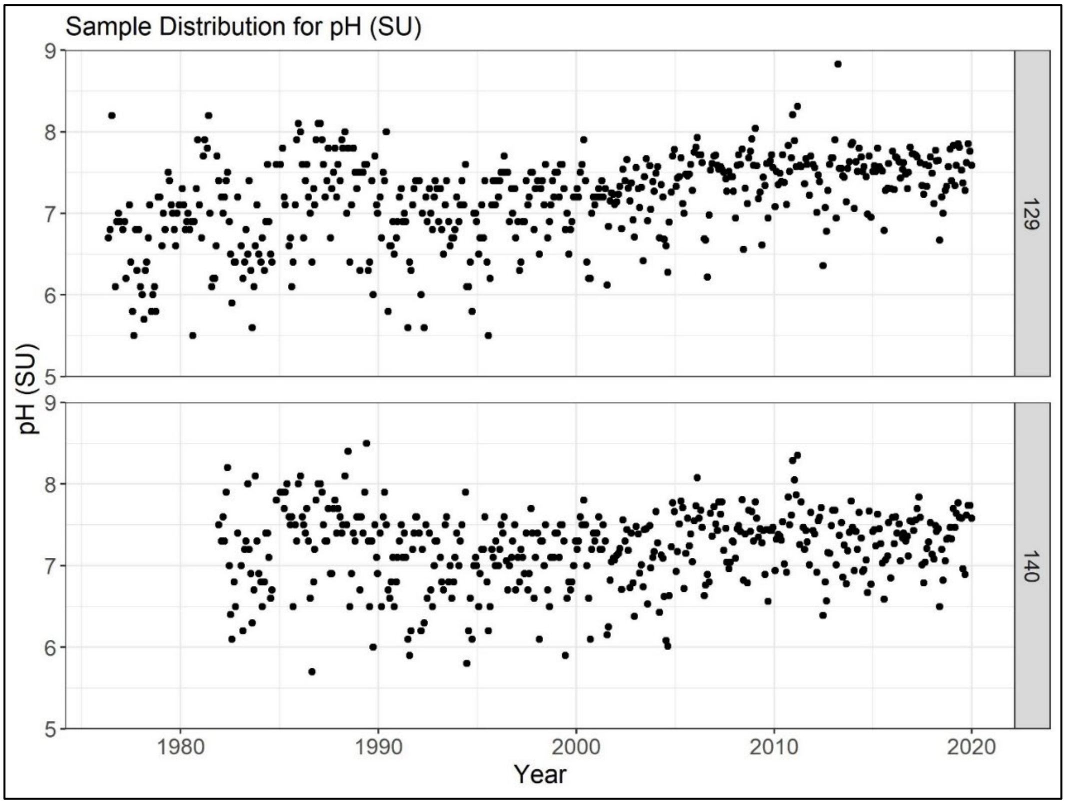

Figure 3-9. Time series of pH levels (SU) for Hillsborough County Environmental Protection Commission Stations 129 and 140 in the Upper Little Manatee River.

3.4 Lower River Water Quality

Five EPC stations were included in the water quality analysis for the Lower Little Manatee River (Table 3-4, Figure 3-11). Data collection began in 1974 for Stations 112 and 113 and in 2009 for the remaining stations.

A plot of salinity distributions at the five evaluated EPC locations is provided in Figure 3-12 for reference to the expected physical chemistry of each sampling station. These data are based upon a period of record when data were being recorded at all stations (2009-2019) and highlight the general distribution of water quality sampling locations along the salinity gradient.

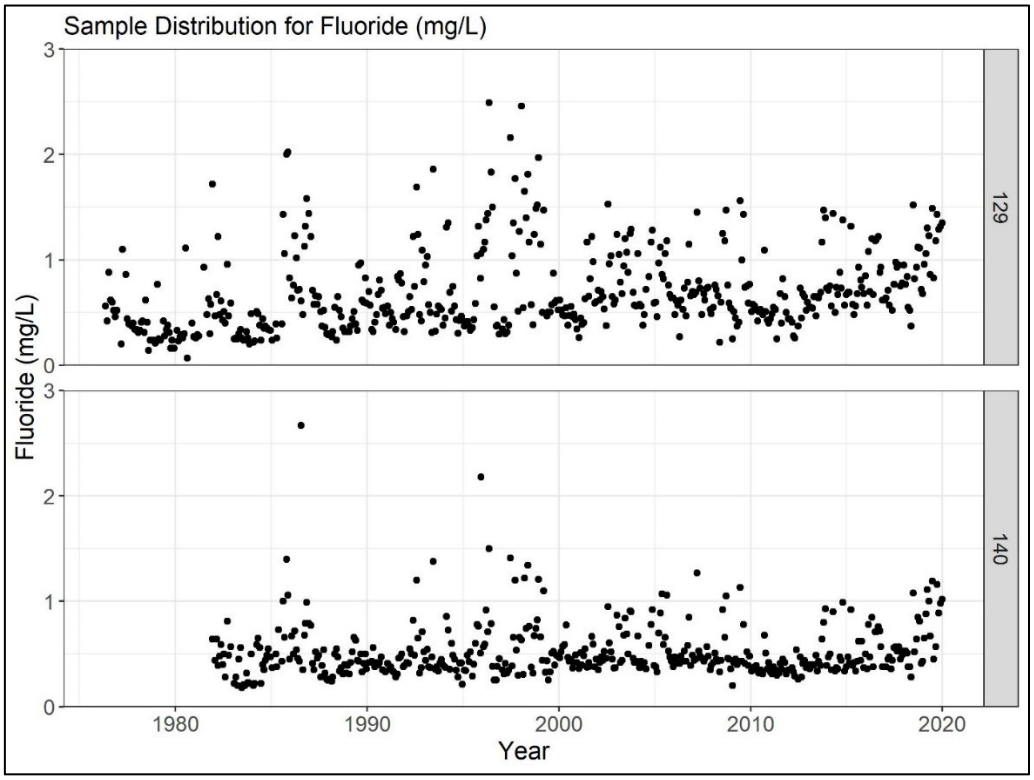

Figure 3-10. Time series of fluoride concentrations (mg/L) for Hillsborough County Environmental Protection Commission Stations 129 and 140 in the Upper Little Manatee River.

Table 3-4. Routine water quality sampling stations in the Lower Little Manatee River.

Site Identification No.	Latitude	Longitude	WBID	First Sample	Most Recent Sample
112	27.7043	-82.4487	1742C	Jan. 1976	Dec. 2019
113	27.6719	-82.3521	1742A	Jan. 1973	Dec. 2019
180	27.71567	-82.4699	1742C	Jan. 2009	Dec. 2019
181	27.68103	-82.4305	1742C	Jan. 2009	Dec. 2019
182	27.67222	-82.417	1742C	Jan. 2009	Dec. 2019

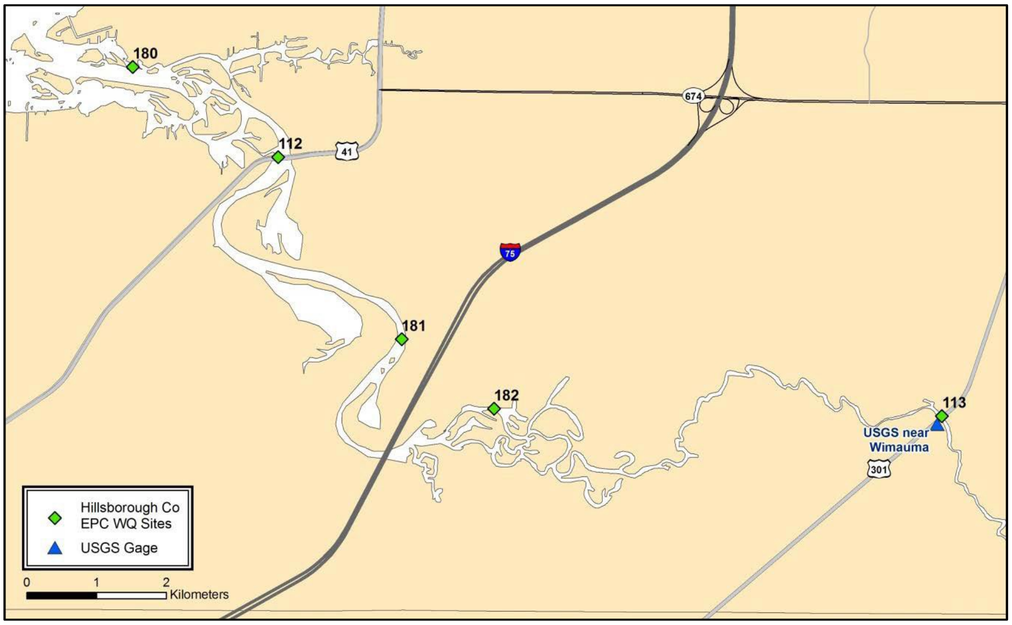

Figure 3-11. Hillsborough County Environmental Protection Commission (EPC) and US Geological Survey (USGS) station locations in the Lower Little Manatee River (from Jacobs and JEI 2020, Appendix D).

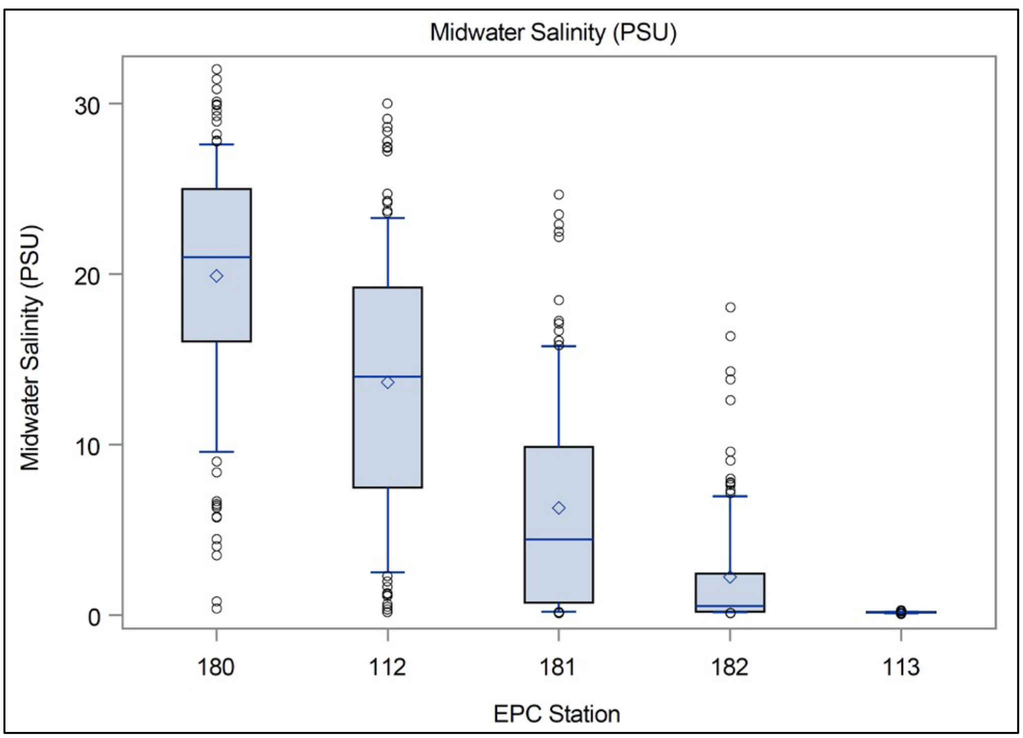

Figure 3-12. Salinity distribution (psu) at five Hillsborough County Environmental Protection Commission (EPC) stations in the Lower Little Manatee River; see Figure 3-10 for station locations (from Jacobs and JEI 2020 in Appendix D). Boxed values include the 25th to the 75th percentiles with the centerline reflecting the 50th percentile value. Outliers are indicated by circle, representing values outside of the 1.5*Interquartile Range.

3.4.1 Chlorophyll *a* and Dissolved Oxygen

The station-specific annual distribution of geographic mean uncorrected chlorophyll *a* concentrations are provided in Figure 3-13, where stations are oriented from downstream (top) to upstream (bottom). A black dashed line denoting the 11 µg/L DEP threshold for chlorophyll *a* (per 62-303.353 (2), F.A.C) is provided within each panel of the plot. The DEP threshold is provided for reference only and is not intended to represent a determination of impairment. The annual geometric means were generally below the 11 µg/L DEP threshold, though at Stations 181 and 182, where salinity tended to be <10 practical salinity units (psu), the annual geometric means were more likely to exceed the threshold value. This is typical of the physical and chemical characteristics of tidal rivers, where the initial mixing of fresh and estuarine waters creates a zone of high primary productivity in oligohaline and mesohaline waters (Vargo 1989, 1991). After conducting Seasonal Kendall Tau trend tests, there were no consistent temporal chlorophyll *a* trends at the five EPC stations, nor were there consistent relationships with flow by regression analysis (Table 3-5). Chlorophyll *a* declined over time at Station 112 after accounting for the effects of flow (Table 3-5).

Dissolved oxygen percent saturation levels tended to be above the 42 percent DEP threshold for estuarine waters (per 62-302.553, F.A.C) at all stations (Figure 3-14). Distributions of long-term dissolved oxygen measurements reported as mid-water concentrations are provided in Figure 3-15, which shows inter-annual variation in dissolved oxygen distributions over time. The distributions indicate that hypoxic conditions (concentrations less than 2 mg/L) are rare at the examined locations, occurring three times (<0.01 percent of samples). Results of the Seasonal Kendall Tau trend tests indicated flow-adjusted dissolved oxygen levels were increasing over time at Stations 112 and 180; regression analysis demonstrated a negative relationship between dissolved oxygen and flow at Stations 112, 113, and 180 (Table 3-5). Bottom dissolved oxygen concentrations for the EPC stations were also examined for the frequency of hypoxia threshold exceedance. This was rare, occurring three times (0.4 percent of samples), at Station 112 during the summer months (Figure 3-16).

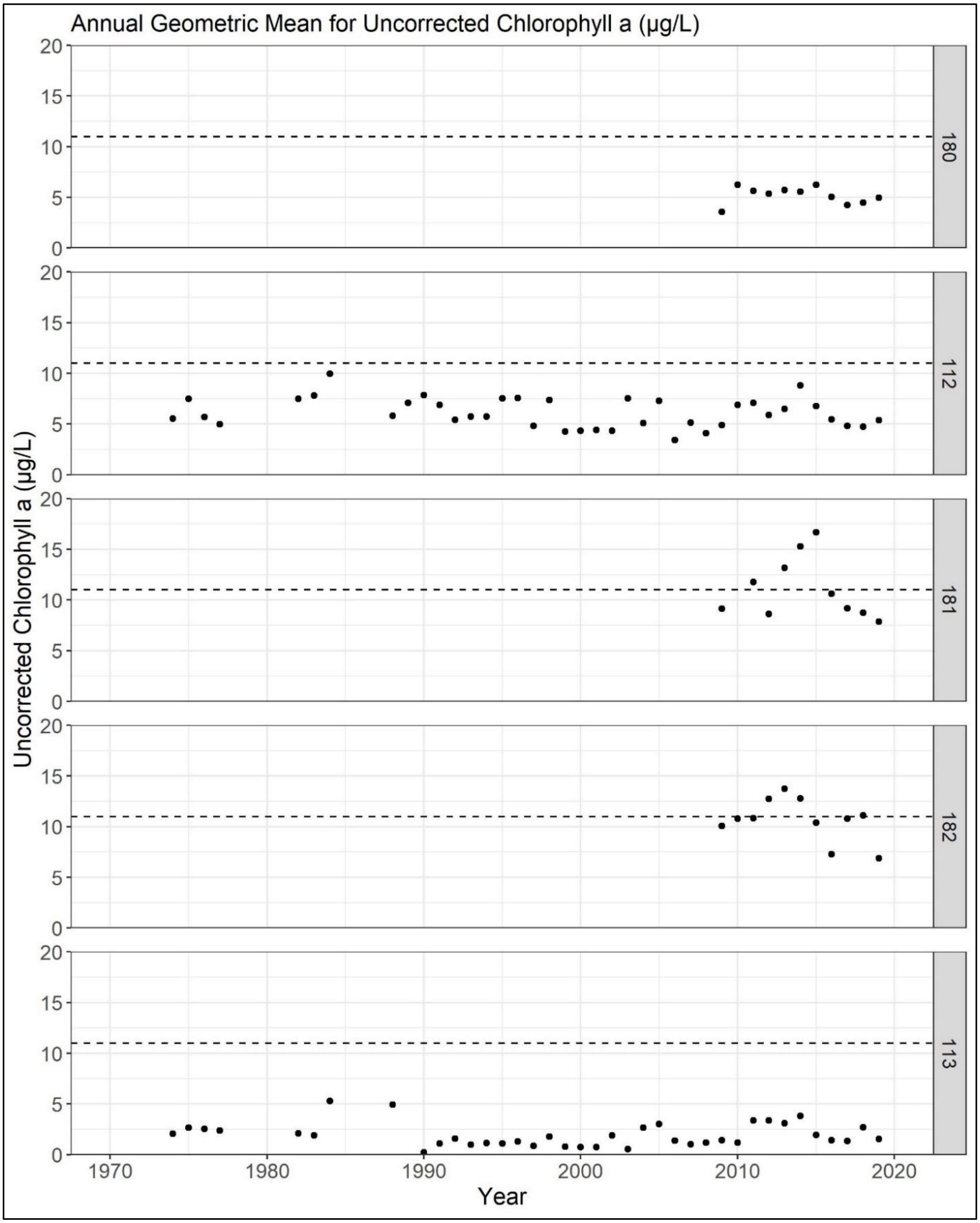

Figure 3-13. Annual geometric mean uncorrected chlorophyll *a* concentrations (µg/L) for the period of record at five Hillsborough County Environmental Protection Commission stations in the Lower Little Manatee River, with stations listed from downstream (top) to upstream (bottom). The dashed horizontal lines represent the 11 µg/L Florida Department of Environmental Protection chlorophyll *a* threshold.

Table 3-5. Results of Seasonal Kendall Tau trend tests with time for Hillsborough County Environmental Protection Commission Stations 112, 113, 180, 181, and 182 in the Lower Little Manatee River (from Jacobs and JEI 2020 in Appendix D). A zero value indicates a lack of statistical significance for the regression flow term, -1 indicates a statistically significant inverse relationship between the parameter and flow, and 1 indicates a statistically significant increasing relationship between the parameter and flow.

Water Quality Parameter	Station	Start Year	End Year	# of Samples	Temporal Trend Direction		Regression Results
					Trend	Flow Adjusted Trend	
Uncorrected Chlorophyll *a* (µg/L)	112	1974	2019	403	No trend	Decreasing	1
	113	1974	2019	280	No trend	No trend	1
	180	2009	2019	132	No trend	No trend	1
	181	2009	2019	132	No trend	No trend	0
	182	2009	2019	132	No trend	No trend	-1
Dissolved Oxygen (percent Saturation; Mid-column)	112	2002	2019	209	No trend	Increasing	-1
	113	2002	2019	213	No trend	No trend	-1
	180	2009	2019	130	No trend	Increasing	-1
	181	2009	2019	132	No trend	No trend	0
	182	2009	2019	132	No trend	No trend	0
Total Nitrogen (mg/L)	112	1981	2019	457	Decreasing	Decreasing	1
	113	1981	2019	458	No trend	No trend	1
	180	2009	2019	132	Decreasing	Decreasing	0
	181	2009	2019	132	No trend	Decreasing	1
	182	2009	2019	132	Decreasing	Decreasing	1
Ammonia (mg/L)	112	1974	2019	524	Decreasing	Decreasing	0
	113	1974	2019	522	Decreasing	Decreasing	0
	180	2009	2019	132	Decreasing	Decreasing	0
	181	2009	2019	132	No trend	Decreasing	0
	182	2009	2019	132	Decreasing	Decreasing	0
Organic Nitrogen (mg/L)	112	1975	2019	510	Decreasing	Decreasing	1
	113	1975	2019	511	Increasing	Increasing	1
	180	2009	2019	132	No trend	No trend	0
	181	2009	2019	132	No trend	No trend	1
	182	2009	2019	132	No trend	No trend	1
Nitrate/ Nitrite (mg/L)	112	1983	2019	441	Decreasing	Decreasing	1
	113	1983	2019	440	Decreasing	Decreasing	-1
	180	2009	2019	132	No trend	Decreasing	1
	181	2009	2019	132	No trend	Decreasing	1
	182	2009	2019	132	Decreasing	Decreasing	1
Total Phosphorus (mg/L)	112	1974	2019	543	Decreasing	Decreasing	0
	113	1974	2019	543	Decreasing	Decreasing	1
	180	2009	2019	132	No trend	Decreasing	1

	181	2009	2019	132	No trend	Decreasing	1
	182	2009	2019	132	No trend	Decreasing	1
Ortho-Phosphate (mg/L)	112	1974	2019	359	Decreasing	Decreasing	1
	113	1974	2019	372	Decreasing	Decreasing	1
	180	2009	2019	132	No trend	No trend	1
	181	2009	2019	132	No trend	Decreasing	1
	182	2009	2019	132	No trend	No trend	1
Fecal Coliform (n/100 mL)	112	1974	2019	539	Decreasing	Decreasing	1
	113	1974	2016	504	No trend	No trend	1
	180	2009	2019	132	Decreasing	Decreasing	0
	181	2009	2019	132	No trend	Decreasing	1
	182	2009	2019	132	No trend	Decreasing	1
Fluoride (mg/L)	112	1974	2019	531	Decreasing	Decreasing	-1
	113	1974	2019	510	No trend	Increasing	-1
	180	2009	2019	132	No trend	No trend	-1
	181	2009	2019	132	No trend	Increasing	-1
	182	2009	2019	132	Increasing	Increasing	-1
pH (SU; Mid-column)	112	1974	2019	534	Increasing	Increasing	-1
	113	1974	2019	536	No trend	Increasing	-1
	180	2009	2019	132	Decreasing	No trend	-1
	181	2009	2019	132	No trend	No trend	-1
	182	2009	2019	132	No trend	No trend	-1
Total Suspended Solids (mg/L)	112	1974	2008	187	Decreasing	Decreasing	-1
	113	1974	2008	372	No trend	Decreasing	-1
	180	NA	NA	NA	NA	NA	NA
	181	NA	NA	NA	NA	NA	NA
	182	NA	NA	NA	NA	NA	NA
Turbidity (NTU)	112	1974	2019	543	Decreasing	Decreasing	1
	113	1974	2019	541	No trend	Decreasing	1
	180	2009	2019	132	Decreasing	Decreasing	0
	181	2009	2019	132	No trend	Decreasing	0
	182	2009	2019	132	No trend	Decreasing	1

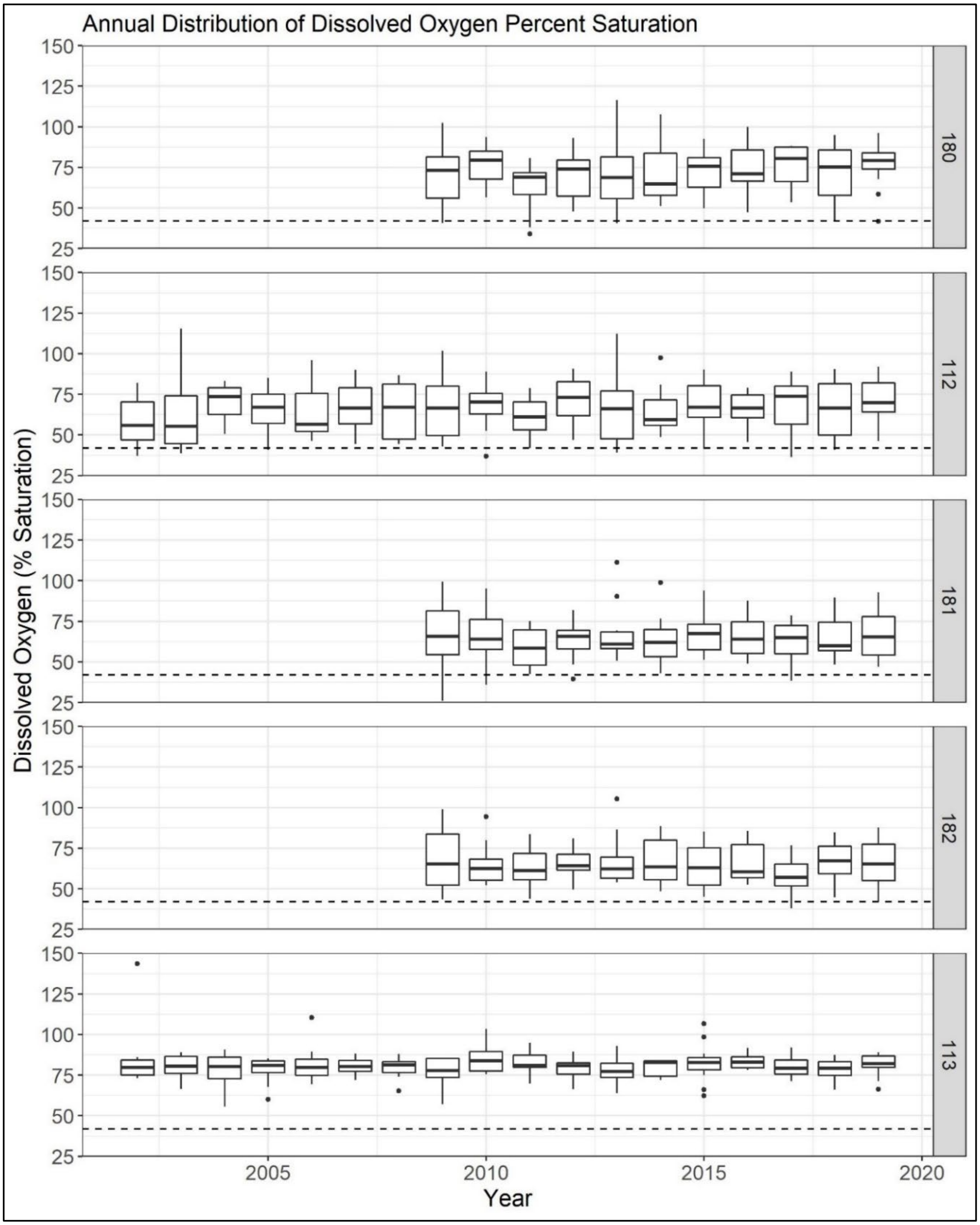

Figure 3-14. Annual distributions of mid-water column dissolved oxygen percent saturation for the period of record at five Hillsborough County Environmental Protection Commission stations in the Lower Little Manatee River, with stations listed from downstream (top) to upstream (bottom). The dashed horizontal lines represent the 42 percent Florida Department of Environmental Protection dissolved oxygen percent saturation threshold. Boxed values include the 25th to the 75th percentiles with the centerline reflecting the 50th percentile value. Outliers are indicated by dots, representing values outside of the 1.5*Interquartile Range.

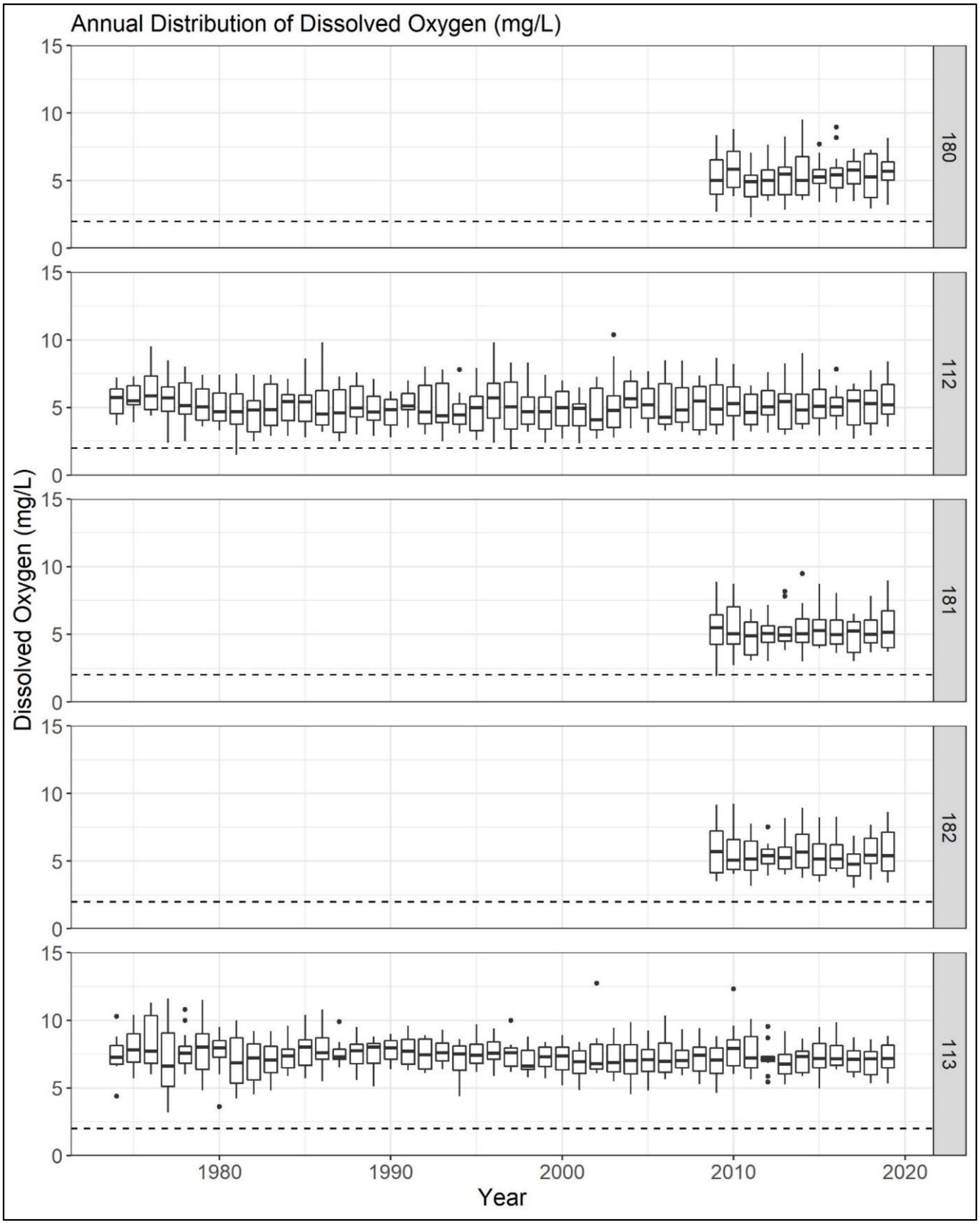

Figure 3-15. Annual distributions of mid-water column dissolved oxygen concentrations (mg/L) for the period of record at five Hillsborough County Environmental Protection Commission stations in the Lower Little Manatee River, with stations listed from downstream (top) to upstream (bottom). The dashed horizontal line represents the 2 mg/L threshold for hypoxic conditions. Boxed values include the 25th to the 75th percentiles with the centerline reflecting the 50th percentile value. Outliers are indicated by dots, representing values outside of the 1.5*Interquartile Range.

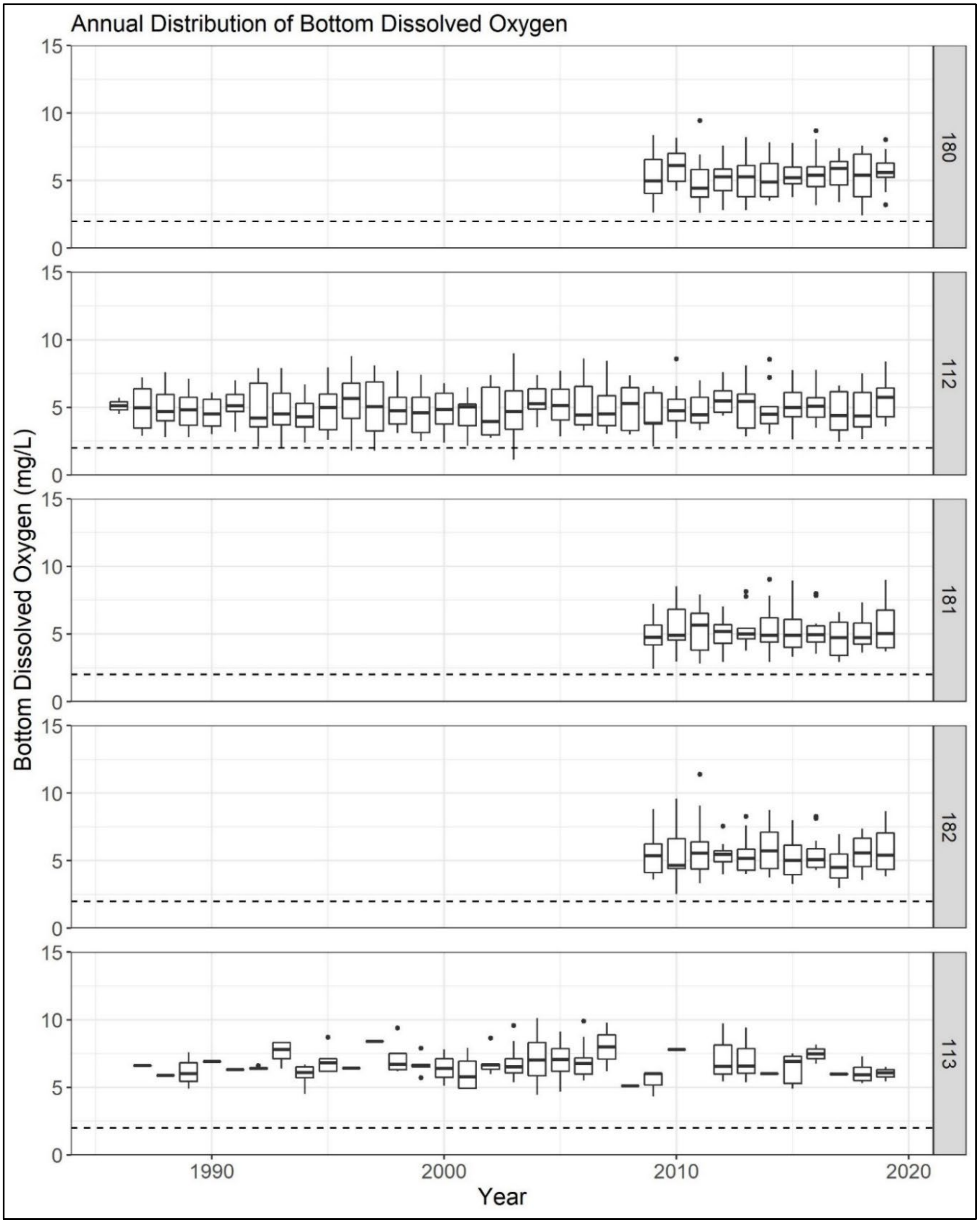

Figure 3-16. Annual distributions of bottom-water column dissolved oxygen concentrations (mg/L) for the period of record at five Hillsborough County Environmental Protection Commission stations in the Lower Little Manatee River, with stations listed from downstream (top) to upstream (bottom). The dashed horizontal line represents the 2 mg/L threshold for hypoxic conditions. Boxed values include the 25th to the 75th percentiles with the centerline reflecting the 50th percentile value. Outliers are indicated by dots, representing values outside of the 1.5*Interquartile Range.

3.4.2 Nitrogen

Based upon Seasonal Kendall Tau trend test results, most forms of nitrogen were either stable or decreasing (indicating improving water quality) over time at EPC stations in the Lower Little Manatee River (Table 3-5). The only exception was organic nitrogen at Station 113, which increased over time. While this result suggests 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. Where significant relationships between flows and nitrogen forms were detected by regression analysis, the relationships were positive (Table 3-5). A representative time series of total nitrogen is provided in Figure 3-17.

3.4.3 Phosphorus

Results of Seasonal Kendall Tau trend tests suggested decreasing flow-adjusted total phosphorus concentrations at all examined EPC stations in the lower river, as well as decreasing flow-adjusted orthophosphate concentrations at Stations 112, 113, and 181 (Table 3-5). This generally suggests an improvement of water quality over time. At nearly all stations, positive relationships between flow and both forms of phosphorus were determined by regression analysis (Table 3-5). Time series plots for total phosphorus are provided in Figure 3-18.

3.4.4 Other Water Quality Parameters

Several other water quality parameters in the Lower Little Manatee River were evaluated, including fecal coliforms, fluoride, pH, total suspended solids, and turbidity. The results of Seasonal Kendall Tau trend analysis on these parameters suggested these water quality parameters were generally either stable or decreasing over time (Table 3-5), demonstrating improving water quality in the estuarine portion of the river. The exceptions to this included increasing fluoride at Stations 113, 181, and 182 (Table 3-5, Figure 3-19) and increasing pH over time at Stations 112 and 113 (Table 3-5, Figure 3-20) with a negative relationship to flow. As previously discussed, groundwater pumping and irrigation runoff may influence pH levels throughout the watershed, although there has been a reduction of irrigation runoff in recent years due to the implementation of BMPs. While mining activity has been linked to increasing levels of fluoride in rivers, a lack of concomitant increase in phosphorus runoff at these stations precludes extractive activity from being the sole cause of an increase in fluoride in the Lower Little Manatee River.

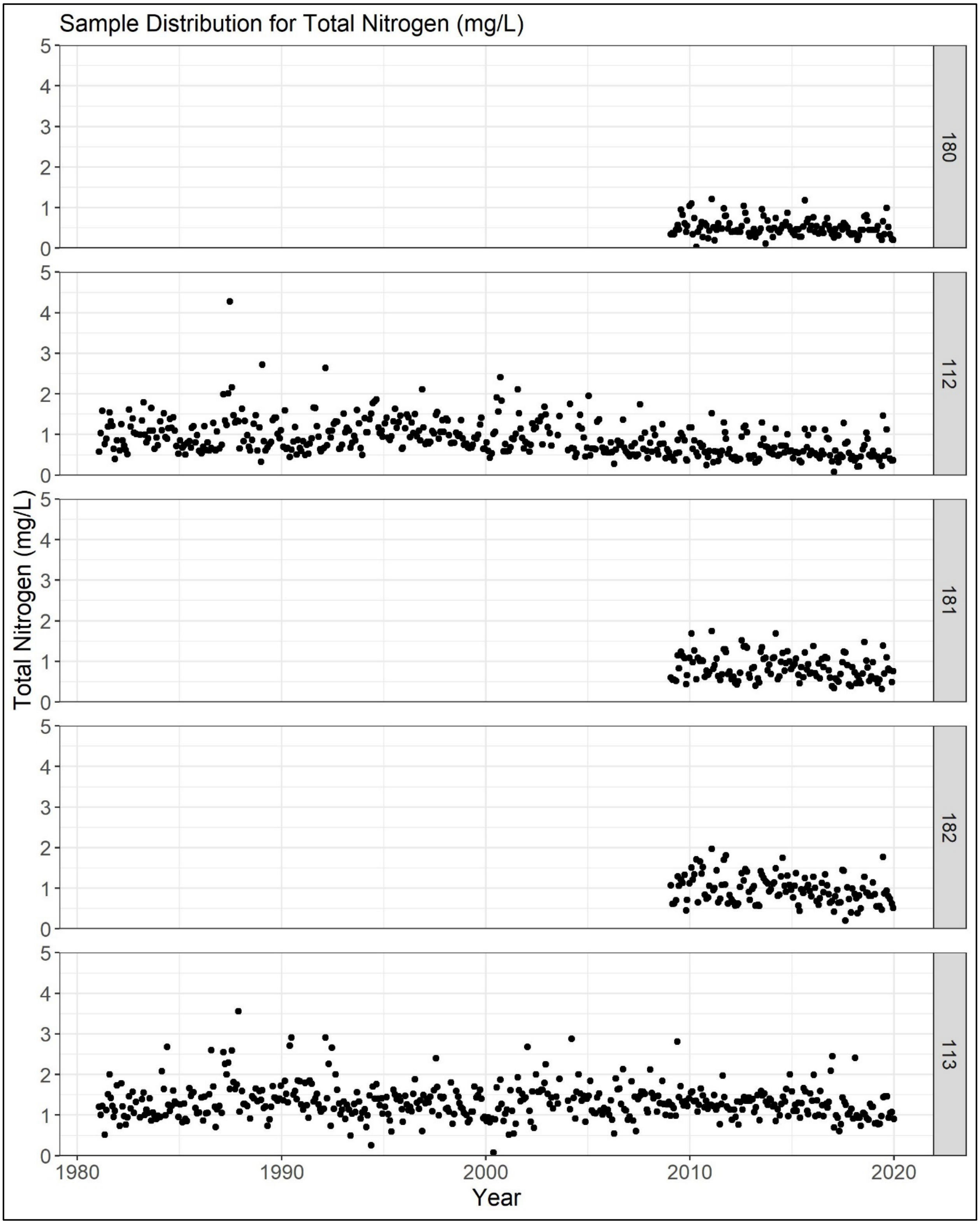

Figure 3-17. Time series of total nitrogen concentrations (mg/L) at five Hillsborough County Environmental Protection Commission stations in the Lower Little Manatee River, shown from downstream (top) to upstream (bottom).

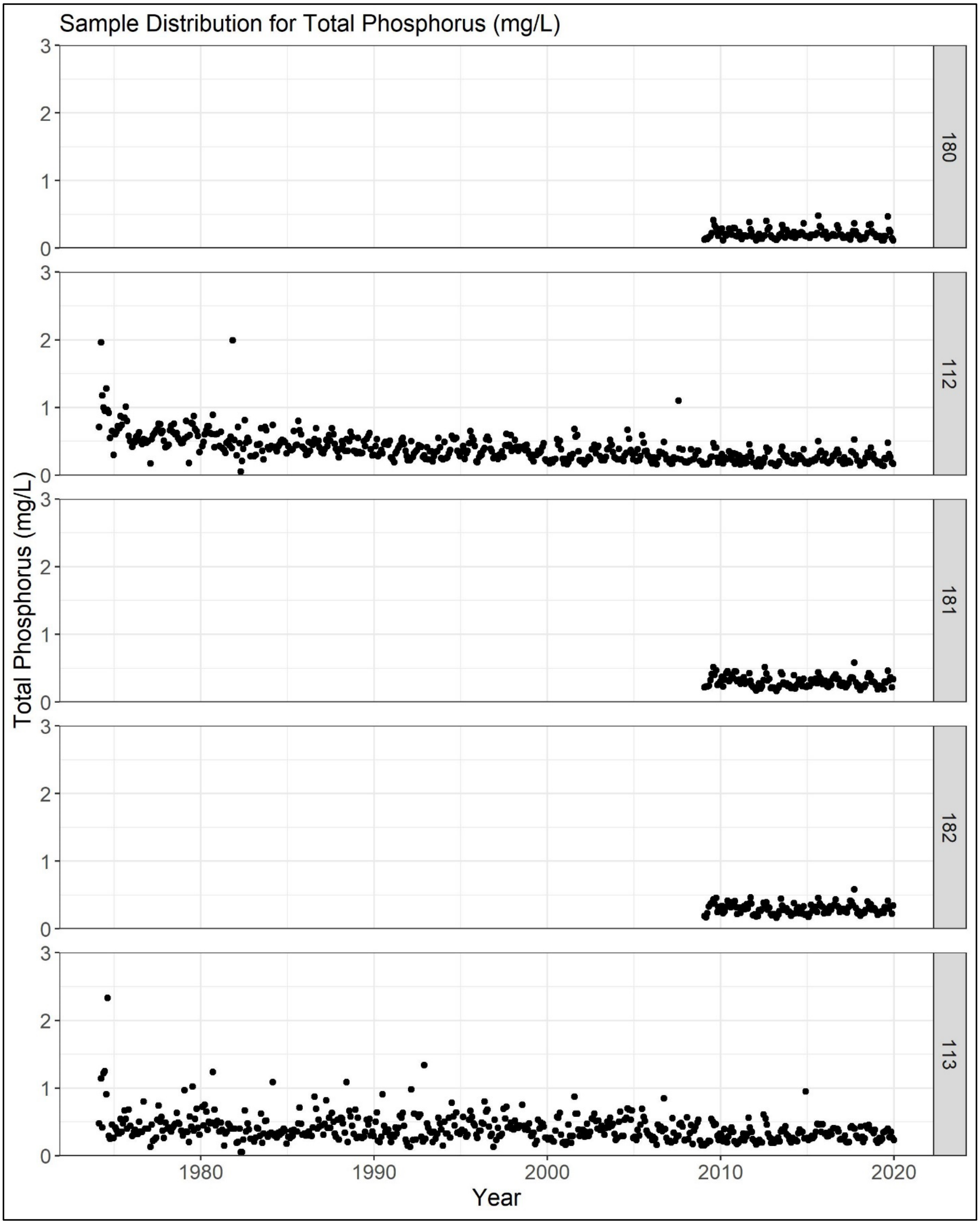

Figure 3-18. Time series of total phosphorus concentrations (mg/L) at five Hillsborough County Environmental Protection Commission stations in the Lower Little Manatee River, shown from downstream (top) to upstream (bottom).

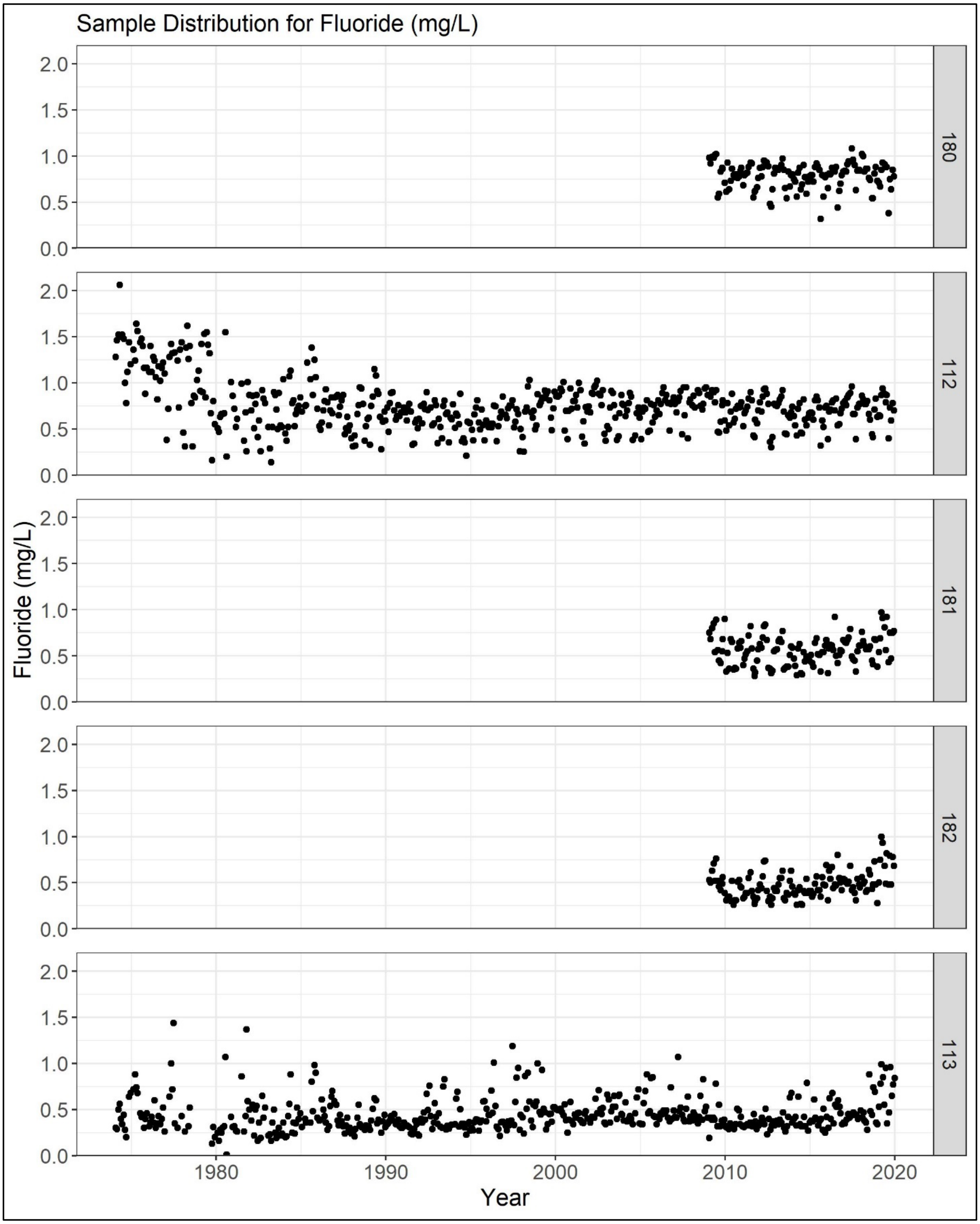

Figure 3-19. Time series of fluoride concentrations (mg/L) at five Hillsborough County Environmental Protection Commission stations in the Lower Little Manatee River, shown from downstream (top) to upstream (bottom).

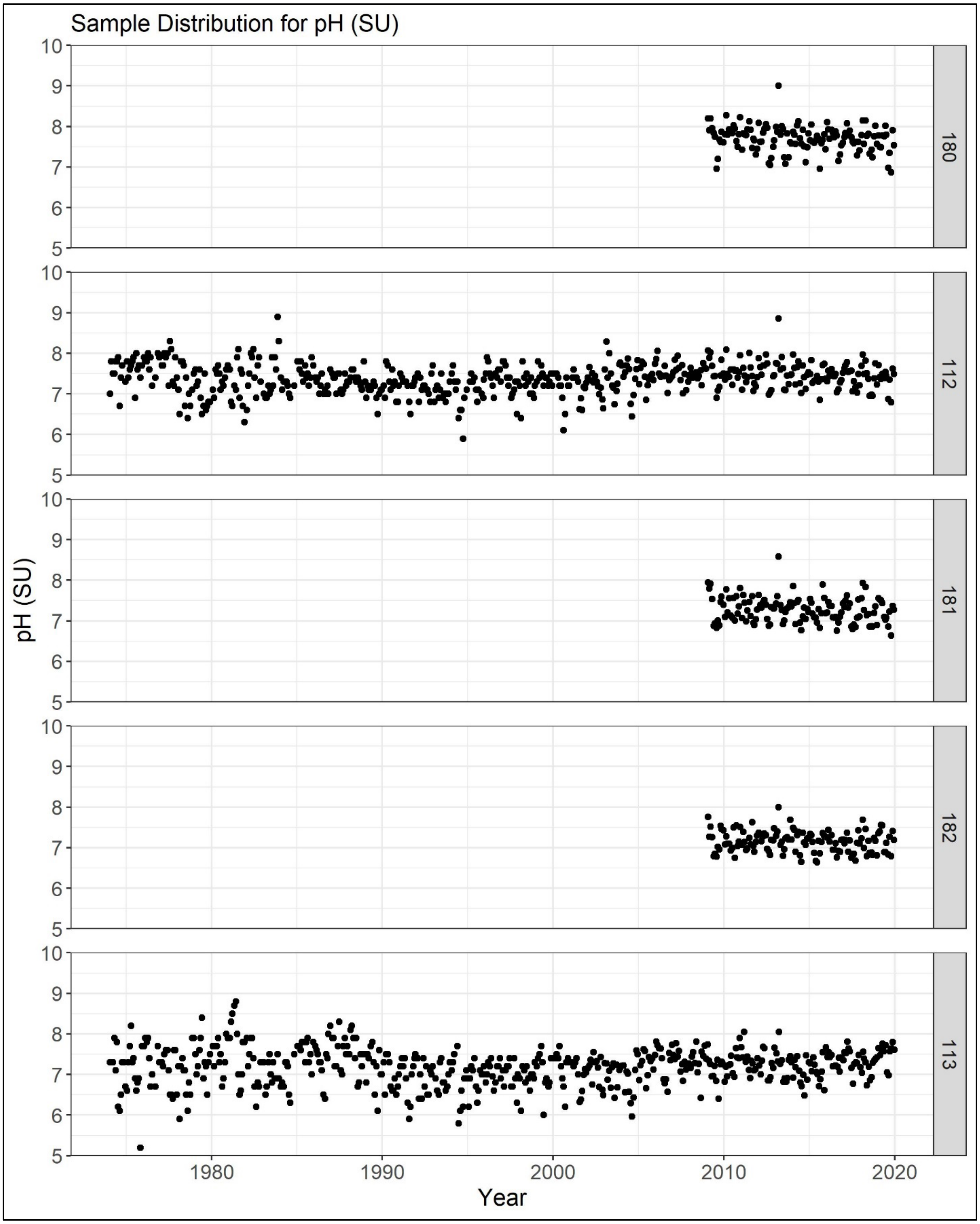

Figure 3-20. Time series of mid-water column pH levels (SU) at five Hillsborough County Environmental Protection Commission stations in the Lower Little Manatee River, shown from downstream (top) to upstream (bottom).

3.5 Summary

According to DEP's November 2022 assessment, the Little Manatee River remains in compliance with state water quality standards for water quality parameters other than fecal coliform. However, a fish consumption advisory for several species based on concentrations of mercury in fish tissues is applicable to the river. Trends in water quality are generally improving over time, though site-specific instances of increasing trends which may have negative impact on water quality were identified. Water quality data collection is ongoing at four stations in the Upper Little Manatee River and five stations in the Lower Little Manatee River and will support future evaluations of the river.

Many water quality parameters exhibited statistically significant relationships with flow, independent of seasonality. However, while Seasonal Kendall Tau trend tests provided a statistical evaluation of changes in assessed water quality parameters over time, they cannot be considered as explanatory models. Residualizing the data against flow prior to conducting Seasonal Kendall Tau trend tests was an attempt to determine if there were changes in water quality parameters over time, after accounting for the relationships between water quality and flow. Changes in some water quality parameters were associated with flow and also changed through time, indicating other unexplained factors in addition to flow were contributing to the water quality changes.

When a large proportion of values associated with a water quality parameter are reported at their detection limit, this can affect time series trend tests and regression results. In both cases, the statistical analyses will be reduced in power. Evaluations of some parameters, including Biological Oxygen Demand, chlorophyll *a*, and ammonia, may have suffered from this artifact. These effects can be seen in the time series plots provided in Jacobs and JEI (2020 in Appendix D).

Streamflow is the product of interactions among rainfall, soil characteristics, storage in the watershed, antecedent conditions, surface and groundwater withdrawals, and effects of natural and anthropogenic land uses. While relationships may be detected between flows and water quality, it is inappropriate to assign causality to flows as a direct effect based solely on statistical outcomes, such as those described in this chapter.

CHAPTER 4 - BIOLOGICAL STATUS AND TRENDS FOR THE LITTLE MANATEE RIVER

Plants and animals in the Little Manatee River have formed diverse communities structured by the gradient from freshwater conditions in the headwaters to the estuarine conditions where the river empties into Tampa Bay. Having a baseline knowledge of these communities is important to effectively detect changes that may be caused by reduced freshwater flows. In addition, this knowledge helps guide which methods and criteria to use for developing minimum flows.

Information regarding the flora and fauna that was obtained by the District for the purposes of minimum flows development or that was collected by others is summarized in this chapter. This summary is not intended to be a compilation of all available studies; but rather, a brief description of the common biological communities of the river. The information summarized here also addresses comments made by the independent panel of scientists (Powell et al. 2012 in Appendix B) that reviewed the initial proposed draft minimum flows for the Upper Little Manatee River concerning a need for more extensive faunistic studies of the river. In response to the panel's comments, long-term benthic macroinvertebrate data collected in the Upper Little Manatee River were obtained from the DEP and summarized. Information regarding the fish community of the Upper Little Manatee River is also included based on a field survey conducted by the Florida Fish and Wildlife Conservation Commission (FWC) in late 2020 and a review of relevant museum records (Nagid and Tuten 2020). The benthic macroinvertebrate community of the Lower Little Manatee River is described below, and lower river nekton information is summarized using data from the FWC's long-term Fisheries-Independent Monitoring (FIM) program, as well as results from a study conducted by Dutterer (2006).

4.1 River Floodplain

This section briefly describes the floodplain of both the Upper and Lower Little Manatee River.

4.1.1 Upper River Floodplain

The floodplain of the Upper Little Manatee River from approximately 12 miles (19.3 km) downstream of State Road 64 to just downstream of US Highway 301 was characterized as part of the District's minimum flows development process (PBS&J 2008 in Appendix K). Relationships among vegetation, soils, and elevation in wetlands in the Upper Little Manatee River floodplain were evaluated at ten study transects (Figure 4-1).

Nine distinct vegetation classes, which included three wetland vegetation classes, were identified. The wetland vegetation classes, which included six or fewer species, were:

- Willow Marsh: This class is comprised exclusively of the obligate wetland species, Carolina willow (*Salix caroliniana*), with smaller components of popash (*Fraxinus caroliniana*) and Dahoon holly (*Ilex cassine)*.
- Tupelo Swamp: The class is characterized by only two tree species, primarily swamp tupelo (*Nyssa aquatica*), an obligate wetland species, in addition to a small component of slash pine (*Pinus elliottii*), a facultative wetland species.

- Hardwood Swamp: This class included six species and is characterized by predominantly the swamp bay (*Magnolia virginiana*), an obligate wetland species, and water oak (*Quercus nigra), a* facultative wetland species.

Note that the three wetland classes above were combined and categorized as FLUCCS Code 6150, Bottom Land Hardwood Swamp, for the floodplain inundation criterion analysis conducted for the Upper Little Manatee River described in Sections 5.3.2, 5.4.3, and 6.2.

Transition vegetation classes (between wetlands and uplands) were characterized by predominantly facultative wetland species, such as laurel oak (*Quercus laurifolia*), which may have been misidentified and is actually sand laurel oak (*Quercus hemisphaerica*), and slash pine in combination with other facultative species. The transition classes included laurel oak/pine hammock, pine/laurel oak hammock, pine/maple hammock, and laurel oak hammock and were composed of six to 23 different species. Species in the two upland classes included primarily the facultative cabbage palm (*Sabal palmetto*) and the upland scrub hickory (*Carya glabra*). The total numbers of species in the palm hammock and oak scrub upland classes ranged from 6 to 11.

Wetlands are not well-developed along the Upper Little Manatee River. No cypress wetlands were documented, and the three wetland classes sampled are characterized by species less tolerant of flooding than cypress. The wetland classes occurred along the three upstream and three downstream transects and were absent along the four mid-reach transects (Figure 4-1). There was no consistent steep increase in cumulative wetted perimeter coincident with a particular shift in vegetation classes along the Upper Little Manatee River transects.

4.1.2 Lower River Floodplain

The tidal portion of the Little Manatee River is long (15 miles or 24 km), narrow (<1 mile or 1.6 km at widest point), and sinuous. The tidal and largely estuarine conditions that extend 15 miles upstream from the river mouth at Tampa Bay to the US Highway 301 bridge crossing can be appropriately divided into three main sections based on vegetation and shoreline habitat characteristics.

The most downstream section heading upstream [river mouth to the US Highway 41 bridge crossing at river kilometer (RKm) 5] is first characterized by numerous islands of Mangrove Swamp (FLUCCS III), with a gradual transition to Saltwater Marshes (FLUCCS Level III) starting at RKm 3 [Figure 4-2, FMRI (1997), Clewell et al. (2002)]. These mangrove marshes consist of red mangrove (*Rhizophora mangle*), a viviparous aerial prop-rooting tree that provides vital habitat in estuarine Florida ecosystems. The saltwater marsh grasses consist of needlerush (*Juncus roemerianus*), a regionally common salt-tolerant plant of the rush family that is also ecologically valued in Florida's estuarine environments. The shorelines are moderately developed along this most downstream section of the river but spans of natural habitat shorelines do exist on both banks (Figure 4-2). Seagrasses, including Shoalgrass (*Halodule wrightii*), Turtlegrass (*Thalassia testudinium*), and Manateegrass (*Syringodium filiforme*), are patchily distributed, with dense stands occurring only at the river mouth (Figure 4-3, Johansson et al. 2018). According to seagrass mapping by the District in 2020, patchy seagrass covers 0.17 square miles (0.43 square kilometers) within the boundary of the Little Manatee River watershed.

The estuary constricts at the US Highway 41 bridge (RKm 5), converging into a single channel that is connected to three tidal embayments: Mill Bayou (RKm 5), Hayes Bayou (RKm 7), and Bolster Bayou (RKm 10). This middle section of the Lower Little Manatee River extends from US Highway 41 to the Interstate 75 bridge crossing at RKm 12 (Figure 4-2). The shorelines along the river's mainstem are mostly developed in this middle section, but upland and wetland forested patches do exist. Saltwater marshes consisting of smooth cordgrass (*Spartina alternifora*) and needlerush are predominantly present in the three bayous, with some forested patches also existing [Figure 4-2, FMRI (1997), Clewell et al. (2002)].

The third and final upstream section of the Lower Manatee River estuary extends from the Interstate 75 bridge to the US Highway 301 bridge crossing (RKm 24). Heading upstream, this section of river begins as a series of braided, but well-defined channels snaking across the landscape, to a point where the channels converge and constrict near RKm 17, progressing to the US Highway 301 bridge as a singular, narrow winding river channel (Figure 4-2). Vegetation in the braided section of this reach is characterized by saltwater marsh shorelines [black rush, cattail (*Typha* sp.), leather fern (*Acrostichum aureum*), and sawgrass (*Cladium jamaicense*)] and interspersed mixed wetland forest (FMRI 1997, Clewell et al. 2002). Tidal water level fluctuations are pronounced up to where the braided channels constrict, with minor fluctuations extending upstream towards the US Highway 301 bridge crossing.

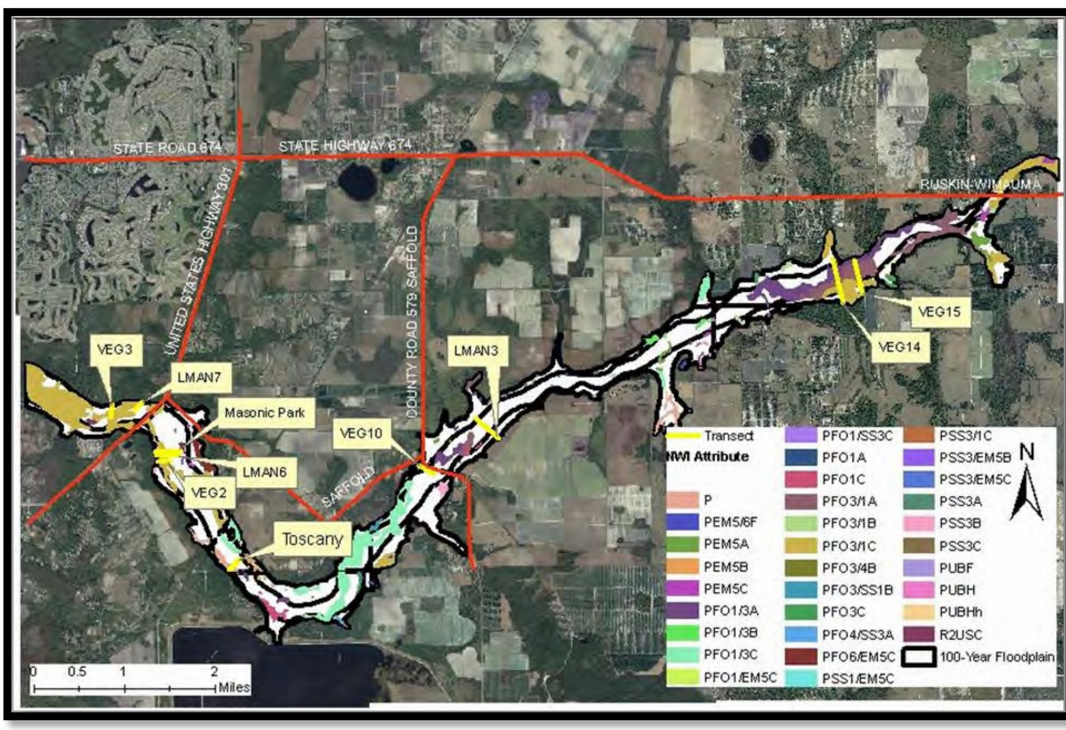

Figure 4-1. Location of vegetation transects and their extent along the Upper Little Manatee River study corridor (from PBS&J 2008 in Appendix K). The legend refers to National Wetlands Inventory (NWI) Attributes of community types within the riparian corridor, which are defined in PBS&J (2008, Appendix K).

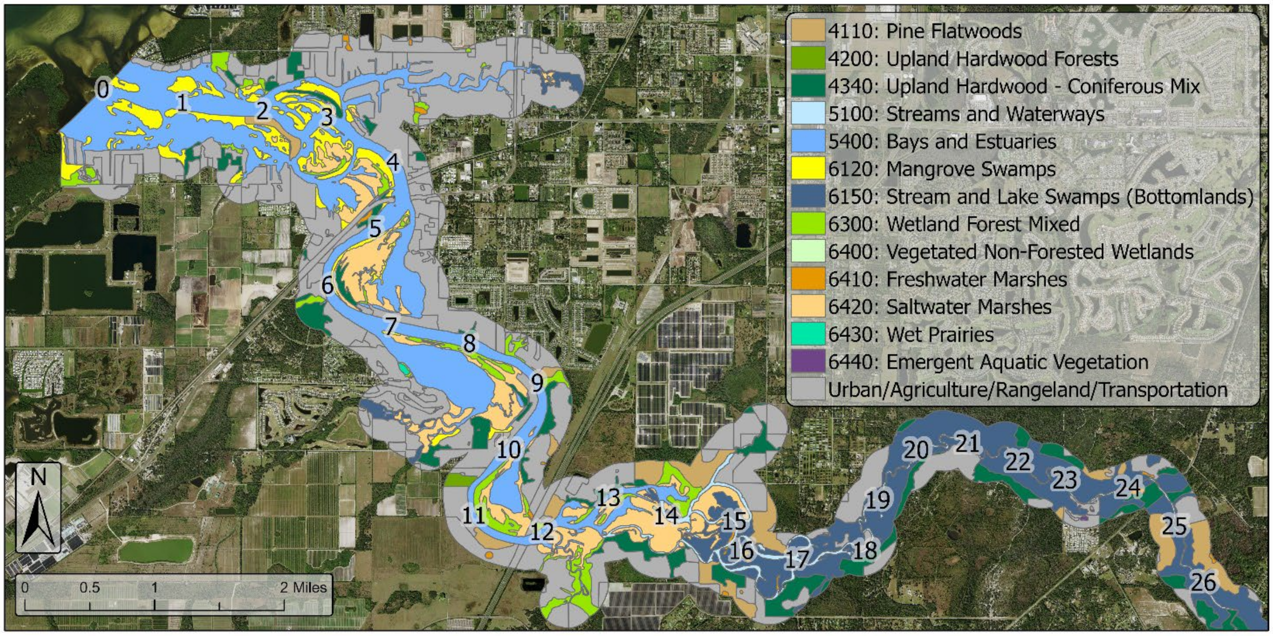

Figure 4-2. Measured river kilometers and distribution of major vegetation communities on the Lower Little Manatee River (Florida Land Use, Cover and Forms Classification 2020, SWFWMD 2021a).

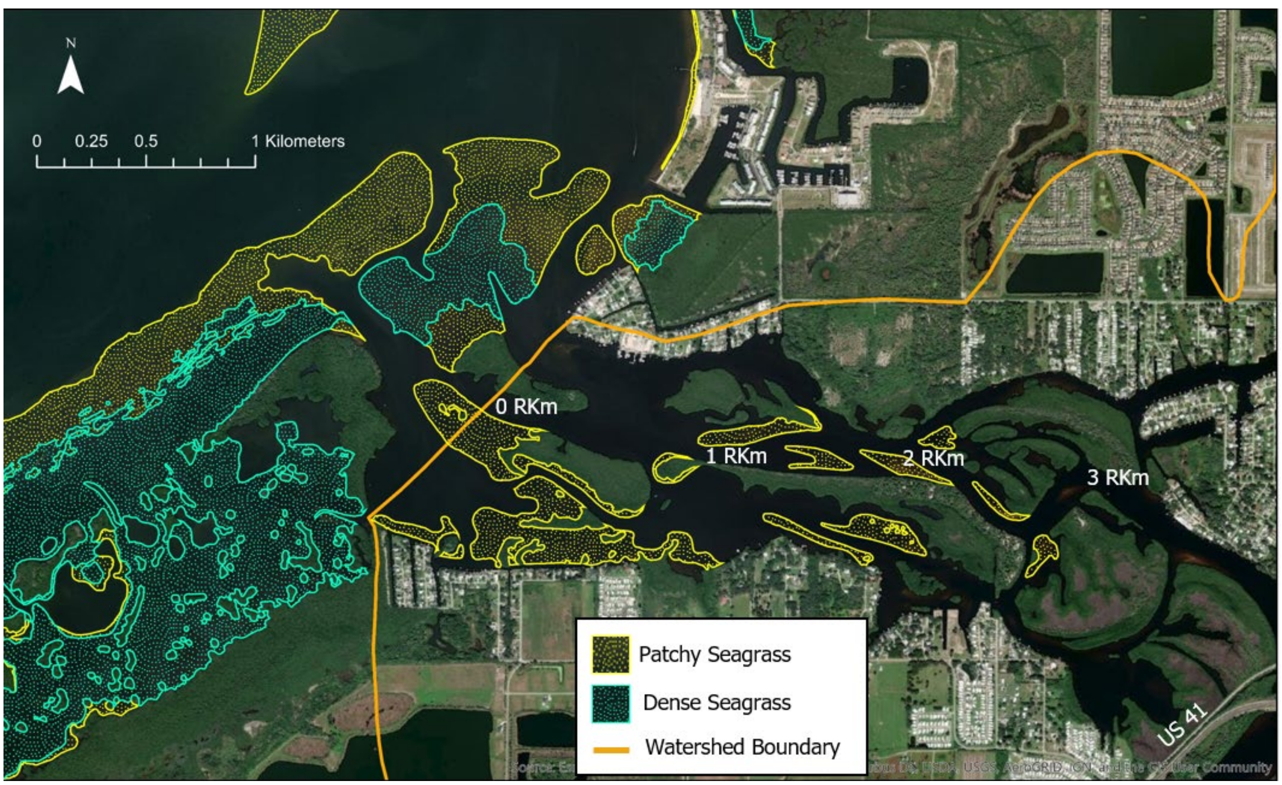

Figure 4-3. Seagrass distribution and density in the Lower Little Manatee River and adjacent portion of Tampa Bay (from SWFWMD 2021b). "Patchy" seagrass indicates coverage from 10 to 25 percent and "Dense" seagrass coverage ranged from >25 to 100 percent.

4.2 Benthic Macroinvertebrates

Benthic organisms are relatively sedentary and are effective indicators of a variety of environmental factors, including habitat quality and salinity (Boesch and Rosenberg 1981, USEPA 1999, DEP 2011). Most lack the mobility to escape large or rapid fluctuations in environmental conditions, and they occupy a variety of niches with respect to energy transfer. Benthic invertebrates process organic material as detritivores, suspension feeders, and deposit feeders, forming an essential link in the food web by transferring energy to secondary consumers, including other benthic organisms, finfish, and avifauna (Grabe and Janicki 2008 in Appendix K). The term, benthic macroinvertebrates, typically refers to organisms that are visible without magnification.

The DEP has conducted Stream Condition Index (SCI) assessments in the Upper Little Manatee River for many years. The SCI assessment is a procedure used in Florida that measures the degree to which flowing, fresh waters support a healthy, well-balanced biological community, as indicated by benthic macroinvertebrates (DEP 2011). The information resulting from the SCI assessments conducted at two sites in the upper river is summarized in the following paragraphs.

Several studies on benthic macroinvertebrates have been conducted in the Lower Little Manatee River (Dames and Moore 1975, Grabe et al. 2004, Grabe et al. 2005, Estevez 2006, JEI 2007, Grabe and Janicki 2008 in Appendix L). Selected information from some of these lower river studies is summarized below.

As mentioned in the beginning of this chapter, the summary below is not intended to be a compilation of all available studies. Instead, its purpose is a brief description of benthic macroinvertebrate community of both the upper and lower river that supports the methods used to develop minimum flows.

4.2.1 Upper River Benthic Macroinvertebrates

The DEP has been monitoring the benthic macroinvertebrate community of the Upper Little Manatee since 2008 using the Stream and River Habitat Assessment (HA) and SCI assessment methods. Two monitoring locations have been established: at US Highway 301 (1742A) near RKm 25 and upstream of CR 579 (1742B) near RKm 36 (Figure 4-4).

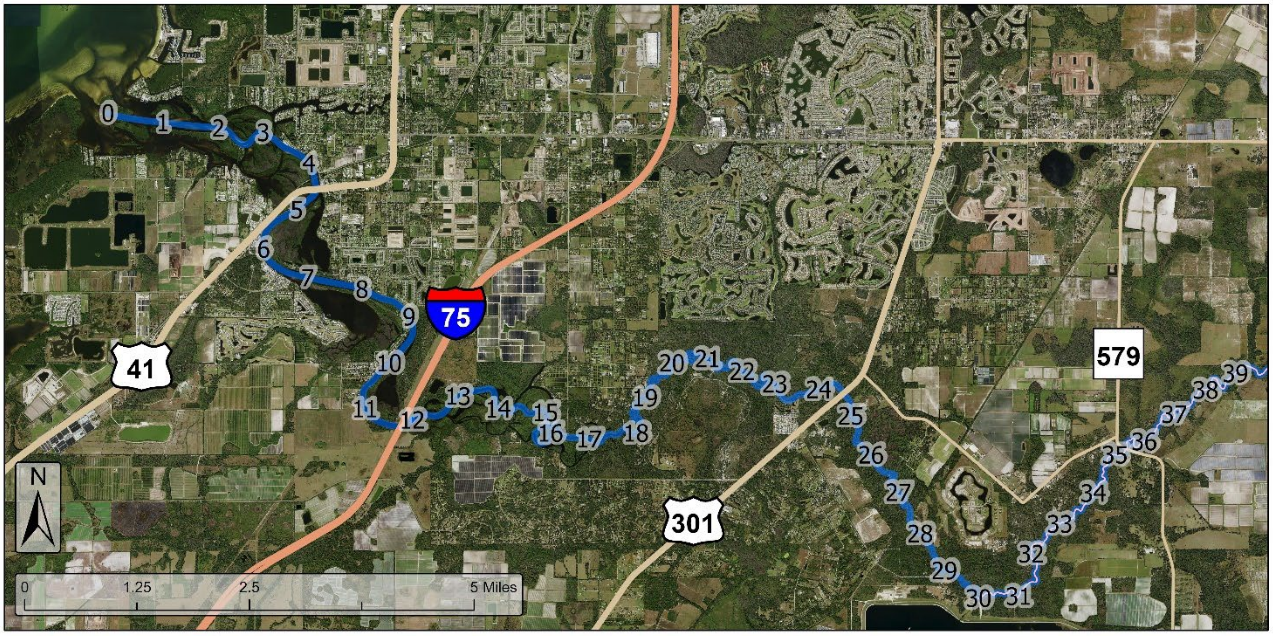

Figure 4-4. Location of major road crossings and measured river kilometers along the Little Manatee River.

The SCI assessment measures the biological health of benthic macroinvertebrates in Florida streams and rivers, and the HA determines overall habitat quality by mapping, measuring, and observing attributes known to have potential effects on stream biota. The DEP has developed standard operating procedures for these methods, and those using these methods in the field must demonstrate proficiency through rigorous training and testing, as well as continued field and online testing to maintain proficiency.

Habitat and SCI assessments have been conducted yearly at the US Highway 301 station from 2008 through 2019, when sampling conditions were appropriate; scores for all HAs at this site ranged in the Suboptimal to Optimal range, indicating high quality habitat for benthic macroinvertebrates. From 2008 through 2019, SCI scores averaged 55.3 (range of 24-72) at this location, which is indicative of a healthy benthic macroinvertebrate community and indicates that the upper river is healthy in the presence of the existing surface water withdrawals from FP&L. A score of <35 indicates a faunal imbalance (DEP 2011). Habitat assessments conducted upstream of CR 579 during 2012 indicated Optimal benthic macroinvertebrate habitat, and the resulting SCI score for this event was 53, indicating a healthy benthic macroinvertebrate community (DEP 2011).

Since 2008, almost 200 taxa of benthic macroinvertebrates have been collected from the US Highway 301 location (Table 4-1). In 2012, 34 benthic macroinvertebrate taxa were collected upstream of CR 579 (Table 4-2). At both locations, many types of mayflies (Ephemeroptera) and caddisflies (Trichoptera) were collected (highlighted in gray), which are indicative of high habitat quality (Rasmussen 2004).

Table 4-1. Benthic macroinvertebrate taxa collected by the DEP in the Little Manatee River at US Highway 301 from 2008 through 2019. Mayflies (Ephemeroptera) and caddisflies (Trichoptera) are highlighted in gray.

Common Name	Scientific Name	Total Number Collected
Non-Biting Midge	*Ablabesmyia mallochi*	11
Midge	*Ablabesmyia peleensis*	1
Non-Biting Midge	*Ablabesmyia rhamphe* grp.	5
Mite	Acariformes	2
Worm	*Allonais inaequalis*	1
Freshwater Snail	Amnicola	22
Freshwater Limpet	Ancylidae	71
Damselfly	*Argia*	72
Blue-Ringed Dancer	*Argia sedula*	1
Moth	*Argyractis*	1
Water Mite	*Arrenurus*	37
Arachnid	Atractides	2
Biting Midge	Atrichopogon	22
Mayfly	Baetidae	11
Minnow Mayfly	*Baetis intercalaris*	24
Molluscs	Bivalvia	5
Squaregill Mayfly	Caenidae	2
Mayfly	*Caenis*	140
Minnow Mayfly	*Callibaetis floridanus*	8
Damselfly	Calopterygidae	1
Crayfish	Cambaridae	15
Gall Midge	Cecidomyiidae	2
Biting Midge	Ceratopogonidae	1
Tube Maker Caddisfly	*Cernotina*	3
Netspinning Caddisfly	*Cheumatopsyche*	160
Non-Biting Midge	Chironomidae	71
Non-Biting Midge	*Chironomus*	2
Non-Biting Midge	*Cladotanytarsus*	2
Non-Biting Midge	*Cladotanytarsus* cf. *daviesi*	1
Water Mite	Clathrosperchon	1
Narrow-Winged Damsel Fly	Coenagrionidae	79
Asian Clam	*Corbicula fluminea*	26
Eastern Dobsonfly	*Corydalus cornutus*	2
Grass Moth	Crambidae	8
Non-Biting Midge	*Cricotopus bicinctus*	12
Non-Biting Midge	*Cricotopus* or *Erthocladius*	1
Non-Biting Midge	Cryptotendipes	1
Mosquito	Culicidae	3

Snout Beetle	Curculionidae	1
Salvinia Weevil	*Cyrtobagous salviniae*	2
Crustacean	Decapoda	2
Dero Worm	*Dero digitata* complex	1
Non-Biting Midge	*Dicrotendipes neomodestus*	2
Non-Biting Midge	*Dicrotendipes simpsoni*	1
Whirlgig Beetle	*Dineutus*	1
Fruit Fly	Drosophilidae	1
Long-Toed Water Beetle	Dryopidae	2
Riffle Beetle	*Dubiraphia vittata*	25
Worm	*Eclipidrilus*	2
Worm	*Eclipidrilus palustris*	3
Riffle Beetle	Elmidae	1
Bluet Damsel Fly	*Enallagma*	13
Worm	Enchytraeidae	1
Water Scavenger Beetle	*Enochrus ochraceus*	1
Eastern Pondhawk Dragonfly	*Erythemis simplicicollis*	1
Mottled Fingernail Clam	*Eupera cubensis*	14
Biting Midge	Forcipomyia	1
Snail	Gastropoda	10
Leech	*Glossiphoniidae*	2
Midge	*Goeldichironomus fluctuans*	6
Club-Tailed Dragonfly	Gomphidae	1
Non-Biting Midge	*Gymnometriocnemus*	1
Leech	*Helobdella stagnalis*	1
Leech	*Helobdella triserialis*	4
Flat-Headed Mayfly	Heptageniidae	15
Rubyspot Damselfly	*Hetaerina*	1
Leech	*Hirudinea*	1
Amphipod	*Hyalella azteca*	68
Mud Snail	Hydrobiidae	213
Netspinning Caddisfly	*Hydropsyche*	29
Netspinning Caddisfly	*Hydropsyche rossi*	7
Netspinning Caddisfly	*Hydropsychidae*	7
Microcaddisfly	*Hydroptila*	1
Water Mite	*Hygrobates*	2
Mayfly	*Labiobaetis*	2
Mayfly	*Labiobaetis propinquus*	126
Non-Biting Midge	*Labrundinia johannseni*	8
Non-Biting Midge	*Labrundinia neopilosella*	2
Non-Biting Midge	*Labrundinia pilosella*	3
Non-Biting Midge	*Larsia*	1

Moth	Lepidoptera	6
Skimmer Dragonfly	Libellulidae	9
Crane Fly	*Limonia*	1
Pond Snail	*Lymnaea*	1
Pond Snail	Lymnaeidae	2
Flat-Headed Mayfly	*Maccaffertium*	15
Flat-Headed Mayfly	*Maccaffertium exiguum*	11
Flat-Headed Mayfly	*Macromia illinoiensis*	1
Illinois River Cruiser Dragonfly	*Macromia illinoiensis georgina*	1
Cruiser Dragonfly	Macromiidae	1
Riffle Beetle	*Macronychus glabratus*	1
Snail	*Melanoides*	25
Ramshorn Snail	*Menetus*	2
Velvet Water Bug	*Merragata brunnea*	1
Water Treader	Mesoveliidae	3
Riffle Beetle	*Microcylloepus pusillus*	473
Ramshorn Snail	*Micromenetus*	3
Detritus Worm	Naididae	7
Non-Biting Midge	*Nanocladius*	1
Non-Biting Midge	*Nanocladius crassicornus*	1
Long-Horned Caddisfly	*Nectopsyche*	23
Long-Horned Caddisfly	*Nectopsyche exquisita*	16
Long-Horned Caddisfly	*Nectopsyche pavida*	7
Caddisfly	*Neotrichia*	139
Arthropod	*Neumania*	1
Tube Maker Caddisfly	*Neureclipsis*	2
Shadowdragon Dragonfly	*Neurocordulia alabamensis*	2
Dark Fish Fly	*Nigronia*	1
Alligator Siltsnail	*Notogillia wetherbyi*	1
Soldier Fly	*Odontomyia*	1
Long-Horned Caddisfly	*Oecetis* sp. e *floyd*	1
Beetle Mite	*Oribatida*	1
Microcaddisfly	*Oxyethira*	9
Glass Shrimp	*Palaemonetes*	11
Biting Midge	*Palpomyia/bezzia* grp.	2
True Water Bug	*Paraplea*	1
Moth	*Parapoynx*	3
Non-Biting Midge	*Paratanytarsus*	1
Creeping Water Bug	*Pelocoris*	1
Water Beetle	*Peltodytes*	9
Non-Biting Midge	*Pentaneura inconspicua*	35
Moth	*Petrophila*	1

Bladder Snail	*Physa*	47
Bladder Snail	Physidae	6
Air-Breathing Snail	*Planorbella*	7
Flatworm	*Platyhelminthes*	9
Flat-Footed Fly	*Platypeza*	1
Tube Maker Caddisfly	Polycentropodidae	2
Non-Biting Midge	*Polypedilum*	1
Non-Biting Midge	*Polypedilum fallax*	6
Non-Biting Midge	*Polypedilum flavum*	438
Non-Biting Midge	*Polypedilum illinoense* grp.	86
Non-Biting Midge	*Polypedilum scalaenum* grp.	22
Non-Biting Midge	*Polypedilum trigonus*	2
Apple Snail	*Pomacea*	2
Worm	*Pristina*	1
Worm	*Pristina proboscidea*	1
Crayfish	*Procambarus*	2
Tiny Blue-Winged Olive Mayfly	*Pseudocloeon propinquum*	28
Tiny Blue-Winged Olive Mayfly	*Pseudosuccinea columella*	1
Serrate Crownsnail	*Pyrgophorus platyrachis*	284
Water Strider	*Rhagovelia obesa*	1
Non-Biting Midge	*Rheocricotopus*	1
Non-Biting Midge	*Rheotanytarsus exiguus* grp.	118
Non-Biting Midge	*Rheotanytarsus pellucidus*	22
Black Fly	*Simulium*	36
Worm	*Slavina appendiculata*	6
Water Mite	*Sperchon*	1
Water Mite	Sperchonidae	1
Fingernail Clam	Sphaeriidae (mollusca)	13
Rove Beetle	Staphylinidae	1
Beetle	*Stenelmis*	29
Non-Biting Midge	*Stenochironomus*	29
Weevil	*Tanysphyrus lemnae*	1
Non-Biting Midge	*Tanytarsus buckleyi*	9
Non-Biting Midge	*Tanytarsus messersmithi*	1
Non-Biting Midge	*Tanytarsus sepp*	7
Non-Biting Midge	*Tanytarsus* sp. a *epler*	2
Non-Biting Midge	*Tanytarsus* sp. c *epler*	11
Non-Biting Midge	*Tanytarsus* sp. f *epler*	8
Non-Biting Midge	*Tanytarsus* sp. g *epler*	1
Non-Biting Midge	*Tanytarsus* sp. l *epler*	2
Non-Biting Midge	Tanytarsus sp. l epler complex	1
Non-Biting Midge	*Tanytarsus* sp. t *epler*	1

Non-Biting Midge	*Tanytarsus* sp. y *epler*	1
Non-Biting Midge	*Thienemanniella lobapodema*	1
Crane Fly	*Tipula* sp.	2
Crane Fly	Tipulidae	4
Long-Horned Caddisfly	*Triaenodes*	10
Non-Biting Midge	*Tribelos fuscicornis*	2
Caddisfly	Trichoptera	3
Little Stout Crawler Mayfly	*Tricorythodes albilineatus*	4
Beetle	*Tropisternus*	1
Worm	Tubificidae	18
Water Mite	*Unionicola*	3
Non-Biting Midge	*Xestochironomus*	3

Table 4-2. Benthic macroinvertebrate taxa collected by the DEP in the Little Manatee River upstream of CR 579 in 2012. Mayflies (Ephemeroptera) and caddisflies (Trichoptera) are highlighted in gray.

Common Name	Scientific Name	Total Number Collected
Non-Biting Midge	*Ablabesmyia mallochi*	4
Freshwater Limpet	Ancylidae	4
Mayfly	Baetidae	2
Netspinning Caddisfly	*Cheumatopsyche*	58
Non-Biting Midge	Chironomidae	13
Narrow-Winged Damsel Fly	Coenagrionidae	1
Asian Clam	*Corbicula fluminea*	4
Non-Biting Midge	*Cricotopus*	1
Non-Biting Midge	*Cricotopus bicinctus*	1
Non-Biting Midge	*Cryptochironomus*	1
Non-Biting Midge	*Dicrotendipes neomodestus*	1
Worm	*Eclipidrilus palustris*	3
Riffle Beetle	*Microcylloepus pusillus*	37
Worm	*Nais communis complex*	12
Non-Biting Midge	*Nanocladius*	1
Caddisfly	*Neotrichia*	11
Microcaddisfly	*Oxyethira*	1
Non-Biting Midge	*Paratanytarsus*	3
Non-Biting Midge	*Pentaneura inconspicua*	1
Bladder Snail	*Physa*	5
Flatworm	*Platyhelminthes*	1
Non-Biting Midge	*Polypedilum flavum*	47
Ribbon Worm	*Prostoma*	1
Tiny Blue-Winged Olive Mayfly	*Pseudocloeon propinquum*	44
Non-Biting Midge	*Rheotanytarsus exiguus grp.*	2

Worm	*Slavina appendiculata*	3
Fingernail Clam	Sphaeriidae	1
Beetle	*Stenelmis*	4
Non-Biting Midge	*Stenochironomus*	2
Non-Biting Midge	*Tanytarsus* sp. a *epler*	6
Non-Biting Midge	*Tanytarsus* sp. c *epler*	20
Non-Biting Midge	*Tanytarsus* sp. l *epler*	1
Non-Biting Midge	*Tanytarsus* sp. s *epler*	2
Caddisfly	Trichoptera	1

4.2.2 Lower River Benthic Macroinvertebrates

In Tampa Bay and its associated estuaries, benthic macroinvertebrate communities commonly include aquatic insects, worms, snails, clams, shrimp, and other crustaceans that reside on or near the surface sediment layer (JEI 2018b in Appendix E). These organisms are generally sessile, although some species may undergo migrations into the water column or produce planktonic larvae. Several studies on benthic macroinvertebrates that have been conducted in the Lower Little Manatee River were summarized by Grabe and Janicki (2008 in Appendix L). A mollusk survey was also conducted specifically to characterize mollusk populations in the Little Manatee River estuary (Estevez 2006) in support of minimum flows development.

Data for the benthic macroinvertebrate assemblages summarized in Grabe and Janicki (2008 in Appendix L) in the Lower 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 Lower Little Manatee River as a control site to evaluate the effects of freshwater withdrawals in the nearby Alafia River. Samples were collected by the EPC as part of the Tampa Bay Benthic Monitoring Program between 1996-1998 and subsequently through 2004 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 through early June 2005 from the Lower Little Manatee River mainstem and Bolster (RKm 10), Hays (RKm 7), and Mill (RKm 5) Bayous. Samples were collected from RKm 0 to just upstream of RKm 17 (Figure 4-5). Transects were established every 0.5 km in the main stem of the river, and Ruskin Inlet and intertidal areas were excluded (JEI 2005). Two samples were collected at random locations within each 0.5-km segment from RKm 0 to RKm 17. Eight samples were collected from Mill Bayou, 16 from Hayes Bayou, and four from Bolster Bayou. A total of 235 samples included in the data summary were collected: 139 from EPC wet season surveys during 1996-2004 and 96 dry season samples collected for the District in 2005 (Figure 4-5).

The Lower Little Manatee River benthic macroinvertebrate community was dominated by crustacean taxa, particularly the amphipods, *Grandidierella bonnieroides* and *Apocorophium louisianum* (Grabe and Janicki 2008 in Appendix L). Dominant taxa were generally similar between wet and dry season surveys, although the rank orders differed (Tables 4-3 and 4-4). The number of taxa generally declined with upstream location irrespective of season, but the abundance of benthic macroinvertebrates did not show any consistent longitudinal trend during either season. Only four taxa (identified to genus or species) were among the ten ranked dominants in both seasons: the amphipods, *Grandidierella bonnieroides* and *Apocorophium louisianum*; the isopod, *Cyathura polita*, and the Atlantic paper mussel (*Amygdalum papyrium*).

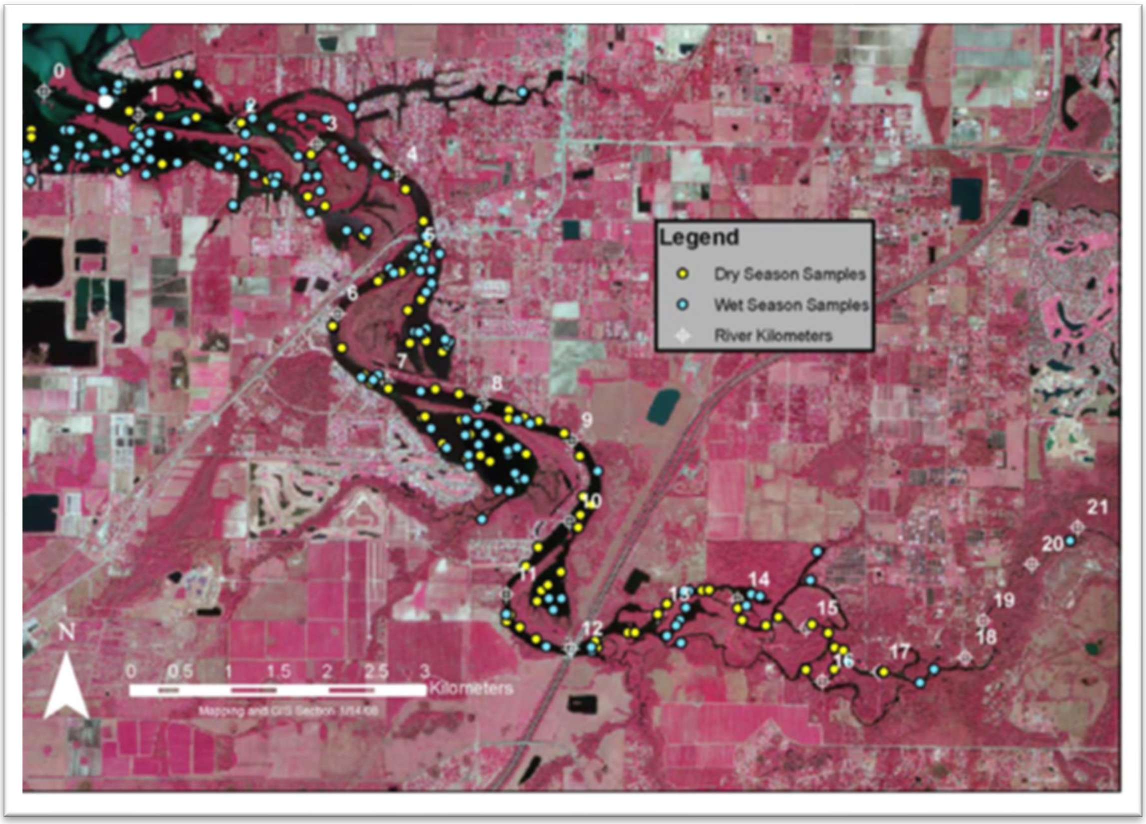

Figure 4-5. Location of benthic macroinvertebrate samples collected between 1996-2005 in the Lower Little Manatee River (from Grabe and Janicki 2008 in Appendix L). River kilometer (RKm) system corresponds with distance from the mouth of the river at RKm 0.

A 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 lower river, which was generally similar in multivariate community structure. The dry season benthos showed evidence of a shift in assemblages at RKms 6 through 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 in Appendix L). Principal component analysis identified changes in community structure associated with oligohaline (0-5 psu), mesohaline (5-18 psu), and polyhaline (18-30 psu) salinity classes. Interestingly, two taxa, the amphipod, *Grandidierella bonnierodes*, and the isopod, *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.

Table 4-3. The top fifty ranked dominant benthic macroinvertebrate taxa collected in multiple studies of the Lower Little Manatee River during the wet season from 1996 through 2004 (from Grabe and Janicki 2008 in Appendix L).

Common Name	Scientific Name	Frequency of Occurrence	Mean Density (#/m^2)	Dominance	Mean Salinity at Capture (psu)	Mean Center of Abundance (RKm)
Amphipod	*Apocorophium louisianum*	32	1,550	23.52	7.1	5.0
Amphipod	*Grandidierella bonnieroides*	53	586	18.61	8.0	8.1
Sludge worm	Tubificidae	64	315	14.98	8.2	7.8
Amphipod	*Ampelisca holmesi*	39	376	12.80	15.2	0.7
Amphipod	*Cerapus* spp.	28	441	11.74	16.3	1.7
Isopod	*Cyathura polita*	63	194	11.68	8.1	5.8
Isopod	*Xenanthura brevitelson*	42	143	8.19	12.5	3.5
Polychaete worm	*Monticellina dorsobranchialis*	26	220	7.99	21.0	0.4
Polychaete worm	*Laeonereis culveri*	49	106	7.60	8.1	5.0
Atlantic paper mussel	*Amygdalum papyrium*	37	132	7.38	16.2	1.1
Brachiopod	*Glottidia pyramidata*	20	182	6.38	19.4	0.0
Oligochaete worm	*Tubificoides brownie*	23	154	6.29	15.4	1.9
Polychaete worm	*Aricidea philbinae*	33	106	6.24	17.9	0.9
Tube-building amphipod	*Ampelisca abdita*	36	77	5.55	12.2	1.8

Non-biting midge	*Polypedilum scalaenum*	43	64	5.55	4.7	8.0
Plate mysella	*Mysella planulata*	22	88	4.65	19.4	0.5
Green tanaid crustacean	*Leptochelia* spp.	29	58	4.34	12.8	3.0
Oligochaete worm	*Tubificoides motei*	17	94	4.22	7.0	6.5
Conrad's false mussel	*Mytilopsis leucophaeata*	21	72	4.11	7.3	8.7
Bristle worm	*Heteromastus filiformis*	35	42	4.04	10.2	2.9
Polychaete worm	*Fabricinuda triloba*	18	79	3.99	18.9	1.1
Tube-dwelling polychaete	*Hobsonia florida*	28	44	3.71	12.0	3.3
Tube-dwelling polychaete	*Streblospio gynobranchiata*	28	43	3.65	11.4	4.0
Isopod	*Edotea triloba*	37	30	3.49	12.4	2.1
Barnacle	*Cirripedia*	7	145	3.37	12.5	0.1
Sea snail	*Acteocina canaliculata*	24	42	3.35	18.9	0.4
Hooded shrimp	*Cyclaspis* cf. *varians*	20	50	3.34	18.3	0.5
Amphipod	*Ampelisca vadorum*	23	43	3.31	17.7	2.6
Oligochaete worm	*Tubificoides wasselli*	15	59	3.13	20.1	0.4
Harris mud crab	*Rhithropanopeus harrisii*	34	23	2.97	11.5	4.1
Dwarf surf clam	*Mulinia lateralis*	17	39	2.73	17.8	0.4

Polychaete worm	*Aricidea taylori*	16	37	2.57	19.9	0.8
Ribbon worm	*Amphiporus bioculatus*	17	32	2.45	17.1	0.6
Bivalvia mollusc	Bivalvia mollusc	29	15	2.21	8.7	5.4
Midge	*Polypedilum halterale*	15	29	2.21	0.9	11.6
Mud snail	Hydrobiidae	17	25	2.18	4.6	9.2
Stout tagelus clam	*Tagelus plebeius*	30	13	2.10	9.4	3.4
Non-biting midge	*Chironomus* spp.	16	19	1.84	3.3	6.2
Polychaete worm	*Capitella capitata*	19	15	1.78	13.8	1.5
Asian clam	*Corbicula fluminea*	5	57	1.78	0.1	17.2
Sea snail	*Haminoea succinea*	16	14	1.56	15.7	0.4
Zombie snail	*Nassarius vibex*	22	10	1.53	20.4	0.4
Narrowed macoma clam	*Macoma tenta*	12	16	1.48	18.6	0.3
Non-biting midge	*Procladius* spp.	14	14	1.45	1.10	11.0
Ribbon worm	*Archinemertea* sp. A	20	9	1.37	10.1	3.4
Ribbon worm	*Nemertea* K	11	15	1.36	14.7	1.0
Hooded shrimp	*Oxyurostylis smithi*	12	11	1.22	18.8	0.1
Snail	*Pyrgophorus platyrachus*	6	21	1.19	0.3	13.0
Bloodworm	*Glycera americana*	17	7	1.18	20.7	0.3
Pointed venus	*Anomalocardia auberiana*	14	9	1.17	17.4	1.0

Table 4-4. The top fifty ranked dominant benthic macroinvertebrate taxa collected in the Lower Little Manatee River during the dry season of 2005 (from Grabe and Janicki 2008, Appendix L).

Common Name	Scientific Name	Frequency of Occurrence	Mean Density (#/m^2)	Dominance	Mean Salinity at Capture (psu)	Mean Center of Abundance (RKm)
Amphipod	*Grandidierella bonnieroides*	76	3,668	42.96	14.9	6.5
Amphipod	*Apocorophium louisianum*	48	3,552	33.59	14.6	6.9
Tube-building amphipod	*Ampelisca abdita*	43	2,135	24.65	15.3	3.0
Isopod	Cyathura polita	61	657	16.29	14.5	6.9
Atlantic paper mussel	Amygdalum papyrium	27	954	13.05	15.0	1.8
Sludge worm	Tubificidae	35	655	12.32	11.9	11.9
Tiger scud	*Gammarus tigrinus*	26	593	10.1	8.5	13.9
Asian clam	*Corbicula fluminea*	20	315	6.46	6.0	14.4
Bristle worm	*Heteromastus filiformis*	24	196	5.58	14.7	2.7
Ribbon worm	*Nemertea*	27	169	5.49	16.9	2.6
Polychaete worm	*Laeonereis culveri*	29	116	4.73	15.7	5.5
Slender flatworm	*Euplana gracilis*	18	123	3.83	14.3	3.8
Oligochaete worm	*Tubificoides heterochaetus*	13	144	3.52	14.3	7.7

Polychaete worm	*Aricidea philbinae*	7	256	3.44	15.5	0.9
Amphipod	*Ampelisca holmesi*	6	267	3.26	14.4	1.7
Polychaete worm	*Monticellina dorsobranchialis*	8	148	2.80	16.7	0.2
Sea anemone	Athenaria	3	335	2.58	15.5	2.1
Midge	*Polypedilum scalaenum*	13	68	2.43	10.1	10.8
Non-biting midge	*Cryptochironomus* spp.	13	62	2.30	15.2	11.6
Isopod	*Xenanthura brevitelson*	11	64	2.16	15.9	3.5
Green tanaid crustacean	*Leptochelia* spp.	5	135	2.11	14.3	2.0
Tube-dwelling polychaete	*Streblospio gynobranchiata*	13	48	2.03	14.1	4.6
Carolina marsh clam	*Polymesoda caroliniana*	12	48	1.95	12.4	6.4
Scud	*Apocorophium lacustre*	4	132	1.87	5.4	14.0
Bivalvia mollusc	Bivalvia mollusc	10	50	1.82	12.0	5.7
Tube-dwelling polychaete	*Hobsonia florida*	14	34	1.78	17.3	5.0
Non-biting midge	*Cladotanytarsus* spp.	6	50	1.41	7.2	15.5
Amphipod	*Hourstonius laguna*	9	30	1.33	14.4	4.3

Oligochaete worm	*Tubificoides brownie*	4	57	1.23	12.1	10.1
Polychaete worm	*Eteone heteropoda*	6	37	1.20	17.0	1.9
Hooded shrimp	*Cyclaspis* cf. *varians*	8	25	1.15	16.2	2.6
Polychaete worm	*Capitella capitata*	7	27	1.13	10.1	2.7
Polychaete worm	*Glycinde solitaria*	6	32	1.13	18.9	0.5
Amphipod	*Ameroculodes miltoni*	5	27	0.95	16.3	2.3
Polychaete worm	*Phyllodoce arenae*	5	25	0.91	21.0	1.1
Isopod	*Edotea triloba*	6	21	0.90	10.8	8.8
Clam worm	*Neanthes succinea*	6	21	0.90	19.6	2.4
Florida lyonsia clam	*Lyonsia floridana*	6	18	0.85	22.6	0.9
Amphipod	*Melita elongate*	3	37	0.85	23.7	1.4
Non-biting midge	*Polypedilum halterale*	2	53	0.83	18.8	14.3
Polychaete worm	*Paraprionospio pinnata*	6	16	0.80	16.7	0.7
Polychaete worm	*Fabricinuda triloba*	5	18	0.78	16.1	0.6
Polychaete worm	*Leitoscoloplos robustus*	5	18	0.78	18.4	1.5
Non-biting midge	*Procladius* spp.	5	18	0.78	18.7	11.9

Plate mysella	*Mysella planulata*	4	21	0.74	14.2	1.0
Conrad's false mussel	*Mytilopsis leucophaeata*	5	16	0.73	16.3	6.9
Hooded shrimp	*Oxyurostylis smithi*	4	14	0.60	19.3	1.0
Oligochaete worm	*Tectidrilus wasselli*	2	25	0.58	10.4	0.0
Fragile mactra clam	*Mactra fragilis*	3	14	0.52	17.2	0.8
Polychaete worm	*Prionospio* spp.	2	14	0.43	14.4	0.0

Sampling for the mollusk survey conducted in the Lower Little Manatee River in August 2006 occurred from the river mouth to RKm 16.5 on 1-km intervals from RKm 6-12, at 4 stations upstream of RKm 12 (13, 13.75, 14.5, and 16.5), and at 4 stations downstream of RKm 6 (0, 1.5, 3, and 4.5) (Figure 4-4, Estevez 2006). A total of 26 taxa was collected, with Asian clams (*Corbicula fluminea*) being the most common. Carolina marsh clams (*Polymesoda caroliniana*), olive nerite snails (*Neritina usnea*), and marsh periwinkle sea snails (*Littoraria irrorata*) also were abundant. About one third of the taxa collected were represented by dead-only material. Taxa accumulated monotonically in a downstream direction, and there was a break in the community structure at RKm 5, where only oysters and mussels were collected (Figure 4-6). Species richness was highest at RKm 6-8, where more live material was collected. While salinity data were not collected during this study, the distributional patterns of taxa were likely related to salinity gradients along the lower river.

As indicated by the summary above, protecting habitat for benthic macroinvertebrates, whether it be physical habitat and adequate flow in the upper river or ranges of low-salinity habitat in the lower river, is an important factor to consider when developing minimum flows. Because of that, the methods used to develop minimum flows for both the upper and lower river addressed the protection of habitat for benthic macroinvertebrates.

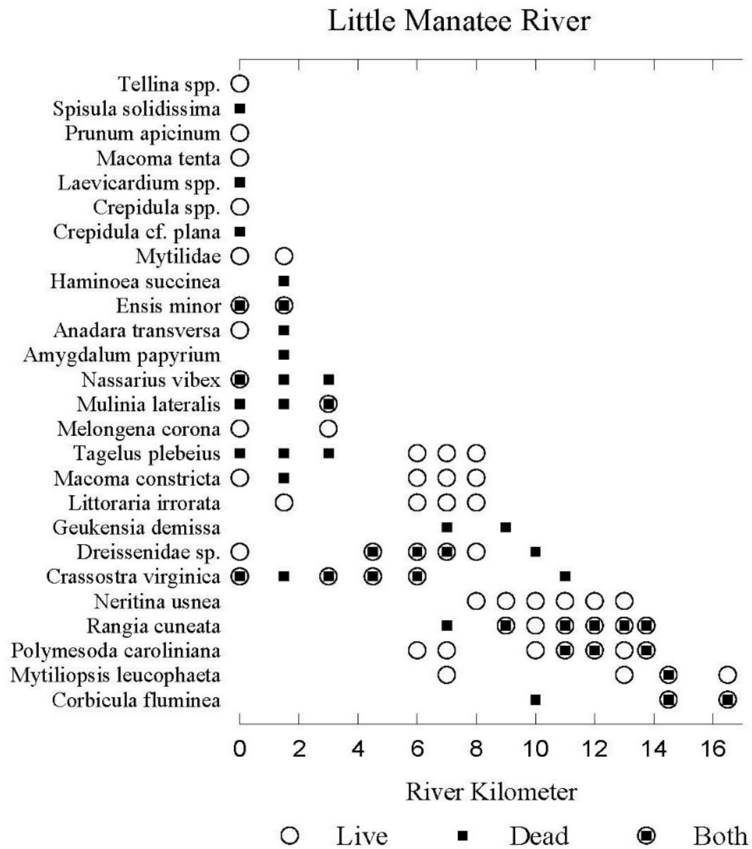

Figure 4-6. Downstream sort of species occurrences for live and dead material by river kilometer (from Estevez 2006). *Tellina* spp. = bivalve mollusk, *Spisula solidissima* = surf clam, *Prunum apicinum* = common Atlantic marginella sea snail, *Macoma tenta* = tent macoma clam, *Laevicardium* spp. = egg cockle clam, *Crepidula* spp. = slipper snail, *Crepidula cf. plana* = eastern white slippersnail, Mytilidae = bivalve mollusk, *Haminoea succinea* = amber glassy bubble snail, *Ensis minor* = jacknife clam, *Anadara transversa* = transverse ark clam, *Amygdalum papyrium* = Atlantic paper mussel, *Nassarius vibex* = bruised nassa sea snail, *Mulinia lateralis* = dwarf surf clam, *Melongena corona* = Florida crown conch, *Tagelus plebeius* = stout tagelus clam, *Macoma constricta* = constricted macoma clam, *Littoraria irrorata* = marsh periwinkle sea snail, *Geukensia demissa* = Atlantic ribbed mussel, Dreissenidae sp. = freshwater mussel, *Crassostra virginica* = eastern oyster, *Neritina usnea* = olive nerite snail, *Rangia cuneata* = Gulf wedge clam, *Polymesoda caroliniana* = Carolina marsh clam, *Mytiliopsis leucophaeta* = dark false mussel, *Corbicula fluminea* = Asian clam.

4.3 Fish and Other Nekton

Below is a summary of the Upper Little Manatee River fish community resulting from a recent field survey and a compilation of available museum records. The nekton (e.g., fish, crabs, shrimp) community of the Lower Little Manatee River is well characterized as a result of the FWC's long-term FIM program and is summarized below. Larval fish (ichthyoplankton) that utilize the Lower Little Manatee River were characterized in a field study described in this section. The summary below is not intended to be a compilation of all available studies but a brief description of the nekton community of both the upper and lower river that supports the methods used to develop minimum flows.

4.3.1 Upper River Fish Community

Few fish surveys of the Little Manatee River upstream of US Highway 301 have been conducted, most likely because of shallow water depths and lack of developed boat ramps. A survey was conducted by the FWC on September 10, 2020, in about 0.5 miles (0.6 km) of the river upstream of the US Highway 301 bridge (Nagid and Tuten 2020). Fish sampling was conducted at four locations (Figure 4-7) using a mini electrofishing boat.

Figure 4-7. Sampling locations on the Upper Little Manatee River where the FWC collected fish on September 10, 2020.

Sixteen species of freshwater and marine fish were collected by the FWC (Table 4-5). Most of the fish species collected were freshwater species typical of Southwest Florida river systems, although two non-native, freshwater species and three marine species were collected.

Fish collected from the Upper Little Manatee River that are in museum collections are listed in Table 4-6. Voucher specimens for 34 species of Upper Little Manatee River fish are included in the museum collections. Thirteen species found in the museum collections were also collected in September 2020. The additional 21 fish species in museum collections that were not collected in

2020 include 7 non-native taxa (Table 4-6). Many of the native species found in the museum collections and not collected in 2020 would most likely be collected if more extensive fish sampling of the Upper Little Manatee River was conducted.

Table 4-5. Species and number of fish collected from the Upper Little Manatee River by the Florida Fish and Wildlife Conservation Commission on September 10, 2020 (from Nagid and Tuten 2020).

Common Name	Scientific Name	Type	Site 1	Site 2	Site 3	Site 4	Total Captures
Asian Swamp Eel	*Monopterus javanensis*	Freshwater (Non-native)			3	5	8
Bluegill	*Lepomis macrochirus*	Freshwater	1				1
Golden Silverside	*Labidesthes vanhyningi*	Freshwater		2			2
Coastal Shiner	*Notropis petersoni*	Freshwater	5				5
Common Snook	*Centropomus undecimalis*	Marine	6			1	7
Eastern Mosquitofish	*Gambusia holbrooki*	Freshwater	11				11
Florida Gar	*Lepisosteus platyrhincus*	Freshwater			1	1	2
Hogchoker	*Trinectes maculatus*	Marine			3	15	18
Largemouth Bass	*Micropterus salmoides*	Freshwater			1	2	3
Redbreast Sunfish	*Lepomis auritus*	Freshwater			1		1
Redear Sunfish	*Lepomis microlophus*	Freshwater			1		1
Seminole Killifish	*Fundulus seminolis*	Freshwater			1		1
Spotted Sunfish	*Lepomis punctatus*	Freshwater	6			3	9
Striped Mojarra	*Eugerres plumieri*	Marine	1				1
Vermiculated Sailfin Catfish	*Pterygoplichthys disjunctivus*	Freshwater (Non-native)		1	1		2
White Catfish	*Ameiurus catus*	Freshwater		1	1		2
Total			30	4	13	27	74

Table 4-6. Voucher fish specimens collected from the Upper Little Manatee River (upstream of US Highway 301) that are in various museum collections (from Nagid and Tuten 2020).

Common Name	Scientific Name	Year	Institution	Catalog #
Asian Swamp Eel*	*Monopterus javanensis*	2008	UF	238744
Bluefin Killifish	*Lucania goodei*	1952	TU	4642
		1995	UF	241101
		2014	UF	236261
Bluegill	*Lepomis macrochirus*	1980	UF	171640
		1992	UF	90816
		2008	UF	238752
		2011	YPM	YPM ICH 025274
		2014	UF	236263
Bluespotted Sunfish	*Enneacanthus gloriosus*	1980	UF	171574
Coastal Shiner	*Notropis petersoni*	1952	TU	4639
		1980	UF	171568
		1992	UF	90809
		1994	UF	100516
		1995	UF	112941
		2008	UF	238749
		2011	YPM	YPM ICH 026207
		2014	UF	236203
Common Wolf Fish*	*Hoplias malabaricus*	1975	FSBC	9593
Dollar Sunfish	*Lepomis marginatus*	1952	TU	4645
		1978	UF	41608
Eastern Mosquitofish	*Gambusia holbrooki*	1952	TU	4638
		1992	UF	90811
		1994	UF	100517
		1995	UF	241104
		2008	UF	238742
		2011	YPM	YPM ICH 026210
		2014	UF	236267
Everglades Pygmy Sunfish	*Elassoma evergladei*	1963	UF	10326
		1992	UF	90818
Florida Gar	*Lepisosteus platyrhincus*	2011	YPM	YPM ICH 25200
Golden Shiner	*Notemigonus crysoleucas*	1995	UF	112942
Golden Silverside	*Labidesthes vanhyningi*	1952	TU	4641
		1995	UF	241105
		2011	YPM	YPM ICH 26209
		2014	UF	236204
Green Swordtail*	*Xiphophorus hellerii*	2008	UF	238741
Hogchoker	*Trinectes maculatus*	1952	TU	4640
		1978	UF	134425
		1980	UF	172375
		1992	UF	90813
		1994	UF	100522
		1995	UF	241103

		2008	UF	238743
		2011	YPM	YPM ICH 6206
		2014	UF	236264
Ironcolor Shiner	*Notropis chalybaeus*	1995	UF	112940
Jack Dempsey*	*Rocio octofasciata*	2014	UF	236170
Lake Chubsucker	*Erimyzon sucetta*	1995	UF	241098
Largemouth Bass	*Micropterus salmoides*	1952	TU	4637
		1980	UF	171609
		2011	YPM	YPM ICH 026208
		2014	UF	236260
Least Killifish	*Heterandria formosa*	1995	UF	241099
		2014	UF	236262
Longnose Gar	*Lepisosteus osseus*	1979	UF	242209
North African Jewelfish*	*Hemichromis letourneuxi*	2008	UF	238745
Oriental Weatherfish*	*Misgurnus anguillicaudatus*	1994	UF	100519
Pike Killifish*	*Belonesox belizanus*	2008	UF	238746
Redbreast Sunfish	*Lepomis auritus*	1992	UF	90814
		2011	YPM	YPM ICH 025276
Redear Sunfish	*Lepomis microlophus*	1978	UF	120705
		2011	YPM	YPM ICH 025275
Sailfin Molly	*Poecilia latipinna*	1992	UF	90812
		1994	UF	100520
		1995	UF	241106
Seminole Killifish	*Fundulus seminolis*	1952	TU	4636
Spotted Sunfish	*Lepomis punctatus*	1978	UF	127954
		1980	UF	171637
		1992	UF	90817
		1995	UF	186090
		2008	UF	238740
		2011	YPM	YPM ICH 025277
		2014	UF	236266
Tadpole Madtom	*Noturus gyrinus*	1952	TU	4644
		1992	UF	90810
		1995	UF	241100
Taillight Shiner	*Notropis maculatus*	1962	UF	10327
		1980	UF	171346
Walking Catfish*	*Clarias batrachus*	1994	UF	100521
		2008	UF	238751
Warmouth	*Lepomis gulosus*	1992	UF	90815
		1994	UF	100518
		1995	UF	241102
		2014	UF	236265
White Catfish	*Ameiurus catus*	2008	UF	238747
Yellow Bullhead	*Ameiurus natalis*	1994	UF	100523

* = Non-native
UF = University of Florida, TU = Tulane University, YPM = Yale University, FSBC = FWC Florida Wildlife Research Institute

4.3.2 Lower River Fish Community

Dutterer (2006) sampled fish at five locations in the upper portion of the Lower Little Manatee River (Figure 4-8). As a result of electrofishing conducted in April and December 2005, 26 fish species were collected (Table 4-7), including numerous obligate freshwater taxa, such as Largemouth Bass, and estuarine species, such as Common Snook (*Centropomus undecimalis*).

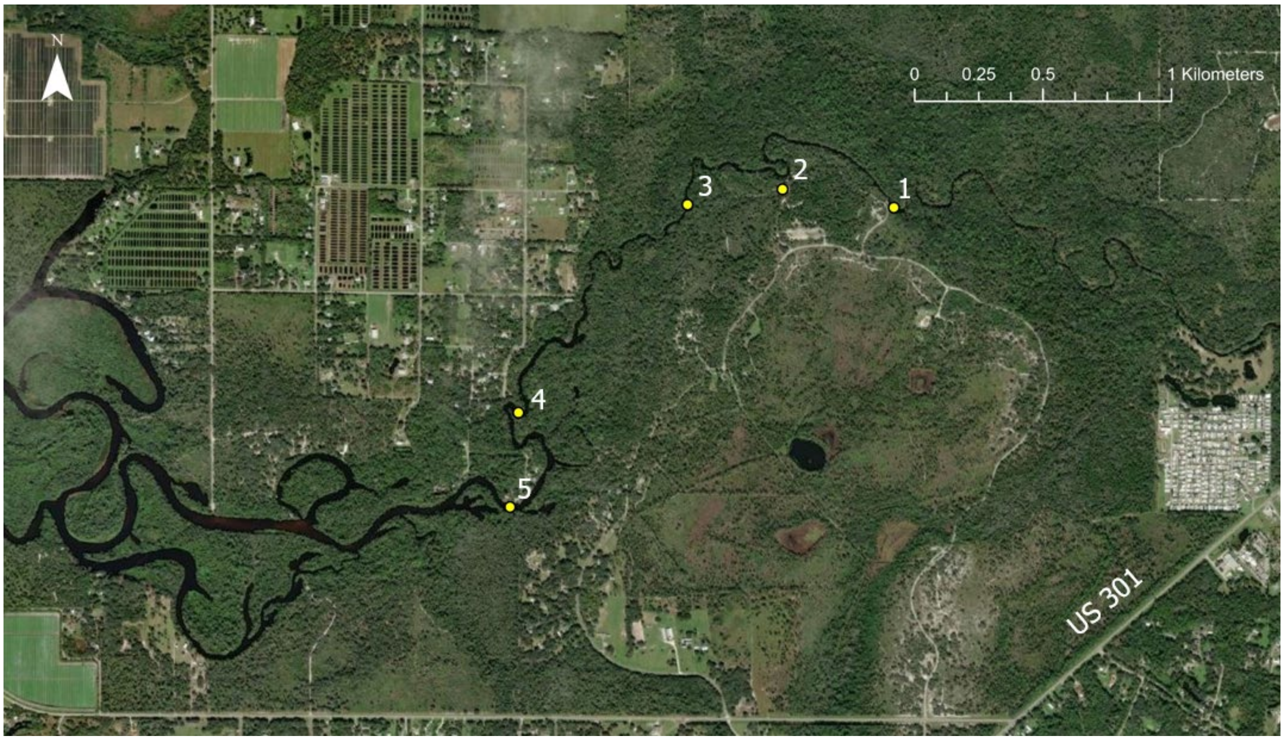

Figure 4-8. Sampling locations on the Lower Little Manatee River where fish were collected by Dutterer in 2005.

The FWC's FIM program has a robust long-term monitoring nekton dataset for the mid-to-lower portion of the Lower Little Manatee River. Monthly stratified-random sampling focused on this estuarine portion of the river began in 1996 from the mouth of the river to approximately 13.5 km (8.4 miles) upstream (Figure 4-9).

The sampling effort is divided into two water-depth-based zones within the system with four 21.3-m seine hauls and three 6.1-m otter trawls collected in each (Figure 4-9). The two gear types used target different age classes and habitats. The seines target young-of-the-year (YOY) and juvenile taxa in shallow water (≤1.8 m), and the trawls target YOY, juvenile, and adult nekton in deep water (1-7.6 m, FWC 2020). Each specimen caught is identified to the lowest practical taxonomic level, and a random subset of at least 10 individuals are measured according to the FIM program's procedure manual. We summarize available data from 1996 through 2020 in the following paragraphs (because of a red tide event, the 2021 data were excluded). The seine haul data were used in the analysis of the effects of changes in flow on favorable estuarine fish habitat, one of the criteria used to develop minimum flows for the Lower Manatee River.

Table 4-7. Fish taxa collected by Dutterer (2006) in the upper portion of the Lower Little Manatee River in 2005.

Common Name	Scientific Name
Florida Gar	*Lepisosteus platyrincus*
Longnose Gar	*Lepisosteus osseus*
American Eel	*Anguilla rostrata*
Asian Swamp Eel	*Monopterus albus*
Taillight Shiner	*Notropis maculatus*
Coastal Shiner	*Notropis petersoni*
Bluefin Killifish	*Lucania goodei*
Brown Bullhead	*Ameiurus nebulosus*
Rainwater Killifish	*Lucania parva*
Seminole Killifish	*Fundulus seminolis*
Banded Pygmy Sunfish	*Elasoma zonatum*
Eastern Mosquitofish	*Gambusia holbrooki*
Sailfin Molly	*Poecilia latipinna*
Largemouth Bass	*Micropterus salmoides*
Bluegill	*Lepomis macrochirus*
Dollar Sunfish	*Lepomis marginatus*
Redbreast Sunfish	*Lepomis auritus*
Redear Sunfish	Lepomis microlophus
Spotted Sunfish	*Lepomis punctatus*
Warmouth Sunfish	*Lepomis gulosus*
Bluespotted Sunfish	*Enneacanthus gloriosus*
Striped Mullet	*Mugil cephalus*
Naked Goby	*Gobiosoma bosc*
River Goby	*Awaous banana*
Hogchoker	*Trinectes maculatus*
Common Snook	*Centropomus undecimalis*

At least 1,915,470 individuals from 135 taxa were caught in 2,546 seine hauls between 1996 and 2020. Bay Anchovy (*Anchoa mitchilli)* dominated the catch numerically, accounting for 71.46 percent of the total catch and yielding a mean catch per unit effort (CPUE) of 790.55 fish/100 m^2 (Table 4-8). Over 90 percent of the total catch was comprised of six taxa: Bay Anchovy, Silversides (*Menidia* spp., 8.58 percent), Mojarras (*Eucinostomus* spp., 4.77 percent)*,* Tidewater Mojarra (*Eucinostomus harengulus*, 1.83 percent), Rainwater Killifish (*Luciana parva*, 1.82 percent), and Spot (*Leiostomus xanthurus*, 1.64 percent). Silversides were the most commonly caught taxa, present in 78.5 percent of seines. Other taxa collected in >50 percent of seines included: Mojarras (73.4 percent), Tidewater Mojarra (67.9 percent), Bay Anchovy (53.4 percent), and Clown Goby (*Microgobius gulosus*, 50.9 percent). Seasonality is evident in the catch, with higher mean taxa richness occurring during the wet summer months (June through August, Figure 4-10).

Approximately 391,508 individuals were caught in 1,772 trawls over the same period of record, representing 116 taxa. Bay Anchovies were the most abundant taxa, accounting for 70.76 percent of the total catch with a mean CPUE of 21.1 fish/100 m^2 (Table 4-9). Six taxa comprised over 90 percent of the total catch: Bay Anchovy, Hogchoker (*Trinectes maculatus*, 6.68 percent), Mojarras (6.33 percent), Spot (2.77 percent), Pinfish (*Lagodon rhomboides*, 2.51 percent), and Pink Shrimp (*Farfantepenaeus duorarum*m 1.57 percent). The most commonly caught taxa was Blue Crab (*Callinectes sapidus*), captured in 54.06 percent of trawls. Other commonly encountered nekton included: Hogchoker (41.81 percent of trawls), Bay Anchovy (39.9 percent of trawls), and Pink

Shrimp (38.88 percent of trawls). Seasonality was also evident in the trawl catch, with greater taxa richness occurring in the traditionally wet months (Figure 4-10).

The annual variation in biological data is expected and can be influenced by several factors, including drought, unusually cold temperatures, severe red tide events, and the influence of tropical storms. Such annual variation is demonstrated by plotting the mean CPUE of taxa contributing to more than 90 percent of both seine (Figures 4-11 and 4-12) and trawl (Figure 4-13 and 4-14) catch. Due to the overwhelming contribution of Bay Anchovies to total catch of both gear types, plots excluding this species are provided to highlight their notable variation in catch. An analysis of a subset of these data (1996-2006) demonstrated the importance of the Little Manatee River estuary in providing habitat throughout the year, as peaks in juvenile abundance of offshore spawners, juvenile nearshore spawners, estuarine spawners, and tidal-river residents occurred in different seasons (MacDonald et al. 2007).

The annual variation in catch of YOY was plotted from 1996 to 2020 for four species caught by seine: Blue Crab, Common Snook, Pinfish, and Red Drum (*Sciaenops ocellatus*) (Figure 4-13). These species were selected because of their ecological (Blue Crab and Pinfish) or recreational (Common Snook and Red Drum) importance. Months of recruitment to gear and standard-length limits for YOY were provided by the FWC (FWC 2020). Blue Crab YOY were those with a carapace length ≤80 mm that recruited to seines from August to March. Because their recruitment dates spanned a calendar year, Blue Crab caught August-December and the following January-March were grouped into the same biological year. Common Snook YOY had a standard length ≤50 mm and recruited to the gear in August-November. Pinfish YOY were those with a standard length ≤80 mm that recruited to seines from January-June. Red Drum YOY had a standard length ≤200 mm and recruited to the gear September-February. Red Drum caught September-December and the following January-February were grouped into the same biological year. Between the four species, recruitment occurred during all months, thus covering the entire flow regime of the river. While annual variation is evident over the period of record, catch in recent years indicated the continued use of the Lower Little Manatee River as an important nursery ground for young fish (Figure 4-15).

Recent studies conducted by the FWC's Fish and Wildlife Research Institute demonstrated the importance of braided channels and associated backwater habitats that overlap with low salinity as providing the most favorable habitat (i.e., a combination of adequate food and refuge) for juvenile Common Snook in the Little Manatee River. Three Little Manatee River tributaries associated with pristine, low-salinity (0.5-1.5 psu) marshes (*Acrostichum* spp. and *Juncus roemarianus*) contributed the most juveniles to the 1-year-old population of Common Snook (Ley and Rolls 2018). Trotter et al. (2021) found that the smallest snook (<250 mm total length) strongly selected for Little Manatee River backwater habitats, such as embayments and small tributaries, while the largest fish (>50 mm total length) selected deep river bends. In addition to depending on coastal wetlands as their juvenile habitat, Common Snook serve as flagship, umbrella species for habitat conservation (Wilson et al. 2022); therefore, protecting their habitat should also benefit other species.

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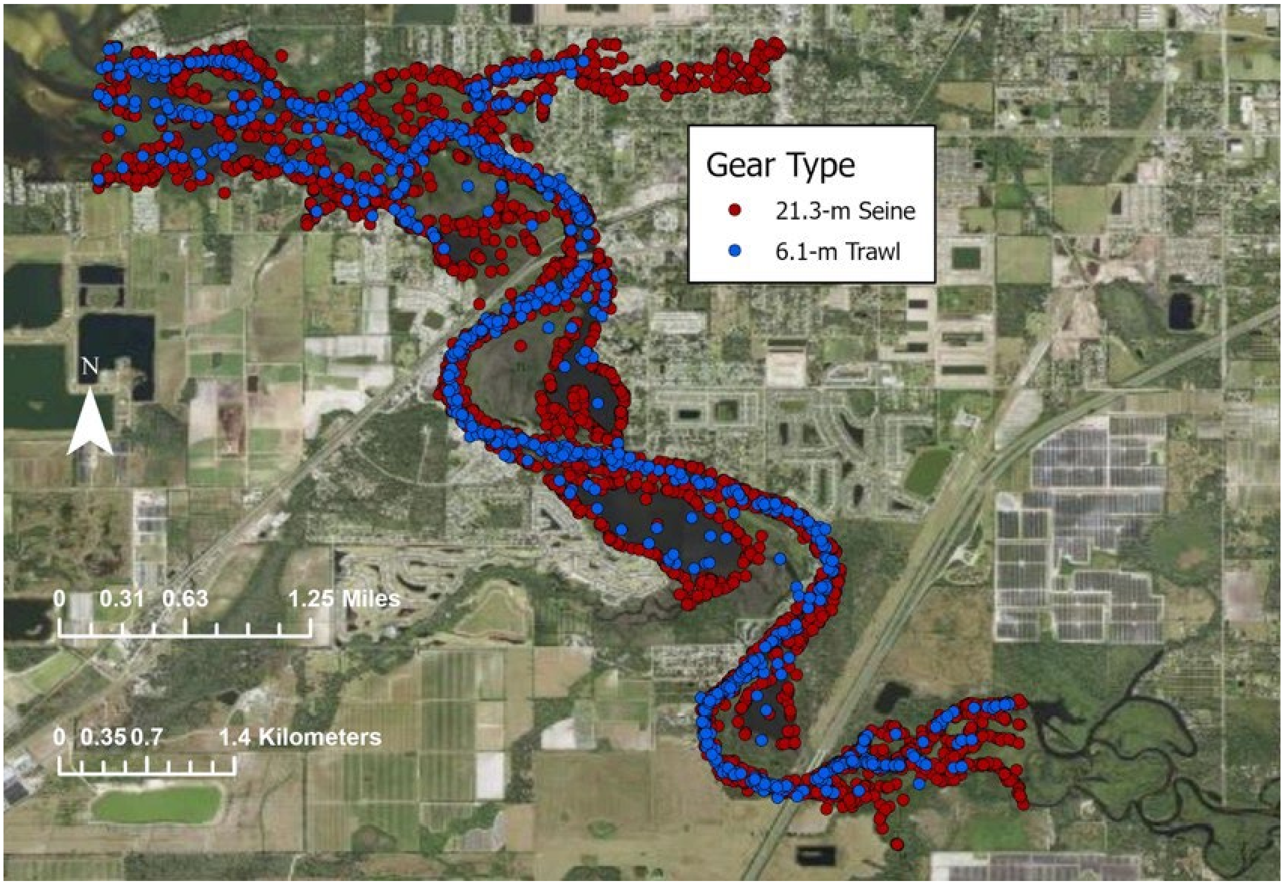


Figure 4-9. All evaluated Fisheries-Independent Monitoring program stratified-random sampling sites by gear type in the Lower Little Manatee River from January 1996 to December 2020.

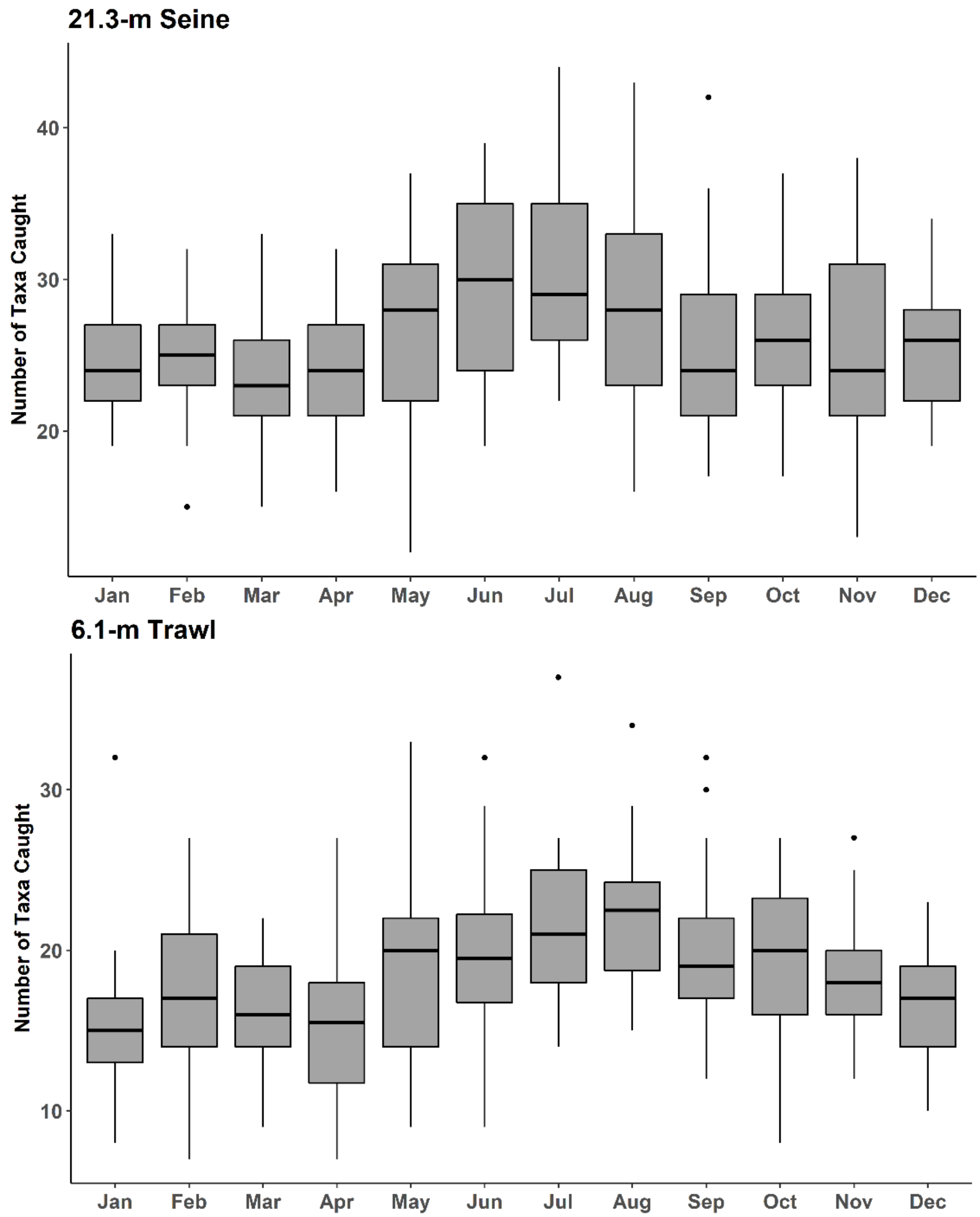


Figure 4-10. The mean number of taxa collected per month by gear type during Fisheries-Independent Monitoring program sampling from January 1996 through December 2020 in the Lower Little Manatee River. Boxes enclose the interquartile range, whiskers indicate 1.5*interquartile range, and dots reflect outliers.

Table 4-8. The thirty most numerically abundant taxa caught by the 21.3-m seine during the Fisheries-Independent Monitoring program's monthly stratified-random sampling in the Lower Little Manatee River from 1996 to 2020. Catch refers to the numbers of individuals caught, catch frequency indicates the number of seine hauls in which each taxon was encountered, and catch per unit effort (CPUE) was calculated according to specifications provided by the Florida Fish and Wildlife Conservation Commission (personal communication with Tim MacDonald, 2020).

Common Name	Scientific Name	Catch (n)	Catch frequency (n)	Max CPUE (n/100 m^2)	Mean CPUE (n/100 m^2)	Mean Salinity at Capture (psu)
Bay Anchovy	*Anchoa mitchilli*	1,368,706	1359	141552.90	790.55	11.72
Silversides	*Menidia* spp.	164,343	1998	3507.353	94.93	10.80
Mojarras	*Eucinostomus* spp.	91,399	1869	1582.353	52.79	11.36
Tidewater Mojarra	*Eucinostomus harengulus*	35,125	1729	1152.941	20.29	12.09
Rainwater Killifish	*Lucania parva*	34,779	752	4682.35	20.09	8.23
Spot	*Leiostomus xanthurus*	31,328	525	9858.82	18.10	13.66
Pinfish	*Lagodon rhomboides*	25,366	1144	2850.00	14.65	12.74
Menhadens	*Brevoortia* spp.	19,586	154	5751.47	11.31	12.82
Striped Anchovy	*Anchoa hepsetus*	16,061	129	7163.24	9.28	18.12
Striped Mullet	*Mugil cephalus*	15,201	275	1655.88	8.78	11.19
Hogchoker	*Trinectes maculatus*	14,790	1155	1211.77	8.54	7.86
Eastern Mosquitofish	*Gambusia holbrooki*	14,781	294	1267.65	8.54	3.40
Clown Goby	*Microgobius gulosus*	11,856	1296	526.47	6.85	10.10
Silver Jenny	*Eucinostomus gula*	7,666	541	335.29	4.43	17.86
Striped Mojarra	*Eugerres plumieri*	7,208	650	325.00	4.16	7.85
Sailfin Molly	*Poecilia latipinna*	7,180	283	851.47	4.15	7.93
Scaled Sardine	*Harengula jaguana*	6,153	71	1486.77	3.55	19.60
Herrings	*Clupeidae* spp.	3,848	2	2835.29	2.22	25.75
Red Drum	*Sciaenops ocellatus*	3,834	423	805.88	2.15	9.43
Small Gobies	*Gobiosoma* spp.	3,321	678	136.76	1.92	8.41
Common Snook	*Centropomus undecimalis*	3,140	733	108.82	1.81	9.06
Naked Goby	*Gobiosoma bosc*	3,120	760	123.53	1.80	9.76
Rough Silverside	*Membras martinica*	2,973	51	1932.35	1.72	13.46
Pink Shrimp	*Farfantepenaeus duorarum*	2,897	675	247.06	1.67	13.01
Silver Perch	*Bairdiella chrysoura*	2,495	125	413.24	1.44	14.01
Gulf Killifish	*Fundulus grandis*	2,109	204	992.65	1.22	11.87
Seminole Killifish	*Fundulus seminolis*	2,018	163	225.00	1.17	2.26
Leatherjacket	*Oligoplites saurus*	1,418	412	188.24	0.82	12.36
Blue Crab	*Callinectes sapidus*	1,353	492	188.24	0.78	9.40
Goldspotted Killifish	*Floridichthys carpio*	1,206	100	219.12	0.70	15.78

Table 4-9. The thirty most numerically abundant taxa caught by the 6.1-m trawl during the Fisheries-Independent Monitoring program's monthly stratified-random sampling in the Lower Little Manatee River from 1996 to 2020. Catch refers to the numbers of individuals caught, catch frequency indicates the number of trawls in which each taxon was encountered, and catch per unit effort (CPUE) was calculated according to specifications provided by the FWC (personal communication with Tim MacDonald, 2020).

Common Name	Scientific Name	Catch (n)	Catch frequency (n)	Max CPUE (n/100 m^2)	Mean CPUE (n/100 m^2)	Mean Salinity at Capture (psu)
Bay Anchovy	*Anchoa mitchilli*	277,039	707	2654.55	21.10	10.48
Hogchoker	*Trinectes maculatus*	26,170	741	184.50	2.04	8.82
Mojarras	*Eucinostomus* spp.	24,771	680	168.26	2.01	12.61
Spot	*Leiostomus xanthurus*	10,853	170	233.63	0.91	10.89
Pinfish	*Lagodon rhomboides*	9,812	374	265.34	0.85	16.61
Pink Shrimp	*Farfantepenaeus duorarum*	6,144	689	41.96	0.48	15.90
Sand Seatrout	*Cynoscion arenarius*	4,983	347	50.76	0.40	9.84
Silver Perch	*Bairdiella chrysoura*	4,305	221	65.57	0.34	15.89
Clown Goby	*Microgobius gulosus*	4,210	653	57.34	0.33	11.71
Blue Crab	*Callinectes sapidus*	3,036	958	6.07	0.24	12.83
Striped Mojarra	*Eugerres plumieri*	2,730	152	33.05	0.20	6.43
Tidewater Mojarra	*Eucinostomus harengulus*	2,329	425	18.62	0.18	11.73
Rainwater Killifish	*Lucania parva*	1,982	73	133.97	0.15	14.25
Southern Kingfish	*Menticirrhus americanus*	1,812	319	33.59	0.14	15.89
Hardhead Catfish	*Ariopsis felis*	1,670	403	67.05	0.13	12.22
Silver Jenny	*Eucinostomus gula*	1,258	149	12.82	0.09	19.02
Small Gobies	*Gobiosoma* spp.	939	256	10.39	0.07	12.43
Sheepshead	*Archosargus probatocephalus*	838	360	3.91	0.07	13.01
Red Drum	*Sciaenops ocellatus*	818	163	5.70	0.07	6.91
Spotted Seatrout	*Cynoscion nebulosus*	494	160	5.40	0.04	13.66
Silversides	*Menidia* spp.	411	36	46.02	0.03	6.19
Gulf Pipefish	*Syngnathus scovelli*	361	185	3.78	0.03	18.83
Blackcheek Tonguefish	*Symphurus plagiusa*	331	96	20.57	0.03	18.88
Atlantic Stingray	*Dasyatis sabina*	329	242	1.65	0.03	14.03
Lined Sole	*Achirus lineatus*	295	101	14.39	0.02	17.43
White Catfish	*Ameiurus catus*	281	45	7.13	0.02	1.26
Naked Goby	*Gobiosoma bosc*	234	156	0.90	0.02	8.23
Inshore Lizardfish	*Synodus foetens*	209	145	0.94	0.02	22.33
Southern Puffer	*Sphoeroides nephelus*	199	129	1.10	0.02	22.12

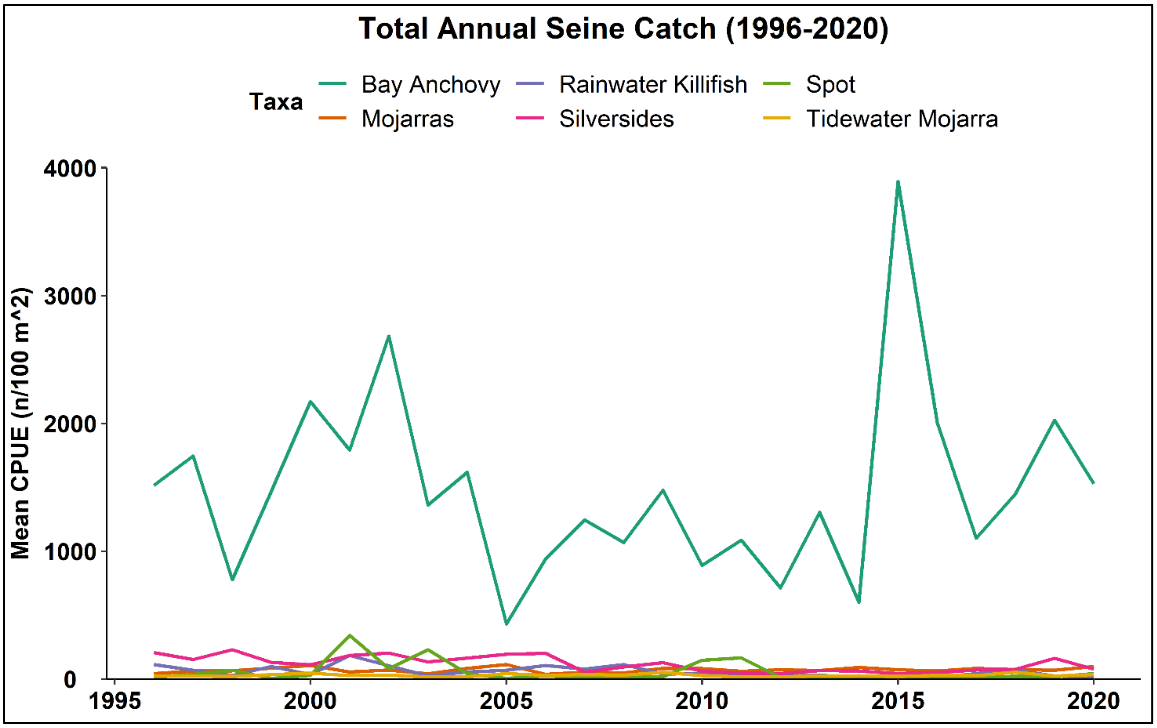


Figure 4-11. The annual variability in mean catch per unit effort (CPUE, number per 100 m^2) for the six taxa that comprise >90 percent of total seine catch in the Lower Little Manatee River during Fisheries-Independent Monitoring program sampling from 1996 to 2020.

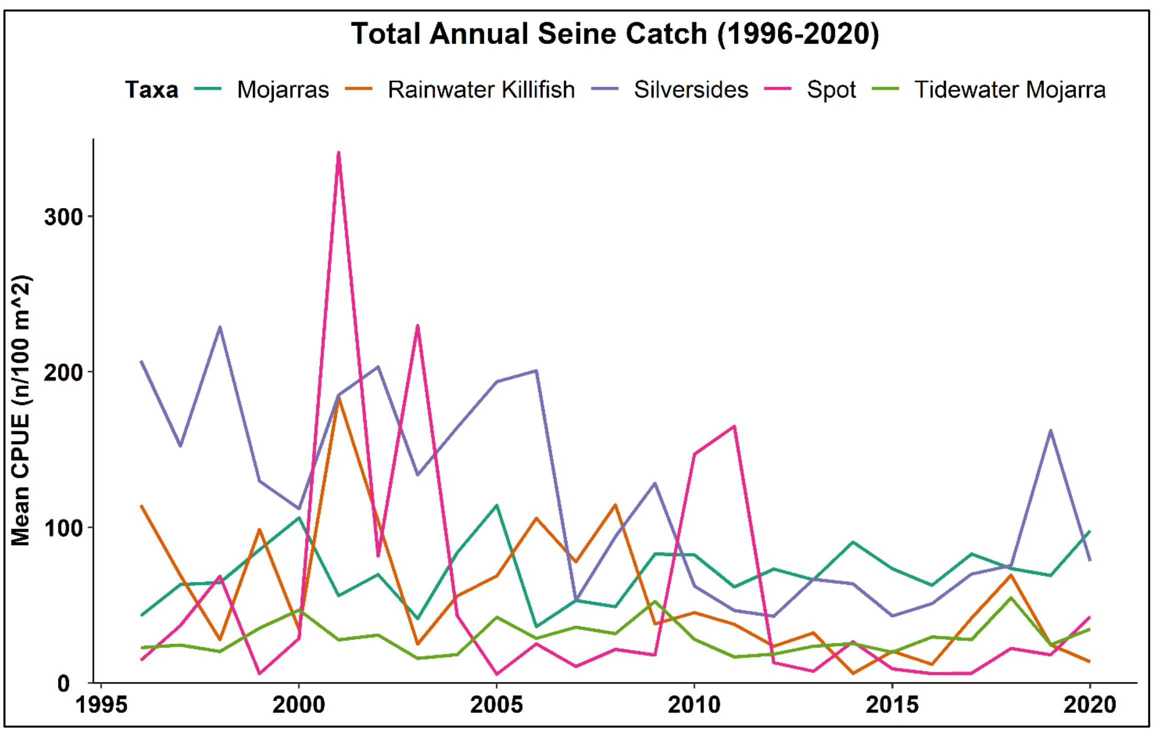


Figure 4-12. The annual variability in mean catch per unit effort (CPUE, number per 100 m^2) for the taxa that comprise >90 percent of total seine catch in the Lower Little Manatee River during Fisheries-Independent Monitoring program sampling from 1996 to 2020, excluding Bay Anchovies.

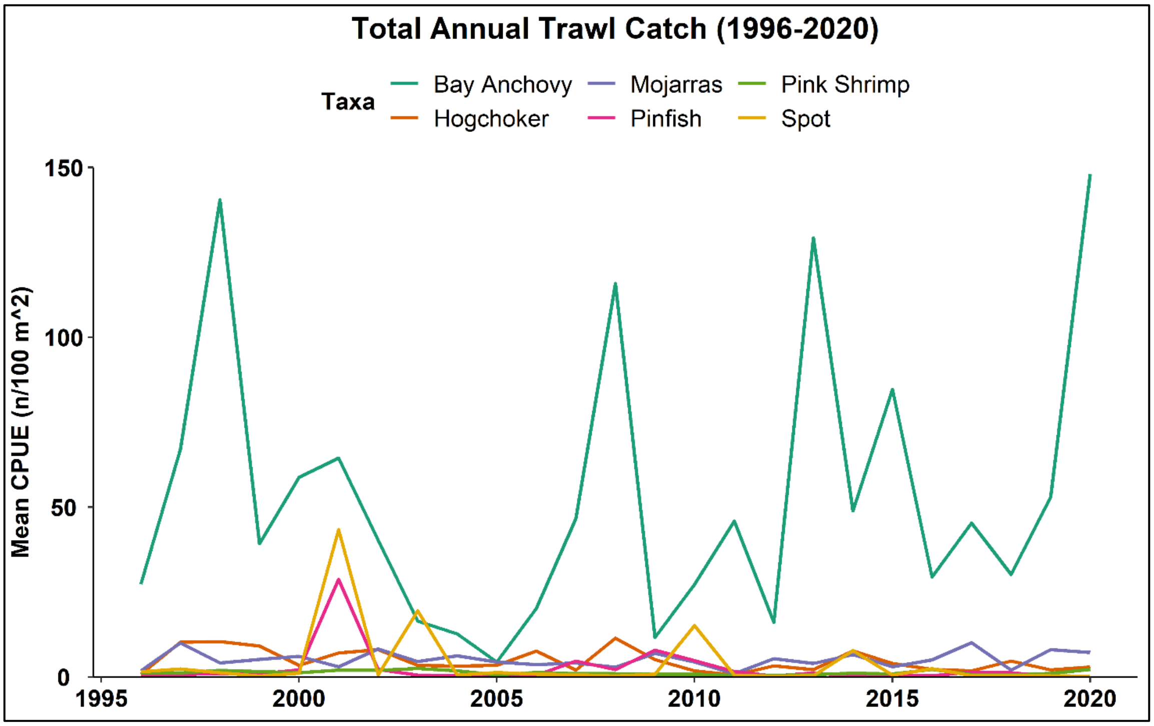


Figure 4-13. The annual variability in mean catch per unit effort (CPUE, number per 100 m^2) for the taxa that comprise >90 percent if trawl catch in the Lower Little Manatee River during Fisheries-Independent Monitoring program sampling from 1996 to 2020.

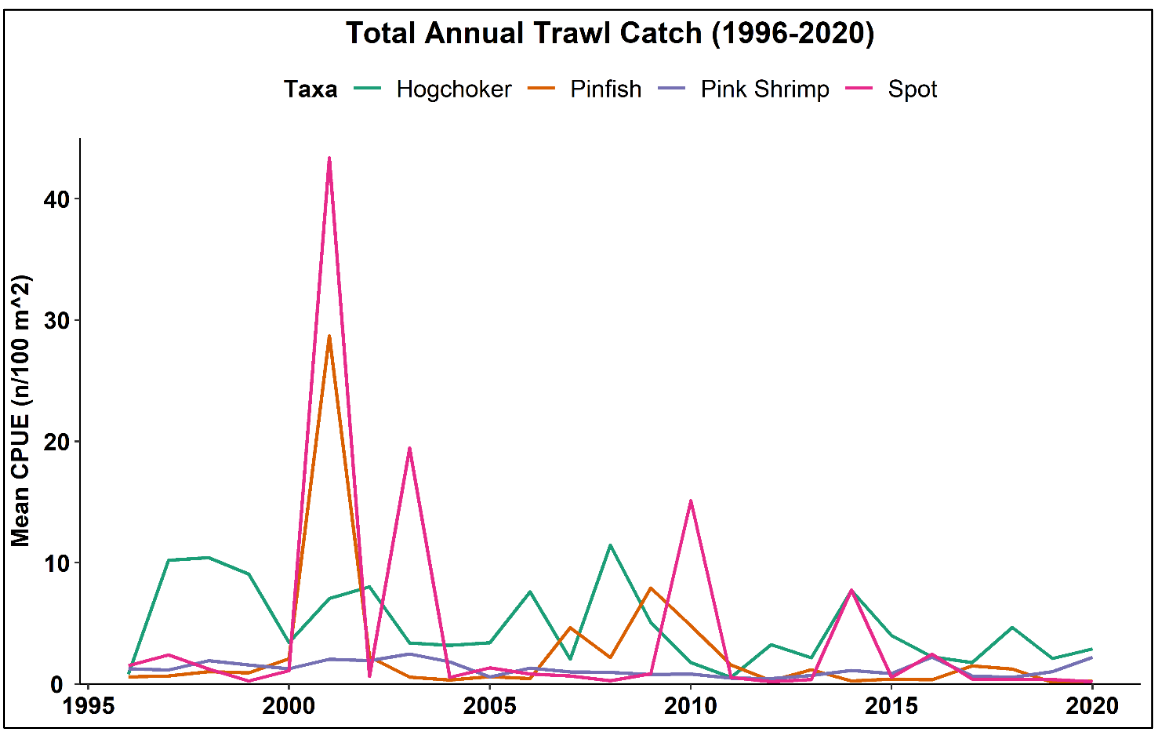


Figure 4-14. The annual variability in mean catch per unit effort (CPUE, number per 100 m^2) for the taxa that comprise >90 percent if trawl catch in the Lower Little Manatee River during Fisheries-Independent Monitoring program sampling from 1996 to 2020, excluding Bay Anchovies.

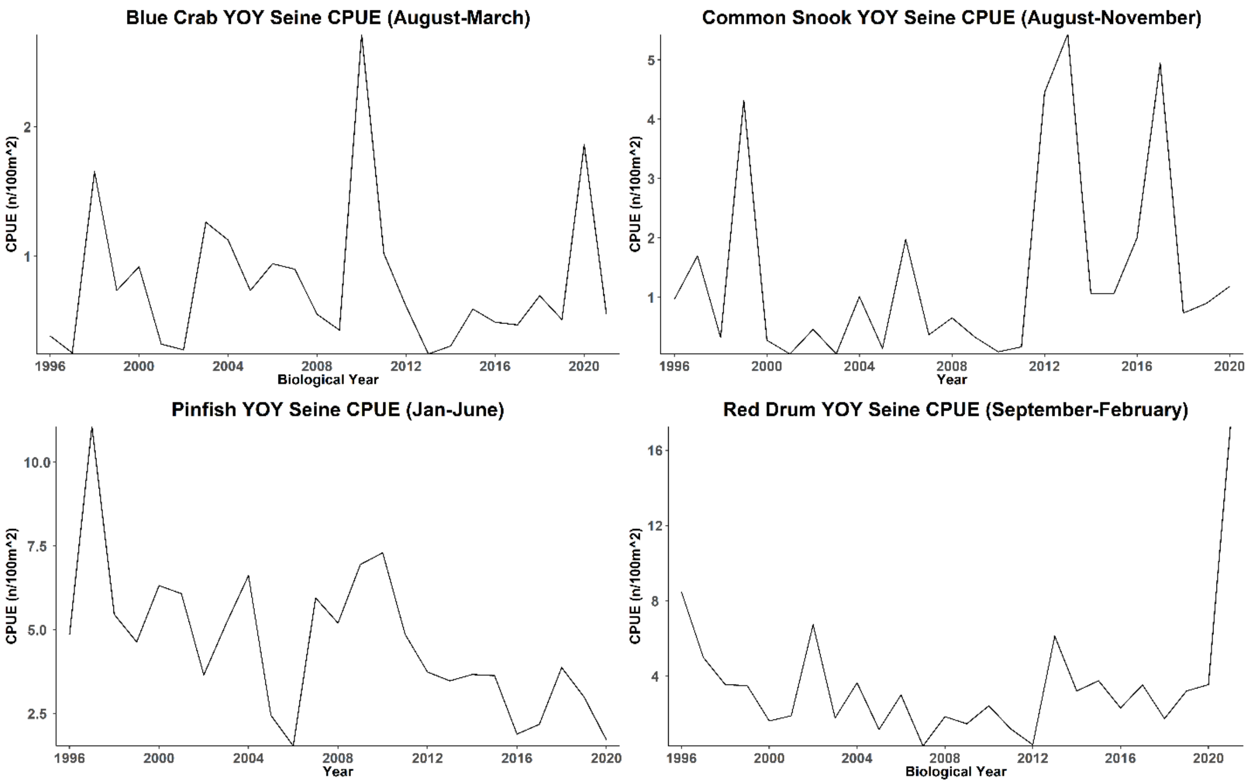


Figure 4-15. Annual young-of-the-year (YOY) 21.3-m seine CPUE (catch per unit effort) from Fisheries-Independent Monitoring program sampling 1996-2020, during specified recruitment windows for Blue Crab (≤ 80 mm carapace width), Common Snook (≤ 50 mm standard length), Pinfish (≤ 80 mm carapace width), and Red Drum (≤ 200 mm carapace width). When recruitment windows spanned calendar years, biological years were used.

4.3.3 Lower River Ichthyoplankton Community

A robust study of the estuarine portion of the Little Manatee River's planktonic community occurred from January 1988 through January 1990 (Peebles and Flannery 1992). These data were re-evaluated in 2008 using newly developed analytical methods (Peebles 2008). From the plankton net samples, collected from fixed locations at two-week intervals, evidence of year-round use of the system as nursery habitat by estuarine fish was obtained. Larval species richness was highest during spring and summer, and many taxa responded to flow rate with predictable shifts in their location of maximum abundance, such as moving upstream during periods of low flow. The thirty most common taxa are provided in Table 4-10, along with their mean CPUE, mean salinity at capture, and center of abundance (km_U), defined as the central geographic tendency for CPUE, where km is distance from the river mouth. Crab larvae dominated the catch.

The summary above, including the mean salinity at capture information listed in Tables 4-8 through 4-10, and the figure below (Figure 4-16) demonstrate that different taxa and different life stages of nekton prefer different ranges of low-salinity habitat. For this reason, methods used to develop minimum flows for the Lower Little Manatee River addressed the protection of the ranges of low-salinity habitat.

Table 4-10. The thirty most common taxa in 480 plankton nets from January 1998 through 1990 (from Peebles and Flannery 1992).

Taxon	Common Name	Number collected (n)	Mean CPUE (no./10^3 m^3)	Mean Salinity at Capture (psu)	Center of Abundance (km_u)
Decapod zoeae	Crab Larvae	3,418,364	103083.9	22.9	0.6
Mysids	Opossum Shrimps	830,986	23243.22	13.2	4.2
Amphipods, gammaridean	Amphipods	777,599	21953.64	9.8	5
Cumaceans	Cumaceans	575,794	16738.28	25	-1.7
Decapod msyis	Shrimp Larvae	483,267	15188.41	20.3	1.8
Calenoid copepods	Copepods	198,057	7027.21	25.2	-2.2
Fish eggs*, percomorph*	Sciaenid Eggs	167,840	5829.41	26.1	-3.1
Lucifer faxoni	Shrimp	107,084	3669.68	25.9	-2.8
Chaetognaths, sagittid	Arrow Worms	57,771	1933.5	26.7	-3.7
Ostracods	Seed Shrimps	54,345	1793.09	25.3	-2.3
Cladoclerans	Water Fleas	51,517	2152.1	23.6	-1.3
Anchoa mitchilli, juveniles	Bay Anchovy	40,838	1110.72	7.2	7
Decapod megalopae, post-zoea	Crab Larvae	26,714	742.58	14.7	1.4
Isopods	Isopods	12,011	328.58	11.3	5.8
Anchoa sp., flexion	Anchovy Larvae	11,287	404.07	25.7	-1.7
Gobiosoma sp., postflexion	Goby Larvae	10,599	303.35	14.8	6
Anchoa mitchilli, eggs	Bay Anchovy	9,868	313.23	25.8	-2.5
Anchoa sp., preflexion	Anchovy larvae	9,169	296.02	24.4	-1.8
Gobiosoma sp., flexion	Goby Larvae	8,052	234.09	18.3	3.3
Anchoa mitchilli, postflexion	Bay Anchovy Larvae	7,908	258.66	22.1	0.3
Microgobius sp., postflexion	Goby Larvae	5,642	184.73	23.6	-0.9
Gobiid, preflexion	Goby Larvae	5,493	162.68	18.8	2.4
Dipteran larvae	Mosquitos, flies	5,376	155.13	0.8	12.3
Microgobius sp., flexion	Goby Larvae	3,093	95.29	21.5	0.5
Brevoortia sp., postflexion	Menhaden Larvae	2,393	71.58	2.8	7.5
Hydromedusae	Hydromedusae	2,359	71.26	17.5	-1.5
Gobiesox stumosus, flexion	Skilletfish Larvae	2,128	60.54	15.7	4.5
Gobiesox stumosus, preflexion	Skilletfish Larvae	1,951	56.3	17.6	2.7
Blenniid, preflexion	Blenny Larvae	1,159	35.1	21.5	0.1
Pelecypods	Clams, Mussels, Oysters	950	25.13	0	13.3

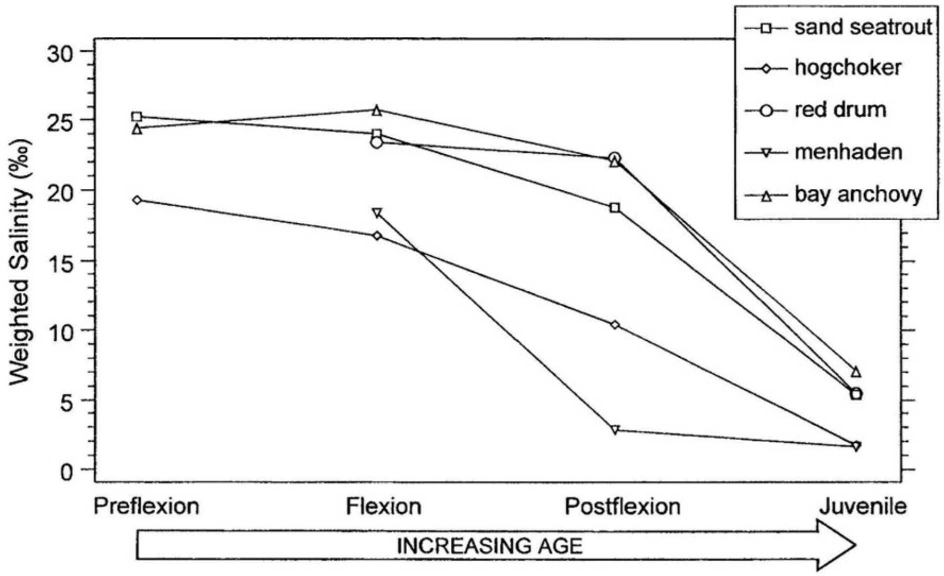


Figure 4-16. The decreasing mean salinity at capture during development for five species of fish in the Little Manatee River (from Peebles and Flannery 1992).

4.4 Florida Manatee

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. 2007) and are generally vulnerable to thermal stress during exposure to temperatures below 20°C (68°F). During low temperature events, they congregate in the warm waters of natural springs or in the warm cooling water discharges of power plants scattered along the coast of Florida. One such thermal refuge exists approximately 7 miles (11 km) north of the Little Manatee River at the Tampa Electric Company power plant in Apollo Beach. Evidence suggests that the location and use of warm-water refuges is a response that calves learn from their mothers; therefore, the potential loss of a refuge can affect generations of manatees (Worthy 2005).

While the US Fish and Wildlife Service designates the Little Manatee River downstream of US Highway 301 as critical habitat for manatees and estuarine habitat use by manatees has been observed, the river is not known to serve as a significant thermal refuge for this species. Therefore, the effects of flow reductions on manatees in the Little Manatee River were not evaluated as part of the minimum flows development.

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

Technical work supporting the development of draft minimum flows for the Upper Little Manatee River was first completed by the District in 2011 (Hood et al. 2011 in Appendix A) and reviewed by a panel of independent scientists (Powell et al. 2012 in Appendix B). Subsequent data collection efforts and analyses (JEI 2018a in Appendix C, Jacobs and JEI 2020 in Appendix D, 2021a, 2021b, 2021c, 2021d) incorporated improvements suggested by the peer review panel and supported development of the proposed minimum flows for the upper river presented in the September 2021 draft report. This report is an update of the 2021 draft report based on the comments of a new peer review panel (Appendix F). The methods described in this chapter to develop the recommended minimum flows for the Upper Little Manatee River are based on the best information currently available and satisfy the comments of the peer review panel regarding the September 2021 draft report (Appendix G).

District efforts to develop minimum flows for the Lower Little Manatee River have been ongoing for more than 20 years. During this time, minimum flows methods for estuarine systems were developed, improved, and used for various analyses (JEI 2018b in Appendix E, Jacobs and JEI 2020 in Appendix D, 2021a, 2021b, 2021c, 2021d). Minimum flows development methods for estuaries have changed and improved over the years, and some of the earlier work supported the minimum flow recommendations for the lower river described in the September 2021 draft report. This report includes methods to develop minimum flows for the lower river, which are described below, that satisfy the comments of the peer review panel regarding the September 2021 draft report (Appendix F and G) and are based on the best information currently available.

5.1 Development of Flow Blocks

For most rivers in the District, there is an average annual flow regime that can be divided into three periods. These three periods are characterized by low, medium, and high flows and for the purpose of developing minimum flows, are termed Block 1, Block 2, and Block 3, respectively (Kelly et al. 2005b). This approach was originally proposed during the independent peer review of the Upper Peace River recommended minimum flows to represent the actual hydrologic and hydroperiodic conditions in the river (Gore et al. 2002). Identification of blocks is associated with flow needs for ecosystem functions, biological assemblages, or populations, and assembly of the blocks form a prescription of minimum flows (Postel and Richter 2003). As noted by the Upper Peace River minimum flows peer review panel, the assumptions behind block techniques are based upon basic ecological theory; organisms and communities occurring in a river have evolved and adapted their life cycles to flow conditions over a long period of pre-development history (Stanford et al. 1996).

Since the development of the Upper Peace River minimum flows was completed, the District has used calendar-based blocks developed by analyzing flow records for long-term USGS gage sites (Kelly et al. 2005b, 2007). Calendar-based flow blocks were also used in earlier work to develop draft minimum flows for the Little Manatee River (Hood et al. 2011 in Appendix A). The independent scientific peer review of earlier work associated with proposed minimum flows for the Upper Little Manatee River (Hood et al. 2011 in Appendix A), recommended using blocks based upon actual flows (flow-based blocks) rather than fixed calendar dates to help reduce unintended negative impacts on biological communities in years where the realized flows are not well-matched to the fixed start and end dates of the calendar-based blocks (Powell et al. 2012 in Appendix B). Flow-based blocks were recently used by the District to re-evaluate the minimum flows for the Lower Peace River and develop minimum flows for Lower Shell Creek (Ghile et al. 2021).

5.1.1 Upper River Flow Block Development

Flow-based blocks for the upper river were developed after and as a result of analyses of fish passage and floodplain inundation, as described in Sections 6.1 and 6.2. The analyses involved use of daily average baseline flows at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage for the period from April 1, 1939, through December 31, 2021. The threshold for fish passage was found to be 29 cfs (at the gage), and this flow was used to differentiate the low-flow Block 1 from the medium-flow Block 2. The threshold for floodplain inundation corresponded with a flow of 96 cfs at the gage and was used as the threshold for differentiating between the medium-flow Block 2 and high-flow Block 3. Based on the sensitivity of the floodplain inundation, the high-flow Block 3 was divided into two subblocks at the flow threshold of 224 cfs for the purposes of minimum flows development (see Section 6.6).

In summary, the flow blocks for the upper river, which are based on the daily average baseline flow at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage, were defined as:

- Block 1 – Flows less than or equal to 29 cfs;
- Block 2 – Flows greater than 29 cfs and less than or equal to 96 cfs; and
- Block 3 – Flows greater than 96 cfs.

For illustrative purposes, the flow blocks are shown in Figure 5-1 along with an annual hydrograph based on median daily baseline flows. Note that 29 cfs is the 34th exceedance percentile, 96 cfs is the 68th exceedance percentile, and 224 cfs is the 84th exceedance percentile, based on daily flows from April 1, 1939, through December 31, 2021.

5.1.2 Lower River Flow Block Development

Based on the complexity of circulation and salinity transport processes, salinity habitats in estuaries are typically affected by freshwater inflow in a highly nonlinear manner. For example, during the dry season when the inflow is low, a 10 percent flow reduction will cause a noticeable relative change of low-salinity habitats; however, during the wet season when flow is high, a 10 percent flow reduction may only cause a minor relative change of low-salinity habitats. As such, it is necessary to evaluate minimum flows for different flow regimes (blocks) separately to protect estuaries.

Early minimum flow evaluations for District estuaries (e.g., Heyl and Kelley 2009) used seasonal blocks based on long-term gaged flow records, with Block 1 being the driest season of the year, Block 3 the wettest, and Block 2 associated with the intervening period. In recent minimum flow evaluations for estuaries (e.g., Ghile et al. 2021), flow-based blocks were used, with Block 1 being flow below a certain low percentile (e.g., 25%) and Block 3 above a certain higher percentile (e.g., 50%). For the Lower Little Manatee River, rather than simply using fixed percentiles, namely the low quarter and the median, to determine flow-based blocks, flow-based blocks were determined through examining response of salinity habitats to flow by reviewing numerous plots.

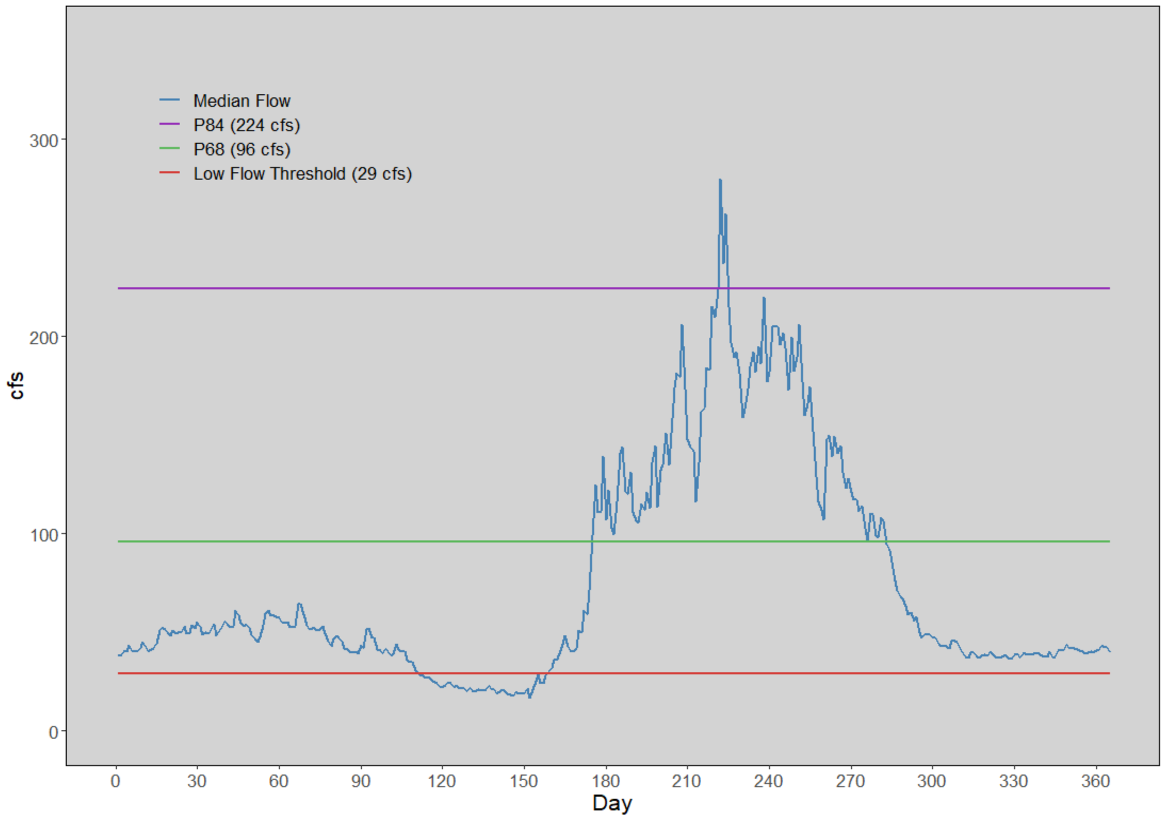


Figure 5-1. Median daily baseline flow hydrograph of observed flows (represented by the blue line) for the Little Manatee River at the US 301 near Wimauma, FL (No. 02300500) gage from April1, 1939 through December 31, 2021 (blue line) and flow-based block thresholds. The boundary between low-flow Block 1 and medium-flow Block 2 is shown as the red horizontal line, and the boundary between Block 2 and the high-flow Block 3 is depicted as the green horizontal line. Block 3 is divided into two subblocks (3a and 3b) as indicated by the purple horizontal line for the purposes of minimum flows development. The daily median flow hydrograph is shown here for reference; blocks were determined by fish passage and floodplain inundation analyses criteria, not on the median flows.

Figure 5-2 is an example of one of the reviewed plots, which are all included in Appendix M. From the example figure, which depicts the volume of less than 2 psu water versus gaged flow at the US Highway 301 bridge, it can be seen that salinity habitats have different sensitivities to flow for different flow regimes. Low-salinity habitats are most sensitive to a flow variation when flow is less than about 28 to 32 cfs. At flows higher than about 95 to 100 cfs, low-salinity habitats are much less sensitive to a flow variation. Based on these relationships, a threshold separating Block 1 from Block 2 for used in analyses for the lower river can reasonably be identified in the range of flows from 28 to 32 cfs, while a threshold separating Blocks 2 and 3 can be associated with flows in the range from 95 to 100 cfs.

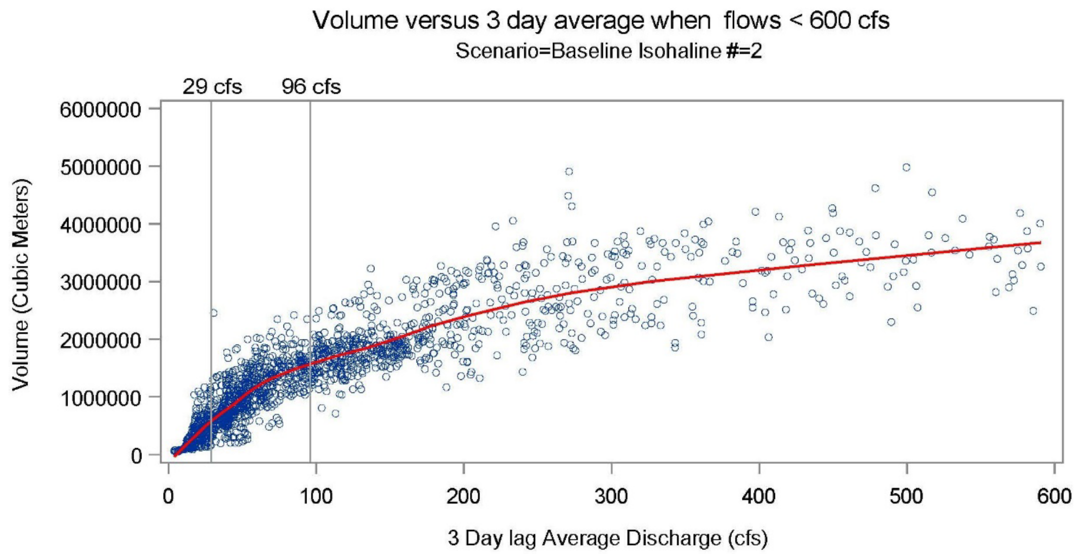


Figure 5-2. Example of flow-salinity relationships reviewed for development of flow-based blocks for the Lower Little Manatee River.

These flow-threshold ranges for the Lower Little Manatee River correspond with those identified for the upper river (29 and 96 cfs). Based on this, the flow blocks defined for the upper river were considered appropriate and reasonable for characterizing the seasonal flow regime of the lower river. Therefore, 29 and 96 cfs were chosen for the definition of flow-based blocks: Block 1 ≤29 cfs, Block 3 >96 cfs, and Block 2 between >29 cfs and ≤96 cfs.

5.2 Development of Baseline Flows

Surface water withdrawals and discharges affect flows in the Little Manatee River. The baseline flow record used for minimum flows analyzed for river was developed through consideration of surface water withdrawals from and augmentation of the river.

As described in Section 2.6, the FP&L Manatee Plant withdraws surface water from the Little Manatee River. Daily withdrawals since 1976 were added to the observed daily flows recorded from April 1939 through December 2021 for the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage to adjust the record for these historic withdrawals.

Surface water from agricultural operations has been identified as a principal source of excess flows to the Upper Little Manatee River (Section 2.7). A detailed investigation was conducted by JEI (2018a in Appendix C) to adjust the flow record for this augmentation based on comments of a panel of independent scientists (Powell et al. 2012 in Appendix B) that reviewed the District's draft minimum flows for the Upper Little Manatee River in 2011 (Hood et al. 2011 in Appendix A). They identified a change in the relationship between flows and rainfall after 1976 and confirmed that river flows for the period prior to 1977 relatively unaffected from effects of mining, surface water withdrawals, and row-crop agriculture.

In addition, JEI (2018a in Appendix C) developed a linear regression that related deviations from long-term averages in rainfall and flows prior to 1977 and used the regression to predict post -1977 flows. The regression was based on monthly river flow values standardized to the long-term average flow and included a combination of Standardized Precipitation Index (SPI) values for Parrish and Plant City rainfall and a categorical month factor to account for the potential for different relationships as a function of season. The R^2 for the model was 0.66 after removing some outliers that had high leverage on the slope of the regression.

Differences between the observed and predicted post-1977 flows, i.e., the regression residuals, were attributed to anthropogenic effects on the rainfall-flow relationship. Based on subtraction of the observed flow from the predicted flow, negative residuals indicated that there was more streamflow than expected based on the predictive relationship, and beginning in 1977, there is a noticeable trend in the residuals (Figure 5-3), suggesting systematic bias due to flow augmentation, as compared to that expected based on the regression model for the pre-1977 period. A noticeable trend in the residuals back towards zero after 2000 is also evident and corresponds with temporal decreases in active agricultural lands in the watershed (Section 2.2), as well as implementation of agricultural BMPs.

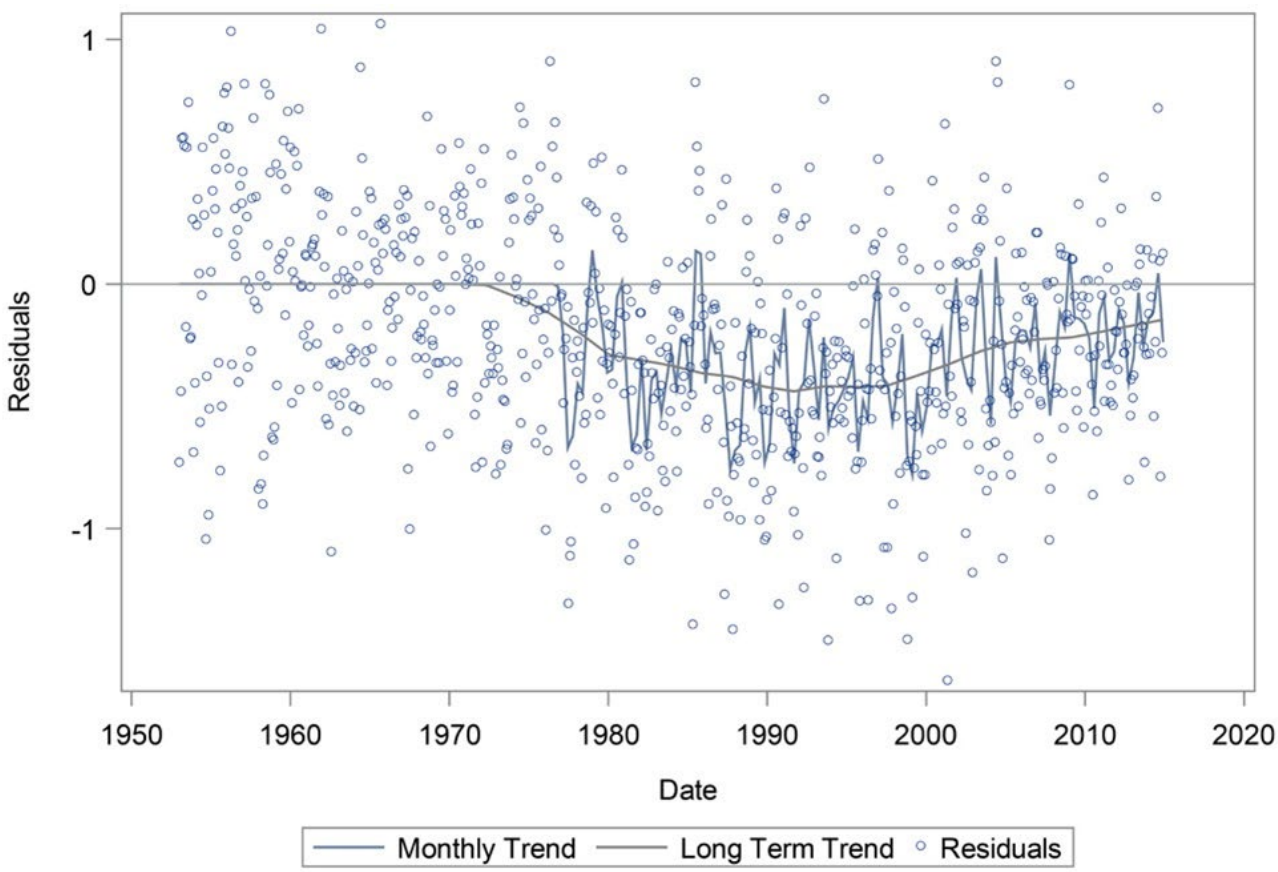


Figure 5-3. Time series of residuals (calculated as predicted – observed) from a Little Manatee River rainfall-flow linear regression equation (from JEI 2018a in Appendix C) and LOESS curves of monthly and long-term trends in post-1976 residuals.

The difference from zero for each monthly LOESS estimate (Figure 5-3) was calculated and back transformed to represent a monthly deviation in units of cfs. The monthly deviations were then used to adjust the daily flow record, which was accomplished using the cumulative probability distribution for the daily flows. In this way, the adjustment was scaled to the deviations in flows from their long-term monthly average. For example, when flows were average, the correction was based on the LOESS curve trend line, which represents the average expected adjustment due to anthropogenic influence. When the daily flows were at their 70th percentile of the cumulative probability distribution, the correction was 1.7 times the LOESS estimated average estimated by the trend line. The adjustment was capped such that it never exceeded twice the LOESS predicted average correction for anthropogenic effects.

The resulting flow-augmentation adjustments for the Little Manatee River are shown as an intra-annual distribution in Figure 5-4 for comparison with estimates of excess agricultural flow from a MIKE-SHE model for the Myakka River (Interflow Engineering, LLC 2008, inset in upper right of Figure 5-4). The adjustments developed for the Little Manatee River are similar to those described by the MIKE-SHE model in terms of both timing and magnitude, with higher excess agricultural flows predicted during the summer wet season for both rivers.

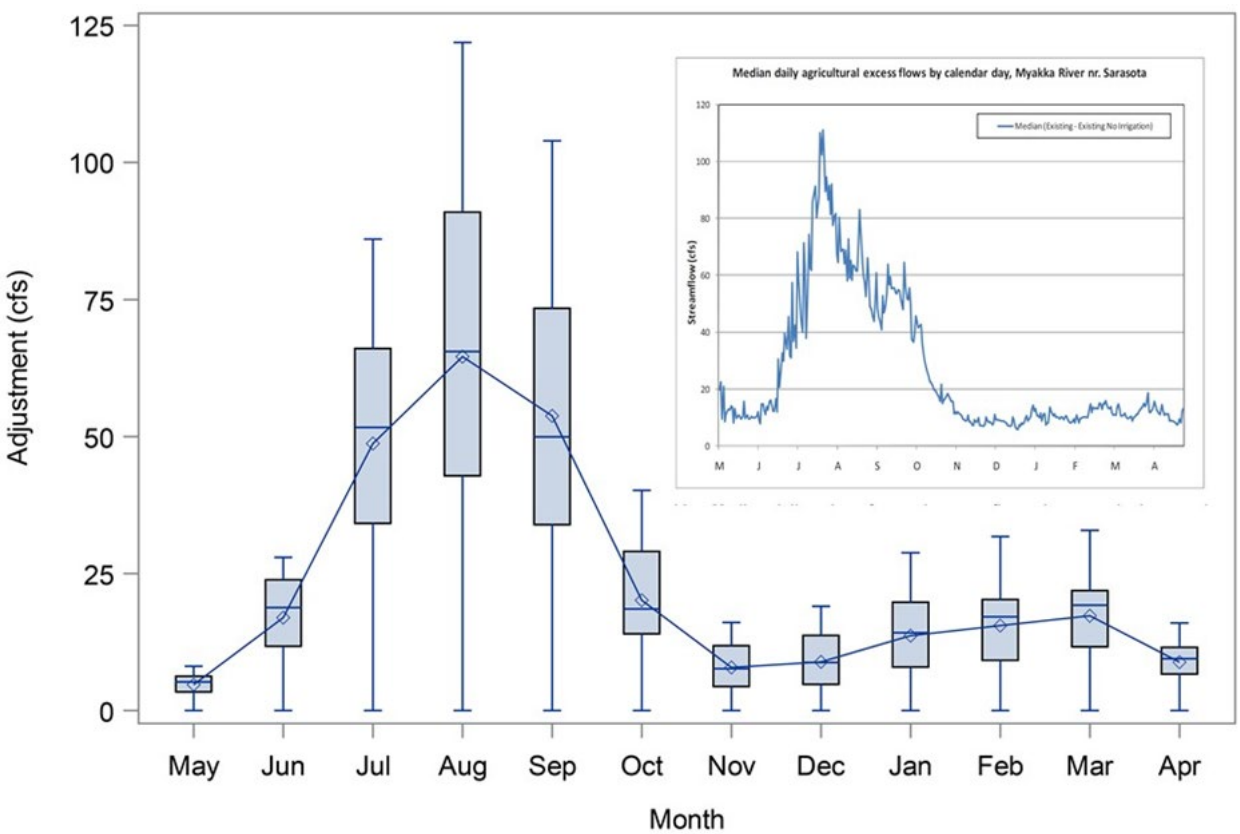


Figure 5-4. Seasonal distribution of estimated excess flows in the Upper Little Manatee River post-1976 with an inset plot of the seasonal distribution of estimated agricultural excess flows in the Myakka River (from Interflow Engineering, LLC 2008) for comparison (from JEI 2018a in Appendix C).

5.3 Resources of Concern for Developing Minimum Flows

The District's approach for developing minimum flows is habitat based. Because river systems include a variety of aquatic and wetland habitats that support diverse biological communities, it is necessary to identify key ecological resources for consideration, and when possible, determine hydrologic requirements for specific habitats associated with the resources. It is assumed that protecting the resources of concern will also provide protection for other ecological aspects or functions of the river system that are more difficult to quantify, such as the transfer of detrital material and the maintenance of river channel geomorphology. Resource management goals that were the focus of the technical analyses for the development of minimum flows for the Little Manatee River and the relevant environmental values associated with each of these goals are listed below.

- Determination of a low-flow threshold to provide protection for ecological resources and human uses of the Little Manatee River by prohibiting withdrawal impacts during critical low-flow periods. Relevant environmental values:

    - 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
    - Navigation

- Maintenance of seasonal hydrologic connections between the Upper Little Manatee River channel and floodplain to ensure the persistence of floodplain structure and function. Relevant environmental values:

    - Recreation in and on the water
    - Fish and wildlife habitats and the passage of fish
    - Transfer of detrital material
    - Aesthetic and scenic attributes
    - Filtration and absorption of nutrients and other pollutants
    - Sediment loads
    - Water quality
    - Navigation

- Maintenance of available instream habitat for fish and benthic macroinvertebrates in the Upper Little Manatee River. Relevant environmental values:

    - Recreation in and on the water
    - Fish and wildlife habitats and the passage of fish
    - Transfer of detrital material
    - Aesthetic and scenic attributes
    - Filtration and absorption of nutrients and other pollutants

    - Sediment loads
    - Water quality
    - Navigation

- Maintenance of biologically relevant salinities over a range of flow conditions that protect the distribution of plankton, nekton (including all life stages), benthic macroinvertebrates (including all life stages), and shoreline vegetation communities in the Lower Little Manatee River. Relevant environmental values:

    - Recreation in and on the water
    - Fish and wildlife habitats and the passage of fish
    - Estuarine resources
    - Transfer of detrital material
    - Aesthetic and scenic attributes
    - Filtration and absorption of nutrients and other pollutants
    - Sediment loads
    - Water quality

- Maintenance of favorable estuarine habitat for nekton (including all life stages) in the Lower Little Manatee River. Relevant environmental values:

    - Recreation in and on the water
    - Fish and wildlife habitats and the passage of fish
    - Transfer of detrital material
    - Aesthetic and scenic attributes
    - Filtration and absorption of nutrients and other pollutants
    - Sediment loads
    - Water quality

The primary approach used for minimum flows development in both the upper and lower portions of the Little Manatee River focused on maintenance of 85 percent of the most sensitive criterion associated with the resource management goals. In addition, a low-flow threshold applicable to both portions of the river was identified to ensure flow continuity for environmental and human-use values.

5.3.1 Little Manatee River Low-Flow Threshold

Because the environmental values of a river may exhibit high sensitivity to impacts at very low rates of flow, a low-flow threshold has been included in minimum flows established for many District rivers. A low-flow threshold is used to identify a flow rate below which no surface water withdrawals would be allowed. Flows less than the low-flow threshold are most likely to occur during the dry season but may occur throughout the year. Wetted perimeter and fish passage analyses have typically been used for low-flow threshold development. Wetted perimeter is defined as the width of the stream bottom and banks in contact with water for a stream channel cross section. A fish passage criterion is defined as the flow corresponding to a water depth of 0.6 ft (0.18) m at a river cross section.

Earlier analyses to develop a low-flow threshold were previously conducted [e.g., Hood et al. (2011) in Appendix A, JEI (2018a in Appendix C), and in the September 2021 draft report] as part of the development of draft minimum flows for the Upper Little Manatee River. These analyses were updated for the development of revised, recommended minimum flows for the river.

Studies on streams in the Southeast United States have demonstrated that the greatest amount of macroinvertebrate biomass per unit reach of stream occurs on the stream bottom (Benke et al. 1985). Although production on a unit area basis may be greater on snag and root habitats, the greater the area of stream bottom along a reach during low-flow conditions, the more productive the habitat (Heinz and Woodard 2013). By plotting the response of wetted perimeter to incremental changes in discharge, an inflection or inflections can be identified in the resulting curve were small decreases in flow result in increasingly greater decreases in wetted perimeter. The inflection point or points represent flows at which the water surface recedes from stream banks and habitat is lost at an accelerated rate (Stalnaker et al. 1995).

A wetted perimeter-discharge curve can be used to identify the lowest breakpoint, which defines the threshold below which aquatic habitat conditions for benthic invertebrates rapidly decline. Riffle sites are typically selected for these types of assessments because they are usually shallow, depth-sensitive areas of a stream that are most impacted by changes in flow, and they are critical habitats for benthic macroinvertebrates that fish eat (Heinz and Woodard 2013). It should be noted, however, that the Upper Little Manatee River has few locations that would be traditionally considered “riffle” habitats since it is generally well incised, shallow, with silty sand bottom, and with few rocky areas.

As shown in Figure 5-5, multiple inflection points can be determined, with the “breakpoint” identified as the lowest inflection point. The lowest infection point is typically defined by the District as the LWPIP and, as was done for the development of the minimum flows for the Little Manatee River described in this report, may be considered along with a fish passage criterion for development of a low-flow threshold.

Ensuring sufficient flows to support the longitudinal connectivity for the natural passage or movement of fishes along a river is an important component of the development of minimum flows. Maintenance of these “fish passage” flows is assumed to promote natural patterns of continuous flow within the channel or river segment, allow for recreational navigation (e.g., canoeing and kayaking), improve aesthetics, and avoid or lessen potential negative effects associated with pool isolation (e.g., high water temperatures, low dissolved oxygen concentrations, localized phytoplankton blooms, and increased predatory pressure resulting from loss of habitat/cover).

To protect benefits associated with longitudinal river connectivity and sustained low flows, a 0.6-ft (0.18-m) fish-passage criterion was used to develop a low-flow threshold for the Upper Little Manatee River. This fish-passage criterion is routinely used by the District for minimum flows development and has been considered acceptable, reasonable, and representing the best available information by numerous peer review panels convened to review minimum flows developed by the District.

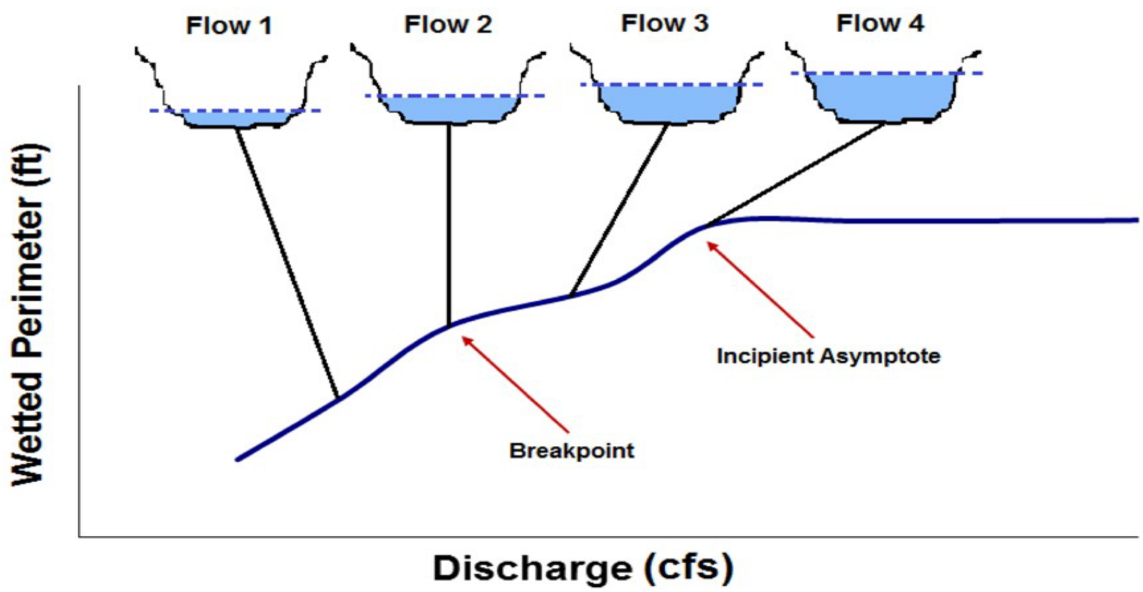


Figure 5-5. Inflection point definitions as described in Figure 2 in Heinz and Woodard (2013) (from JEI 2018a in Appendix C).

5.3.2 Upper River Floodplain Inundation

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

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

The riparian corridor of the Upper Little Manatee River varies considerably, from an incised channel through uplands to broader floodplain areas. Wetland systems are not well developed, and there are no cypress wetlands. Only obligate and facultative wetland tree species were found in the three classes of wetlands identified (Willow Marsh, Tupelo Swamp, and Hardwood Swamp) during a survey of the Upper Little Manatee River floodplain (PBS&J 2008 in Appendix K). These three wetland classes are characterized by species less tolerant of flooding than cypress. Based on the occurrence of these wetlands, a floodplain inundation criterion was evaluated to develop the recommended minimum flows for the Upper Little Manatee River.

5.3.3 Upper River Instream Habitat

Flow determines the physical habitat in streams, which in turn determines biological diversity (Bunn and Arthington 2002). Fish and other aquatic wildlife, including insect larvae that are prey for many species of fish, have habitat requirements that determine their distribution and abundance.

For a minimum flows analysis, it is necessary to quantify effects of flow variation on habitat attributes. For example, velocity and depth, two quantifiable components of flow, can both be important attributes of the habitat for stream-dwelling organisms. Additional attributes of instream habitat include the presence of sand or bedrock, submerged logs, and aquatic vegetation. Instream habitat modeling quantifies these habitat attributes as they change with variation in flows (discharge) and relates attributes to habitat suitability for individual species, taxonomic groups, or functional habitat groups.

In the past, the District typically used the PHABSIM system as one of the approaches for developing minimum flows for the freshwater portions of flowing water bodies. Use of the PHABSIM approach provides a means to quantify changes in available habitat for a particular aquatic species, taxon, group, and/or life stage as a result of changes in stream flow. The PHABSIM system has been characterized as one of the most widely used methods for establishing environmental flows for rivers (Postel and Richter 2003), and its use was recommended in the peer review of the District's proposed minimum flows for the Upper Peace River approximately 20 years ago (Gore et al. 2002). Since the Upper Little Manatee River is primarily well incised with very high banks, PHABSIM analyses were considered appropriate for assessing potential habitat changes for the instream portions of the flow regime.

Field data were collected from two sites in the Upper Little Manatee River as part of the PHABSIM analysis in support of the original development of draft minimum flows for the Upper Little Manatee River (Hood et al. 2011 in Appendix A), and the panel of independent scientific peer reviewers stated that it was unclear if the two sites were representative of the complete range of habitats present in the system, especially those that represent important habitat for aquatic vertebrates and invertebrates (Powell et al. 2012 in Appendix B). The review panel convened in 2012 suggested the District consider revising the PHABSIM analysis by extending the length of the study reaches and adding sufficient transects (cross sections) to represent the upper river and also recommended the District use more accurate hydraulic models in future efforts.

To address concerns of the peer review panel (Powell et al. 2012 in Appendix B), the System for Environmental Flow Analysis (SEFA) modeling software (Jowett et al. 2020) was used to update and refine the District's original PHABSIM analyses for the Upper Little Manatee River. The SEFA is a software program that is capable of analyses similar to the PHABSIM approach but includes additional options and offers a variety of methods for calculating habitat changes with flow. It has the ability to fit rating curves to paired stage and flow data, which can then be used with hydraulic modeling to predict velocity and depth changes with flow (Figure 5-6).

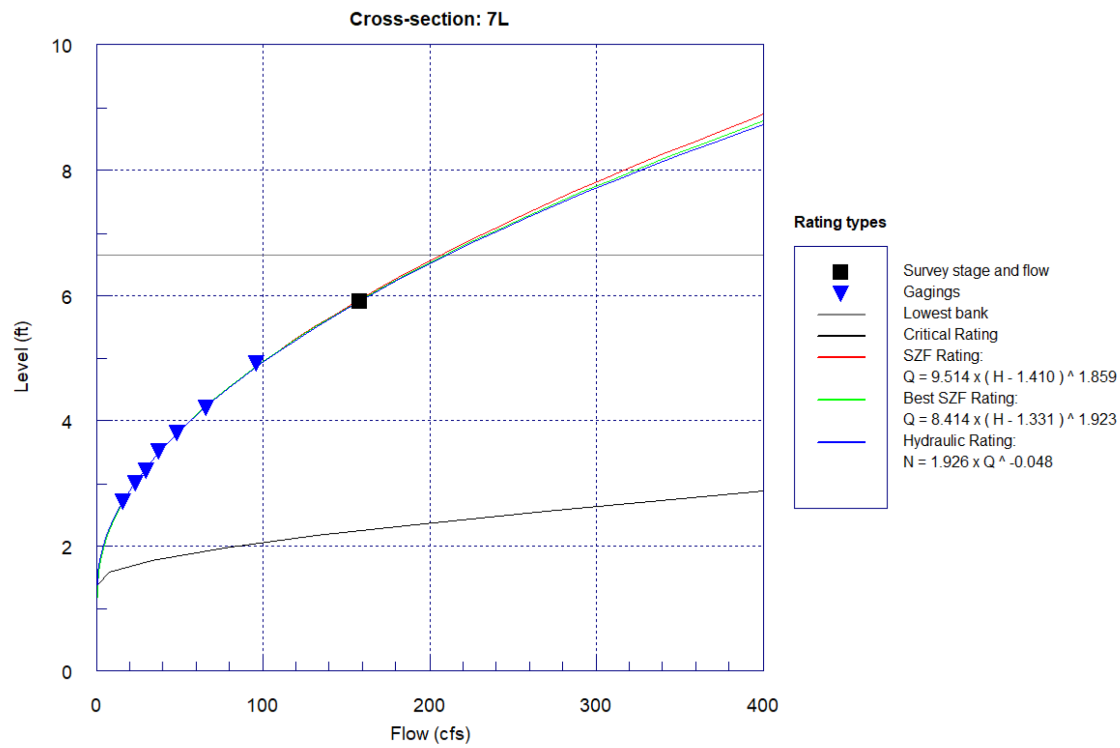


Figure 5-6. Rating curves use stage-flow pairs to predict water level changes with flow.

Maintenance and protection of biodiversity is a primary target of worldwide conservation efforts (Rands et al. 2010). Furthermore, aquatic stream insect biodiversity is dependent upon the presence of a variety of habitats (Voelz and McArthur 2000). Likewise, the complexity of habitats found in running waters contributes to a rich biodiversity of fish species (Allan and Flecker 1993). This variation in habitats offered by flowing streams is quantified in the suite of habitat suitability curves used in the SEFA approach. Identifying and protecting the most sensitive habitats protects those organisms dependent upon those habitats; in addition, it protects all other organisms with less sensitive habitat requirements that are, nonetheless, dependent upon the same physical habitat variables. It also protects the biodiversity of the entire ecosystem.

An initial SEFA, which incorporated an updated USACOE Hydrologic Engineering Center's River Analysis System (HEC-RAS) model for the cross-sectional estimates of area weighted suitability (AWS), was conducted as part of a first re-evaluation of the recommended minimum flows for the upper river (JEI 2018a in Appendix C). This first SEFA did not use field measurements of substrate and cover. A second SEFA, which included substrate and cover data collected from seven sites in the upper river, was completed by the District and used to support development of the proposed minimum flows presented in the September 2021 draft report.

As a result of the September 2021 draft report peer review panel comments (Appendix F and G), the District completed a third SEFA that used the original HEC-RAS model developed for the Upper Little Manatee River (ZFI 2010 in Appendix N). This original HEC-RAS model included ten surveyed cross sections and, as a result of the peer review of the September 2021 draft report, was determined to be the best model to use for the instream analyses.

5.3.4 Lower River Biologically Relevant Salinity Zones

Alterations to the timing and amount of freshwater inflow has a direct and instantaneous impact on salinity and some aspects of water quality and biological communities, while impacts may be indirect and are typically manifested on longer time scales. However, since many estuarine communities are dependent on salinity variation for persistence and reproduction, the District uses the response of salinity distributions to changes in freshwater flow as important, protective criteria for establishing estuarine minimum flows.

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

Bulger et. al (1993) used a principal component analysis (PCA) of fish catch data from the mid-Atlantic region to establish four overlapping, biologically important salinity ranges of 0 to 4 psu, 2 to 14 psu, 1 to 18 psu, and 16 to 27 psu. Using combined data from the nine study rivers in West-Central Florida, JEI (2007) used an PCA of species presence-absence data to identify salinity zones of 0 to 7 psu, 7 to 18 psu, and 18 through 29 psu that were related to macroinvertebrate community structure. In a survey of seven rivers on the coast of West-Central Florida, Clewell et al. (2002) found that freshwater plants that tolerate some combination of salinity levels and durations were primarily located upstream of the median location of 2 psu salinity in the river channels. They also reported that freshwater plants tolerant of low salinity, which are often dominant in brackish marshes (e.g., cattails, sawgrass, and bullrush), were most common where median surface salinity values were less than 4 psu. These plants also occurred in somewhat higher salinity waters but were rarely found where median salinity values exceeded 12 psu. Similarly, in a study of the Suwannee River estuary, Clewell et al. (1999) found that the transition from sawgrass to saltmarsh species occurred where maximum salinities in the dry season were near 10 psu.

Based on these findings and other literature (Jassby et al. 1995, Beck et al. 2000, Kimmerer 2002, SFWMD 2002, Hoyer et al. 2004, Water Resource Associates, Inc. et al. 2005, Tampa Bay Estuary Program 2006, Culter 2010), a range of isohalines (ranging from <2 to <30 psu) were selected to represent the boundaries of salinity zones that are important to either shoreline plant communities, benthic macroinvertebrates, or fishes in the Lower Little Manatee River. The lowest salinity isohaline of <2 psu that we evaluated is often considered as a critical parameter for the health of the estuary and has been used by the District as the lower limit in previous estuarine minimum flows evaluations (Herrick et al. 2019a, 2019b, Ghile et al. 2021).

5.3.5 Lower River Estuarine Fish Habitat

The Lower Little Manatee River provides critical estuarine-dependent fish habitat, and the District uses habitat-based approaches wherever possible to support development of minimum flows. Based on the importance of the Little Manatee River as estuarine fish habitat and since earlier work indicated that the relationship between estuarine fish and benthic macroinvertebrate relative abundance and changes in freshwater flow is highly variable (Peebles and Flannery 1992, MacDonald et al. 2007, Grabe and Janicki 2008 in Appendix L, Peebles 2008, Heyl et al. 2012), habitat suitability indices were developed to estimate the effects of potential flow reductions on estuarine fish habitat preferences.

This approach is consistent with the District's use of other habitat-based approaches to develop minimum flows. It allows for habitat preferences, such as shoreline habitat type and season, to be included in the modeling framework, an improvement to assessments that only consider flow as a driver of fish habitat suitability. Habitat preferences were defined by the Environmental Favorability Function (EFF) approach (Real et al. 2006), which was used to predict the relative favorability of habitats under different flow regimes for fish species of interest that use mid- and low-salinity habitats in the river and exhibit a negative response to increasing salinities. The robust seine haul data from the FWC's FIM program, described in Section 4.3.2, was incorporated into the EFF approach.

The EFF approach has been used 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 habitats within conservation areas (Acevedo et al. 2010a, 2010b). This approach has also 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 (JEI 2014).

The EFF approach was first applied to the Little Manatee River in earlier work supporting the development of draft minimum flows for the Lower River that was described in the September 2021 draft report and has since been revised and improved for the development of minimum flows as further detailed in Section 5.4.6 of this report. Application of the EFF is analogous to that of the SEFA approach described earlier for the Upper Little Manatee River. That is, habitat suitability is evaluated, and the effects of flow reduction scenarios are used to evaluate the change in suitable habitat. In the case of EFF approach, suitable is defined as favorable habitat for occupancy.

5.4 Technical Approaches for Addressing Resources of Concern

This section describes the various methodologies and modeling approaches that were used to evaluate the resources of concern to develop recommended minimum flows for the Little Manatee River.

5.4.1 Upper River HEC-RAS Modeling

The HEC-RAS model allows users to perform one-dimensional, steady flow, one- and two-dimensional, unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modeling. The model is a critical component of the technical analyses for minimum flows development for the Upper Little Manatee River in that it was used to quantify stages, and their effects on ecological criteria, including wetted perimeter, fish passage, navigation, sediment loads, floodplain inundation, and instream habitat.

5.4.1.1 ZFI (2010) HEC-RAS Model

A one-dimensional, steady-state HEC-RAS model was developed for the Upper Little Manatee River (ZFI 2010 in Appendix N) and used in support of the original draft minimum flows development (Hood et al. 2011 in Appendix A). The river segment included in the model extends from the USGS Little Manatee River near Ft. Lonesome, FL (No. 02300100) gage to the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage (Figure 2-3), flowing from east to west for approximately 16 miles (25 km) and providing surface drainage for about 200 square miles (520 square km). Several named tributaries, including Howard Prairie Branch, Pierce Branch, Carlton Branch, Gully Branch, Lake Wimauma Plain, Dug Creek, South Fork, and several smaller unnamed tributaries that drain to the main channel were considered for model development (Figures 2-3 and 5-7).

Cross-section data for the ZFI (2010 in Appendix N) HEC-RAS model were compiled from multiple sources. These sources included ten surveyed transects from the District's Survey section that were obtained in support of minimum flows development, data gathered by ZFI, Inc., and available LiDAR data from the District's GIS and Mapping group for the Little Manatee River watershed. These data sources and break lines were used to generate a triangulated irregular network (TIN). An Arcmap extension, HEC-GeoRAS, was then used to generate more than 400 cross sections, which were exported into the HEC-RAS model (Figure 5-7).

Hydraulic data inputs required for the HEC-RAS model included flow and stage data for the boundary conditions. Daily flow and stage data for these purposes were obtained from the USGS for three sites: Little Manatee River at US 301 near Wimauma, FL (No. 02300500), South Fork Little Manatee River near Wimauma, FL (No. 02300300), and Little Manatee River near Ft. Lonesome, FL (No. 02300100). Since no gaged data were available for numerous tributaries entering the river, the Hydrologic Modeling System (HEC-HMS) was used to estimate daily flows and water depths for the main channel of the Upper Little Manatee River (Reaches 0 to 8 from upstream to downstream) and tributaries, including Howard Prairie Branch, Pierce Branch, Carlton Branch, Gully Branch, Lake Wimauma Plain, Dug Creek, South and several unnamed streams. In total, 17 river reaches were considered in the ZFI HEC-HMS model (Figure 5-8). The following steps were undertaken to generate daily flows at each reach outlet and provide flow apportionment data to be used in the HEC-RAS model:

1. Using the HEC-GeoHMS tool, the approximate locations for subbasin outlets were identified to automatically delineate the subbasin boundaries. A channel cross section, channel length, and slope were determined using DEM data for each subbasin.

2. Thirteen rainfall stations were used for precipitation data, and the weights of each rainfall station for each subbasin were calculated using the Thiessen Polygon method. The simulation period was determined by using the best available rainfall data starting from January 1, 1988 through December 31, 2009.
3. The Natural Resource Conservation Service (NRCS) Curve Number (CN) method in the HEC-HMS model was used to predict rainfall excess (runoff) for each sub-basin. The Muskingum-Cunge Routing method was then used to route runoff through each subbasin.
4. Because of insufficient stream flow and stage data for most of the tributaries, the HEC-HMS model results were compared to the Federal Emergency Management Agency (FEMA) published flows for the 10-, 25-, 50-, and 100-year return periods. The differences between the HEC-HMS model flows and the FEMA flows were within 2 to 10 percent.

Using the HEC-HMS model routed runoff, the flow apportionment ratio for each of the 17 reaches was calculated as listed in Table 5-1. The flow apportionment ratios indicate the flow contribution of each reach relative to the flow measured at the Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage.

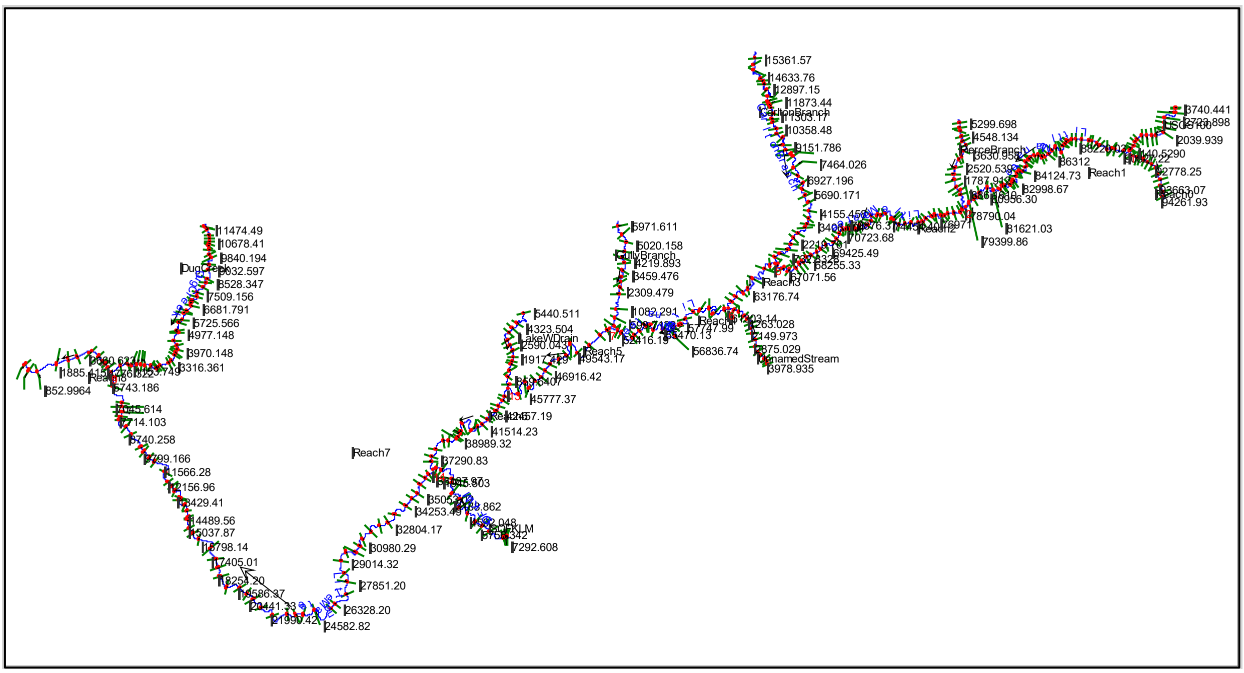


Figure 5-7. Location of the HEC-RAS model cross sections in the 2010 ZFI HEC-RAS model developed for the Upper Little Manatee River.

Table 5-1. Summary of flow apportionment for main-stem river reaches and tributaries in the 2010 ZFI HEC-RAS model developed for the Upper Little Manatee River.

River Name	Reach or Tributary Name	Flow Apportionment Ratio
Little Manatee	0	0.01
	1	0.22
	2	0.32
	3	0.41
	4	0.51
	5	0.56
	6	0.61
	7	0.90
	8	1.00
USGS100	USGS100	0.198
PieceBranch	PieceBranch	0.089
CarltonBranch	CarltonBranch	0.089
UnnamedStream	UnnamedStream	0.089
GullyBranch	GullyBranch	0.044
LakeWDrain	LakeWDrain	0.044
SOFKLM	SOFKLM	0.274
DugCreek	DugCreek	0.089

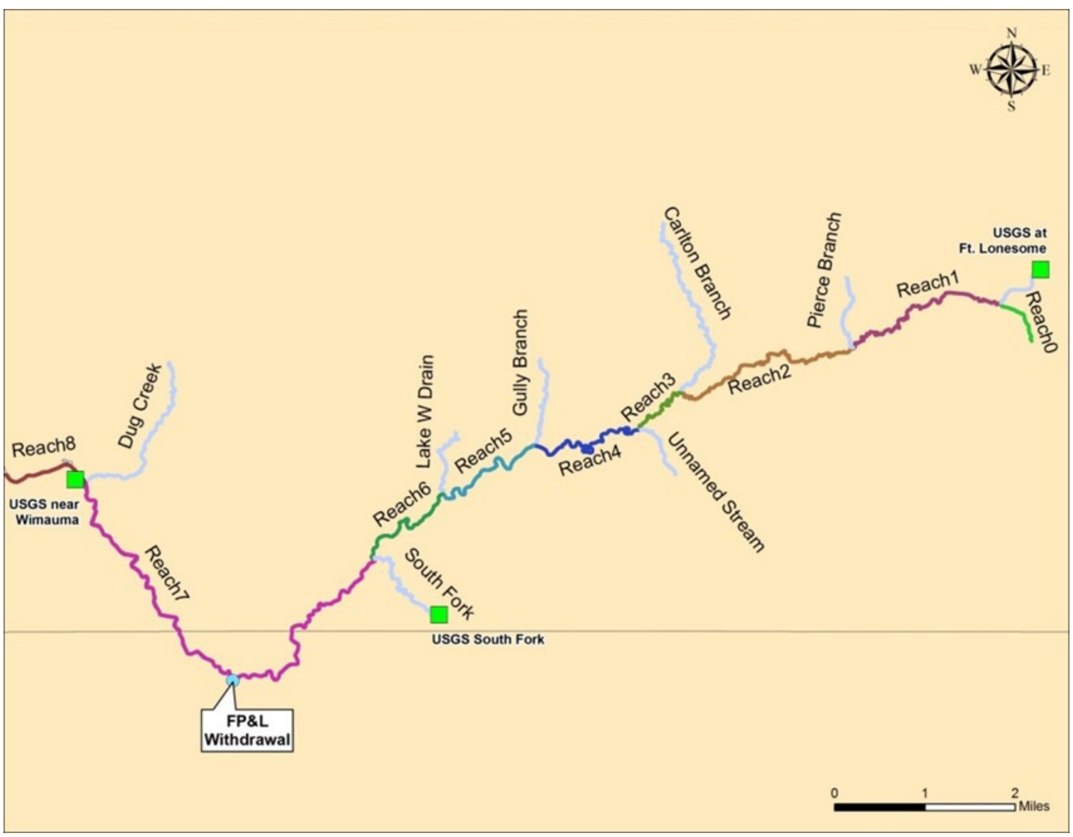


Figure 5-8. Location of the nine main-stem reaches identified for the Upper Little Manatee River.

Normal water depth was used as the downstream boundary condition for all modeled reaches. This boundary condition requires the input of the energy grade line (EGL) slope at the downstream boundary of each reach. The downstream EGL slope was approximated in ArcGIS using the digital elevation model (DEM) data, cross section cut line coverage, and stream centerline coverage. The calculated normal depth at the downstream of the river in the study area is 0.0001.

Model calibration and verification were performed for the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage using the October 2 through 8, 2007 and September 10 through 20, 2009 storm events, respectively. The HEC-RAS model was considered well calibrated and was able to capture the hydrologic response to low, medium, and high flow conditions, even though the model underestimated the water level during high flow conditions of the validation period (Figure 5-9). Details of the model calibration and validation are provided in ZFI (2010 in Appendix N).

The calibrated ZFI (2010 in Appendix N) HEC-RAS model was run for 15 steady flow-stage scenarios to determine stage versus flow and wetted perimeter versus flow relationships for each cross section. These scenarios range from 50 percent to 99 percent exceedance time and were formulated through flow-duration analysis of the baseline flow and stage data at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage for the time period from January 1, 1939, to December 31, 2010.

To develop minimum flows for the upper river, it was necessary to characterize the entire flow range, including flows lower than those included in the ZFI (2010 in Appendix N) HEC-RAS model. To accomplish this goal, we ran the ZFI (2010 in Appendix N) HEC-RAS model for 101 flow rate profile ranging from 0 to 100 percentiles.

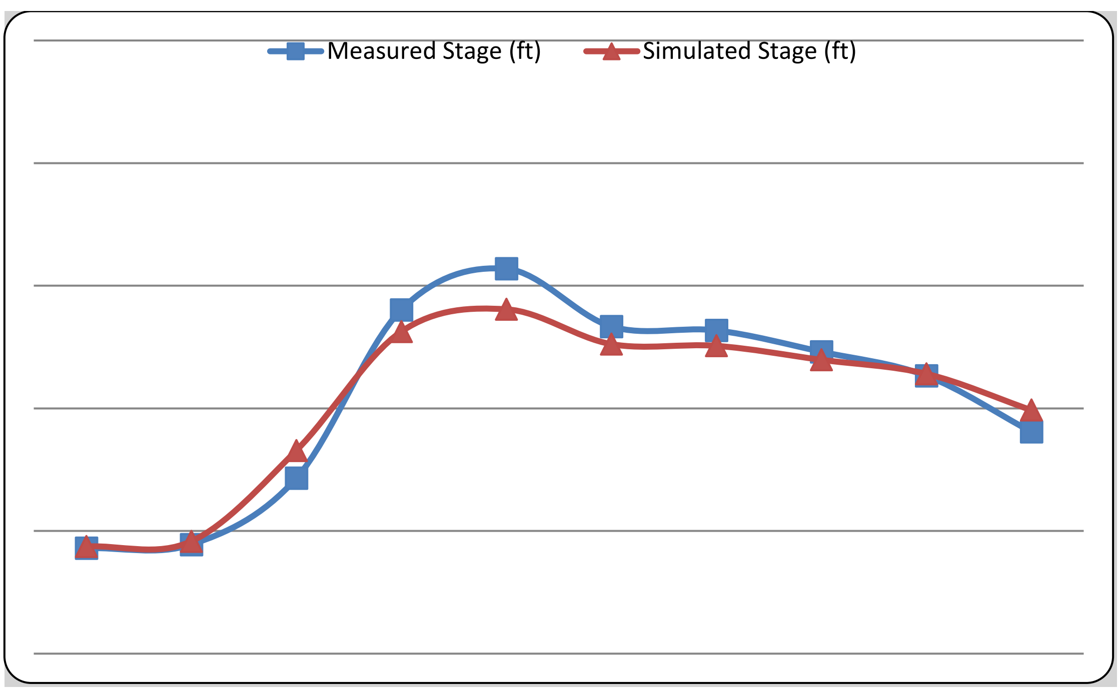


Figure 5-9. Comparison of observed and simulated stage (ft) at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage for the period from September 10 through September 20, 2009 (ZFI 2010 in Appendix N).

5.4.1.2 JEI (2018) HEC-RAS Model

As part of an earlier re-evaluation of the proposed minimum flows for the Upper Little Manatee River, JEI (2018a in Appendix C) updated the HEC-RAS cross section geometry data by importing 125 cross sections from the Surface Water Management Model (SWMM), which was developed by Jones Edmunds, Inc. (2015) for the Little Manatee River as part of the Hillsborough County Watershed Management Plan. A total of 478 cross sections were defined in the updated HEC-RAS model, including the 125 imported from the SWMM and 355 interpolated cross sections (Figure 5-10). The flow apportionment by reach (see Table 5-1) developed by ZFI (2010 in Appendix N) was retained for this model update.

Fifteen SWMM cross sections were selected as calibration cross sections based on their close proximity to the 2010 HEC-RAS model cross sections and their representativeness of the upstream portion of the system. These calibration choices were made to promote consistency between HEC-RAS model predictions and SWMM model outputs.

The JEI (2018a in Appendix C) HEC-RAS model was then run for 101 flow rate profile scenarios to establish flow versus stage rating curves for each cross section. Each profile represents a non-exceedance percentile ranging from 0 to 100 percent at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage for the time period from January 1, 1939, to December 31, 2015. The flow apportionment developed by ZFI (2010) (see Table 5-1) was retained in the JEI (2018) HEC-RAS model.

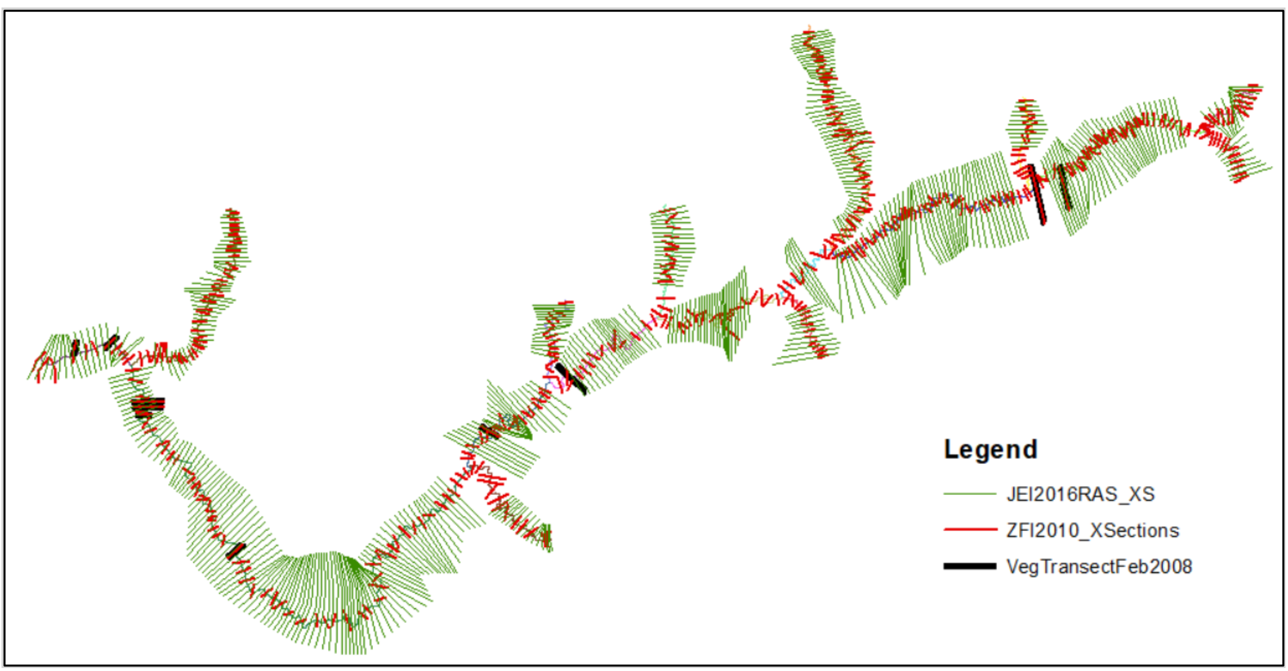


Figure 5-10. Location of cross sections in the Upper Little Manatee River HEC-RAS models. Red and black lines identify cross sections included in the 2010 ZFI model, with the black lines representing ten cross sections surveyed by the District. Green lines identify locations of cross sections included in the 2018 JEI HEC-RAS model.

5.4.1.3 Sources of HEC-RAS Model Uncertainty

The ZFI (2010 in Appendix N) and JEI (2018a in Appendix C) HEC-RAS models for the Upper Little Manatee River are subject to uncertainties associated with model inputs, assumptions, and interpolations. Some sources of uncertainties include:

- The flow apportionment by reach originally developed by ZFI and retained by JEI in the 2018 HEC-RAS model is subjected to uncertainties associated with model inputs and flow estimations. Linear regression curves were developed by ZFI (2010 in Appendix N) to fill in missing hydrologic data; the uncertainty that exists in the regression curves may lead to unfavorable model calibration results at some time periods. Uncertainty associated with spatial interpolation of rainfall data could affect the accuracy of the model. The HEC-HMS model is less accurate than preferred, due to lack of actual flows for calibration. There is uncertainty in the flow apportionment ratios (Table 5-1) as the model was mainly calibrated for large design storms events. The subbasins may exhibit different runoff responses (flow apportionment) for small storm events.
- The imported SWMM model cross sections used in the JEI (2018a in Appendix C) HEC-RAS model were developed based on limited and outdated bathymetric survey data.
- The ZFI (2010 in Appendix N) HEC-RAS model was calibrated to limited flow ranges at one section of the river, while the JEI (2018a in Appendix C) HEC-RAS model was calibrated to more closely match the SWMM model outputs and not calibrated against observed data.
- The ZFI (2010 in Appendix N) HEC-RAS model was run for steady flow rates from the 50^{th} to 90^{th} exceedance percentiles; the low-range flow versus stage curves are, therefore, subject to uncertainty that could affect in-channel habitat analyses.

Upon review of the limitations of both versions of the HEC-RAS model, District staff concluded that the imported SWMM model cross sections better represent the overbank bathymetry of the river corridor, as compared to the cross sections compiled from the DEM by ZFI in 2010. Most of the SWMM model cross sections extend to the outer edge of the wetland areas, so the HEC-RAS model developed by JEI (2018a in Appendix C) was deemed to be a better tool for predicting floodplain inundation at river cross sections.

With the absence of adequate surveyed cross-section data, however, the JEI (2018a in Appendix C) HEC-RAS model may not be able to accurately capture channel depths across many cross sections in the river, as well as river bends. Therefore, the JEI (2018a in Appendix C) HEC-RAS model may not be appropriate to derive stage-flow relationships under medium- to low-flow conditions. In contrast, the ZFI (2010 in Appendix N) HEC-RAS model included ten surveyed transects, and the model can predict flow-stage relationships with reasonable accuracy for in-channel analyses, such as those associated with fish passage, wetted perimeter, navigation, and aquatic habitats.

5.4.2 Little Manatee River Low-Flow Threshold

Wetted perimeter and fish passage analyses were the methods used to develop the low-flow threshold. The low-flow threshold is established at the higher of the two flow standards. The analyses used to develop the low-flow threshold are described in the following sections.

5.4.2.1 Upper River Wetted Perimeter Analysis

Output from the 101 flow profile scenarios of the ZFI (2010 in Appendix N) HEC-RAS model were used to generate a wetted perimeter versus flow plot for each cross section of the Upper Little Manatee River. Plots were visually examined for inflection points, which identify flow ranges that are associated with relatively large changes in wetted perimeter. The LWPIP for flows up to 50 cfs was identified for each cross section. Many cross-section plots displayed no apparent inflection points between the lowest modeled flow and 50 cfs. Inflection points for flows higher than 50 cfs were disregarded since the goal was to identify the LWPIP for flows contained within the stream channel. For cross sections that displayed no distinct break or where the majority of the wetted perimeter was inundated below the lowest modeled flow, the LWPIP was established at the lowest modeled flow.

Flows associated with the LWPIP at each cross section were converted to flows at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage using relationships from the ZFI (2010 in Appendix N) HEC-RAS model output. These cross-section-specific LWPIPs were then evaluated to identify the most sensitive cross sections to support development of a minimum low-flow threshold for the Upper Little Manatee River.

5.4.2.2 Upper River Fish Passage Analysis

For development of minimum flows, it is desirable to maintain longitudinal connectivity along a river corridor, to the extent that this connectivity has historically occurred. The updated ZFI (2010 in Appendix N) HEC-RAS model output was used to assess flows necessary for fish passage at each of the HEC-RAS cross sections by adding the 0.6-ft (0.18-m) depth fish-passage criterion to the elevation of the lowest spot in the channel cross section. The fish-passage criterion is routinely used by the District for development of minimum flows and was found to be acceptable by the panel that reviewed the proposed Upper Peace River minimum flows (Gore et al. 2002), as well as subsequent peer review panels.

Flows at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage were associated with flows at each cross section that resulted in at least 0.6 ft (0.18 m) of water in the deepest part of the channel. These cross-section-specific fish-passage depths were then evaluated to identify the most sensitive cross sections to support development of a minimum low-flow threshold for the Upper Little Manatee River.

5.4.3 Upper River Floodplain Inundation

Floodplain inundation criteria were developed to protect intermittent high flows that support wetland vegetation, biogeochemical processes, and habitat values associated with the floodplain of the Upper Little Manatee River. A prescriptive standard allowing up to a 15 percent change in floodplain inundation from the baseline condition was used to define the limit beyond which further withdrawals would result in significant harm. Although the Upper Little Manatee River is generally well-incised without the extensive floodplains that are common in many other Southwest Florida river corridors (PBS&J 2008 in Appendix K), evaluation of floodplain inundation was considered appropriate for establishing minimum flows for the Upper Little Manatee River.

The 2018 HEC-RAS model (JEI 2018a in Appendix C) included SWMM transects that extended farther into floodplain areas than the 2010 HEC-RAS model (ZFI 2010 in Appendix N). Therefore, the 2018 HEC-RAS model was used to evaluate the extent of floodplain inundation as a function of flows at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage. The HEC-GeoRAS, a geo-processing accessory to HEC-RAS that incorporates a digital elevation layer, was used to import the HEC-RAS model water surface profile simulation data into ArcGIS for spatial mapping of the extent of floodplain inundation. The steps involved in the floodplain inundation modeling were as follows:

1. Water surface elevations from the 101 flow rate profiles simulated with the 2018 HEC-RAS model were converted to triangulated irregular networks (TINs) using HEC-GeoRAS in ArcGIS for the representation of water surfaces.
2. The water-elevation TINs were rasterized in ArcGIS 10.6 at a spatial resolution of the DEM.
3. The rasterized water surface profiles and DEM data were overlain to determine the extent and depths of inundation. Inundated area was defined as the area encompassed by the intersection of the water surface and land surface.
4. The inundation levels for each percentile were then intersected with the 2011 District land use/cover layer (SWFWMD 2011), which was used to characterize the extent of floodplain wetland vegetation within the floodplain of the model domain. All floodplain wetland vegetation in the upper river corridor was categorized as a single District FLUCCS Code (Bottom Land Hardwood Swamp; FLUCCS Code 6150).
5. To quantify a daily inundated wetland area, a flow-inundated area rating curve was developed using flows at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage.
6. Using the rating curve, a daily time series of inundated floodplain wetland area for the baseline condition was generated for the period from 1939 through 2021 using an interpolation function in an Excel spreadsheet.
7. A total available inundated floodplain area was calculated for the baseline condition by summing the daily time-series area values.
8. Steps 6 and 7 were repeated for 30 scenarios associated with 1 to 30 percent reductions in the baseline flows.
9. Decreases in the inundated floodplain wetland habitat availability for each reduced flow scenario were calculated to identify the flow reduction scenario that resulted in no more than a 15 percent reduction in available habitat relative to the baseline condition.

Multiple sources of uncertainty can be associated with our floodplain inundation modeling for the Upper Little Manatee River. These sources can be ascribed to cross-section data and data processing errors associated with DEM development and estimation of inundation from rating curves.

The model domain and the existing wetland vegetation within the model domain are shown in Figure 5-11 along with floodplain wetland vegetation in the watershed that were not included in the model domain. Additional information on the methods used for assessment of floodplain inundation in the river is provided in JEI (2018a in Appendix C).

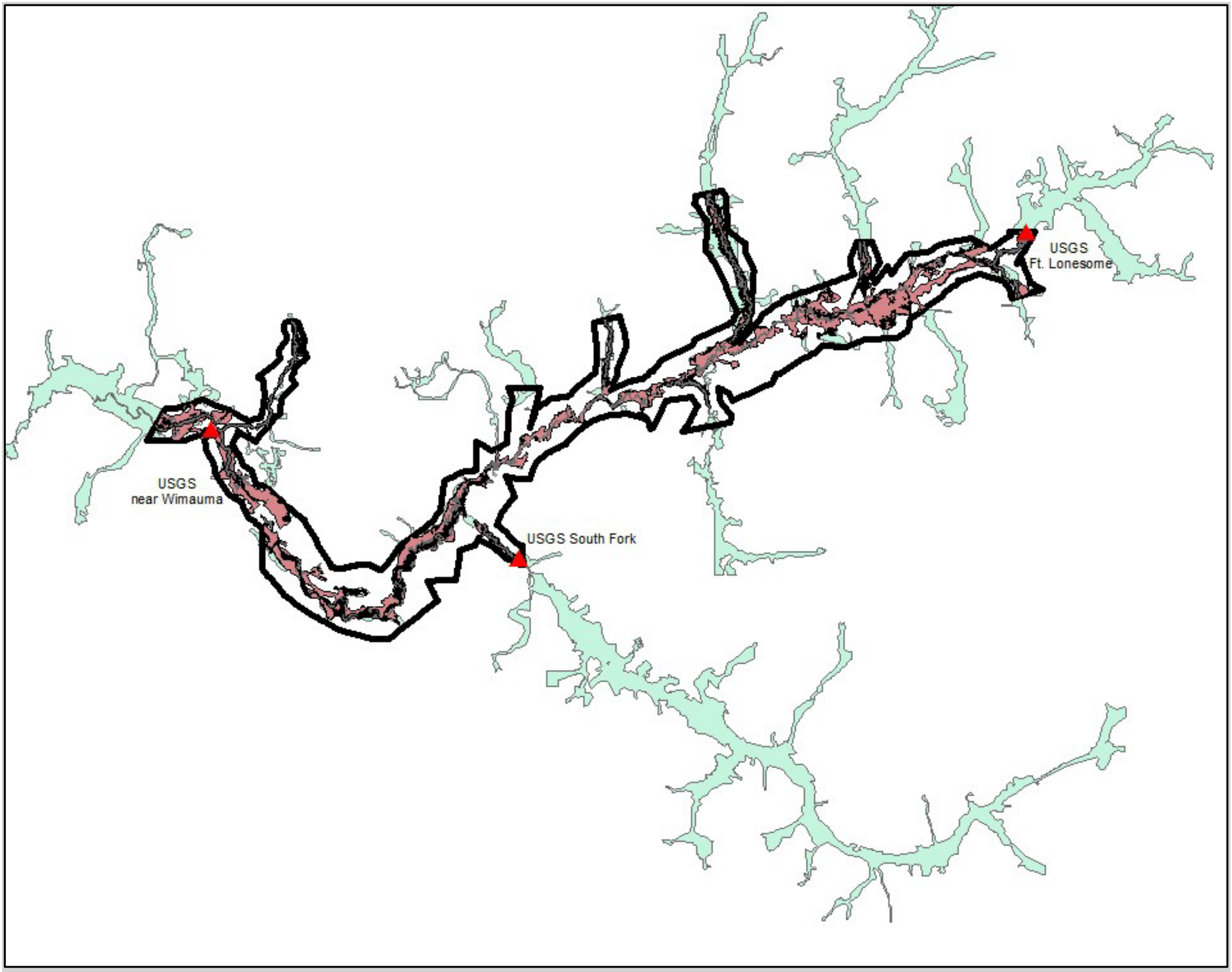


Figure 5-11. The 2018 HEC-RAS model boundary for the Upper Little Manatee River (black outline) and floodplain wetland vegetation within (brown polygons) and outside of (green polygons) the model domain. All wetlands were categorized as a single type in the Upper Little Manatee River (FLUCCS Code 6150: Bottom land Hardwood Swamp) (from JEI 2018a in Appendix C).

5.4.4 Upper River Instream Habitat

Alterations to flow are associated with ecological change across a range of geographical, biological, and physical environments, but the responses are unique to each stream. Site-specific data collection and analysis, rather than broad generalization, is therefore typically necessary for environmental flow analysis (Poff and Zimmerman 2010).

To characterize the potential effects of flow reductions on instream habitats in the Upper Little Manatee River, the District collected physical habitat data on substrate and cover and combined this information with depth and velocity from the 2010 HEC-RAS model (ZFI 2010 in Appendix N) to develop an area-weighted habitat index using the SEFA software. The results demonstrated that habitat availability changes with flows and identified a maximum flow reduction before significant loss of habitat occurred.

Field-collected physical habitat data on substrate and cover were combined with depth and velocity from the 2010 HEC-RAS model (ZFI 2010 in Appendix M) and habitat suitability curves to develop an area-weighted habitat index for selected fish and aquatic macroinvertebrates. This instream habitat modeling analysis used cross-sectional elevation profiles, water surface elevation, velocity, and substrate/cover types at specific locations across the channel, along with suitability profiles for water depth, velocity, and substrate/cover for selected fish and aquatic macroinvertebrates.

A site or reach consists of multiple cross sections. Cross sections, which are individual transects that run perpendicular to the direction of flow, were subdivided into offsets, each with a depth, velocity, and calculated flow value. These measured attributes are then modeled for changes with flow. Increases in flow cause increases in velocity, depth, wetted perimeter, and wetting of substrates that were above water at lower flows. All these changes to physical attributes result in corresponding changes to habitat suitability.

This data was used to derive a taxon-specific single index value referred to as the AWS for each flow rate. The AWS is a non-dimensional (not expressed in any particular unit) index of habitat suitability that varies with discharge. The AWS is an average of many offsets (i.e., horizontal locations/distances along a cross section transect) within one or more cross sections, and that average value is weighted by the width represented by each offset. The default SEFA output is to express AWS in units of area per length of river (ft^2/ft), which is only true if habitat suitability curves are binary, distinguishing perfectly suitable habitat from unsuitable habitat.

The AWS is calculated by multiplying the Combined Suitability Index (CSI) at each offset by the proportion of the reach area represented by that point (i.e., the width and cross section weight) and summing over the reach. The CSI is calculated at each offset by looking up corresponding suitability values for depth, velocity, and substrate or other attributes in habitat suitability curves. For a given flow, each offset has a particular depth, velocity, substrate, or other attribute(s) that can be translated into a suitability value using selected habitat suitability curves. The CSI may be calculated as the product, the geometric mean, or the minimum value of the suitability of depth, velocity, substrate, and other optional attributes. The CSI can be averaged for one or more cross sections and varies between 0 (unsuitable) and 1 (ideal). Typically, a wider cross section will produce larger AWS values than a narrower cross section. Alternative scenarios, for example time series of flows under baseline (unimpacted) conditions, were compared to flow reduction scenarios to determine loss of habitat associated with decreases in flows.

Habitat suitability curves describe relative suitability of depths, velocities, and other attributes for taxonomic, functional and life history groups, which each have their own habitat suitability curves for velocity, depth, and substrate/cover (Figure 5-12). For the SEFA, we used a set of 35 habitat suitability curves corresponding to species, life history stages, larger taxonomic groups of fish and arthropods, and habitat guilds Table 5-2). These habitat suitability groups were selected based on known habitat use within the Upper Little Manatee River (see Sections 4.2.1 and 4.3.1) (Nagid 2022).

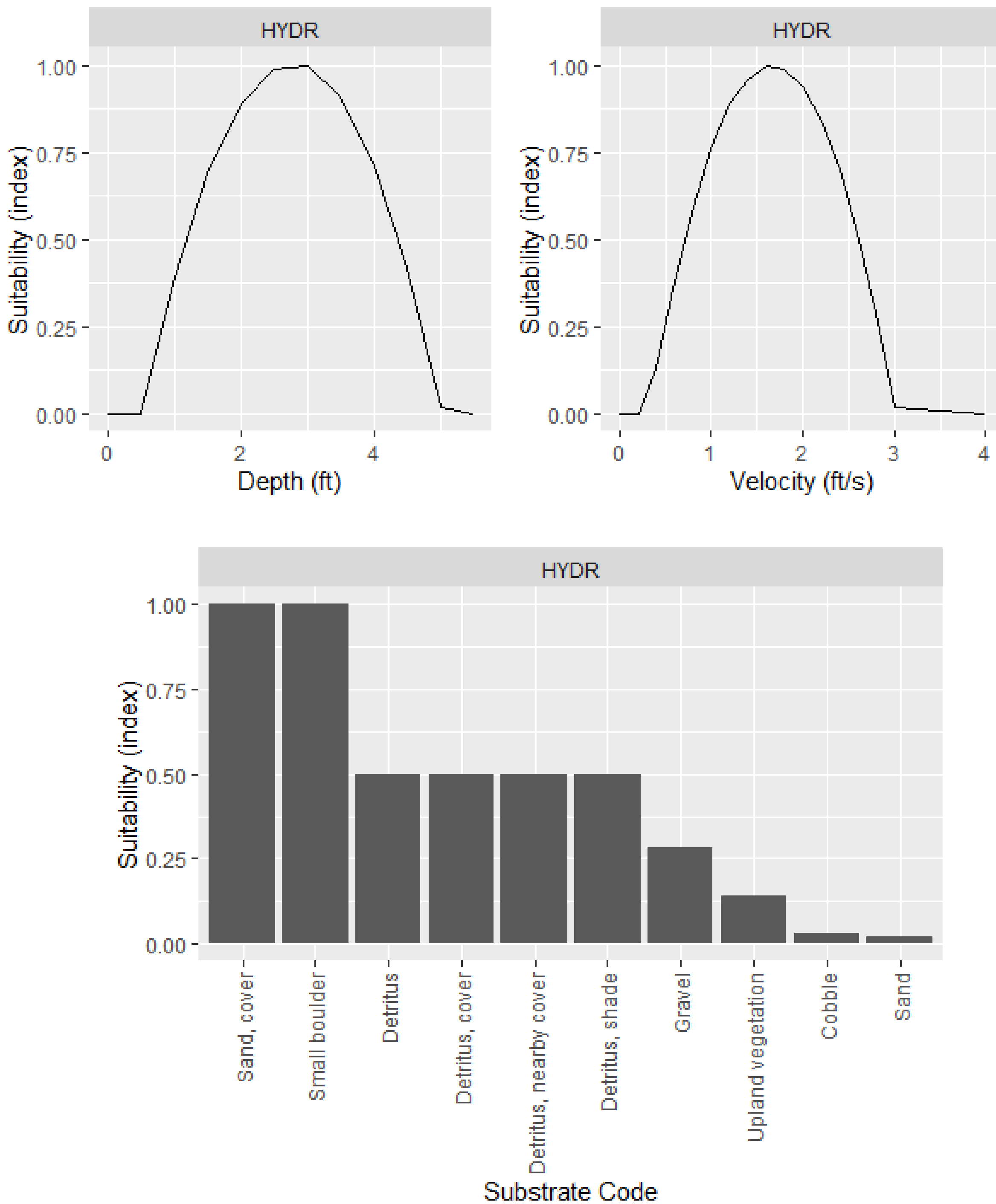


Figure 5-12. Habitat suitability curve examples for HYDR (Hydropsychidae or net-spinning caddisflies) for water depth, velocity, and substrate and cover coding. The y-axes show the weight ascribed to each value of the x-axis on a scale from zero (unsuitable) to one (maximally suitable).

Table 5-2. The habitat suitability groups used in the Upper Little Manatee River SEFA analysis with 4-letter abbreviation codes.

Code	Group Name (Alt. Name)	Stage (Season)
BLUA	Bluegill	Adult
BLUF	Bluegill	Fry
BLUJ	Bluegill	Juvenile
BLUS	Bluegill	Spawning
CCAD	Channel Catfish	Adult
CCFR	Channel Catfish	Fry
CCJF	Channel Catfish	Juvenile (Fall)
CCJP	Channel Catfish	Juvenile (Spring)
CCJS	Channel Catfish	Juvenile (Summer)
CCJU	Channel Catfish	Juvenile
CCSP	Channel Catfish	Spawning
CYPA	Cyprinidae (Shiners)	Adult
DART	Darters	Adult
DPFA	Deep Fast	Guild
DPSL	Deep Slow	Guild
HYDR	Hydropsychidae (Caddisfly)	Total
LMBA	Largemouth Bass	Adult
LMBF	Largemouth Bass	Fry
LMBJ	Largemouth Bass	Juvenile
LMBS	Largemouth Bass	Spawning
PHEM	Ephemeroptera (Mayflies)	Larvae
PSEU	*Pseudocloeon ephippiatum* (Mayfly)	Larvae
REDA	Redbreast Sunfish	Adult
REDF	Redbreast Sunfish	Fry
REDJ	Redbreast Sunfish	Juvenile
REDS	Redbreast Sunfish	Spawning
SHFA	Shallow Fast	Guild
SHSL	Shallow Slow	Guild
SPOA	Spotted Sunfish	Adult
SPOF	Spotted Sunfish	Fry
SPOJ	Spotted Sunfish	Juvenile
SPOS	Spotted Sunfish	Spawning
TINV	Total Invertebrates	All
TRIC	Trichoptera (Caddisflies)	Larvae
TVET	*Tvetenia vitracies* (Midge)	Larvae

Substrate and cover data were collected at 21 transects grouped into 7 sites on the Upper Little Manatee River on July 29 and July 31, 2020 (Figure 5-13). Following data collection, substrate and cover attributes were coded to match habitat suitability curve categories (Table 5-3). Velocities and elevations from the 2010 HEC-RAS model cross sections were matched to substrate and cover to generate SEFA input files. Input files included: transect "offset," "interval," or "station" (horizontal location along the transect); land/sediment surface elevation; water surface elevation or depth; velocity; and substrate/cover coding. In addition, input files contained information about each cross section, such as flow-stage rating curves, weighting values, and stage at zero flow. See Jowett et al. (2020) for more information about options and general SEFA modeling methods.

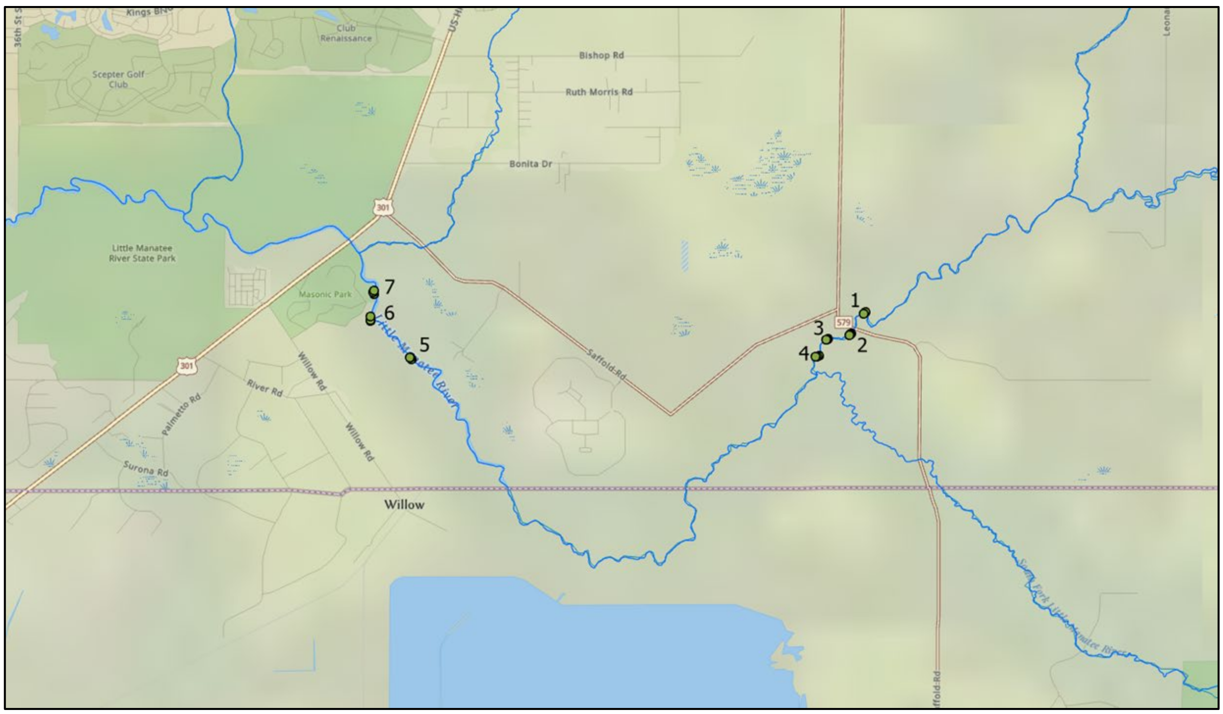


Figure 5-13. The location of the seven sites where substrate/cover was characterized in July 2020 for the SEFA at a total of 21 cross sections along the Upper Little Manatee River.

Table 5-3. Coding for habitat suitability of substrate and cover for the SEFA of the Upper Little Manatee River.

Code	Description
1	No cover and silt **or** terrestrial vegetation
2	No cover and sand
3	No cover and gravel
4	No cover and cobble
5	No cover and small boulder
6	No cover and boulder, angled bedrock, or woody debris
7	No cover and mud or flat bedrock
8	Overhead vegetation and terrestrial vegetation
9	Overhead vegetation and gravel
10	Overhead vegetation and cobble
11	Overhead vegetation and small boulder, boulder, angled bedrock, or woody debris
12	Instream cover and cobble
13	Instream cover and small boulder, boulder, angled bedrock, or woody debris
14	Proximal instream cover and cobble
15	Proximal instream cover and small boulder, boulder, angled bedrock, or woody debris
16	Instream cover or proximal instream cover and gravel
17	Overhead vegetation or instream cover or proximal instream cover and silt or sand
18	Aquatic Vegetation – macrophytes

Relationships between habitat as AWS (y-axis) and flow (x-axis) are referred to as Reach Habitat Curves. For the Upper Little Manatee River curves (Figure 5-14), habitat (AWS) was averaged with equal weighting across all 21 cross sections and scaled for each group as a percent of maximum within the flow range of interest (0 to 96 cfs; see Section 5.1.1 for definition of flow blocks). Flows were reported as USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage equivalents, while each site receives flows apportioned with HEC-RAS model reach location (Table 5-1). The USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage is within Reach 8 of the HEC-RAS model. The downstream sites 5-7 are within Reach 7, and the upstream sites 1-4 are within Reach 6 (Figure 5-13).

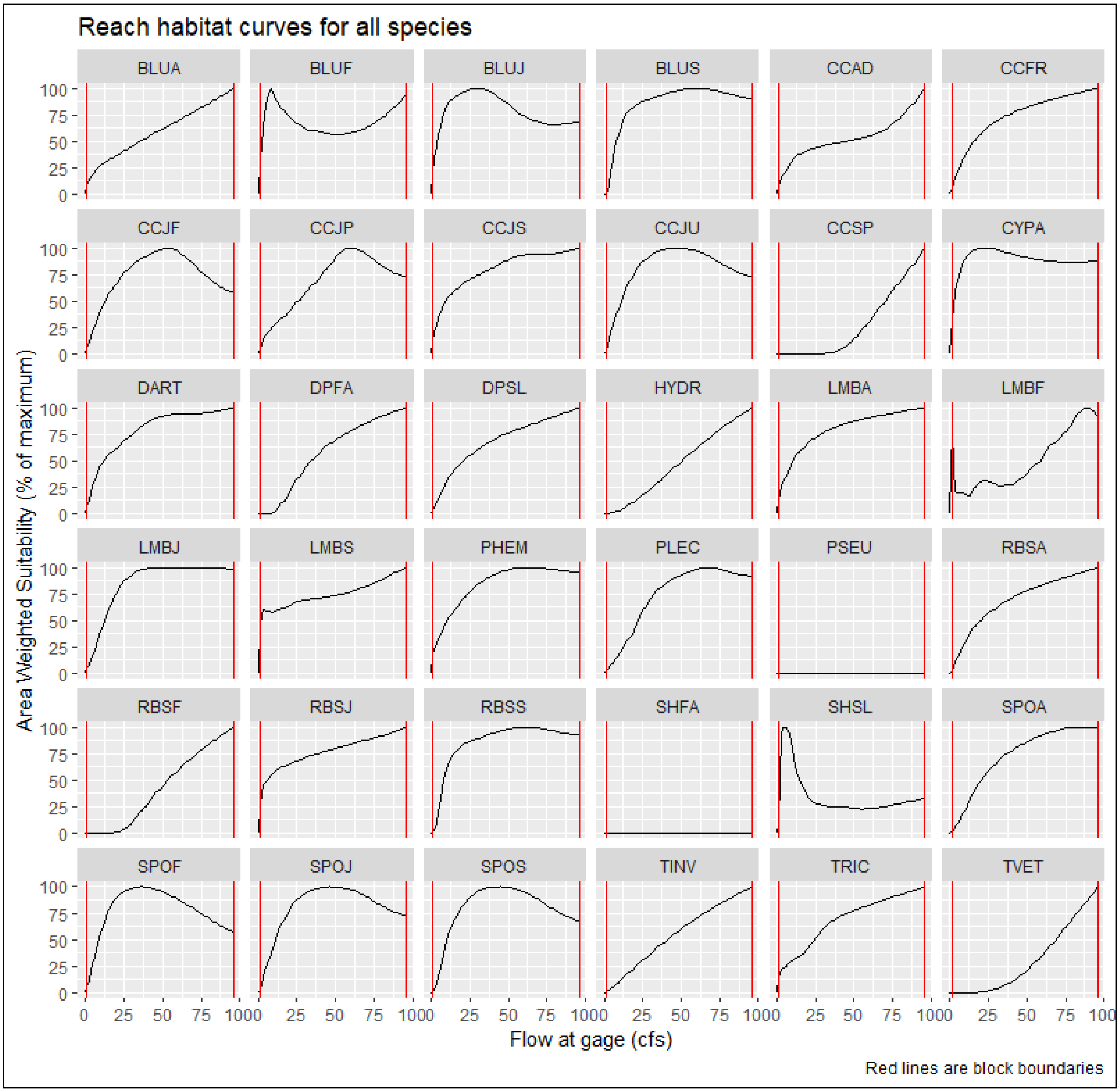


Figure 5-14. Reach habitat curves for all Upper Little Manatee River sites combined (groups defined in Table 5-2). The vertical lines show block flow boundaries of 0 cfs and 96 cfs at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage.

Table 5-4. Flow (cfs) percentiles at upstream sites (1-4), downstream sites (5-7), and the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage drawn from flow profiles in corresponding reaches in the HEC-RAS model output. For inclusion in the habitat loss analysis, species must have at least 10% of total AWS at the 20th percentile flow and at least 1 AWS at the fish passage flow of 29 cfs at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage.

Percentile	Upstream Sites 1-4 (cfs)	Downstream Sites 5-7 (cfs)	USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) Gage (cfs)	Significance
26	18	26	29	Minimum of 1 AWS
50	32	48	53	Median flow
68	58	87	96	Upper Instream boundary

A flow time series for baseline flows includes daily average flows for dates between April 1, 1939, and December 31, 2021 (Figure 5-15). The flow record was filtered to include all dates where the baseline flow at the gage was between 0 and 96 cfs (see Section 5.1.1 for definition of flow blocks). Flow reduction scenarios were created by multiplying each daily flow value by percentages from 75 to 100. As a result, each flow reduction scenario included the same set of dates.

Reach habitat curves (Figure 5-14) were imported to R from the SEFA software and joined to flow time series to create reach habitat time series for each flow reduction scenario. Life-history stages dependent upon month of year had their time series filtered accordingly (Table 5-5). Time series of AWS were condensed into mean values for each habitat suitability group and flow reduction scenario.

A minimum of 1 AWS at the 29 cfs low-flow threshold (which was based on fish passage) ensured there was adequate habitat to avoid uncertainty associated with small sample sizes, as the value of AWS is dependent upon the total cross-sectional width surveyed, as well as the product of the habitat suitability values for corresponding depths, velocities, and substrate/cover attributes. This screening criterion also helped eliminate strongly non-linear responses of AWS to flow. Use of this screening criterion eliminated CCSP, LMBF, PSEU, RBSF, SHFA, and TVET from further analysis. The PSEU and SHFA had no habitat at all flows, while CCSP, LMBF, RBSF, and TVET all had strongly non-linear responses (Figure 5-14).

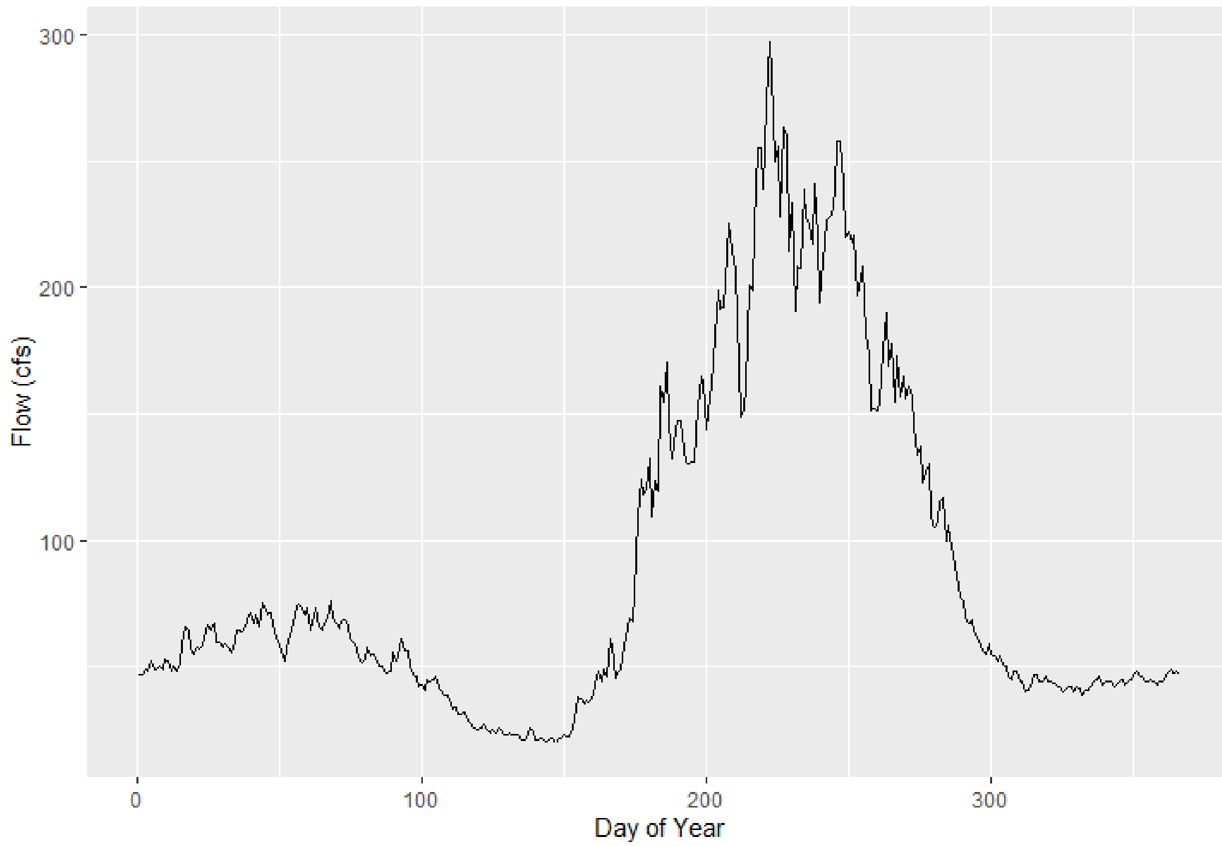


Figure 5-15. Median day-of-year flows under the baseline scenario at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage.

Table 5-5. Months where each habitat suitability group was applied (group abbreviations are defined in Table 5-2). Months filled with blue indicate suitable habitat; white cells indicate exclusion from the analysis.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RBSA	■	■	■	■	■	■	■	■	■	■	■	■
RBSJ	■	■	■	■	■	■	■	■	■	■	■	■
RBSS				■	■	■	■	■	■	■	■	
RBSF					■	■	■	■	■	■	■	■
SHSL	■	■	■	■	■	■	■	■	■	■	■	■
SHFA	■	■	■	■	■	■	■	■	■	■	■	■
DPSL	■	■	■	■	■	■	■	■	■	■	■	■
DPFA	■	■	■	■	■	■	■	■	■	■	■	■
DART	■	■	■	■	■	■	■	■	■	■	■	■
PHEM	■	■	■	■	■	■	■	■	■	■	■	■
TRIC	■	■	■	■	■	■	■	■	■	■	■	■
TINV	■	■	■	■	■	■	■	■	■	■	■	■
PSEU	■	■	■	■	■	■	■	■	■	■	■	■
HYDR	■	■	■	■	■	■	■	■	■	■	■	■
TVET	■	■	■	■	■	■	■	■	■	■	■	■
LMBA	■	■	■	■	■	■	■	■	■	■	■	■
LMBJ	■	■	■	■	■	■	■	■	■	■	■	■
LMBS				■	■	■						
LMBF				■	■	■	■					
BLUA	■	■	■	■	■	■	■	■	■	■	■	■
BLUJ	■	■	■	■	■	■	■	■	■	■	■	■
BLUS				■	■	■	■	■	■			
BLUF				■	■	■	■	■	■	■		
SPOA	■	■	■	■	■	■	■	■	■	■	■	■
SPOJ	■	■	■	■	■	■	■	■	■	■	■	■
SPOS				■	■	■	■	■	■	■	■	
SPOF					■	■	■	■	■	■	■	■
CYPA	■	■	■	■	■	■	■	■	■	■	■	■
CCAD	■	■	■	■	■	■	■	■	■	■	■	■
CCJU	■	■	■	■	■	■	■	■	■	■	■	■
CCSP				■	■	■						
CCFR				■	■	■	■					
CCJP			■	■	■							
CCJS						■	■	■				
CCJF									■	■	■	

5.4.5 Lower River Biologically Relevant Salinity Zones

The Environmental Fluid Dynamics Code (EFDC) model, a hydrodynamic model developed by Hamrick (1996), was used for simulating hydrodynamics and salinity transport processes to develop minimum flows for the Lower Little Manatee River. The EFDC model is a three-dimensional, orthogonal grid model, which is capable of simulating flows and transport processes in surface water systems, including rivers, lakes, estuaries, wetlands, and coastal areas. The physical processes represented in the EFDC model, and many aspects of the computational scheme are similar to those in the Princeton Ocean Model (Blumberg and Mellor 1987) and the USACOE's Chesapeake Bay model (Johnson et al. 1993), which is based on the Curvilinear-Grid Hydrodynamics in 3D (Sheng 1986).

The EFDC model solves the three-dimensional, vertically hydrostatic, free surface, turbulent averaged equations of motion for a variable density fluid. It uses a sigma vertical coordinate and Cartesian or orthogonal horizontal coordinates. Dynamically-coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity, and temperature are also solved. The model incorporates a second-order turbulence closure sub-model that provides eddy viscosity and diffusivity for the vertical mixing (Mellor and Yamada 1982).

Huang and Liu (2007) constructed the EFDC model for the Little Manatee River estuary to investigate the relationship between freshwater inflows and salinity distributions, simulate salinity transport processes, and estimate residence times as a function of freshwater inflow. Their EFDC model was used by JEI to develop and update the recommended minimum flows for the Lower Little Manatee River included in the September 2021 draft report. As a result of peer review panel comments resulting from the review of the September 2021 draft report (Appendix F and G), JEI (2023 in Appendix O) further improved the EFDC model for the Little Manatee River estuary by extending the downstream open boundary from the river mouth out into mid-Tampa Bay and using updated bathymetric and topographic data for the model grid generation, which substantially improved spatial resolution of the grid. The upstream boundary of the simulation domain of the new and improved model remained at the US Highway 301 bridge. Boundary conditions at the downstream open boundaries were obtained from simulated results of another hydrodynamic model that was previously developed for the entire Tampa Bay estuary, as a part of the Old Tampa Bay Integrated Model System project (Sherwood et al. 2016).

The new and improved EFDC model was calibrated and verified against field data measured in the Lower Little Manatee River before it was used to support development of proposed minimum flows. Two independent datasets were required for both model calibration and verification. The datasets consisted of continuous data of all external boundary conditions and observations at selected stations in the river for model calibration and verification for the same model simulation period.

For development of the Huang and Liu (2007) version of the EFDC model, the USGS collected water level, salinity, and temperature data recorded at a time interval of 15 minutes at four stations in the Lower Little Manatee River (Figure 2-3) from March 2004 through March 2006. From the most downstream site to the most upstream site, the four USGS sites were the Little Manatee River at Shell Point near Ruskin, FL (No. 02300554), Little Manatee River at Ruskin, FL (No. 02300546), Little Manatee River at I-75 near Ruskin, FL (No. 02300542), and Little Manatee River near Ruskin, FL (No. 02300532) gages, which were, respectively, 0.5, 5.2, 7.5, and 10.7 miles (0.8, 8.3, 12.1, and 17.2 km) upstream of the river mouth. Water level data was collected at all sites. Surface and bottom specific conductance and temperature were collected at the three most downstream sites. Note that during the EFDC model update, we investigated whether additional data were available for model calibration and verification; since no additional data were available, we used this dataset to calibrate and verify the model.

Hydrological loading to the estuary includes gaged and ungaged flows. The most downstream gage for the freshwater inflow to the Lower Little Manatee River is the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage, which is located 15 miles (24 km) above the mouth of the river at the US Highway 301 bridge. Ungaged freshwater flows from the watershed downstream of this gage were estimated using the Hydrological Simulation Program – Fortran (HSPF) surface water model by Intera and Aqua Terra Consultants (2006 in Appendix P). The HSPF model simulations used inputs of rainfall and other hydrologic information such as land use, evapotranspiration, and infiltration to estimate the runoff from the ungaged subbasins. Gaged and ungaged subbasins in the Little Manatee River watershed are detailed in Hood et al. (2011 in Appendix A). In the model simulations, gaged flows were used as the upstream boundary condition, while ungaged flows from different subbasins were added to their corresponding river segments. Details regarding where measured (gaged) and modeled (ungaged) flows enter the tidal river in the hydrodynamic model can be found in JEI (2023 in Appendix O) along with the other data used as input and for calibration and verification of the Lower Little Manatee River EFDC model.

Continuous data for the six-month period, January 1 to June 30, 2005, were identified for model calibration and verification. The first two months (January 1 to February 28, 2005) of data were used for model calibration, while the other four months (March 1 to June 30, 2005) were for model verification.

In applying the EFDC hydrodynamic model to the Lower Little Manatee River, the estuary was discretized with an orthogonal grid system in the horizontal plane, as shown in Figure 5-16. Horizontal grid sizes range from as small as ~6 m within the upper reaches of the river to as large as to 450 m in offshore Tampa Bay grid cells. The vertical dimension (water depth) is divided into four uniform sigma layers (meaning each vertical layer is one-quarter of the water column depth), with this vertical structure adopted to resolve vertical mixing in this shallow water system, where most of the river is shallower than 1.5 m relative to the NAVD88 vertical datum.

Model coefficients, such as bottom frictions and diffusions, were adjusted until satisfactory model predictions were achieved during the calibration period, from January 1 to February 28, 2005. The calibrated EFDC model was then used to run for four more months, from March 1 to June 30, 2005, to produce simulated water levels, salinities, and temperatures, which were compared to measured real-time data to verify the performance of the model. Details about the model calibration and verification processes for the Lower Little Manatee River EFDC model are documented in JEI (2023 in Appendix O).

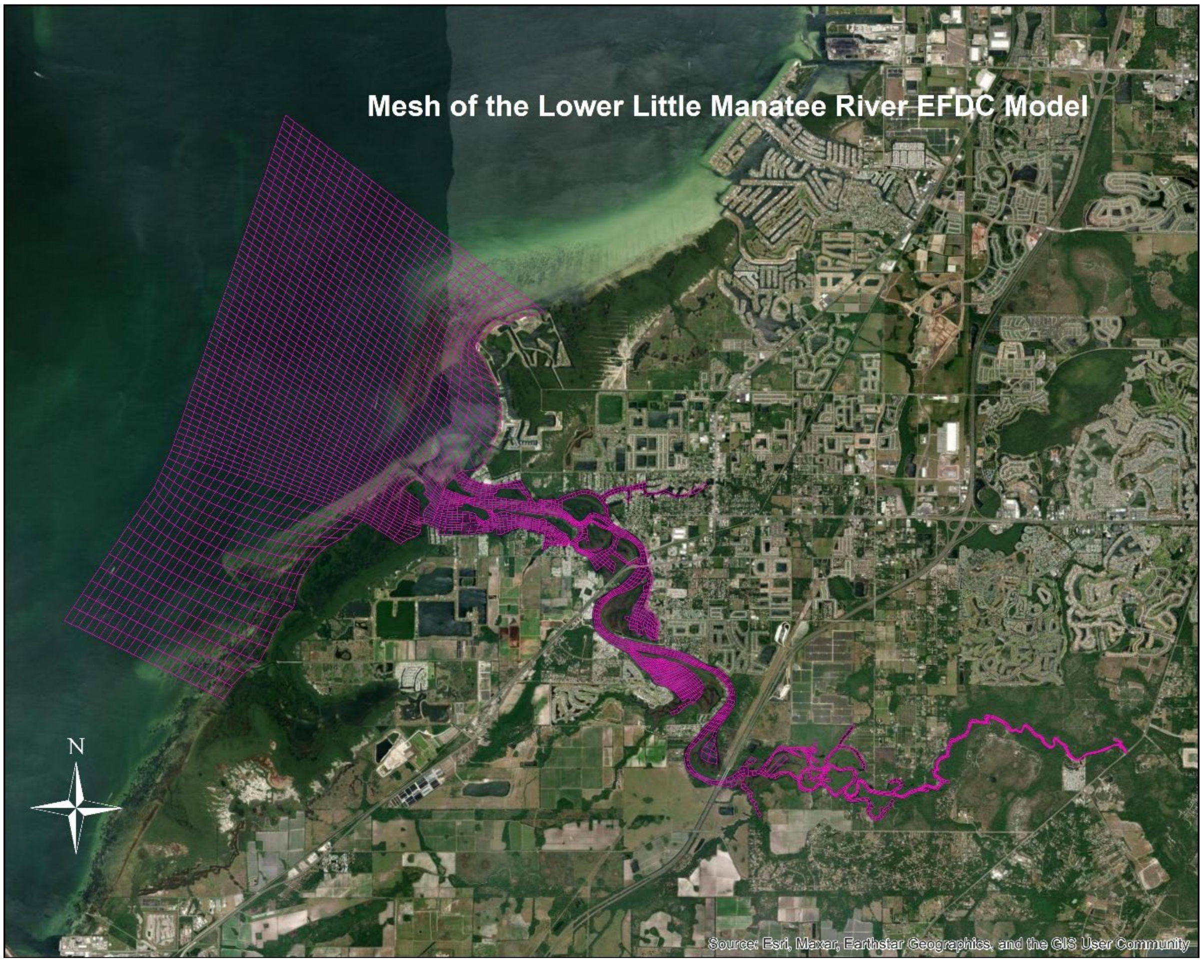


Figure 5-16. The orthogonal grid system (horizontal view) for the EFDC model of the Lower Little Manatee River estuary.

Statistics used to assess performance of the Lower Little Manatee River estuary EFDC model included:

- Coefficient of Determination (R^2),
- Root Mean Square Error (RMSE),
- Mean Error (ME),
- Absolute Mean Error (AME), and
- Skill Statistic.

The Skill Statistic is defined as follows:

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

Where:

- y^M is simulated value (for water surface elevation, salinity, or temperature),

- y^D is the observed value, and
- $\overline{y^D}$ is the mean of the measured values over the time period.

Perfect agreement between simulated and observed data would result in a Skill of 1, with the value declining to zero as agreement declines.

For the model calibration period (January 1 to February 28, 2005), the range and overall statistics from the comparison of simulated and observed water surface elevation, salinity, and temperature are provided in Table 5-6 for the three downstream-most river sites: USGS Little Manatee River at Shell Point near Ruskin, FL (No. 02300554) near the mouth of the river, at USGS Little Manatee River at Ruskin, FL (No. 02300546), and at USGS Little Manatee River at I-75 near Ruskin, FL (No. 02300542). The site near Ruskin (No. 02300532) is included in the summary for water surface elevation comparison only, as this is the only data type available at this upstream-most site. Table 5-7 provides the same set of measures for the verification period, March 1 to June 30, 2005. More details about model calibration and verification for the Lower Little Manatee River EFDC model are reported in JEI (2023 in Appendix O).

Table 5-6. Calibration statistics range and overall, for the Lower Little Manatee River EFDC model.

Parameter	Skill	R^2	RMSE (cm)	ME (cm)	AME (cm)
Elevation (Range)	0.96 - 0.99	0.87 - 0.96	5 - 8	-2 - 6	4-7
Overall Elevation	0.98	0.91	8	2	5
Parameter	**Skill**	**R^2**	**RMSE (psu)**	**ME (psu)**	**AME (psu)**
Salinity (Range)	0.77 -0.90	0.46 – 0.80	2.4 - 4.1	-2.7 – 1.9	1.7 – 3.2
Overall Salinity	0.96	0.89	3.6	-0.9	2.5
Parameter	**Skill**	**R^2**	**RMSE (deg C)**	**ME (deg C)**	**AME (deg C)**
Temperature (Range)	0.82 – 0.93	0.75 – 0.85	1.2 – 2.1	-1.7 - -0.8	1.1 – 1.8
Overall Temperature	0.88	0.77	1.7	-1.1	1.4

Table 5-7. Verification statistics range and overall for the Lower Little Manatee River EFDC model.

Parameter	Skill	R^2	RMSE (cm)	ME (cm)	AME (cm)
Elevation Range	0.97 - 0.99	0.90 - 0.97	4 - 8	-4 – 5	3-6
Overall Elevation	0.98	0.92	7	1	5
Parameter	**Skill**	**R^2**	**RMSE (psu)**	**ME (psu)**	**AME (psu)**
Salinity (Range)	0.79 -0.93	0.48 – 0.85	1.3 - 5.0	-1.9 – 2.5	0.7 – 3.3
Overall Salinity	0.97	0.91	3.2	-0.2	2.0
Parameter	**Skill**	**R^2**	**RMSE (deg C)**	**ME (deg C)**	**AME (deg C)**
Temperature (Range)	0.90 – 0.98	0.85 – 0.97	1.1 – 1.9	-1.6 - -0.7	0.9 – 1.7
Overall Temperature	0.94	0.90	1.6	-1.1	1.4

Figure 5-17 shows mean monthly simulated water column average salinity distributions during periods when high salinity reached relatively far upstream in February 2005 (top panel) and when low salinity reached relatively far downstream in March 2005 (bottom panel). During February 2005, the mean gaged flow at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage was 59 cfs, whereas the mean flow at the site during March 2005 was 295 cfs. The much greater flows during March resulted in the location of the monthly mean ≤2 psu isohaline extending downstream from near RKm 11 in February to around RKm 8 in March.

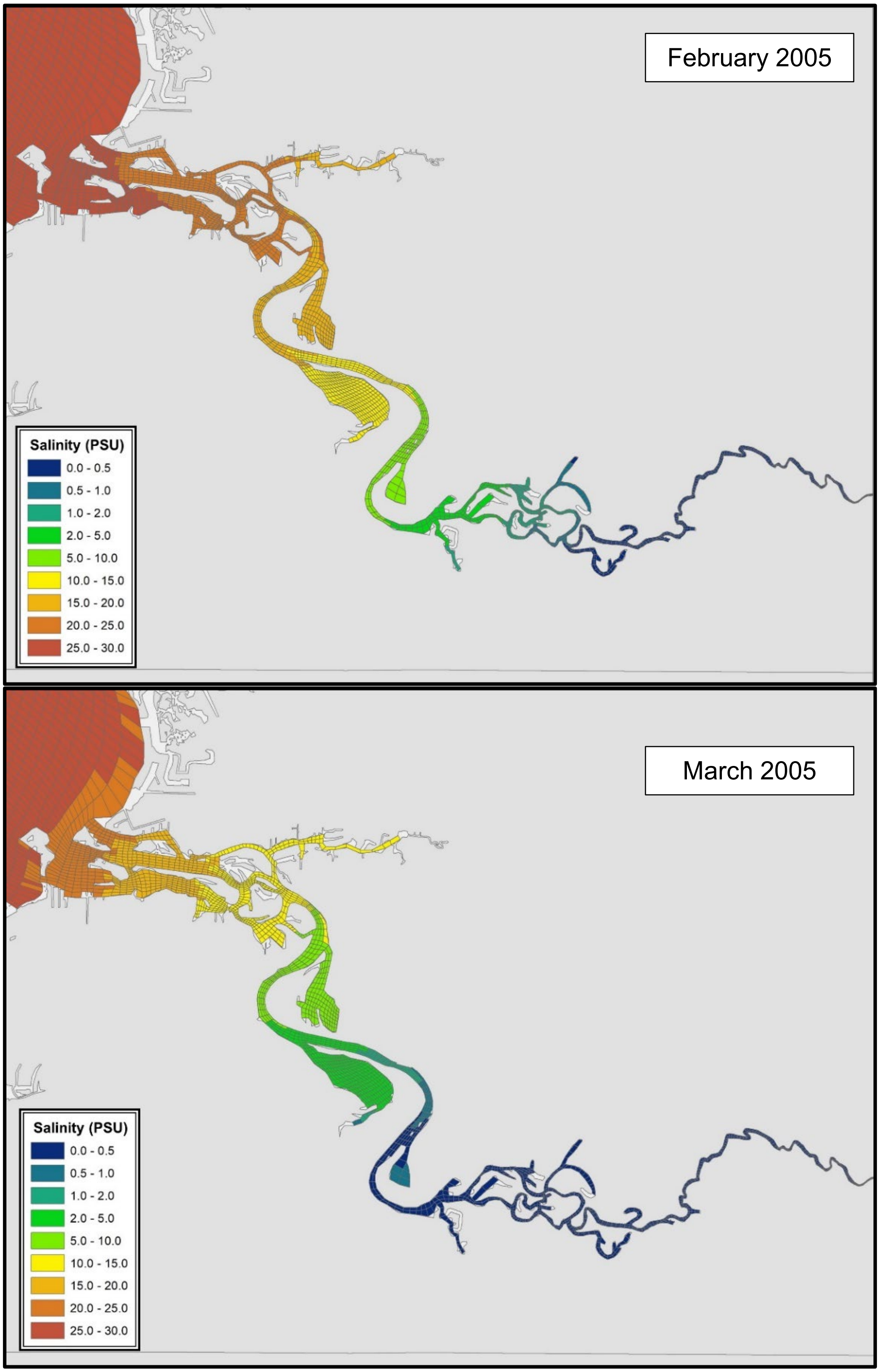


Figure 5-17. Monthly mean water column salinity for Lower Little Manatee River for February (top panel) and March (bottom panel) 2005, illustrating the occurrence of higher salinities relatively further upstream in February and lower salinities extending further downstream in March.

5.4.6 Lower River Estuarine Fish Habitat

The EFF analysis is based on logistic regression and was implemented using the Logistic Procedure in SAS (SAS Institute, Inc. 2014). The probability of occurrence ($P(y=1|x)$) of a particular species collected in a shore seine was estimated as a function of environmental variables, including season, site-specific salinity recorded at the time of capture, and shoreline habitat classifications where a seine was used to sample fish (Figure 5-18). A quadratic salinity term was evaluated within the model to capture salinity preferences that may be optimal within the middle range of the entire salinity distribution and shore-type/season interactions were explored. Models were reduced for parsimony to only those environmental variables statistically significant at alpha = 0.10. A screening-level analysis was performed on all species with capture frequency greater than 5 percent and only those taxa with a statistically significant and negative relationship (i.e., negative linear coefficient) with salinity were retained for further analysis.

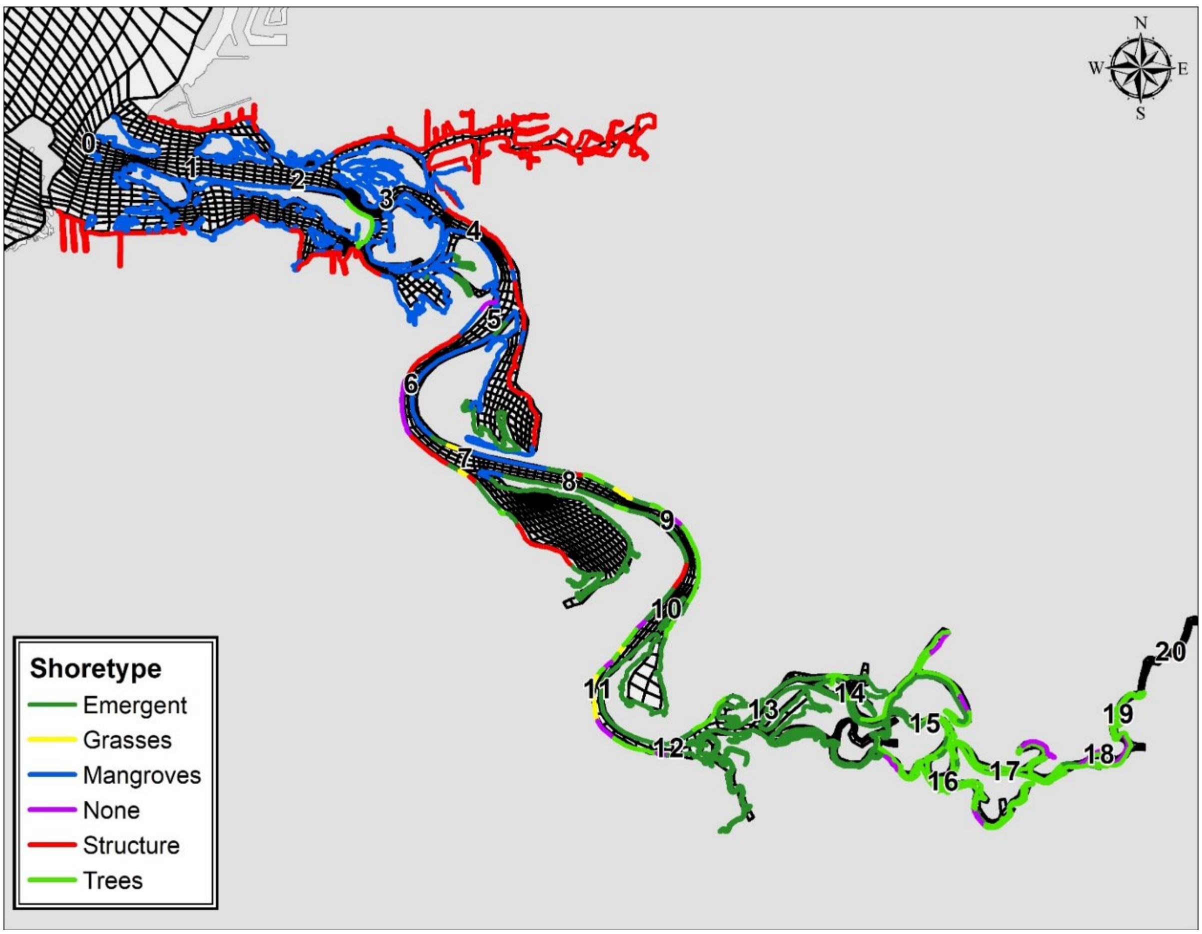


Figure 5-18. The Lower Little Manatee River EFDC model grid, shoreline, and dominant shore-type categories used in the EFF approach for assessing fish habitat favorability.

The general logistic regression equation is:

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

Where:

$\hat{y}$ = logit estimate (log odds)

Ln = Natural log

P = Probability of occurrence

α = Intercept

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

X_1 = Salinity (ppt)

X_j = Season

X_k = Shore habitat

X_{jk} = Shore* Season interaction

Logistic regression is an optimal tool for estimating the probability of occurrence when, at one end of some environmental gradient, such as salinity, the outcome (i.e., taxa presence) is very likely to occur and at the other end of the gradient, the outcome almost never occurs. However, in many cases, the prevalence of a taxon does not approach 100% at either end of the environmental gradient, and therefore, the predicted probabilities do not either. In these cases, classification success is affected by the relative proportions of presence and absences (Hosmer and Lemeshow 2000), as well as the "cutpoint" value chosen to identify a predicted probability as a predicted presence of the taxon (Liu et al. 2005).

Real et al. (2006) proposed a post-hoc modification of the output of logistic regression to compensate for the differences in species prevalence by adjusting the intercept term by the log odds of the empirical occurrence of the species being modeled. The adjustment was defined as:

$$\hat{y}' = \hat{y} - \mathrm{Ln}\left[\frac{n1}{n0}\right]$$

Where:

$n1$ = # of presences

$n0$ = # of absences

Ln = natural log transformation

$\hat{y}$ = predicted value

$\hat{y}'$ = EFF predicted value

Exponentiation of the logit of the favorability, ŷ', yields the "EFF" described by Real et al. (2006). Since the EFF centers the outcomes to their average predicted probability of occurrence, a cut-point probability value of 0.5 was used to assign "favorable" (i.e., values greater than the overall average) and "unfavorable" (values less than or equal to the overall average) predictions for each species. Since categorical effects were present in the model, the predicted conditional means were used in place of the grand mean to adjust the logits to a favorability score.

To estimate the effects of flow reductions, a salinity prediction was generated for each date and each 0.1 river kilometer increment in the LOESS regression model time series (1996-2021) for each flow reduction scenario and combined with the total shoreline length of each shore-type category in that increment. This dataset was then used as input to the EFF modeling framework to estimate the daily total amount of shoreline classified as favorable by the model. The LOESS regression methods are described in the paragraphs below.

As described in the September 2021 draft report and in JEI (2018b in Appendix E), empirical salinity prediction models were developed to extend the period of daily salinity predictions beyond the 2000-2005 period evaluated by the EFDC model 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 the FWC FIM program data collection. Several forms of regression models were evaluated, including Ordinary Least Squares (OLS), Local (LOESS), Thin Plate Spline, and Multivariate Adaptive regression techniques (SAS Institute, Inc. 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 psu) and under-prediction more prevalent at higher salinities (i.e., >20 psu) relative to historical OLS regressions previously reported.

A comparison suggested that the LOESS regression methods resulted in a better statistical fit over the entire salinity distribution relative to either the OLS or the other nonparametric methods. The LOESS regression used iteratively reweighted least squares and a low-order polynomial to avoid over-fitting of the data and reduce the influence of outliers (SAS Institute, Inc. 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, Inc. 2014). Final model predictors included natural log transformed daily flow, the 3-day-lag average flow, river kilometer (units = 0.1 Rkm increment), a flow-river kilometer interaction term, and month. A comparison of the OLS and LOESS model fits is provided in Figure 5-19 below.

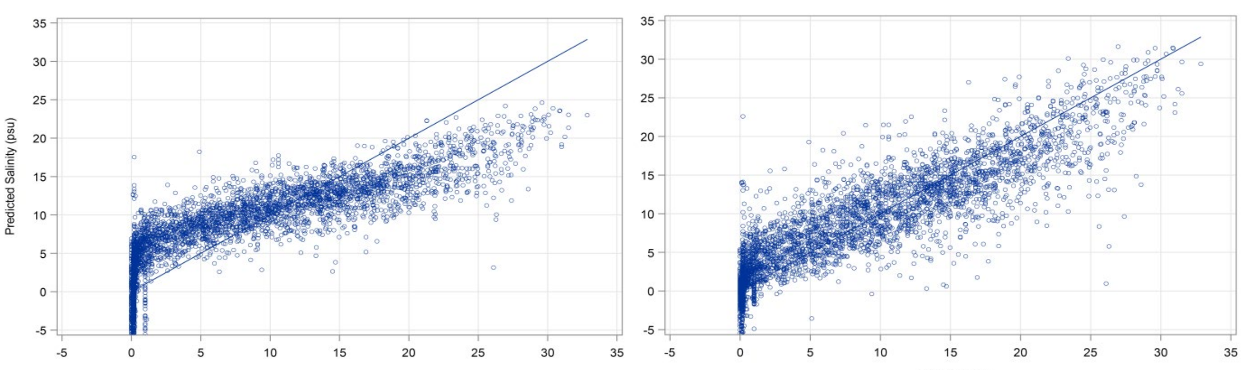


Figure 5-19. Predicted and observed plots for OLS regression (left) and LOESS regression (right) (from JEI 2018b in Appendix E).

The LOESS model was updated in 2020 for the analysis included in the September 2021 draft report and then updated again using data through 2021 for this revised draft report, such that the salinity model currently included a period of record of observed data between 1973 and 2021. The smoothing factor identified in the 2018 analysis (0.156) was retained for the model updates since the AICC fitting algorithm is highly computationally intensive resulting in extremely slow processing times for the management scenario runs. The sampling frequency distribution throughout the lower river used to develop the final LOESS salinity model is provided in Figure 5-20.

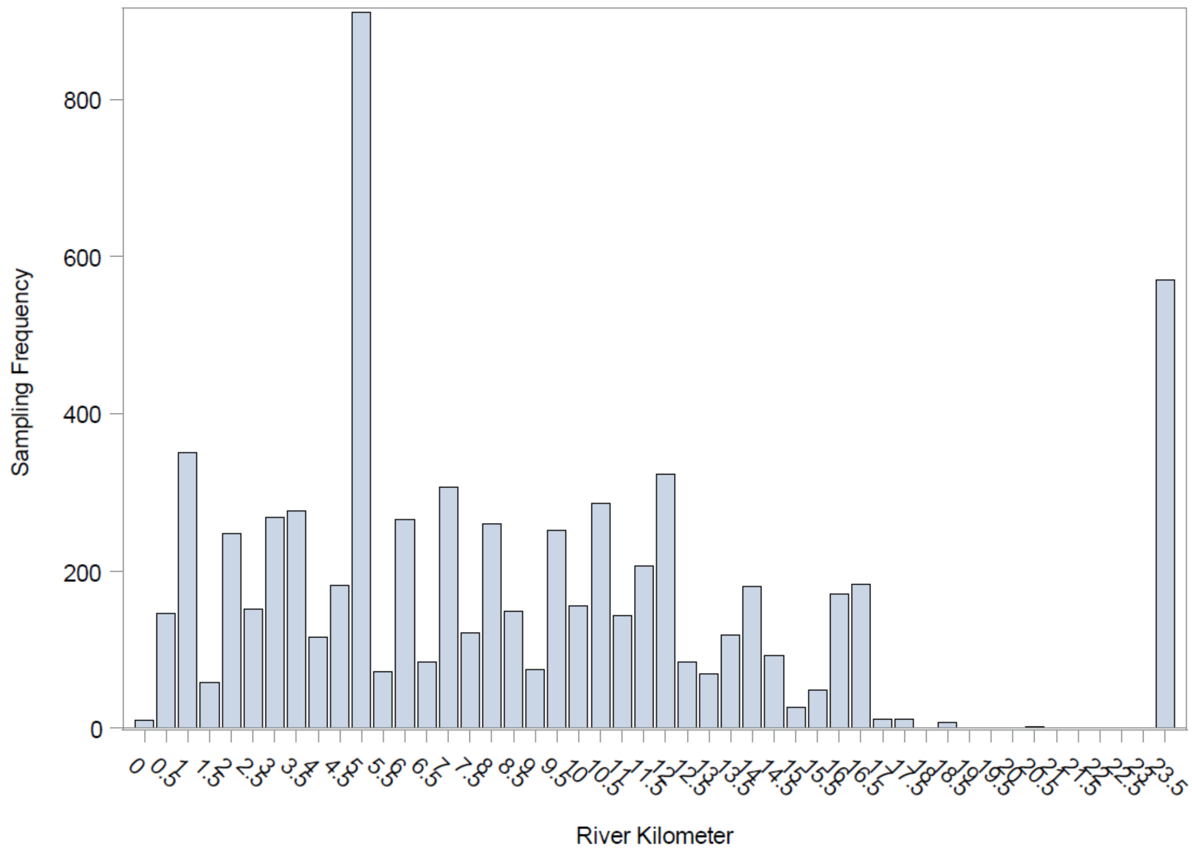
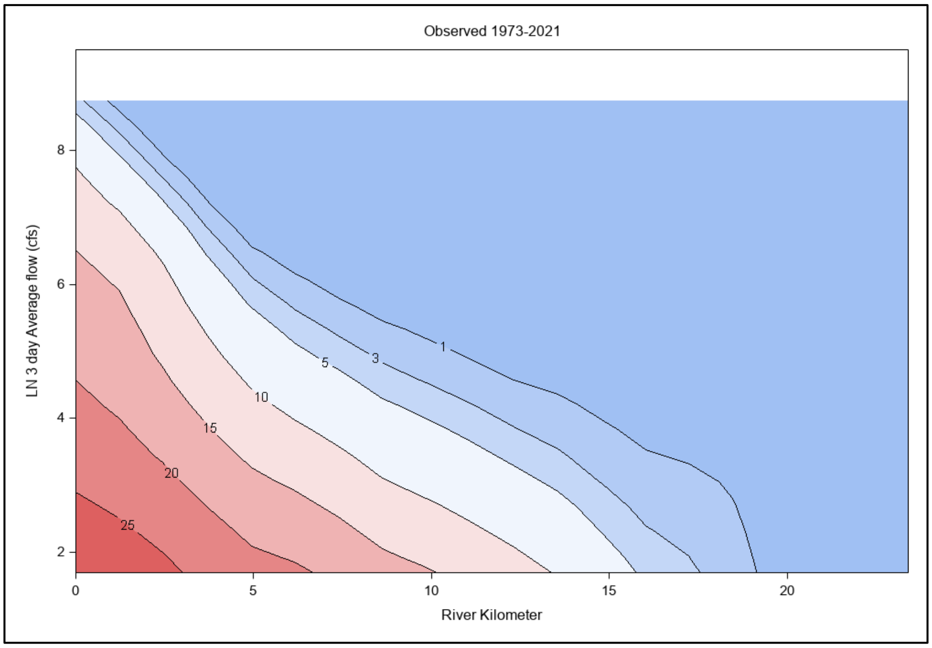


Figure 5-20. Sampling frequency distribution of water column average salinity measurements throughout the Lower Little Manatee River used in the LOESS regression modeling.

The final fit statistics for the model retain the good fit to the data described in JEI (2018b in Appendix E) and are summarized in Table 5-8. A contour plot of the observed and predicted data, displaying the average expected value as a function of river kilometer and 3-day lag average flow (natural log transformed) is provided in Figure 5-21. The projections are very similar for all isohalines above 5 psu. For isohalines of 5 psu or less, the model predicts higher salinities further upstream in the river than the simple contour of the observed salinity data. However, this is not necessarily due to prediction bias of the LOESS model. As shown in Figure 5-20 and described in JEI (2018b in Appendix E), there is a paucity of data between RKm 17 and RKm 23.5 (the US Highway 301 bridge). This artifact of the data availability may result in inadequate averaging of the observations and interpolation between those observations for the salinity contour plot. The model predictions interpolate between those locally weighted means near RKm 17 and 23, while the observed contours do not. It should be noted as described in JEI (2018b in Appendix E) that salinities were nearly exclusively near zero at the US Highway 301 bridge.

Table 5-8. Fit statistics for final LOESS regression model for predicting salinity in the Lower Little Manatee River (from JEI 2018b in Appendix E).

Model R Square	Intercept	Slope	Root Mean Square Error	Mean Error	Absolute Mean Error	Relative Error
0.840	1.904	0.837	3.254	-0.368	2.679	-0.0105



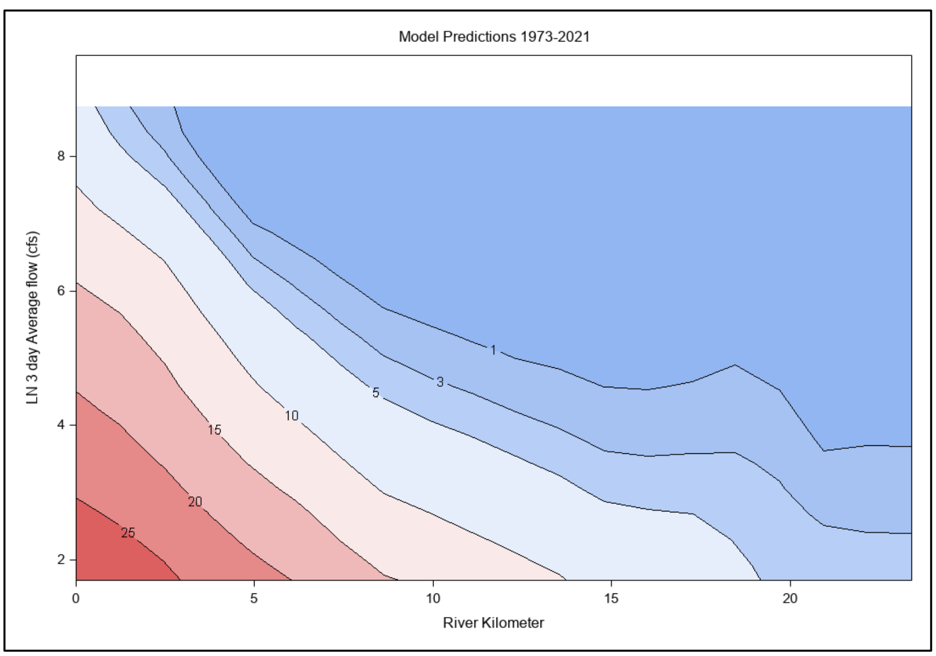


Figure 5-21. Contour plots of observed (top) and LOESS regression model predicted salinities (bottom) between 1983 and 2021.

As described in Section 5.3.5, an earlier version of the EFF analysis to evaluate the effects of reduced flows on favorable estuarine fish habitat was included in the September 2021 draft report. Based on peer review panel and FWC comments, the analysis was revisited, and additional work was conducted based on meetings and consultation with FWC to see if the analysis could be improved. Improvements included:

- A new EFDC model grid was developed, which allowed for the use of a shoreline file for the Lower Little Manatee River. This shoreline file was then used to classify shore type based on the FIM program data collection, District land-use classifications, and confirmation using satellite imagery (Figure 5-18). The shoreline and associated shore-type designations allowed for the evaluation of changes in total shoreline length, which is a more representative parameter to evaluate than total area or volume since the FIM data is collected by seines along the shoreline.

- Several recreationally and economically important species, including Red Drum, Blue Crab, Pink Shrimp, Sheepshead (*Archosargus probatocephalus*), and Mangrove Snapper (*Lutjanus griseus*), were re-evaluated. The re-evaluation included partitioning the data into size classes representative of different life history stages of these species.

- The EFF adjustment was modified to use the conditional modeled means of the categorical variables as the basis for adjustment to ensure that the cutpoint for assigning favorability was exactly 0.5 in all cases.

- The computational efficiency of the computer code was improved to allow for the evaluation of the entire period of record of available FIM program data within a single computational "run." Note that the period of record of FIM program data that were used for the analysis was from 1996-2020; the 2021 data were excluded because of a red tide event.

CHAPTER 6 – RESULTS OF THE MINIMUM FLOWS ANALYSES FOR THE LITTLE MANATEE RIVER

The results used to evaluate resources of concern for the development of recommended minimum flows for the Upper and Lower Little Manatee River are described in this chapter.

6.1 Little Manatee River Low-Flow Threshold

Results of wetted perimeter and fish passage analyses were used to develop a recommended low-flow threshold for the Little Manatee River. Since this river system is well-confined from the SA to the underlying UFA where nearly all groundwater use occurs and is, therefore, only subject to impacts from surface water withdrawals, the low-flow threshold was applied to the recommended minimum flows for Block 1 for both the upper and lower river.

6.1.1 Upper River Wetted Perimeter Analysis

The ZFI (2010 in Appendix N) HEC-RAS model was used to identify a potential minimum low-flow threshold protective of benthic habitat by identifying a LWPIP for model cross sections as described in Sections 5.3.1 and 5.4.2.1. Flow required at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage to inundate the LWPIP at 217 HEC-RAS cross sections in the Little Manatee River is provided in Figure 6-1. The majority of cross sections exhibited no LWPIP or LWPIPs associated with flows above 50 cfs at the gage and for these cross sections, the LWPIP was established at the lowest modeled flow of 5.9 cfs.

At one cross section in Reach 7, the LWPIP occurs at 7.6 cfs; at one transect in Reach 5, the LWPIP occurs at 14 cfs; and at one transect in Reach 4, the LWPIP occurs at 22 cfs. Hence, a flow of 22 cfs at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage was used to define the LWPIP for the river.

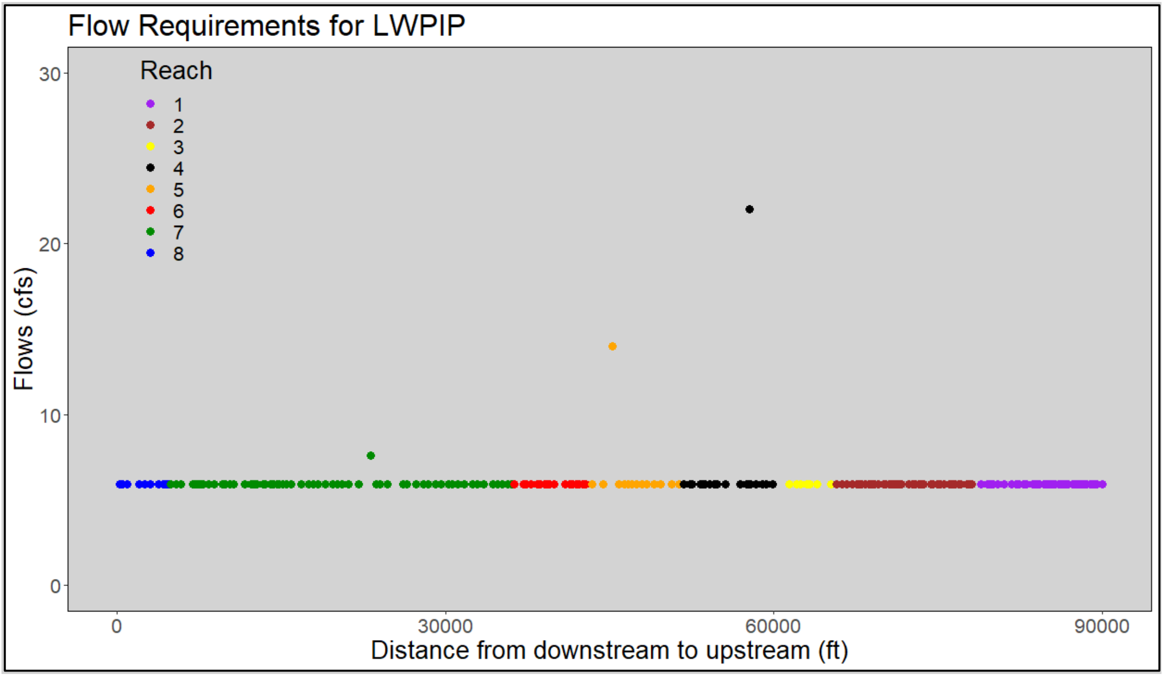


Figure 6-1. Flow at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage required to inundate the lowest wetted perimeter inflection points (LWPIP) in the 2010 HEC-RAS model Upper Little Manatee River reaches (color coded).

6.1.2 Upper River Fish Passage

To assess the water surface elevation requirements for fish passage, the lowest flow percentile that resulted in 0.6 feet (0.18 m) of hydrologic depth at each model cross section in the 2010 HEC-RAS model was identified. The results representing reach-specific flow values associated with maintaining the depth requirement for fish passage for each cross section are presented in Figure 6-2. Similar to the wetted perimeter analysis, the reach-specific required flow are translated at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage.

To maintain fish passage depth at the most restrictive cross section, a flow of 29 cfs is required at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage. Therefore, 29 cfs was used to define the fish passage criteria for the river.

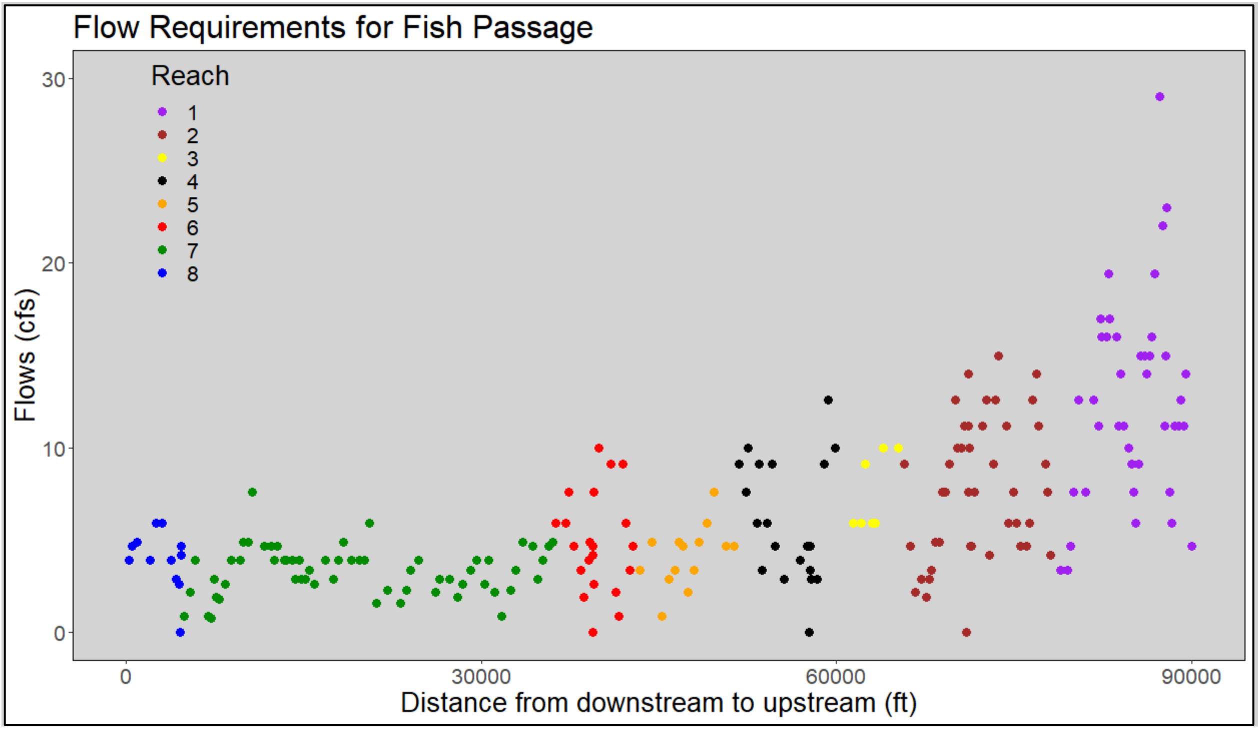


Figure 6-2. Flow required at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage to inundate the deepest part of the channel to a depth of 0.6 ft (0.18 M) in 2010 HEC-RAS model for the Upper Little Manatee River reaches (color coded).

6.1.3 Recommended Low-Flow Threshold

A low-flow threshold of 29 cfs was identified for the Upper Little Manatee River at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage site. The low-flow threshold was established at the higher of the fish passage and wetted perimeter criteria and is, therefore, expected to provide protection for ecological and cultural values associated with both. Although flow in the river at the gage site may be expected to drop below the low-flow threshold naturally, the threshold is intended to serve as a limit to surface withdrawals throughout the year, with no withdrawals permitted from the river unless the threshold flows are exceeded.

6.2 Upper River Floodplain Inundation Results

The floodplain wetland inundation analysis was based on the relationship between flow percentiles at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage site and inundated floodplain wetlands throughout the upper river (Figure 6-3) developed using the 2018 HEC-RAS model, as described in Section 5.4.3. Iterative analyses of daily inundated floodplain wetlands area for the 1939 through 2021 baseline flow time series and inundated floodplain wetlands area for reduced baseline flow conditions were conducted to determine flow reduction that could occur without exceeding a 15 percent decrease in the mean inundated area for the 1939 through 2021 period associated with the baseline flows.

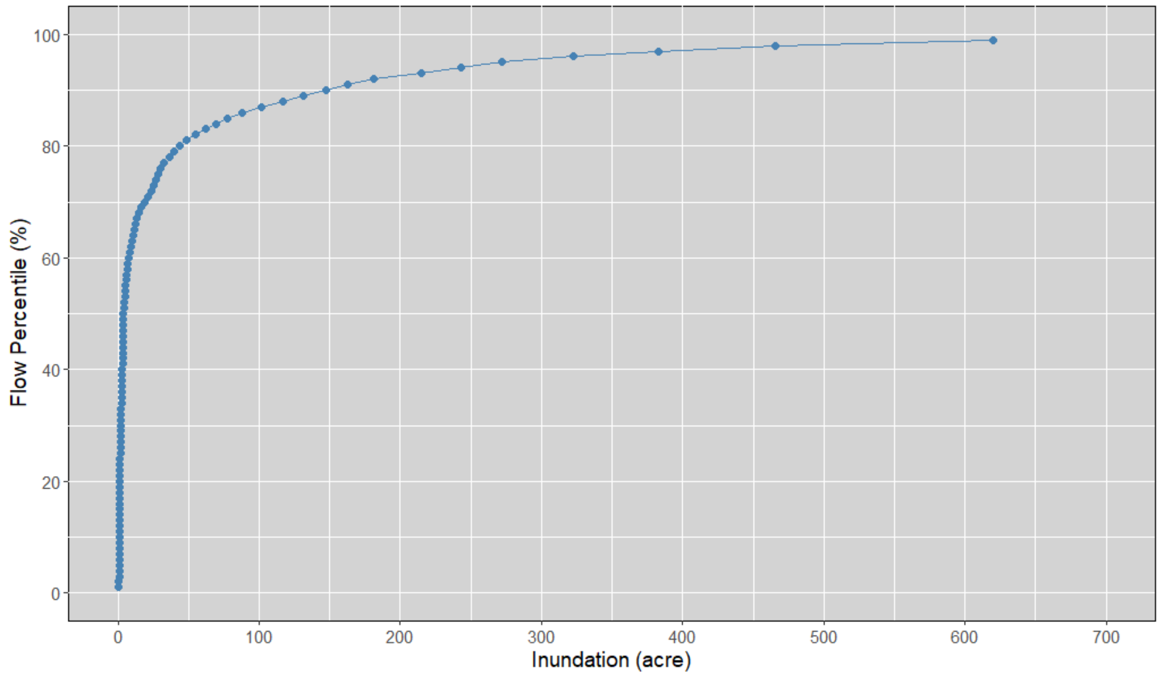


Figure 6-3. Inundated floodplain area associated with the upper river versus flow at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage site.

Based on historic flow records, inundation of floodplain habitats in the Upper Little Manatee River is primarily expected during Block 3 when flows exceed the capacity of the river channel and spill over the riverbanks onto adjacent floodplains. However, some floodplain areas may be inundated when the flows in the river are low. This can occur when rainfall or water from previous high-flow conditions becomes trapped in low-lying floodplain areas or depressions that, based on river stage, may temporarily not be connected to the river channel as exemplified by the river cross section shown in Figure 6-4.

Identification of isolated, inundated floodplain areas may be important for characterization of flow-related floodplain inundation patterns. However, determinations regarding whether inundated floodplain areas isolated from the river channel occur as a result of “trapped” rainfall or represent previous overbank flow conditions can be difficult. In addition, the occurrence of isolated inundated areas at individual model cross sections can be confounded by channel-floodplain surface water connections between cross sections.

Given these difficulties, a sensitivity analysis to efficiently identify flow-related thresholds that correspond with decreases in inundated floodplain wetland area in the upper river was performed. For the analysis, percent-of-flow reductions that would result in a 15 percent decrease in the total inundated wetland areas were assessed for flows at and above 1st percentile, 2nd percentile, . . . up to 99th percentile (Figure 6-5).

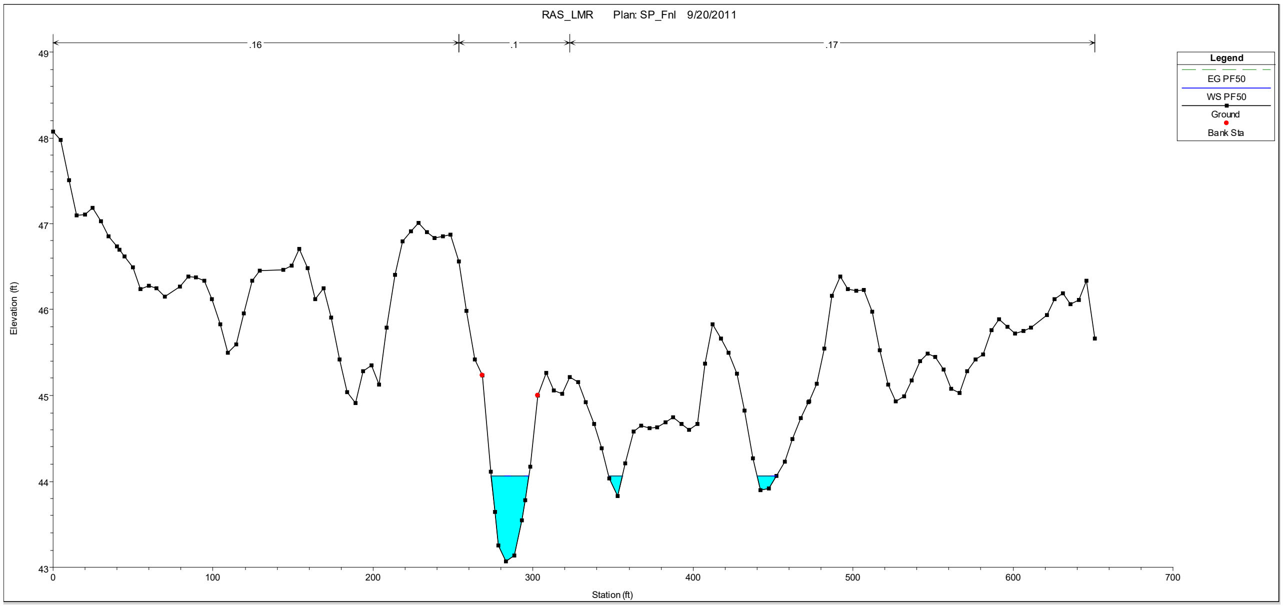


Figure 6-4. An example of a HEC-RAS model cross section where some depressions remain inundated when the flow in the river is low and not connected to adjacent floodplains.

Three relationships of sensitivity between the percent-of-flow reductions that would result in a 15 percent decrease in the amount of total inundated wetlands and river flows were identified. As shown in Figure 6-5, the slope of the relationship changes from relatively no gradient to a gentle downward trend, and finally to steep downward trend over the full range of river flows. Flow thresholds at which these slope changes occur were numerically approximated by iteratively fitting three straight lines to the dataset and identifying a maximum combined coefficient of determination (R^2) for the three lines. This combined R^2 value was derived as the average of the R^2 values for the three individual lines and does not have any statistical meaning. It was simply used as an index for dividing the dataset into three parts based on slope changes.

The maximum combined R^2 was obtained by separating the data at 68th and 84th flow percentiles (Table 6-1). For flows between the 1st to 68th percentile, the 15 percent decrease in the total inundated wetlands exhibited no sensitivity to flow reductions. This suggests that overbank flooding does not start until the flow is above the 68th percentile, which is approximately 96 cfs at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage. This 96 cfs flow threshold was, therefore, used to define the threshold between the medium-flow, Block 2 and the high-flow, Block 3. Water starts to overflow from the channel onto the adjacent floodplain in Block 3, and the area of inundation becomes more sensitive to reductions of higher flows (Tables 6-2 and 6-3). Based on this inundation response to flow and because flooding pulses play an important role in connecting the river laterally with its floodplain and sustaining related ecological functions, Block 3 was divided into two subblocks (Block 3a for low floodplain and Block 3b for high floodplain) at the 84th flow percentile (224 cfs at the gage).

For flows between the 68th and 84th flow percentiles (low floodplain), percent-of-flow reductions between 13.8 and 12.4 percent (average = 13 percent) would result in 15 percent or less reduction in the total inundated wetlands in the Upper Little Manatee River (Table 6-2). For flows above the 84th percentile (high floodplain), percent-of-flow reductions between 12.4 and 6.6 percent (average

= 10 percent) would result in 15 percent or less reduction in the amount of total inundated wetlands (Table 6-3).

Based on the respective averages of 13 and 10 percent allowable flow reductions for the two high-flow ranges identified for Block 3, minimum flows for the Upper Little Manatee River of 87 percent of the baseline flow for flows greater than 96 cfs and less than or equal to 224 cfs at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage for the low floodplain (Block 3a) (Table 6-2) and 90 percent of the baseline flows for flows greater than 224 cfs at the gage for the high floodplain (Block 3b) are recommended (Table 6-3).

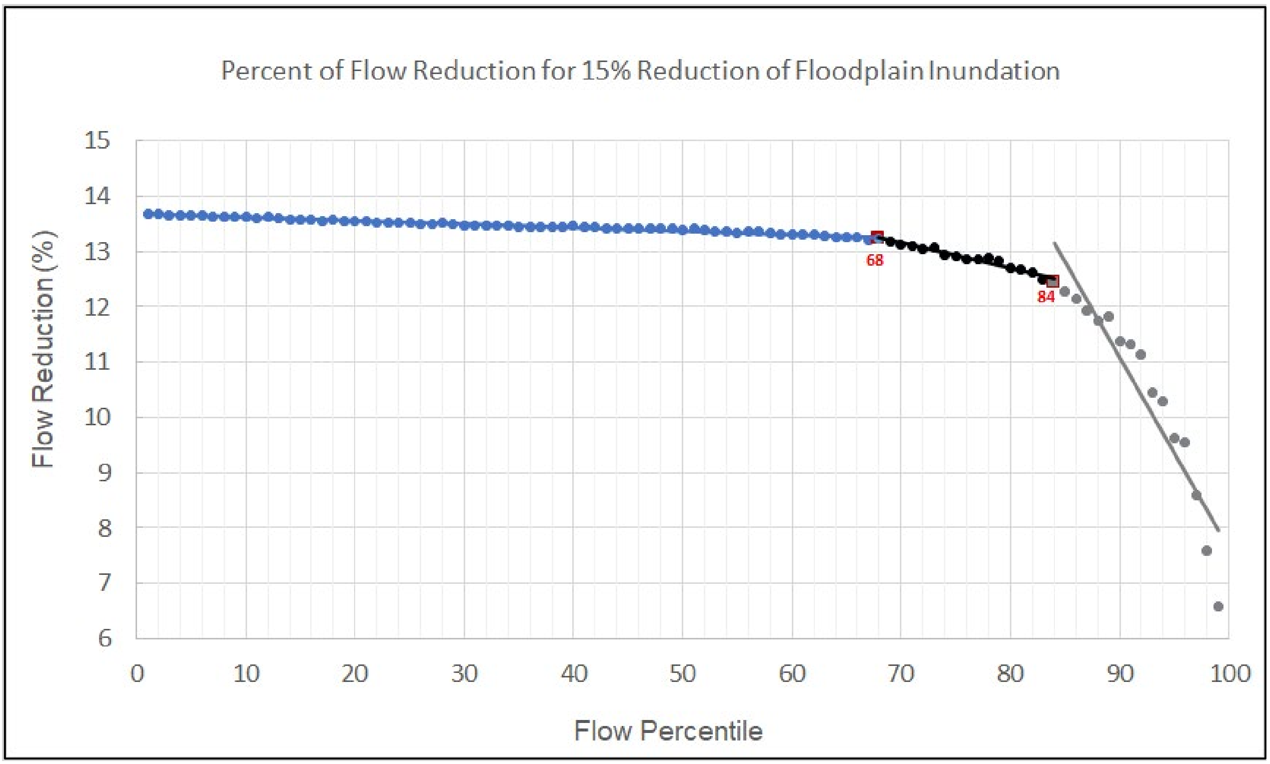


Figure 6-5. The sensitivity between the percent-of-flow reductions that would result in a 15 percent decrease in the amount of total inundated wetlands and river flow percentiles.

Table 6-1. An arithmetic mean of combined coefficient of determination (R^2) for three straight lines indicating the maximum R^2 value at 68th and 84th flow percentiles used to describe thresholds between Block 2 and Blocks 3 and within Block 3.

Arithmetic mean of the three R^2										
		B2/B3								
		67th	68th	69th	70th	71st	72nd	73rd	74th	75th
B3a/B3b	80th	0.930	0.929	0.924	0.916	0.905	0.891	0.875	0.853	0.813
	81st	0.936	0.935	0.931	0.925	0.916	0.905	0.894	0.879	0.855
	82nd	0.940	0.940	0.936	0.931	0.924	0.915	0.908	0.895	0.879
	83rd	0.940	0.940	0.936	0.931	0.925	0.917	0.912	0.896	0.884
	84th	0.942	0.942	0.939	0.934	0.929	0.923	0.919	0.905	0.896
	85th	0.940	0.940	0.937	0.933	0.927	0.922	0.919	0.905	0.898
	86th	0.936	0.937	0.934	0.930	0.925	0.920	0.918	0.905	0.899
	87th	0.931	0.932	0.929	0.926	0.921	0.917	0.915	0.903	0.898
	88th	0.929	0.930	0.927	0.924	0.920	0.916	0.915	0.905	0.901
	89th	0.938	0.939	0.937	0.934	0.931	0.927	0.927	0.917	0.913
	90th	0.931	0.932	0.931	0.929	0.926	0.922	0.922	0.913	0.909

Table 6-2. Key results of the Upper Little Manatee River floodplain analysis for Block 3 between 96 and 224 cfs (i.e., the 68th and 84th percent flow percentiles). Percent-of-flow reductions that result in a 15 percent decrease in the amount of total inundated wetlands based on flows at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage from 1939 through 2021.

Allowable flow reductions result in a 15 percent decrease in the amount of total inundated wetlands for Block 3, flows between 96 and 224 cfs			
Flow Percentile	**Flow (cfs)**	**Inundation Area (acre)**	**Allowable flow reductions (percent)**
68th	96.15	15.00	13.2
69th	100.80	16.68	13.2
70th	105.45	18.50	13.1
71st	110.34	21.10	13.1
72nd	115.00	23.60	13.1
73rd	120.26	25.21	13.1
74th	127.00	26.98	12.9
75th	133.00	28.52	12.9
76th	140.00	30.36	12.9
77th	146.93	32.78	12.9
78th	154.01	36.86	12.9
79th	163.00	39.65	12.8
80th	173.93	43.85	12.7
81st	184.51	48.73	12.7
82nd	196.17	55.35	12.6
83rd	210.00	62.00	12.5
84th	224.00	69.77	12.4
Allowable average withdrawal			**13**

6.3 Upper River Instream Habitat

For the SEFA results, the timeseries of AWS were condensed into mean values for each habitat suitability group and flow reduction scenario for flows up to 96 cfs, the threshold between Block 2 and Block 3. These mean values of AWS show different responses to decreased flow scenarios (Figure 6-6). Only 4 assessed groups, the net-spinning caddisflies (Hydropsychidae or HYDR), the deep-fast guild (DPFA), total invertebrates (TINV), and adult Bluegill (BLUA), showed at least 15 percent loss of habitat with up to 25 percent loss of flow (Figure 6-7). All other groups were either less sensitive or had insufficient habitat at less than 1 AWS at the 29 cfs fish passage flow (Table 6-4).

The most sensitive habitat suitability group was the Hydropsychidae (HYDR), which exhibited a 15 percent loss in mean habitat associated with flow reductions greater than 12 percent (Figure 6-7). The minimum flow recommendation based on the SEFA results is, therefore, 88 percent of the baseline unimpacted flows for instream flows up to 96 cfs at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage. Reasons for the sensitivity of HYDR over the range of flows from 0 to 96 cfs, which is the range of flows included in Blocks 1 and 2, are discussed below.

Table 6-3. Key results of the Upper Little Manatee River floodplain analysis for Block 3 greater than 224 cfs (i.e., the 85th and higher flow percentiles). Percent-of-flow reductions that result in a 15 percent decrease in the amount of total inundated wetlands based on flows at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage from 1939 through 2021.

Allowable flow reductions result in a 15 percent decrease in the amount of total inundated wetlands for Block 3, flows above 224 cfs			
Flow Percentile	Flow (cfs)	Inundation Area (acre)	Allowable flow reductions (percent)
85th	241.45	77.83	12.3
86th	260.00	88.13	12.1
87th	282.09	101.56	11.9
88th	306.00	116.81	11.7
89th	331.48	131.15	11.8
90th	366.00	147.28	11.4
91st	401.51	162.74	11.3
92nd	444.00	181.03	11.1
93rd	501.00	215.17	10.4
94th	562.00	242.83	10.3
95th	646.65	272.33	9.6
96th	758.00	322.83	9.6
97th	925.00	382.80	8.6
98th	1160.00	465.40	7.6
99th	1680.00	619.71	6.6
Allowable average withdrawal			**10**

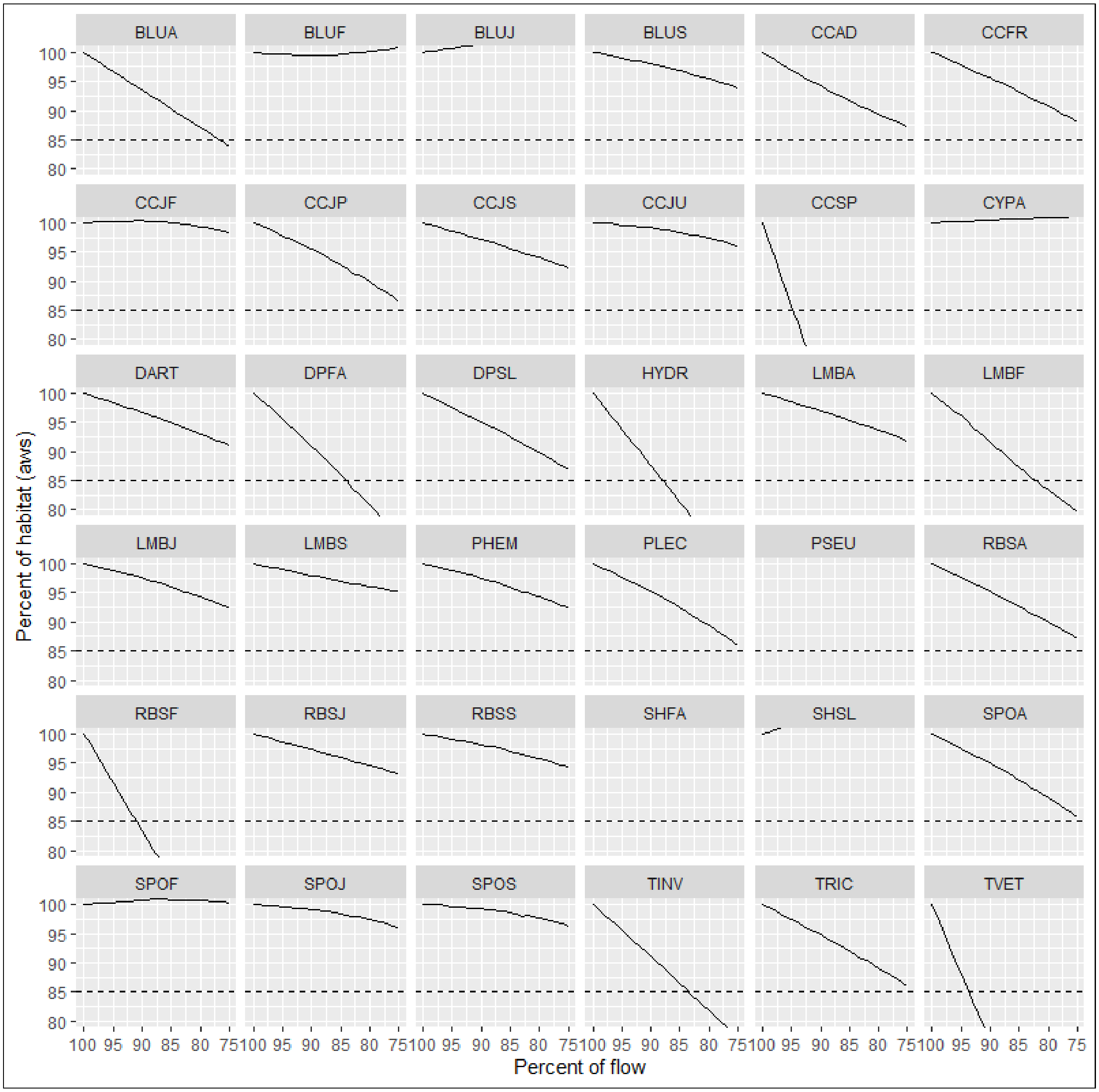


Figure 6-6. Habitat loss for all groups (defined in Table 5-2). The dotted line shows the critical 15 percent loss of habitat. The nearest integer percent of flow above the crossing point where habitat intersects the critical loss of 15 percent is the minimum allowable percent of flow.

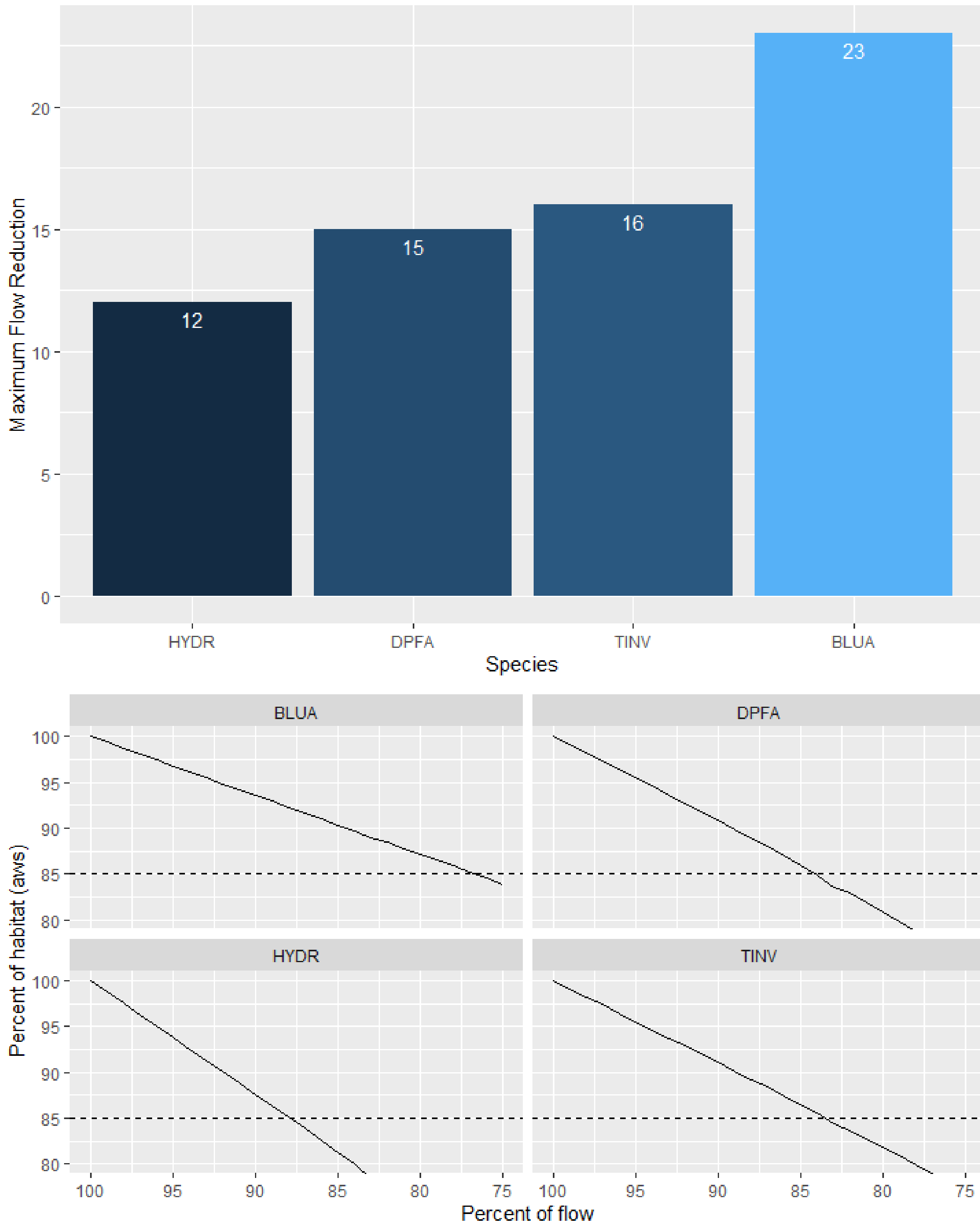


Figure 6-7. Maximum allowable flow reduction for the four most sensitive groups (defined in Table 5-2).

Table 6-4. Maximum allowable flow loss for all groups. The four most sensitive groups are highlighted.

Code	Group Name (Alt. Name)	Stage (Season)	Maximum Allowable Flow Loss (Percent)
BLUA	Bluegill	Adult	23
BLUF	Bluegill	Fry	>25
BLUJ	Bluegill	Juvenile	>25
BLUS	Bluegill	Spawning	>25
CCAD	Channel Catfish	Adult	>25
CCFR	Channel Catfish	Fry	>25
CCJF	Channel Catfish	Juvenile (Fall)	>25
CCJP	Channel Catfish	Juvenile (Spring)	>25
CCJS	Channel Catfish	Juvenile (Summer)	>25
CCJU	Channel Catfish	Juvenile	>25
CCSP	Channel Catfish	Spawning	Insufficient habitat
CYPA	Cyprinidae (Shiners)	Adult	>25
DART	Darters	Adult	>25
DPFA	Deep Fast	Guild	15
DPSL	Deep Slow	Guild	>25
HYDR	Hydropsychidae (Caddisfly)	Total	12
LMBA	Largemouth Bass	Adult	>25
LMBF	Largemouth Bass	Fry	Insufficient habitat
LMBJ	Largemouth Bass	Juvenile	>25
LMBS	Largemouth Bass	Spawning	>25
PHEM	Ephemeroptera (Mayflies)	Larvae	>25
PSEU	*Pseudocloeon ephippiatum* (Mayfly)	Larvae	Insufficient habitat
RBSA	Redbreast Sunfish	Adult	>25
RBSF	Redbreast Sunfish	Fry	Insufficient habitat
RBSJ	Redbreast Sunfish	Juvenile	>25
RBSS	Redbreast Sunfish	Spawning	>25
SHFA	Shallow Fast	Guild	Insufficient habitat
SHSL	Shallow Slow	Guild	>25
SPOA	Spotted Sunfish	Adult	>25
SPOF	Spotted Sunfish	Fry	>25
SPOJ	Spotted Sunfish	Juvenile	>25
SPOS	Spotted Sunfish	Spawning	>25
TINV	Total Invertebrates	All	16
TRIC	Trichoptera (Caddisflies)	Larvae	>25
TVET	*Tvetenia vitracies* (Midge)	Larvae	Insufficient habitat

The average and maximum depth for all 21 cross sections included in the SEFA increases with flow (Figure 6-8). These average and maximum depths correspond to the rising arm of the habitat suitability curve for HYDR (Figure 6-9). This means that over the range of within-channel flows in the upper river, there is a steep increase in habitat suitability for depth associated with an increase in flows, based on the geometry and hydrology of the surveyed cross sections.

The average and maximum velocity for all 21 cross sections surveyed also increases with flow (Figure 6-10). These average and maximum velocities correspond to the rising arm of the habitat suitability curve for HYDR (Figure 6-11). This means that over the range of flows of interest, there is a steep increase in habitat suitability for velocity associated with an increase in flows, based on the geometry and hydrology of the cross sections surveyed.

The most common substrate/cover attribute for the upper river is sand with instream, proximal, or overhead cover (Figure 6-12). Other less frequent types include detritus, sand, and SAV. These correspond to the most suitable substrate and cover preferences of HYDR (Figure 6-13).

The habitat suitability curves for HYDR were based on data collected by Warren and Nagid (2008) in the northern Withlacoochee River, Florida. The curves for depth (Figure 6-9) and velocity (Figure 6-11) are directly translated from the northern Withlacoochee River data, converted from cm to ft (Figure 6-14). Substrate suitability was modified from the data collected on the northern Withlacoochee River (Figure 6-15) to match the categorization of other habitat suitability curves (Figure 6-13).

As discussed in Warren and Nagid (2008), caddisflies in the family Hydropsychidae are most commonly found on snags (Figure 6-15). Within the substrate and cover coding scheme used for the habitat suitability curves, Code 17 (sand with overhead, proximal, or instream cover) includes snags as part of the “instream cover” (Table 5-3) and is, therefore, one of the most suitable habitat categories for these caddisflies (Figure 5-12).

Based on these summaries of depths, velocities, and substrate types in the surveyed river reach, and their corresponding habitat suitabilities for HYDR, it makes sense that this taxonomic group is sensitive to reduced flows, and the simulations bear that out.

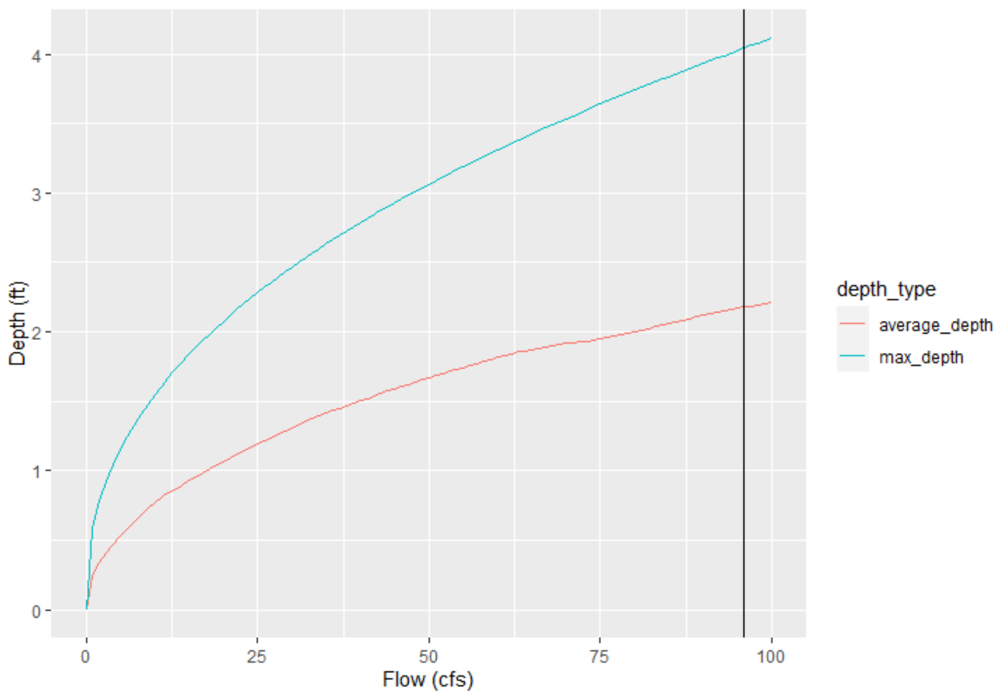


Figure 6-8. The average depth and maximum depths across the reach for simulated flows from 0 to 96 cfs. Values represent averages across all 21 cross sections included in the SEFA. The maximum depth is 4.04 ft and average depth is 2.18 ft at 96 cfs.

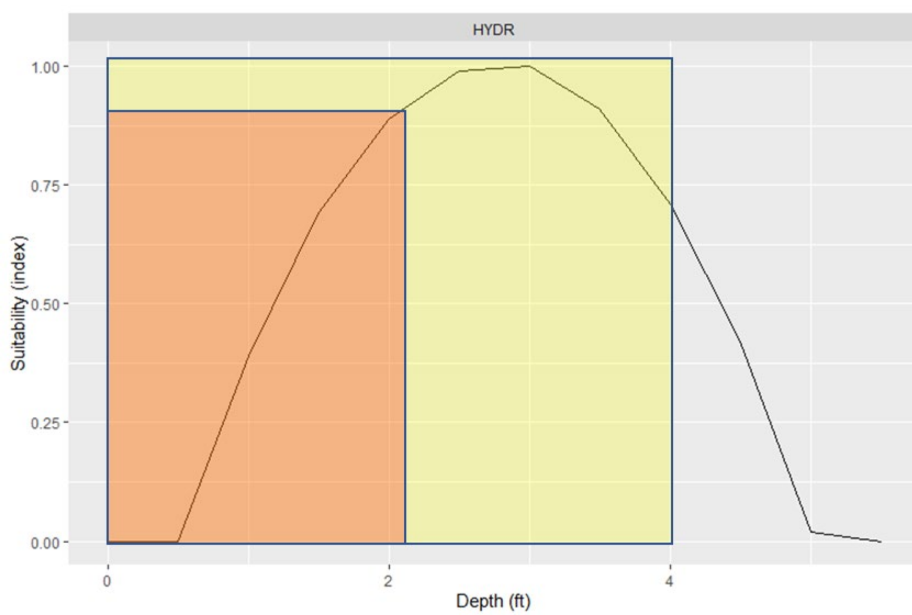


Figure 6-9. The Hydropsychidae (HYDR) depth suitability with average and maximum depths highlighted. The HYDR has zero suitability until 0.5 ft, and rises to a maximum of 1 at 3 ft. The average depth is entirely within the rising arm of the HYDR depth suitability curve (orange box), while the maximum depth spans the entire rising arm of the HYDR depth suitability curve (yellow box).

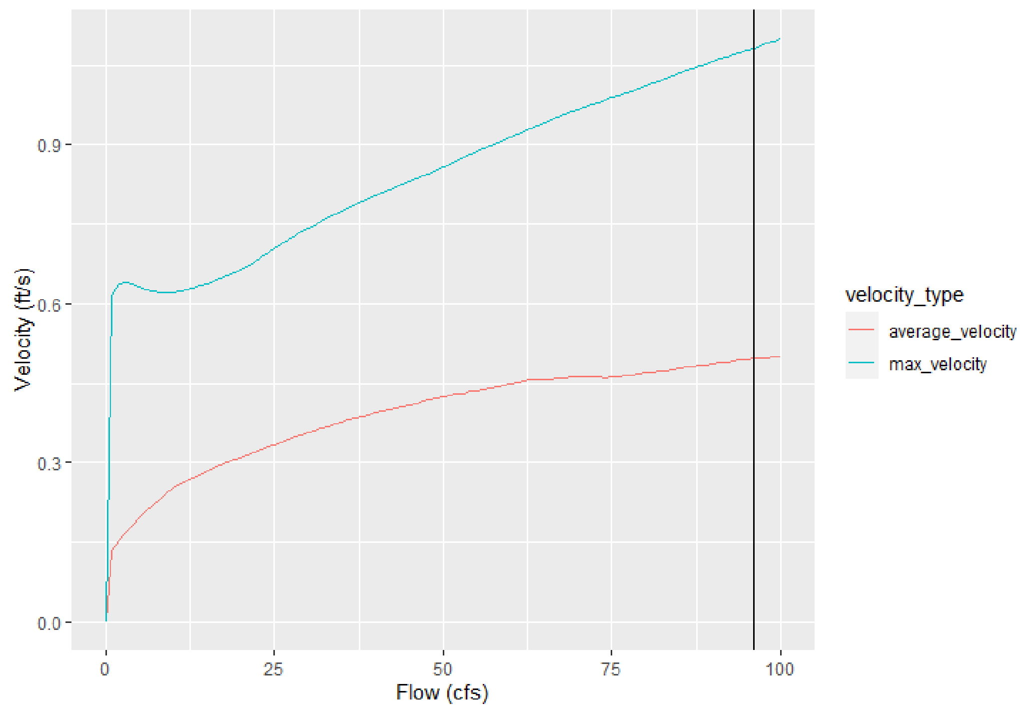


Figure 6-10. The average and maximum velocity across the reach for simulated flows from 0 to 96 cfs. The values represent averages across all 21 cross sections included in the SEFA. Average velocity is 0.50 and maximum velocity is 1.08 at 96 cfs.

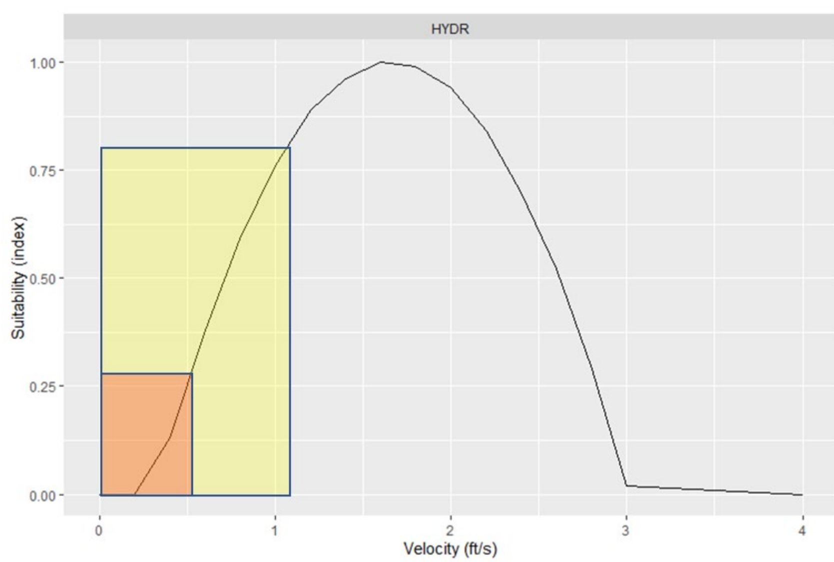


Figure 6-11. The Hydropsychidae (HYDR) velocity suitability with average and maximum depths highlighted. The HYDR has zero suitability until 0.2 ft/s, and rises to a maximum of 1 at 1.6 ft/s. The average (orange box) and maximum velocities (yellow box) across the reach are entirely within the rising arm of the HYDR velocity suitability curve.

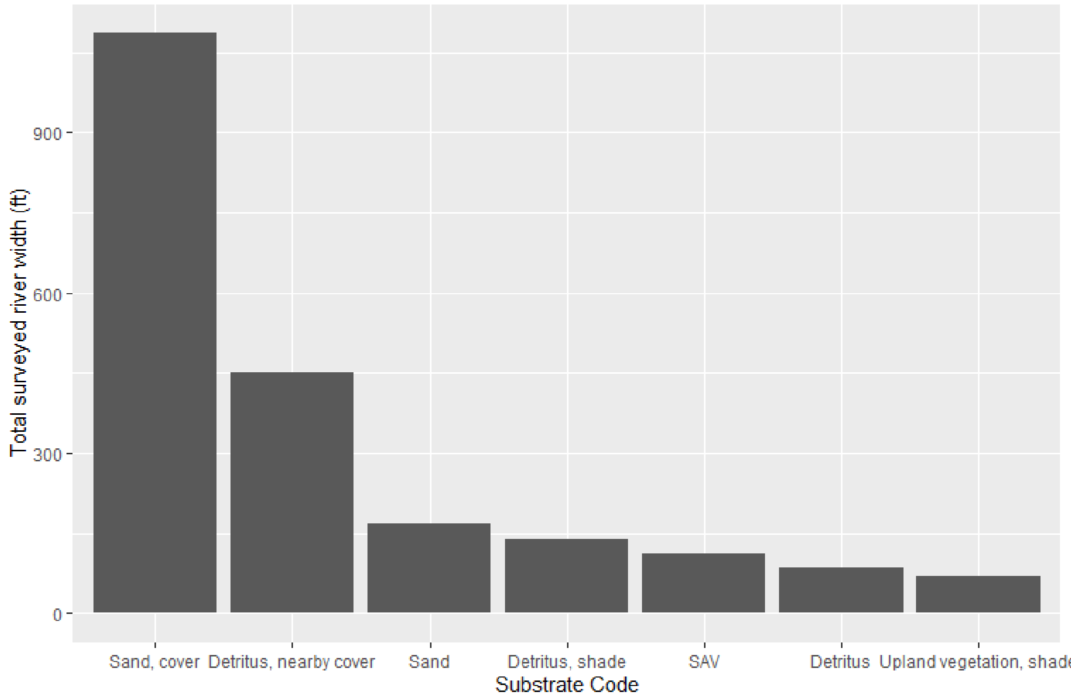


Figure 6-12. The frequency distribution of substrates sampled on the Upper Little Manatee River.

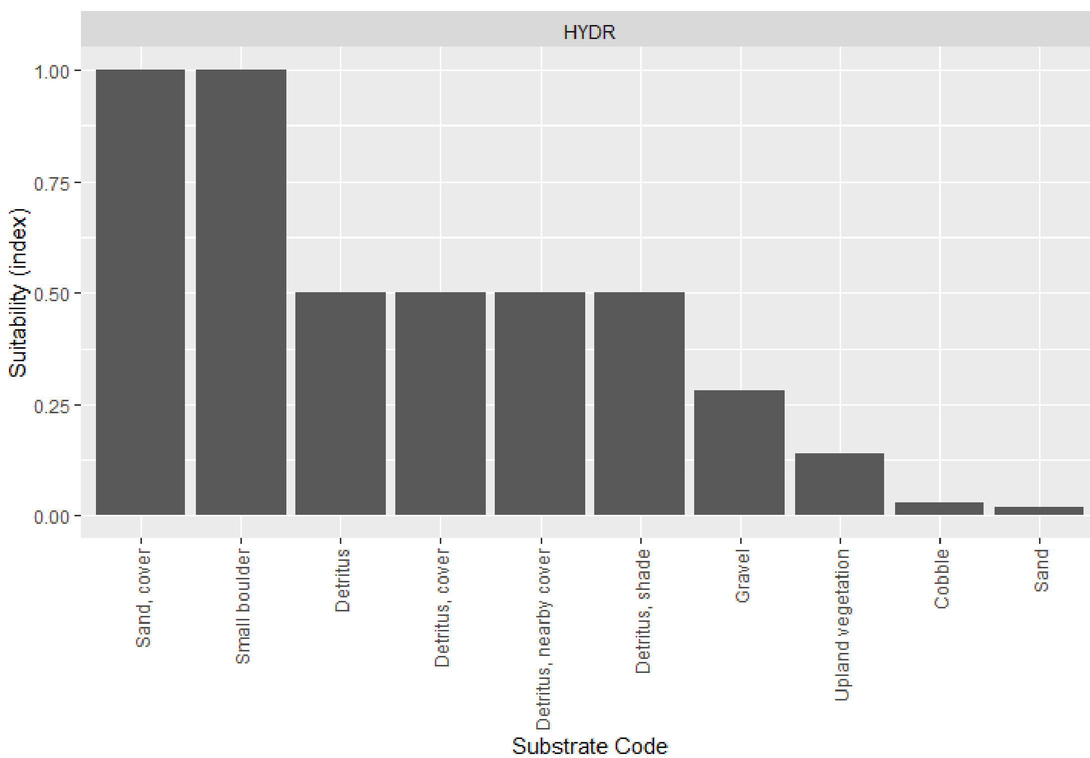


Figure 6-13. Habitat suitability for Hydropsychidae (HYDR) substrate and cover attributes.

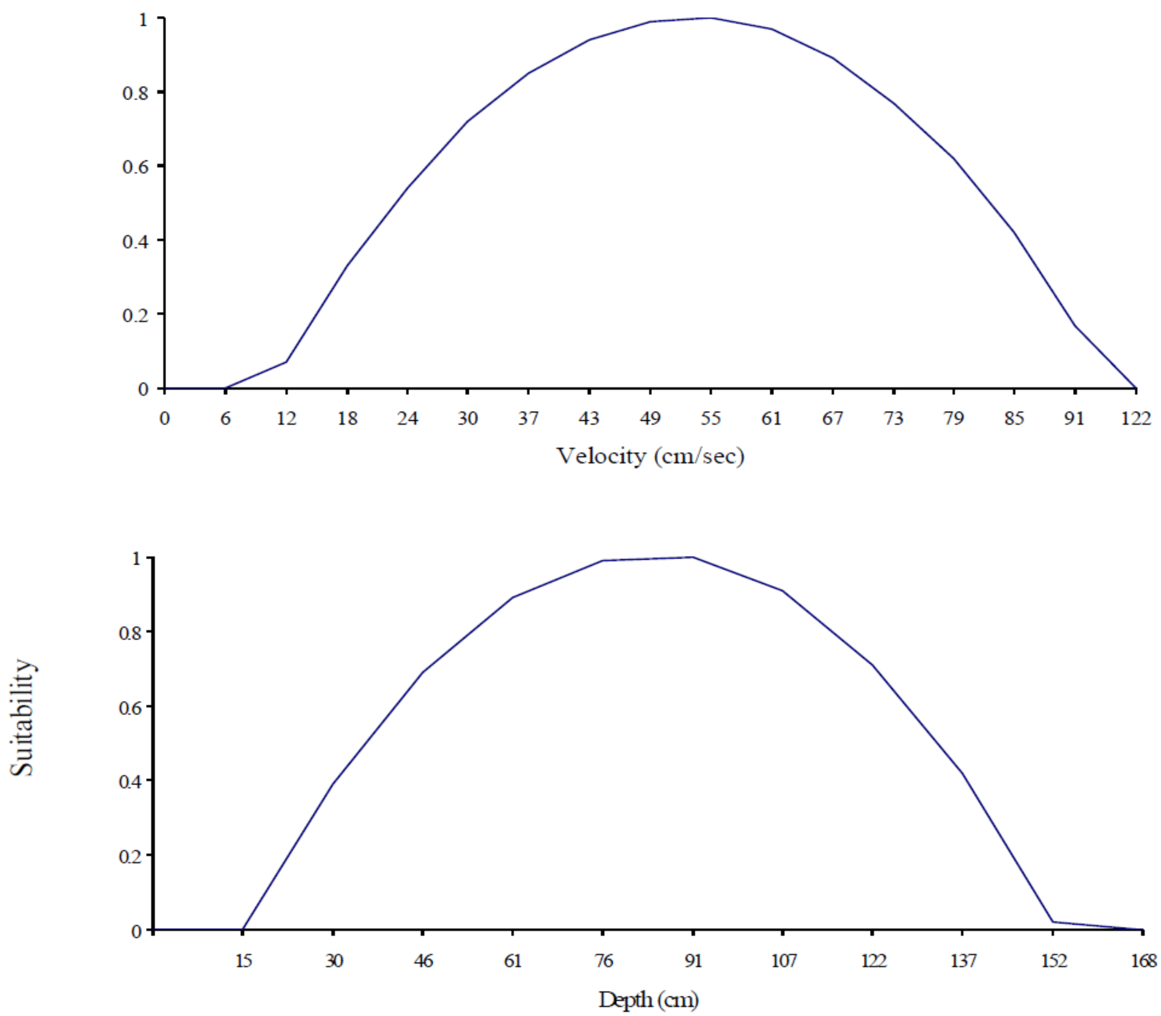


Figure 6-14. Depth and velocity habitat suitability curves for Hydropsychidae (HYDR) based on northern Withlacoochee River data (from Warren and Nagid 2008).

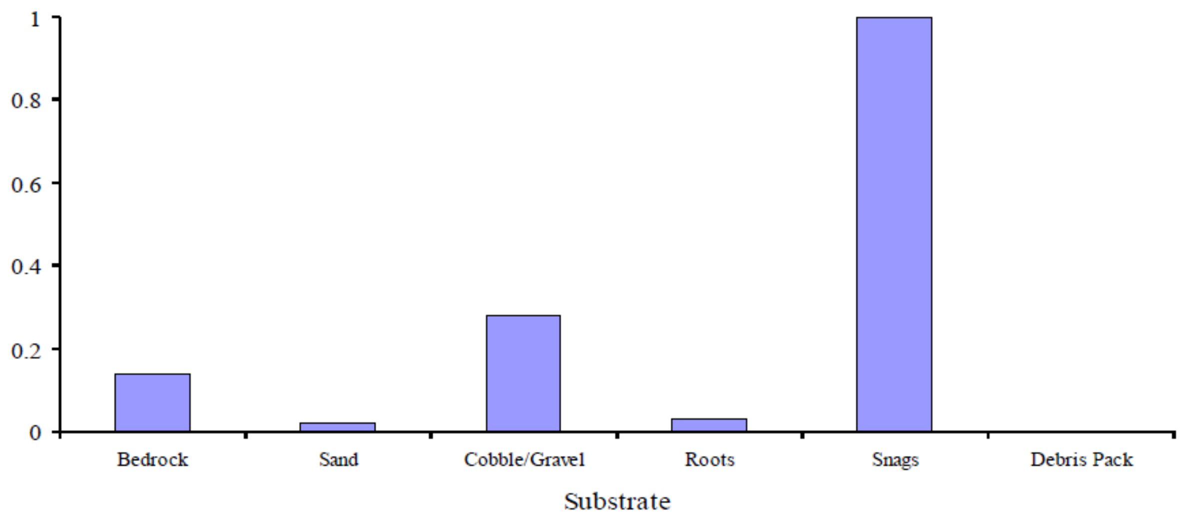


Figure 6-15. Substrate suitability for Hydropsychidae (HYDR) from northern Withlacoochee River data (from Warren and Nagid 2008).

6.4 Lower River Biologically Relevant Salinity Zones

After the EFDC model was calibrated and verified against measured data of water level, salinity, and temperature, it was used to conduct a baseline and eight reduced baseline freshwater flow simulations. Flow reduction scenarios ranged from 5 to 40 percent, in increments of 5 percent. The simulation period for all scenario runs was from December 1999 to June 2005, with December 1999 treated as a spin-up period (i.e., the time the model takes for the input/out values to reach a steady state under applied forcing). As such, the actual simulation period was 5.5 years, from January 2000 to June 2005.

Salinity habitats calculated for each scenario included water volumes, bottom areas, and shoreline lengths associated with every increment of 1 psu of salinity isohaline from 0 to 30 psu. The response of salinity habitats to the freshwater inflow is generally nonlinear. The analysis of salinity habitats was completed for three flow-based blocks: Block 1 (≤29 cfs), Block 2 (>29 cfs to ≤96 cfs), and Block 3 (>96 cfs). Refer to Section 5.1.2. for the additional description of the three flow-based blocks.

The salinity habitat analysis involved examining changes of water volume, bottom area, and shoreline length relative to those under the baseline flow condition for every 1 psu increment of the salinity isohaline. The relative changes of salinity habitats were calculated as percentage reductions (negative) for all salinity habitats under each isohaline for each flow block. As the model period included only the first six months of 2005, the model results from those six months were excluded in the analysis for calendar year across flow-based blocks.

Figures 6-16 through 6-18 show relative changes of water volume, bottom area, and shoreline length, respectively, for various salinity isohalines for Blocks 1, 2, and 3. These results are consistent with those from minimum flow evaluations for other riverine estuaries, including the Lower Alafia River (Flannery et al. 2008) and the Lower Peace River (Ghile et al. 2021). Generally, salinity volumes, bottom areas, and shoreline lengths of oligohaline habitats were much more sensitive to the flow reduction than those of mesohaline and polyhaline habitats. The nonlinear response of salinity habitats in the Little Manatee River estuary to flow reductions can be clearly seen in Figures 6-16 through 6-18, as salinity habitats were more sensitive to the flow reduction in Block 1 than in Blocks 2 and 3.

It should be pointed out that to develop an efficient model that can reasonably simulate hydrodynamics and salinity transport in the lower river, some extra model grids were added to the upstream part of the simulation domain, roughly the upstream two thirds of the river segment between I-75 and US Highway 301. This part of the river is narrow and meandering and requires many extremely fine grids to resolve the river bathymetry, making the model very inefficient due to the increased number of grids and the significantly reduced simulation time step. To avoid using these extremely fine grids in the simulation domain and make the model more efficient, this part of the river was discretized with a grid size that is roughly comparable to the length scale of the river width but with some extra grids added to the simulation domain. These added grids were mostly outside the riverbanks and within the freshwater zone. Although these added grids led to over-representation of the water volume and bottom area for this part of the river within the model, their inclusion facilitated successful model runs, without seriously compromising the accuracy of the simulation of the longitudinal distribution of salinity along the river. Also, for calculation of salinity habitats, such as water volume and bottom area for certain isohalines, these extra grids were excluded, so that errors associated with the over-representation of water volume and bottom area for this part of the river were minimized.

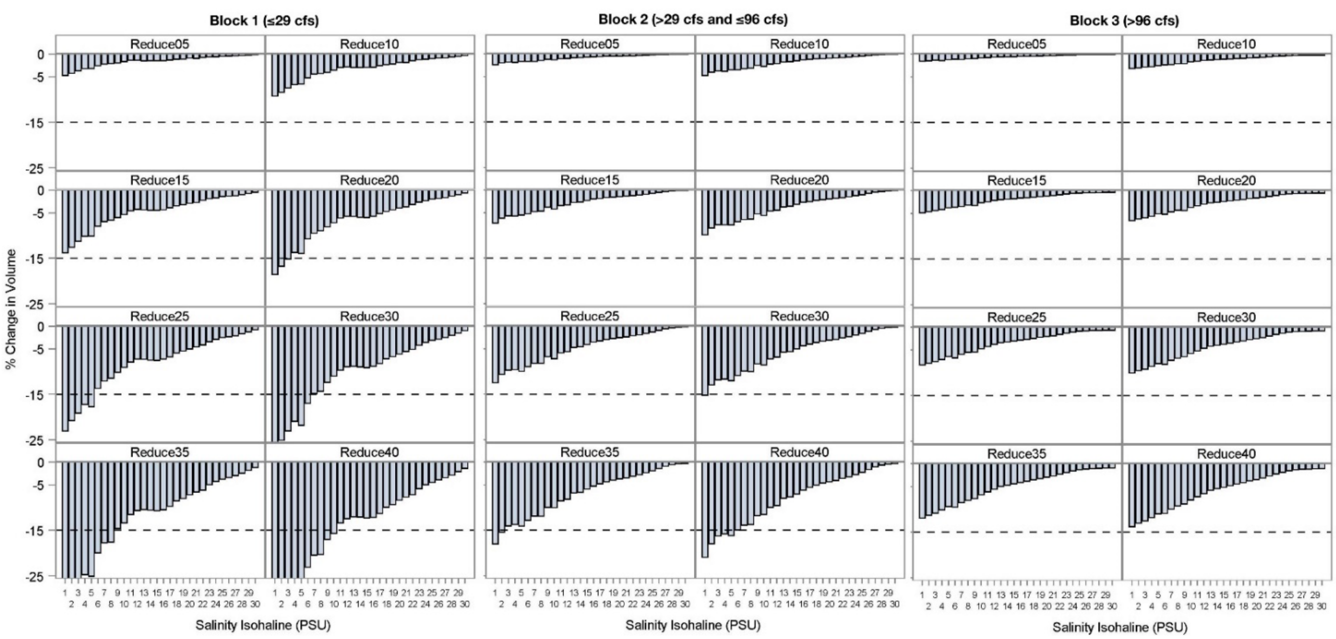


Figure 6-16. Relative changes of water volumes (relative to those of the baseline flow condition) for every psu of the isohaline for 5 through 40 percent flow reduction scenarios (in 5 percent increments) for Blocks 1 (left panel), 2 (center panel), and 3 (right panel) during the EFDC model period from 2000 through 2004 (from JEI 2023 in Appendix O).

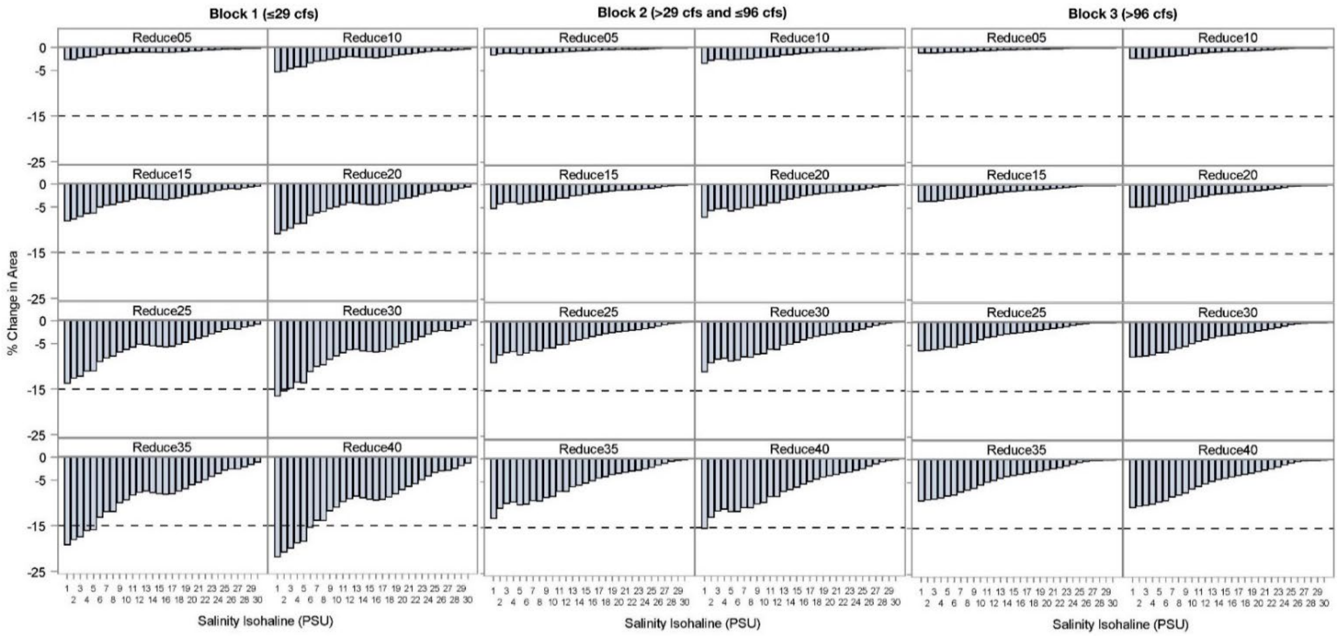


Figure 6-17. Relative changes of bottom areas (relative to those of the baseline flow condition) for every psu of the isohaline for 5 through 40 percent flow reduction scenarios (in 5 percent increments) for Blocks 1 (left panel), 2 (center panel), and 3 (right panel) during the EFDC model period from 2000 through 2004 (from JEI 2023 in Appendix O).

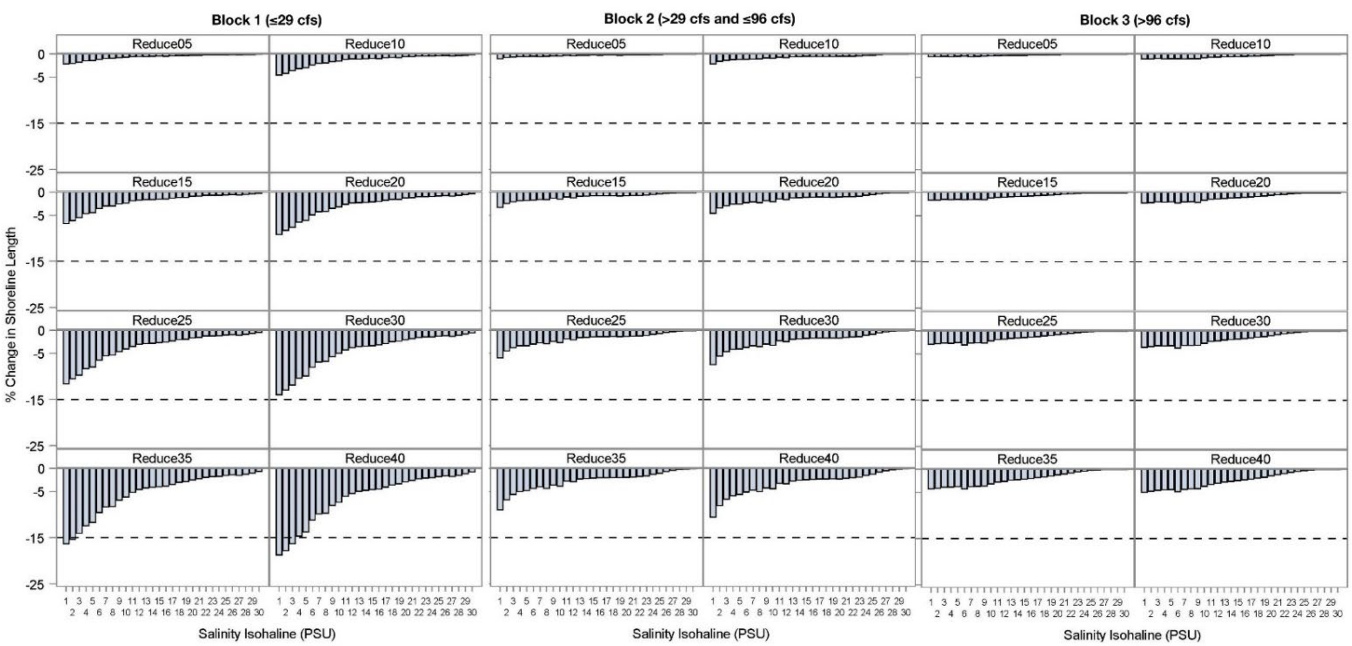


Figure 6-18. Relative changes of shoreline lengths (relative to those of the baseline flow condition) for every psu of the isohaline for 5 through 40 percent flow reduction scenarios (in 5 percent increments) for Blocks 1 (left panel), 2 (center panel), and 3 (right panel) during the EFDC model period from 2000 through 2004 (from JEI 2023 in Appendix O).

Volume and bottom area for salinity ≤2 psu is often considered as critical parameters for the health of the estuary and have been used in several previous minimum flow evaluations for estuaries (Herrick et al. 2019a, 2019b, Ghile et al. 2021). Like previous minimum flows evaluations, we focused on water volume, bottom area, and shoreline length for salinity ≤2 psu in the following discussion. Note that since the ≤2 psu was the most sensitive to reductions in flow, protecting this low-salinity habitat also protects the habitat up to 30 psu.

With a 20 percent flow reduction, the water volume of the 2 psu isohaline habitats would be reduced by more than 15 percent in Block 1 (Figure 6-16). Low-salinity bottom areas were less sensitive than low-salinity volumes. A 15 percent reduction of ≤2 psu bottom area will not occur until the flow reduction reaches almost 30 percent in Block 1 (Figure 6-17). Low-salinity shoreline lengths were least sensitive to flow reduction. A 15 percent reduction of ≤2 psu shoreline length corresponded to almost 35 percent of flow reduction in Block 1 (Figure 6-18).

In Block 2, a 35 percent flow reduction would result in more than a 15 percent reduction of ≤2 psu water volume but did not trigger a 15 percent reduction of ≤2 psu bottom area and shoreline length with a 40 percent reduction of flow. Similar to Block 1, water volume of ≤2 psu is more sensitive to flow reduction than ≤2 psu bottom area, which is more sensitive than ≤2 psu shoreline length in Block 2.

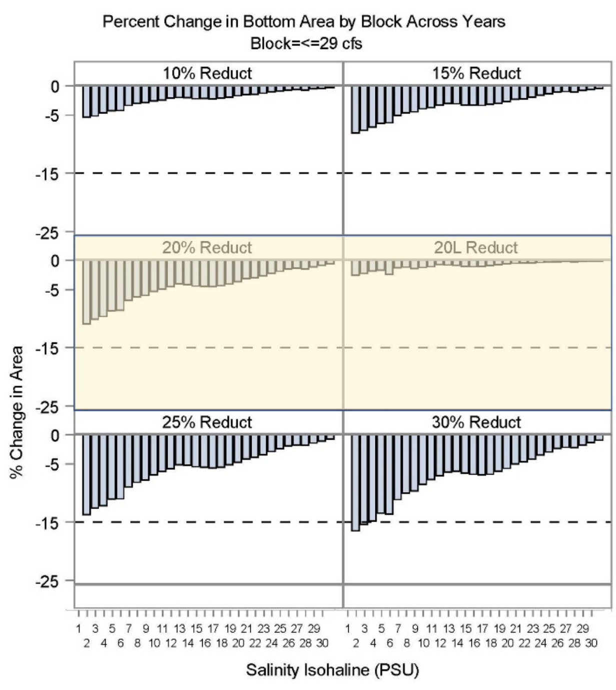
In Block 3, a 15 percent reduction of ≤2 psu salinity volume, bottom area, and shoreline length did not occur for any simulations, including the maximum simulated flow reduction of 40 percent. Similar to Blocks 1 and 2, water volume for salinity ≤2 psu is most sensitive to flow reduction, while ≤2 psu shoreline length is least sensitive to flow reduction in Block 3.

Model results shown in Figures 6-16 through 6-18 can be interpolated to calculate the percentage of flow reduction from baseline conditions that would result in the 15 percent reduction of salinity habitats for salinity ≤2 psu. For ≤2 psu volume, a 17.9 percent flow reduction would cause it to be reduced by 15 percent when the inflow falls in Block 1 or when the flow at the USGS Little Manatee River at US Highway 301 near Wimauma, FL (No. 02300500) gage is 29 cfs or less. In Block 2, when the inflow is between 29 and 96 cfs, a 34.2 percent reduction of the freshwater flow could trigger ≤2 psu volume to be reduced 15 percent. For ≤2 psu bottom area, a 15 percent loss would occur when the inflow is reduced 29.4 percent at the gage site in Block 1. For shoreline length, a 15 percent decline could be caused by a 34.3 percent flow reduction in Block 1. With a flow reduction of 40 percent or less, a 15 percent reduction of ≤2 psu water volume in Block 3 would not occur. A 15 percent reduction of ≤2 psu bottom area and shoreline length would also not occur when the flow at the gage is reduced by 40 percent or less in Blocks 2 and 3.

A low-flow threshold of 29 cfs is proposed for the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage to ensure that a minimum water depth at an upstream cross section is maintained. Because this gage site is the upstream boundary condition of the simulation domain of the EFDC model, the low-flow threshold could enhance protection of low-salinity habitats in the estuary. Because critical low-salinity habitats, such as ≤2 psu water volume, may be reduced by 15 percent or more with a 17.9 percent flow reduction during Block 1 (Figure 6-16), it was meaningful to see how salinity habitats in the river would respond to the proposed low-flow threshold of 29 cfs when the inflow was reduced by 17.9 percent.

Figure 6-19 shows the percentage changes of salinity habitats relative to those under the baseline flow condition for 10 percent, 15 percent, 20 percent, 20 percent including the low-flow threshold, 25 percent, and 30 percent flow reductions during Block 1. The left panel shows bottom areas of different isohalines, and the right panel is for volume. Results for the middle two graphs of each panel highlight differences the 29 cfs low-flow threshold makes on the relative changes of salinity habitats for the 20 percent flow reduction scenario.

Because daily flow ≤ 29 cfs at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage falls in Block 1, the 29 cfs low-flow threshold allows no flow reduction during Block 1 days. At this site, freshwater inflow was reduced by 20 percent during Block 2 and 3 days only. It could be postulated that relative changes of salinity habitats in Block 1 would be 0 percent, because under these conditions the estuary receives the same amount of freshwater inflow as the baseline flow. However, this is not the case (Figure 6-19). Due to the use of flow-based blocks, Block 1 days are not necessarily in sequence, and there may be some Block 2 or even Block 3 days between two Block 1 days. As a result, the 20 percent flow reduction on the preceding days will affect salinity habitats on the Block 1 day, causing reductions of salinity habitats on the Block 1 day. Nevertheless, these relative habitat reductions are much smaller than those caused by the 20 percent flow reduction without the proposed low-flow threshold of 29 cfs.



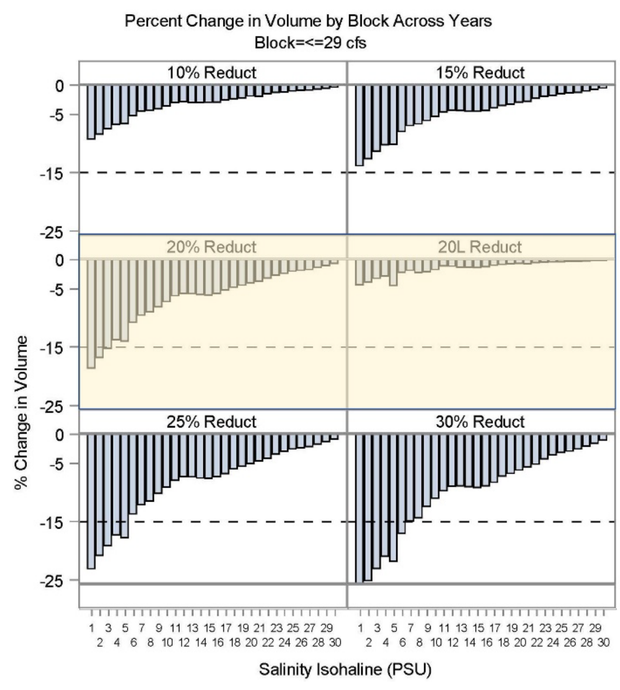


Figure 6-19. Percentage reductions in bottom area (left panel) and volume (right panel) associated with various salinity isohalines relative to those under the baseline flow condition during Block 1, with difference in low-salinity habitat changes for the 20 percent and 20 percent with proposed low-flow threshold (20L Reduct) reductions scenarios highlighted to emphasize effects of the low-flow threshold (from JEI 2023 in Appendix O).

Results of the EFDC hydrodynamic modeling to evaluate changes in low-salinity habitat in the Lower Little Manatee River as a result of flow reductions are summarized (and rounded up) in Table 6-5. As discussed above, an evaluation of the effect of the low-flow threshold of 29 cfs proposed for the

Upper Little Manatee River demonstrated that it would also provide protection to Lower Little Manatee River low-salinity habitat. The identified proposed low-flow threshold of 29 cfs is, therefore, recommended for both the Upper and Lower Little Manatee River for the Block 1 proposed minimum flows.

Table 6-5. Percent-of-flow reductions that result in a 15 percent decrease in the amount of low-salinity habitat (volume, bottom area, and shoreline length) at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage based on results of the EFDC model.

	Block 1 (≤29 cfs)	Block 2 (>29 and ≤96 cfs)	Block 3 (>96 cfs)
Volume	18	34	>40
Bottom Area	29	>40	>40
Shoreline Length	34	>40	>40

6.5 Lower River Estuarine Fish Habitat

The results of the updated EFF model evaluation were consistent with previous evaluations. Eleven species exhibited a higher probability of occurrence at low- or mid-range salinities than at higher salinities and were considered most useful for assessing potential flow-related habitat favorability changes. The estuarine fish species evaluated included: Sheepshead, Common Snook, Striped Mojarra (*Eugerres plumieri*), Eastern Mosquitofish (*Gambusia holbrooki*), Naked Goby (*Gobiosoma bosc*), Rainwater Killifish (*Lucania parva*), Clown Goby, Sailfin Molly (*Poecilia latipinna*), Red Drum, Hogchoker, and gobies less than 20 mm (small gobies, *Gobiosoma* sp.). The effects of flow reductions were quantified as the percent change in area of favorable habitat (i.e., shoreline length) within the domain of the estuarine model segment.

Species most sensitive to flow reductions were tidal river residents and included Eastern Mosquitofish, Naked Goby, Hogchoker, and small gobies less than 20 mm. More transient, estuarine-dependent species, such as Common Snook, Sheepshead, and Red Drum, were less sensitive to flow reductions though all showed negative responses to flow reductions over the evaluation period.

When the species-specific percent reductions were examined by flow-based blocks, the lower flow blocks were more sensitive to changes in flows than the high flow block. For Block 1, several species exhibited close to a 15 percent reduction in favorable habitat with a 10 percent reduction in flows (Figure 6-20 and Table 6-6). These species included Eastern Mosquitofish, Hogchoker, Naked Goby, and Striped Mojarra. These species are principally tidal river resident species that spend the majority of their lives within the lower river; though, Striped Mojarra tend to exit the river systems more frequently than the other species.

The results for Block 2 (Figure 6-21 and Table 6-7) suggested that Clown Goby and small gobies exhibited a greater than 15 percent change at a 15 percent flow reduction, while Rainwater Killifish, Striped Mojarra, Common Snook, and Hogchoker exhibited a similar but slightly lower response with 15 percent flow reduction. Gobies are bottom-dwelling, resident species that appear more sensitive to changes in salinity associated with the flow reductions.

The results for Block 3 suggested that a 15 percent reduction in favorable habitat was associated with nearly a 30 percent reduction in flow (Figure 6-22 and Table 6-8). As observed for Blocks 1 and 2, the Clown Goby and small gobies were more sensitive to flow reductions than transient species.

These modeling efforts were performed because nekton (e.g., fish, shrimp, crabs) have been identified as an important resource of the Lower Little Manatee River. For this analysis, reductions in preferential habitat were considered detrimental to the long-term success of tidal river fish species, though these species are adapted to life in an environment that can undergo rapid changes in physical chemistry, even on a daily basis, given tidal exchange, intense rainfall events, and wind-driven estuarine mixing. Despite the natural variability, the EFF models are useful indicators of potential flow-related changes in favorable habitat for a number of fish species and provide additional lines of evidence to consider in support of the development of minimum flows.

The model results provide best estimates of potential changes in favorable habitat for selected fish species as a function of potential flow reductions; however, it is acknowledged that the models used for the analyses include uncertainty that is not fully incorporated into the predicted changes in habitat favorability. For example, the logistic regression models used in the EFF analysis provide coefficients describing the rate of change in the log-odds of occurrence as a function of changes in salinity. That coefficient has uncertainty (i.e., a standard error), which was not incorporated into the assessment. Instead, the coefficient was accepted as the best estimate of the true underlying relationship, which is common practice in establishing lines of evidence in support of evaluating flow reduction scenarios for management purposes. Likewise, the LOESS salinity-flow model contains uncertainty which was not propagated through the modeling construct. Therefore, it is not possible to state with statistical certainty that the observed changes in favorable habitat were due explicitly to changes in flows associated with the flow reduction scenarios. Instead, the results are described as best estimates of the potential relative changes that would occur for these species. In some rare cases, the quadratic term in the model imparted a predicted increased probability of occurrence during low flows at highest salinities which was discounted for this analysis. Finally, the EFF analyses were used to identify the availability of preferential habitat and are not a determination of adequate habitat for the occurrence of the particular fish species within the Lower Little Manatee River.

Minimum flows recommendations based on the interpolation of the results of the EFF analyses are summarized in Table 6-9. Since these results are more protective that those obtained as a result of the EFDC hydrodynamic modeling of low-salinity habitat, the proposed minimum flows for the Lower Little Manatee River summarized in the following section for Blocks 2 and 3 are based on the EFF analyses of estuarine fish habitat. As already mentioned, the low-flow threshold of 29 cfs will apply to the proposed minimum flows for Block 1 for both the Upper and Lower Little Manatee River.

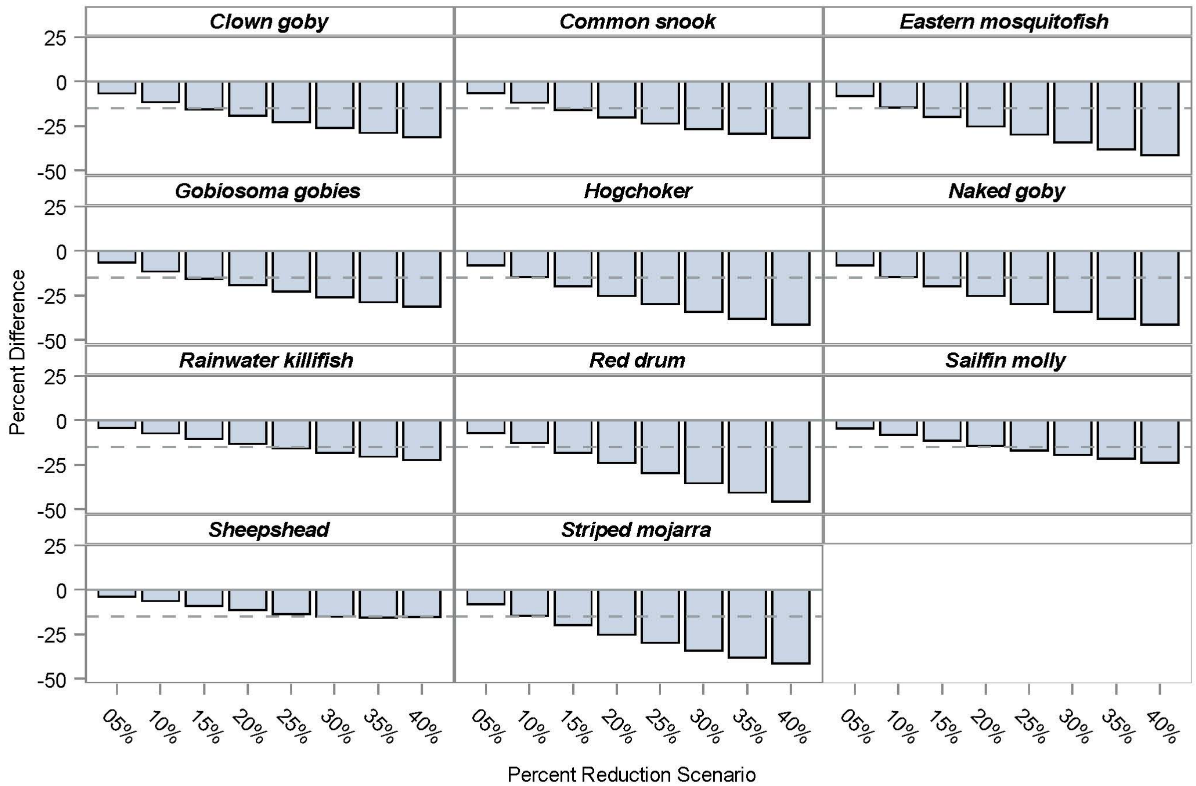


Figure 6-20. Average percent difference in favorable fish habitat as a function of percent changes in flows between 5 and 40 percent for Block 1. The horizontal broken line represents a negative 15 percent change in habitat used for minimum flows determination.

Table 6-6. Percent reduction in favorable habitat in the Lower Little Manatee River across years (1996-2021) for Block 1.

Fish Species	Flow Reduction Scenario							
	5 Percent	10 Percent	15 Percent	20 Percent	25 Percent	30 Percent	35 Percent	40 Percent
Clown Goby	-6.7	-11.6	-15.8	-19.4	-23.0	-26.1	-29.0	-31.5
Common Snook	-6.7	-12.0	-16.1	-20.3	-23.7	-26.9	-29.6	-31.7
Eastern Mosquitofish	-8.2	-14.7	-20.0	-25.4	-30.0	-34.3	-38.3	-41.5
Gobiosoma sp. gobies	-6.7	-11.7	-15.8	-19.4	-23.0	-26.2	-29.0	-31.5
Hogchoker	-8.2	-14.7	-20.0	-25.4	-30.0	-34.3	-38.3	-41.5
Naked Goby	-8.2	-14.7	-20.0	-25.4	-30.0	-34.3	-38.3	-41.5
Rainwater Killifish	-4.2	-7.4	-10.5	-13.4	-15.9	-18.4	-20.5	-22.5
Red Drum	-7.1	-12.8	-18.4	-24.1	-29.9	-35.5	-40.8	-45.8
Sailfin Molly	-4.7	-8.3	-11.4	-14.4	-17.0	-19.5	-21.7	-23.9
Sheepshead	-3.9	-6.5	-9.1	-11.6	-13.8	-15.2	-15.7	-15.3
Striped Mojarra	-8.2	-14.7	-20.0	-25.4	-30.0	-34.3	-38.3	-41.5

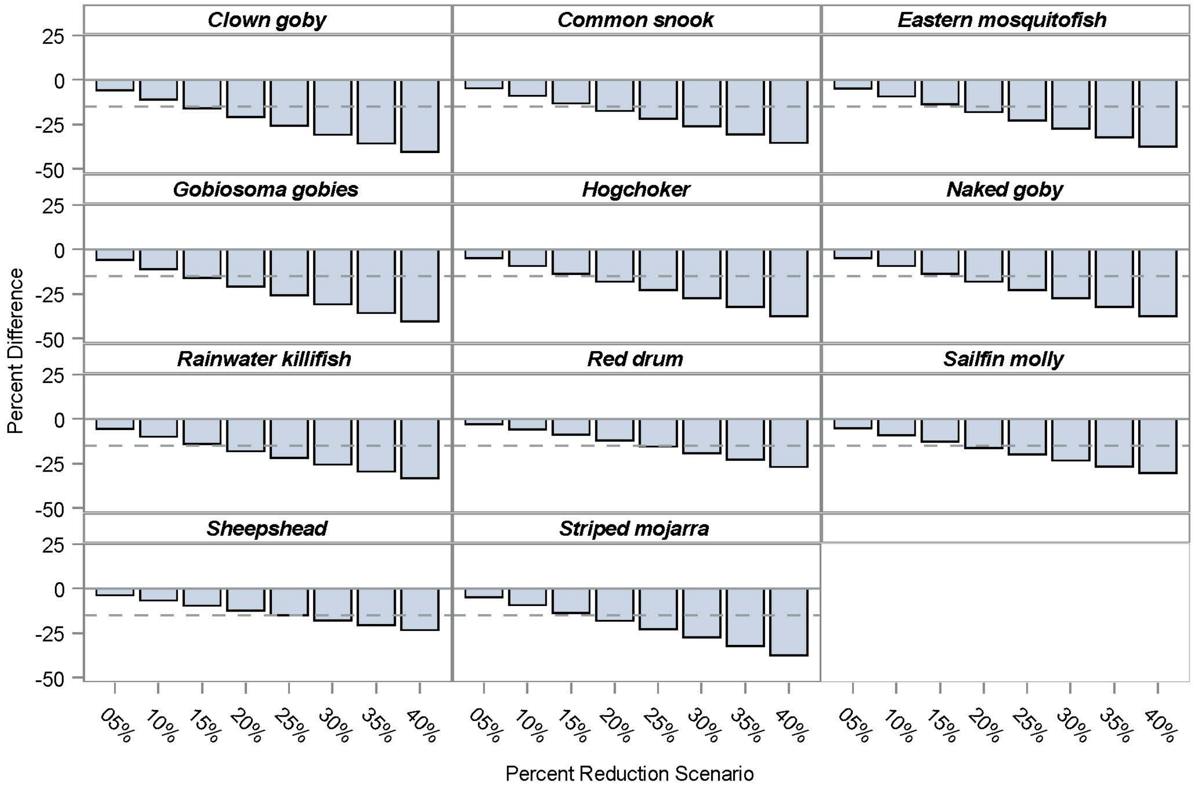


Figure 6-21. Average percent difference in favorable fish habitat as a function of percent changes in flows between 5 and 40 percent for Block 2. The horizontal broken line represents a negative 15 percent change in habitat used for minimum flows determination.

Table 6-7. Percent reduction in favorable habitat in the Lower Little Manatee River across years (1996-2021) for Block 2.

Fish Species	Flow Reduction Scenario							
	5 Percent	10 Percent	15 Percent	20 Percent	25 Percent	30 Percent	35 Percent	40 Percent
Clown Goby	-6.0	-11.1	-16.0	-20.9	-25.9	-31.0	-35.9	-40.7
Common Snook	-4.8	-9.1	-13.3	-17.6	-21.9	-26.3	-30.8	-35.5
Eastern Mosquitofish	-4.9	-9.4	-13.8	-18.2	-22.9	-27.6	-32.4	-37.6
Gobiosoma sp. gobies	-6.0	-11.1	-16.0	-20.9	-25.9	-31.0	-35.9	-40.7
Hogchoker	-4.9	-9.4	-13.8	-18.2	-22.9	-27.6	-32.4	-37.6
Naked Goby	-4.9	-9.4	-13.8	-18.2	-22.9	-27.6	-32.4	-37.6
Rainwater Killifish	-5.5	-10.1	-14.2	-18.2	-21.9	-25.8	-29.6	-33.4
Red Drum	-3.0	-6.0	-9.0	-12.2	-15.6	-19.2	-23.1	-27.0
Sailfin Molly	-5.2	-9.3	-12.9	-16.4	-19.9	-23.4	-26.9	-30.4
Sheepshead	-3.8	-6.8	-9.7	-12.4	-15.2	-17.9	-20.7	-23.4
Striped Mojarra	-4.9	-9.4	-13.8	-18.2	-22.9	-27.6	-32.4	-37.6

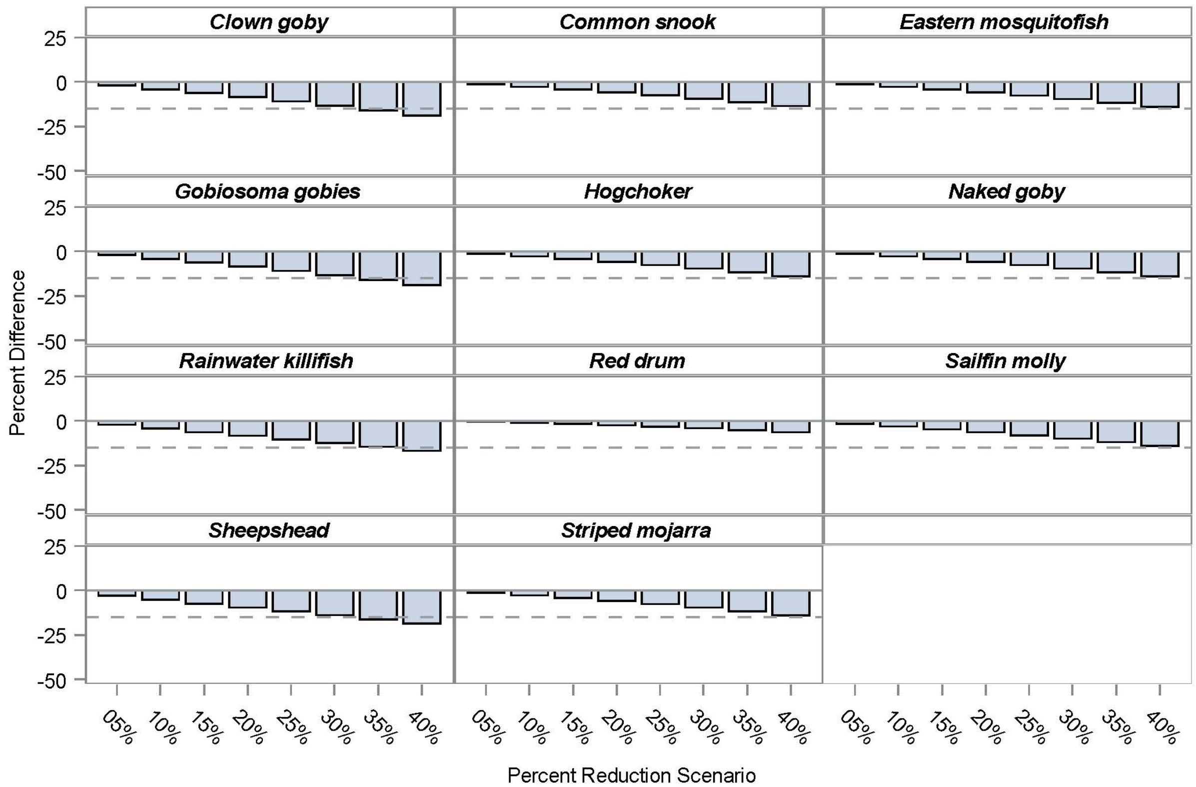


Figure 6-22. Average percent difference in favorable fish habitat as a function of percent changes in flows between 5 and 40 percent for Block 3. The horizontal broken line represents a negative 15 percent change in habitat used for minimum flows determination.

Table 6-8. Percent reduction in favorable habitat in the Lower Little Manatee River across years (1996-2021) for Block 3.

Fish Species	Flow Reduction Scenario							
	5 Percent	**10 Percent**	**15 Percent**	**20 Percent**	**25 Percent**	**30 Percent**	**35 Percent**	**40 Percent**
Clown Goby	-2.1	-4.2	-6.4	-8.6	-11.0	-13.5	-16.2	-19.1
Common Snook	-1.4	-2.8	-4.3	-5.9	-7.6	-9.5	-11.5	-13.7
Eastern Mosquitofish	-1.4	-2.9	-4.4	-6.0	-7.8	-9.7	-11.8	-14.0
Gobiosoma sp. gobies	-2.1	-4.2	-6.4	-8.6	-11.0	-13.5	-16.2	-19.1
Hogchoker	-1.4	-2.9	-4.4	-6.0	-7.8	-9.7	-11.8	-14.0
Naked Goby	-1.4	-2.9	-4.4	-6.0	-7.8	-9.7	-11.8	-14.0
Rainwater Killifish	-2.2	-4.4	-6.4	-8.4	-10.4	-12.5	-14.6	-16.9
Red Drum	-0.5	-1.1	-1.8	-2.5	-3.3	-4.2	-5.2	-6.4
Sailfin Molly	-1.6	-3.2	-4.8	-6.5	-8.2	-10.0	-12.0	-14.1
Sheepshead	-2.9	-5.3	-7.6	-9.7	-11.8	-14.0	-16.4	-18.8
Striped Mojarra	-1.4	-2.9	-4.4	-6.0	-7.8	-9.7	-11.8	-14.0

Table 6-9. Proposed minimum flows at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage that result in less than a 15 percent reduction in the amount of estuarine fish habitat (shoreline length) based on results of the EFF analysis.

Block 1 (≤29 cfs)	Block 2 (>29 and ≤96 cfs)	Block 3 (>96 cfs)
90 percent of the flow on the previous day	87 percent of the flow on the previous day	68 percent of the flow on the previous day

6.6 Summary of Proposed Minimum Flows

Resource management goals that were addressed with analyses used to develop proposed minimum flows for the Little Manatee River included the following:

- Determination of a low-flow threshold to provide protection for ecological resources and recreational use of the Little Manatee River during critical low-flow periods.
- Maintenance of seasonal hydrologic connections between the Upper Little Manatee River channel and floodplain to ensure the persistence of floodplain structure and function.
- Maintenance of available instream habitat for fish and benthic macroinvertebrates in the Upper Little Manatee River.
- Maintenance of biologically relevant salinities that protect the distribution of plankton, nekton (including all life stages), benthic macroinvertebrates (including all life stages), and shoreline vegetation communities in the Lower Little Manatee River.
- Maintenance of favorable estuarine habitat for nekton in the Lower Little Manatee River.

The primary criteria used for minimum flows development, through the use of flow-based blocks, in both the upper and lower portions of the Little Manatee River was maintenance of 85 percent of the most sensitive criterion associated with the resource management goals. In addition, a low-flow threshold was applied to Block 1 to ensure fish passage, habitat protection, and flow continuity associated with various environmental and human-use values. Based on the results of the analyses described in the previous sections to evaluate the resources of concern, the proposed minimum flows for the Upper and Lower Little Manatee River are described in Tables 6-10 and 6-11.

For the Upper Little Manatee River (Table 6-10), the minimum flow is a monotonically increasing function of the adjusted flow at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage. However, because the allowable percentage reduction in Block 2 is higher than that in Block 1 (0 percent,) the minimum flow would abruptly decrease when the flow switches from Block 1 to Block 2. To avoid this sudden decrease of the minimum flow and maintain its monotonicity, transition flow-ranges were determined, in which the minimum flow is maintained at the maximum minimum flow associated with the lower flow block. Therefore, the proposed minimum flow for Block 2 is a maximum of 29 cfs or an allowable 12 percent flow reduction. For the same reason, the proposed minimum flow for Block 3 for the low floodplain (Block 3a) is a maximum of 85 cfs or an allowable 13 percent flow reduction.

For the Lower Little Manatee River (Table 6-11), the minimum flow is a monotonically increasing function of the adjusted flow at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage. However, because allowable withdrawals differ among blocks, the minimum flow could abruptly decrease when the flow switches from Block 1 to Block 2 or from Block 2 to Block 3. To avoid these sudden flow decreases and maintain the monotonicity of the minimum flow, transition flow-ranges were determined, in which the minimum flow is maintained at the maximum minimum flow associated with the lower flow block. For example, the maximum of the minimum flow for Block 1 is 29 cfs. For the Block 2 transition flow-range, the minimum flow should, therefore, never be less than 29 cfs or an allowable 13 percent flow reduction. For the Block 3 transition flow-range, the minimum flow should not be less than 84 cfs or a maximum allowable flow reduction of 32 percent.

Table 6-10. Proposed Minimum Flows for the Upper Little Manatee River.

Flow-Based Block	If Previous Day's Flow, Adjusted for Upstream Withdrawals, is:	Minimum Flow is:	Potential Allowable Flow Reduction is:
1	≤29 cfs	Flow on the Previous Day	0 cfs
2	>29 cfs and ≤96 cfs	29 cfs or 88 Percent of Flow on the Previous Day, Whichever is Greater	12 Percent of Flow on the Previous Day
3a	>96 cfs and ≤224 cfs	85 cfs or 87 Percent of Flow on the Previous Day, Whichever is Greater	13 Percent of Flow on the Previous Day
3b	>224 cfs	90 Percent of Flow on the Previous Day	10 Percent of Flow on the Previous Day

Table 6-11. Proposed Minimum Flows for the Lower Little Manatee River.

Lower Little Manatee River			
Flow-Based Block	**If Previous Day's Flow, Adjusted for Upstream Withdrawals, is:**	**Minimum Flow is:**	**Potential Allowable Flow Reduction is:**
1	≤29 cfs	Flow on the Previous Day	0 cfs
2	>29 cfs and ≤96 cfs	29 cfs or 87 Percent of Flow on the Previous Day, Whichever is Greater	13 Percent of Flow on the Previous Day
3	>96 cfs	84 cfs or 68 Percent of Flow on the Previous Day, Whichever is Greater	32 Percent of Flow on the Previous Day

The minimum flows for both the Upper and Lower Little Manatee River are to be established at the Hillsborough County EPC's Water Quality Monitoring Station No. 1616 (Figure 6-23), a former monitoring location included Tampa Bay Water's Hydro-Biological Monitoring Program, and are based on daily average flows at the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage adjusted for upstream withdrawals for the period of record from April 1, 1939 through December 31, 2021.

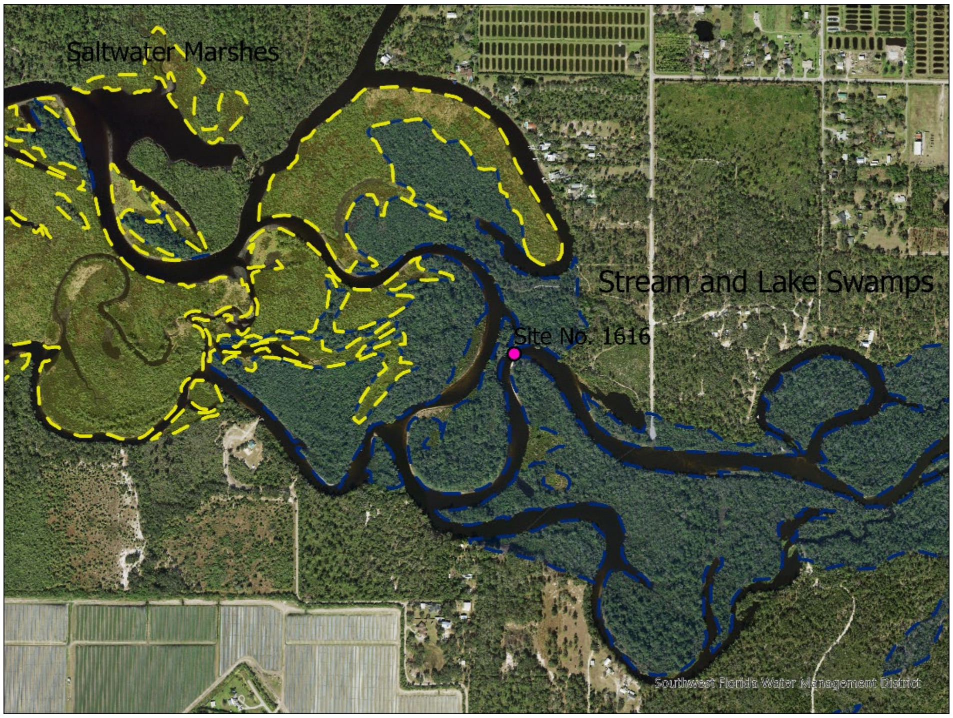


Figure 6-23. Location of the Hillsborough County Environmental Protection Commission's Water Quality Monitoring Station No. 1616 (located at longitude -82.40557 W and latitude 27.66662 N), which was used to define the boundary between the Upper and Lower Little Manatee River for minimum flows purposes. This location was selected based on a review of water quality and biological data. Saltwater Marshes (FLUCCS Code 6420) are defined by the yellow dashed line and Stream and Lake Swamps, Bottomlands (FLUCCS Code 6150) are defined by the blue dashed line (Florida Land Use, Cover and Forms Classification 2020, SWFWMD 2021a).

6.7 Consideration of Environmental Values

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

Primary factors considered for development of the recommended minimum flows for the Little Manatee River included potential, flow-related changes to upper river floodplain wetland inundation, upper river instream habitat, lower river salinity-based habitat, and lower river nekton habitat. Based on the assessments associated with these factors, the recommended minimum flows are protective of all relevant environmental values identified for consideration in the Water Resource Implementation in Rule, as well as those included in the Water Resources Act of 1972 that pertain to the establishment of minimum flows.

6.7.1 Recreation in and on the Water

The Recreation in and on the Water Environmental Value was considered for the Little Manatee River through characterization of water depths, and assessment of potential changes in floodplain inundation, fish and invertebrate habitats, water levels, and salinities.

Using the bathymetric information included in the HEC-RAS model, water levels were considered to ensure that the upper river floodplain (Sections 5.3.2. 5.4.3, and 6.2) and upper river instream habitat (Sections 5.3.3, 5.4.4, and 6.3), including the passage of fish (Sections 5.3.1, 5.4.2.2, and 6.12), were protected under the proposed minimum flows, which also protects recreation in the Upper Little Manatee River.

Some recreational activities, such as fishing, wildlife and natural system observation and study, and swimming, can be associated with water salinities. These activities were, therefore, considered through use of the EFDC hydrodynamic model (Sections 5.3.4, 5.4.5, and 6.4) and EFF (and associated LOESS) model (Sections 5.3.5, 5.4.6, and 6.5) analyses to evaluate potential changes in salinity habitats of ≤ 1, 2, …, ≤ 30 psu with an increment of 1 psu. Results from the modeling efforts were used to develop minimum flow recommendations, which are expected to support maintenance of natural salinity distributions throughout the Lower Little Manatee River.

In addition, because of the Little Manatee River's importance for canoeing and kayaking (a state-designated Paddling Trail begins at the US Highway 301 bridge and goes west for 10 miles (16.1 km) downstream, recreational navigation was evaluated specifically (see Section 6.7.10 below).

6.7.2 Fish and Wildlife Habitat and the Passage of Fish

To support consideration of the Fish and Wildlife Habitat and the Passage of Fish Environmental Value, information summarizing the nekton and benthic macroinvertebrate communities of both the Upper and Lower Little Manatee River were summarized in Chapter 4. These communities include taxa that use various portions of the river system in part based on their tolerance of narrow or broad ranges of salinities.

Using the ZFI (2010 in Appendix N) HEC-RAS model developed for the Upper Little Manatee River (Section 5.4.1), a low-flow threshold of 29 cfs was developed (Sections 5.3.1, 5.4.2, 6.1.1, and 6.1.2) and is proposed to protect the passage of fish in the Upper Little Manatee River. In addition, the recommended low-flow threshold was also shown to be protective of low-salinity habitat in the lower river (Section 6.4) and recommended for minimum flows to be established for the lower river.

A SEFA was conducted to develop minimum flows for the Upper Little Manatee River that protect fish and wildlife instream habitat (Sections 5.3.3, 5.4.4, and 6.3). Flows and water levels were also evaluated during this investigation to ensure important fish and wildlife floodplain habitat was considered and protected in the upper river (Sections 5.3.2, 5.4.3, and 6.2).

Modeling of spatial and temporal distributions of habitats based on water volume, bottom area, and shoreline length associated with salinities ≤1, 2, …, 30 psu with the EFDC hydrodynamic model (Sections 5.3.4, 5.4.5 and 6.4) provided a means for evaluating potential flow-related changes in habitats for fish and other taxa. In addition, estuarine fish habitat was specifically evaluated using the EFF model analysis and ended up being the most sensitive criteria for developing minimum flows for the lower river (Sections 5.3.5, 5.4.6, and 6.5). Results from these analyses were used to identify block-specific, percent-of-flow reductions that are protective of these salinity-based-habitats and were used to develop recommended minimum flows for the Lower Little Manatee River.

6.7.3 Estuarine Resources

Estuarine resources were considered for development of recommended minimum flows for the Lower Little Manatee River through data collection, characterization, and analysis of physical, hydrological, chemical, and ecological aspects of the system. Physical and hydrological characterizations of the lower river are discussed in Chapter 2, and water quality characteristics of the system are summarized in Chapter 3. Summaries of the estuarine resources of concern, including the floodplain, nekton, and benthic macroinvertebrates, are included in Chapter 4.

Assessment of potential, flow-related changes in the spatial and temporal distributions of salinity-based habitats, on which these estuarine resources depend, associated with every isohaline ≤ 30 psu (1-psu increment) with the EFDC hydrodynamic model (Sections 5.3.4, 5.4.5, and 6.4) provided a means for evaluating potential flow-related changes on estuarine resources. Estuarine fish habitat was specifically evaluated using the EFF model analysis and ended up being the most sensitive criteria for developing minimum flows for the lower river (Sections 5.3.5, 5.4.6, and 6.5).

6.7.4 Transfer of Detrital Material

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

The Transfer of Detrital Material Environmental Value was considered for development of recommended minimum flows for the Little Manatee River through use of a percent-of-flow approach intended to maintain characteristics of the baseline flow regime and patterns of upper river floodplain inundation (Sections 5.3.2, 5.4.3, and 6.2) and associated salinity-based habitats (Sections 5.3.4, 5.4.5, and 6.4) expected in the absence of withdrawal impacts. Maintenance of upper river floodplain habitats and lower river salinity-based habitats is expected to support their structural and functional contributions to detrital transfer processes, including roles as sources or sinks for detritus generation, export, and use.

Transfer of detrital material was defined for the evaluation as the movement by water of loose organic material and debris and associated decomposing biota from the overbanks in the floodplain to the main channel. Based on the floodplain inundation analysis (Section 6.2), 96 cfs is a flow threshold in which water starts to overflow from the channel onto the adjacent floodplain. A one- and a seven-day flow duration above 96 cfs were identified as the primary source of detritus in the Little Manatee River. These events were assumed to transfer detritus to the main channel, where it would be subsequently transferred downstream. The extent to which the number of these events and their duration are expected to change as a function of the proposed minimum flows for the Upper Little Manatee River (Table 6-12).

Reducing the baseline conditions by the allowable percent-of-flow reductions associated with the recommended minimum flows, for Blocks 1, 2 and 3, respectively is predicted to result in 10 percent decreases in number of one-day events continuously exceeding 96 cfs. Decreases in the number of seven-day events above 96 cfs associated with associated with the recommended minimum flows is also predicted to 15 percent from baseline conditions. Based on these results, the recommended minimum flows for the Little Manatee River ensure that the transfer of detrital material attributes of the system is protected.

Table 6-12. Number one and seven-day events continuously exceeding 96 cfs in the Upper Little Manatee River under the baseline and minimum flows scenarios evaluated using flows at USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage between October 1, 1939, and December 31, 2021.

Station	Floodplain Inundation Threshold (cfs)	Number of One-day Events above 96 cfs (average events per year)			Number of Seven-day Events above 96 cfs (average events per year)		
		Under Baseline	Under Proposed Minimum Flows	Change (percent)	Under Baseline	Under Proposed Minimum Flows	Change (percent)
USGS Gage	96	137	123	10	91	77	15

6.7.5 Maintenance of Freshwater Storage and Supply

The environmental value, maintenance of freshwater storage and supply is protected through implementation of the District's Water Use Permitting Program, in part, based on the inclusion of conditions in water use permits which stipulate that permitted withdrawals will not lead to violation of any adopted minimum flows or levels. Additionally, the cumulative impact analysis that occurs for new water use permits or increased allocations for existing permits must demonstrate that existing legal users and established minimum flows or levels are protected, further linking minimum flows and levels with the protection of freshwater storage and supply.

The Maintenance of Freshwater Storage and Supply Environmental Value was also considered through development of minimum flows for the Little Manatee River that include block-specific, allowable percent-of-flow reductions that can be easily used to develop permit conditions for existing and future surface water withdrawals. In addition, the recommended low-flow threshold for the river can be directly linked with consideration of the maintenance of freshwater storage and supply.

The District's Environmental Resource Permitting Program also incorporates freshwater storage and minimum flow and level considerations. Design requirements for permitted stormwater treatment and management systems stipulate that where practical, these systems shall be designed to: maintain water tables, base flows and low flows at the highest practicable level; preserve site environmental values, not waste freshwater through overdrainage; not lower water tables which would adversely affect existing legal users; preserve site groundwater recharge characteristics; and retain water on-site for use and re-use for irrigation and other reasonable beneficial uses. In addition, permitted stormwater systems must not reduce or suppress flows water levels such that an established minimum flow or level is not achieved.

6.7.6 Aesthetic and Scenic Attributes

Aesthetic and scenic attributes of the Little Manatee River are inextricably linked to other environmental values, such as recreation in and on the water, fish and wildlife and the passage of fish, estuarine resources, transfer of detrital material, filtration and absorption of nutrients and other pollutants, sediment loads, water quality and navigation. As discussed in previous and subsequent sub-sections of this chapter, all of these environmental values have been considered and, in some cases, associate with specific criteria used in habitat-based methods to develop minimum flow recommendations for the both the Upper and Lower Little Manatee River. As a result, the recommended minimum flows ensure that the aesthetic and scenic attributes of the system are protected.

6.7.7 Filtration and Absorption of Nutrients and Other Pollutants

The Filtration and Absorption of Nutrients and Other Pollutants Environmental Value was considered by assessing system bathymetry, upper river floodplain inundation and instream habitat, and lower river salinity-based and estuarine fish habitats. Consideration of this environmental value is associated with other environmental values that are discussed in previous and subsequent sections of this chapter, including those associated with recreation in and on the water, fish and wildlife and the passage of fish, estuarine resources, transfer of detrital material, sediment loads, and water quality.

6.7.8 Sediment Loads

Sediment loads typically increase during flood events, when floodplains are inundated, and large flows transport large quantities of sediment during these infrequent events. Sediment loads in rivers and estuaries are also dependent on water velocities and residence time.

Sediment loads were considered for development of recommended minimum flows for the Little Manatee River through use of a percent-of-flow approach intended to maintain characteristics of the baseline flow regime and patterns of upper river floodplain inundation (Sections 5.3.2, 5.4.3, and 6.2) and associated lower river salinity-based habitats (Sections 5.3.4, 5.4.5, and 6.4). Maintenance of floodplain and salinity-based habitats is expected to support their structural and functional contributions to detrital transfer processes, including roles as sources or sinks for detritus generation, export, and use.

A key protection metric is whether the long-term sediment loads will significantly be impacted by the recommended minimum flows for the Little Manatee River. Major changes in the sediment transport regime could cause net erosion or deposition of sediment in the channel, thereby changing the natural sediment regime (SJRWMD 2017). For this analysis, sediment loads for baseline and minimum flows conditions were estimated using the Engelund-Hansen Method to evaluate that the baseline sediment regime would not be significantly altered due to the maximum flow reductions that could be allowed based on recommended minimum flows for the Little Manatee River.

The Engelund-Hansen Method (Engelund and Hansen 1972), which predicts total sediment load based on a stream power approach, is highly recommended for sandy bed rivers, such as Florida rivers. The Engelund-Hansen Method is used to predict sediment load based on numerous variables that could include mean flow velocity, bed level shear stress, particle size, specific gravity, and channel width. The steps involved in the sediment load evaluation were as follows:

1. Critical shear stress by particle size classification for sediment mobility was obtained from Berenbrock and Tranmer (2008) (Table 6-13). Sediment mobility for a given particle size is assumed to occur when the bed shear stress exceeds these critical shear stress. The particle size distribution in the Little Manatee River is generally in the range of medium to very coarse sand. Using this grain size range, an average shear stress of 0.01 pound per square foot (lb/ft^2) was identified as a critical average shear stress for sediment transport for the Upper Little Manatee River.
2. The ZFI (2010 in Appendix N) HEC-RAS model was run for 101 flow profiles and provided 101 flow-bed shear-velocity relationships at each HEC-RAS cross section. These 101 flow profiles ranged from one percent to 99 percent exceedance time and were obtained through flow-duration analysis of the flow data at the USGS Little Manatee at US 301 near Wimauma, FL (No. 02300500) gage for the time period from October 01, 1939, to December 31, 2021.
3. A flow-sediment discharge rating curve was developed at each cross section using the Engelund-Hansen method and the 101 flow-shear-stress scenarios.
4. A daily sediment discharge for the baseline condition was generated at each cross section for the period from 1939 through 2021 using the rating curves and an interpolation function in an Excel spreadsheet.
5. Mean annual sediment loads were calculated at the outlet of the nine reaches in the ZFI HEC-RAS model (see Figure 5-8).
6. Steps 3 and 4 were repeated for the minimum flows condition.
7. Relative changes in sediment loads between baseline and minimum flows conditions were calculated to ensure that the long-term sediment loads will not significantly be impacted by the recommended minimum flows for the Little Manatee River.

Table 6-13. Critical shear stress by particle-size classification for determining approximate condition for sediment mobility at 20° Celsius (from Berenbrock and Tranmer 2008)

Particle Name	Particle Diameter (mm)	Critical Shear Stress (lb/ft2)
Coarse cobble	128 – 256	2.24 - 4.46
Fine cobble	64 – 128	1.076 - 2.24
Very coarse gravel	32 – 64	0.518 - 1.076
Coarse gravel	16 – 32	0.244 - 0.518
Medium gravel	8 – 16	0.114 - 0.244
Fine gravel	4 – 8	0.054 - 0.114
Very fine gravel	2 – 4	0.026 - 0.054
Very coarse sand	1 – 2	0.0094 - 0.026
Coarse sand	0.5 – 1	0.0054 - 0.0094
Medium sand	0.25 – 0.5	0.00388 - 0.0054
Fine sand	0.125 – 0.25	0.0029 - 0.00388
Very fine sand	0.0625 – 0.125	0.0022 - 0.0029
Coarse silt	0.0310 – 0.0625	0.001652 - 0.0022
Medium silt	0.0156 – 0.0310	0.00126 - 0.001652
Fine silt	0.0078 – 0.0156	0.000756 - 0.00126

The mean annual sediment loads under the baseline scenario ranged from 52 tons in Reach 0 to 142,360 tons in Reach 7 over the 82-year period of record (Table 6-14). The proposed minimum flows scenario reduced these events at eight of the nine reaches. Expressed as a percent change from the Baseline scenario, the difference between scenarios ranged from 0 to 14 percent. Reaches 4, 5, and 8 had the highest percent change.

Table 6-14. Sediment loads (tons/year) in the Upper Little Manatee River under the baseline and recommended minimum flows scenarios using the Engelund-Hansen Method (Engelund and Hansen 1972).

Reach	Sediment Loads (Tons/Year)		Percentage Change
	Baseline	MFLs	
Reach 0	52	52	0
Reach 1	38,930	33,896	13
Reach 2	32,136	28,237	12
Reach 3	5,763	5,213	9
Reach 4	31,743	27,417	14
Reach 5	67,857	58,113	14
Reach 6	36,955	32,724	11
Reach 7	142,360	124,603	12
Reach 8	13,086	11,224	14

The recommended minimum flows for the Little Manatee River are, therefore, not expected to negatively affect sediment loads. Any changes in sediment loads associated with implementation of the recommended minimum flows are expected to be negligible.

6.7.9 Water Quality

Water quality of the Little Manatee River was summarized in Chapter 3. The Water Quality Environmental Value was also considered through the protection of numerous related environmental values that were considered in the development of minimum flows. These values include recreation in and on the water, fish and wildlife habitat and the passage of fish, estuarine resources, transfer of detrital material, maintenance of freshwater storage and supply, aesthetic and scenic attributes, and filtration and absorption of nutrients and other pollutants. The recommended minimum flows for the Little Manatee River are, therefore, not expected to negatively affect water quality or impair the water designated use of either water body.

6.7.10 Navigation

Commercial and recreational boating, mainly in the form of canoeing and kayaking, in the Little Manatee River is extensive. Navigation has been defined as the safe passage for legal operation of vessels requiring sufficient water depth, sufficient channel width, and appropriate water velocities (SJRWMD 2017, ATM and JEI 2017). The Little Manatee River is generally too shallow for commercial vessels east of US Highway 41; however, there is vibrant ecotourism and recreational boating throughout the river. Ten miles (16.1 km) of the Little Manatee River below US Highway 301 is a state-designated paddling trail, and Canoe Outpost operates a canoe and kayak rental operation with guided tours. Above US Highway 301 (the focus of this evaluation), the river narrows and shallows (https://www.paddleflorida.net/little-manatee-paddle.htm). There is a launch site for canoes and kayaks at the State Road 579 bridge, about 6.5 miles (10.5 km) upstream of the US Highway 301 bridge that is used by Canoe Outpost and individuals as a put-in site. Above State Road 579, the river is characterized by bottomland hardwood swamp with shallow depths, and emergent and fallen trees within the river channel, which is not consistently maintained for navigation. However, under certain flow and water level conditions, it is possible to put in at Leonard Lee Road and canoe or kayak downstream. If the water is too high, overhanging and fallen vegetation will limit recreational navigation in this stretch of the river. If the water is too low, the depth will be insufficient for canoeing or kayaking.

The critical depth for canoe and kayak navigation in the Upper Little Manatee River is defined as a water depth of 0.5 ft (0.15 m), which was identified as the typical draft of a canoe in the minimum flow evaluation for the Lower Santa Fe River (HSW 2021) and verified as a reasonable estimate of the maximum draft of a recreational canoe (https://boatbuilders.glen-l.com/51934/approximating-displacement-canoes-kayaks/). As discussed in Section 6.1.2, 29 cfs maintains the fish passage depth of 0.6 feet (0.18 m) at the most restrictive cross section in the upper river. Therefore, the proposed low-flow threshold of 29 cfs at the USGS Little Manatee River at US 301 near Wimauma gage is protective of canoe and kayak navigation, since the critical depth needed for canoe and kayak navigation is shallower than that needed for fish passage.

CHAPTER 7 – MINIMUM FLOWS STATUS ASSESSMENT AND FUTURE RE-EVALUATION

The current status of the flow regime of the Little Manatee River was assessed to determine whether flows in the river are currently and are projected over the next 20 years to remain above limits associated with the recommended minimum flows. These assessments were completed because the Florida Water Resources Act of 1972 stipulates that if the existing flow or level in a water body is below, or projected to fall within 20 years below, an applicable minimum flow or level, the DEP or the governing board as part of the regional water supply plan shall adopt or modify and implement a recovery strategy to either achieve recovery to the established minimum flow or level as soon as practical or prevent the existing flow or level from falling below the established minimum flow or level.

Based on consideration and review of available flow records for the USGS Little Manatee River at US 301 near Wimauma, FL (No. 02300500) gage, the recommended minimum flows for the Little Manatee River are being met and are also expected to be met over the next 20 years. Also, based on review of existing and permitted water withdrawals from the river, as well as continued implementation of the District's Water Use Permitting program and regional water supply planning efforts, the proposed minimum flows are expected to be met during the next 20-year planning period and beyond. Therefore, development of a recovery strategy or specific prevention strategy is not necessary at this time.

Because water withdrawals, climatic variation, structural alterations, and other changes in the watershed and contributing groundwater basin can influence flow regimes, minimum flow status assessments for the Little Manatee River will be completed by the District on an annual basis, on a five-year basis as part of the regional water supply planning process, and on an as-needed basis in association with permitting and project-related activities. In addition, consideration of these factors that affect river flows, as well as additional information relevant to the minimum flows that may become available, the District is committed to the periodic re-evaluation and, as necessary, revision of the minimum flows established for the Little Manatee River. In support of this commitment, the District, in cooperation with the USGS, will continue to monitor and assess the status of flows in the Little Manatee River, as well as other portions of the watershed, and continue to work with others on refinement and development of tools used for the development of the recommended minimum flows and those that may be developed for future re-evaluations.

7.1 Potential Impacts of Sea Level Rise

Similar to minimum flows evaluations for Crystal River/Kings Bay (Herrick et al. 2019b) and the Lower Peace River (Ghile et al. 2021), potential impacts of sea level rise (SLR) were assessed as part of the minimum flows development for the Lower Little Manatee River. Based on DeWitt et al. (2020), we considered intermediate-low, intermediate, and high SLR estimates from the NOAA's US Global Change Research Program 2017 project (Sweet et al. 2017), over a 40-year period, from 2002 to 2041. The NOAA has SLR estimates at a few stations on Florida's West Coast, including the Cedar Key, St. Petersburg, Clearwater, and Ft. Myer stations. Among them, the St. Petersburg station is very close to the mouth of the Little Manatee River. During 2002 – 2041, intermediate-low, intermediate, and high SLR values at the NOAA St. Petersburg station are estimated to be 0.71', 1.07', and 1.78' (or 0.22 m, 0.33 m, and 0.54 m), respectively.

In the SLR model runs, 0.22 m, 0.33 m, and 0.54 m were added to the water level boundary conditions at the open boundaries of the EFDC hydrodynamic model simulation for the intermediate-low, intermediate, and high SLR estimates, respectively. Because of the use of four uniform sigma layers (layers with equal vertical extent), the added elevation at the open boundaries for an SLR scenario is also uniformly distributed to each sigma level with each gaining one quarter of the elevation increase in its vertical thickness. Without any information on how salinity would be altered at the open boundaries in Tampa Bay under the influence of the SLR, we assumed that the SLR additional elevation did not affect salinity profiles at the open boundaries. Therefore, model runs with and without SLRs used the same salinity time series as salinity boundary conditions, although the SLR runs involved thicker sigma levels. The modified boundary conditions at these open boundaries were then used to drive the model to simulate effects of intermediate-low, intermediate, and high SLR estimates on salinity habitats in the Lower Little Manatee River.

Adding the SLR estimate to the water level at the open boundary is a simple, but rough, way of considering effects of SLR on salinity habitats in the estuary. This approach only considers the direct effects of increased SLR on the estuary. With an added SLR, the estuary will become deeper with a decreased effect of the bottom friction on the water movement, allowing the salt wedge to migrate further upstream. There are many other factors that are associated with SLR, but they were not included in the consideration of its potential impacts on salinity habitats. These other factors may include altered rain patterns in the region and different salinity and temperature characteristics in the Gulf of Mexico.

Following the way potential impacts of SLR were analyzed in the minimum flows re-evaluation for the Lower Peace River (Ghile et al. 2021), six SLR scenario runs were conducted using the EFDC hydrodynamic model. They include the baseline flow and recommended minimum flow with the intermediate-low, intermediate, and high SLR estimates. Model results of these scenario runs allowed us to examine how different SLR estimates would affect salinity habitats under the baseline flow condition and under the recommended minimum flow condition. They also allowed us to examine if the proposed minimum flows are valid for different SLR projections. By verifying if the proposed minimum flows would cause more than 15 percent reduction of critical salinity habitats with the existence of SLR, the latter examination gives us hints if a future re-evaluation of the proposed minimum flows is likely to be necessary. Because the main purpose of the assessment of the potential impacts of SLR is to determine if a re-evaluation is required, we compared simulated salinity habitats under the minimum flow condition with three SLR estimates with those under the baseline flow condition with the same SLR estimates. As salinity habitats respond to flow differently for different flow blocks, the comparisons were made for different flow blocks.

Figure 7-1 shows the percentage changes of salinity volumes for isohalines 1, 2, …, 30 psu under the proposed minimum flow condition for the intermediate-low, intermediate, and high SLR estimates relative to those under the baseline flow condition for the three SLR scenarios. The left, center, and right panels in the figure are for Blocks 1, 2, and 3, respectively. The top, middle, and bottom graphs in each panel are comparisons for the intermediate-low (titled as ‘MFL Intermed-Low SLR’ in the graph), intermediate (titled as ‘MFL Intermed SLR’ in the graph), and high SLR scenarios, respectively. As can be seen from Figure 7-1, during Block 1, the proposed minimum flow would not cause salinity volumes to be reduced more than 15 percent if any of the SLR water surface elevations occurred. Similarly, during Blocks 2 and 3, none of the salinity volumes would be reduced more than 15 percent for any of the three SLR projections.

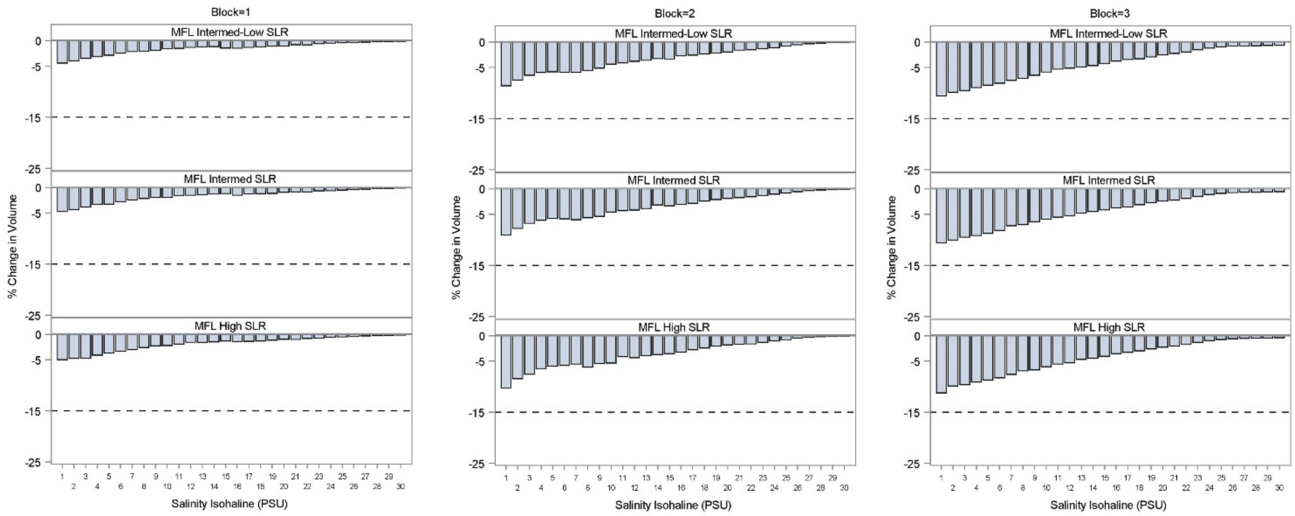


Figure 7-1. Percentage changes of simulated water volumes of isohalines 1, 2, … 30 psu under the minimum flow condition with the intermediate-low, intermediate, and high sea level rise (SLR) projections relative to those under the baseline flow condition with the three SLR projections.

Figure 7-2 presents percentage changes of bottom areas for isohalines 1, 2, …, 30 psu under the proposed minimum flow condition for the intermediate-low, intermediate, and high SLR estimates relative to those under the baseline flow condition with the three SLR projections, in the same way as that in Figure 7-1. As for volume changes, no reductions in bottom area of 15 percent or more for any of the isohalines are predicted to occur during Blocks 1, 2, or 3, with the proposed minimum flow in place if any of the SLR scenarios were to occur.

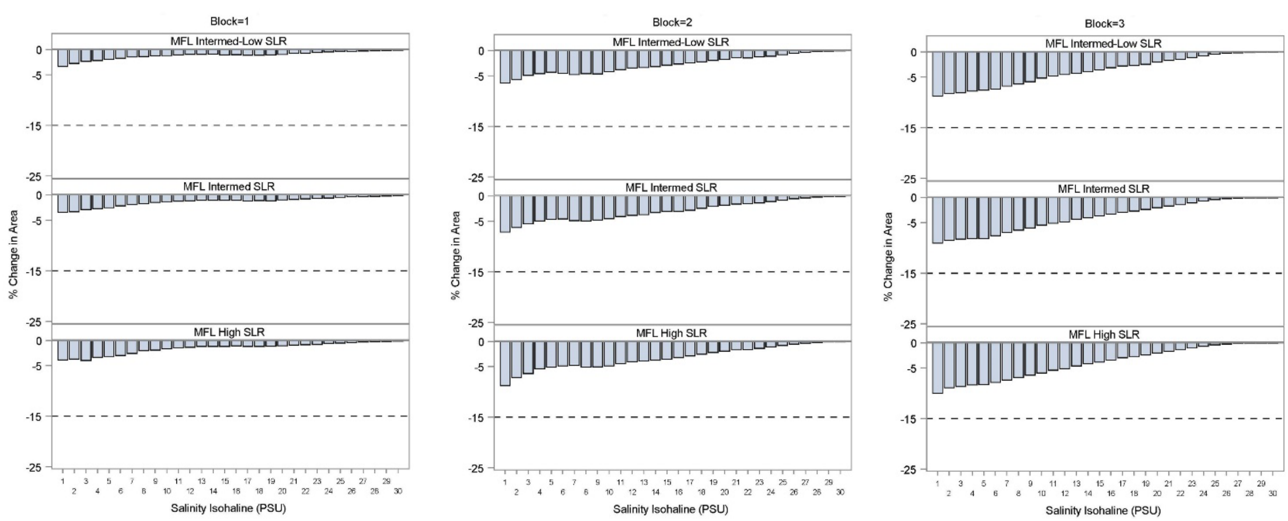


Figure 7-2. Percentage changes of simulated bottom areas of isohalines 1, 2, … 30 psu under the minimum flow condition with the intermediate-low, intermediate, and high sea level rise (SLR) projections relative to those under the baseline flow condition with the three SLR projections.

Figure 7-3 provides the percentage changes of shoreline lengths for isohalines 1, 2, …, 30 psu under the proposed minimum flow condition for the intermediate-low, intermediate, and high SLR estimates relative to those under the baseline flow condition with the three SLR projections, in the same way as that in Figures 7-1 and 7-2. As for volume changes and bottom area changes, no reductions in shoreline length of 15 percent or more for any of the isohalines are predicted to occur during Blocks 1, 2, or 3, with the proposed minimum flow in place if any of the SLR scenarios were to occur.

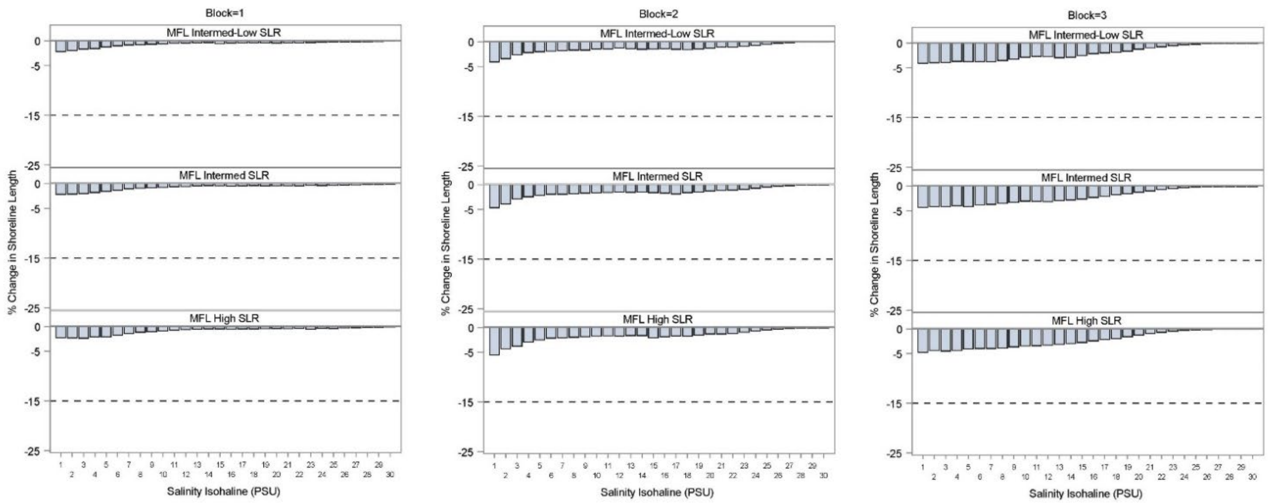


Figure 7-3. Percentage changes of simulated shoreline length of isohalines 1, 2, … 30 psu under the minimum flow condition with the intermediate-low, intermediate, and high sea level rise (SLR) projections relative to those under the baseline flow condition with the three SLR projections.

Based on the information obtained from the results of the analyses presented above, low-salinity habitats were relatively insensitive to the proposed minimum flow during Block 1 when SLR occurred, and only slightly more sensitive during Blocks 2 and 3. For all the potential SLR water elevation increases evaluated, and for each of the three habitat metrics of concern, none of the SLR scenarios with the minimum flow in place resulted in a 15 percent or more change in any of the salinity isohalines. The greatest potential reductions in habitat isohaline metrics were found during Blocks 2 and 3 for the Intermediate and High SLR scenarios, suggesting that if an intermediate SLR or a high SLR condition were to occur then a re-evaluation of the proposed minimum flow in the future should be considered.

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APPENDICES (BOUND SEPARATELY)

Appendix A: Hood, J., M. Kelly, J. Morales, and T. Hinkle. 2011. Proposed Minimum Flows and Levels for the Little Manatee River – Peer Review Draft. Prepared by the Southwest Florida Water Management District, Brooksville, Florida.

Appendix B: Powell, G., G. Grossman, and M. Wentzel. 2012. Review of Minimum Flows and Levels for the Little Manatee River, Florida. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Appendix C: Janicki Environmental, Inc. (JEI). 2018a. Reevaluation of the Proposed Minimum Flows for the Upper Segment of the Little Manatee River, Draft Report. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Appendix D: Jacobs Engineering Group (Jacobs) and Janicki Environmental, Inc. (JEI). 2020. Little Manatee River System MFLs Development Support, Task 4.2 Technical Memorandum, Water Quality. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Appendix E: Janicki Environmental Inc. (JEI). 2018b. Draft Recommended Minimum Flows for the Little Manatee River Estuary, Draft Report. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Appendix F: Initial Peer Review Report, Re-evaluation of Minimum Flows for the Little Manatee River System. 2021. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Appendix G: Holzwart, K.R., Y. Ghile, X. Chen, G. Herrick, K. Deak, J. Miller, R. Basso, and D. Leeper. 2023. Southwest Florida Water Management District Draft Response to the Initial Peer Review of the Recommended Minimum Flows for the Little Manatee River, September 2021 Draft Report. Prepared by the Southwest Florida Water Management District, Brooksville, Florida.

Appendix H: Final Peer Review Report, Re-evaluation of Minimum Flows for the Little Manatee River System. 2021. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Appendix I: Compilation of Public and Stakeholder Comments
Appendix I1: Comments Through June 2023, Pages 1 – 531
Appendix I2: Comments Through June 2023, Pages 532 – 1356
Appendix I3: Comments From July Through November 2023

Appendix J: Summary of September 2023 Public Workshop

Appendix K: Post, Buckley, Shuh, and Jernigan, Inc. (PBS&J). 2008. Characterization of Woody Wetland Vegetation Communities Along the Little Manatee River, Draft. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Appendix L: Grabe, S. and T. Janicki. 2008. Analysis of Benthic Community Structure and its Relationship to Freshwater Inflows in the Little Manatee River Estuary. Prepared for the Southwest Florida Water Management District. Brooksville, Florida.

Appendix M: Plots of Information Used to Develop the Lower Little Manatee River Flow Blocks.

Appendix N: ZFI Engineering and Construction, Inc. (ZFI). 2010. HEC-RAS Modeling of the Little Manatee River. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Appendix O: Janicki Environmental, Inc. (JEI). 2023. Hydrodynamic Model Development, Calibration, Verification, and Evaluation of Flow Reduction and Sea Level Rise Scenarios in Aid of Minimum Flows Development for the Lower Little Manatee River. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.

Appendix P: Intera and Aqua Terra Consultants. 2006. Estimating the Ungaged Inflows in the Little Manatee River Basin, Florida. Prepared for the Southwest Florida Water Management District, Brooksville, Florida.