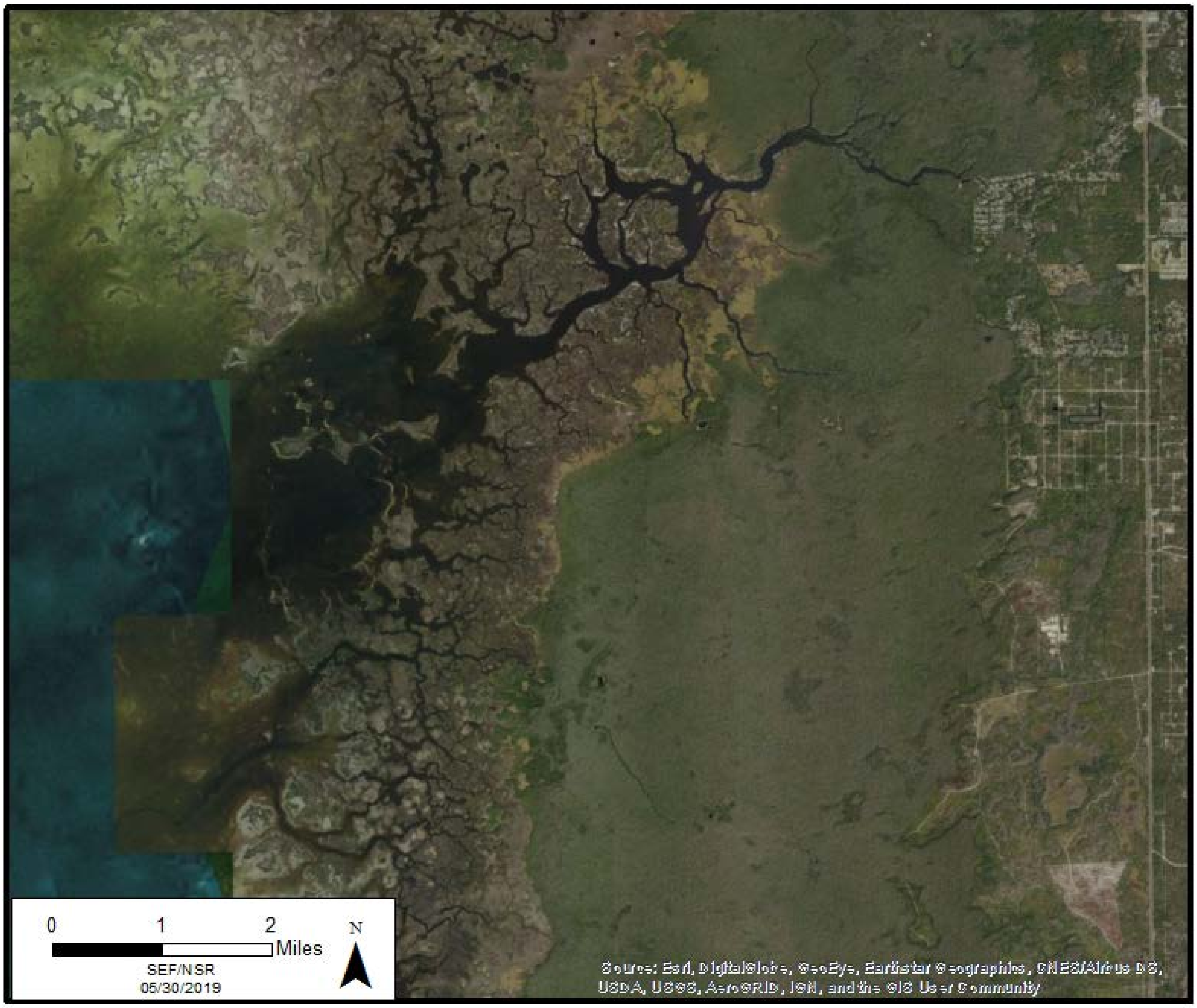
Reevaluation of Minimum Flows for the Chassahowitzka River System

Final Draft



October 2019

Southwest Florida
Water Management District

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Brooksville, Florida 34604-6899

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Reevaluation of Minimum Flows for the Chassahowitzka River System

October 2019

The geological evaluation and interpretation contained in the report entitled *Reevaluation of Minimum Flows for the Chassahowitzka River System* has been prepared by or approved by a Certified Professional Geologist in the State of Florida, in accordance with Chapter 492, Florida Statutes.

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EXECUTIVE SUMMARY

The Southwest Florida Water Management District (District) is directed by the Florida Legislature to establish minimum flows for rivers and springs within its jurisdiction. Minimum flows are defined in Section 373.042(1) Florida Statutes as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." Once adopted into District rules, minimum flows can be used for water supply planning, water use permitting and environmental resource regulation.

This report identifies recommended minimum flows that were developed as part of the reevaluation of minimum flows currently established for the Chassahowitzka River System. District Rule (Section 40D-8.041(16), Florida Administrative Code) establishes minimum flows for the Chassahowitzka River System, and requires reevaluation of the minimum flows in 2019, six years from initial adoption in 2013. As part of the reevaluation, recommended minimum flows were developed using the best information available, as required by the Florida Statutes, and were based on all relevant environmental values identified in the Florida Water Resource Implementation Rule (Section 62-40.473, Florida Administrative Code) for consideration when setting minimum flows.

The Chassahowitzka River System includes the Chassahowitzka River, contributing tributaries, all unnamed and named springs that discharge to the river, and Blind Springs. This system description is applicable for the current minimum flows reevaluation; however, the system may also alternatively be referred to as the Chassahowitzka River/Chassahowitzka Spring Group and Blind Springs. The Chassahowitzka River flows approximately 6 miles (9.7 kilometers) through Citrus and Hernando Counties to the mouth in Chassahowitzka Bay, which is connected to the Gulf of Mexico. The Chassahowitzka River System is fed by 17 named springs. The entire system is influenced by tides and saltwater from the Gulf of Mexico. All non-artificial water bodies in the Chassahowitzka River System are classified as Outstanding Florida Waters, a designation associated with Florida's anti-degradation policy (Rule 62-302.700, F.A.C.). In addition, the Chassahowitzka River is designated a Southwest Florida Water Management District Surface Water Improvement and Management (SWIM) Priority Waterbody and as such, has a comprehensive SWIM Plan approved by the Springs Coast Steering Committee and the District's Governing Board in August 2017.

The recommended minimum flows for the Chassahowitzka River system are 92 percent of flows that would occur in the absence of withdrawal impacts; allowing up to an 8 percent reduction from unimpacted flows. This recommendation is made on the basis of three criteria which are all equally sensitive to simulated reductions in flow: area and volume of salinity-based habitats less than or equal to 1 practical salinity unit and temperature-based habitat for Common Snook. Groundwater modeling (Northern District Model version 5.0) indicates current (2015) withdrawal impacts reduce flows by 1.4 percent, with projected demand increasing this to as much as 2.0 percent by 2035. Because current withdrawal impacts are less than the maximum allowable 8 percent reduction associated with the proposed minimum flow, development of a recovery strategy concurrent with adoption of the proposed minimum flow would not be necessary at this time. Likewise, a prevention strategy would not be needed because projected impacts of 2.0 percent are less than the maximum allowable of 8 percent reduction associated with the proposed minimum flow.

A peer review for this minimum flows reevaluation was conducted in two phases from February through June 2019. The first phase was an initial peer review that culminated in recommendations for changes to the report documentation and analyses and provided initial conclusions on the technical defensibility of the minimum flows reevaluation. Following submittal of the Initial Peer Review Report, District staff made changes to the minimum flows report and one of the appendices along with providing additional technical documents in response to the recommendations. Based on the District responses to comments, additional technical documentation, and the updated documents, no unresolved recommendations remain, and the panel supported the conclusions presented within the minimum flows report and the use of the three critical habitats as the defining metrics.

Updates to data collection and analysis supporting the minimum flow reevaluation included new shoreline vegetation mapping, submerged aquatic vegetation surveys, oyster health assessment, a barnacle survey, fish community sampling, development of a new hydrodynamic model for characterizing system salinities and temperatures, use of a new criterion associated with temperature-based habitat for Common Snook, development and use of the updated Northern District groundwater flow model, and new water quality analysis. Findings associated with use of these improved data and tools are generally consistent with the previous work completed for the District's original minimum flows evaluation, which identified a minimum flow that would allow up to a 9 percent reduction in unimpacted flows. That original finding was not however incorporated into the conservative minimum flow for the river system that the Governing Board established in 2013 and which only allows up to a 3 percent reduction from unimpacted flows.

Simulations of reduced flows used for the minimum flow reevaluation were based on gaged flows at the United States Geological Survey (USGS) Chassahowitzka River near Homosassa, FL gage (No. 02310650). The long-term average flow for all "approved" daily data from February 20, 1997 to September 1, 2016 at this gage was 58.9 cubic feet per second (cfs). Adjusted for withdrawal impacts of 1.4 percent, the long-term unimpacted flows would average 59.7 cfs, and minimum flows, corresponding to 92 percent of the unimpacted flow would average 55 cfs over the same time period.

The District will continue to implement its general, three-pronged prevention strategy that includes monitoring, protective water-use permitting, and regional water supply planning to ensure that the adopted minimum flow for the system continues to be met. In addition, the District will continue to monitor flows in the system to further our understanding of the structure and functions of the Chassahowitzka River System and to develop and refine our minimum flow development methods.

CHAPTER 1 - INTRODUCTION

1.1 2013 Minimum Flows Evaluation and Rule

This report documents a reevaluation of the minimum flow established for the Chassahowitzka River System in 2013 by the Southwest Florida Water Management District (SWFWMD or "District"). The Chassahowitzka River System includes the Chassahowitzka River, contributing tributaries, all unnamed and named springs that discharge to the river, and Blind Springs. This system description is applicable for the current minimum flows reevaluation; however, the system may also alternatively be referred to as the Chassahowitzka River/Chassahowitzka Spring Group and Blind Springs. In the absence of consistent, long-term flow data at Blind Springs and others, the minimum flow, and protection afforded by it, for these springs is equivalent to that established for the Chassahowitzka River/Chassahowitzka Spring group as a whole.

The currently established minimum flow for the system is supported by technical data, analyses, methodologies, models, and assumptions described in a 2012 District report (Heyl et al. 2012). Habitats and biological resources assessed and considered for the original minimum flow effort included salinity habitats, gross primary productivity, and manatee thermal habitat. Warm-water habitat necessary to avoid acute temperature stress in manatees was the most sensitive metric evaluated.

The District staff recommendation included in Heyl et al. (2012) was for a maximum allowable 9 percent reduction from flows that would occur in the absence of withdrawal impacts. This recommendation was equivalent to a minimum flow of 91 percent of unimpacted flows. This recommendation was developed following review of data and methods by a peer review panel (Powell et al. 2010), which supported the District staff recommendation.

Following public comment on and review of the staff-recommended minimum flow for the Chassahowitzka River System, the District Governing Board approved a minimum flow of 97 percent of unimpacted flows, which would allow up to a 3 percent reduction from unimpacted flows, and that minimum flow was adopted as Rule 40D-8.041(16), Florida Administrative Code (F.A.C.) into the District's Water Levels and Rates of Flow in 2013 (**Box 1**). The term "natural flow" identified in the rule may be considered synonymous with "unimpacted flows." Because the rule was adopted in 2013, reevaluation of the minimum flow for the Chassahowitzka River System is scheduled to occur before the end of 2019.

Chapter 40D-8 (Florida Administrative Code)
Water Levels and Rates of Flow
40D-8.041 Minimum Flows.

(16) Minimum Flow for the Chassahowitzka River System.

(a) For purposes of this rule, the Chassahowitzka River System includes the watercourse from the Chassahowitzka Main Springs Complex to the Gulf of Mexico, including contributing tributaries, Blind Springs and all named and unnamed springs that discharge to the river.

(b) The Minimum Flow for the Chassahowitzka River System is 97% of the natural flow as measured at the United States Geological Survey (USGS) Gage Chassahowitzka River near Homosassa (Gage No. 02310650). Natural flow is defined for the purpose of this rule as the flow that would exist in the absence of water withdrawal impacts. The Minimum Flow at any point downstream from this Gage is measured as the previous day's natural flow at that point minus 3%.

(c) The District will reevaluate the Minimum Flow within six years of adoption of this rule.

Box 1. Rule 40D – 8.041(16), Florida Administrative Code.

1.2 Legal Directives and Use of Minimum Flows and Levels

1.2.1 Relevant Statues and Rules

The purpose of this report is to reevaluate the minimum flows recommendation for the Chassahowitzka River System by establishing the minimum spring discharges necessary to prevent significant harm to the water resources and ecology of the system. Florida Statutes and Florida Administrative Code provide the following guidance for setting minimum flows:

1. Section 373.042 of The Florida Water Resources Act of 1972 (Chapter 373, Florida Statutes or F.S.) directs the Department of Environmental Protection (DEP) or the District to establish minimum flows for all surface watercourses in the area. This section states that "the minimum flow and minimum water level shall be calculated by the department and the governing board using the best information available." This statute also establishes the priority list and schedule which is annually updated and approved by the governing board. Section 373.042 also allows for the establishment of an independent scientific peer review panel.
2. Section 373.0421, F.S., allows for considerations of changes and structural alterations. In cases where dams, or extensive channelization have altered the hydrology of a system for flood control and water supply purposes, the District attempts to balance protecting environmental values with the human needs that are met by these alterations. This section also 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.
3. Rule 62-40.473 of The Florida Water Resource Implementation Rule (Chapter 62-40, F.A.C.), provides goals, objectives and guidance regarding the establishment of minimum flows and levels. 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. Rule 40D – 8.041(17) within the District's Water Level and Rates of Flow Rules (Chapter 40D-8, F.A.C.) describes the Minimum Flow for the Chassahowitzka River System and establishes a schedule for its reevaluation (see section 1.1 above).

The District's Minimum Flows and Levels Program addresses all relevant requirements expressed in the Water Resource Implementation Rule and the Water Resources Act of 1972. The Chassahowitzka River system is a flowing surface water course, and as such its volume of flowing water must be protected from significant harm. Establishing minimum flows that address all relevant requirements expressed in the Florida Water Resources Act of 1972 and the Water Resource Implementation Rule will support water-use permitting, water-supply planning and other water management activities that can provide this protection.

The District has developed specific methodologies for establishing minimum flows or minimum water levels for lakes, wetlands, rivers, springs and aquifers, subjected the methodologies to independent, scientific peer-review, and in some cases, adopted the methods into its Water Level and Rates of Flow Rule. In addition, regulatory components of recovery strategies necessary for the restoration of minimum flows and minimum water levels that are not currently being met have been adopted into the District's Recovery and Prevention Strategies for Minimum Flows and Levels Rule (Chapter 40D-80, F.A.C.). A summary of efforts completed for the District's Minimum Flows and Levels Program is provided by Hancock *et al.* (2010).

The District has established and codified minimum flows for 18 river segments into its Water Level and Rates of Flow Rule. Minimum flows recommendations, peer reviews, appendices with technical documents, and other related material are available from the District's Minimum Flows and Levels (Environmental Flows) Program web page.

1.2.2 Environmental Values

As part of its intention to provide goals, objectives, and guidance concerning establishment of minimum flows and water levels, Rule 62.40.473, F.A.C., within the Water Resource Implementation Rule, states that "consideration shall be given to natural seasonal fluctuations in water flows or levels, nonconsumptive uses, and environmental values associated with coastal, estuarine, riverine, spring, aquatic and wetlands ecology, including:

(a) Recreation in and on the water;

(b) Fish and wildlife habitats and the passage of fish;

(c) Estuarine resources;

(d) Transfer of detrital material;

(e) Maintenance of freshwater storage and supply;

(f) Aesthetic and scenic attributes;

(g) Filtration and absorption of nutrients and other pollutants;

(h) Sediment loads;

(i) Water quality; and

(j) Navigation."

The ways in which these environmental values are protected by the methods and results of this revaluation of minimum flows for the Chassahowitzka River System are provided in Chapter 7.

1.3 Vertical Datum

The District is in the process of converting 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. While the NGVD 29 datum is used for most elevation values included within this report, in some circumstances elevation data were collected or reported relative to mean sea level or relative to NAVD 88. As necessary, elevations relative to the differing datums were converted to alternate datums in accordance with the District's internal operating procedure for minimum flows and levels data collection, summarization, reporting and rule development (Leeper 2016).

1.4 Development of Minimum Flows and Levels in the Southwest Florida Water Management District

The development of Minimum Flows proceeds from the following premises:

1. Alterations to hydrology will have consequences for the environmental values listed in Rule 62.40.473, F.A.C., and section 1.2.2 of this report.
2. We can measure criteria linked to these environmental values. We can also quantify links between flow alterations and measured criteria.
3. Flows may be reduced from non-withdrawal impacted conditions yet be of sufficient magnitude to protect the water resources and ecology of the area that are associated with the identified environmental values.

An established body of scientific work supports all three of these premises by relating hydrology, ecology, and human-use values associated with water resources (Poff and Zimmerman 2010; Postel and Richter 2012). For example, consider a pristine, unaltered river with no local groundwater or surface water withdrawal impacts. We expect this hydrologic regime to respond in proportion to the magnitude of any new water withdrawals. Small withdrawals may produce a new hydrologic regime that is indistinguishable from the unimpacted regime, while large withdrawals could produce substantially altered regimes. An intermediate hydrologic regime will protect the water resources and ecology from significant harm while allowing for deviation from the historical hydrological condition. Our objective is to define such an intermediate hydrologic regime that prevents significant harm yet allows for withdrawals that may shift the regime away from historical or theoretically optimal conditions.

Rivers demonstrate a range of flows in response to both short- and long-term rainfall patterns. The typical pattern of variation in flows is termed a "hydrologic regime". The environmental flows literature supports protecting the natural hydrologic regime (Annear et al. 2004; Hill et al. 1991; Olsen and Richter 2006; Poff et al. 1997; Postel and Richter 2012; Richter et al. 1996). The District's approach to developing minimum flows, and those used by other Florida water management districts (Mace 2007; Neubauer et al. 2008; South Florida Water Management District 2002; Water Resources Associates, Inc. et al. 2005) have been developed to help maintain natural hydrologic regimes, albeit with some allowance for water withdrawals.

Based on the importance of the hydrologic regime to river system integrity, the District has employed a percent-of-flow approach for establishing minimum flows (Flannery et al. 2002).

Percent-of-flow approaches have been advocated for minimum flow determinations world-wide (Richter et al. 2011). The District's percent-of-flow method identifies flow reductions as percentages of flows that may be withdrawn directly from a river or from aquifers that contribute flows to a river without causing significant harm. By proportionally scaling water withdrawals to the rate of flow, the percent-of-flow approach is considerably more protective of flow variability than simple low-flow thresholds (Richter et al. 2011).

For minimum flow evaluations of some surface-water runoff driven rivers in the District, the percent-of-flow approach has been superimposed on seasons referred to as "blocks." In these runoff-dominated systems, three blocks are typically identified, with each block associated with specific, allowable percent-of-flow reductions. However, while flow in the Chassahowitzka River demonstrates some seasonal variation, it does not exhibit strong, distinct seasonal patterns which would necessitate two or more percentages to be applied at different times of year. Therefore, it is appropriate to establish a single allowable percent-of-flow reduction which applies to the entire year for the Chassahowitzka River System.

The development of minimum flows for coastal systems such as the Chassahowitzka River System necessarily involves the evaluation of flow effects on downstream estuaries. Estuaries account for approximately three-quarters of the Florida coastline (Kleppel *et al.* 1996), and these habitats serve as spawning areas, nurseries or other habitat for more than 95 percent of Florida's recreationally and commercially harvested fish, shellfish and crustaceans (Florida Fish and Wildlife Conservation Commission 2007). Thus, we must also take into consideration how changing flows in rivers can subsequently impact these coastal communities.

1.4.1 Significant Harm

Minimum flows must be established to prevent significant harm to the water resources or ecology of the Chassahowitzka River System (Section 373.042, F.S.). However, no definition of significant harm is given in the statute. This makes the District or DEP responsible for determining the conditions that constitute significant harm in each system.

The District uses two categories of criteria for determining significant harm:

1) natural breakpoints, inflections, or thresholds; and
2) presumptive, habitat- or resource-based criteria.

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

In the Chassahowitzka River system, the District is responsible for collecting and analyzing data on flows, water levels, salinity, temperature, water quality, shoreline vegetation, submerged aquatic vegetation, fish communities, invertebrates including oysters and barnacles, and manatees. Despite this abundance of data, and review of environmental flows literature, no natural breakpoints, inflections, or thresholds associated with reduced flows have been identified for this system. In such instances when natural breakpoints, inflections, or thresholds are not available, the District has used a presumptive, 15% reduction in habitats or resources as a measure of significant harm. This 15% reduction criterion lacks the clear, ecological basis a natural threshold would carry, but does have advantages over a presumptive, flow-based criterion. For example, a 10% reduction in flows, applied across systems, may be overly restrictive in some systems and under-protective in others. By modeling changes to habitats and resources with incremental flow reductions, the 15% standard is sensitive to habitat or resource losses unique to each system. Because of this sensitivity, the 15% standard, as a habitat- or resource-based presumption is preferable to a flow-based presumption. It is also important to note that the consideration of multiple criteria based on the 15% change standard (e.g., assessing flow-related changes in salinity and thermally-based habitats) is a means for dealing with uncertainty associated with individual criteria that may be inherent in, for example, modeling approaches used for criteria assessment.

The District has successfully used a 15 percent habitat- or resource reduction standard as a criterion for significant harm starting with the suggestion of the peer review panel for the upper Peace River (Gore et al. 2002). This 15 percent resource reduction standard states that the minimum flow is that below which more than 15 percent of measured criteria would be lost or become unavailable. Criteria for setting minimum flows are selected based on their relevance to the environmental values and confidence in their predicted responses to flow alterations. A weight of evidence approach is used to determine if the most sensitive criteria is that with which minimum flows will be set, or if multiple criteria will be averaged.

We typically express minimum flows as a fraction of baseline, unimpacted flows. Suppose a 10 percent reduction in flow resulted in a 15 percent reduction in fish habitat. In such a case, our minimum flows would be set at 90 percent of unimpacted flows to prevent loss of more than 15 percent of the resource. This percent-of-flow approach has been used to establish and implement minimum flows in numerous District systems and has been supported by multiple independent peer reviews (Flannery et al. 2002; Herrick et al. 2017; Heyl 2008; Heyl et al. 2010, 2012; Leeper et al. 2012).

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 peer-review panel that considered the District's proposed minimum flows for the upper Peace River. In their report, the panelists note that "*In general, instream flow analysts consider a loss of more than 15 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 System (PHABSIM) for analyzing flow, water depth and substrate preferences that define aquatic species habitat availability.

Use of a 15 percent change in ecological criteria linked to environmental values as constituting significant harm and therefore, for development of minimum flow recommendations, has been extended by the District to evaluate changes beyond the original instream habitat (PHABSIM) application. Because the ecological integrity of a river depends upon diverse factors including salinity, temperature, and other measurable variables, the 15 percent standard has been used to identify significant harm as the loss or reduction of: habitat associated with invertebrates and fish in freshwater and estuarine systems; days and spatial extent of floodplain inundation; population size or abundance of fish and invertebrates; temperature-based habitats for the Florida manatee (*Trichechus manatus latirostris*); and salinity-based habitats in estuaries. The determination of significant harm as the loss of 15% of these and other ecological criteria linked to environmental values has been incorporated into numerous minimum flows included in the District's Water Levels and Rates of Flow Rule.

Nineteen 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.

Environmental flows, of which minimum flows may be considered a subset, have been studied worldwide. Many systems that have received attention are much more heavily altered than those within the District. For example, the published research on environmental flows includes systems that have withdrawals in excess of 50 percent, impoundments or both, e.g., Murray-Darling in Australia (Overton et al. 2009), San Francisco Bay (Kimmerer 2002), and many more reviewed by Poff and Zimmerman (2010). Two independent reviews of existing literature both concluded that although the majority of studies (86% - 92%) recorded ecological changes in response to reduced flow, there are no universal responses that can be used to confidently apply presumptive, flow-based thresholds for harm across systems (Lloyd et al. 2004; Poff and Zimmerman 2010). In their literature review, Lloyd et al. (2004) conclude that across rivers, relationships between flow and ecological responses are not simple, and no simple thresholds were detected. In order to apply presumptive, flow-based criteria, we would need to be able to assume simple relationships between flow and ecological responses, which Lloyd et al. (2004) found do not exist across rivers. Poff and Zimmerman (2010) reviewed 165 papers and found "strong and variable ecological responses to all types of flow alteration." A presumptive, habitat- or resource-based standard for significant harm avoids the assumption of simple, consistent relationships between flow and ecological responses by using available data to predict changes in incremental flow reductions when natural thresholds either do not exist or are not represented by the current, best information available.

Potential loss of habitats and resources in other systems has been managed 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) note, "…*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 percent to 20 percent reduction in natural flows will provide high to moderate levels of protection, respectively (Richter et al. 2011). More recently, Gleeson and Richter (2017) suggest that "high levels of ecological protection will be provided if groundwater pumping decreases monthly natural baseflow by less than 10% through time." Presumptive flow-based criteria such as these assume that resources are protected when more detailed relationships between flow and resources of interest are not available. Habitat- or resource-based presumptions of harm are based on data and analyses linking incremental reductions in flow to reductions in resources or habitats. As such, the 15% habitat- or resource-based standard makes more use of the best information available than a presumptive, flow-based criterion would. In the absence of natural breakpoints, inflections, or thresholds, the 15% presumptive habitat or resource based standard for significant harm represents the District's best use of the best available information.

1.4.2 Flow Definitions

To address all relevant requirements of the legal mandates described above and aid in the understanding of information presented in this report, we find it helpful to elaborate on several flow-related definitions and concepts found herein.

1. Flow refers to streamflow or discharge – the volume of water flowing past a point for a given unit of time.
2. Long-term is defined in Rule 40D-8.021, F.A.C., as an evaluation period for establishing minimum flows and levels that spans the range of hydrologic conditions which can be expected to occur based upon historical records.
3. Reported, measured, gaged, and observed flows can be directly measured, however, in practice, flows are derived from relationships to directly-measured stage (elevation) and velocity data. The U.S. Geological Survey (USGS) commonly use an index velocity approach, which uses acoustically measured velocity and cross-sectional area to calculate discharge for reported flows in tidal rivers and their contributing springs. Use of regression equations relating water levels in groundwater to surface water levels near the spring vent has also been used by the USGS for these systems (Knochenmus and Yobbi 2001).
4. Modeled flows are flows that are derived using a variety of modeling approaches. Examples include flows predicted using numerical 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.
5. Impacted flows are flows that include withdrawal-related impacts. Impacted flows can be *reported flows*, and they can also be *modeled flows*.
6. Unimpacted, baseline, or historic(al) flows occurred in the absence of withdrawal impacts. Unimpacted flows may be *observed flows* if data exists prior to any withdrawal impacts. More typically, unimpacted flows are long-term flows adjusted for withdrawals and/or other alterations. Rule 40D-8.021, F.A.C., defines "historic" as "a Long-term period when there are no measurable impacts due to withdrawals and Structural Alterations are similar to current conditions."
7. 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."
8. A hydrologic (flow) regime is the overall pattern in 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 as provided in Section 373.042(1), F.S." The emphasis on a flow regime, rather than a single minimum flow value, reflects the natural variation present in flowing water systems (Poff et al. 1997). Expressing a minimum flow as an allowable percentage of a flow addresses the intent of protecting the flow regime as allowable flow changes are proportionally-scaled to the magnitude of flow.

1.4.3 Adaptive Management

This reevaluation of minimum flows in the Chassahowitzka River System reflects the application of an adaptive management strategy for dealing with uncertainty in this complex, dynamic system. Uncertainty is an unavoidable consequence of the ever-changing natural and anthropogenic processes within and affecting the Chassahowitzka River System. From both scientific and management perspectives, there is uncertainty associated with determining withdrawal impacts on physical, biological, and chemical aspects of the system.

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

The initial evaluation (Heyl et al. 2012) and rulemaking that resulted in establishment of the existing minimum flows for the Chassahowitzka River System in 2013 were completed using the best information and the most accurate tools available for predicting withdrawal impacts. However, as with all natural systems management, there was uncertainty associated with the initial recommended minimum flows, and this uncertainty was one of the factors contributing to the scheduling of a reevaluation of the system in 2019. Between development of the initial minimum flow recommendation and this 2019 reevaluation, the District has continued monitoring the system (including collection of data on fish, plants, invertebrates, water quality, water flows and levels), evaluated withdrawals that may affect the system, and has updated the most accurate tools for predicting withdrawal impacts on this system. In addition to supporting this 2019 reevaluation, the newly developed information has been used for annual status assessments which have indicated the established minimum flows continue to be met.

This 2019 reevaluation of minimum flows closes the loop for a single iteration of an adaptive management process by assembling, evaluating and using the best information currently available to develop revised, recommended minimum flows for the Chassahowitzka River System. The minimum flow recommendations resulting from this reevaluation are made in acknowledgment of the continued, unavoidable uncertainty in our understanding of natural patterns and processes inherent to the system as well as uncertainty associated with predicting the consequences of future water withdrawals. Continued adaptive management of the Chassahowitzka River System will require ongoing monitoring, assessment, and periodic reevaluation of minimum flows.

1.5 Differences Between the Original Minimum Flow Evaluation and this 2019 Reevaluation

This report documents a 2019 reevaluation of the current minimum flow established in 2013 for the Chassahowitzka River System and the original, technical information summarized by Heyl et al. (2012) that supported that effort. Much of the technical data, analyses, methodologies, models and assumptions described in the 2012 District report also support the current minimum flow reevaluation; however, the reevaluation effort includes substantial updates of this information. Important updates for the reevaluation include:

Surface water modeling improvements: The Laterally Averaged Model for Estuaries (LAMFE) model replaces the Environmental Fluid Dynamics Code (EFDC) model. This application of the LAMFE model can fit the river bathymetry better than the previous application of the EFDC model for the Chassahowitzka River, which is narrow and meandering. This application of the LAMFE model in the Chassahowitzka River minimum flow re-evaluation has much longer periods for calibration, verification, and flow reduction scenario runs than the previous application of the EFDC model (Table 1-1). LAMFE model verification statistics represent an improvement of the 2012 EFDC model statistics. The LAMFE surface water modeling effort is described in Chapter 6.

1) **Newer, more extensive flow and water quality data:** The evaluation described in the 2012 report was based on water level, flow, water quality, and biological assessment data collected prior to 2010. The 2019 reevaluation used more recent and comprehensive data. Flows were measured in several tributaries, including Crab, Baird, Crawford, and Potter creeks, to better parameterize the LAMFE model. Updated USGS gage data for previously assessed sites are summarized in Chapter 2 of this report. The latest water quality information includes data collected by the Districts Data Collection Bureau. The District hired the consultant Janicki Environmental Inc. and WSP, Inc. (2018 [Appendix 8]) to analyze these and other water quality data to look for links between water quality and flow. This information is provided in Chapter 3.

2) **Biological status and trends were updated:** The District conducted a new, more thorough and extensive mapping of shoreline vegetation, surveyed oysters and barnacles, cooperated with the Florida Fish and Wildlife Conservation Commission (FWC) to conduct seasonal fish community surveys, and monitored submerged aquatic vegetation (SAV). This information is provided in Chapter 4.

3) **Groundwater modeling improvements:** The hydrogeologic model used to predict effects of groundwater withdrawals on river and spring flows has been updated (current version is the Northern District Model Version 5 or NDM5). New hydrological and water use data that have become available since the 2012 evaluation have been incorporated into model development and simulations. These updates are described in Chapter 5.

The District's 2019 reevaluation of the currently established minimum flows for the Chassahowitzka River System represents a complete, new evaluation with new, expanded data sets, updated models and other analytical tools. The data, modeling and other analytical updates are responsible for differences in conclusions between the previous 2012 evaluation and the current 2019 reevaluation. This report is a summary of the most recent data and analyses; it is not a revision of the previous 2012 report. This report does not follow the same chapter and heading structure from the previous 2012 report, but all elements found in the 2012 report can be found in this newer 2019 reevaluation report (Table 1-2.).

Table 1-1. Updates to surface water modeling for the Chassahowitzka River System minimum flow reevaluation EFDC = Environmental Fluids Dynamic Code; LAMFE = Laterally Averaged Model for Estuaries

Model	Calibration	Verification	Scenarios
2012 EFDC	2006-2007 manatee season	None described in report (Dynamic Solutions LLC 2009)	2006-11-01 to 2007-02-28 (4 mo)
2019 LAMFE	(2012-11-18 to 2015-12-31) (3 y)	2016-01-01 to 2017-03-28) (15 mo)	2007-10-11 to 2018-02-15 (10 y, 4 mo)

Table 1-2. Updates of the 2012 Chassahowitzka River System minimum flows report included in this report on the 2019 minimum flows reevaluation.

2012 Report Section	Updates Included in this 2019 Report
2.1 Watershed and Springshed	Chapter 2. New figures of watershed and springshed. Added physiography. Land use and cover updated to include data from both before and after 2006.
2.2 Climate	Moved to hydrologic evaluation chapter (Chapter 5).
2.3 Flow and Hydrogeology	Moved to hydrologic evaluation chapter (Chapter 5).
2.4 Historical Change in Discharge 2.5 Historical Discharge Measurements	Discharge records at gages discussed in Section 2.3; Withdrawal and climate impacts discussed in hydrologic evaluation chapter (Chapter 5).
2.6 Ungaged Flow Estimates	Discussed in hydrodynamic modeling chapter (Chapter 6) and hydrodynamic modeling technical memo (Chen 2019a [Appendix 7]. .
Chapter 3 Estuary Characteristics	Reorganized information into other chapters.
3.1 Physical	Physical description of channels and springs moved to Chapter 2. Bathymetry included in hydrodynamic modeling technical memo (Chen 2019a)
3.2 Sea Level Change	Moved to hydrodynamic modeling chapter (Chapter 6) and technical memo (Chen 2019a).
3.3 Bottom Habitats	SAV discussed in Chapter 4 with other biological information.
3.4 Sediments	Included in discussion of bottom substrates (Section 2.4).
3.5 Tidal Wetlands and Riparian Habitats	New shoreline vegetation survey discussed in Chapter 4.
Chapter 4. Tide, salinity, and water quality	Tides and salinity discussed in gage data in Chapter 2, water quality discussed in Chapter 3.
4.1 Tide	Physical description of tide included in gage data section of Chapter 2.
4.2 Salinity	Salinity at gages discussed in Chapter 2. Salinity in water quality data discussed in Chapter 3. Salinity as hydrodynamic model output discussed in Chapter 6.
4.3 Water Quality	New, comprehensive analysis of water quality data in Chapter 3.
Chapter 5. Biological Characteristics	Moved to Chapter 4
5.1 Benthos	New data and analyses included in Section 4.2.
5.2 Fish	New data and analyses included in Section 4.3.
5.3 Mollusk	New oyster data, other mollusks and general benthic invertebrates information evaluated in Section 4.2.3.

5.4 Manatee	Evaluated in Section 4.4.
5.5 Gross Primary Productivity	No further evaluation done.
7 Technical Approach	Chapter 5 describes hydrologic evaluation, Chapter 6 describes surface water hydrodynamic modeling, and Chapter 7 describes development of minimum flows based on best available information.
8 Conclusions	Included in new Chapter 7 recommendation.

CHAPTER 2 - PHYSICAL SETTING AND DESCRIPTION OF THE CHASSAHOWITZKA RIVER SYSTEM

The Chassahowitzka River System includes several named rivers and creeks, surface drainage basins, a spring group consisting of many individual spring vents, and an associated springshed (Figure 2-1.). Rule 40D-8.041(16) adopted in 2013 states the Chassahowitzka River System includes the watercourse from the Chassahowitzka Main Springs Complex to the Gulf of Mexico, including contributing tributaries, Blind Springs and all named and unnamed springs that discharge to the river. This description is applicable for the current minimum flows reevaluation for the system, which can alternatively be referred to as the Chassahowitzka River, Chassahowitzka Spring Group and Blind Springs.

The Chassahowitzka River and its springshed spans portions of Citrus and Hernando Counties (Figure 2-2.Figure 2-2.). Both Citrus and Hernando Counties are entirely within the boundaries of the District. The Chassahowitzka River and its springshed is one of five first-magnitude springs systems that define the Springs Coast region. Listed from north to south these springs systems are: Rainbow, Crystal River/Kings Bay, Homosassa, Chassahowitzka, and Weeki Wachee.

White (1970) places the Chassahowitzka Group springshed across four physiographic regions (Figure 2-3.). The District (Jones et al. 2011, Champion and Starks 2001) and others (e.g., Knochenmus and Yobbi 2001) have used the physiographic regions of White (1970) to describe the physiography of its springsheds in past reports. The Drowned Karst region extends offshore from the mouth to shallow depths (less than 20 feet) and is brackish due to freshwater discharge from springs. The Chassahowitzka River runs through the Coastal Swamps region, characterized by wetlands where poorly drained, saturated organic soils overlie carbonate rocks of the Upper Floridan aquifer. Recharge is variably low to nonexistent in the Coastal Swamps province (Jones et al. 2011). The springshed extends into the Gulf Coastal Lowlands region which consists of scarps and terraces that create rolling hills capped by aeolian sands. The Gulf Coastal Lowlands experience moderate to high recharge (Jones et al. 2011). The springshed further extends into the Brooksville Ridge, characterized by rolling hills that consist of remnant marine deposits modified by subaerial erosion, karstification, and wave action. Recharge in the Brooksville Ridge area is high because it is a karst terrain with internal drainage to the upper Floridan aquifer (Kimrey and Anderson 1987).

Surface water contributions to the Chassahowitzka River come from the Chassahowitzka River drainage basin HUC 03100207 (Figure 2-4). The drainage basin or watershed extends over approximately 92 square miles in Citrus and Hernando Counties.

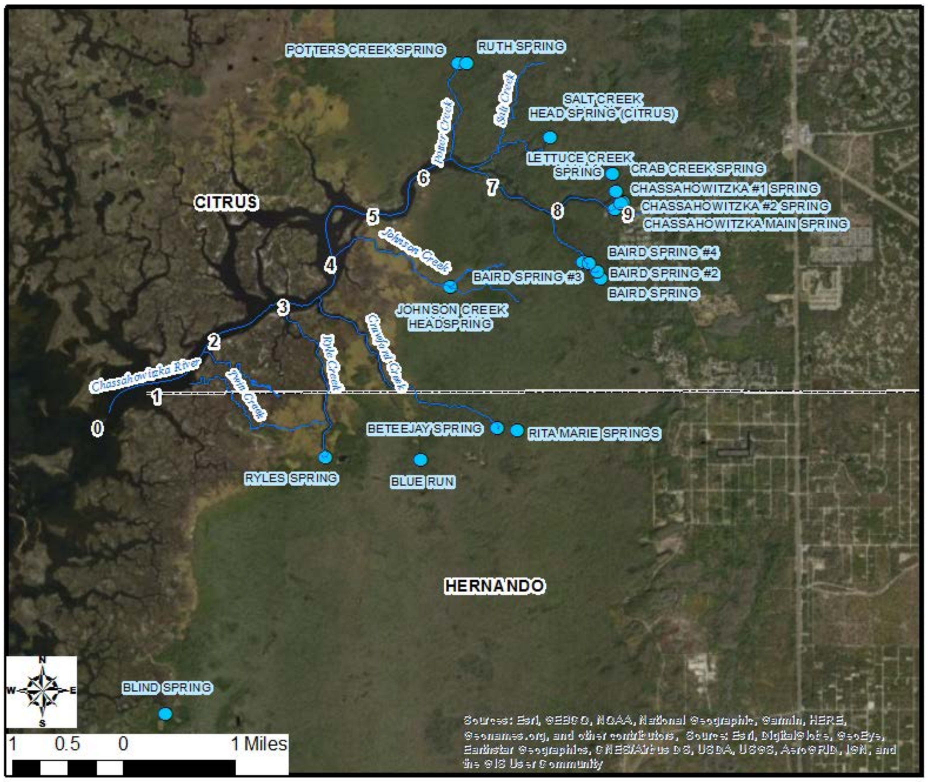


Figure 2-1. Chassahowitzka River segments and associated springs. River kilometers 0 to 9 labeled.

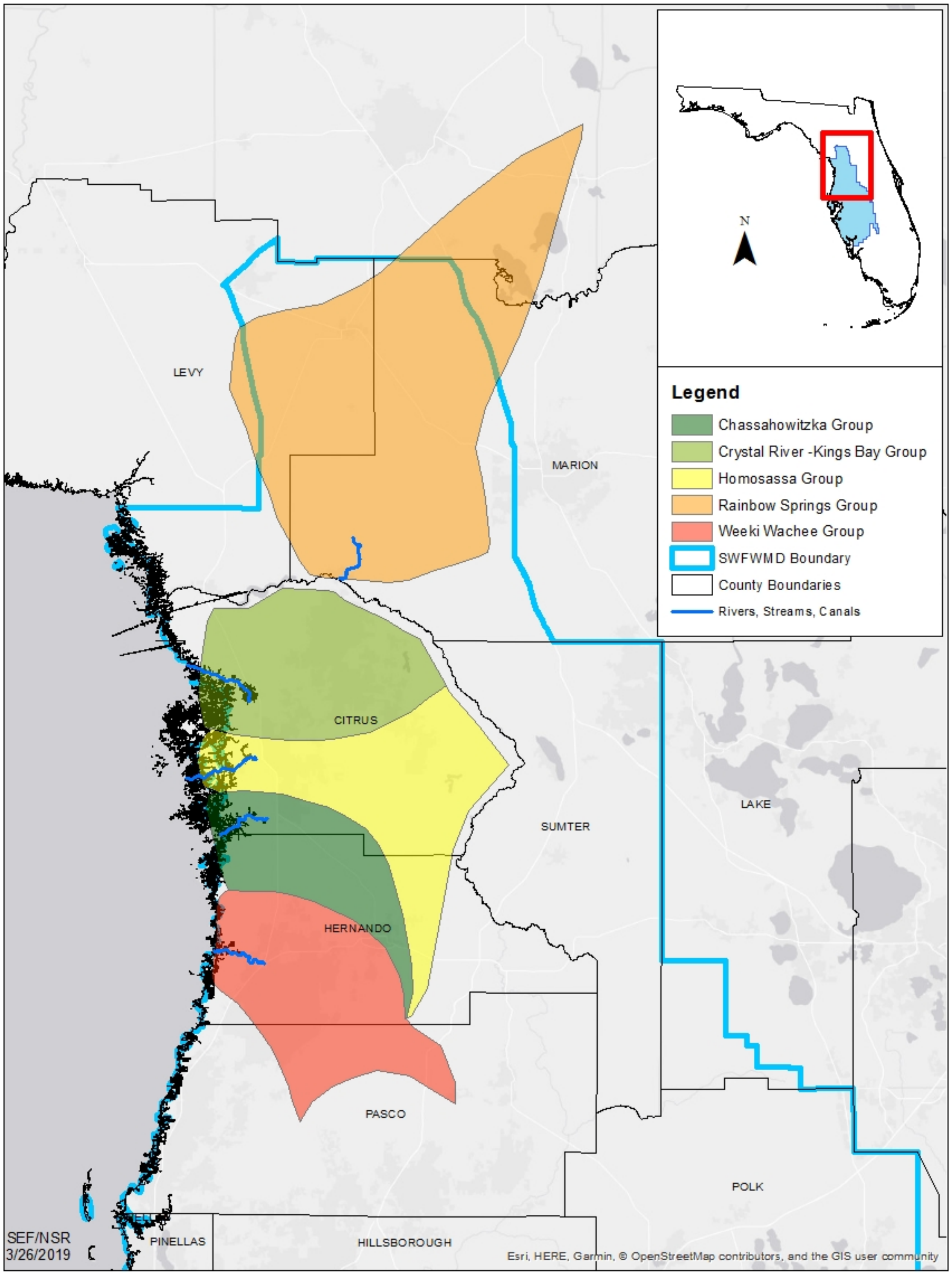


Figure 2-2. Five first-magnitude springs systems are located within the Southwest Florida Water Management District. Inset shows extent of springs coast within state of Florida and District boundary. Rivers (blue lines) are relatively small compared with springsheds (shaded areas).

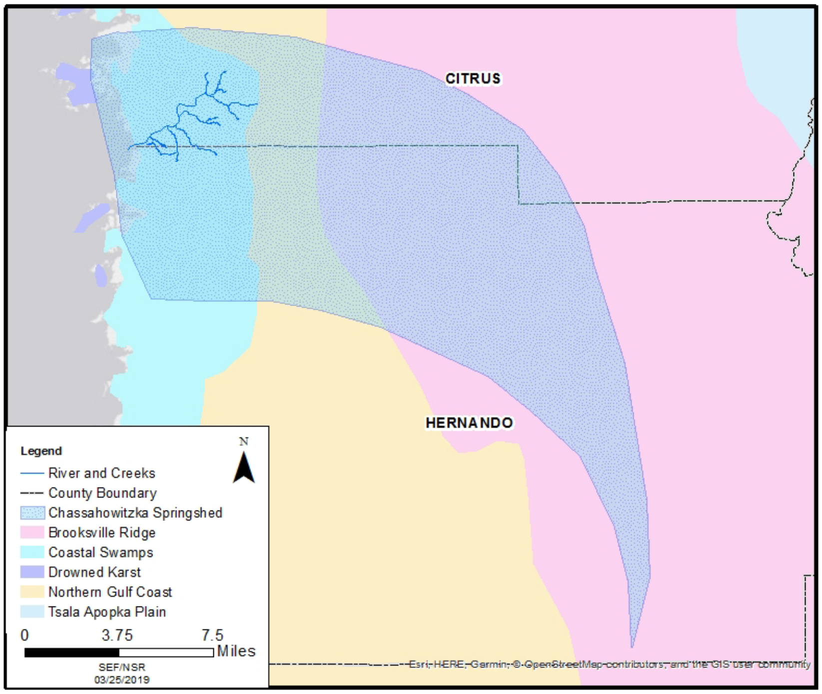


Figure 2-3. Physiographic subdivisions of White (1970) surrounding the Chassahowitzka River springshed.

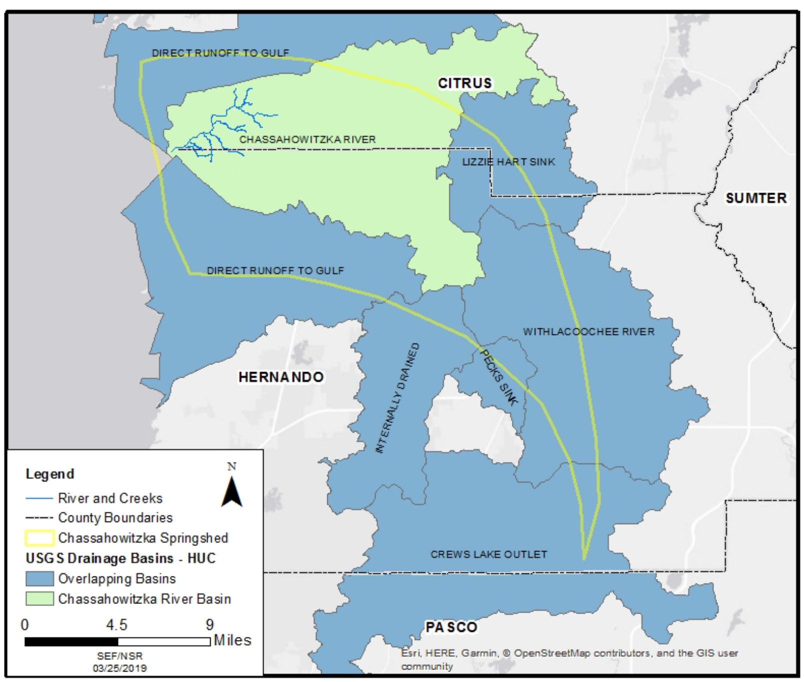


Figure 2-4. The Chassahowitzka springshed intersects eight USGS surface drainage basins. Basin names are shown for intersected basins.

2.1 Location and Description of River Segments and Springs

The Chassahowitzka River System includes numerous tributaries and springs (Figure 2-1.). River segments with Geographic Names Information System (GNIS) include the Chassahowitzka River, Baird Creek, Salt Creek, Potter Creek, Johnson Creek, Crawford Creek, Ryle Creek, Lone Cabbage Creek, and Twin Creek.

The Chassahowitzka River flows approximately 6 miles (9.7 kilometers) to the mouth in Chassahowitzka Bay, which is connected to the Gulf of Mexico. The river was designated an “Outstanding Florida Water” by the Florida Department of Environmental Protection (DEP) in 1979. The Chassahowitzka River system is fed by 17 named springs (Figure 2-1.).

The Chassahowitzka Main Spring is located between river kilometer (Rkm) 8 and 9 on the main stem of the Chassahowitzka River (Figure 2-5). The main spring is 360 ft. northeast of the boat ramp, in the middle of the river. This spring is at the head of a large pool that measures 147 ft north to south and 135 ft east to west (Scott et al. 2004). The spring is in about 20 ft of water, with a bottom that slopes gently toward the vent, which is a crevice about 25 ft long and 1-2 ft wide (Champion and Starks 2001). The Chassahowitzka Main Spring is tidally influenced. Champion and Starks (2001) report an average salinity at Chassahowitzka Main Spring of 0.5 psu (1,040 µS/cm).

The spring run from Chassahowitzka #1 Spring flows into the Chassahowitzka Main Spring pool about 100 feet upstream from the main spring. Chassahowitzka #1 Spring issues from two large holes separated by about 15 ft. Swimmers can be seen diving into one hole and surfacing from the other several seconds later. The spring pool measures 69 ft north to south and 81 ft east to west. The depth over the vents is 8.2 ft. The Chassahowitzka #1 Spring is tidally influenced. Champion and Starks (2001) report an average salinity at Chassahowitzka #1 Spring of 0.4 psu (851 µS/cm).

There are several other spring vents, including Chassahowitzka #2 Spring, along the spring run between the Chassahowitzka #1 vents and the Chassahowitzka Main Spring Pool. Chassahowitzka Spring #2 is located approximately 175 ft downstream from Chassahowitzka Spring #1. From this point, their combined flow travels approximately 100 ft southwest down a shallow, limestone and sand-bottomed run into the upper Chassahowitzka River. The Chassahowitzka #2 Spring measures 30 ft from north to south and 20 ft from east to west. The spring consists of at least five spring vents clustered on the bottom of the Chassahowitzka Spring #1 run. The spring pool has a sand and limestone bottom. It is possible for a swimmer to enter one of the Chassahowitzka #2 Spring vents and exit through a different vent.

The Crab Creek Spring pool measures 75 ft in diameter and it consists of at least four separate spring vents. The Crab Creek Spring provides flow to Crab Creek, which flows 700 ft southwest to the Chassahowitzka River. The largest vent is on the east side of the spring pool with a depth of 8 ft. A private estate occupies the northern side of the spring pool with lowland forest surrounding the rest of the area. Crab Creek Spring is tidally influenced. Champion and Starks (2001) report an average salinity at Crab Creek Spring of 2.4 psu (4,480 µS/cm).

Baird Spring is located approximately 0.5 miles south of the Chassahowitzka Main Spring (Champion and Starks 2001) (Figure 2-6). The spring forms the headwaters of Baird Creek which flows northward into the Chassahowitzka River. The spring emanates from a large fracture in the limestone. The fracture is 3-5 feet wide and 20 feet in length. This spring is a popular swimming hole for locals and may be accessed by hiking or canoeing. The spring is tidally influenced. Champion and Starks (2001) report an average salinity at Baird Spring of 5.9 psu (10,390 µS/cm).

Ruth Spring is located approximately 300 feet east of Potter Creek. Ruth Spring forms a small run that feeds into Potter Creek and the vent is formed from a large fracture in the limestone approximately 10 feet deep and 2-3 feet wide. Potter Creek feeds into the Chassahowitzka River approximately 2 miles west of the main spring. This spring is tidally influenced. Champion and Starks (2001) report an average salinity at Ruth Spring of 1.1 psu (2,200 µS/cm).

Beteejay Spring, located approximately 2.5 miles west of US 19 in northwest Hernando county, lies at the head of Crawford Creek, a small tributary of the Chassahowitzka River. The spring pool is approximately 100 feet in diameter. The spring vent discharges from the southern edge of the pool in several feet of water. The spring is tidally influenced and situated on private property. Champion and Starks (2001) report an average salinity at Beteejay Spring of 0.4 psu (821 µS/cm).

Blue Run is located on state property and may be accessed by boat from the Chassahowitzka River. Blue Run is at the head of a small tributary flowing into Crawford Creek. The vent is a fissure approximately 20 feet deep located in the upstream portion of the pool. The spring is surrounded by undisturbed Florida swampland. This spring is tidally influenced. Champion and Starks (2001) report an average salinity at Blue Run of 6.2 psu (10,900 µS/cm).

Blind Spring is located 5.2 mi (8.4 km) southwest of the town of Chassahowitzka at the head of Blind Creek, which flows west into the Gulf of Mexico (Scott et al. 2004). Access to the spring is by water only. Blind Spring has a roughly circular spring pool measuring 90 ft (27.4 m) in diameter. Depths near the center reach 55 ft (16.8 m). There are submerged limestone shelves along the north side of the pool. Algae and dark silt deposits are common along the bottom and sides of the spring. According to Scott et al. (2004), in March 2003, during a period of heavy rain, there was a large boil on the spring surface, and the water was extremely tannic and murky. The water reportedly becomes clear and bluish during drier periods. Blind Spring is the reemergence of a subterranean section of Blind Creek. Blind Creek forms in the eastern edge of the Chassahowitzka Swamp. Beauford Spring is near the head waters of Blind Creek. From Beauford Spring, Blind Creek travels approximately 2.8 miles (4.5 km) northwest and into a siphon. The siphon is approximately 0.7 miles (1.1 km) southeast of Blind Spring. The creek flows underground toward Blind Spring and reemerges as Blind Spring. From Blind Spring, the creek travels another 1.8 miles (2.9 km) north and west through open brackish and salt marsh to the Gulf of Mexico. Blind Spring and lower Blind Creek are tidally influenced. Swift tidal currents have scoured the limestone bottom for a few hundred feet (100 m) below Blind Spring. There are numerous limestone fissures and vent openings in and along the first 400 ft (121.9 m) of Blind Creek below Blind Spring. Blind Spring is situated on the west side of the Chassahowitzka National Wildlife Refuge, at the ecological boundary between coastal palm-hardwood-cedar hammock and open salt marsh.

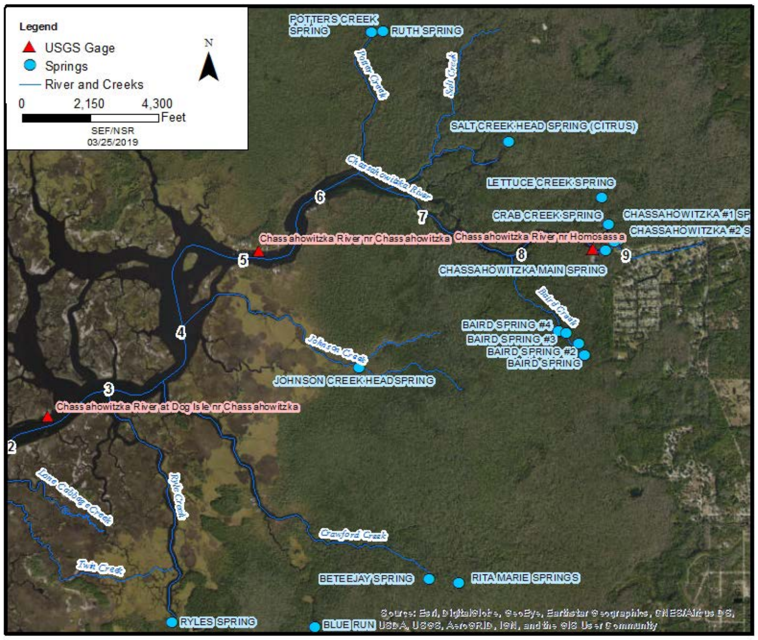


Figure 2-5. Chassahowitzka Main Spring and associated springs. USGS Gage 02310650 Chassahowitzka River near Homosassa shown, along with named spring vents. River kilometer 9 labeled upstream from main spring.

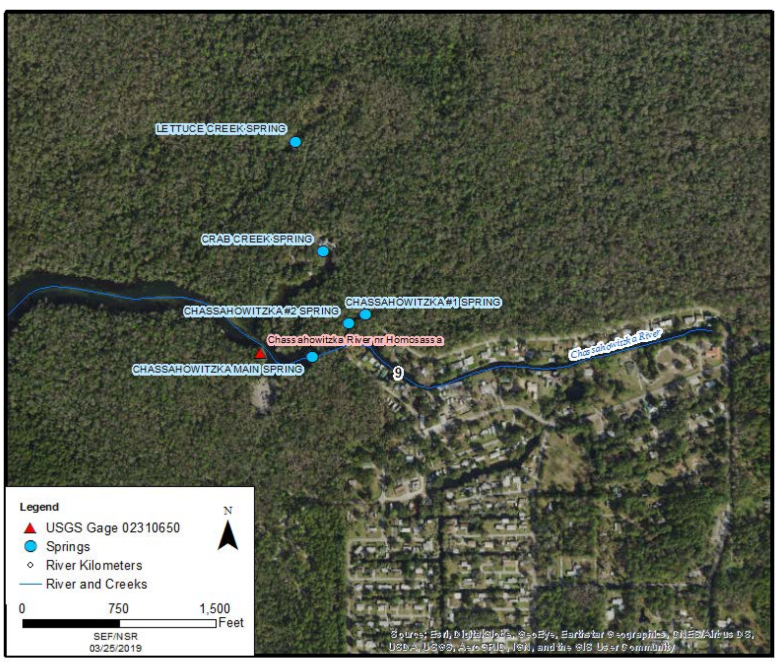


Figure 2-6. The Chassahowitzka River and springs from Rkm 2-9, showing Baird Spring, Ruth Spring, and Beteejay Spring.

2.2 Watershed Land Use and Cover

Land use and cover in the Chassahowitzka River basin of the Chassahowitzka River System currently includes a mix of urbanized or developed lands, agricultural lands, forested uplands, wetlands and water (Figure 2-7.). Based on the Florida Land Use, Cover and Forms Classification System (Florida Department of Transportation 1999), urban and built-up lands and those used for transportation, communication and utilities in 2011 accounted for twenty-eight percent of the 58,705 acres within the Chassahowitzka River Basin (Table 2-1.). Lands classified as upland forest accounted for forty percent of the basin area, and water and wetlands accounted for twenty-four percent of the landscape. There is very little development along the Chassahowitzka River. The town of Chassahowitzka, which is located upstream and east of Chassahowitzka #1 includes many canals that have been dredged for residences. Downstream development along the river is limited to approximately 15-20 camps and homes downstream of Chassahowitzka Main Spring.

Changes in land use and cover within the Chassahowitzka River basin were evaluated using geographic information system layers representing land use/cover classifications for the area in 1990, 1995, 1999 and 2004 through 2011. For the analyses, Esri ArcMap software was used to clip land use/cover layers to the boundaries delineated by the Chassahowitzka River Drainage Basin. With the exception of the Urban and Built-Up, Agriculture, and Upland Forest land use/cover classes, land use/cover in the watershed exhibited little change in the years examined between 1990 and 2011 (Table 2-1.). Increases in urbanized lands have been associated primarily with decreases in forested uplands and agriculture lands.

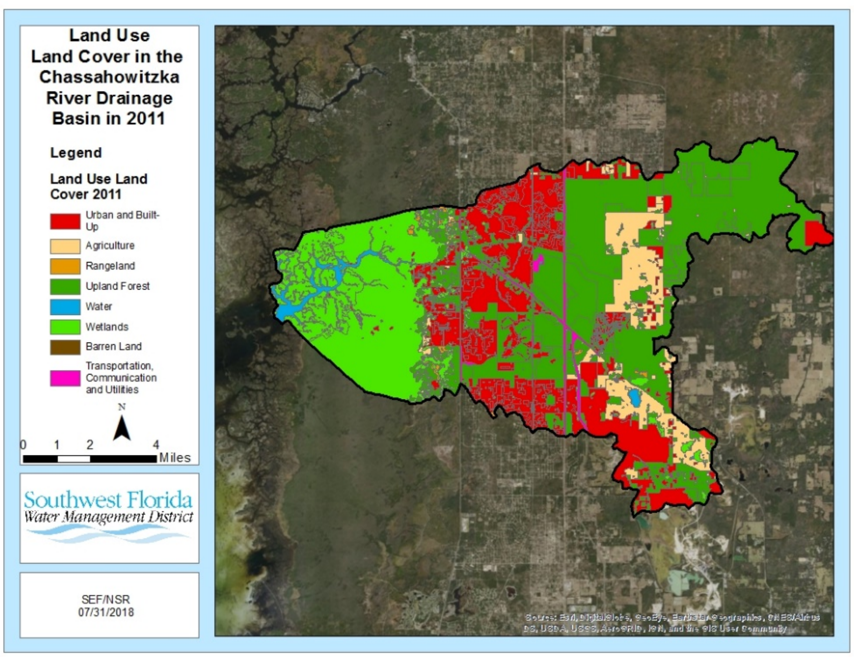


Figure 2-7. Land use/cover in the Chassahowitzka River Drainage Basin in 2011, based on the Florida Land Use, Cover and Forms Classification System.

Table 2-1. Land use/cover by acres in the Chassahowitzka River Drainage Basin or watershed for selected years based on Land use/cover classes of the Florida Land Use, Cover and Forms Classification System. Total area in basin is 58,706 acres

Land Use/ Cover Class	1990	1995	1999	2004	2005	2006	2007	2008	2009	2010	2011
Urban and Built-Up	12,290	12,105	12,447	14,378	14,581	14,694	14,867	14,982	15,011	15,023	15,023
Agriculture	6,809	6,532	6,571	6,578	6,400	6,393	6,166	5,963	5,907	5,907	5,025
Rangeland	198	2,188	2,275	324	307	307	303	303	303	303	267
Upland Forest	24,930	23,239	22,562	22,494	22,482	22,427	22,491	22,575	22,603	22,590	23,509
Water	1,062	1,187	1,158	1,190	1,178	1,162	1,113	1,086	1,085	1,128	1,121
Wetlands	12,505	12,540	12,570	12,690	12,706	12,671	12,716	12,747	12,747	12,705	12,711
Barren Land	242	100	303	6	6	6	6	6	6	6	6
Transportation, Communication and Utilities	669	814	819	1,045	1,045	1,045	1,043	1,043	1,043	1,043	1,043

2.3 Gage Data

The purpose of this section is to provide an overview of the available USGS gage data and general temporal trends. Specific modeling applications using the data are addressed in the hydrodynamic modeling Appendix 7 (Chen 2019a).

USGS gages provide the bulk of the hydrological data needed to characterize surface water levels, flows, salinity, and temperature throughout the system. There are four gages within the Chassahowitzka River system that are currently monitored by the USGS in cooperation with the District (Figure 2-8.), and the daily data associated with these gages (Table 2-2. A) differ depending on the period of record and the types of data being collected within and among gage sites. The full records for data at these gages, including both approved and provisional data can be found at the USGS National Water Information System web site (USGS 2018). In addition to daily data, 15-minute data are often reported, as are field measurements and data averaged over monthly and yearly time periods. Average values of daily data show differences among locations in flow, temperature, and salinity (Table 2-2. B).

Periods of record often differ for parameters within and among gage sites. These periods of record are critical for comparing data within and among gages and parameters – it is important to compare different gages or parameters over the same period of record, or the risk of confounding comparisons of interest with temporal changes may be high. Of course, temporal changes are also of interest, but unfortunately most periods of record are shorter than we would like. Gage data are presented here to briefly summarize the temporal trends in flows, levels, temperature, and salinity that have occurred during the periods of record for gages in this system. Another purpose of this section is to familiarize the reader with data that are available from these gages. Some simple linkages between flows, levels, salinities, and temperatures are described here.

However, application of this data to hydrodynamic modeling to address detailed quantitative links between these parameters is covered more thoroughly in later chapters and appendices.

Note that salinity values are reported as practical salinity units which are a dimensionless quantity. At times, practical salinity units are abbreviated as “psu”. If no units are given in reference to salinity, this is because salinity is a dimensionless ratio and has no units.

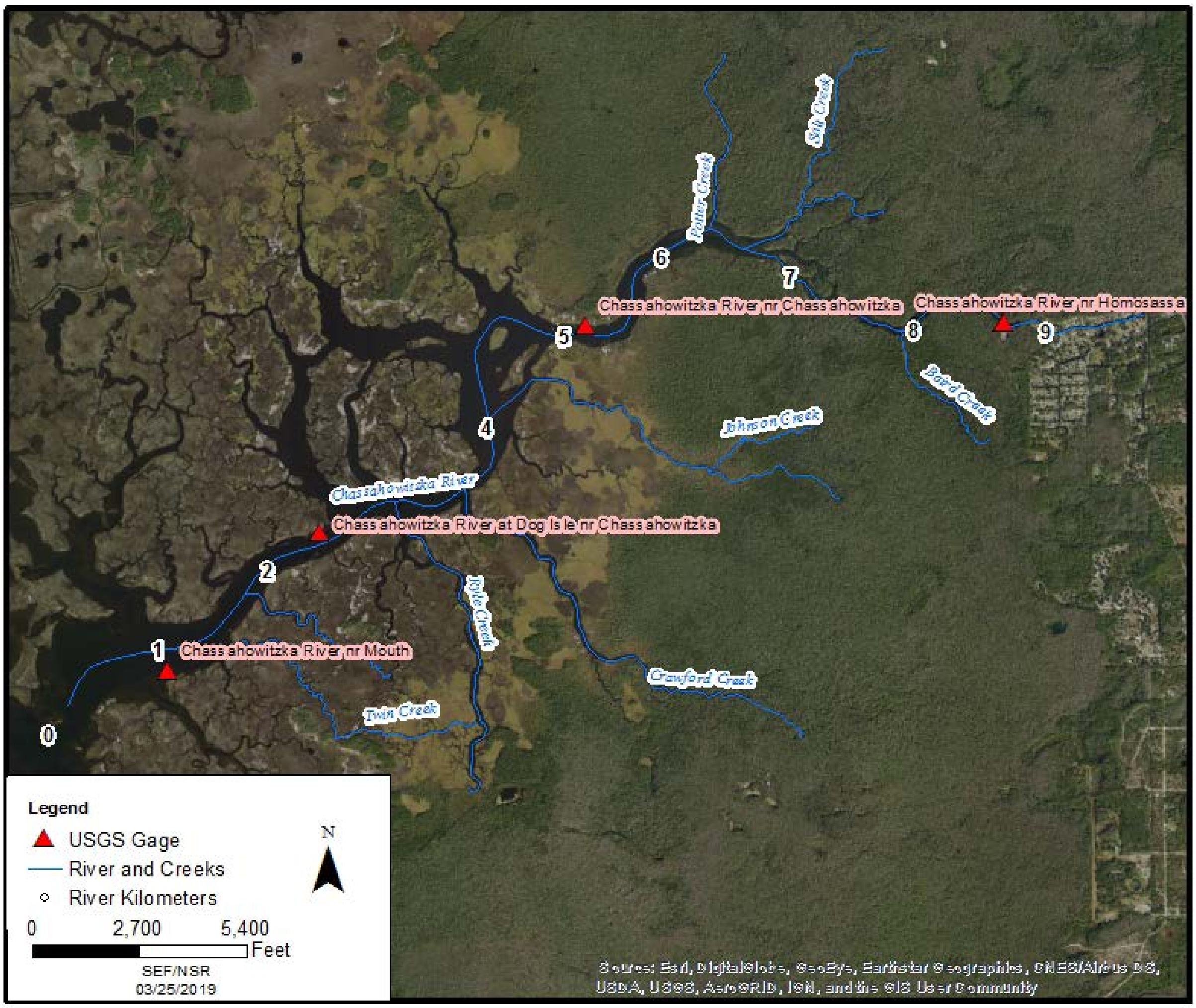


Figure 2-8. Current USGS gages in Chassahowitzka River System.

Table 2-2. A) Periods of record for approved daily data as of July 30, 2018 for four USGS gages in the Chassahowitzka River System. Full records and additional data including 15-minute data are available at the USGS National Water Information System website. B) Average daily data at four USGS gages in the Chassahowitzka River system. Shown are averages of daily maxima and minima for salinity, average of daily maximum temperature, and the average of daily average flow as reported by USGS. Specific conductance at 25° C converted to salinity using equation by Lewis (1980) as reported in Schemel (2001).

A

Gage	Stage or Gage Height	Discharge	Specific Conductance	Temperature
USGS Chassahowitzka River near Homosassa, FL (No. 02310650)	Min/Max: 2010-10-01 to 2017-12-05	Regression: 1997-02-20 to 2012-10-14 Tidally Filtered: 2012-11-18 to 2017-12-05	Min/Max: 2004-06-28 to 2018-02-12	Min/Max: 2004-06-28 to 2018-02-12
USGS Chassahowitzka River near Chassahowitzka, FL (No. 02310663)	Min/Max: 2010-10-01 to 2017-12-05	Tidally Filtered: 2005-02-25 to 2017-12-05	Min/Max: 2003-06-06 to 2018-06-04	Min/Max: 2003-05-02 to 2018-06-04
USGS Chassahowitzka River at Dog Island near Chassahowitzka, FL (No. 02310673)	Min/Max: 2010-10-01 to 2018-04-26	No Data	Min/Max: 2005-09-13 to 2018-06-04	Min/Max: 2005-09-13 to 2018-06-04
USGS Chassahowitzka River at Mouth near Chassahowitzka, FL (No. 02301674)	Min/Max: 2010-10-01 to 2018-02-11	No Data	Min/Max: 2006-06-01 to 2017-10-03	Min/Max: 2005-10-12 to 2017-10-03

B

Gage	Salinity (min)	Salinity (max)	Temp (max)	Tidally Filtered Daily Flow (mean cfs)
02310650	0.9 psu	3.5 psu	24 °C	62
02310663	3.1 psu	9.4 psu	26 °C	91
02310673	7.0 psu	14.6 psu	25 °C	No Data
02310674	9.3 psu	16.1 psu	25 °C	No Data

2.3.1 Chassahowitzka River near Homosassa, FL (Gage No. 02310650)

The Chassahowitzka River near Homosassa, FL gage (No. 02310650) is located Lat 28°42'54", long 82°34'37", on the left bank just downstream from head of springs, 4.9 mi upstream from mouth, and 5.1 mi southeast of Homosassa (Figure 2-8) (USGS 2018). Datums for the gage are the National Geodetic Vertical Datum of 1929 (NGVD29) and 0.675 ft. below the North American Vertical Datum of 1988 (NAVD88). Prior to 1978, the gage datum was 10.00 ft below NGVD29. The sonde at the site used for measuring specific conductance and temperature is located at an elevation of 1.60 ft below NGVD29.

The Chassahowitzka River near Homosassa, FL gage (No. 02310650) shows a tidal cycle in stage with an amplitude of about two feet between low-low and high-high tides (Figure 2-9). Tides are highest in summer months (Figure 2-10).

Streamflow at this site is significantly affected by astronomical tides. The residual discharges are not total "freshwater" flow, but a combination of freshwater and water storage caused by higher or lower Gulf of Mexico mean water levels. Discharge measurements are made about 300 ft downstream from head of springs; measurements made prior to November 1997 include flow from Crab Creek. By convention, the USGS has established ebb (seaward) flows as positive flow and flood (landward) flows as negative flows.

Over the course of a typical year, tidally filtered flows peak in the low 70s (cfs) in September and slowly decline to lows in the mid-50s (cfs) in July and August before rebounding to their annual highs (Figure 2-11). Tidally filtered flows average 61.8 cfs and vary between 54.2 and 69.5 for eighty percent of the time (Table 2-3). Daily records over the period of record show flows oscillating above and below the average value of 62 cfs (Figure 2-12.).

From 1997-02-20 to 2012-10-14, gaged flows are from regression with Weeki Wachee Well water levels (Table 2-3.). These records precede the installation of index velocity equipment and reporting of tidally filtered flow (Figure 2-13.).

Field measurements of flow at Chassahowitzka River near Homosassa Gage 02310650 date to 1930, but only nine measurements were taken before 1964 (Figure 2-14.). Measurements from 1988 and before were taken downstream from Crab Creek, and thus show higher values than measurements taken in 1997 and later (Figure 2-15.) (Heyl et al. 2012). No measurements were taken from 1989 through 1996. Measurements were resumed in 1997 (Table 2-3.).

Discharge is driven by interactions between tide and groundwater levels. Increasing tides in summer months (Figure 2-10) contribute to decreasing flows in May and June (Figure 2-11.). In July and August, flows rebound due to increasing aquifer levels (Figure 2-16., Table 2-4.), while tides remain high through September and October.

Salinity varies with tide (Figure 2-17.). Salinity typically varies from lows around 1 to highs between 3 and 4 psu, with higher salinities occurring with higher sea levels in the summer (Figure 2-18.).

Temperatures vary by about 1.5°C over the course of a day (Figure 2-19.). In the winter, temperature ranges from lows near 21°C to highs near 23°C. In the summer, lows are near 23°C and highs reach 25°C.

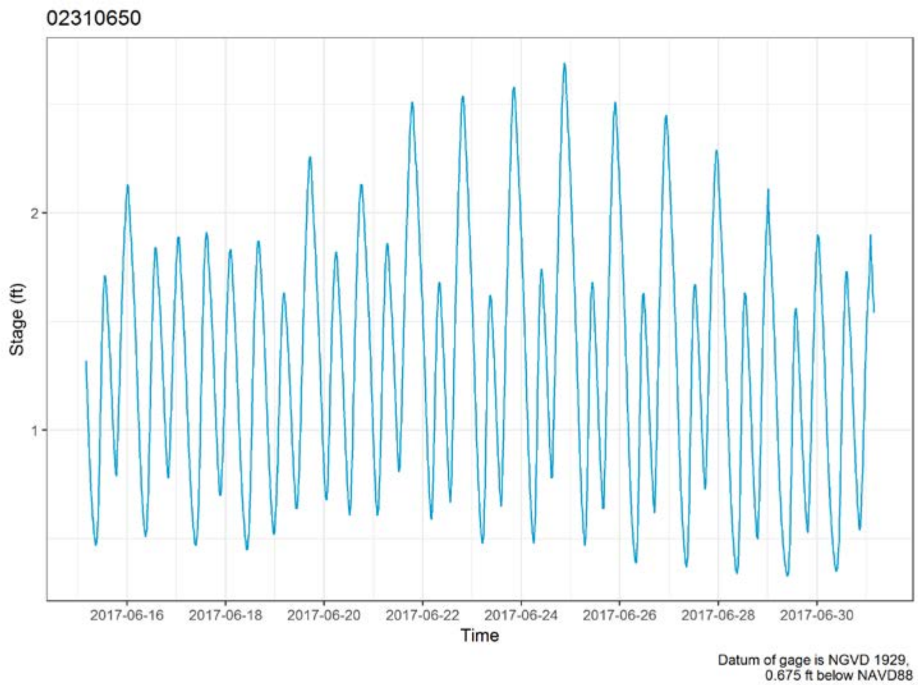


Figure 2-9. Tidal stage at Chassahowitzka River near Homosassa, FL gage (No. 02310650). Data shown from June 15 to June 30, 2016 to illustrate typical tidal cycles.

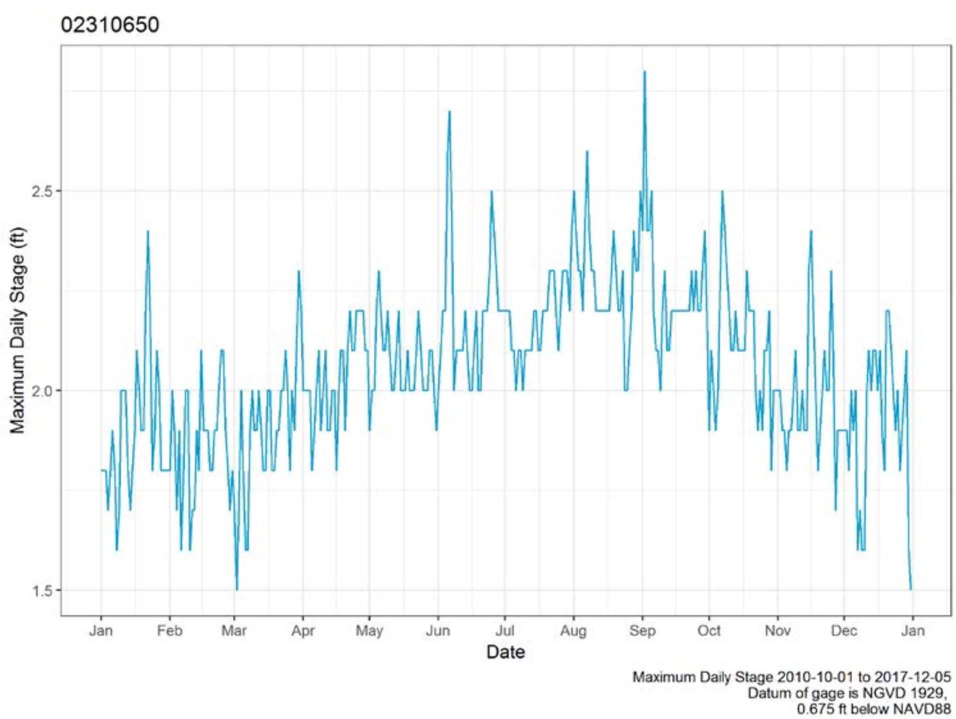


Figure 2-10. Average of maximum daily stage for each day of year at Chassahowitzka River near Homosassa, FL gage (No. 02310650).

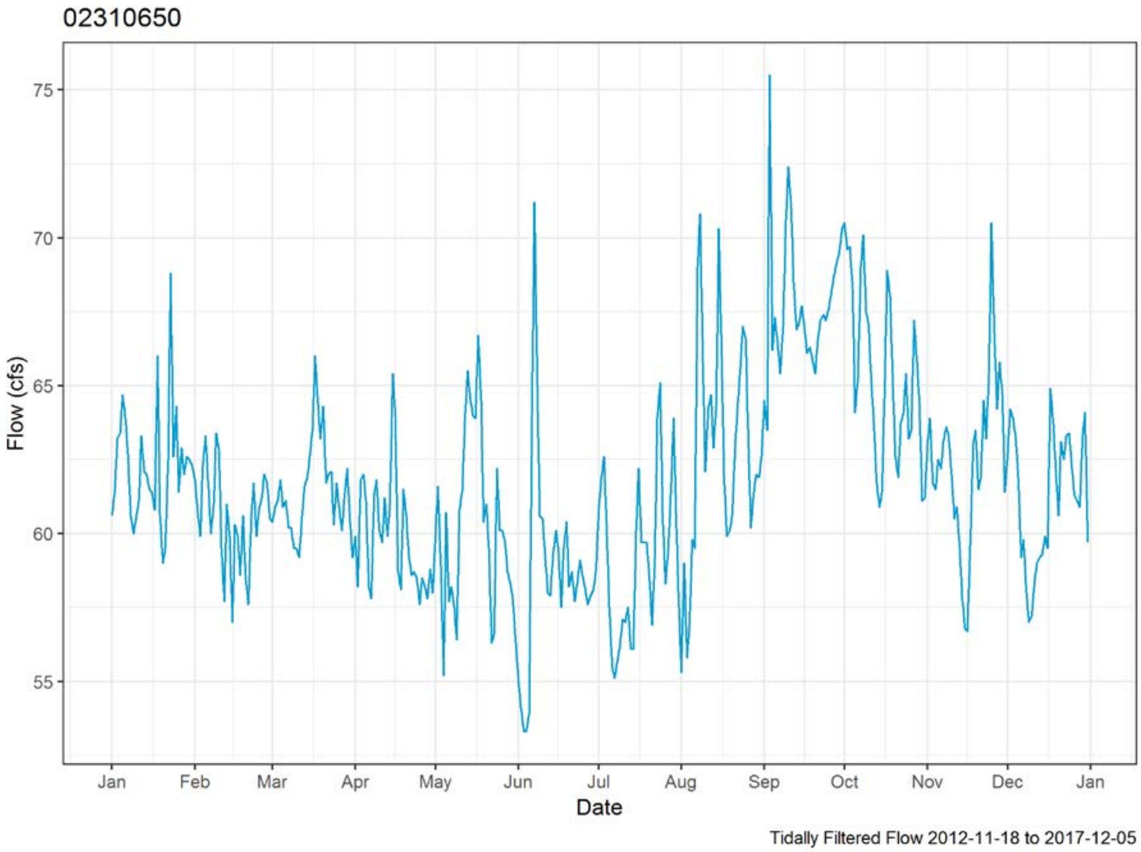


Figure 2-11. Tidally filtered flow on day-of-year average at Chassahowitzka River near Homosassa, FL gage (No. 02310650).

Table 2-3. Summary statistics on "approved" tidally filtered (index velocity), regression-based flows, and field measurements at Chassahowitzka River near Homosassa, FL gage (No. 02310650) (cfs).

Flow Record	start	end	min	10th	25th	mean	median	75th	90th	max
Index Velocity (n = 1903)	11/17/2012	10/15/2018	40.3	53.9	57.6	62.8	62	66.8	73.1	115
Tidally Filtered (n = 1,471)	11/18/2012	12/5/2017	39	54.2	57.8	61.8	61.4	65.5	69.5	112
Regression (n = 5,009)	02/20/1997	10/14/2012	24.9	47.4	53	58.9	58	65	72	87.1
Field Meas. incl. Crab Creek (n = 145)	10/09/1930	10/24/1988	23	73	109	130	132	158	169	414
Field Meas. (n = 464)	04/02/1997	06/05/2018	-55.5	-0.04	38.0	59.3	69.8	86.9	99.1	126

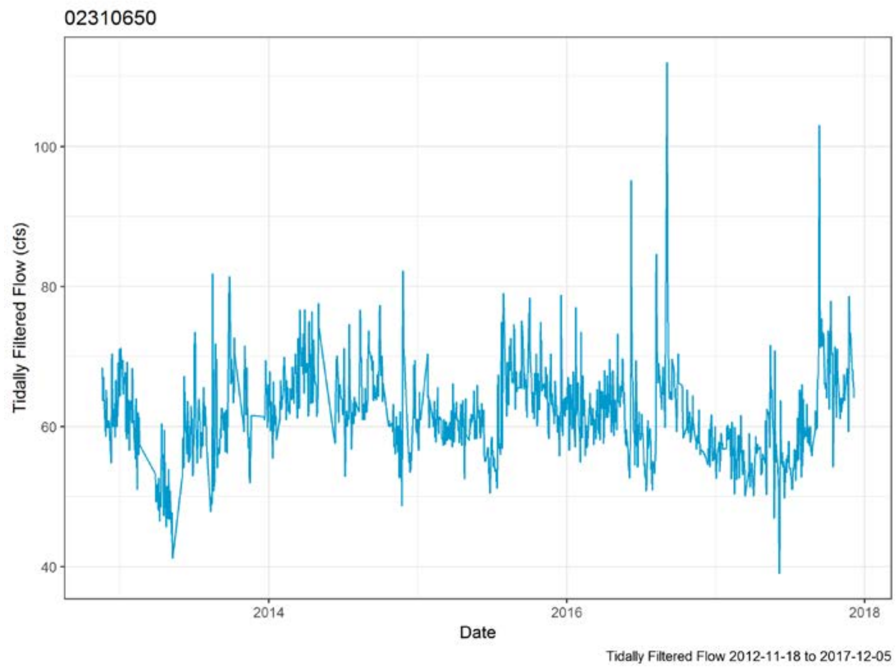


Figure 2-12. Tidally filtered flow from full daily period of record 2012-11-18 to 2017-12-05 at Chassahowitzka near Homosassa, FL gage (No. 02310650).

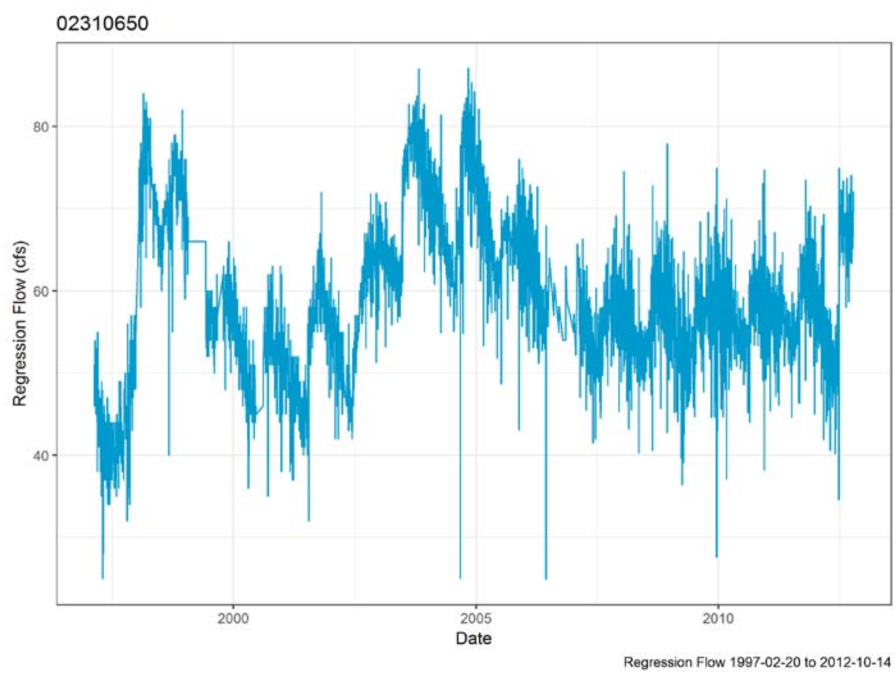


Figure 2-13. Regression flow from full daily period of record 1997-02-20 to 2012-10-14 at Chassahowitzka near Homosassa, FL gage (No. 02310650).

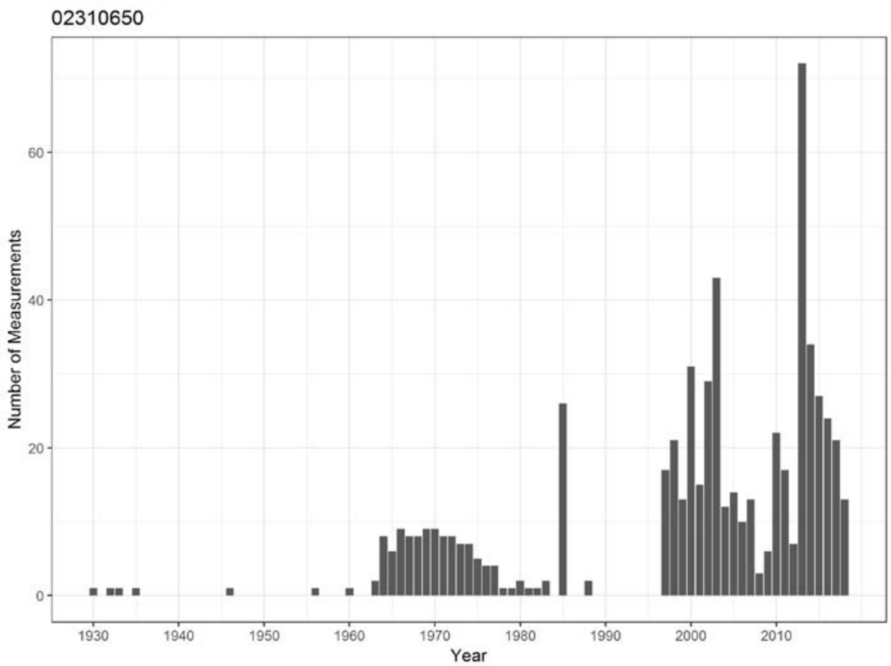


Figure 2-14. History of field measurements of flow at Chassahowitzka near Homosassa, FL gage (No. 02310650).

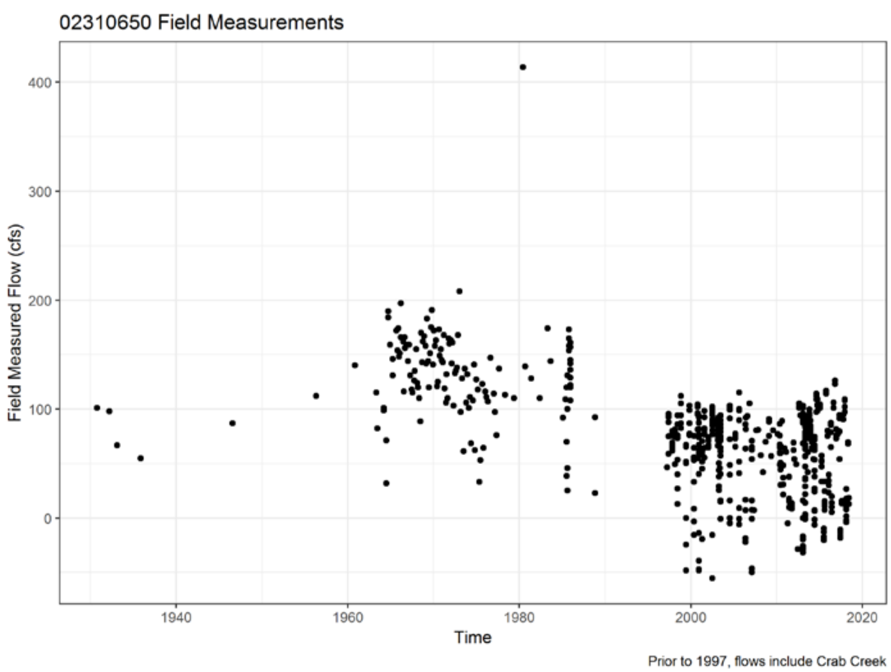


Figure 2-15. Field measurements of flow at Chassahowitzka near Homosassa, FL gage (No. 02310650). Prior to 1997, flows include Crab Creek, and are therefore not directly comparable with flows after 1997 (Heyl et al. 2012).

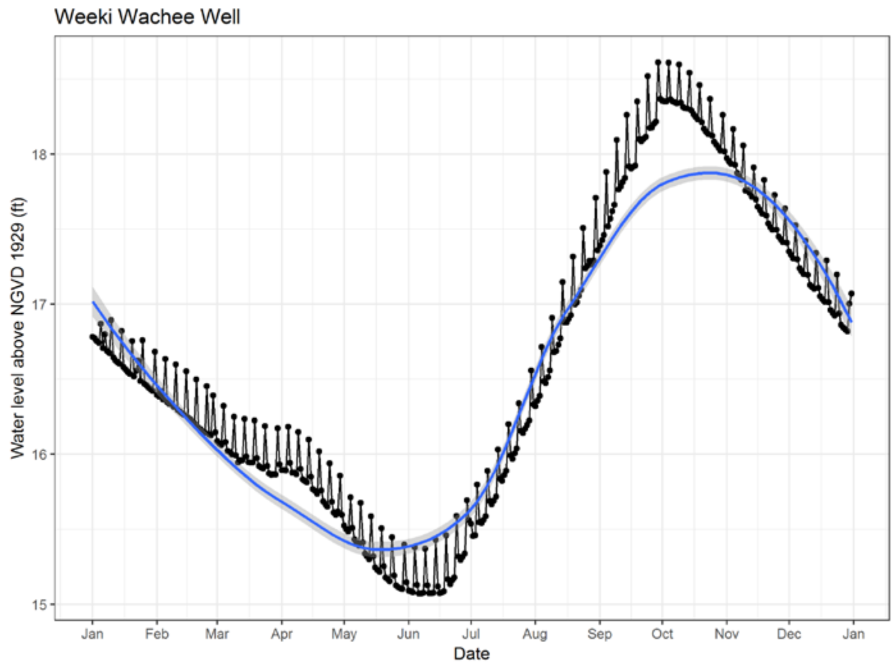


Figure 2-16. Average daily water levels in Weeki Wachee Well USGS 283201082315601 for day of year over long-term period of record (06/15/1966 to 12/11/2017). Blue lines are loess smoothers with grey standard error. Points show average values, and black lines are linear interpolation between data points. Spikes can be seen on 5, 10, 15, 20, 25, 30 of each month because measurements were only taken on those dates prior to 1974-10-01, skewing those particular days of the month to higher values. The well was relocated on 2013-04-30, which has been adjusted by adding 0.3 ft to match with old well location following regression adjustment by USGS (Kevin Grimsley, personal communication, 2018).

Table 2-4. Summary statistics for water levels (ft) in Weeki Wachee Well USGS 283201082315601.

start	end	min	10th	25th	mean	median	75th	90th	max	n
6/15/1966	12/11/2017	10.7	13.3	14.5	16.6	16.5	18.4	20.4	23.9	16,268

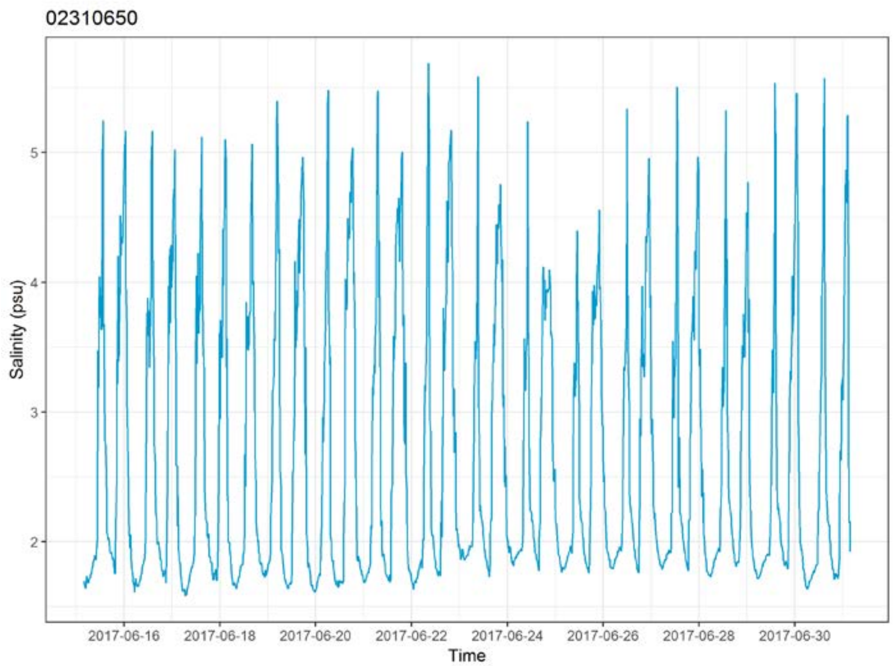


Figure 2-17. Tidal variation in salinity at Chassahowitzka near Homosassa, FL gage (No. 02310650) June 22 to June 26, 2016. Specific conductance at 25° C converted to salinity using equation by Lewis (1980) as reported in Schemel (2001).

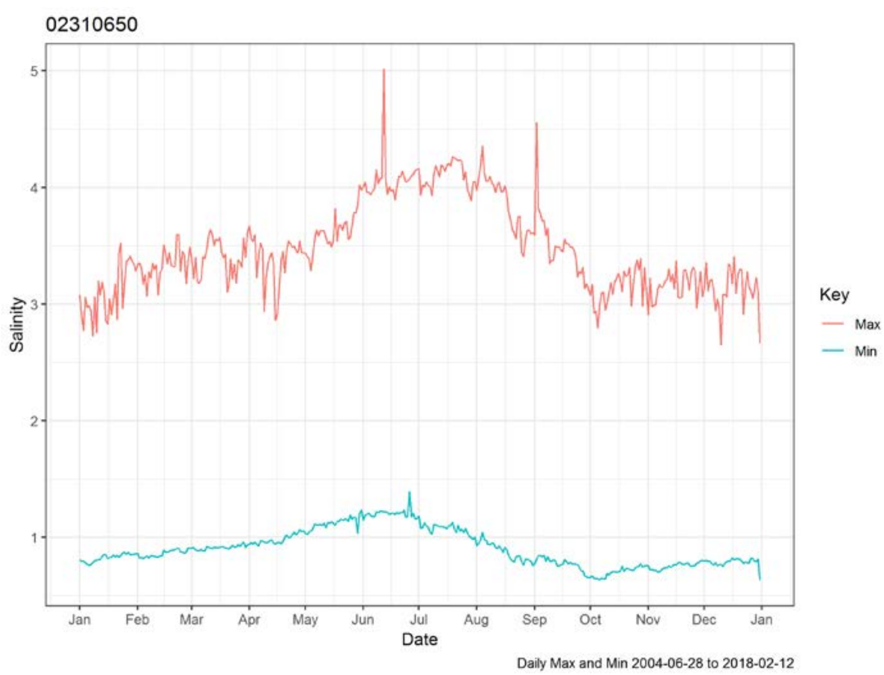


Figure 2-18. Salinity on day of year at Chassahowitzka River near Homosassa, FL gage (No. 02310650). Specific conductance at 25° C converted to salinity using equation by Lewis (1980) as reported in Schemel (2001).

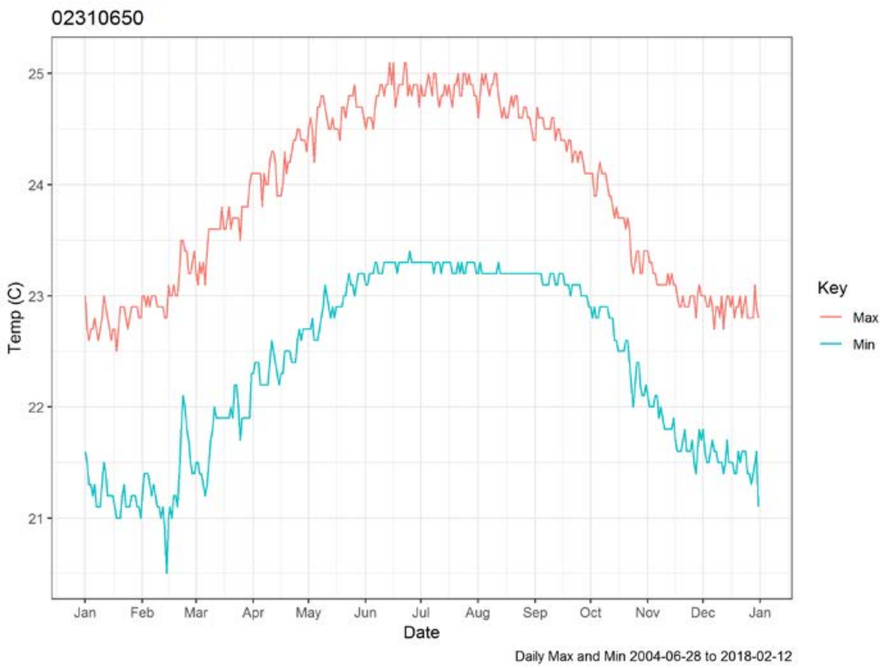


Figure 2-19. Temperature at Chassahowitzka River near Homosassa, FL gage (No. 02310650).

2.3.2 Chassahowitzka River near Chassahowitzka, FL (gage No. 02310663)

The Chassahowitzka River near Chassahowitzka gage (No. 02310663) is at Lat 28°42'54" N, long 82°36'23" W, on private dock, on right edge of water, 0.3 mi upstream from confluence with Johnson Creek, and 2.0 mi west of Chassahowitzka (Figure 2-8.) (USGS 2018). The datums of the gage are NGVD29 and 0.71 ft. below NAVD1988. Specific conductance and temperature sensors positioned approximately 3.5 ft below NGVD29.

The Chassahowitzka River near Chassahowitzka, FL gage (No. 02310663) shows a tidal cycle in stage with an amplitude of about 2.5 feet between low-low and high-high tides (Figure 2-20.). Tides are highest in summer months (Figure 2-21.).

Streamflow at this site is significantly affected by astronomical tides. The residual discharges are not total "freshwater" flow, but a combination of freshwater and water storage caused by higher or lower Gulf of Mexico mean water levels. The residual discharge is used to estimate mean daily discharge values. By convention, the USGS has established ebb (seaward) flows as positive flow and flood (landward) flows as negative flows.

Over the course of a typical year, flows peak near 200 cfs in August and are lowest in October and November (Figure 2-22.). Daily flows average 91 cfs and vary between 26 and 152 for the middle fifty percent of the time (Table 2-5.). Negative flows indicate the ability of rising tides to make net flow into the system (i.e., upstream) on >10% of days. Tidally filtered flows are measured using an index velocity method.

Discharge is driven by interactions between tide and groundwater levels. In mid-April through mid-June, low flows (< 75 cfs) (Figure 2-22.) coincide with high stages at gage (> 2 ft) (Figure 2-21.) while aquifer levels are at their annual lowest levels (< 16 ft) (Figure 2-16.). Flows are highest in August through mid-September (> 125 cfs), while aquifer levels rise to a peak in mid-September through November (> 18 ft).

Salinity varies with tide (Figure 2-23). Throughout the year, daily lows of salinity typically are around 2.5 to 4, while daily maxima are typically between 7 and 13 psu (Figure 2-24). High salinities in May correspond to annual low flows (Figure 2-22.).

Temperatures vary by about 2.5°Celsius over the course of a day (Figure 2-25). In the winter, temperature ranges from lows near 16°C to highs near 21°C. In the summer, lows are near 26°C and highs reach 30°C.

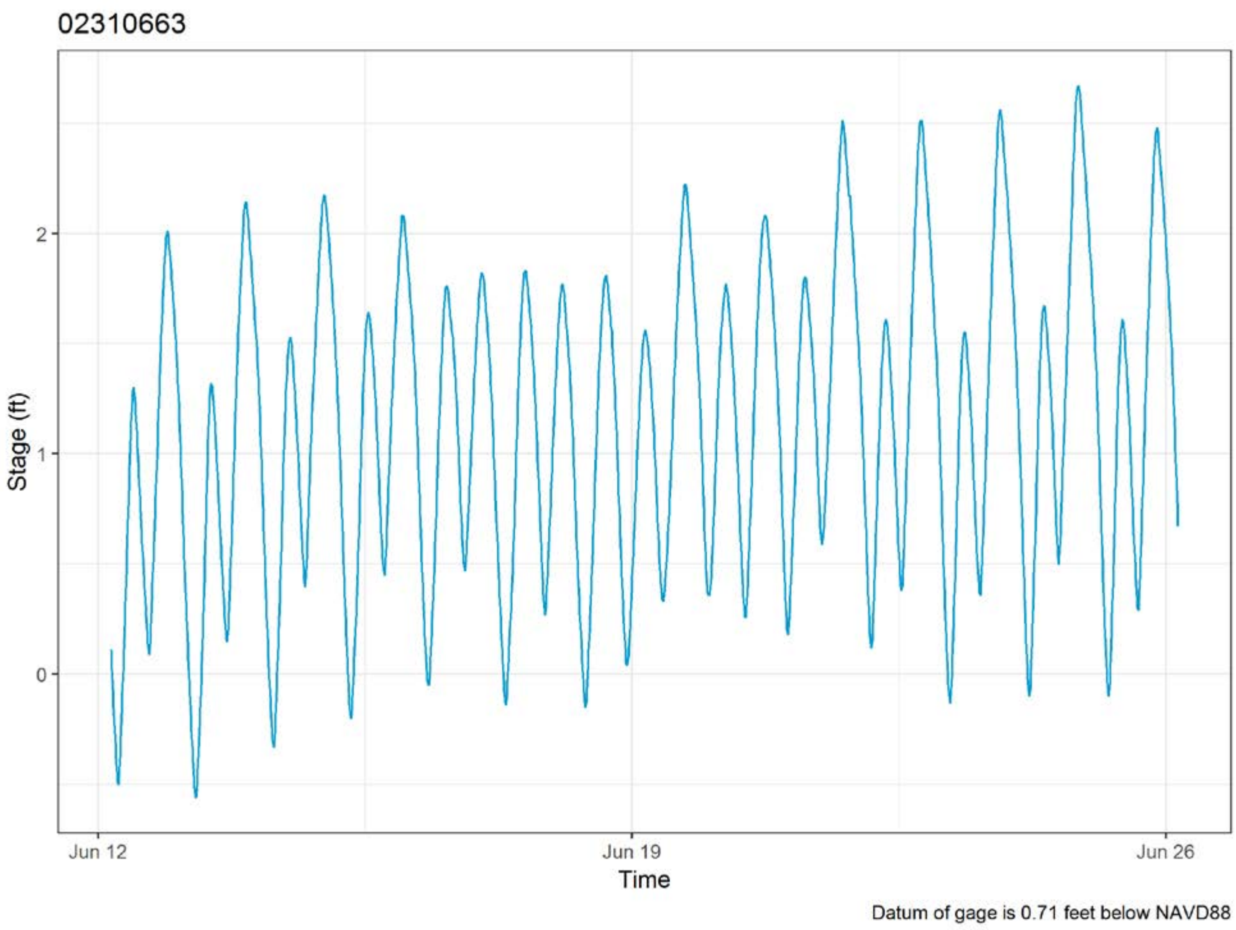


Figure 2-20. Tidal variation in stage at Chassahowitzka River near Chassahowitzka, FL gage (No. 02310663)

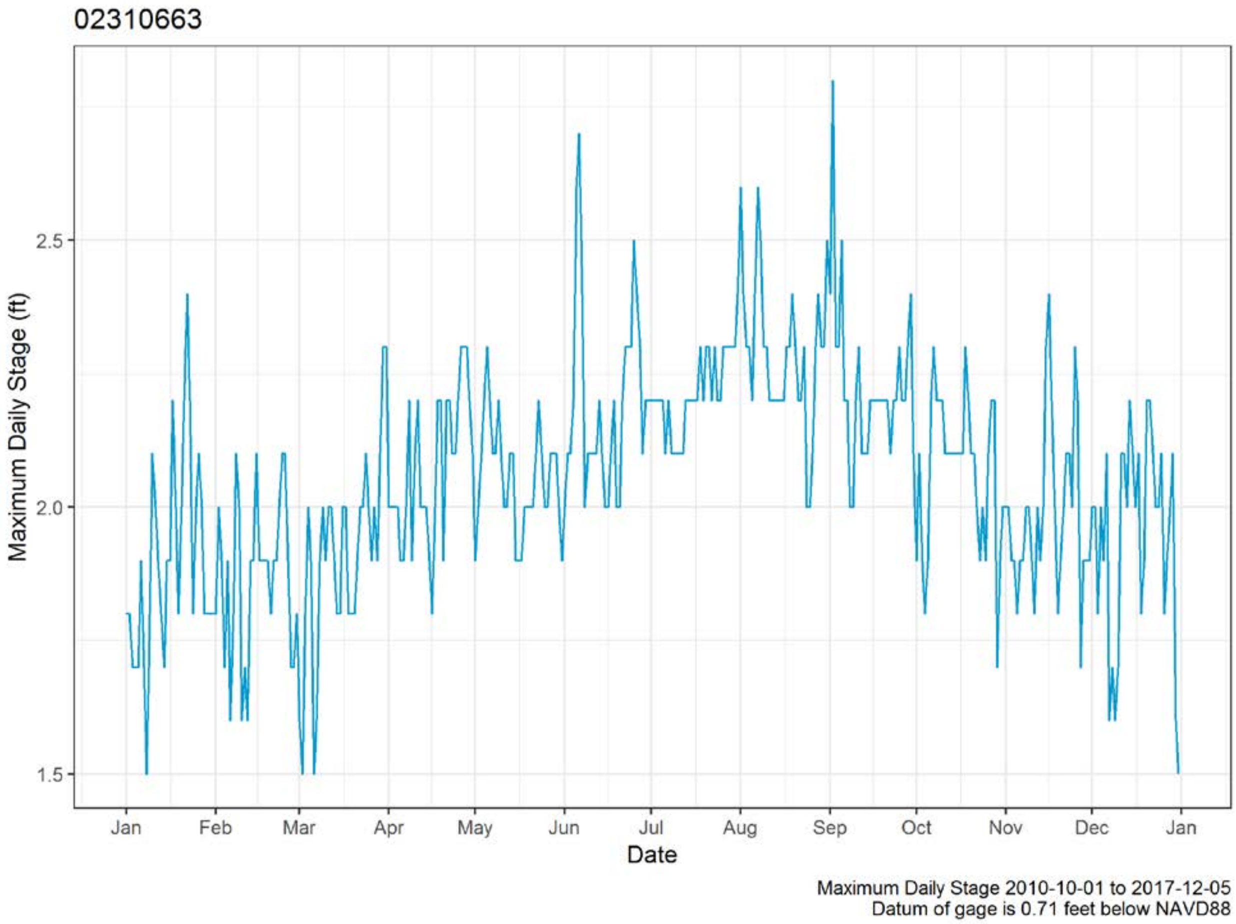


Figure 2-21. Average of maximum daily stage for each day of year at Chassahowitzka River near Chassahowitzka, FL gage (No. 02310663)

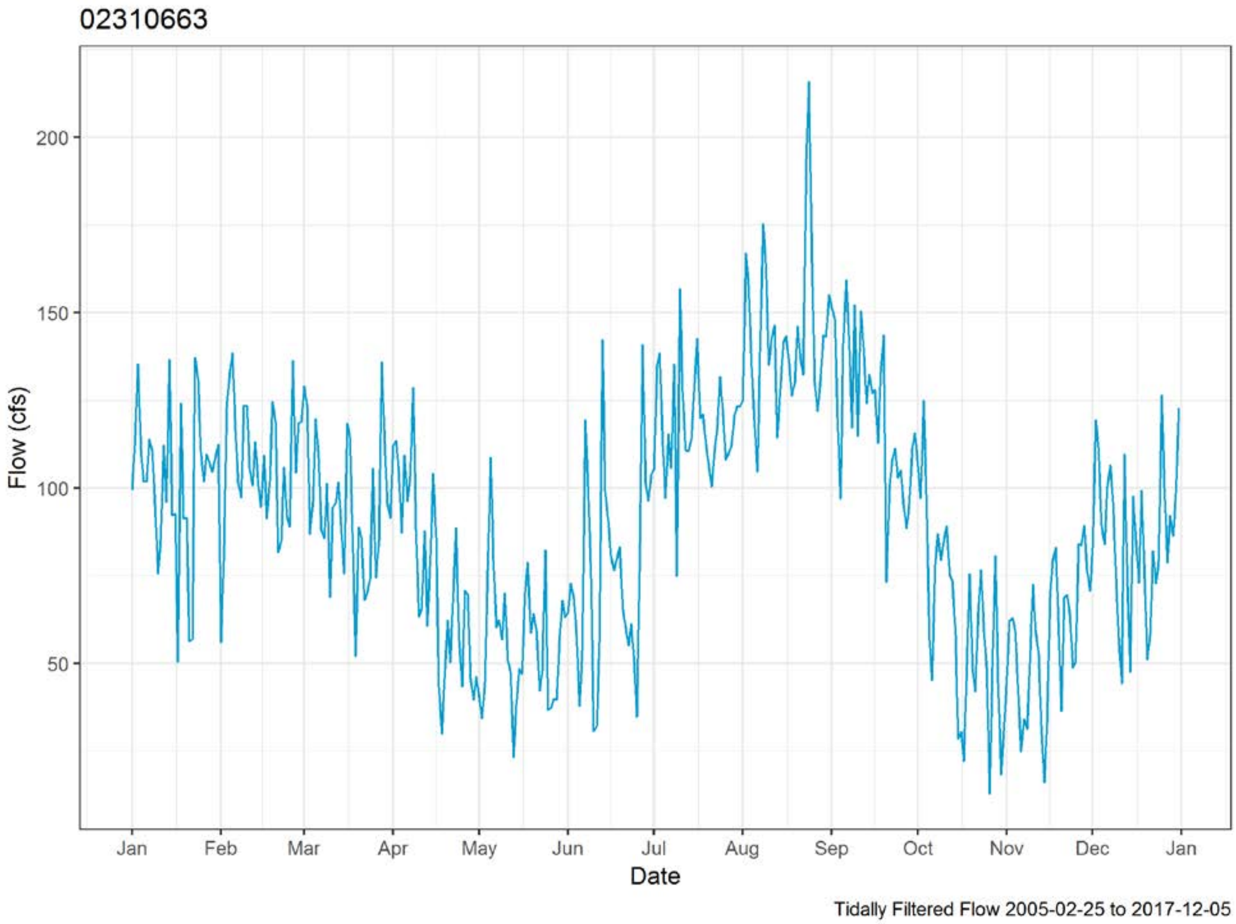


Figure 2-22. Tidally filtered flow on day of year at Chassahowitzka River near Chassahowitzka, FL gage (No. 02310663).

Table 2-5. Summary statistics for flow (cfs) at Chassahowitzka River near Chassahowitzka, FL gage (No. 02310663).

start	end	min	10th	25th	mean	median	75th	90th	max
2/25/2005	12/5/2017	-648	-32.0	25.9	90.8	90.2	151.8	215	1,010

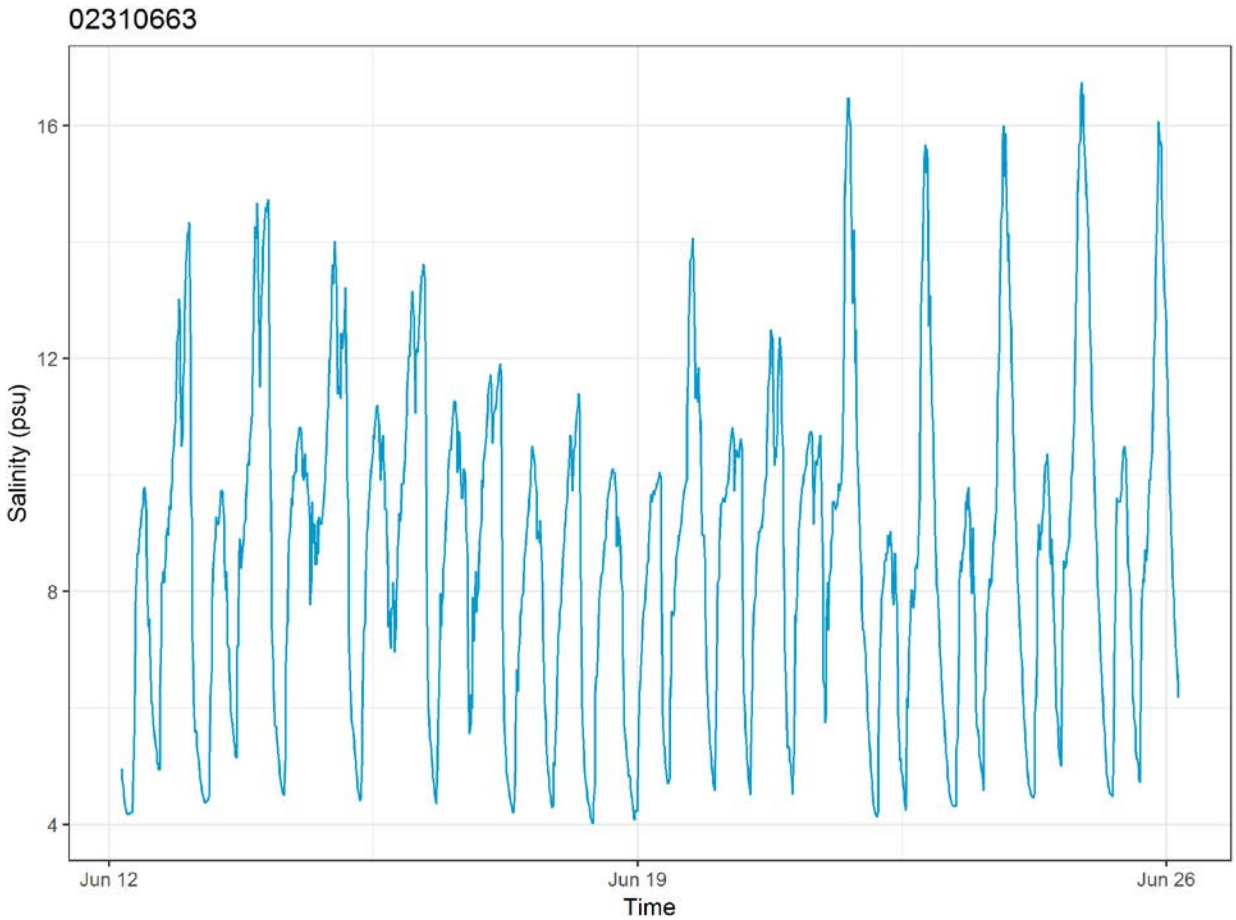


Figure 2-23. Tidal cycles in salinity at Chassahowitzka River near Chassahowitzka, FL gage (No. 02310663) from June 22 to June 26, 2017. Specific conductance at 25° C converted to salinity using equation by Lewis (1980) as reported in Schemel (2001).

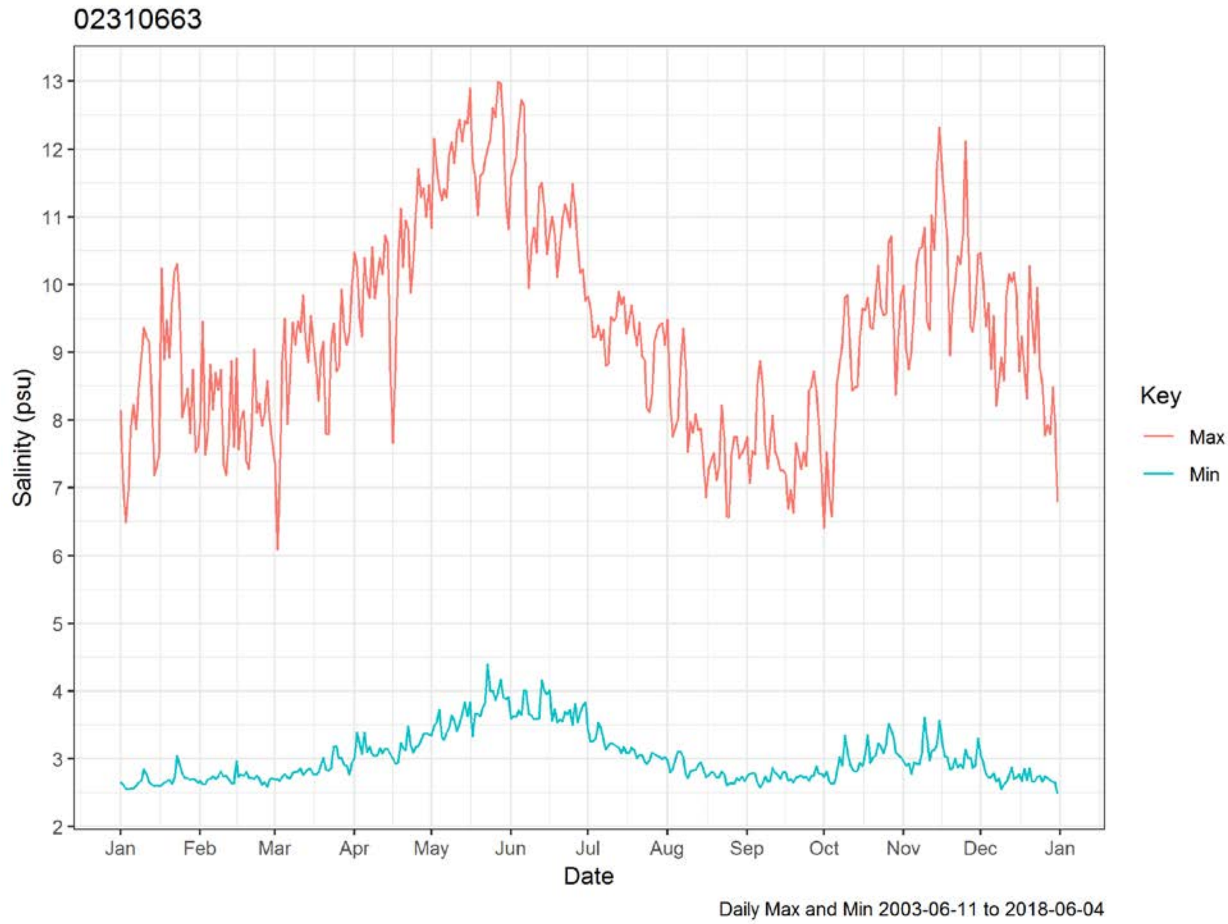


Figure 2-24. Salinity on day of year at Chassahowitzka River near Chassahowitzka, FL gage (No. 02310663). Specific conductance at 25° C converted to salinity using equation by Lewis (1980) as reported in Schemel (2001).

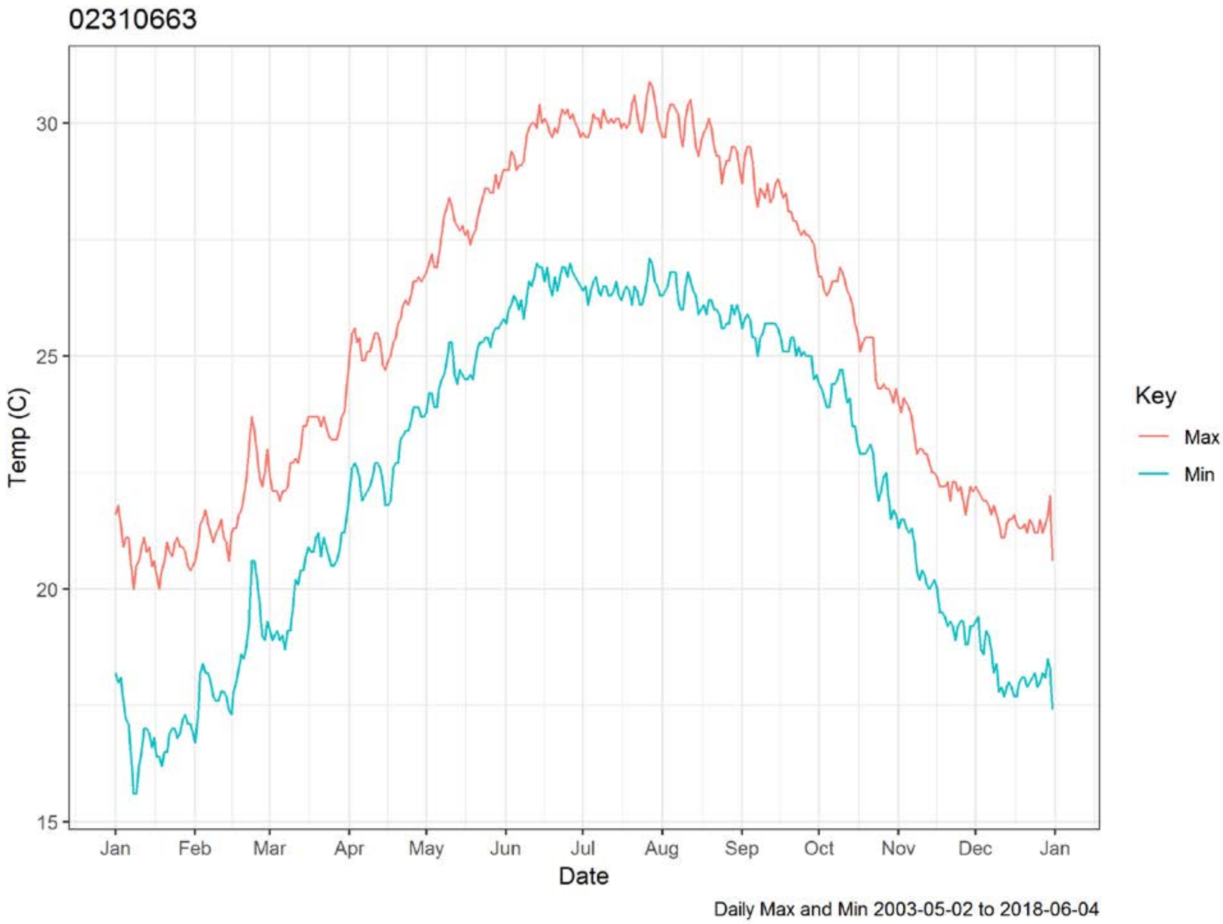


Figure 2-25. Temperature on day of year at Chassahowitzka River near Chassahowitzka, FL gage (No. 02310663). Daily variation shown as difference between daily min and max.

2.3.3 Chassahowitzka River at Dog Island near Chassahowitzka, FL (gage No. 02310673)

The Chassahowitzka River at Dog Island near Chassahowitzka, FL gage (No. 02310673) is at Lat 28°42'09.5" N, long 82°37'29.0" W, on southeast corner of a dock on Dog Island in the Chassahowitzka National Refuge, about 1.09 miles upstream from the mouth of the Chassahowitzka River. The gage is 0.6 miles downstream of Crawford Creek and 3.8 miles downstream from the head springs of the river (Figure 2-8.) (USGS 2018). The datum of the gage is NAVD88. The top specific conductance and temperature sensor is at a depth of 1.6 ft below NAVD 88 and the bottom sensor is at a depth of 2.8 ft below NAVD 88.

The Chassahowitzka River at Dog Island near Chassahowitzka, FL gage (No. 02310673) shows a tidal cycle in stage with an amplitude of about two feet between low-low and high-high tides (Figure 2-26.). Tides are highest in summer months (Figure 2-27.).

Flow is not measured at this gage.

Salinity varies with tide (Figure 2-28.). Salinity typically varies from lows around 5 to 10, while daily maxima range from 10 to 18, depending on time of year (Figure 2-29.). There is very little stratification between top and bottom sensors, which are placed 1.2 ft apart at 1.6 ft below NAVD88 and 2.8 ft below NAVD88. High salinities in May and June correspond to annual low flows measured at upstream gages (Figure 2-24.).

Temperatures vary by about 2.5°Celsius over the course of a day (Figure 2-30.). In the winter, temperature ranges from lows near 14°C to highs near 19°C. In the summer, lows are near 28°C and highs reach 31°C.

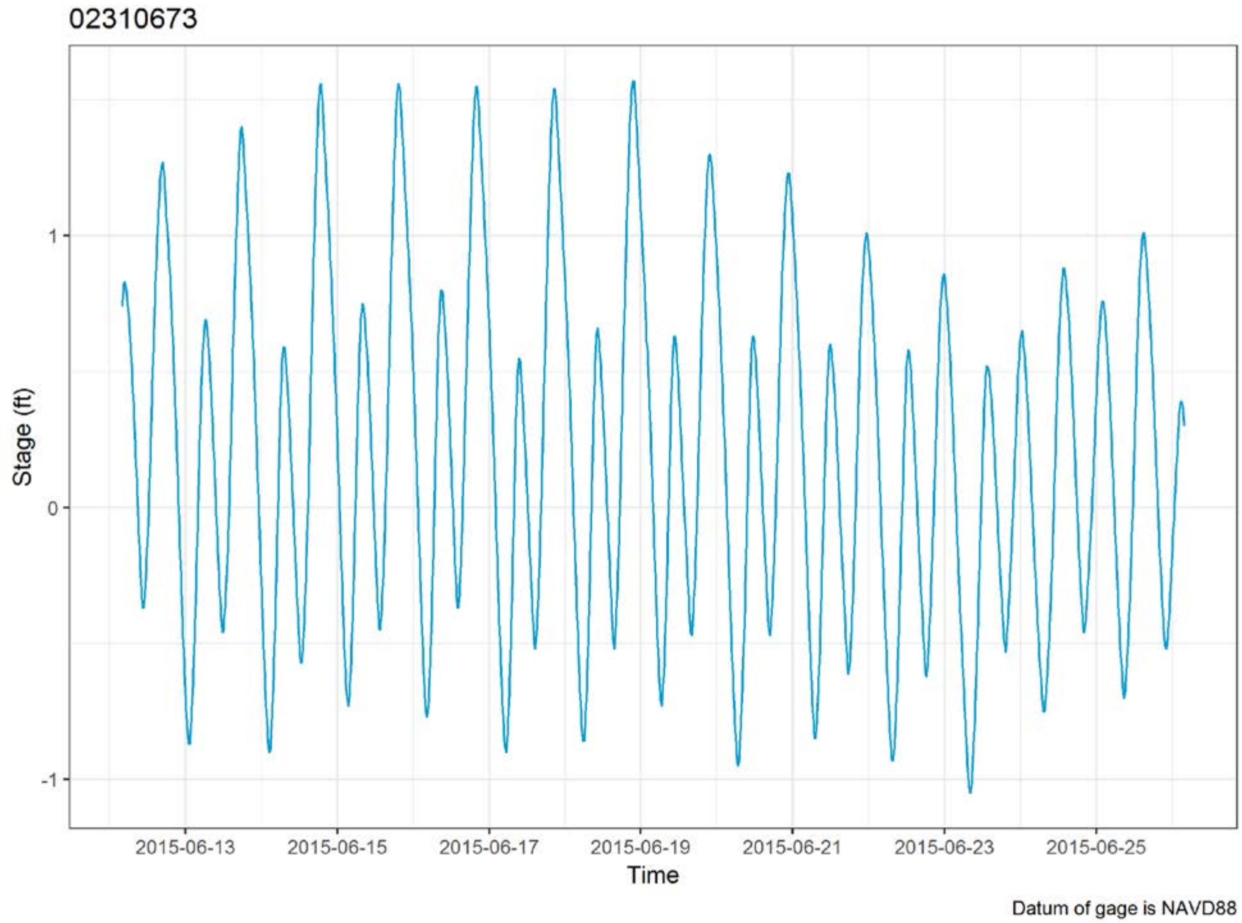


Figure 2-26. Tidal variation in stage at Chassahowitzka River at Dog Island near Chassahowitzka, FL gage (No. 02310673).

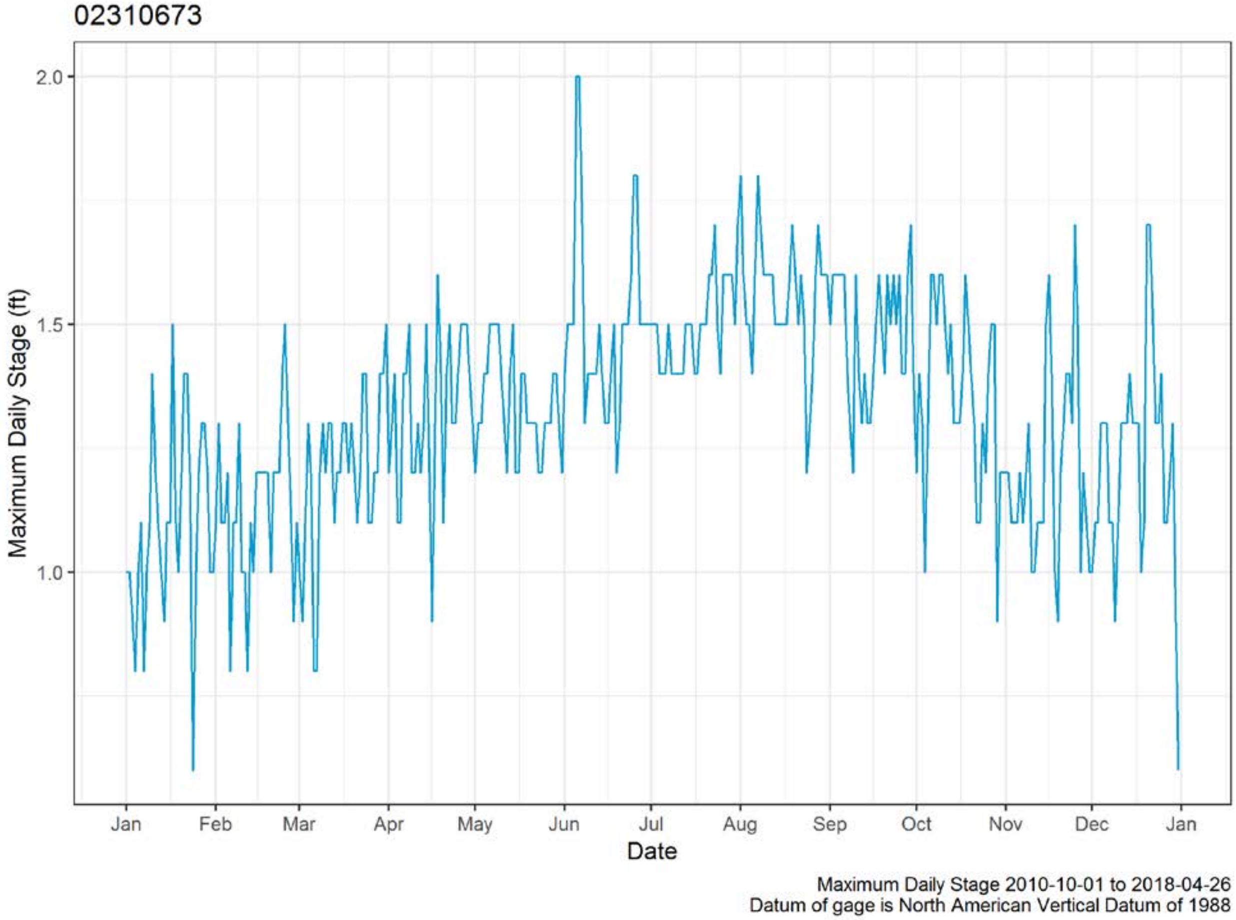


Figure 2-27. Maximum daily stage over day of year at Chassahowitzka River at Dog Island near Chassahowitzka, FL gage (No. 02310673).

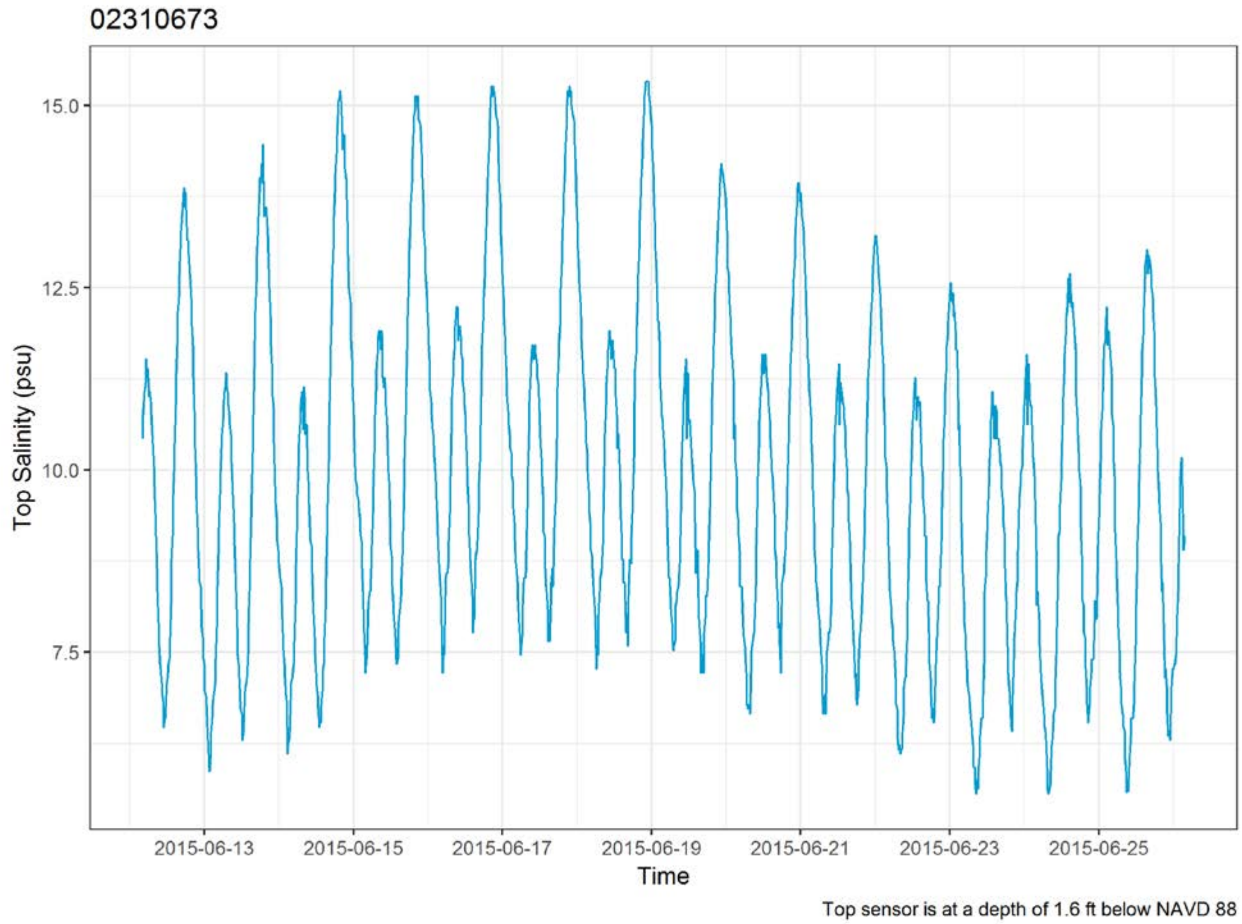


Figure 2-28. Tidal cycles in salinity at Chassahowitzka River at Dog Island near Chassahowitzka, FL gage (No. 02310673). Specific conductance at 25° C converted to salinity using equation by Lewis (1980) as reported in Schemel (2001).

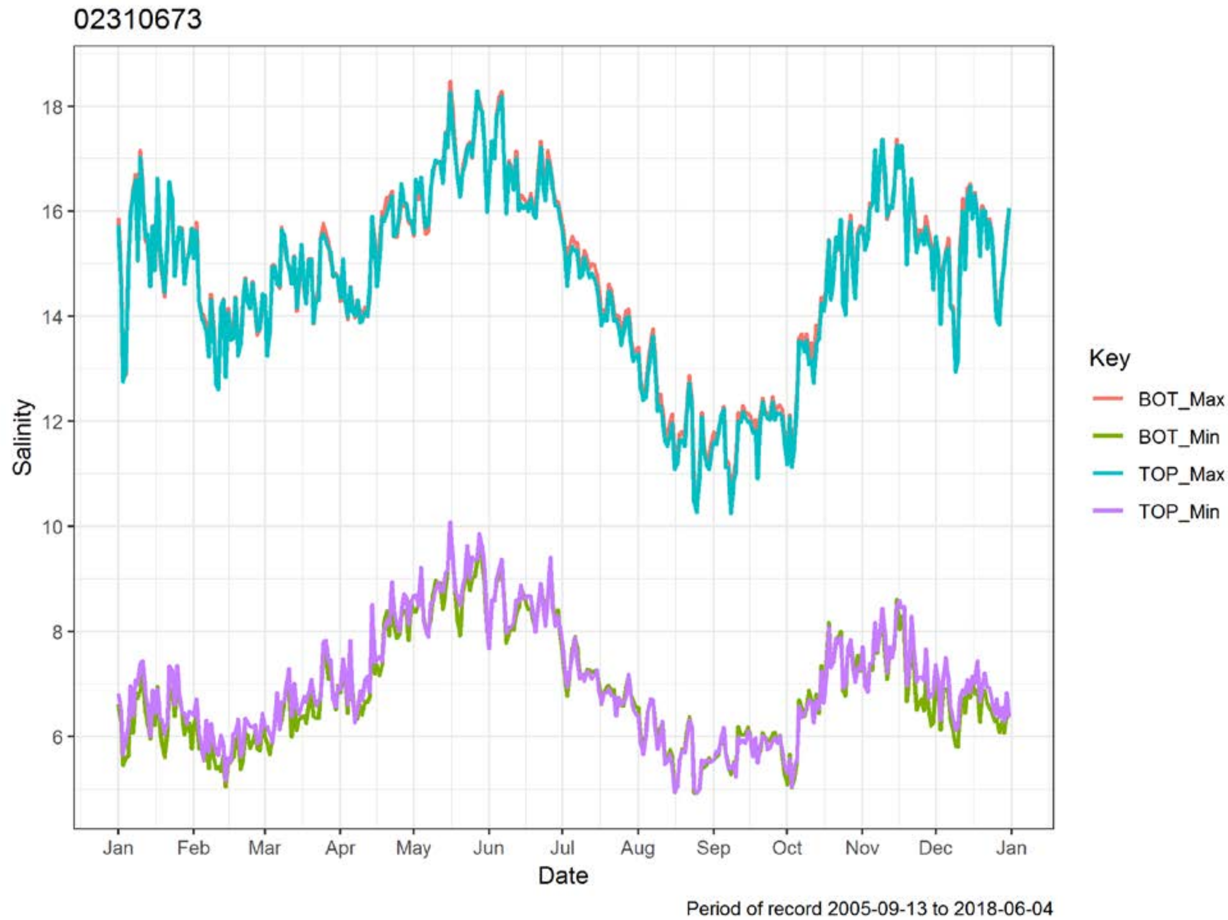


Figure 2-29. Daily minima and maxima in salinity at Chassahowitzka River at Dog Island near Chassahowitzka, FL gage (No. 02310673). Specific conductance at 25° C converted to salinity using equation by Lewis (1980) as reported in Schemel (2001).

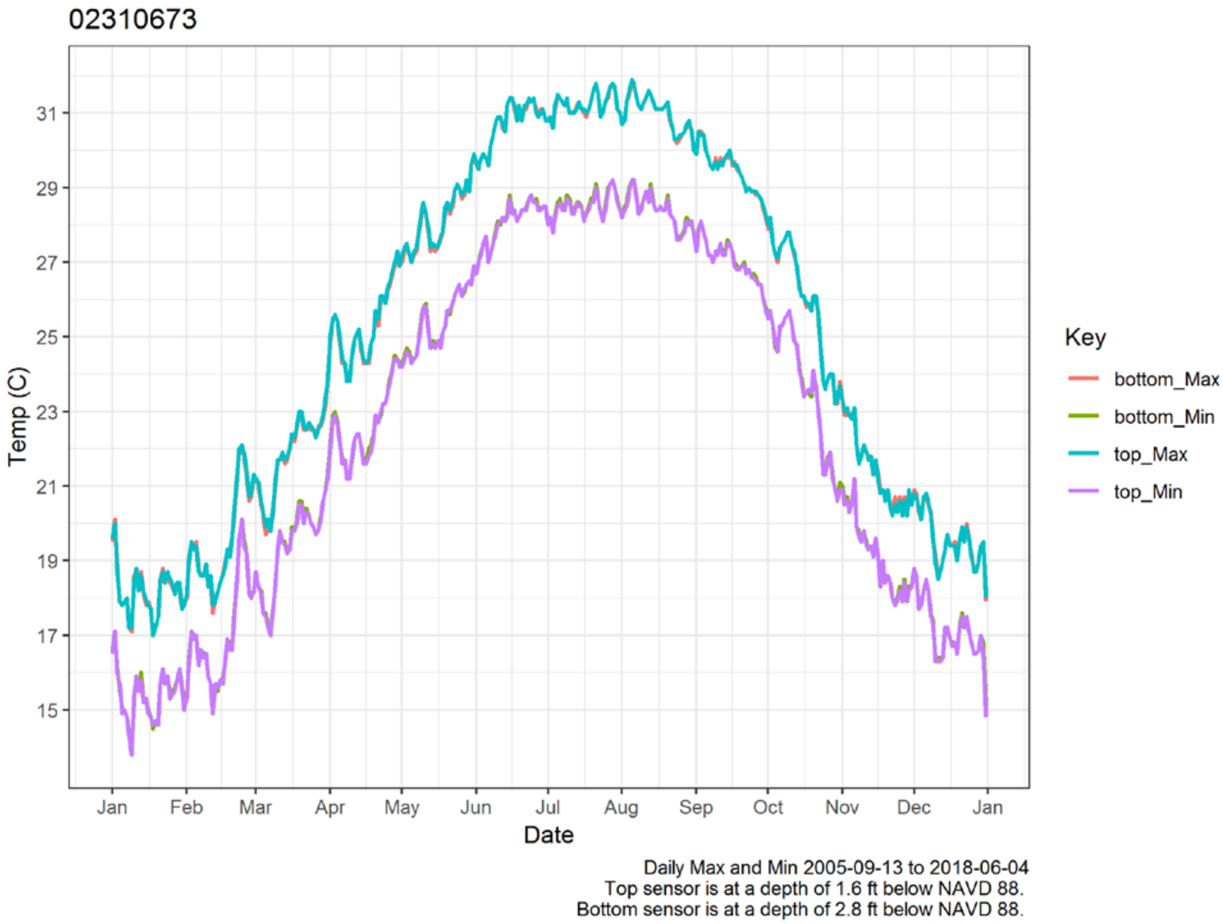


Figure 2-30. Temperature at Chassahowitzka River at Dog Island near Chassahowitzka, FL gage (No. 02310673).

2.3.4 Chassahowitzka River at Mouth near Chassahowitzka, FL (gage No. 02310674)

The Chassahowitzka River at Mouth near Chassahowitzka, FL gage (No. 02310674) is located at Lat 28°41'40" N, long 82°38'21" W, on a boundary marker for the Chassahowitzka National Refuge, about 1000 feet north of John's Island and considered at the mouth of the Chassahowitzka River. The gage is just downstream from May Creek, 1.09 miles downstream of Dog Island, 1.7 miles downstream of Crawford Creek and 4.9 miles downstream from the head springs of the river (Figure 2-8.) (USGS 2018). The datum of the gage is NAVD88. The top specific conductance and temperature sensor elevation is 2.8 ft below NAVD 88. Bottom sensor elevation is 6.2 ft below NAVD 88.

The Chassahowitzka River at Mouth near Chassahowitzka, FL gage (No. 02310674) shows a tidal cycle in stage with an amplitude of about three feet between low-low and high-high tides (Figure 2-31.).

Flow is not recorded at this gage.

Salinity varies over the course of a day with tide, by time of year, and between top and bottom sensors (Figure 2-32.). Both time of year and tide change salinity by around 6 to 7 psu. Seasonally, maximum salinities range from around 12 to 20, while minimum salinities range from 6 to 13. The difference between top and bottom salinities is usually less than one psu.

Temperatures range from lows around 15°C in winter to highs around 31°C in summer. The difference between daily minimum and maximum temperatures is around 2°C, while difference between top and bottom is mostly less than 0.1°C (Figure 2-33.).

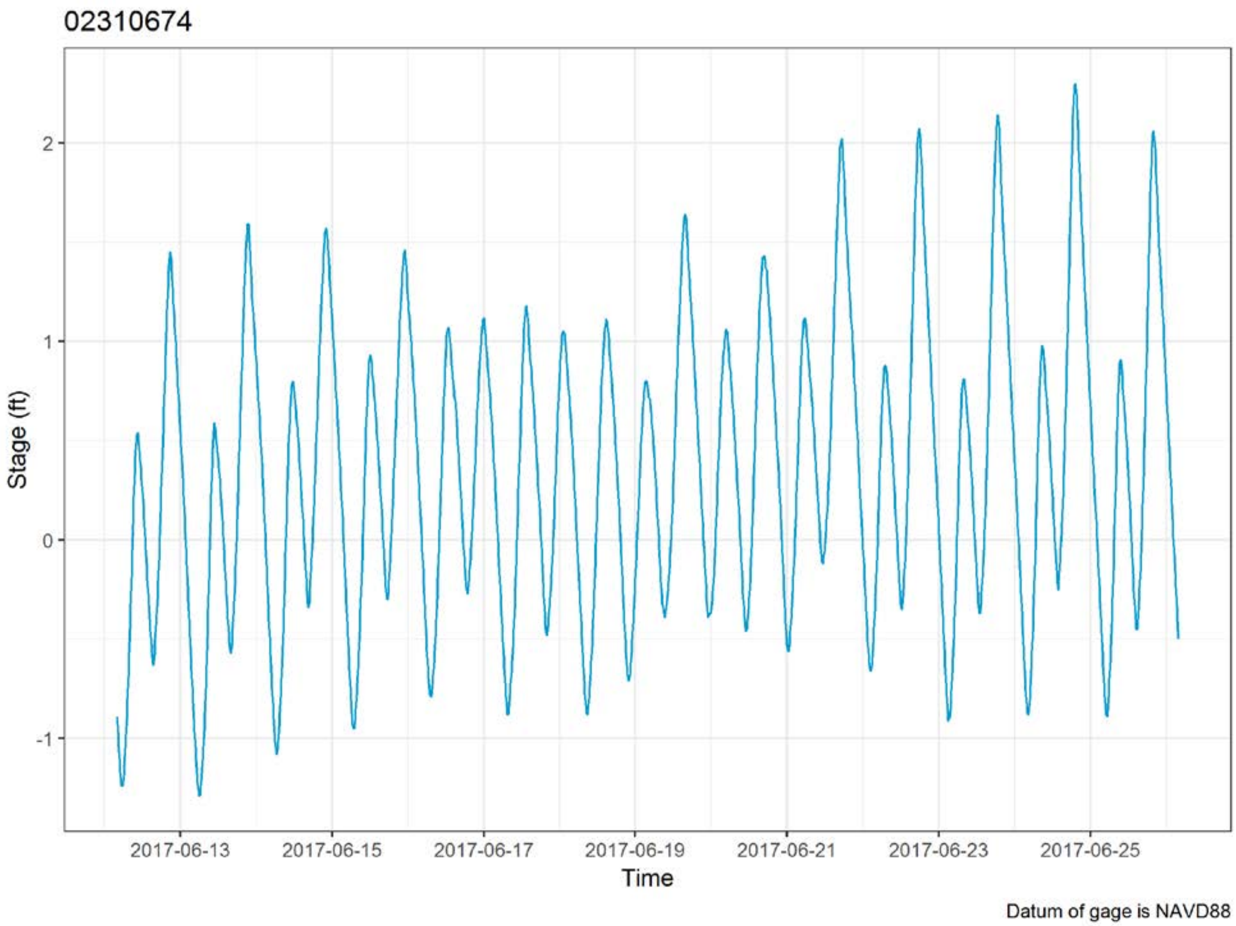


Figure 2-31. Tidal variation in stage at Chassahowitzka River at Mouth near Chassahowitzka, FL gage (No. 02310674).

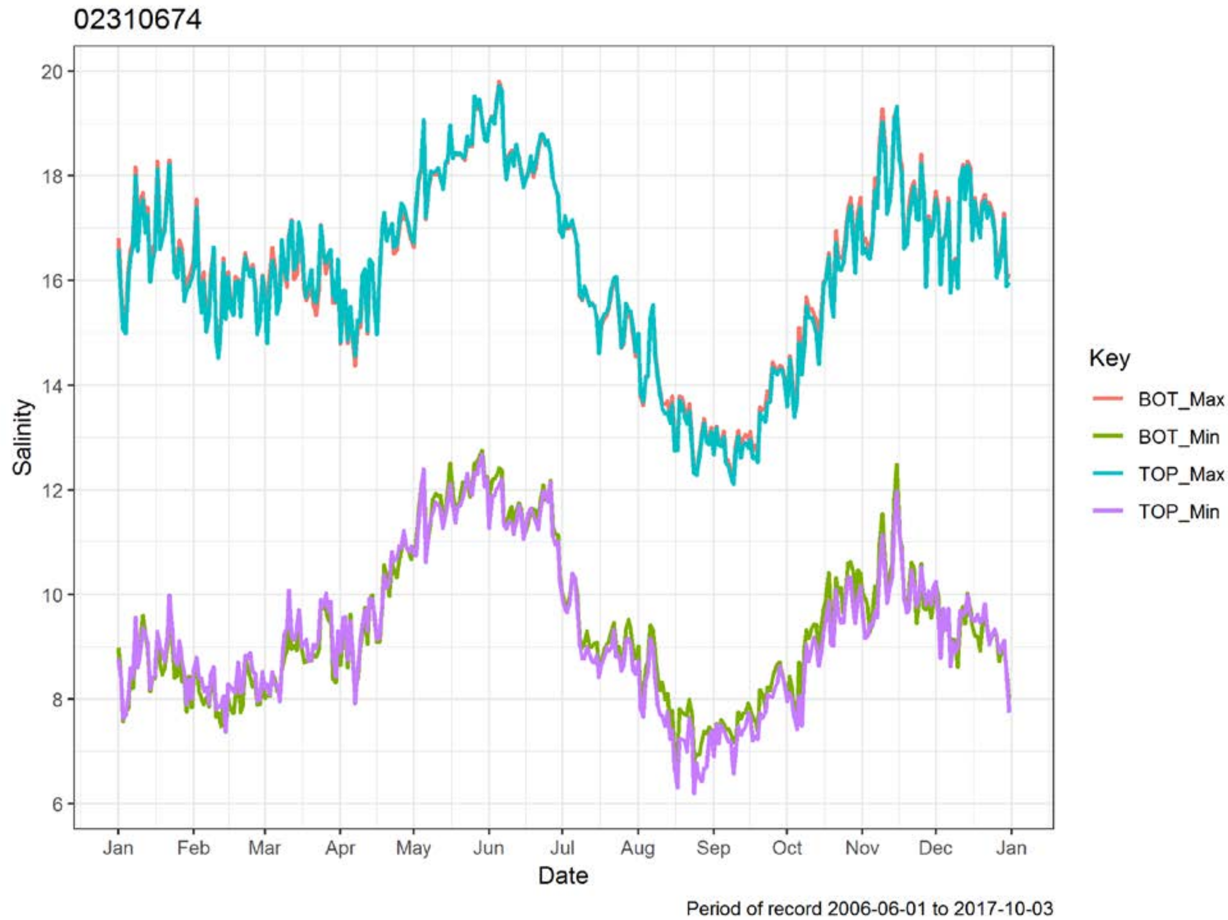


Figure 2-32. Daily minima and maxima in salinity at Chassahowitzka River at Mouth near Chassahowitzka, FL gage (No. 02310674). Specific conductance at 25° C converted to salinity using equation by Lewis (1980) as reported in Schemel (2001).

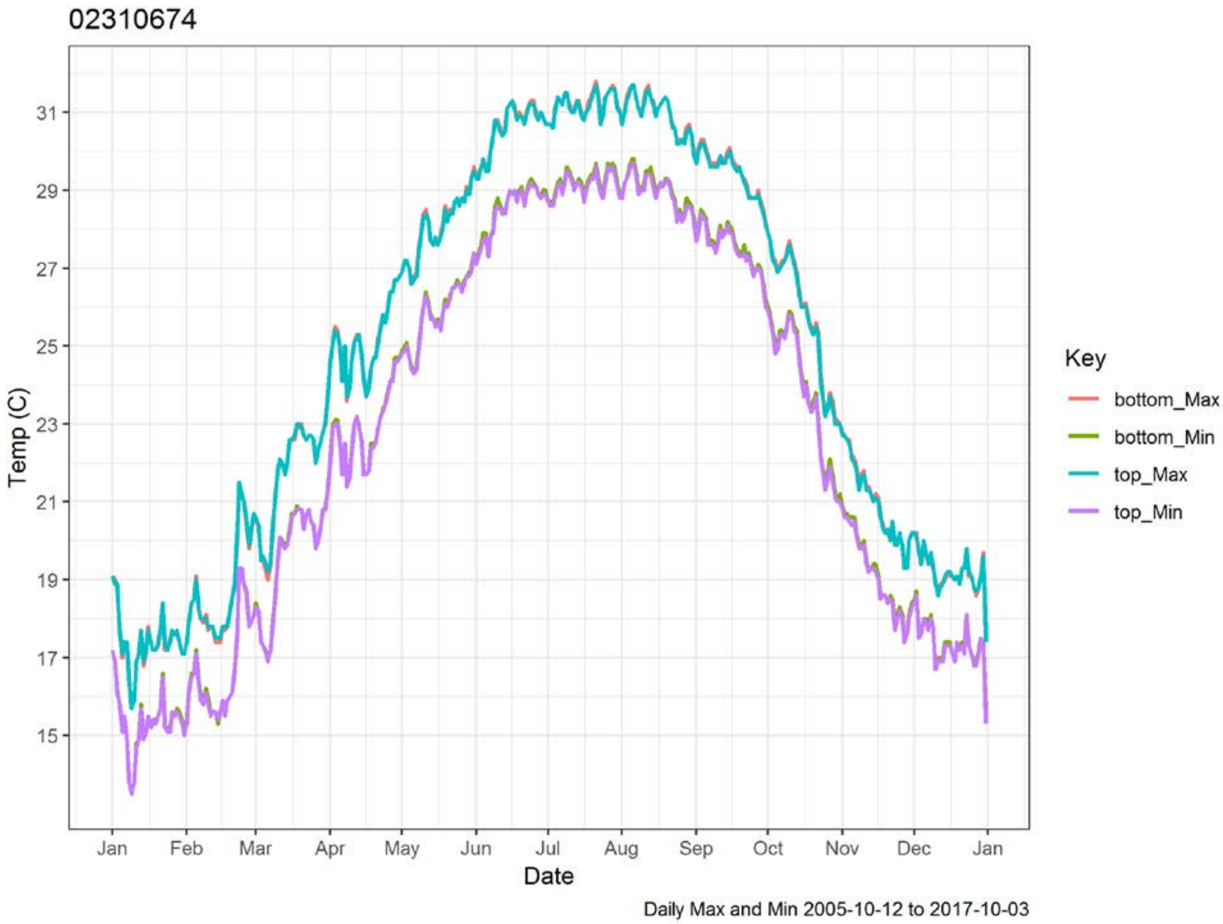


Figure 2-33. Temperature at Chassahowitzka River at Mouth near Chassahowitzka, FL gage (No. 02310674).

2.4 Bottom Substrates

As part of a District-funded study of several Gulf coastal rivers, Frazer *et al.* (2001) report that sand is the most common bottom type in the Chassahowitzka River, where it was the dominant substrate at 41.7 percent of the 100 sites sampled annually in 1998, 1999 and 2000 at 20 transects. Mud was the second most common substrate, dominant at 38 percent of the sampled sites and a mix of mud and sand was dominant at 15.7 percent of the sites. Similar results regarding substrate types were reported by Frazer *et al.* (2006) based on sampling of the river from 2003 through 2006 at the same sites surveyed between 1998 and 2001.

Arcadis (2016 [Appendix 4]) collected data on river bottom sediments in October 2015. They found sediment character is mostly fine sand transitioning to silty sand in the area of Rkm 6, both with trace organic detritus. This transition correlates with an overall increase in percent fines in the downstream direction. Sediment thickness in the Chassahowitzka River ranges from approximately 1 to 9 feet of penetrable thickness. A thick sequence at transect 6.0 (Rkm 6.8) appears at the confluence with Salt Creek, while thick sediments at transect 8.5 (Rkm 5.5) appear just upstream form a sharp bend in the river. A sharp bend will cause a sudden decrease in river velocity, which may result in increased sedimentation in that area.

2.5 Flow Records

2.5.1 Differences in Flow Records

There are many flow records that were used in the development of this minimum flows evaluation. A general flow record was developed based on the reported discharges at gaging stations summarized in section 2.3. This general flow record was then modified for use in water quality analyses described in Chapter 3 and for hydrodynamic modeling described in Chapter 6 and Chen (2019a [Appendix 7]). These flow records differ in their periods of record, data frequency, treatment of missing dates, scaling of impacts, and inclusion of additional inputs at tributaries and adjustments for net flow (Table 2-6).

The general flow record, more fully described below, has a period of record limited to the gaged flows at the USGS Chassahowitzka River near Homosassa, FL gage (No. 02310650). Daily flows are used as reported and approved by the USGS. On dates when data is missing, no flows are reported, and these are left blank in the flow record. No additional flows are added nor are adjustments made for tidal water movement past this gage.

The water quality flow record is constructed in the same manner as the general record except that it predicts flows prior to the gage period of record and fills in missing data by regression with the Weeki Wachee well (see Chapter 3.5.1). This in-filling was done to make use of water quality data for dates when gaged flow data was missing.

The LAMFE model flow record is constructed using 15-minute data. Like the general record, missing data was left missing. Impacts were kept at a constant value of 1.4% based on the most recent NDM estimate. In addition, the LAMFE model needs to more accurately predict net spring flows at the main springs and tributaries. Thus, additional flows were added as described in Chapter 3 of the hydrodynamic modeling report Chen (2019a [Appendix 7]). These additional flows were added as proportions of the gaged flows in order to accurately model the locations and quantities of spring water additions to the system.

Table 2-6. Differences in flow records

Record	Period of Record	Data Frequency	Missing Dates	Impacts	Inputs
General	1997-02-20 to 2018-10-15	Daily	Left missing	Gradually increased	Gaged only
Water Quality	1975-01-01 to 2018-10-15	Daily	Estimated	Gradually increased	Gaged only
LAMFE	2007-10-11 to 2018-02-15	15-minute	Left missing	Constant	Adjusted for tides and tributaries

2.5.2 The General Flow Record

Gage Flow data from USGS Chassahowitzka River near Homosassa, FL gage (No. 02310650) were downloaded from USGS NWIS using the dataRetrieval R package (De Cicco et al. 2018). This gage reports discharge (param code 00060) in two forms: as regression flow and as index velocity flow. Data were filtered to include only approved values. Approved regression data consists of 5009 observations from 1997-02-20 to 2012-10-14. Approved index velocity data consists of 1903 observations from 2012-11-17 to 2018-10-15. The combined record consists of 6912 observations over 7908 days from 1997-02-20 to 2018-10-15 (Figure 2-34). Missing dates were not in-filled with data from other sources or interpolation between dates.

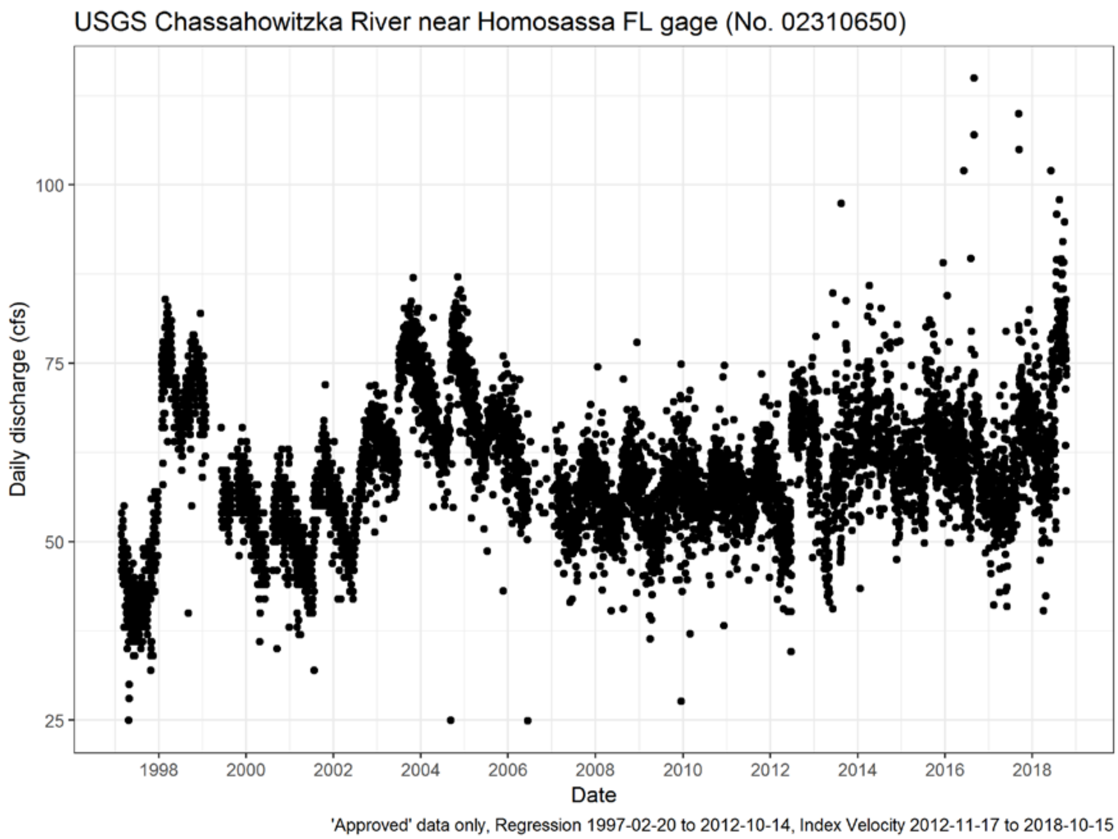


Figure 2-34. Complete flow record of daily mean discharge values reported as “approved” at USGS Chassahowitzka River near Homosassa FL gage (No. 02310650). Data consists of 6912 observations over 7908 days from 1997-02-20 to 2018-10-15.

CHAPTER 3 - WATER QUALITY CHARACTERISTICS AND RELATIONSHIPS WITH FLOW

3.1 Introduction

Water quality is one of 10 “Environmental Values” defined in the State Water Resource Implementation Rule (Chapter 62-40 F.A.C.) to be considered when establishing minimum flows. The water quality constituents of the Chassahowitzka River and estuary discussed here are reviewed in the context of the original 2012 MFL report (Heyl et al. 2012) but are not intended to duplicate that work. This chapter presents an overview of the status and trends for water quality parameters of concern, specifically those parameters related to existing state standards. In addition, this chapter summarizes the results of a project completed by Janicki Environmental, Inc. and WSP, Inc. under a District Task Work Assignment (TWA 18TW0001116) (Janicki Environmental, Inc. and WSP, Inc. 2018 [Appendix 8]). The purpose of this project was to conduct an exploratory evaluation of water quality and flow relationships for the Chassahowitzka River. Specific tasks associated with this project consisted of data gathering, exploratory data analysis, stochastic predictive modeling, and synthesizing information to support the revaluation of minimum flows for the Chassahowitzka River. 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 Appendix 8. The inclusion of adopted water quality standards is for informational purposes only and are not intended to be a determination of impairment.

3.1.1 Water Quality Classification

Under Rule 62-302.200, F.A.C., Florida’s surface water quality standards consist of four components: 1) the designated use or classification of each water body, 2) the surface water quality criteria (numeric and narrative) for each water body, which are established to protect its designated use, 3) the anti-degradation policy, and 4) moderating provisions, such as mixing zones. Each surface water body in Florida is classified according to its present and future most beneficial use, referred to as its designated use, with class-specific water quality criteria for select physical and chemical parameters, which are established to protect the water body’s designated use (Chapter 62-302, F.A.C.). Most coastal waters of Hernando and Citrus Counties, including the Chassahowitzka River upstream to about river kilometer 5.0, are classified as Class II waters with a designated use of shellfish propagation or harvesting (Rule 62-302.400(16)(b), F.A.C.). The upper portion of the Chassahowitzka River and the springs associated with the Chassahowitzka River system are all designated as Class III waters with designated uses of recreation and the propagation and maintenance of a healthy, well-balanced population of fish and wildlife (Rule 62-302.400, F.A.C.). All water bodies in the Chassahowitzka River system are classified as Outstanding Florida Waters, a designation associated with Florida’s anti-degradation policy (Rule 62-302.700, F.A.C.). In addition, the Chassahowitzka River is also designated a Southwest Florida Water Management District Surface Water Improvement and Management (SWIM) Priority Waterbody and as such, has a comprehensive SWIM Plan, approved by the Springs Coast Steering Committee and the District’s Governing Board in August 2017 (Southwest Florida Water Management District 2017).

3.1.2 Impaired Waters Rule

Section 303(d) of the Federal Clean Water Act requires each state to identify and list "impaired" waters where applicable water quality criteria are not being met. To meet the reporting requirements of the Federal Clean Water Act, the State of Florida publishes the Integrated Water Quality Assessment for Florida. Assessment is made based on specific segments each assigned a specific Waterbody Identification (WBID). There are several WBIDs that make up the Chassahowitzka River (Figure 3-1.). These WBIDs have corresponding limits for select water quality parameters identified as numeric nutrient criteria (NNC) and total maximum daily loads (TMDLs) (Table 3-1).

The most recent assessment report to date was published in June 2018 (Florida Department of Envrionmental Protection 2018). As of August 21, 2018, none of the Chassahowitzka WBIDs were on the Statewide Comprehensive Verified List of Impaired Waters. However, this is partly because 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, but it is removed from the verified list. The original minimum flow report (Heyl et al. 2012) for the Chassahowitzka River system cited several WBIDs as being impaired for nutrients (algal mats) and mercury (in fish tissue). Chassahowitzka Planning Unit WBIDs previously verified for mercury (fish tissue) have been removed from the verified impaired waters list (“delisted”) because they have either been reclassified or now have a DEP-adopted mercury Total Maximum Daily Load (TMDL). Similarly, Chassahowitzka Springs Group-Crab Creek Spring (WBID 1348Z), Chassahowitzka River-Baird Creek-Baird Springs-Ruth Springs (1348D), and Beteejay Spring (WBID 1361B) have been “delisted” from the impaired waters list for nutrients (algal mats) because they have a DEP-adopted nitrate TMDL (Dodson et al. 2014).

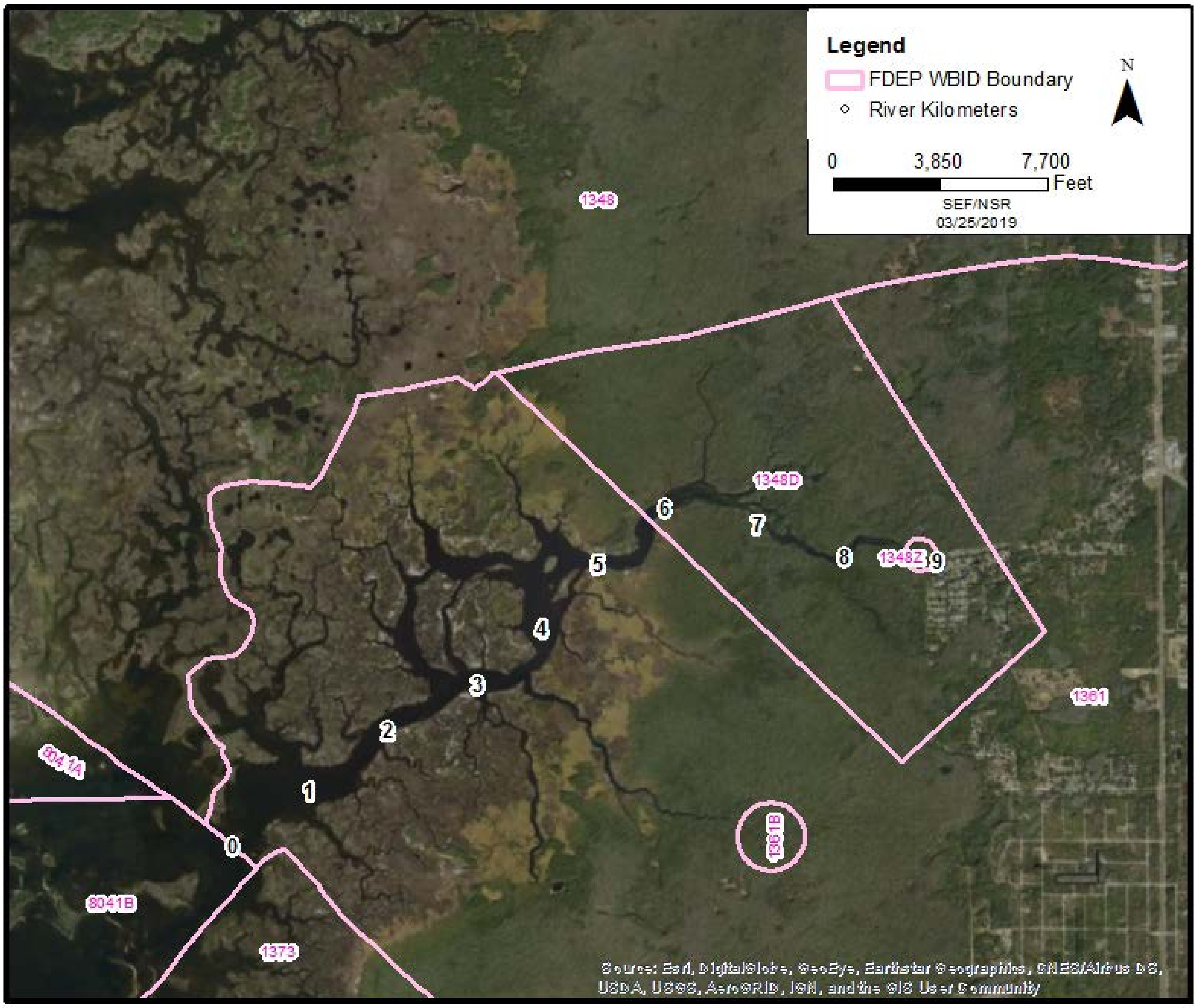


Figure 3-1. Map of Chassahowitzka River with DEP Waterbody ID (WBID) boundaries and the river kilometer (Rkm) system used for the development of this minimum flows evaluation.

Table 3-1. Numeric Nutrient Criteria (NNC) and Total Maximum Daily Loads (TMDL) associated with Water Body IDs (WBID) in the Chassahowitzka River system.

	NNC			TMDL	
	Total Nitrogen	Total Phosphorus	Chlorophyll a	Total Nitrogen	Nitrate
WBID 1361					
Chassahowitzka River-Estuary Segment	0.44 mg/L	0.021 mg/L	3.9 µg/L		
WBID 1631B					
Beteejay Spring					0.23 mg/L
WBID 1348D					
Chassahowitzka River-Baird Creek				0.25 mg/L	
Crab Creek Spring					0.23 mg/L
Baird #1 Spring					0.23 mg/L
WBID 1348Z					
Chassahowitzka Main Spring					0.23 mg/L
Chassahowitzka #1 Spring					0.23 mg/L

3.1.3 Numeric Nutrient Criteria

Given the global extent of water quality degradation associated with nutrient enrichment, eutrophication poses a serious threat to potable drinking water sources, fisheries, and recreational water bodies (Chislock et al. 2013). Nutrient enrichment continues to be a major issue in Florida waters. In 2011, the state of Florida adopted quantitative nutrient water quality standards to facilitate the assessment of designated use attainment for its waters and to provide a better means to protect state waters from the adverse effects of nutrient over enrichment (Florida Department of Environmental Protection 2009). To that end, the DEP developed numeric criteria for causal variables (phosphorus and nitrogen) and/or response variables (chlorophyll), recognizing the hydrologic variability (waterbody type) and spatial variability (location within Florida) of the nutrient levels of the state’s waters, and the variability in ecosystem response to nutrient concentrations. Because nutrient effects on aquatic ecosystems are moderated by many natural factors (e.g., light penetration, hydraulic residence time, presence of herbivore grazers and other food web interactions, and habitat considerations), the DEP recognized that determining the appropriate protective nutrient regime is largely a site-specific undertaking, requiring information about ecologically relevant responses (Florida Department of Environmental Protection 2013).

In July 2013, the DEP published site-specific numeric nutrient criteria (NNC) for the Springs Coast including the estuarine segment of the Chassahowitzka River. The estuarine segment extends from the mouth of the river upstream to the point at which the river becomes predominantly fresh and is that part of the river contained within WBID 1361; the Chassahowitzka River estuary. This

WBID 1361 has an established site-specific NNC for total phosphorous (TP), total nitrogen (TN), and chlorophyll concentrations (Table 3-1). To date, the Chassahowitzka River Estuary segment is meeting the NNC criteria for TP, TN, and chlorophyll, and is therefore not classified as impaired.

The upper portion of the Chassahowitzka River contained within WBID 1348D, is a tidal freshwater segment and therefore is exempt from NNC criteria development, per Rule 62-302.400, F.A.C., which states "numeric values…for nutrient and nutrient response values do not apply…to tidal tributaries that fluctuate between predominantly marine and predominantly fresh water during typical climatic and hydrologic conditions."

3.1.4 Total Maximum Daily Loads (TMDL)

Section 303(d) of the federal Clean Water Act requires states to submit to the U.S. Environmental Protection Agency (EPA) a list of surface waters that do not meet applicable water quality standards (impaired waters) and establish a 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 waterbody segments 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.

In 2012, several of the springs discharging to the Chassahowitzka River and the tidal freshwater segment of the Chassahowitzka River itself (WBID 1348D) were placed on the verified impaired list for nutrients based on the presence of algal mats. Nitrate-nitrogen was determined by the DEP to contribute to the ecological imbalance of several springs that discharge into the Chassahowitzka River (Dodson et al. 2014). The presence of filamentous algal mats in the spring pools and portions of the mainstem of the Chassahowitzka River was the primary line of evidence for this imbalance (Dodson et al. 2014). Based on laboratory studies (Stevenson et al. 2007; Stevenson et al. 2004) and other nutrient algae studies (Dodson et al. 2014), the DEP adopted a TMDL nitrate concentration of 0.23 mg/L for the following springs: Chassahowitzka Main Spring (WBID 1348Z), Chassahowitzka #1 Spring (1348Z), Crab Creek Spring (WBID 1348D), Baird #1 Spring (WBID 1348D), and Beteejay Spring (WBID 1361B) (Table 3-1). In addition to the nitrate TMDL, there is also a total nitrogen TMDL of 0.25 mg/L for Chassahowitzka River-Baird Creek (WBID 1348D).

It is important to note that the nitrate and total nitrogen TMDL is based solely on the relationship between nitrogen and filamentous algae and not phytoplankton algae which can also increase in biomass with increasing anthropogenic nutrient enrichment (DEP 2013). However, chlorophyll-nutrient relationships in tidal spring-fed estuaries like the Chassahowitzka River system are extremely complex and very difficult to detect. Traditionally, nitrogen has been viewed as the predominant limiting nutrient in marine waters. However, there are many exceptions to this traditional view, particularly in coastal ecosystems, where such generalizations have limited practical meaning for water management (Frazer et al. 2002).

3.1.5 Water Clarity

Secchi depth is a measure of light penetration into a waterbody and is a function of the absorption and scattering of light in the water (Lee et al. 1995). There are primarily three factors or characteristics of a water that affect the depth to which light will penetrate. One factor is the amount of color, either in true solution or in a colloidal or suspended form in the water. Color-causing materials, the forms (dissolved or colloidal) of which are typically controlled by the amounts and forms of iron present, are often described as "humics" or "tannins." Phytoplankton (algae) in the water column also scatter and absorb light. Therefore, the presence of high concentrations of algae in a waterbody reduces light penetration and hence reduces Secchi distance. Third, inorganic clastic (erosional) materials (measured as turbidity) scatter and absorb light, reducing the water's transparency.

In much of the Chassahowitzka River, the water is sufficiently clear to see through the water column to the river bottom. Therefore, a horizontal Secchi disk is used in which the disk is placed just below the surface of the water and oriented perpendicular to the bottom. The observer swims away from the disk until it can no longer be seen. That distance is reported as Secchi-horizontal (Total).

3.2 Overview of Water Quality Data Sources

Multiple water quality datasets are available for the Chassahowitzka River system, but differences in sampling location, sampling frequency, and laboratory procedures used for their development made it difficult to combine them. This section summarizes sources of water quality and other data types used for this minimum flow reevaluation. A quality control data screening procedure was employed (Janicki Environmental, Inc. and WSP, Inc. 2018) to identify any potential anomalous values in each assessed dataset. While anomalous data points were identified, no data were eliminated from the database that was developed based on the screening procedures. A Microsoft Access database was created of all available water quality, hydrologic, and other available ancillary datasets compiled for the Chassahowitzka River.

3.2.1 Active Water Quality Data Collection

Ongoing, active water quality sampling networks include three District projects: Coastal Rivers Project P108, COAST Project P529, and Spring Vents Project P889 (Table 3-2). Since 2017, the District has also deployed continuous recording devices at three locations along the Chassahowitzka River. Continuous recorders collect a limited suite of water quality data at 15-minute to one-hour intervals and transmit these data remotely via cellular transmission. This gives the District the ability to monitor certain water quality parameters across diurnal and tidal cycles, and during storms and other significant events.

Surface-water stations sampled as part of the District's Coastal Rivers Project P108 are shown in Figure 3-2. Sampling began in late 2005 and included bimonthly sampling until 2011 after which sampling switched to a quarterly frequency. Coastal Rivers Project P108 samples are grab samples collected by District staff and analyzed at the NELAC-certified District water chemistry laboratory in Brooksville, FL for the standard District suite of laboratory analytes (Table 3-3).

Several field, or in-situ, water quality parameters are also collected concurrently with grab sample collection (Table 3-3).

COAST Project P529 began in 1997 as a District-funded University of Florida project to monitor potential impacts of increased nitrogen loading from springs to the nearshore coastal waters of the Springs Coast, extending from Waccasassa Bay southward to Anclote Key (Jacoby et al. 2012; Jacoby et al. 2015). Originally, there were 50 stations sampled along the Springs Coast monthly for a limited suite of field and laboratory parameters by the University of Florida between 1997 and 2010. In 2013, the District resumed water quality monitoring for a subset of the original 50 stations and expanded the suite of water quality parameters to match the standard District suite for the Coastal Rivers Project P108 network (Table 3-3). For the Chassahowitzka River, there were 10 fixed stations sampled until 2010 (Figure 3-3.). In 2013, the District resumed sampling on a quarterly basis for seven of the original ten stations. It is important to note that while most of these stations fall outside of the Chassahowitzka River hydrodynamic model domain (Chen 2019a [Appendix 7]), they were included in this analysis to explore any observed relationships between water quality and spring flow.

The District has been collecting water quality data in springs since the early 1990s in response to concerns about increasing nitrate concentrations (Jones et al. 2011). The principal spring vents of the Chassahowitzka River have been monitored by the District since 1993. There are seven active spring vents sampled under Spring Vents P889 (Figure 3-4). Spring vent samples are collected at or near low tide by using a sampling pump attached to a tube set into the spring vent. The standard District suite of water quality parameters for spring vents is based on the suite of groundwater quality parameters (Table 3-4) and differs slightly from the suite of surface water parameters (Table 3-3).

Since 2017, the District has been collecting continuous water quality data at three locations on the Chassahowitzka River (Figure 3-5.). Despite having a short period of record, these recorders have collected an enormous amount of data at hourly sampling intervals. Continuous recorders have a relatively limited, though ecologically important, parameter suite (Table 3-5). In addition to the District’s continuous recorders, the USGS through a joint funding agreement with the District has a continuous nitrate sensor deployed at the Chassahowitzka River near Homosassa, FL gage (No. 02301650) located near the headsprings (Figure 3-5.).

Table 3-2. Active District water quality monitoring networks. From 1996 – 2010, COAST Project P529 was a District-funded University of Florida project. The District resumed sampling a subset of the original stations in 2013 on a quarterly basis but added several more water quality parameters to the original list of parameters.

Monitoring Network	Period of Record	Annual Sampling Frequency	Number of Sampling Events
Coastal Rivers Project P108	2005 – 2017	Bi-monthly /quarterly after 2011	65
COAST Project P529	1996 – 2017	Monthly/quarterly after 2013	140
Spring Vents Project P889	1993 – 2017	Quarterly	120

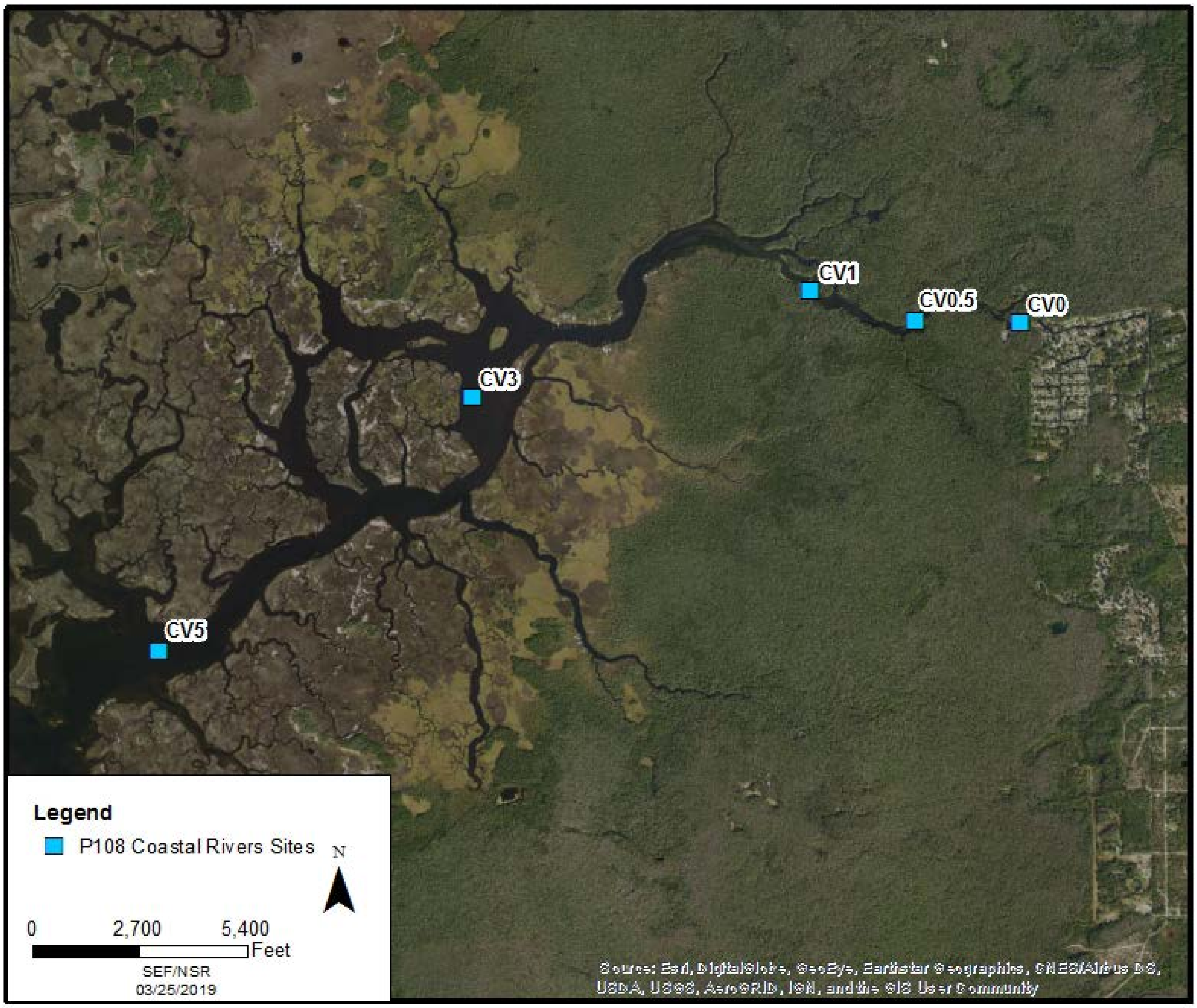


Figure 3-2. Active surface-water sampling locations for the Coastal Rivers Project P108 monitoring network.

Table 3-3. Standard District suite of field and laboratory surface water quality parameters (* denotes field parameters collected in-situ concurrent with grab sample collection).

Parameters	
Ammonia (N) (Total)	pH (Total)*
Calcium (Dissolved)	Phaeophytin (Total)
Chlorophyll a (Total)	Phosphorus- Total (Total)
Color (Dissolved)	Potassium (Dissolved)
Depth (Total)*	Residues- Nonfilterable (TSS) (Total)
Depth, bottom (Total)*	Residues- Volatile (Total)
Dissolved Oxygen (Total)*	Salinity (Total)*
Iron (Dissolved)	Secchi-horizontal (Total)*
Magnesium (Dissolved)	Secchi-vertical (Total)*
Nitrate-Nitrite (N) (Total)	Sodium (Dissolved)
Nitrite (N) (Total)	Specific Conductance (Total)*
Nitrogen- Total (Total)	Temperature (Total)*
Orthophosphate (P) (Dissolved)	Turbidity (Total)

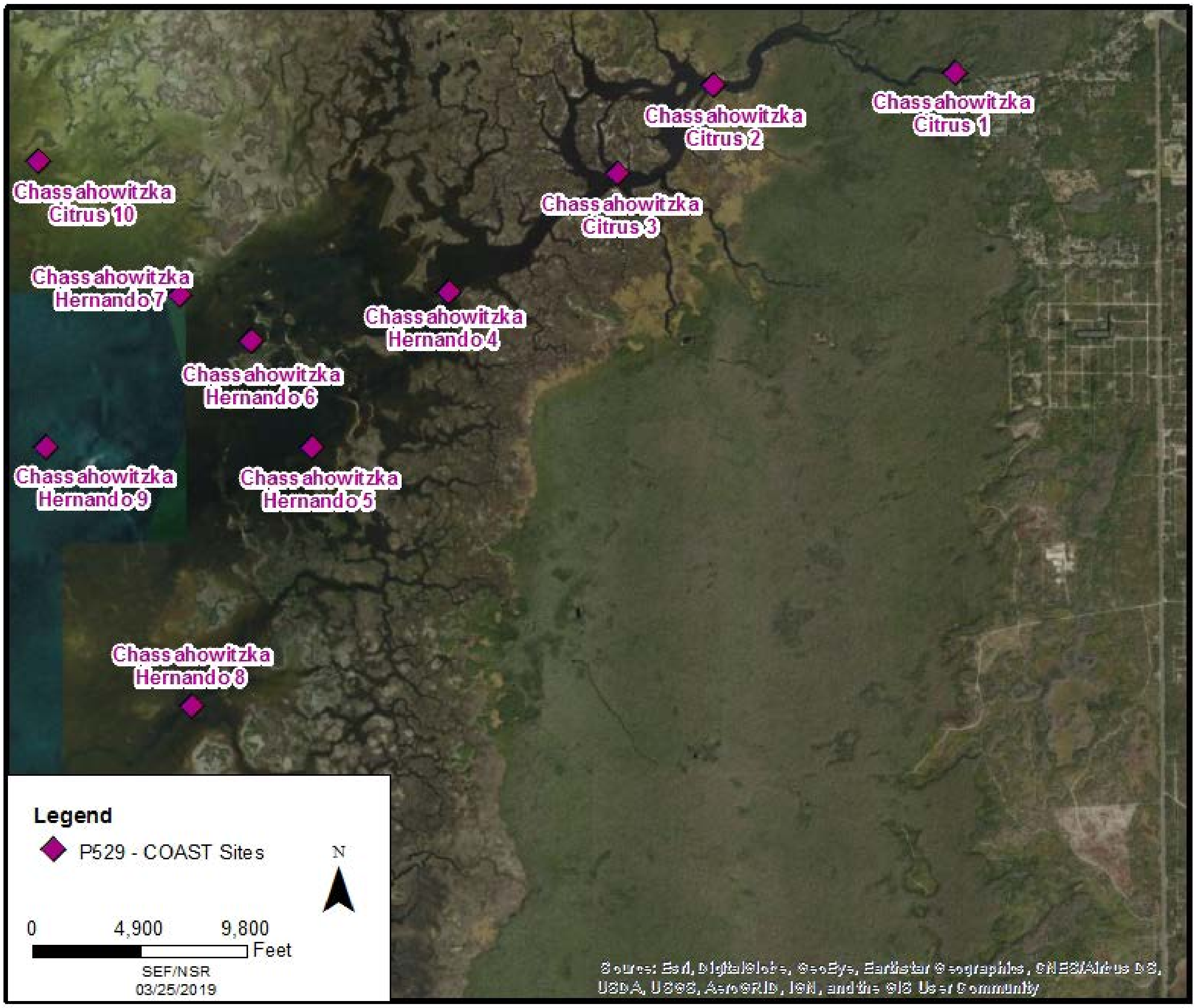


Figure 3-3. COAST Project P529 sample locations. Ten stations were originally sampled until 2010 for a limited suite of water quality parameters. In 2013, the District expanded the suite of parameters and resumed sampling at seven of the ten original sites. Chassahowitzka Citrus 1, 2, and 3 were discontinued because of overlap with other active stations under project P108.

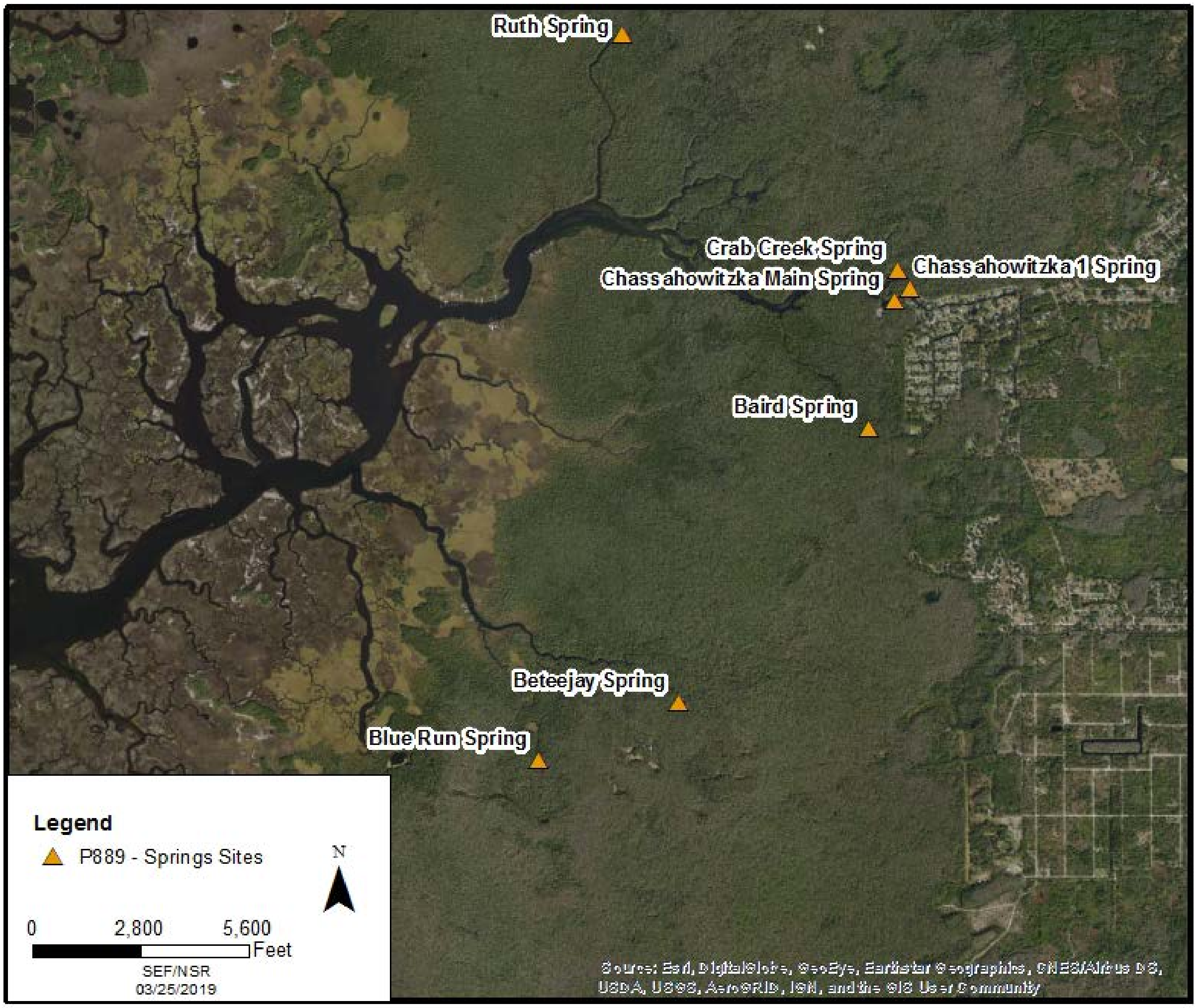


Figure 3-4. Active spring vent sampling locations for the Chassahowitzka River under the District's Spring Vents Project P889.

Table 3-4. Standard District groundwater parameters for Spring Vents Project P889 (* denotes field parameters collected in-situ concurrent with grab sample collection).

Parameters	
Alkalinity (Total)	Nitrogen- Total (Total)
Aluminum (Dissolved)	Orthophosphate (P) (Dissolved)
Ammonia (N) (Total)	pH (Total)*
Boron (Dissolved)	Phosphorus- Total (Total)
Calcium (Dissolved)	Potassium (Dissolved)
Carbon- Total Organic (Total)	Residues- Filterable (TDS) (Dissolved)
Chloride (Dissolved)	Silica – Dissolved (Dissolved)
Color (Dissolved)	Sodium (Dissolved)
Dissolved Oxygen (Total)*	Specific Conductance (Total)*
Fluoride (Dissolved)	Strontium (Dissolved)
Iron (Dissolved)	Sulfate (Dissolved)
Magnesium (Dissolved)	Temperature (Total)*
Manganese (Dissolved)	Turbidity (Total)
Nitrite (N) (Total)	

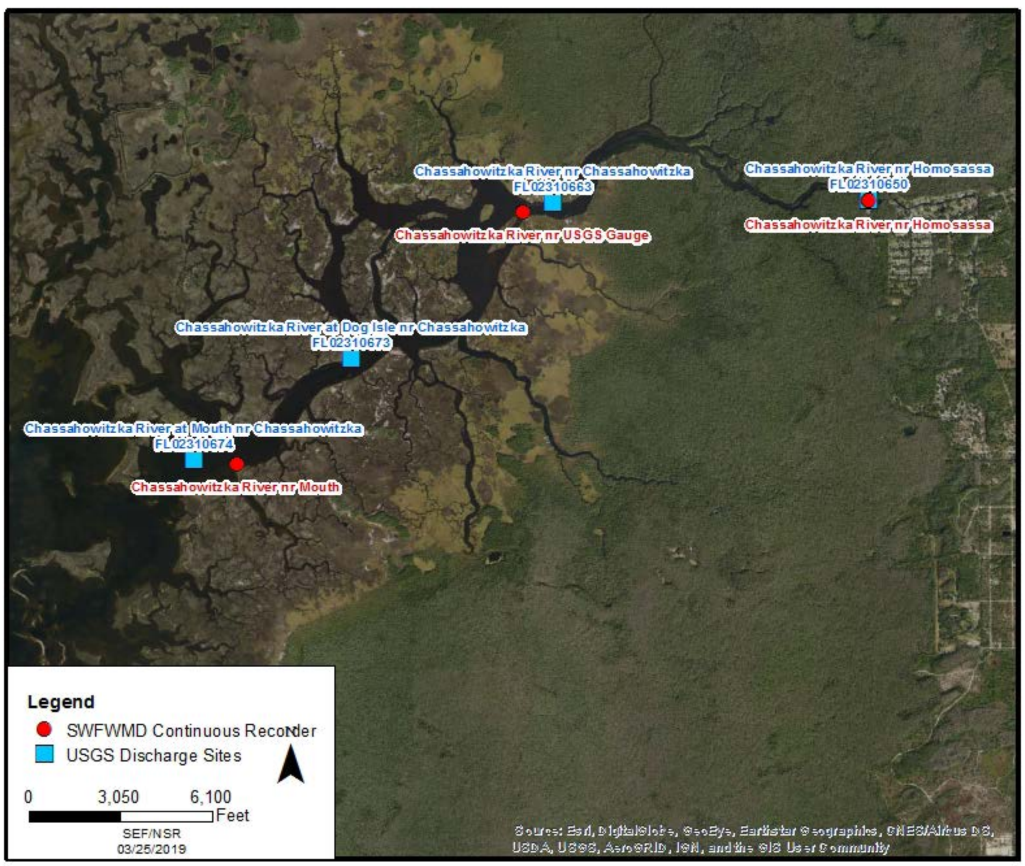


Figure 3-5. Location of the three District continuous recorders (red circles) for water quality on the Chassahowitzka River. Blue squares show the locations of the USGS river discharge gages. The most upstream USGS gage – Chassahowitzka River near Homosassa, FL (gage No. 02310650) – also has a continuous nitrate sensor.

Table 3-5 Parameters measured at "Chassahowitzka River near Mouth" and "Chassahowitzka Near USGS Gage" continuous recorders.

Parameters	
Temperature	fDOM
Depth	Chlorophyll
Conductivity	Turbidity
pH	Salinity
Dissolved Oxygen (mg/L and %)	Nitrate
Light Spectrum	Dark Spectrum

3.2.2 Inactive Water Quality Data Collection

In addition to data for active, ongoing water quality monitoring described in Section 3.2.1, data are available for a variety of water quality stations previously sampled in the Chassahowitzka River. Of particular note was the University of Florida 5 Rivers Project, a District-funded, spatially intensive water quality and biological monitoring study conducted by the University of Florida (Frazer et al. 2001) between August 1998 and November 2011 (with a gap between 2001 and 2003). The University of Florida 5 Rivers Project was a multi-year research project on five rivers along Florida's Springs Coast: the Weeki Wachee, Chassahowitzka, Homosassa, Crystal and Withlacoochee rivers. The general objective of the project was to quantitatively describe the physical, chemical and vegetative characteristics of each of the rivers (Frazer et al. 2001). Since the first report in 2001, other reports have been published using these transect data (Frazer et al. 2006; Frazer et al. 2002). For the Chassahowitzka River, 20 transects were established along the length of the river (Figure 3-6.), with three sampling points per transect for the 15 upstream transects and a single sample for the 5 most downstream transect. Both field and a limited suite of water quality parameters (Table 3-6) were collected (with a total of approximately 138 samples per transect over the study period.

In addition to the University of Florida 5 Rivers stations, several other inactive stations and associated data exist for the Chassahowitzka River (Figure 3-7.). Most of these stations, for example those in the Chassahowitzka canals upstream of Chassahowitzka Main Spring (Figure 3-7., inset), are of limited use for this minimum flow reevaluation because of the relatively limited number of samples collected and the types of water quality parameters measured.

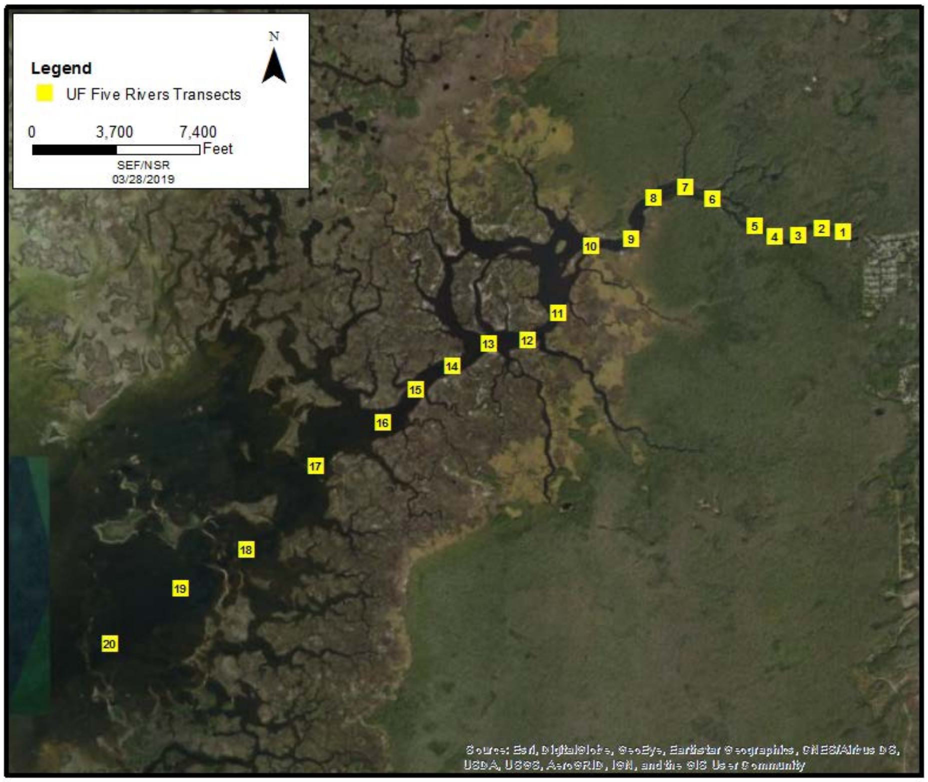


Figure 3-6. The inactive University of Florida 5 Rivers Project transect locations on the Chassahowitzka River.

Table 3-6. Water quality parameters for the University of Florida 5 Rivers Project.

Alkalinity (Total)	**Specific Conductivity**
Chlorophyll a	Soluble Reactive Phosphorous
Color	Temperature
Dissolved Oxygen	Total Nitrogen
Ammonium	Total Phosphorous
Nitrate	pH
Salinity	

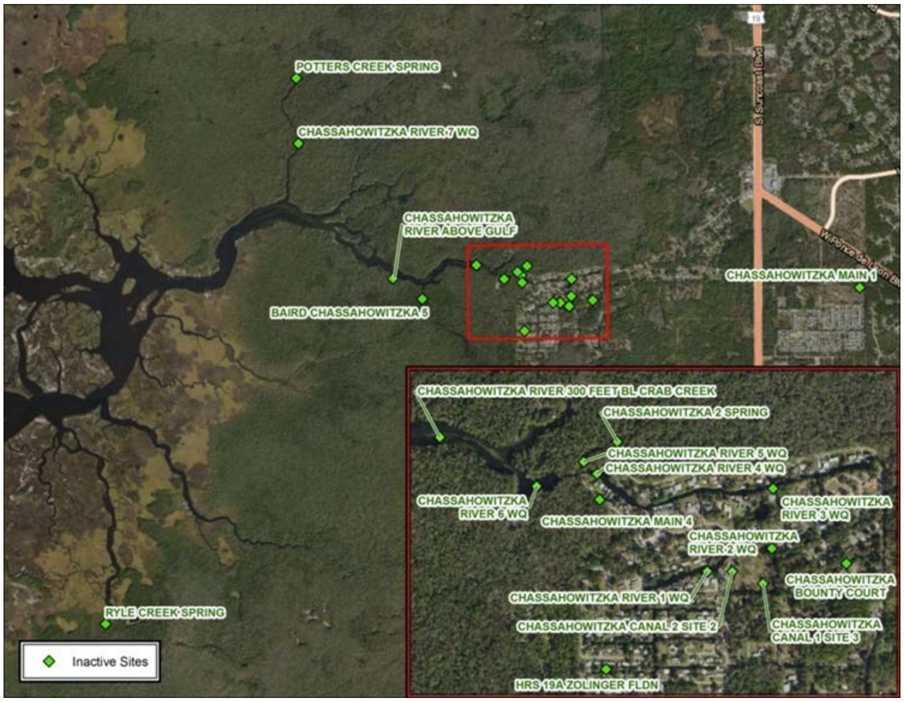


Figure 3-7. Inactive water quality monitoring stations on the Chassahowitzka River other than those for the University of Florida 5 Rivers Project shown in Figure 3-6.

3.3 Spatial Variations in Water Quality Constituents

This section summarizes the spatial variation in select water quality constituents for the Chassahowitzka River and estuary system. The University of Florida 5 Rivers transect data from 1998 to 2011 are presented here because of their high spatial resolution. The 20 sites, or transects, were located at approximately 0.5 km intervals along the main stem of the river (Figure 3-6). Details of the sampling design and in-depth results and discussion from the 5 Rivers Project can be found in Frazer et al. (2001) and (Frazer et al. 2006). Additionally, data from the five Coastal Rivers Project P108 (Figure 3-2) and select COAST Project P529 (Figure 3-3) fixed stations are also presented here to include more recent data.

3.3.1 Total Nitrogen

Nitrogen occurs in water as nitrite or nitrate anions (NO_2^- and NO_3^-), in cationic form as ammonium (NH_4^+), and at intermediate oxidation states as a part of organic solutes (Hem 1986). Total nitrogen (TN) is the sum of inorganic and organic nitrogen species. For the Chassahowitzka River system, data from the active Coastal Rivers Project P108 network shows a spatial gradient in total nitrogen concentrations within the mainstem of the river from a peak near the headsprings to a low point approximately 8 kilometers (Rkm 1) downstream of the headsprings (Figure 3-8). The inactive University of Florida 5 Rivers Project data do not show a strong spatial trend. Nitrogen dynamics in tidal freshwater and estuarine systems are complex and there are many factors that contribute to this longitudinal pattern. Water column nitrogen is a function of internal nitrogen cycling across the sediment-water interface, uptake by benthic primary producers, loss of nitrogen through dilution with Gulf coastal waters, and loss of nitrogen through denitrification.

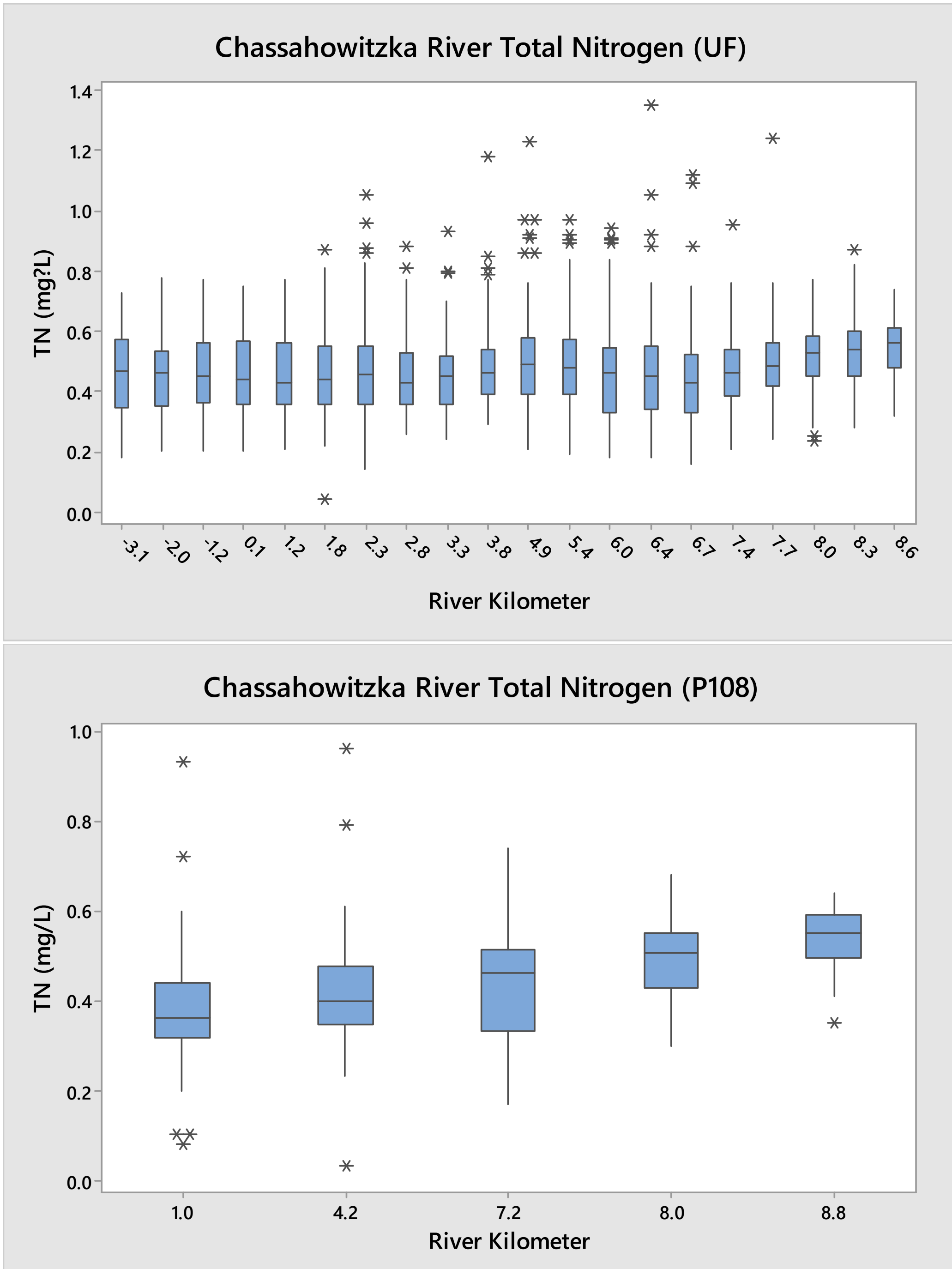


Figure 3-8. Distribtuon of total nitrogen concentrations from the University of Florida 5 Rivers Project (UF) transect data collection effort between 1998 and 2011 and from the active Coastal Rivers Project (P108) data collection effort between 2005 and 2017. Boxes represent the interquartile ranges and stars represent outliers.

3.3.2 Nitrate + Nitrite

In the water column, inorganic nitrogen is mostly in the form of nitrate (NO_3^-) but can also occur as nitrite (NO_2^-) though in much lower concentrations. In fact, nitrite is seldom present in concentrations large enough to influence ionic balance to a noticeable degree (Hem 1986). For brevity, the terms "nitrate," "nitrate + nitrite," "NO3," and "NOX" can be used interchangeably. Because nitrate is an inorganic form of nitrogen, it is readily available for uptake by phytoplankton and submerged aquatic vegetation (SAV) including benthic and epiphytic algae, and to a lesser extent, seagrass. Increases in ambient concentrations of nitrate from anthropogenic sources including fertilizer and wastewater can lead to increases in unwanted algal growth, and in high enough concentrations, can lead to eutrophication.

There are strong longitudinal gradients in nitrate along the Chassahowitzka River (Figure 3-9.). Nitrate concentrations are greatest near the headsprings and decline rapidly within the first few kilometers of the river then continue to gradually decrease to near laboratory detection limits close to the mouth of the river.

Nitrate concentrations decline much more rapidly with distance from the headsprings than total nitrogen (Figure 3-10.). This difference is likely caused by the transformation of inorganic nitrate to organic nitrogen by phytoplankton algae suspended in the water column. Virtually all nitrates are removed from the water column near the mouth of the river (Rkm 0). Conversely, total nitrogen concentrations at the head springs are almost entirely in the form of nitrate. For the University of Florida 5 Rivers data, the average concentration of total nitrogen at the head springs (Rkm 8.6) is 0.55 mg/L and the average nitrate concentration at the same location is 0.49 mg/L, a difference of only 0.06 mg/L. The active Coastal Rivers Project P108 data show a similar pattern with an average total nitrogen concentration near the head springs of 0.53 mg/L and an average nitrate concentration of 0.48 mg/L, a difference of only 0.05 mg/L. At the mouth of the river (Rkm -3.1), the nitrate concentration has decreased to 0.01mg/L while total nitrogen concentration remains relatively elevated at 0.46 mg/L. This suggests that almost all the nitrogen being exported to the nearshore coastal waters is in the form of organic nitrogen and not inorganic nitrate.

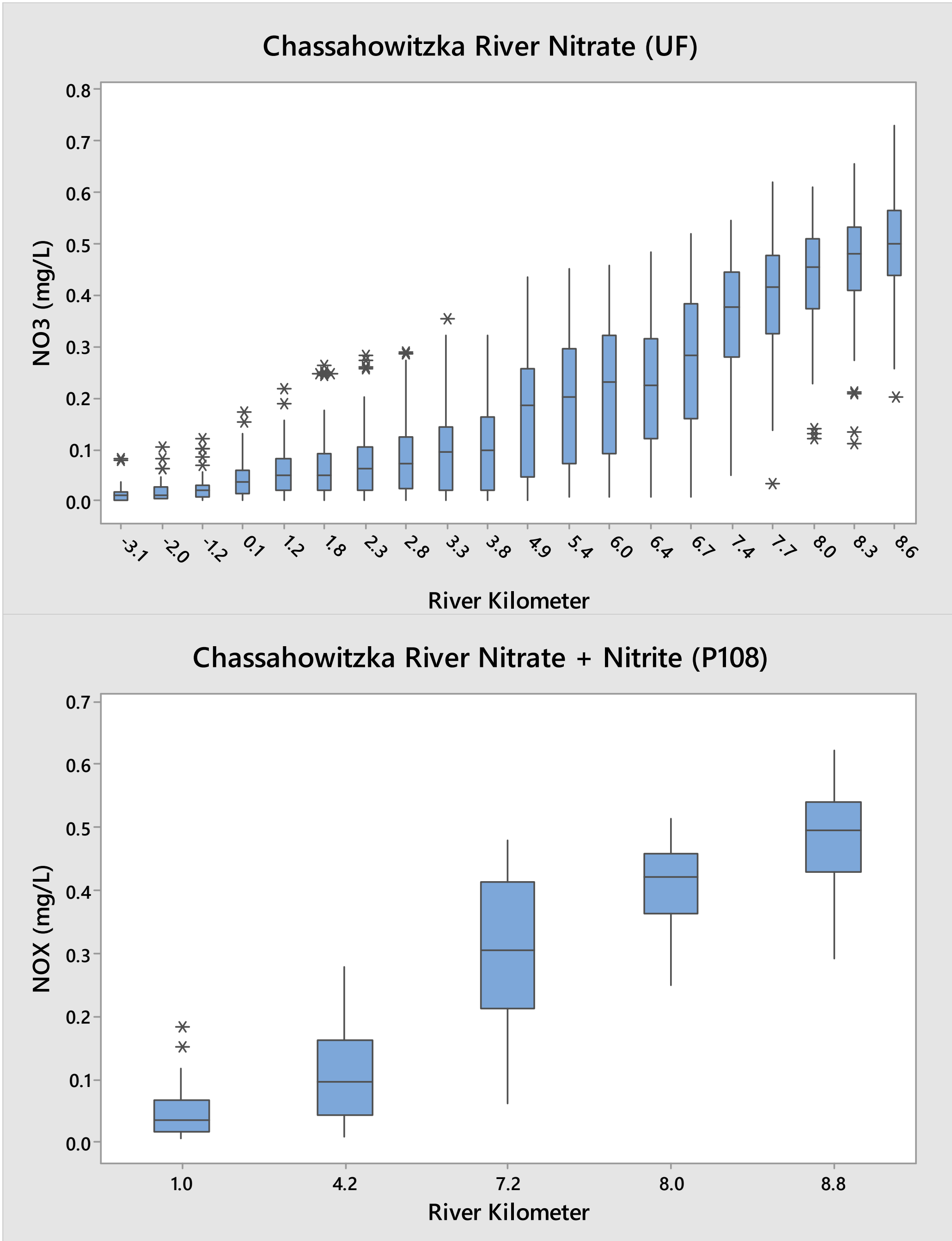


Figure 3-9. Distribtuon of nitrate concentrations from the University of Florida 5 Rivers Project (UF) transect data collection effort between 1998 and 2011, and the Coastal Rivers Project (P108) active water quality sampling network between 2006 and 2017. Boxes represent the interquartile ranges and stars represent outliers.

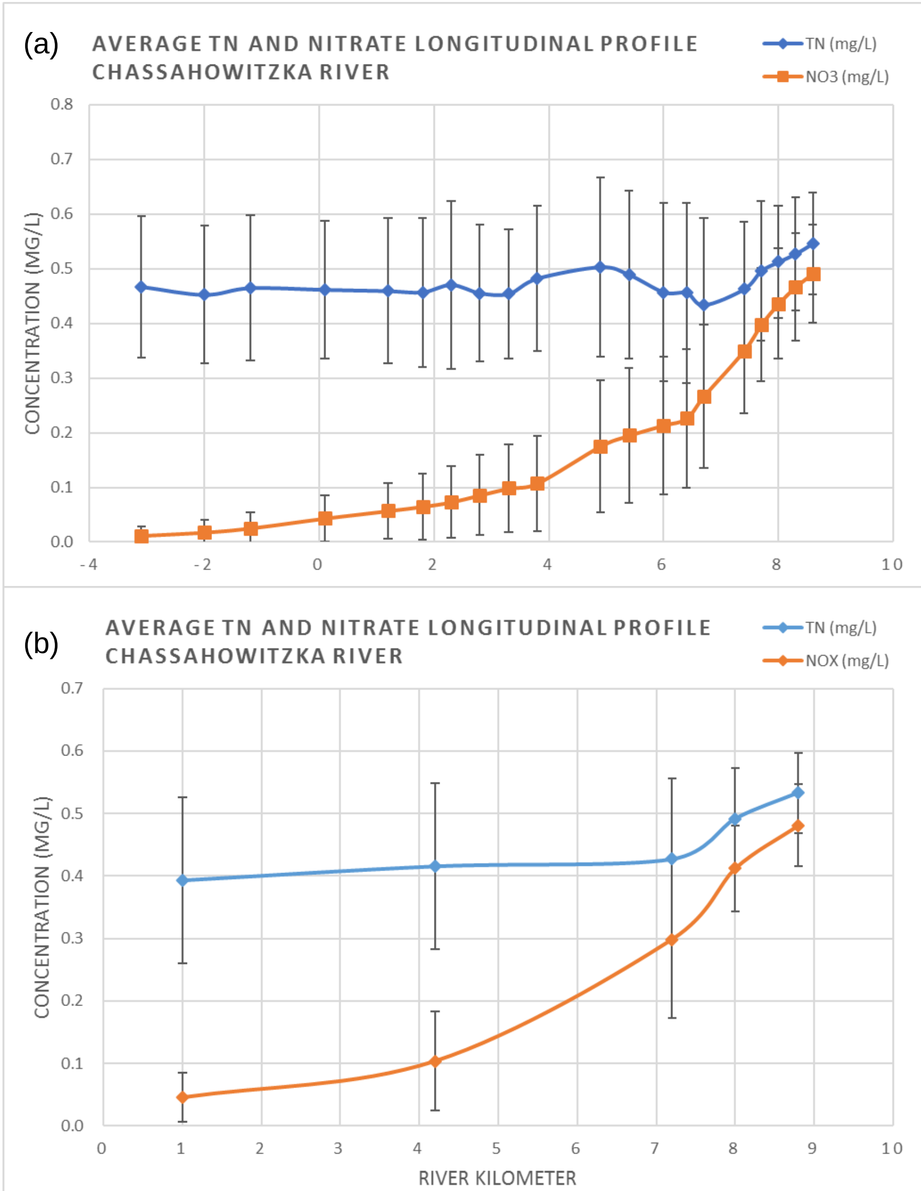


Figure 3-10. Longitudinal profiles of total nitrogen and nitrate concentrations from (a) the University of Florida 5 Rivers Project transect data collection effort between 1998 and 2011, and (b) the Coastal Rivers Project P108 active water quality sampling network between 2006 and 2017. Error bars represent the standard deviation for each station.

3.3.3 Total Phosphorous

Along with nitrogen, phosphorous is one of the most important nutrients supporting plant growth and often is the nutrient limiting primary production in freshwater and marine systems. Excessive nitrogen loading to estuarine waters can result in phosphorous limitation in systems where nitrogen limitation would be expected (Bianchi 2013). Like total nitrogen, total phosphorous (TP) can be divided into organic and inorganic species. Reactive phosphorous is that fraction of TP that is used to describe the potentially bioavailable phosphorous (Delaney 1998) and is discussed in more detail in the following section.

Longitudinal profiles of TP in the upper part of the Chassahowitzka River downstream to approximately Rkm 6.4 are relatively flat (Figure 3-11). Beyond Rkm 6.4, TP concentrations increase to Rkm 4.9 followed by a gradual decrease in concentration out to the mouth of the river. This increase in TP concentration roughly corresponds to the transition zone between the tidal freshwater and marine river segments. Near Rkm 4.9 is a sharp transition between brackish-tidal fresh forested wetlands upstream and the salt marsh-mangrove dominated wetlands downstream. Because the Chassahowitzka River is intimately coupled with the adjacent wetland areas, this increase in TP is likely a function of phosphorous flux from the adjacent wetland complex to the river.

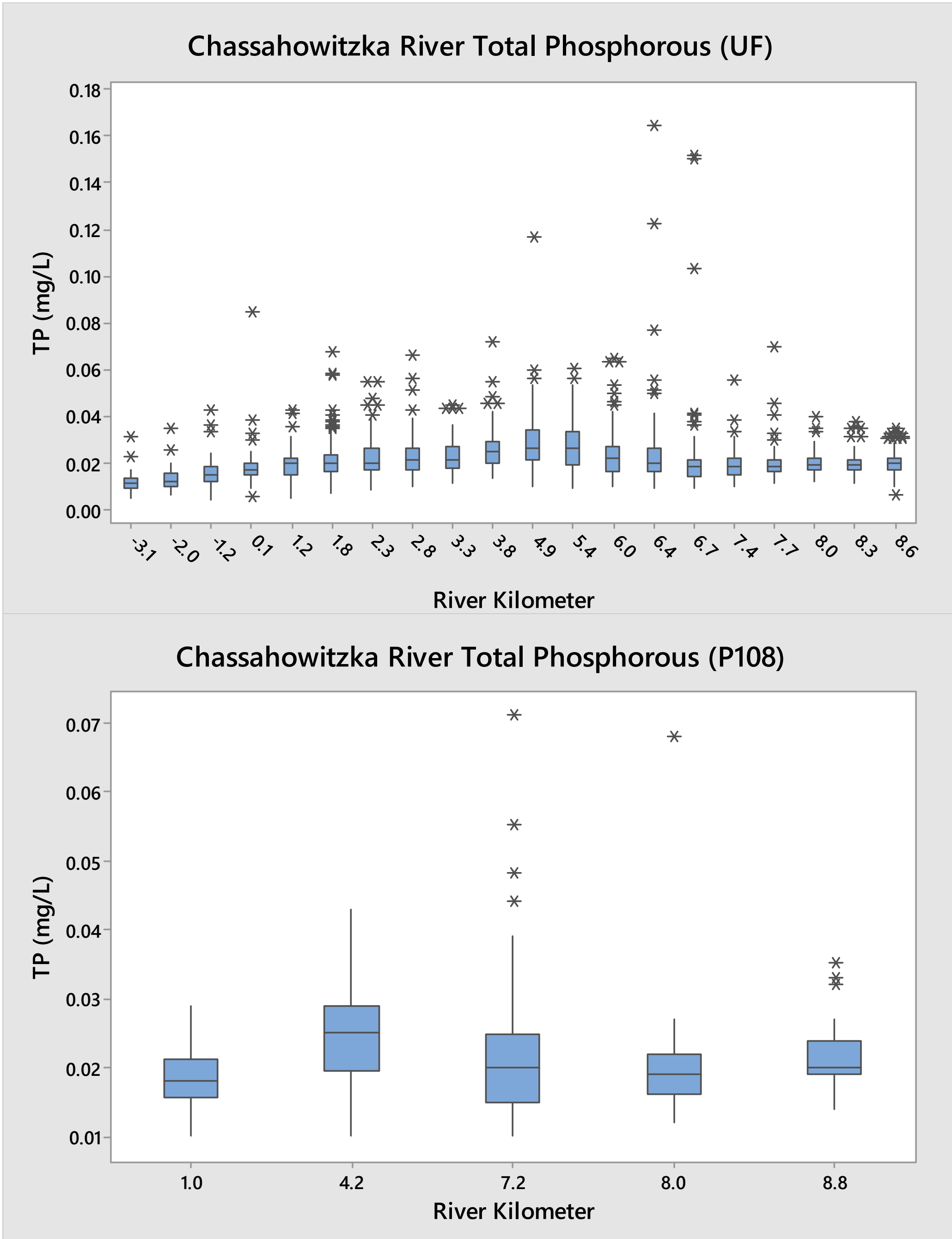


Figure 3-11. Distribution of total phosphorous concentrations from the University of Florida 5 Rivers Project (UF) transect data collection effort between 1998 and 2011, and the Coastal Rivers Project (P108) active water quality sampling network between 2006 and 2017. Boxes represent the interquartile ranges and stars represent outliers.

3.3.4 Soluble Reactive Phosphorous and Orthophosphate

Soluble reactive phosphorous (SRP) is characterized as the phosphorous fraction that forms a phosphomolybdate complex under acidic conditions (Strickland and Parsons 1972). A significant fraction of SRP is in the form of orthophosphate (Ortho-P). While SRP and Ortho-P are not the same thing, they are proportional to one another and therefore can both be useful in understanding how phosphorous behaves in the water column. SRP concentrations were reported by the University of Florida for the 5 Rivers Project while Ortho-P is reported by the District for the active Coastal Rivers Project P108 monitoring network. Both SRP and Ortho-P concentrations display similar longitudinal profiles over their respective periods of record (Figure 3-12) characterized by a gradual decline in concentration all the way out to the mouth of the river and into the Gulf of Mexico. Like inorganic nitrogen, both soluble SRP and Ortho-P concentrations decrease to near zero near the mouth of the river.

Comparing SRP and Ortho-P with total phosphorous illustrates the proportionality of inorganic phosphorous as a function of the total phosphorous concentrations in the water column (Figure 3-13). Within the upper kilometer of the river (Rkm 7.4), total phosphorous concentrations remain relatively constant with only a gradual decrease. Conversely, SRP and Ortho-P both show a sharp decrease in concentration over the same area suggesting that inorganic phosphorous is being assimilated by primary producers, likely phytoplankton, in the water column. By Rkm 6.7, TP increases rapidly while SRP and Ortho-P remain relatively constant or, in the case of the University of Florida 5 Rivers Project data, slightly decrease. This rapid increase in total phosphorous without an increase in SRP or Ortho-P, suggests an external input of organic phosphorous to the water column, either from the adjacent wetland complex, via the sediment-water interface, from benthic SAV, or both.

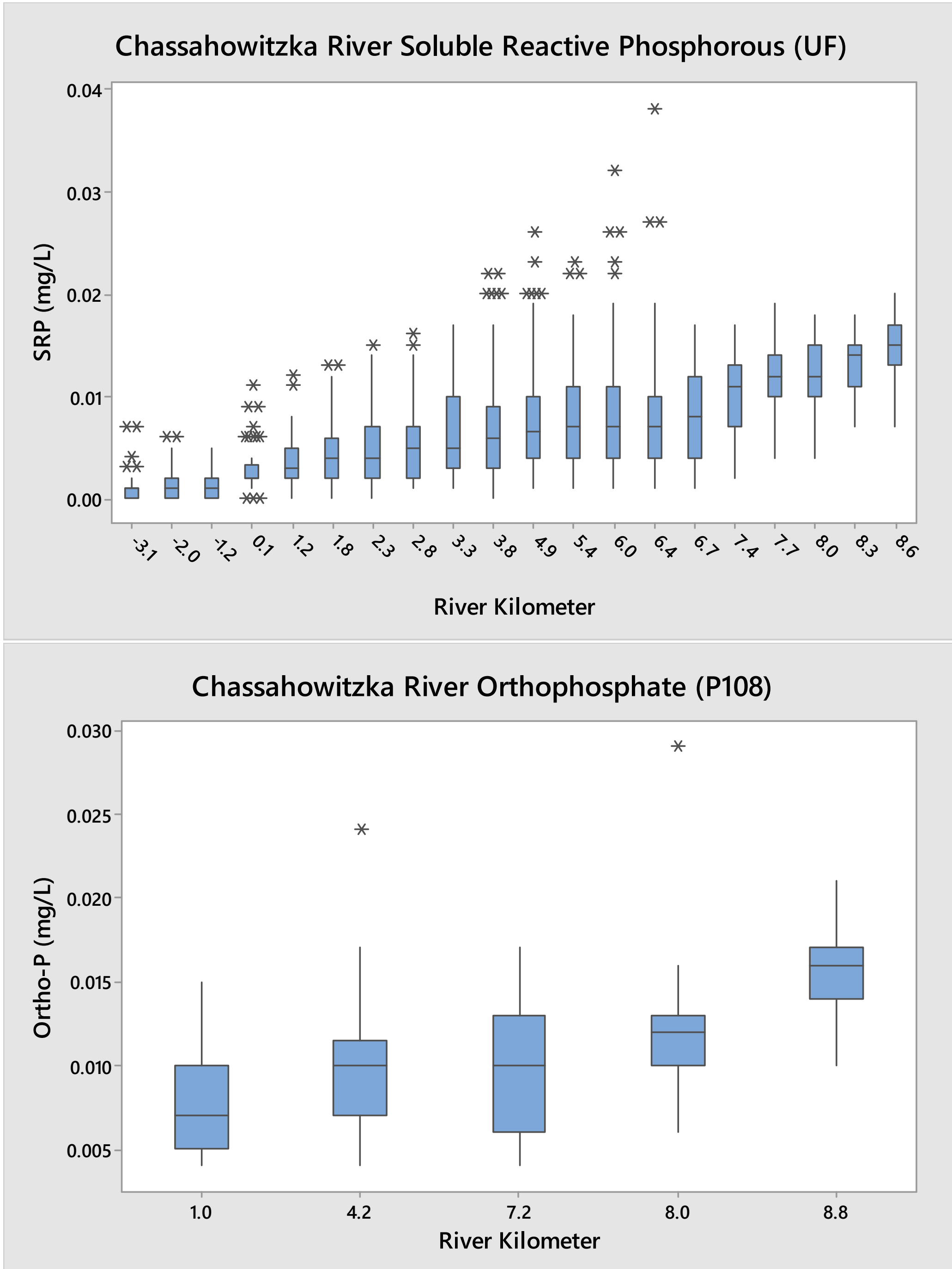


Figure 3-12. Distribution of soluble reactive phosphorous concentrations from the University of Florida 5 Rivers Project (UF) transect data collection effort between 1998 and 2011, and the Coastal Rivers Project (P108) active water quality sampling network between 2006 and 2017. Boxes represent the interquartile ranges and stars represent outliers.

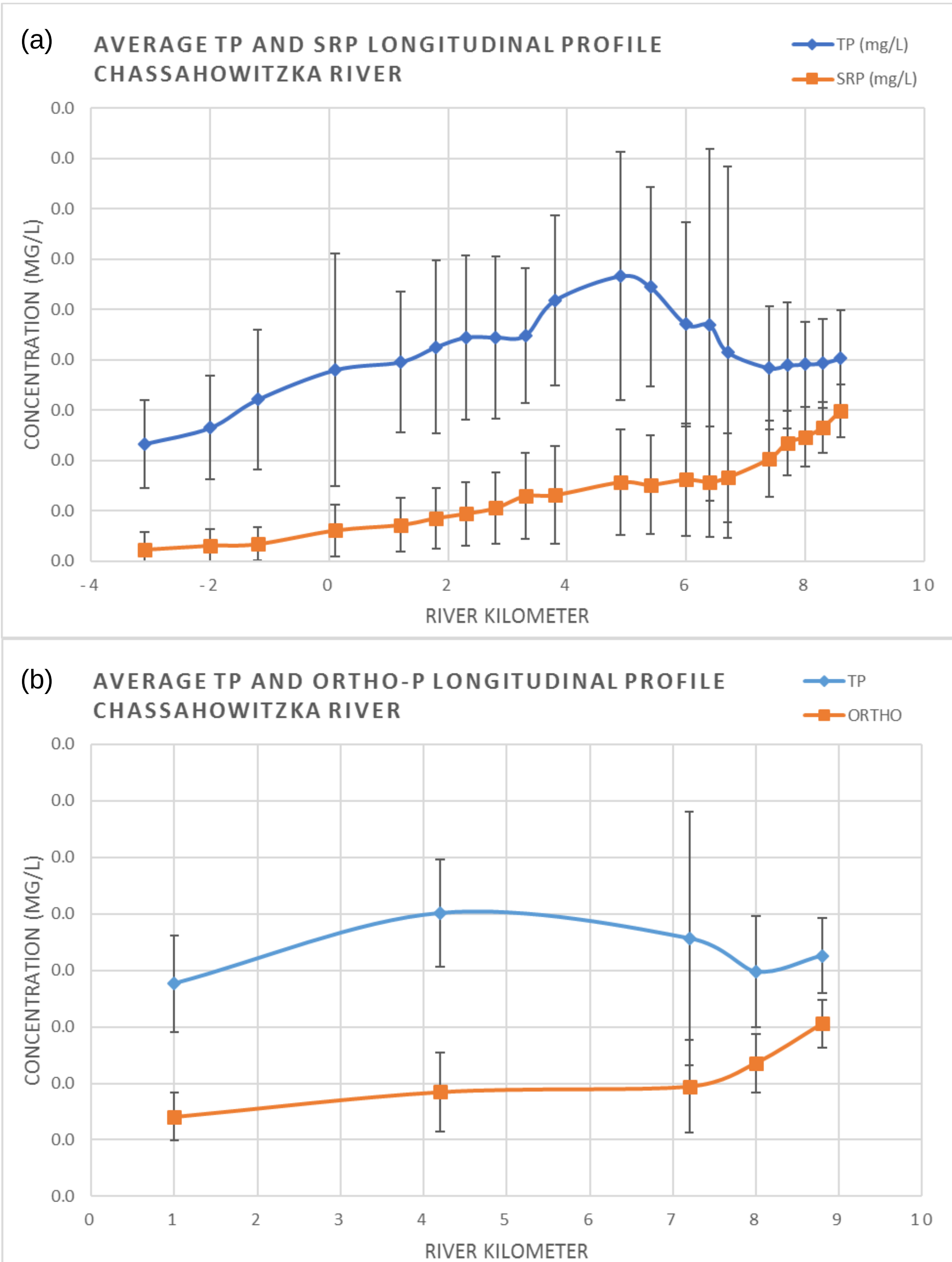


Figure 3-13 Longitudinal profiles of total phosphorous (TP) and soluble reactive phosphorous (SRP) concentrations from (a) the University of Florida 5 Rivers Project transect data collection effort between 1998 and 2011, and longitudinal profiles of total phosphorous (TP) and orthophosphorous (ORTHO) from the Coastal Rivers Project (P108) active water quality sampling network between 2006 and 2017. Error bars represent the standard deviation for each station.

3.3.5 Chlorophyll

All plants, including algae, contain photosynthetic pigments, the most common being the chlorophylls. Chlorophylls are cyclic tetrapyrrole compounds with a magnesium atom chelated at the center of the ring system (Kirk 1994). There are several types of chlorophylls including chlorophyll *a*, *b*, and *c*. The most abundant of these light harvesting pigments is chlorophyll *a*. For this report, the term chlorophyll is used to denote chlorophyll *a* concentration.

Chlorophyll concentration is a useful indicator of phytoplankton biomass but among the various species of algae, chlorophyll concentrations vary widely (Kirk 1994) and may also vary substantially within individual algal cells depending upon ambient environmental conditions. Chlorophyll is also a good predictor of light penetration. Because chlorophyll absorbs light primarily in the blue wavelengths and secondarily in the red wavelengths, green light is reflected and can turn water green at elevated chlorophyll concentrations. Elevated chlorophyll concentrations are often indicative of eutrophic conditions.

Similar longitudinal patterns emerge across both the University of Florida 5 Rivers Project, the active Coastal Rivers Project P108, and COAST Project P529 sampling networks (Figure 3-14.). These data show a moderate chlorophyll maximum between Rkm 4.9 and Rkm 7.4. This region of elevated chlorophyll concentrations represents an area where high levels of phytoplankton biomass can occur. Chlorophyll maxima are a normal feature of tidal freshwater estuaries and represents an area within the estuary of maximum primary productivity (Bukaveckas et al. 2011). More recent data from the five Coastal Rivers Project P108 stations and the COAST Project P529 stations also capture a chlorophyll maximum between Rkm 2.9 and 7.2 despite the lower spatial resolution of these datasets (Figure 3-14.).

The reasons for the existence of this chlorophyll maximum are complex and are a function of many factors including flow, residence time, and nutrient concentrations (particularly nitrogen and phosphorous). Exploratory data analysis suggests that relationships among chlorophyll, nitrogen, and phosphorous distribution exist in the river (Figure 3-15). Figure 3-15 B and D suggest that chlorophyll production increases as inorganic nitrogen and phosphorous concentrations decrease. However, caution must be taken not to infer too much from these relationships. There are numerous feedback mechanisms between phytoplankton and nutrient concentrations and many external factors that come into play.

A central objective of the University of Florida transect data collection effort was to investigate the nutrient limitations of five Gulf Coastal rivers and estuaries including the Chassahowitzka (Frazer et al. 2006; Frazer et al. 2002). While elevated concentrations of nitrate-nitrogen is a concern, results from the effort indicate the Chassahowitzka River frequently contains a surplus of phosphorus and nitrogen (Frazer et al. 2002), suggesting phytoplankton may be insensitive to variations in nutrient concentrations. In those instances when nutrients are limiting, previous research in this system and others along the Springs Coast has indicated a strong potential for phosphorus limitation of algal growth rather than nitrogen limitation (Frazer et al. 2006; Frazer et al. 2002). These relationships bear further investigation and are the subject of continued research by the District and other resource management organizations. Another cautionary observation from Figure 3-15 are the large standard deviation error bars associated with chlorophyll concentration. These large error bars indicate that conditions within the mainstem of the Chassahowitzka River are extremely variable, especially between Rkm 4 and 7 (Figure 3-16.).

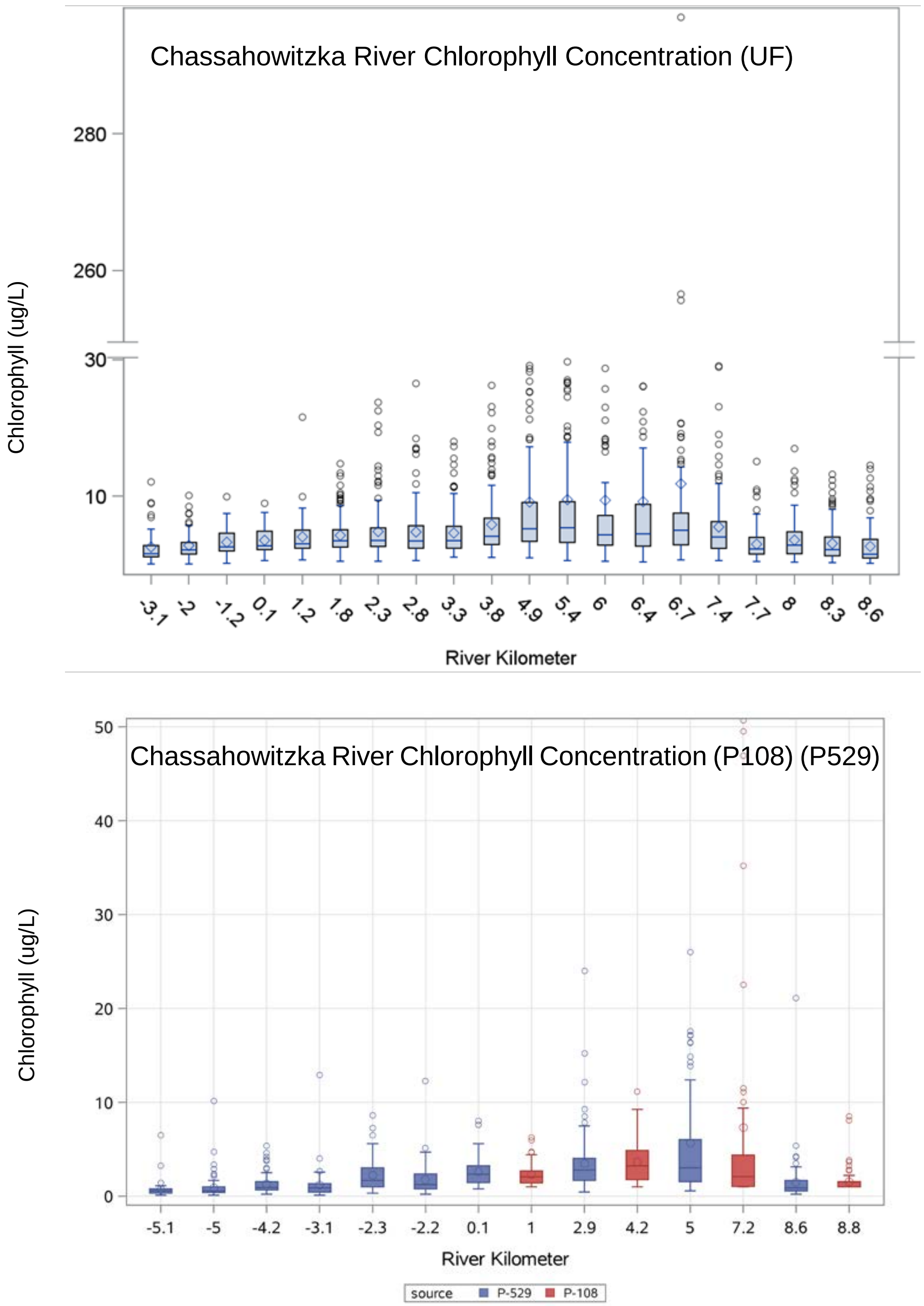


Figure 3-14. Distribtuon of chlorophyll concentrations from the University of Florida 5 Rivers Project (UF) transect data collection effort between 1998 and 2011 and at fixed locations in the Chassahowitzka River from the Coastal Rivers Project (P108) and COAST Project (P529) active sampling networks in the Chassahowitzka River. Note broken y-axis for UF data in top panel. Boxes represent the interquartile ranges and stars represent outliers.

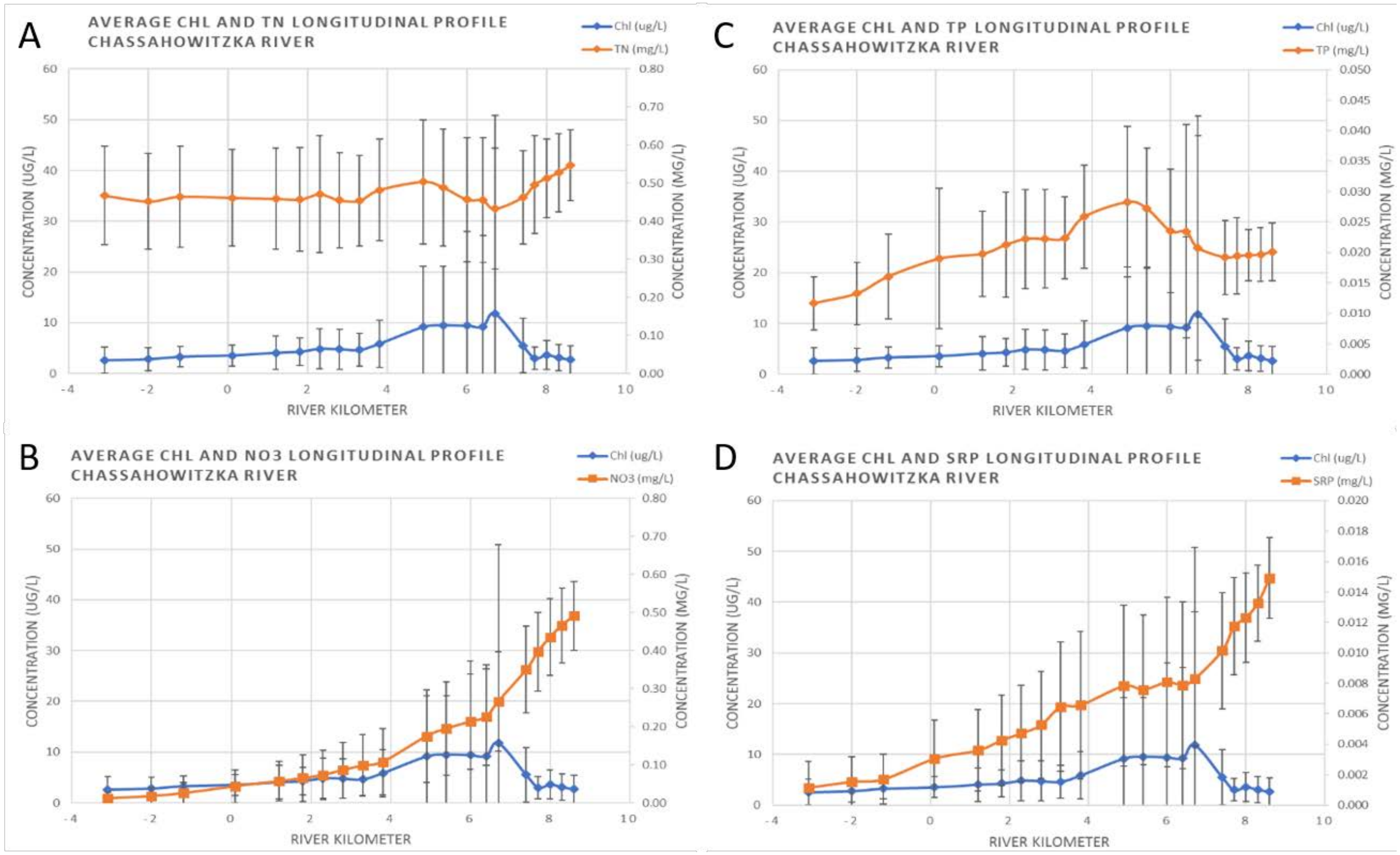


Figure 3-15. Relationship between chlorophyll concentration and various nutrient concentrations from the University of Florida 5 River Project transect data collection effort between 1998 and 2011. Panels represent chlorophyll and total nitrogen (A), chlorophyll and nitrate (B), chlorophyll and total phosphorous (C), and chlorophyll and soluble reactive phosphorous (D), respectively. Error bars represent the standard deviation for each station.

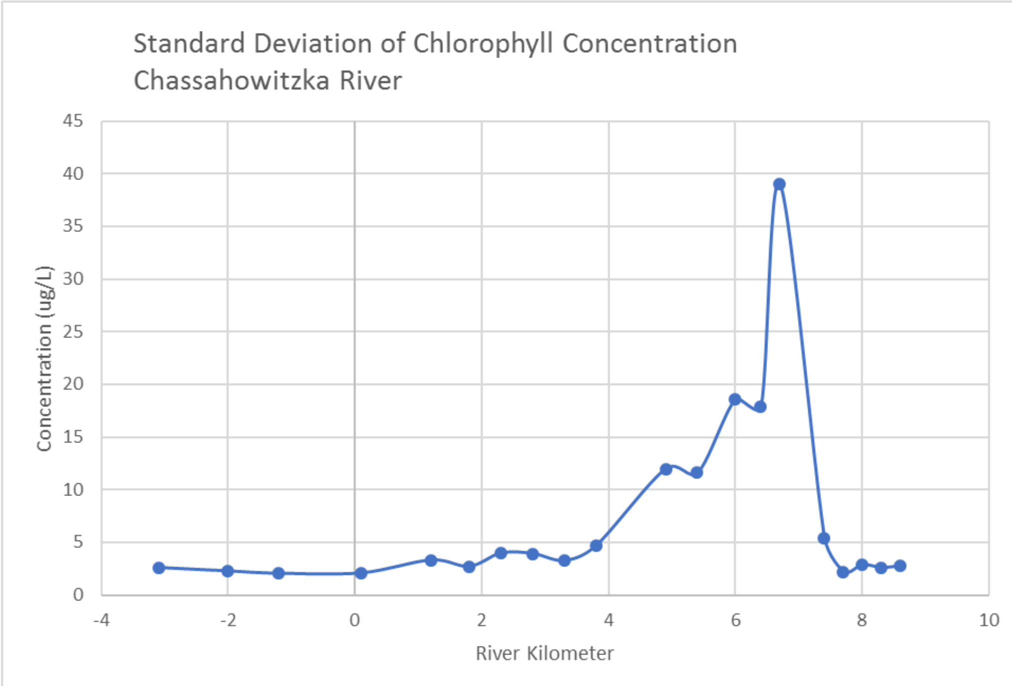


Figure 3-16. Period of record chlorophyll standard deviation of the mean for the University of Florida 5 Rivers Project between 1998 and 2011.

3.3.6 Water Clarity

For the Chassahowitzka River, much like other spring-fed rivers, water clarity is greatest near the headsprings and then rapidly decreases further downstream. Within the first river mile downstream from the headsprings (including stations CV0, CV0.5, and CV1), clarity decreases by approximately 75% (Figure 3-17). Past CV1, as one traverses toward the mouth of the river (at CV3 and CV5), water clarity is relatively low and less variable than further upstream.

Given this strong longitudinal gradient in clarity, it is important to understand the causes of light attenuation in the water column. Light propagation through the water column is a function of the amount of absorption and scattering in the water column (Lee et al. 1995). There are three water quality constituents that typically affect clarity: turbidity or total suspended solids (TSS), chlorophyll, and color or colored dissolved organic matter (CDOM). In the Chassahowitzka River, only the TSS and chlorophyll affect water clarity under ordinary conditions. Although colored dissolved organic matter (CDOM) can also affect clarity, color in the Chassahowitzka River is relatively low, often below laboratory detection and has minimal impact on water clarity. On occasion during extreme rain events, CDOM, measured in platinum cobalt units (PCU), can be in sufficiently high quantities to cause the water color to temporarily turn brown.

Phytoplankton is a major attenuator of light via absorption primarily in the blue and red wavelengths. Chlorophyll approximates the abundance of phytoplankton in the water column but can also come from other plant material such as epiphytic and benthic algae suspended in the water column. Regardless of the source, chlorophyll is strongly correlated with Secchi distance in the Chassahowitzka River, though the relationship is truncated at the laboratory detection limit of 1ug/L (Figure 3-18a). Total suspended solids (TSS) are a measure of the amount of material suspended in the water column. Loss of clarity by TSS is primarily through scattering of photons. For the Chassahowitzka River, TSS strongly correlates with Secchi distance (Figure 3-18b).

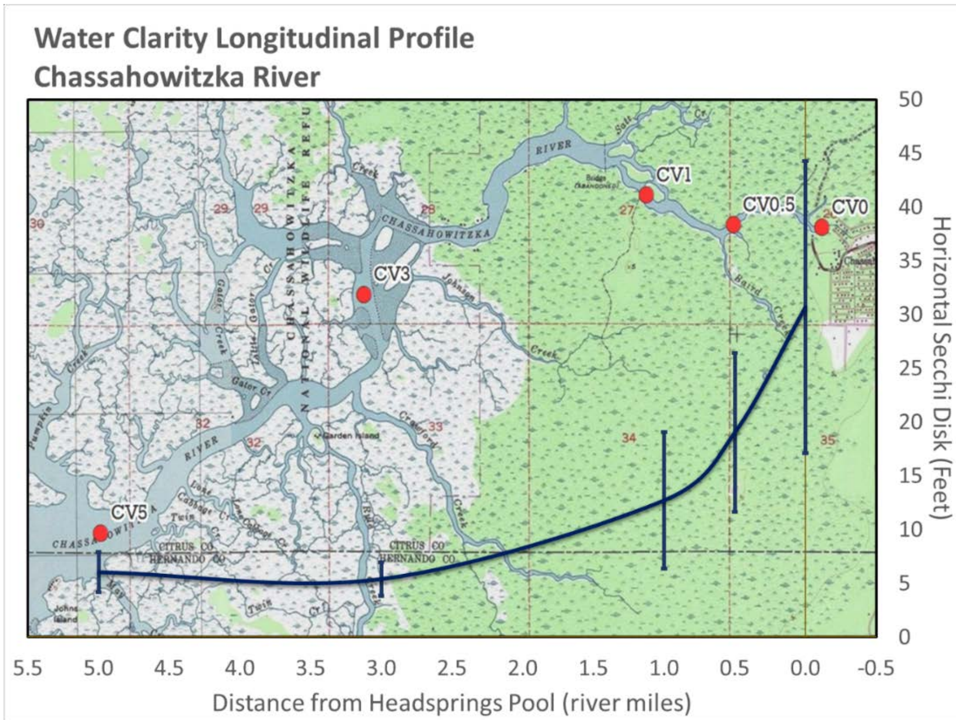


Figure 3-17. Water clarity in the Chassahowitzka River, as measured by horizontal Secchi. Data are from the five active water quality P108 stations CV0 – CV5 (red dots) and are the average over the period 2006-2017. Error bars represent the standard deviation for each station.

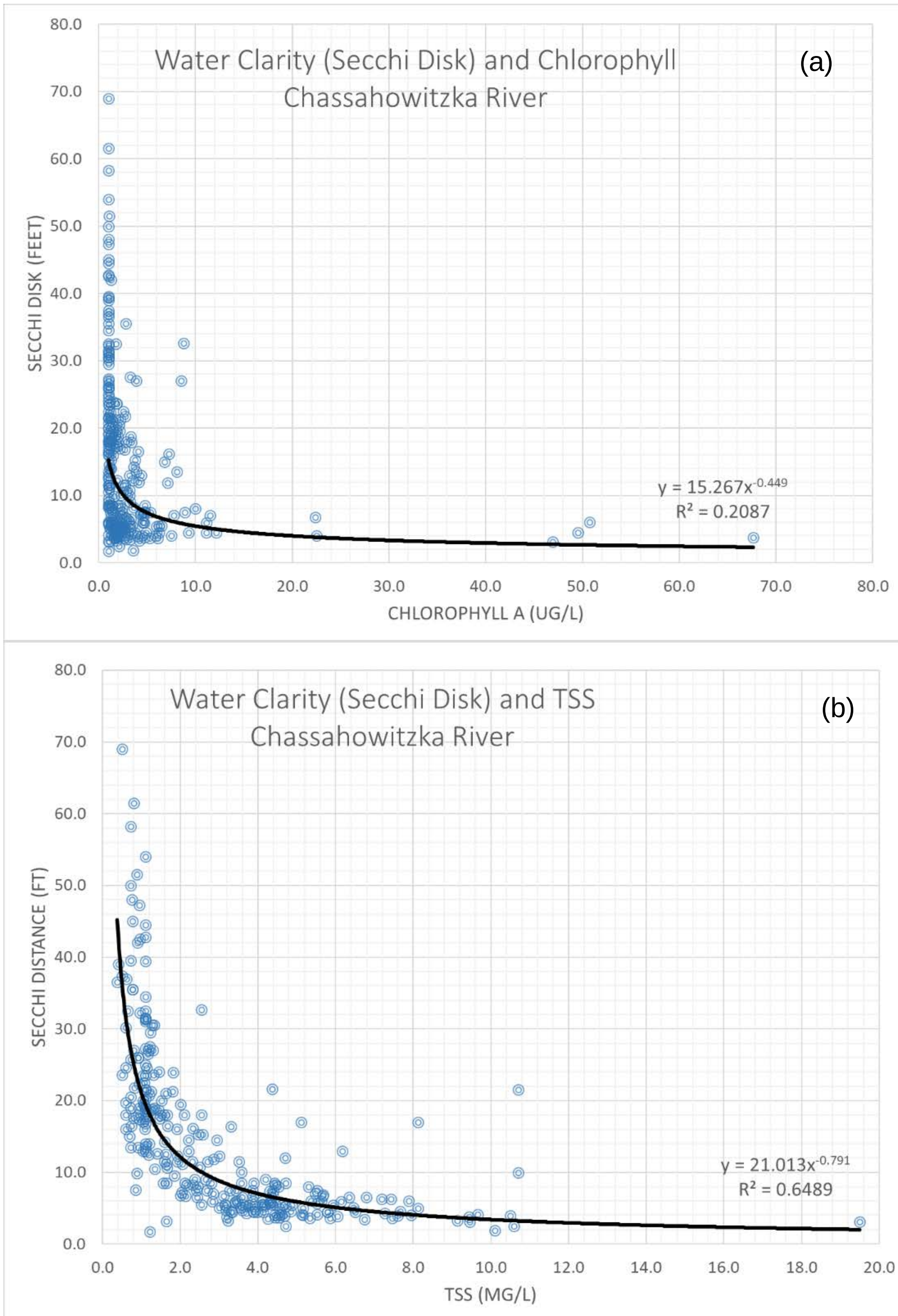


Figure 3-18. The relationships between water clarity as measured by Secchi disk and (a) chlorophyll concentration, and (b) total suspended solids (TSS). Data are from the five Coastal Rivers Project P108 fixed stations for the period 2006-2017. Chlorophyll has a minimum laboratory detection limit of 1.0ug/L and therefore the figure in (a) is truncated at the minimum detection limit.

3.4 Temporal Variation in Water Quality Constituents

This section provides a general description of the temporal variability for selected water quality constituents that may be affected by anthropogenic influences. Data presented here are primarily from locations actively being sampled from the five Coastal Rivers Project P108 (Figure 3-4.), COAST Project P529 (Figure 3-3.), and the Spring Vents Project P889 (Figure 3-4.) fixed stations.

Janicki Environmental, Inc. and WSP, Inc. (2018) evaluated long-term trends by station for all available water quality data using the seasonal Mann-Kendall (SMK) test for trend (Hirsch and Slack 1984; Hirsch et al. 1982) which was developed by the USGS in the 1980s to analyze trends in surface-water quality throughout the United States. More information on these analyses and individual time series plots for each station can be found in Appendix 8.

3.4.1 Total Nitrogen

For the Chassahowitzka River, there was no significant trend in the average annual total nitrogen concentration for the period 2006 through 2017 (Figure 3-19) based on data from all Coastal Rivers Project P108 stations. Throughout the period of record for these data, the TN concentration for the Chassahowitzka River has exceeded the adopted WBID 1361 TMDL of 0.25 mg/L total nitrogen every year.

Average annual TN masks some trends that emerge when total nitrogen concentrations are plotted by Coastal Rivers Project P108 station (Figure 3-20). Total nitrogen concentrations for the 2006 through 2017 period exhibit an increasing trend for the upper-most station (CV0 at Rkm 8.8). There appears to be no trend at station CV0.5 (Rkm 8) and decreasing trends at the lower three stations (CV1, CV3, and CV5).

Coastal Rivers Project P108 stations CV3 and CV5 fall within WBID 1361 which has an NNC of 0.44 mg/L. Total nitrogen concentration has decreased slightly over the past 11 years and is currently under the NNC at both stations (Figure 3-21).

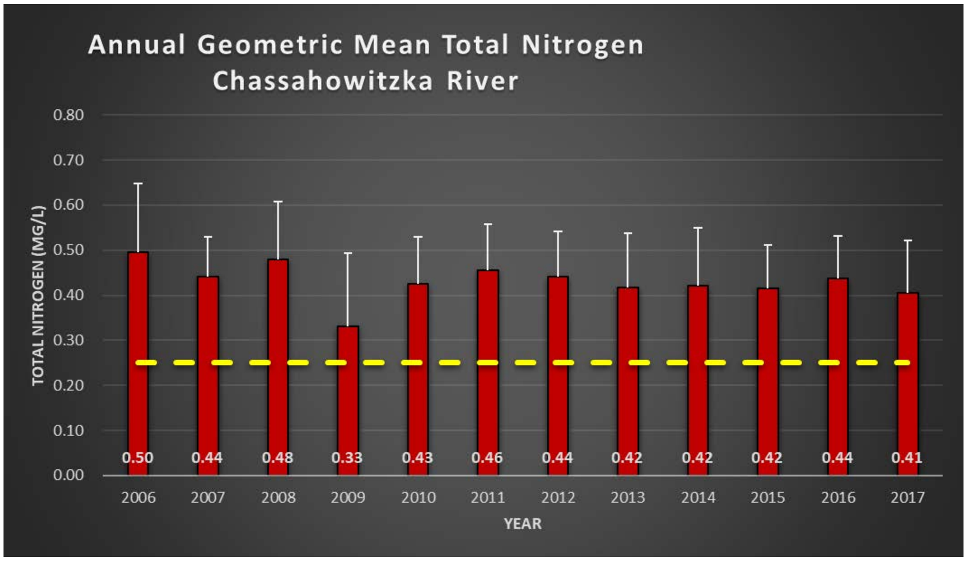


Figure 3-19. River-wide total nitrogen concentration expressed as annual geometric mean for the period 2006 through 2017. Error bars represent the standard deviation for each year. Data are from the five P108 fixed stations. Yellow dashed line depicts the TN TMDL of 0.25 mg/L for the Chassahowitzka River WBID 1361. TMDL is assessed as annual geometric mean for data collected within the applicable WBID 1361. Annual river-wide total nitrogen is compared with the TMDL value for comparison only and not compliance estimation.

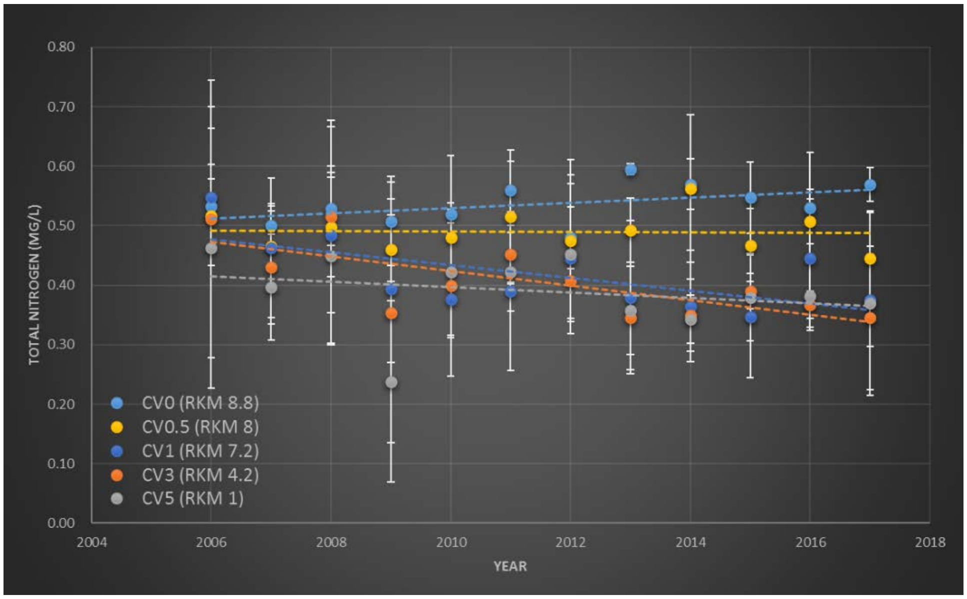


Figure 3-20. River-wide average annual total nitrogen across the period 2006 through 2017 for the five Coastal Rivers Project P108 fixed water quality monitoring stations. Error bars represent the standard deviation for each year.

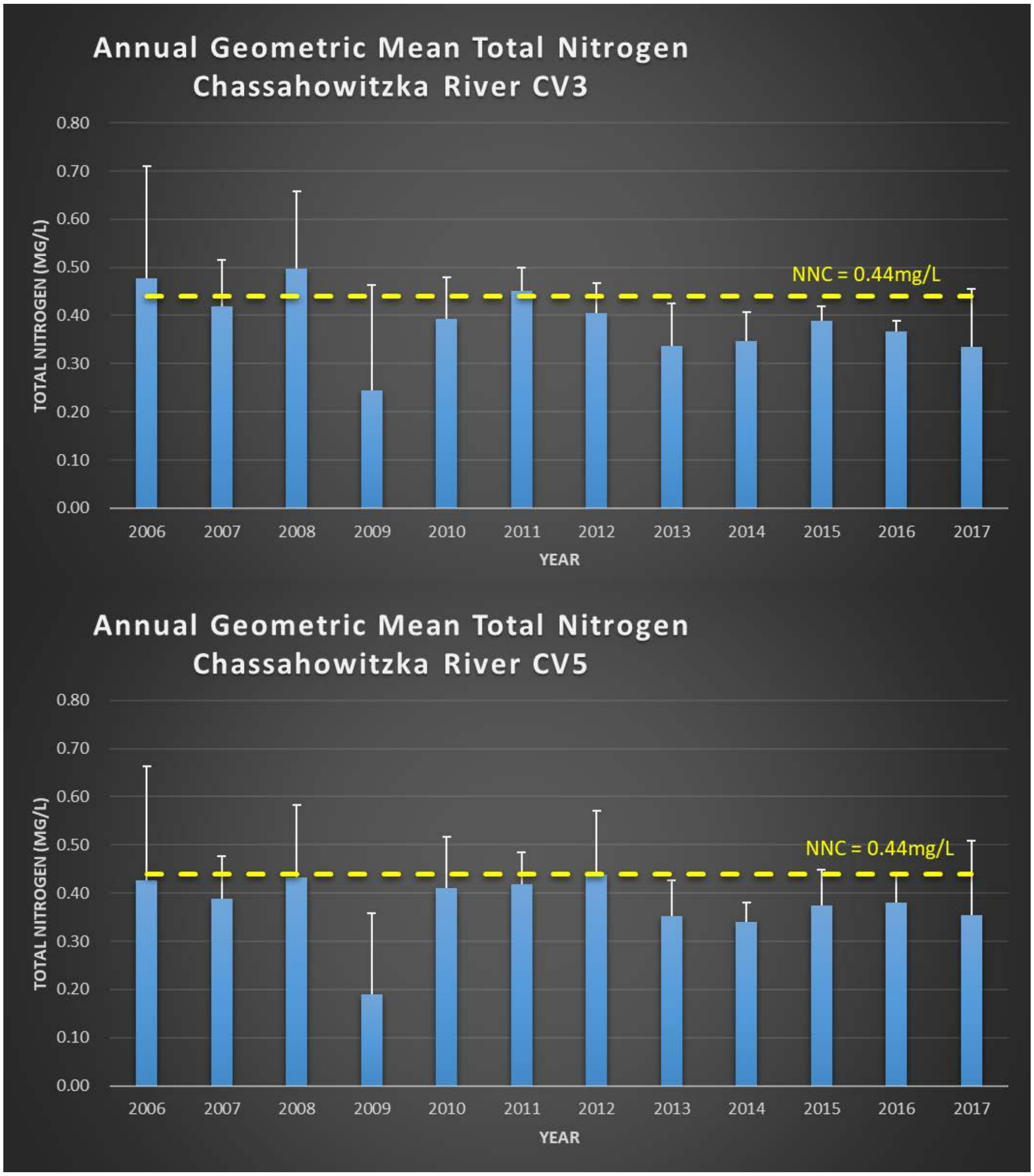


Figure 3-21. Total nitrogen concentration expressed as annual geometric mean for the period 2006 through 2017 for downstream stations CV3 (Rkm 4.2) and CV5 (Rkm 1). Error bars represent the standard deviation for each year. Data are from two of the Coastal Rivers Project P108 fixed stations. Yellow dashed line depicts the TN NNC of 0.44mg/L for the Chassahowitzka River WBID 1361. Total nitrogen is compared with the NNC value for comparison only and not for compliance estimation.

3.4.2 Nitrate + Nitrite

Elevated concentrations of nitrate continue to be an issue in many of the springs discharging into the Chassahowitzka River. In 2014, the DEP adopted a nitrate TMDL for the Chassahowitzka Springs Group, Crab Creek Spring, Baird Spring, Ruth Spring, and Beteejay Spring contained within WBID 1361, 1361B, 1348D, and 1348Z (Dodson et al. 2014). The nitrate TMDL of 0.23 mg/L was based on the relationship between nitrate and the growth of filamentous algae, namely the freshwater cyanobacteria *Lyngbya wollei* (Dodson et al. 2014). Over the period of record beginning in 1993, nitrate concentrations have continued to increase in all the monitored springs included in the Chassahowitzka Springs group (Figure 3-22). All five springs on the TMDL list show similar temporal trends. Of the five on the TMDL list, Baird Spring has the lowest nitrate concentrations followed by Beteejay Spring (Figure 3-22). The DEP is addressing the increasing trends in nitrate through the Basin Management Action Plan (BMAP) process which is the blueprint for restoring impaired waters by reducing pollutant loads to meet established TMDLs.

For the river, nitrate concentrations across the five Coastal Rivers Project P108 stations (Figure 3-23) show no trend. Relatively large error bars are indicative of the large concentration gradient in nitrate from the headsprings toward the mouth of the river (Figure 3-9.). Because of this strong gradient, averaging all five Coastal Rivers Project P108 stations together masks any potential surface water nitrate trends.

When the nitrate time series is evaluated by station (Figure 3-24.) an increasing trend in nitrate is evident for the upper most station (CV0 at Rkm 8.8). The other four stations show, at most, slight increasing trends, which moving further downstream become less pronounced.

The increase in nitrate at CV0 is consistent with the increasing trends in the spring vents. However, this increasing trend is less evident at downstream stations, suggesting that nitrate is quickly assimilated into biomass or denitrified. This uptake may be the cause of upstream impairment by filamentous algae; the general process of rapid nitrate uptake by algae forms the basis for DEP determination of impairment based on filamentous algae growth.

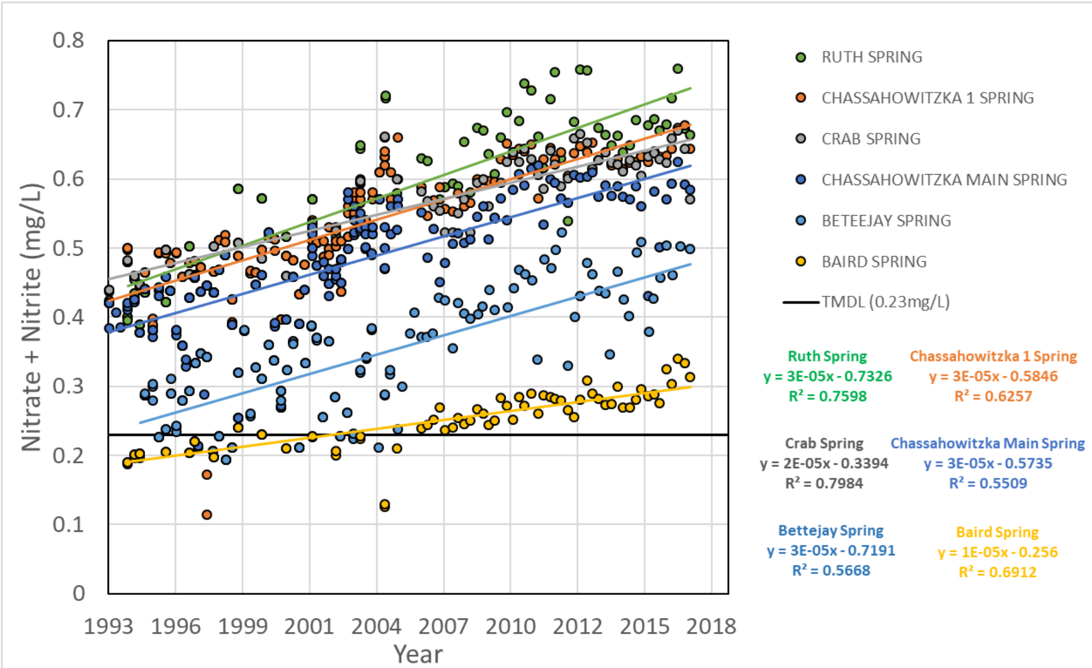


Figure 3-22 Time series of nitrate + nitrite for the Chassahowitzka River Springs that currently have an adopted TMDL for nitrate. Black line represents the TMDL of 0.23 mg/L for named springs.

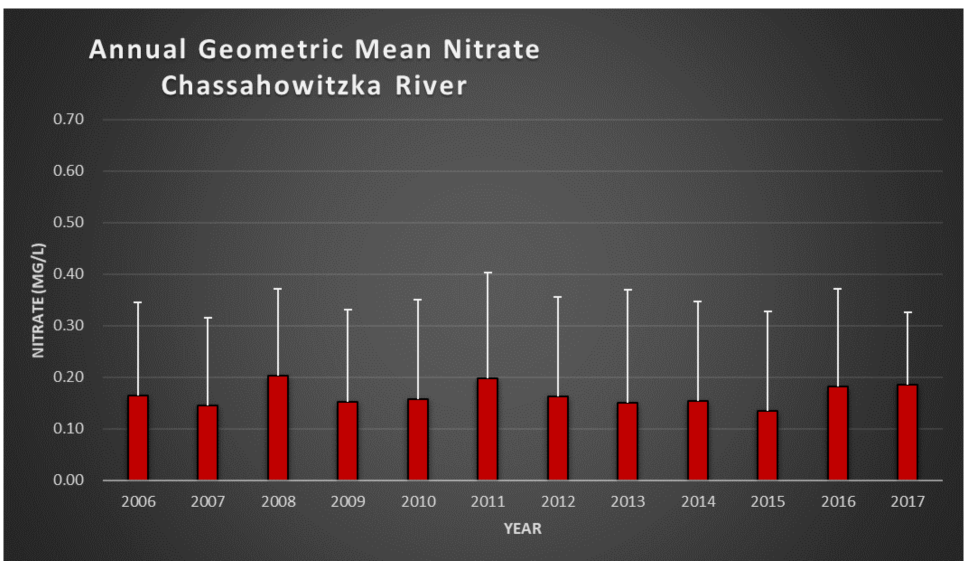


Figure 3-23. River-wide nitrate concentration expressed as annual geometric mean for the period 2006 through 2017. Error bars represent the standard deviation for each year. Data are from the five P108 fixed stations.

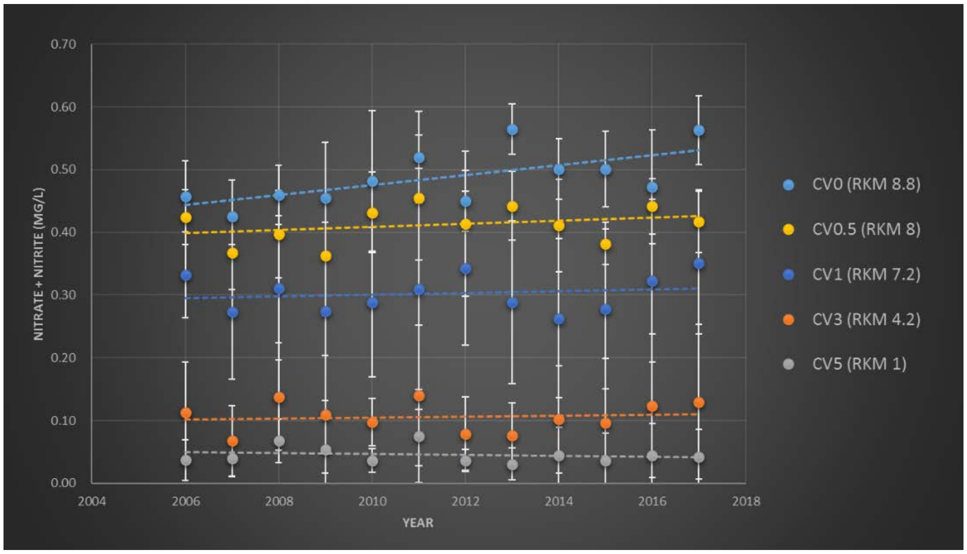


Figure 3-24. Average nitrate concentration by station for the period 2006 through 2017 for the five P108 fixed water quality monitoring stations. Error bars represent standard deviations for each year.

3.4.3 Total Phosphorous

There has been no observed, long-term trend in total phosphorous concentrations in the river from 2006 through 2017 (Figure 3-25.). Though much attention has been placed on the potential negative ecological effects of increased nitrogen, phosphorous is an important nutrient affecting the production of phytoplankton in the Chassahowitzka River and throughout the Springs Coast (Frazer et al. 2002). Phosphorous often limits phytoplankton productivity in these surface waters; therefore, small increases in phosphorous concentrations could have dramatic effects on phytoplankton production and the initiation of algal blooms. Frazer et al. (2002) reported that in the Chassahowitzka River and estuary, algal growth was limited by phosphorous in 40% of all experiments and co-limited by phosphorous and nitrogen in another 40% of experiments conducted. Most importantly, Frazer et al. (2002) concluded that nitrogen was the limiting nutrient on only two occasions or 4% of all experiments conducted in the Chassahowitzka River system. As nitrate concentrations continue to increase in the spring vents discharging into the Chassahowitzka River, it is likely that nitrogen will continue to be in ample supply, so phosphorous will likely be the limiting nutrient for phytoplankton growth.

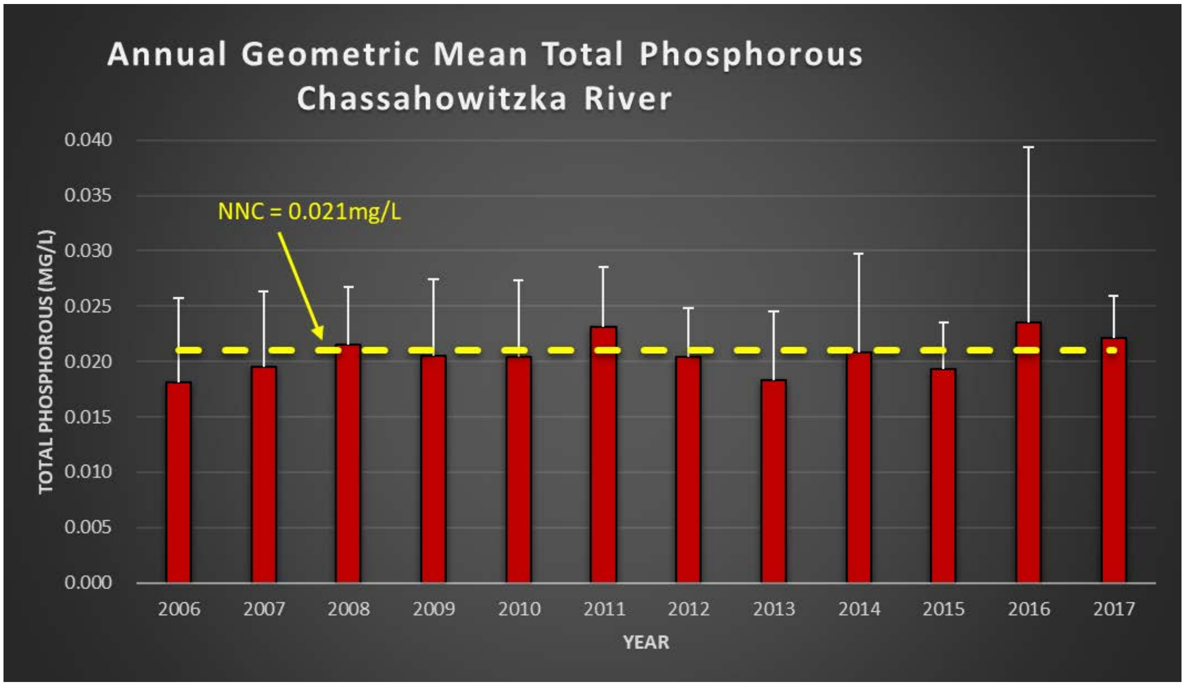


Figure 3-25. River-wide total phosphorous concentrations expressed as annual geometric mean for the period 2006 through 2017. Error bars represent the standard deviation for each year. Data are from the five P108 fixed stations. Yellow dashed line depicts the TP NNC of 0.021mg/L for the Chassahowitzka River WBID 1361. Annual river-wide total phosphorous is compared with the NNC value for comparison only and not for compliance estimation.

3.4.4 Soluble Reactive Phosphorous and Orthophosphate

River-wide ortho-P concentrations show no significant trend over the 11-year period of record from 2006 through 2017 (Figure 3-26.). Temporal patterns in orthophosphate may be masked because of the longitudinal concentration gradient in orthophosphate (Figure 3-12).

When each of the five P108 stations are assessed separately, some interesting patterns emerge (Figure 3-27.). At CV0 (Rkm 8.8) and CV0.5 (Rkm 8), orthophosphate concentrations have increased slightly over time. Conversely, concentrations have decreased slightly for stations CV1 (Rkm 7.2), CV3 (Rkm 4.2), and CV5 (Rkm 1).

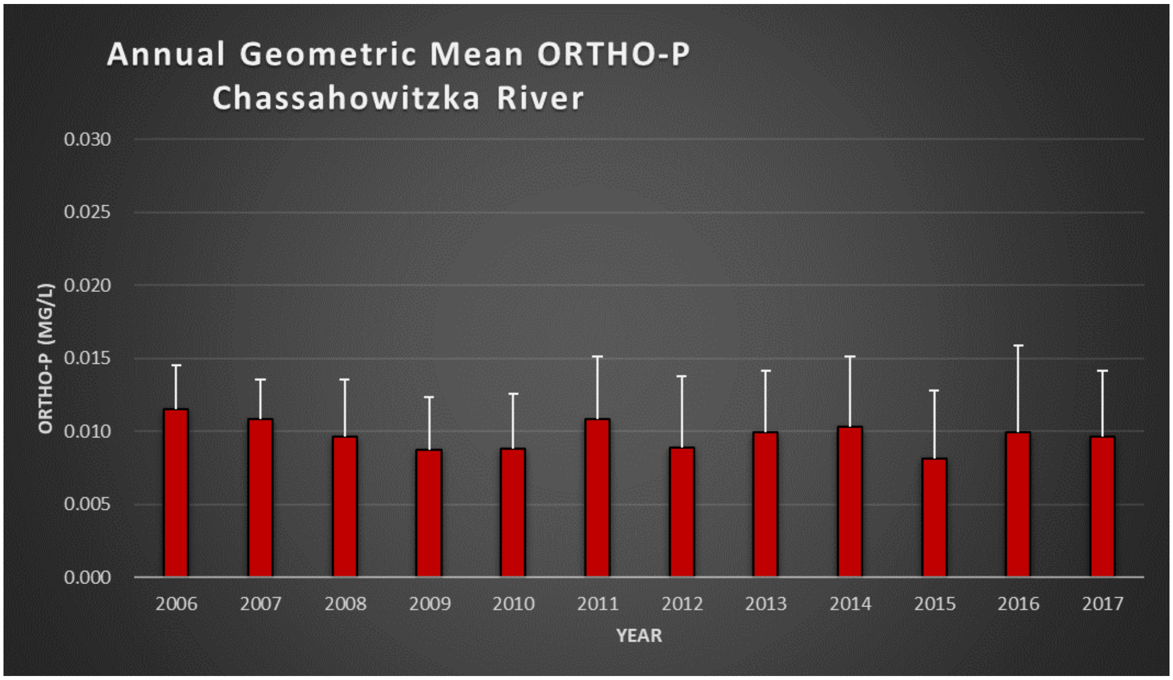


Figure 3-26. River-wide orthophosphorous concentrations expressed as annual geometric mean for the period 2006 through 2017. Error bars represent the standard deviation for each year. Data are from the five P108 fixed stations.

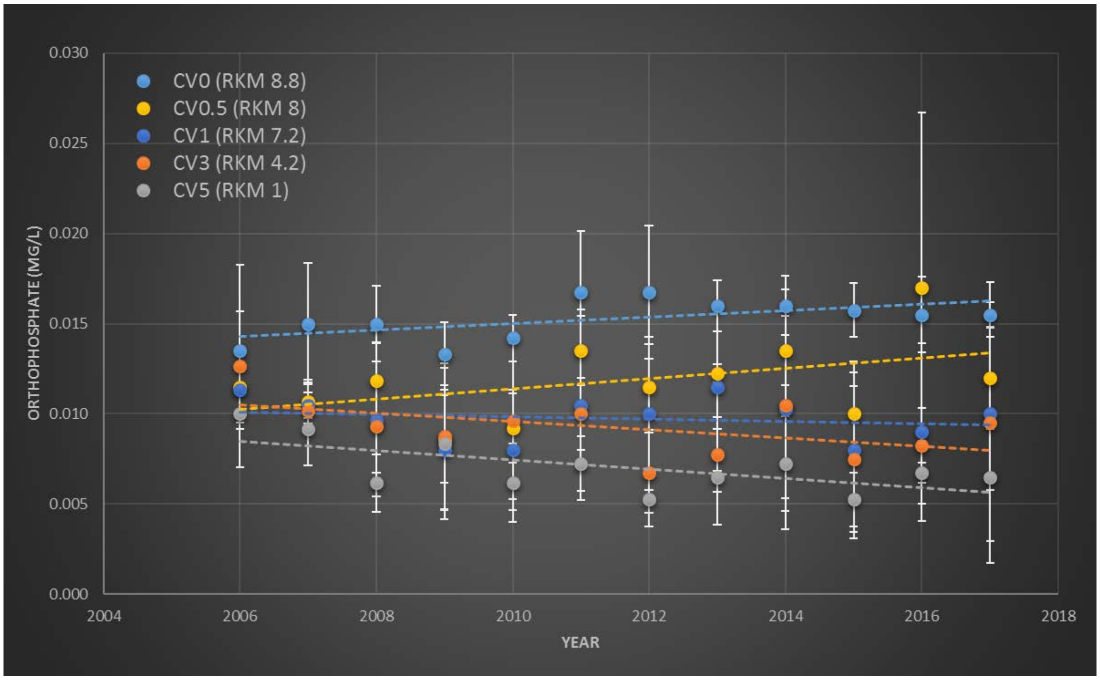


Figure 3-27. Average orthophosphate concentration by station for the period 2006-2017 for the five P108 fixed water quality monitoring stations. Error bars represent the standard deviation for each year.

3.4.5 Chlorophyll

Chlorophyll concentrations for the upper most Coastal Rivers Project P108 station CV0 (Rkm 8.8) were relatively low, with most values below the laboratory minimum detection limit of 1.00 µg/L. Periodically, chlorophyll concentrations at CV0 exceed the minimum detection limit, and for two events (6/4/2008 and 6/29/2010) chlorophyll concentrations exceeded 8.00 µg/L. Annual average chlorophyll concentrations across the five Coastal Rivers Project P108 stations show no trend over the 11-year period from 2003 through 2017 (Figure 3-28).

Using the more spatially rich University of Florida 5 Rivers Project data also shows considerable inter-annual variation and no significant trend through the relatively shorter period of record (Figure 3-29). Elevated river-wide chlorophyll concentrations in 1998 is likely a function of the extreme El Niño event that occurred during the 1997-1998 winter. The cause of the 2010 spike in average annual chlorophyll is not known but the largest concentrations occurred during the May and November sampling events which are typically the times of year when chlorophyll concentrations are maximum and correspond to the arrival of spring and the end of the rainy season, respectively.

There is a site-specific numeric nutrient criteria (NNC) for chlorophyll for WBID 1361 which is the section of the lower river from Rkm 0 to Rkm 5.8 (Figure 3-1.). The Coastal Rivers Project P108 stations CV3 and CV5 are contained within this WBID boundary. The chlorophyll NNC for this WBID is an annual geometric mean concentration of 3.9 µg/L. When annual geometric mean chlorophyll concentrations for these two active Coastal Rivers Project P108 stations are compared with the chlorophyll NNC, station CV3 (Rkm 4.2) exceeded the chlorophyll NNC in 2016 (Figure 3-30). Station CV5 (Rkm 1) remains well below the chlorophyll NNC for the 11-yer period of record (Figure 3-30). It is important to note that specific spatial areas, temporal time periods, and statistics are required to determine impairment with this NNC standard. The analyses shown here are not meant to determine impairment but are compared with NNC standard values to establish a frame of reference for the concentrations measured at these stations.

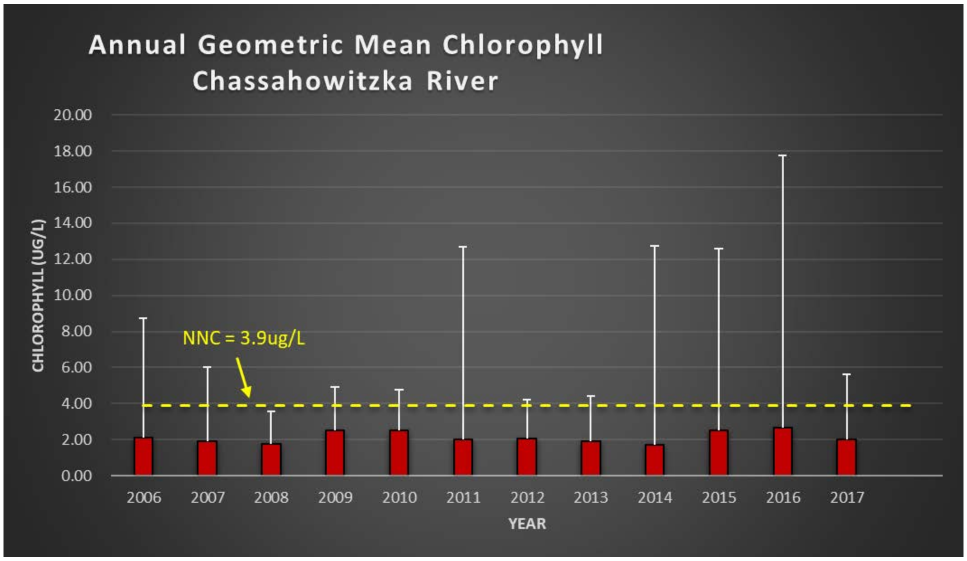


Figure 3-28. River-wide average chlorophyll concentrations expressed as annual geometric mean for the period 2006 through 2017. Error bars represent the standard deviation for each year. Data are from the five Coastal Rivers Project P108 fixed stations. Yellow dashed line depicts the chlorophyll NNC of 3.9ug/L for the Chassahowitzka River WBID 1361. Annual river-wide chlorophyll is compared with the NNC value for comparison only and not for compliance estimation.

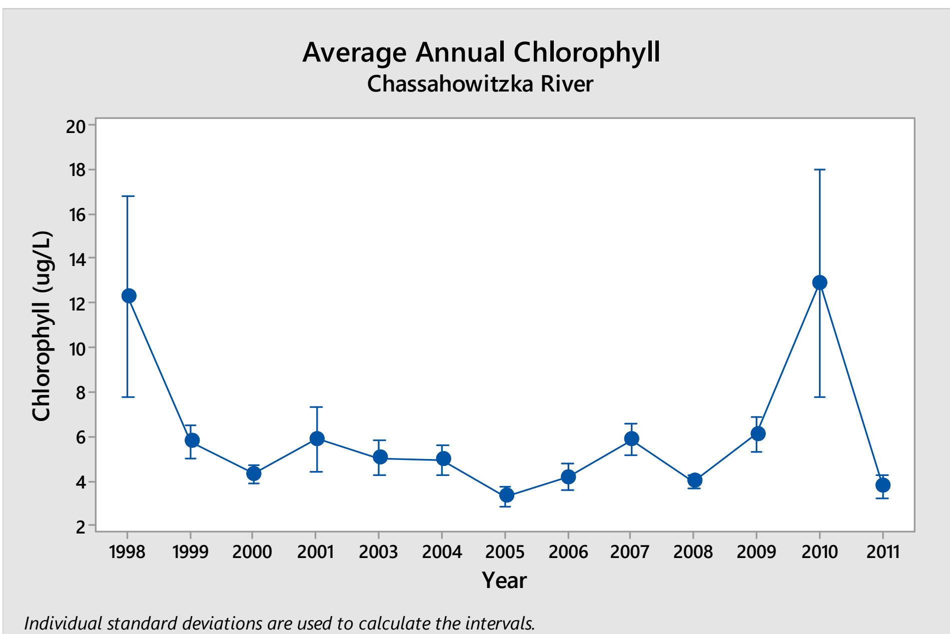


Figure 3-29. River-wide average chlorophyll concentrations for the period 1998 through 2011. Data are from the University of Florida 5 Rivers Project.

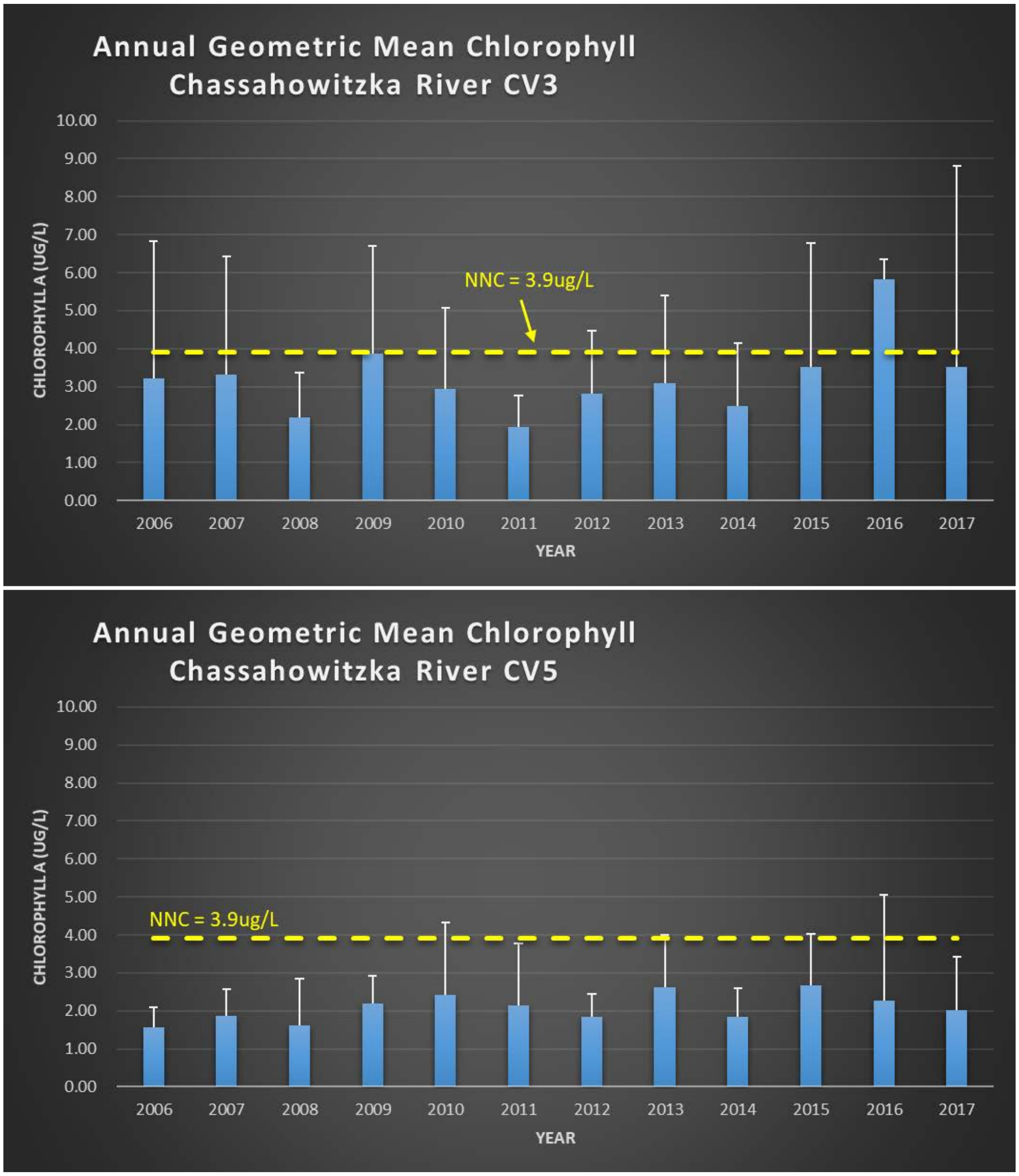


Figure 3-30. Annual geometric mean of chlorophyll concentration at downstream stations CV3 (Rkm 4.2) and CV5 (Rkm 1). Error bars represent the standard deviation for each year. Yellow dashed line depicts the chlorophyll NNC of 3.9ug/L for the Chassahowitzka River WBID 1361. Chlorophyll is compared with the NNC value for comparison only and not for compliance estimation.

3.4.6 Water Clarity

For the Chassahowitzka River, there is considerable interannual variability in water clarity, as measured using a horizontal Secchi disk. The spatial variability in water clarity as explained in section 3.3.6, is much greater than the temporal variability described here. Because of the strong spatial variability, temporal trends were analyzed separately for each of the five Coastal Rivers

Project P108 fixed stations. Figure 3-31 shows the annual geometric mean of water clarity for station CV0 near the headsprings. At first glance, there appears to be a decreasing trend in clarity over time. However, this trend is not statistically significant using linear regression. Further, the unusually low average geometric mean for 2017 was caused by missing data. The remaining four Coastal Rivers Project P108 stations also showed no temporal trend in water clarity.

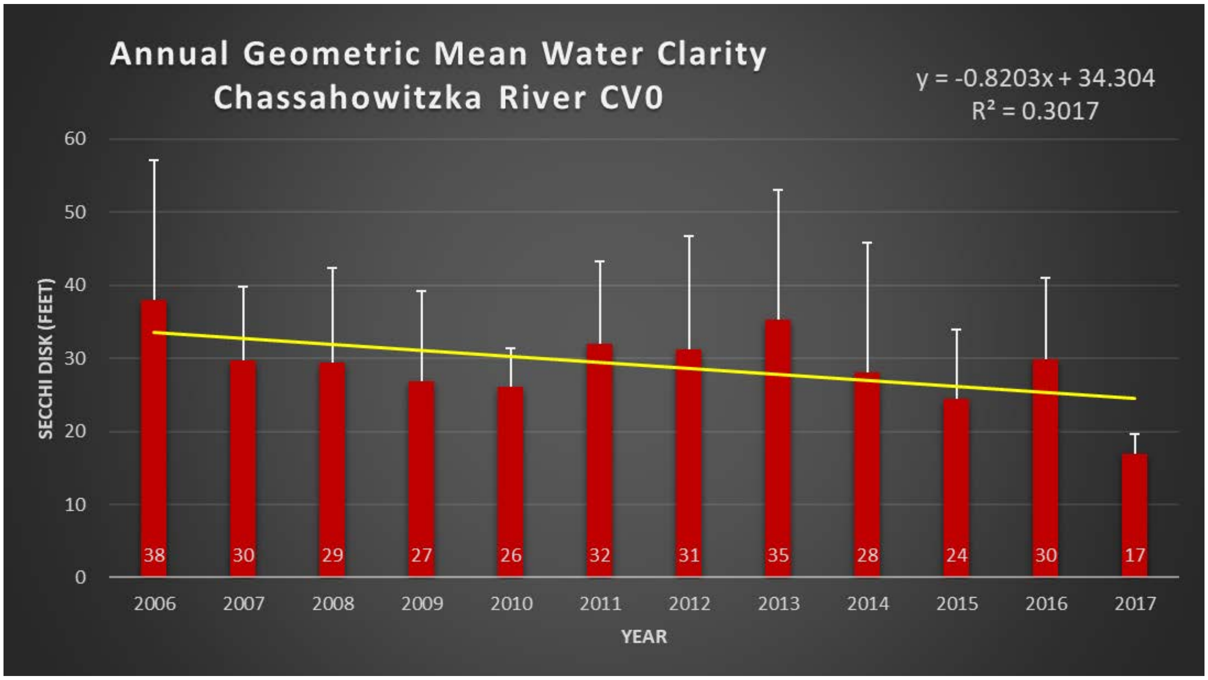


Figure 3-31. Average water clarity for the period 2006 through 2017 expressed as Secchi distance annual geometric mean. Data are from CV0, the upper most station of five Coastal Rivers Project P108 fixed stations. Error bars represent the standard deviation for each year. Missing data for 2017 are responsible for the unusually low average Secchi disk for that year. Using linear regression, there was no significant trend in clarity over the period (p=0.064, R2=0.30).

3.5 Relationship between Flow and Water Quality Constituents

3.5.1 Flow Record for Water Quality Analysis

Simulation of an unimpacted flow record was necessary to compare water quality conditions that would occur with unimpacted flows to gaged flows impacted by withdrawals. For this simulation, withdrawal impacts were gradually increased from zero to present day levels. This was done because some water quality data extends back to 1993 in the Chassahowitzka River System, when withdrawal impacts were less than they are today. Methods for simulating gradual increases in impacts are detailed below.

Gage Flow data from USGS Chassahowitzka River near Homosassa, FL gage (No. 02310650) were downloaded from USGS NWIS. Where index velocity data were available, they were used, otherwise regression data were used (this gage offers both). Data from USGS Weeki Wachee Well near Weeki Wachee, FL (No. 283201082315601) and USGS Weeki Wachee FLDN REPL Well near Weeki Wachee, FL (No. 2831540823701) were used to predict missing values at the discharge gaging station and to extend records to dates prior to the gaged streamflow record. Weeki Wachee well data were adjusted for relocation by adding 0.3 ft to the newer (REPL) well levels following methods used for updating regression equations by the USGS (Kevin Grimsley, personal communication). For all dates prior to 1975, the withdrawal impact was considered to be zero. For dates from Jan. 1, 1975 to Dec. 31, 2004 the impact was linearly increased daily from 0 to 1% because the 2005 withdrawal impact estimated with the NDM was 1%. For all dates from Jan. 1, 2005 to Dec. 31, 2009, the impact was linearly increased daily from 1% to 1.3% based on the 1.3% withdrawal impact for 2010 estimated with the NDM. For all dates from Jan. 1, 2010 to Dec. 31, 2014, the impact was linearly increased daily from 1.3% to 1.4% because the 2015 impact estimated with the NDM was 1.4%. For all dates from Jan. 1, 2015 onward, the impact was considered to be 1.4%. Regardless of time period, missing values were replaced by linear interpolation between adjacent values. These methods are consistent with methods used in the original 2012 minimum flows report for creating a long-term historical flow record and have been updated with new data.

3.5.2 Spring Vents

Linear regression analysis was used to test the hypothesis that concentrations of selected water quality constituents in spring flows were related to system-wide flows (Janicki Environmental, Inc. and WSP, Inc. 2018). Water quality constituents for seven system springs (Figure 3-4.) were assessed.

The District has previously developed acceptance criteria for using regression analysis in support of minimum flows evaluations for the Chassahowitzka River (Heyl et al. 2012). These criteria require that regressions must include a) a minimum of 10 observations per variable, b) no significant serial correlation and c) an adjusted coefficient of determination (R^2) of at least 0.3. In addition, to be considered for setting minimum flows, regressions would need to be useful for demonstrating increased harm with decreased flows.

There are three general patterns detectable by linear regressions: 1) no relationship – indicating quantity of flows are not associated with concentrations; 2) positive relationships – indicating concentrations increase along with increasing flows; and 3) negative (inverse) relationships – indicating concentrations decrease when flows increase. Harm may be associated with decreased flows when inverse relationships cause increased concentrations of potentially harmful water quality constituents such as nitrogen or phosphorus. Furthermore, these inverse relationships would need to be consistent among water quality monitoring stations and locations throughout the system for them to be used as criteria for setting minimum flows. Regressions that met the District's acceptance criteria are described below. However, there were no spatially consistent inverse relationships with potentially harmful constituents such as nitrogen or phosphorus necessary to consider any of these regressions as criteria for setting minimum flows.

An example of the results for the Chassahowitzka 1 Spring site is provided in Figure 3-32., with all plotted constituents displaying inverse relationships with flow (i.e., constituent concentrations decrease with increasing flows). The greatest number of significant results was observed in the

Chassahowitzka 1 Spring and the Chassahowitzka Main Spring, and many of the same constituents exhibited significant inverse relationships with flow at Beteejay Spring. While these water quality constituents exhibited decreases with increasing flow, these constituents are natural components of groundwater in the region and do not pose an ecological threat to the system.

Statistically significant relationships with flow were observed for some forms of nitrogen, but these were tenuous, with low numbers of observations and less than 50% of the total variability explained by regressions (Table 3-7). Further, 6 of the 8 significant relationships were with nitrite, a transient species found in very low concentrations. The results of the nitrogen regressions were also conflicting with respect to the direction of the relationship with flow. For example, the strongest nutrient relationship observed in the Chassahowitzka Spring group in this study was for nitrite (total) at Blue Run Spring with an R^2 value of 66% and $p < 0.001$; the results suggest a small magnitude positive relationship; increasing concentrations with increasing flow. However, the results of the same analysis for nitrite in Blue Run and Ruth Springs suggest an inverse relationship.

In a technical memorandum by Heyl et al. (2012), included as an appendix to the District's original minimum flow report for the Chassahowitzka River System, the relationships between nitrate + nitrite nitrogen and flows in spring systems of the Homosassa and Chassahowitzka rivers were examined. The memorandum indicated that flows in the Chassahowitzka have been declining since the 1960s, and that since monitoring began in 1993, concentrations have been cyclic but with a slight overall positive trend. Since nitrate concentrations have increased over time, the memorandum evaluated whether changes in nitrate concentrations were the result of change in flow or time. For the Chassahowitzka data, Heyl et al. (2012) noted that once the time effect was accounted for, the relationship with flow was not significant. The trend over time was attributed to inland management practices that increased nitrogen loads to the springshed.

In an analysis of the relationships of nitrate to flows in springs in the Suwannee River Water Management District (Upchurch et al. 2008), the objective was to address the question "*can management of spring flows be utilized to mitigate nitrate discharging from the springs?*" The analytes reported included spring discharge and nitrate + nitrite using data obtained from all the first and most of the second magnitude springs within the Suwannee River Water Management District (n=52). The report concluded that minimum flows cannot be utilized to control nitrate discharging from the springs by promoting high discharge. Data from 50% of the springs showed that nitrate concentrations increased as discharge from the springs increased. Forty-five percent of the remaining springs showed no correlation between discharge and nitrate, and only 5% (2 springs with poor data) had relationships where high discharge was related to lower nitrate concentrations.

Despite the existence of many significant water quality relationships with flow, there was no evidence that decreased flows would cause increased harm associated with the assessed water quality constituents. The positive relationships between major ions (e.g. TDS and its constituents) and flow would only be problematic if they were considered contaminants. However, many of these constituents are trace nutrients that are valuable for biological productivity. In addition, even if the concentrations decrease with flow, the total mass of the constituent may be increasing, and total mass may be a more important driver of response of biota in the receiving water bodies. In summary, there was no evidence that the relationship of any of these constituents with flow would result in significant harm to the receiving waters of the Chassahowitzka River. Future research should consider the utility of developing nitrate loadings from the head springs. In summary, there is no evidence that relationships between any assessed water quality constituents and decreased flow would result in significant harm to the receiving waters of the Chassahowitzka River System.

As shown in Figure 3-22, nitrate levels have been increasing over time in water discharged from spring vents. This spring discharge is the source of nitrates to the spring pools and river system. Therefore, increasing flows will increase the total amount of nitrogen (loading) fed into the system. The intuitive wisdom that increasing flows will decrease concentrations does not apply to this system where spring flows are the source of nitrates.

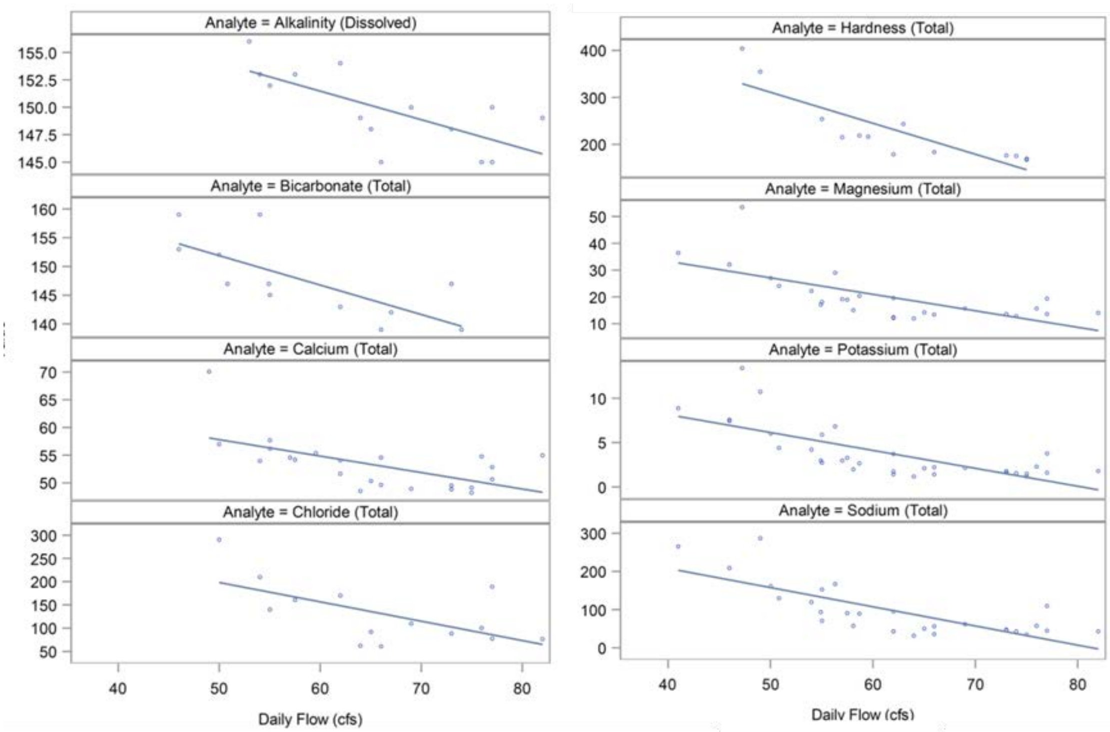


Figure 3-32. Regression relationships between selected water quality constituents (all units are in milligrams per liter) at the Chassahowitzka 1 spring sampling site and flows in the Chassahowitzka River System.

Table 3-7. Significant regression results for nitrogen constituents in Spring Vents Project P889 data. Asterisk (*) indicates regressions for same day flow, otherwise regressions are for 3-day lagged flow.

Spring Name	Parameter	Units	Intercept	Slope	DF	R Square	P Value
Chass. 1	*Nitrite (N) (Dissolved)	mg/L	0.01	-0.0001	31	0.33	0.0005
Chass. Main	*Nitrite (N) (Dissolved)	mg/L	0.01	-0.0001	38	0.31	0.0002
Beteejay	Nitrate (N) (Total)	mg/L	0.49	-0.0036	14	0.47	0.0034
Blue Run Spring	Nitrite (N) (Dissolved)	mg/L	0.02	-0.0002	19	0.36	0.0041
Blue Run Spring	Nitrite (N) (Total)	mg/L	-0.01	0.0003	13	0.66	0.0002
*Ruth Spring	Nitrite (N) (Dissolved)	mg/L	0.01	-0.0001	23	0.31	0.0041
Crab Creek Spring	Nitrate (N) (Dissolved)	mg/L	0.24	0.0043	14	0.41	0.0072
Crab Creek Spring	Nitrite (N) (Dissolved)	mg/L	0.01	-0.0001	24	0.32	0.0026

3.5.3 River Mainstem

It has been suggested that residence time may be linked to phytoplankton algae growth and increasing flows will reduce residence times and therefore reduce harmful algal growth. Residence time is not one quantity, but can be measured in various ways, one of which is water age, which is the time it takes for a molecule of water to travel a distance from the headsprings downstream. At any given time and under any flow regime, water age increases with distance downstream (Figure 3-33).

Water age at the most upstream point to beyond Rkm 4 increases as 3-day average flow increases from 30 to 50 cfs. As flows increase from 50 to 80 cfs, residence times in the uppermost portion of the river decrease. However, rather than focusing on residence time as an intermediary between flows and algal growth, the following analyses focus directly on the abundance of phytoplankton as estimated by chlorophyll concentration. This is because the environmental characteristic of interest to most users of the river is water clarity, which is partly driven by chlorophyll via absorption of electromagnetic energy primarily in the blue and red wavelengths.

As explained in section 3.3.6, chlorophyll is only one of two major attenuators of light in the Chassahowitzka River, the other being TSS. Therefore, caution should be taken when attempting to assign cause and effect relationships between chlorophyll and clarity, and clarity and flow. In fact, Janicki Environmental, Inc. and WSP, Inc. (2018) found no significant correlation between Secchi disk and flow for any of the stations that reported Secchi disk. The only exception was for a single station, Chassahowitzka Crab Creek MFL in which a positive correlation between vertical Secchi disk and flow was reported by Janicki Environmental, Inc. and WSP, Inc. (2018). However, the vertical Secchi disk values were the same as the total water column depth indicating the samplers could see the disk on the bottom. Therefore, the significant relationship found by Janicki Environmental, Inc. and WSP, Inc. (2018) has nothing to do with clarity.

Regardless of the relationship between chlorophyll and clarity, chlorophyll concentration is a widely accepted indicator of eutrophication and therefore an important ecological parameter to monitor. In an initial screening of data, non-linear relationships were found between flows and chlorophyll for several of the University of Florida 5 Rivers Project transect sites in the upper portion of the mainstem of the river (Janicki Environmental, Inc. and WSP, Inc. 2018). The University of Florida 5 Rivers Project data was selected for these analyses because its sampling design was spatially intensive with 20 transect locations within 9 kilometers of the river and because of the relatively long period of record (Figure 3-34). The statistical approach used identifies risk of exceeding a threshold chlorophyll value and associates that risk with rates of flow. Chlorophyll concentration is related to phytoplankton abundance and an important contributor to water clarity (Figure 3-17).

The analysis we used identifies a threshold value and calculates risk of individual samples exceeding that value. To perform this analysis a threshold must be selected, and that threshold should be relevant to the system being studied. District staff identified a value of 3.9 µg/L as the most relevant threshold to use. Note, it is critical to distinguish between our use of this value as a threshold for analysis and its prescribed use as a criterion for determining impairment within the Estuary-Specific Numeric Interpretations of the Narrative Nutrient Criterion (NNC) (Table 3-1). This value, taken as the NNC, is applicable only within WBID 1361 (see Figure 3-34) and as an annual geometric mean value according to Rule 62-302.532, F.A.C. Contributing to our decision to use this 3.9 µg/L value, associated with the downstream 1361 WBID, is that the upstream WBID (1348D) does not have a chlorophyll NNC value. We used this same value of 3.9 µg/L, but for a different purpose than determination of impairment of the NNC. Thus, an instance of a single exceedance of this threshold, or an increased risk of this exceedance across several repeated samples both inside and outside the WBID boundary cannot and should not be interpreted in the context of impairment of the NNC.

To test the hypothesis that exceedances of the 3.9 µg/L chlorophyll threshold were related to spring flow, a generalized linear mixed effects model predicted the probability of an exceedance of the 3.9 µg/L chlorophyll threshold (a binomial response; either the threshold is exceeded, or it is not) as a function of flow.

Fifteen flow reduction scenarios were developed for use with the generalized linear mixed effects model. The scenarios included 1% to 15% reductions in flow from the unimpacted flow record for the Chassahowitzka River, in 1% increments. The period from 1998 through 2017 was used for these simulations because this period approximates the full period of record for the Chassahowitzka River near Homosassa, FL gage (No. 02310650). Chlorophyll responses were predicted for the entire system, while comparisons between the flow reduction scenarios and the unimpacted (no flow reduction) flow scenario were limited to the area between University of Florida 5 Rivers Project sites 1 and 10 (i.e. upstream of Rkm 4.9) because this portion of the system is most likely to be directly influenced by spring flows (Figure 3-34.).

Model predictions for the flow reduction scenarios were evaluated using two forms: Best Linear Unbiased Predictions (BLUPs) and Best Linear Unbiased Estimates (BLUEs). BLUPs more accurately represent differences among sites within the focus area, while BLUEs generate artificially smooth transitions from one site to the next.

Results show that both BLUPs and BLUEs predict increased risks of exceedance of the 3.9 µg/L chlorophyll threshold with increased flow reductions (Figure 3-35). BLUEs predict more sensitive responses to all flow reductions. The interpretation of these results for minimum flows determination is discussed further in Chapter 7.

To date, the District has not used phytoplankton distributions as the principal determinant for establishing minimum flows. Chlorophyll concentrations have, however, been used to support the establishment of a low-flow threshold for the Lower Alafia River (Flannery et al. 2008) Moreover, chlorophyll concentrations were recently used by the South Florida Water Management District in comparison to state water quality standards as a line of evidence supporting derivation of a revised minimum flow for the Caloosahatchee River estuary (South Florida Water Management District 2018). Based on these examples, there are alternative modeling approaches that consider actual chlorophyll concentrations (rather than risks of exceedance) as a response variable. However, there are currently no applicable standards for identifying “significant harm” associated with increased chlorophyll concentrations.

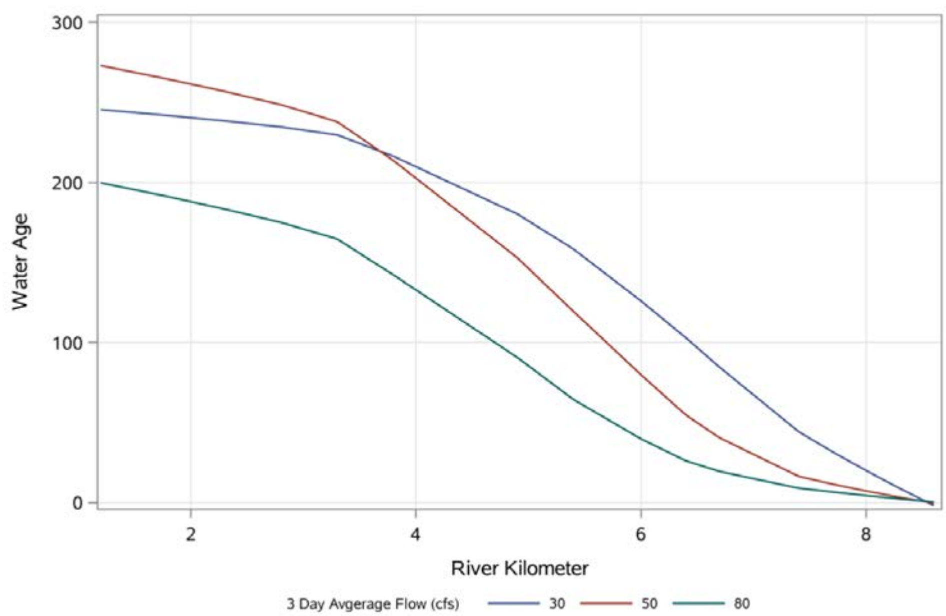


Figure 3-33. Water age as a measure of “residence time” varies with average flow and river kilometer.

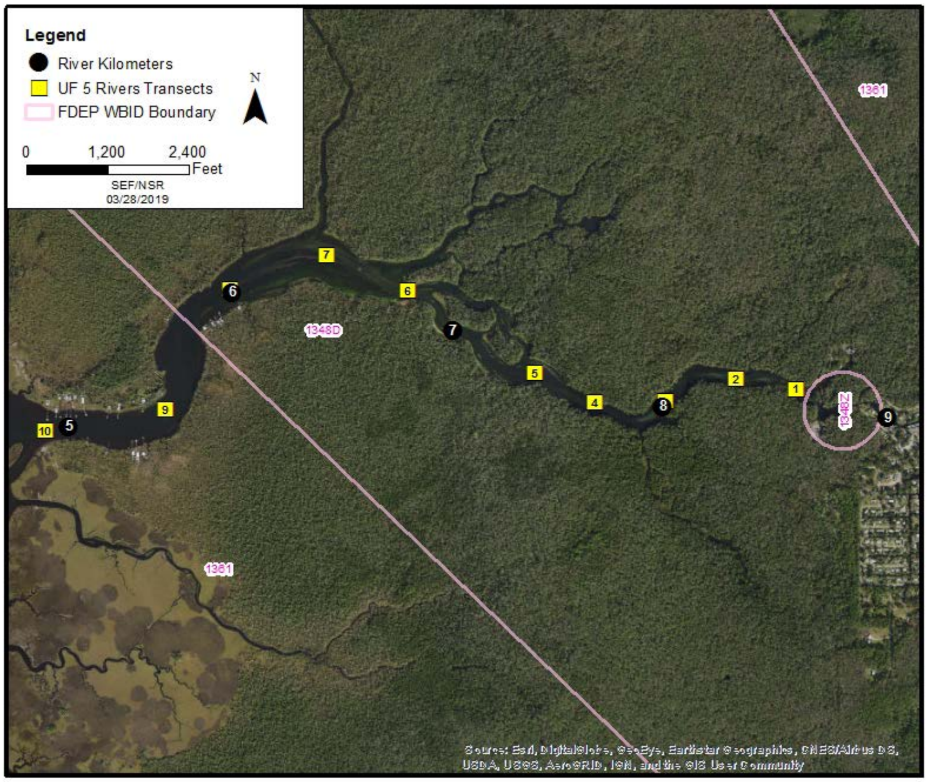


Figure 3-34. River kilometer, WBID boundaries (upper panel), and University of Florida 5 Rivers Project transect numbering system (lower panel) for the Chassahowitzka River. This area used for relative comparisons of chlorophyll concentrations between flow-reduction and unimpacted (no flow reduction) scenarios.

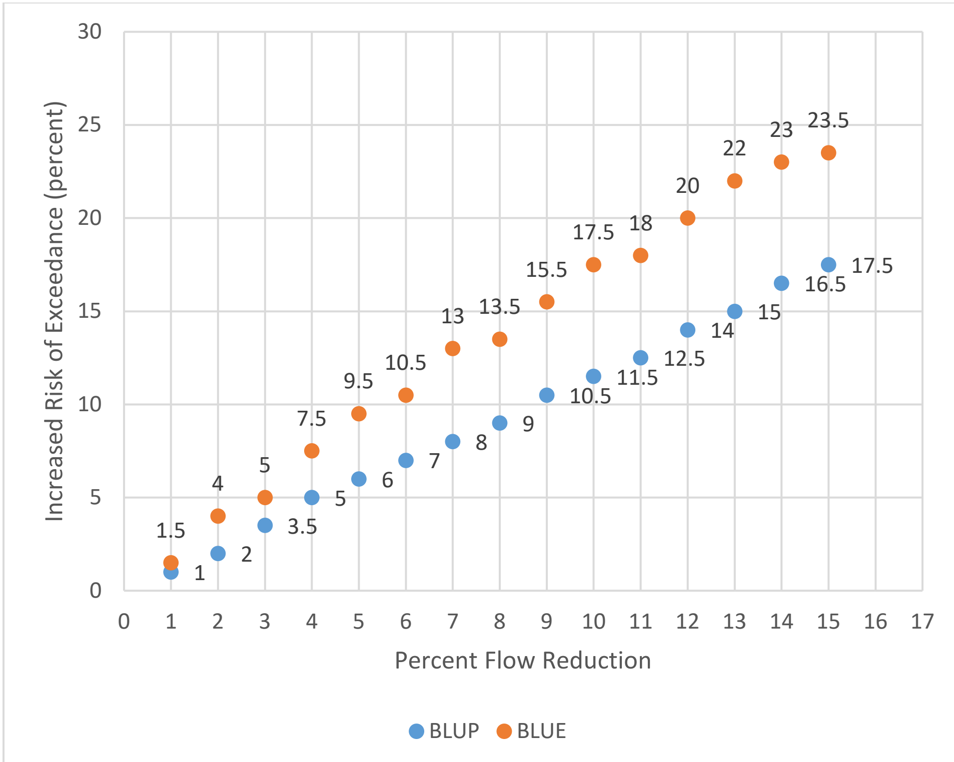


Figure 3-35. Increased risk of exceeding the 3.9 µg/L chlorophyll threshold with flow reductions as predicted by BLUPs and BLUEs. Increased risks are compared between flow reduction scenarios and the unimpacted flow scenario.

3.5.4 Estuary

JEI (Janicki Environmental, Inc. and WSP, Inc. 2018) also developed and assessed regressions between water quality constituents and flow at estuary sites beyond the mouth of the river (Rkm 0) using the same statistical methods as for spring vent sites (see Section 3.5.2). Estuary sites analyzed include four COAST Project (P529) sampling stations and three transects from the previously completed University of Florida 5 Rivers Study (Figure 3-36.). Two Project Coast sites (9, 10) were deemed too far removed from the mouth of the river to be useful for this evaluation.

Salinity was the principal water quality constituent affected by springs flows (Table 3-8). Salinity in the estuary beyond the mouth of the river decreases with increasing flows. Similar results were reported by Yobbi and Knochenmus (1989), who found salinity isohalines moved from the river out to the Gulf of Mexico.

Given that the estuarine area examined in this current analysis is so far removed from the flow of the Chassahowitzka springs, there is little utility in directly using these regressions to support the establishment of minimum flows for the Chassahowitzka River System. Furthermore, the hydrodynamic model described in Chapter 6 is a much more precise and accurate tool for predicting salinity changes associated with flow reductions.

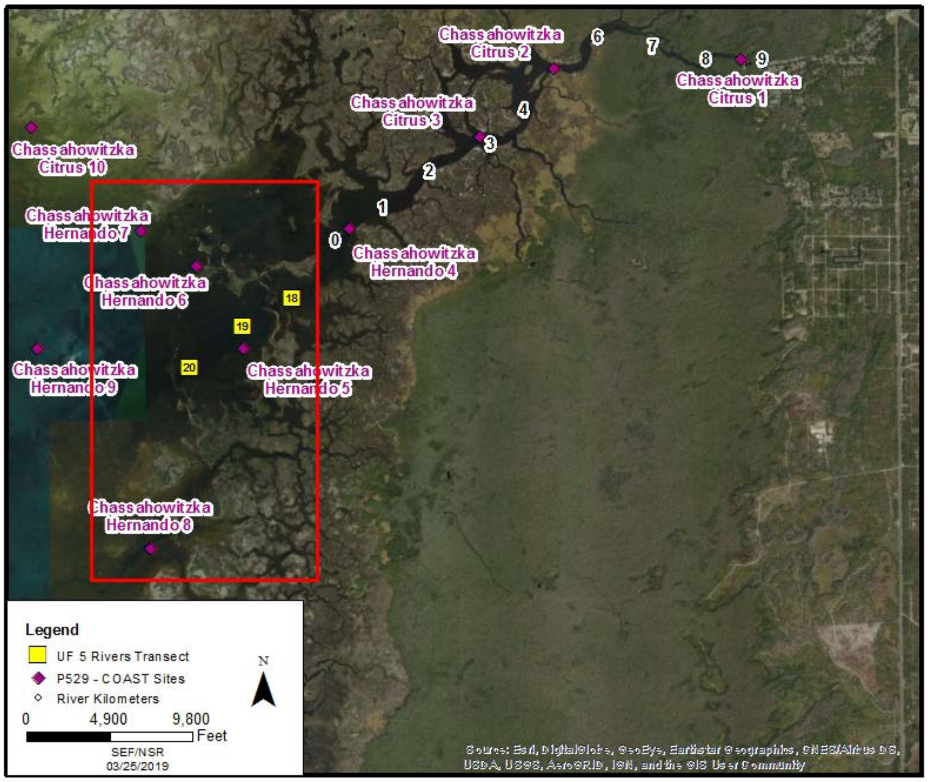


Figure 3-36. Sampling areas in the Chassahowitzka River estuary outside of the Chassahowitzka River System hydrodynamic model domain investigated for regressions with flow (highlighted with red rectangle).

Table 3-8. Significant regression results for estuary data.

Site Name	Parameter	Intercept	Slope	DF	R Square	P Value
CHASSAHOWITZKA HERNANDO 5	Salinity (Total)	35.4046	-0.3257	215	0.32	0.0000
CHASSAHOWITZKA HERNANDO 7	Salinity (Total)	37.9703	-0.3207	214	0.30	0.0000
CHASSAHOWITZKA HERNANDO 8	Salinity (Total)	37.9498	-0.3221	215	0.32	0.0000
Transect 18 - 3	Salinity (Total)	37.2142	-0.3780	43	0.35	0.0000
Transect 19 - 3	Salinity (Total)	39.9059	-0.3981	43	0.34	0.0000
Transect 20 - 3	Salinity (Total)	40.2606	-0.3735	43	0.32	0.0001

CHAPTER 4 - BIOLOGICAL STATUS AND TRENDS FOR THE CHASSAHOWITZKA RIVER SYSTEM

Plants and animals in the Chassahowitzka River System have historically formed diverse communities structured by the estuarine gradient from freshwater headsprings to the saltwater mouth of Chassahowitzka Bay. Because salinity and temperature are responsible for structuring communities of fish, invertebrates and plants throughout the system, it is important to have a baseline knowledge of these communities in order to effectively detect changes in these communities that may be caused by reduced flows or decreased water quality. Since the original minimum flows evaluation and rulemaking in 2013, the District has continued monitoring vegetation, fish, and other biological aspects of this system as part of our adaptive management strategy for dealing with uncertainty in this inherently complex system.

4.1 Vegetation

4.1.1 Land Cover

The areas surrounding the Chassahowitzka River and associated springs are dominated by a few cover types (Figure 4-1.). The main springs and the headwaters are surrounded by hardwood hammocks, FLUCCS code 615. This community, often referred to as bottomland or stream hardwoods, is usually found on but not restricted to river, creek and lake flood plain or overflow areas. This category has a wide variety of predominantly hardwood species of which some of the more common components include red maple, river birch, water oak, sweetgum, willows, tupelos, water hickory, bays, and water ash and buttonbush. Associated species include cypress, slash pine, loblolly pine and spruce pine. The lower portion of the river, starting at Rkm 5 and extending downstream, is surrounded by salt marsh, FLUCCS code 642. The communities included in this category will be predominated by one or more of the following species: Cordgrasses - *Spartina alterniflora, Spartina cynosuroides, Spartina patens, Spartina spartinae*; Needlerush - *Juncus roemerianus*; Seashore Saltgrass - *Distichlis spicata*; Saltwort - *Batis maritima;* Glassworts - *Salicornia sp.*; Fringerush - *Finbristylis castanea*; Salt Dropseed - *Sporobolus virginicus*; Seaside Daisy - *Borrichia frutescens*; Salt Jointgrass - *Paspalum vaginatum*. The hardwood hammock and salt marsh are punctuated by scattered patches of wetland forest FLUCCS code 630. This category includes mixed wetlands forest communities in which neither hardwoods nor conifers achieve a 66 percent dominance of the crown canopy composition.

4.1.2 Shoreline vegetation surveys

Clewell et al. (2002) compared vegetation distributions to salinity and other physical information for seven rivers including the Chassahowitzka. The Chassahowitzka River was sampled at 84 sites between September 1989 and March 1990. Vegetation was sampled by placing a 1.5 m by 3 m PVC frame on the bank of the river and estimating percent coverage within the frame. The short edge was placed at the most waterward plant stem. The long edge was extended toward shore. Observations of presence/absence were recorded for species within 2 m on either side of the quadrat, but not extending beyond the 3 m shoreward distance of the quadrat.

The District contracted Water and Air Research, Inc. (2018a [Appendix 10]) to update the shoreline vegetation mapping for the Chassahowitzka River System. In this effort, the entire shoreline within the LAMFE boundary was mapped. The shoreline was divided into 30 ft. segments extending 5 ft inland from the shoreline. Species presence/absence was noted along with dominance (> 50 % coverage) and codominance (2 or more species with > 25% coverage).

These more recently collected shoreline data are presented here in two ways. The first involves mapping of the shoreline in 30 ft segments as described above following the methods of Water and Air Research, Inc. (2018a). The second compares data across methods by attempting to modify the most recent data to match past data. This was done by identifying the quadrat locations from Clewell et al. (2002) and mapping all species identified in 2018 from the three closest 30 ft. segments to that quadrat location. Changes in distribution and abundance were difficult to discern given differences in sampling methods between the two surveys. Observed differences could be actual changes in vegetative distribution and abundance, but they could also be due to differences in survey methods.

Shoreline vegetation associated with hydric hammocks and freshwater stream margins found along the banks of the Chassahowitzka River in 2018 include red maple (*Acer rubrum*), sweetbay (*Magnolia virginiana*), southern wax myrtle (*Morella cerifera*), swamp bay (*Persea palustris*), and swamp laurel oak (*Quercus laurifolia*) (Figure 4-2.). These species are found primarily above Rkm 6 and are associated with FLUCCS code 615. In their earlier review of seven coastal Florida rivers, Clewell et al. (2002) ranked *Morella cerifera*, *Persea palustris*, and *Magnolia virginiana* as 16, 19, and 20 out of 24 common plants in terms of salt tolerance (*Acer rubrum* and *Quercus laurifolia* were not ranked).

Saltwater tolerant plants associated with downstream reaches of the Chassahowitzka River System include red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans)* and white mangrove (*Laguncularia racemosa*) (Figure 4-3.). There are no mangrove forests identified at the community level, and these plants are limited to areas identified as saltmarsh and other wetland forested mixed. It is common for mangroves to grow along the fringes of saltmarshes (Florida Natural Areas Inventory 2010).

The most common species were black needlerush (*Juncus roemerianus*), sawgrass (*Cladium jamaicense*), and cabbage palm (*Sabal palmetto*) (Water and Air Research, Inc. 2018a). Black needlerush was present throughout salt marsh vegetation from Rkm 1-5 in both 1990 and 2018 but was newly present in 13 sites while newly absent from only two sites (Figure 4-4.). Sawgrass was newly absent from Rkm 1 to the mouth of Crawford Creek, present in both surveys from Crawford Creek to the mouth of Salt Creek near Rkm 7, and newly present upstream from Salt Creek to Rkm 8.5 (Figure 4-4.).

Large changes in red mangroves (*Rhizophora mangle*) and smooth cordgrass (*Spartina alterniflora*) were noted by Water and Air Research, Inc. (2018a). These species are common inhabitants of salt marshes (Florida Natural Areas Inventory 2010). Smooth cordgrass was newly observed at a clear majority of sites from Rkm 1 to Rkm 7 (Figure 4-5.). Red mangrove was newly observed from Rkm 1 to Rkm 6 (Figure 4-5.). Mangroves occur near their northern limit in this area of the Florida coast. The mangrove community's ability to persist is dependent on surviving hard freezes. These new observations of mangroves are more likely linked to return frequency of freezing temperatures than to changes in salinity or any other factor.

Cabbage palm was newly present and abundant upstream of Rkm 5 (Figure 4-6.). Lack of previous observations of cabbage palm are likely due to changes in sampling methodology and emphasize the importance of this change in methodology. Southern red cedar was also noted for the first time and was common from Rkm 5 upstream to the head springs (Figure 4-6.).

In summary, freshwater plants are found in upstream areas of the Chassahowitzka River System, surrounded by hydric hardwood hammocks. Saltwater tolerant plants are found further downstream associated with saltmarshes. Sawgrass appears to have moved upstream, but this may reflect differences in survey methodology. Sawgrass is saltwater tolerant, but less so than black needlerush or smooth cordgrass. Black needlerush is located throughout saltmarsh areas and extends approximately 1 km into hardwood areas to Rkm 6. Saltmarsh cordgrass, red mangrove, cabbage palm, and southern red cedar all were found much more commonly in 2018 compared with their occurrence in the previous, 1990 survey. The most recent survey results are indicative of a diverse plant community at a dynamic but stable equilibrium that is reflective of the environmental gradient of the river system.

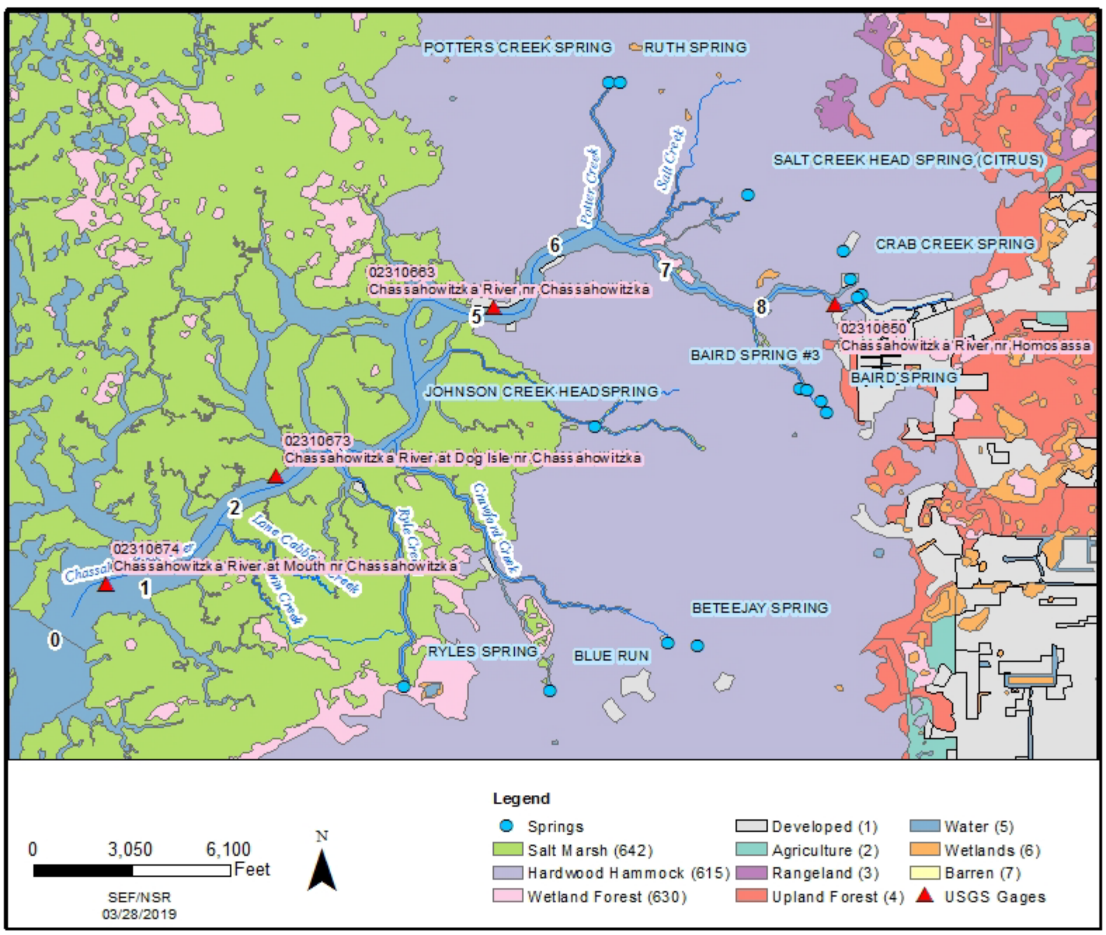


Figure 4-1. 2011 Land cover classification using FLUCCS codes (in parentheses).

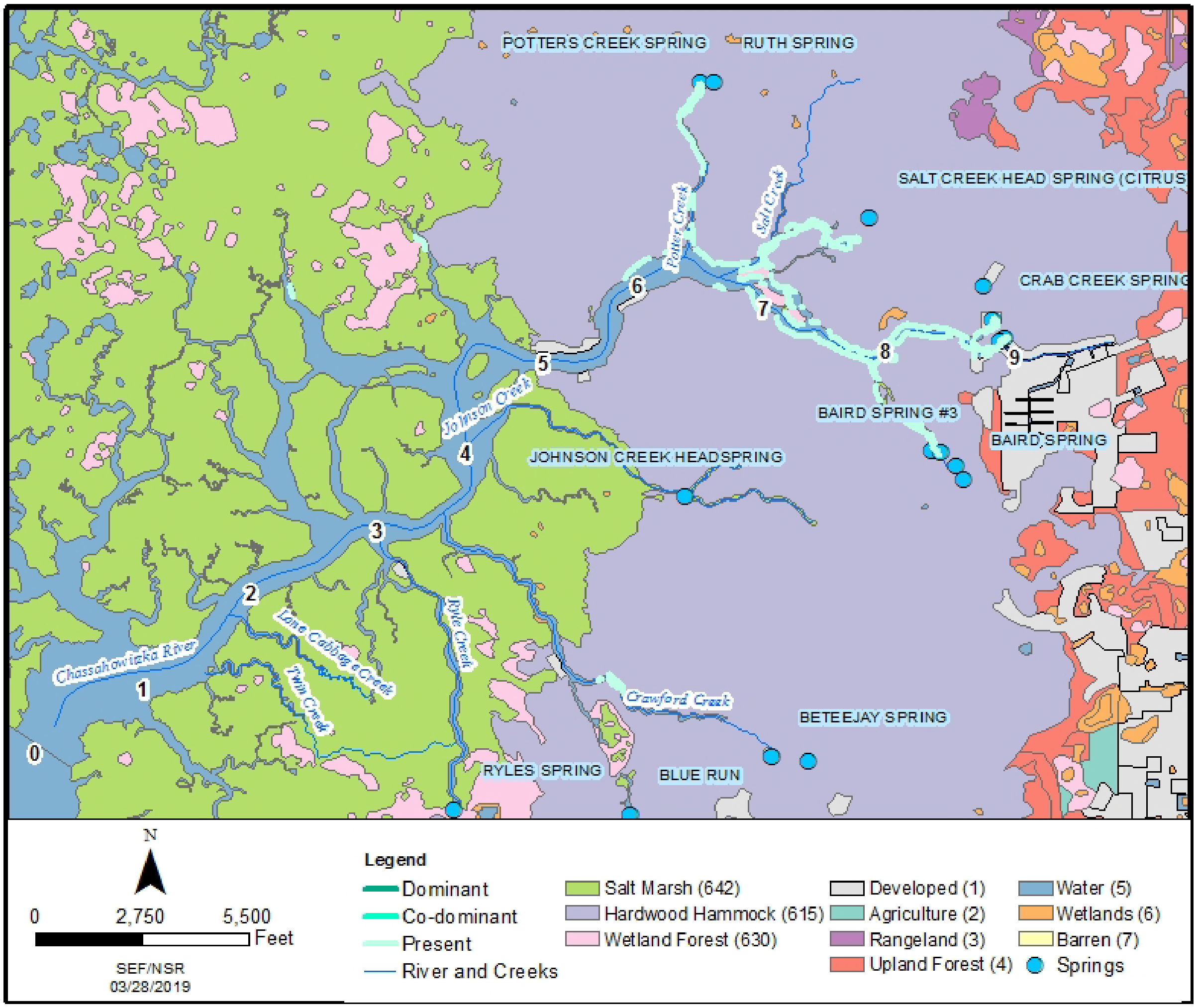


Figure 4-2. Tree species associated with freshwater stream margins and Hardwood Hammocks including red maple (*Acer rubrum*), sweetbay (*Magnolia virginiana*), southern wax myrtle (*Morella cerifera*), swamp bay (*Persea palustris*), and swamp laurel oak (*Quercus laurifolia*). 2011 Land cover classification using FLUCCS codes (in parentheses).

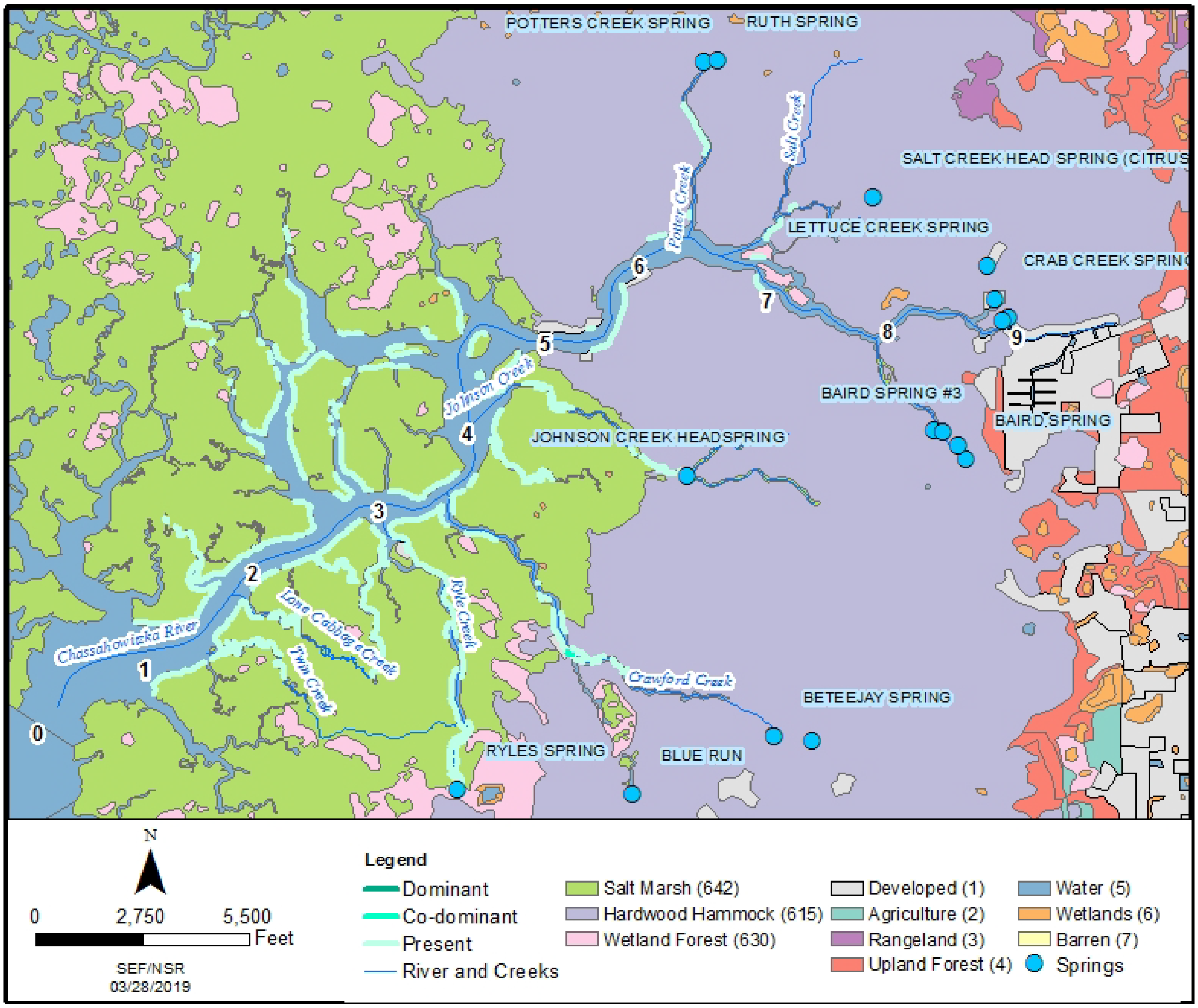


Figure 4-3. Distribution of red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemosa*) in 2018 survey. 2011 Land cover classification using FLUCCS codes (in parentheses).

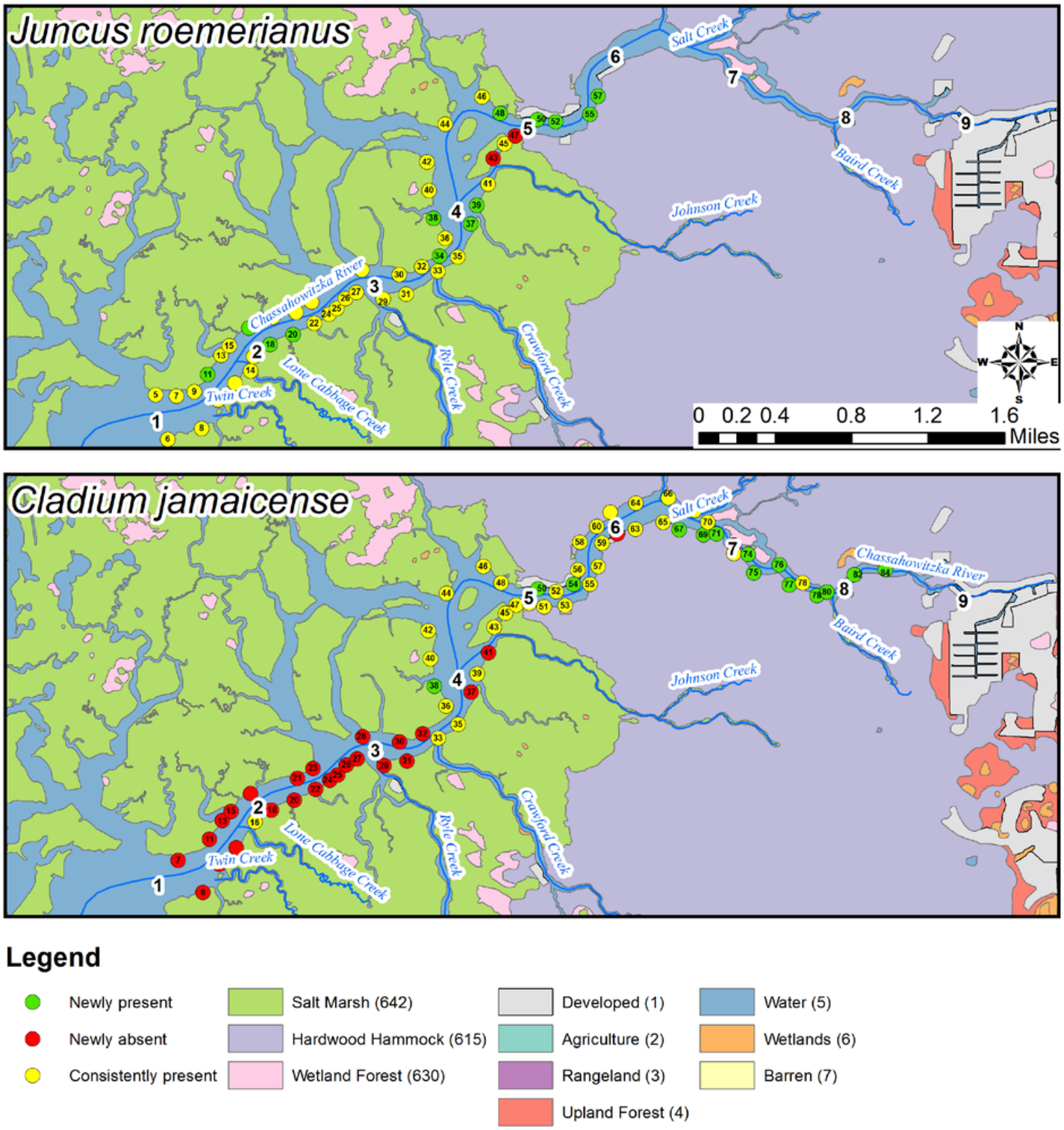


Figure 4-4. Changes in observations of black needlerush (*Juncus roemerianus*) and sawgrass (*Cladium jamaicense*) from 1990 and 2018 surveys. 2011 Land cover classification using FLUCCS codes (in parentheses).

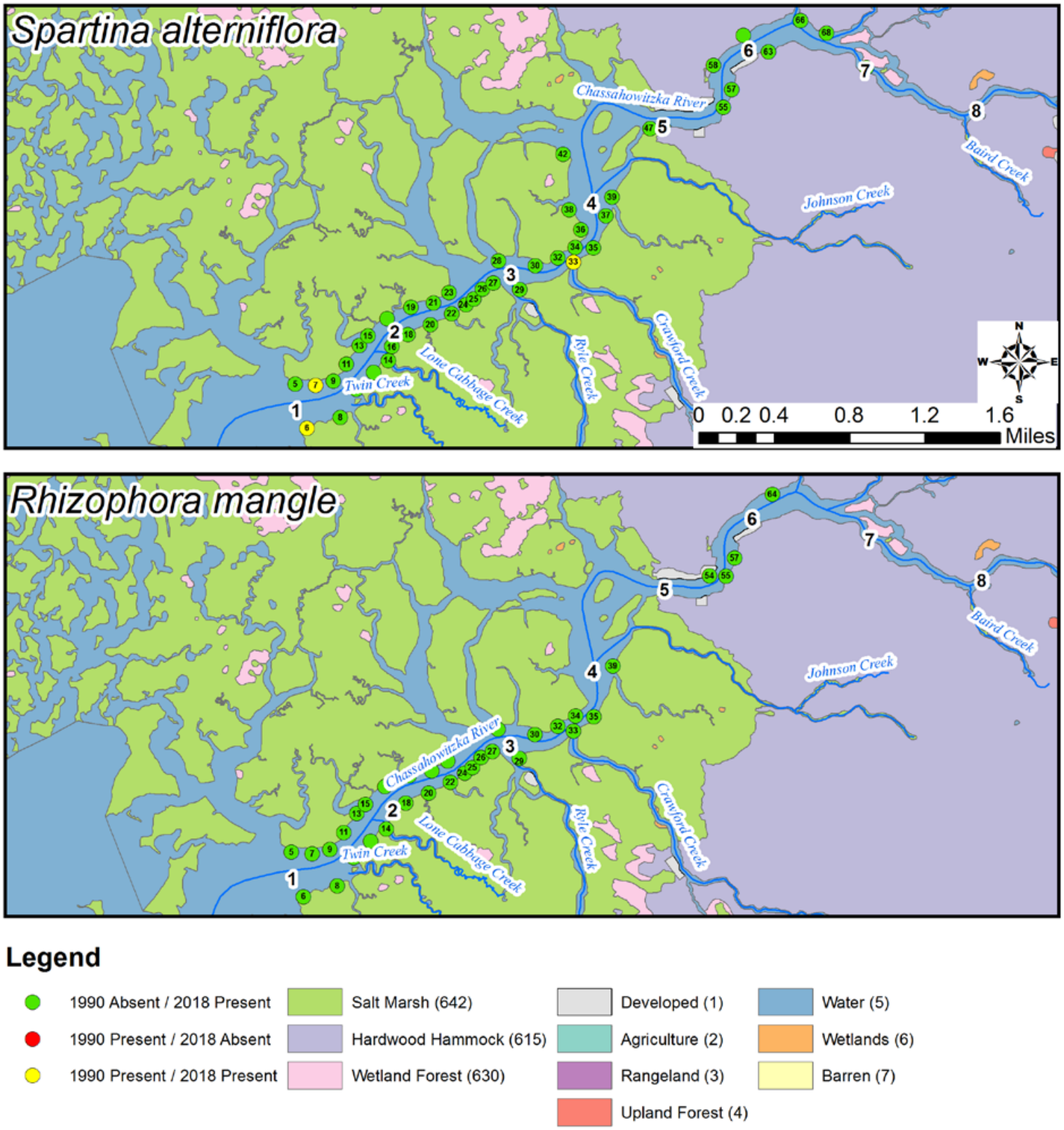


Figure 4-5. Changes in observations of saltmarsh cordgrass (*Spartina alterniflora*) and red mangrove (*Rhizophora mangle*) from 1990 and 2018 surveys. 2011 Land cover classification using FLUCCS codes (in parentheses).

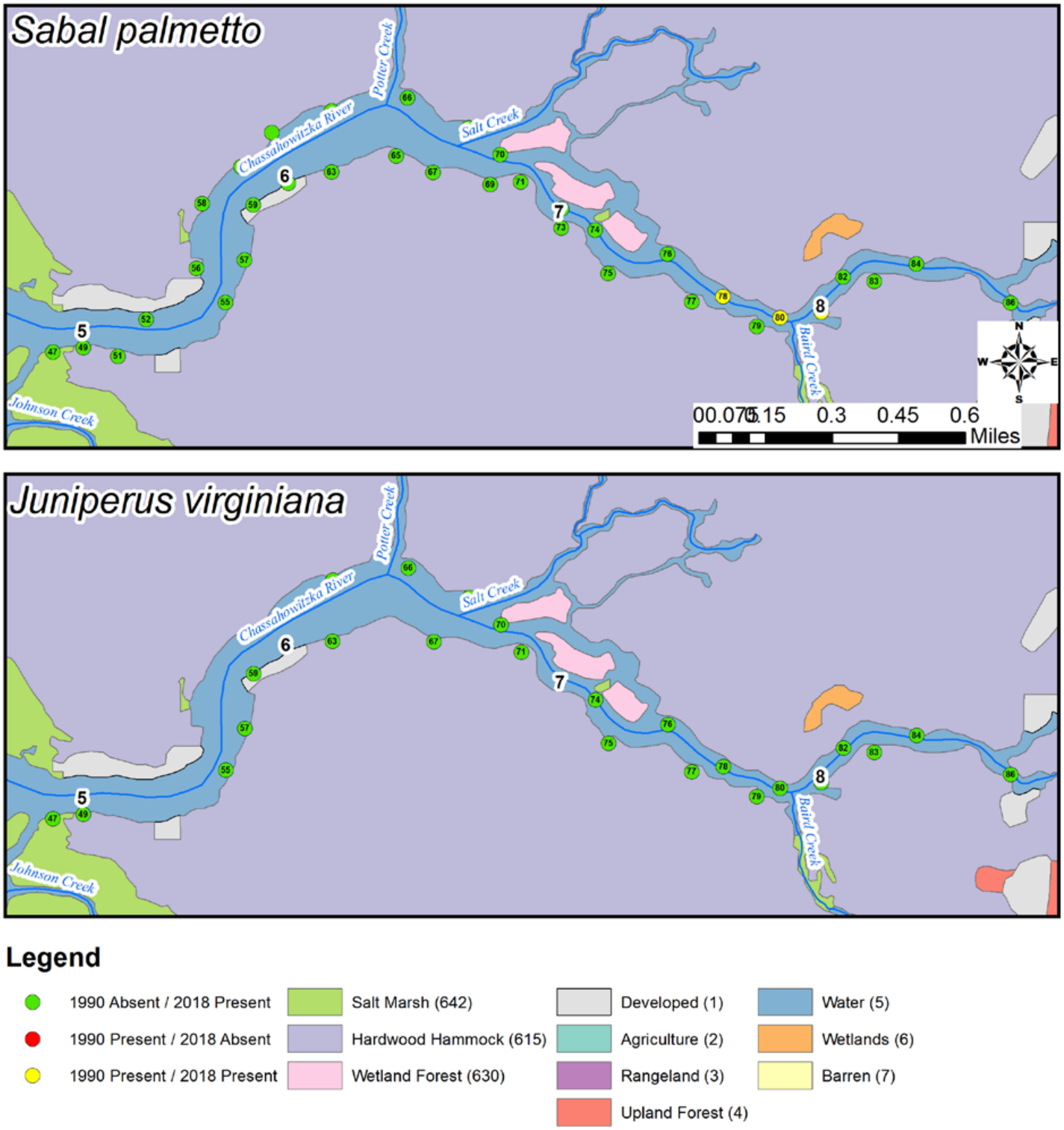


Figure 4-6. Changes in observations of cabbage palm (*Sabal palmetto*) and southern red cedar (*Juniperus virginiana*) from 1990 and 2018 surveys. 2011 Land cover classification using FLUCCS codes (in parentheses).

4.1.3 Submerged Aquatic Vegetation

Dixon and Estevez (1997) collected data on cover and abundance of submerged aquatic vegetation (SAV) at stations in the Gulf of Mexico and collected data on physical and chemical properties within the Chassahowitzka River from May 20 to May 22, 1996. The areas sampled in the gulf are outside our model domain and are relatively insensitive to changes in flow compared with locations within the river. Dixon and Estevez (1998) sampled SAV again from May 19-21 and on September 15-17, 1997. As before, the SAV sampling was conducted outside the entrance marker to the Chassahowitzka River. However, Dixon and Estevez (1997, 1998) state that beds of tapegrass (*Vallisneria*), pondweed (*Potamogeton* p*ectinatus, Potamogeton illinoensis)* and H*ydrilla* were visible at the confluence with Crab Creek. They also note floating mats of Enteromorpha-like algae, Eurasian water milfoil *(Myriophyllum spicatum),* and *Hydrilla verticillata* near Rkm 5. Toutant et al. (2004) note these were much reduced in May 2000, but they also did not quantify SAV within the river. Near Rkm 3 and Rkm 4, Dixon and Estevez (1997, 1998) note *Ruppia maritima* presence. Dixon and Estevez (2001) summarized findings from their two previous efforts.

Leverone (2006) surveyed macrophytes at 0.5km intervals from the mouth of the river to the headspring area. A transect was established at each interval and ten quarter-meter square quadrats were analyzed along each transect. Percent cover of each macrophyte species was measured using the Braun-Blanchet method. Macrophytes found included drift algae and rooted algae such as: *Hydrilla verticillata, Myriophyllum spicatum, Najas guadalupensis, Potamogeton pectinatus, Ruppia maritima, Vallisneria americana,* and *Zanichellia palustris.* Coverage varied by transect location and by quadrat location across transects. The purpose of this report was to collect, identify, enumerate and summarize the benthic communities within the Chassahowitzka River. There is no interpretative discussion or analysis of results given in Leverone (2006).

District interpretation of data provided in tables in Leverone (2006) is as follows (Table 4-1.). There are four main patterns of distribution of SAV in the Chassahowitzka River: organisms limited to saltwater (rooted algae are the only member of this group), organisms occupying the middle river (includes *M. spicatum* and *R. maritima*), organisms limited to freshwater, upstream areas (this includes *N. guadalupensis, P. pectinatus, V. americana*, and *H. verticillata*), and organisms ubiquitous throughout (drift algae). Drift algae were found throughout the river, while rooted algae were found from Rkm 0-1. Eurasian water milfoil (*Myriophyllum spicatum*) was found from Rkm 0.5 to 6.5 and at 9.0, and *Ruppia maritima* was found from Rkm 1 to 6.0, with three absences at 3.0, 4.5, and 5.5. These two species constitute the lower river SAV flora. *Zanichellia palustris* was found only at Rkm 6.5. Upper river SAV flora include 4 species (presence at Rkm): *Hydrilla verticillata* (7 – 9)*, Najas guadalupensis* (6.5 – 9)*, Potamogeton pectinatus* (6.5 – 9), and *Vallisneria americana* (6.5 – 7.5, 9). Greater than 80% of the bottom at Rkm 9 was covered in SAV.

The District contracted Applied Technology and Management (2016 [Appendix 3]) to collect SAV data in 2015 following methods developed by Frazer et al. (2001, 2006) so that results could be compared across years. Prior to the 2015 data collection effort, data on the vegetative community in the Chassahowitzka River were collected once each year for 1998 – 2000 and 2003 – 2011 using 20 transects with five stations on each transect -this is the Frazer et al. (2001, 2006) methodology (Figure 4-7.). No data were collected in 2001, 2002, 2012, 2013, or 2014. The SAV data that were collected included: biomass for total SAV, macroalgae, and angiosperms; bottom substrate type; percent of canopy shading; percent of total SAV cover. For 1998 – 2000, there are no percent total SAV cover data.

Frazer et al. (2001) sampled SAV in the Chassahowitzka River and compared results with four other rivers. Sampling of submerged aquatic macrophytes, macroalgae, and periphyton was conducted during the period August through September for each year of the project, 1998 – 2000. Macrophytes and macroalgae were sampled at 20 regularly spaced transects. Along each transect, five stations were sampled for submerged vegetation, with one in the middle and two to either side approximately one-third and two-thirds the distance to the shoreline. At each of the resulting 100 stations, a 0.25 m^2 quadrat was placed on the bottom and the above-ground biomass contained within the quadrat removed by divers and transported to the surface. These methods were repeated for the Chassahowitzka, Homosassa, and Weeki Wachee rivers in 2003 – 2011 and again in 2015 (Frazer et al. 2006; Applied Technology and Management 2016). Biomass of the flowering plant constituent of SAV varies with location downstream and exhibits considerable variation from year to year (Figure 4-8.). Algal biomass also varies by location and year (Figure 4-9.). Total flowering plant (angiosperm) biomass was significantly lower in 2015 compared with the average of years 1998 – 2011 (Applied Technology and Management 2016) (Figure 4-10.). Total SAV percent cover was also lower in 2015 than in 1998 – 2011 (Table 4-2.).

In 2015, SAV was found in all 20 transects (Figure 4-11.)(Applied Technology and Management 2015 [Appendix 2]). *Chaetomorpha* was found only at transect 5.25. Filamentous algae were most abundant upstream near spring heads. *Hydrilla verticillata* was most abundant near spring vents (Figure 4-12.). *Myriophyllum spicatum* was dense between transects 0.5 and 1.5 and scattered throughout the rest of the river. *Najas guadalupensis* was found throughout. *Potamogeton pectinatus* was found at 0.75, 1, and 7.5. *Ruppia maritima* and *Ulva* sp. where only found at a few sites (Figure 4-13.). *Vallisneria americana* showed a patchy distribution with centers of abundance around transect 1 and transect 5.5.

The District has continued monitoring SAV percent cover using the same transects as in Frazer et al. (2001), adding August 2017 to the data set (Figure 4-14.). Percent coverage and biomass appear to fluctuate from year to year. Therefore, findings at any particular point in time cannot be generalized to characterize the river as a whole or to infer long-term trends. The data on SAV in the Chassahowitzka River indicate a community that fluctuates in the distribution and abundance of its constituent species, and the declines in biomass or coverage in one year are often followed by recoveries in the following year.

Table 4-1. Species presence for SAV in the Chassahowitzka River modified from Table 3 of Leverone (2006). BARE = bare bottom, DRF = drift algae, ROOT = rooted algae, MYR = *Myriophyllum spicatum*, RUP = *Ruppia maritima*, ZAN = *Zanichellia palustris*, NAJ = *Najas guadalupensis*, POT = *Potamogeton pectinatus*, VAL = *Vallisneria americana*, HYD = *Hydrilla verticillata*. Braun-Blanquet coverage scores averaged across 10 quadrats per transect: X = 0.1 -1.4, XX = 1.5 – 2.4, XXX = 2.5 – 3.4, XXXX = 3.5 – 4.4, XXXXX = 4.5 – 5. At Rkm 9.0, all species were "very dense", bottom > 80% cover with SAV.

Rkm	BARE	DRF	ROOT	MYR	RUP	ZAN	NAJ	POT	VAL	HYD
0.0	X	XXX	XXX							
0.5	X	XXX	X	X						
1.0	XX	X	X	X	X					
1.5	X	XXX		X	X					
2.0	XX			X	X					
2.5	XXXX	X		X	X					
3.0	XXX	X		X						
3.5		X		X	XXX					
4.0	XX	X		X	X					
4.5				XX						
5.0		XXXX		X	XXX					
5.5		XXXXX		XX						
6.0	X	XXX		X	X					
6.5		XXXXX		X		XXXXX	X	X	XX	
7.0		X					XXX	X	XXXX	X
7.5		XXXX					X	XXX	X	X
8.0		X					X	XX		X
8.5		X					X	XX	X	XX
9.0				XX			XX	XX	XX	XX

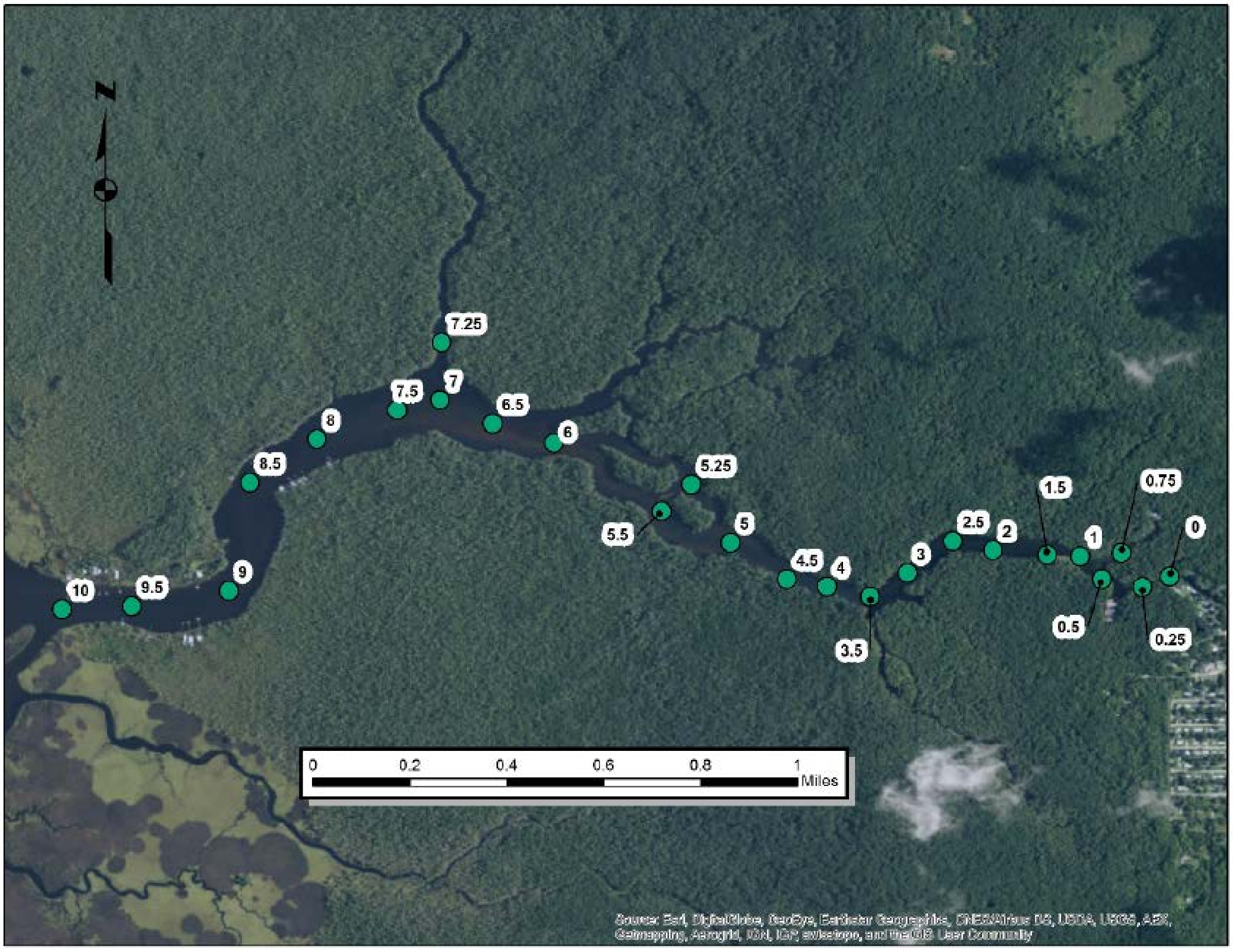


Figure 4-7. SAV transects in Chassahowitzka (Applied Technology and Management 2016). Transect 10 is approximately at Rkm 5, transect 7.5 at Rkm 6, transect 5.5 at Rkm 7, transect 3.5 at Rkm 8, and transect 0 at Rkm 9.

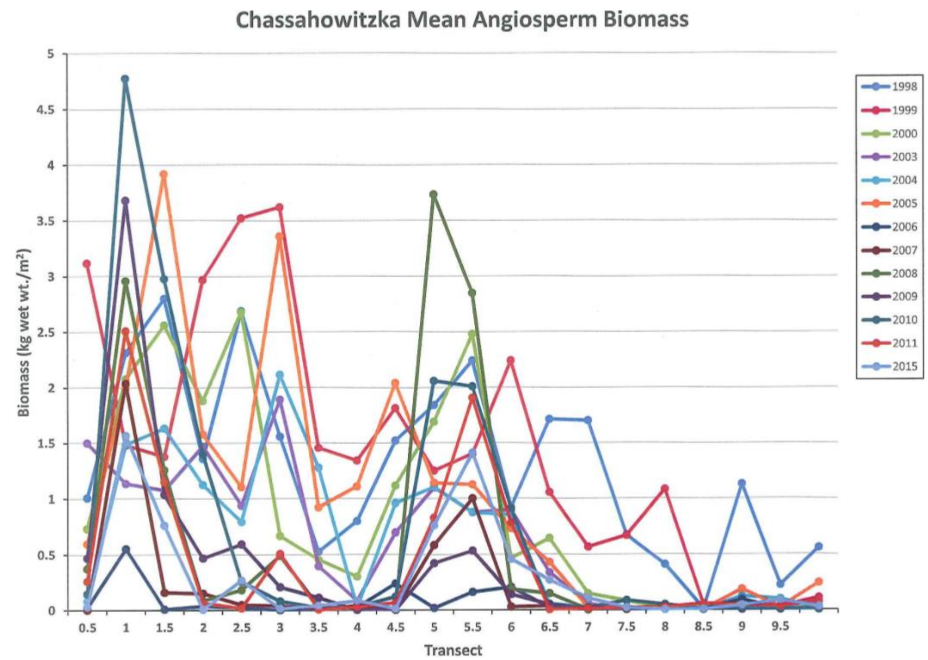


Figure 4-8. Chassahowitzka River flowering plant SAV biomass by transect from Applied Technology and Management (2016).

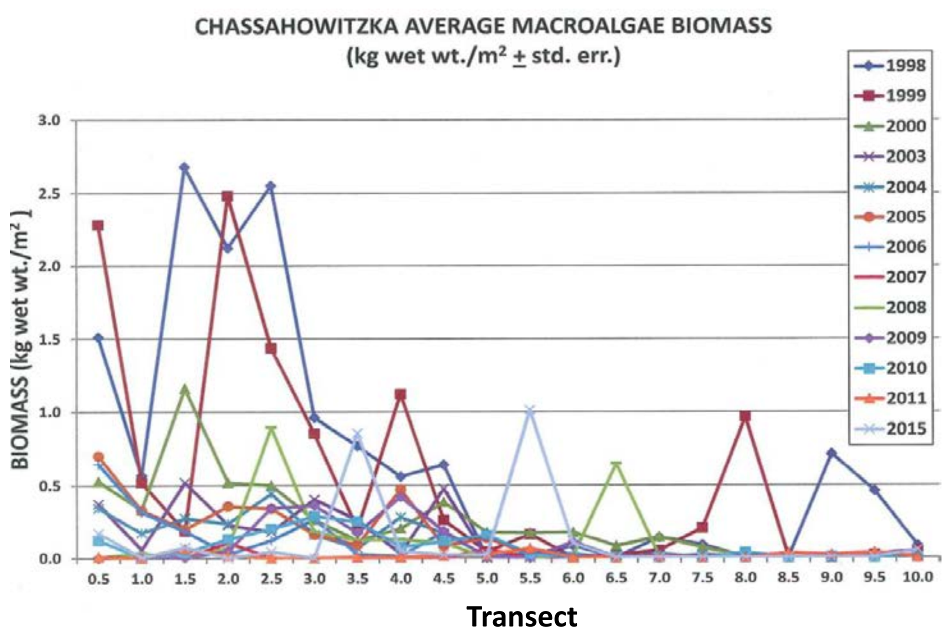


Figure 4-9. Chassahowitzka River algal SAV biomass by transect. Reproduced from Applied Technology and Management (2016).

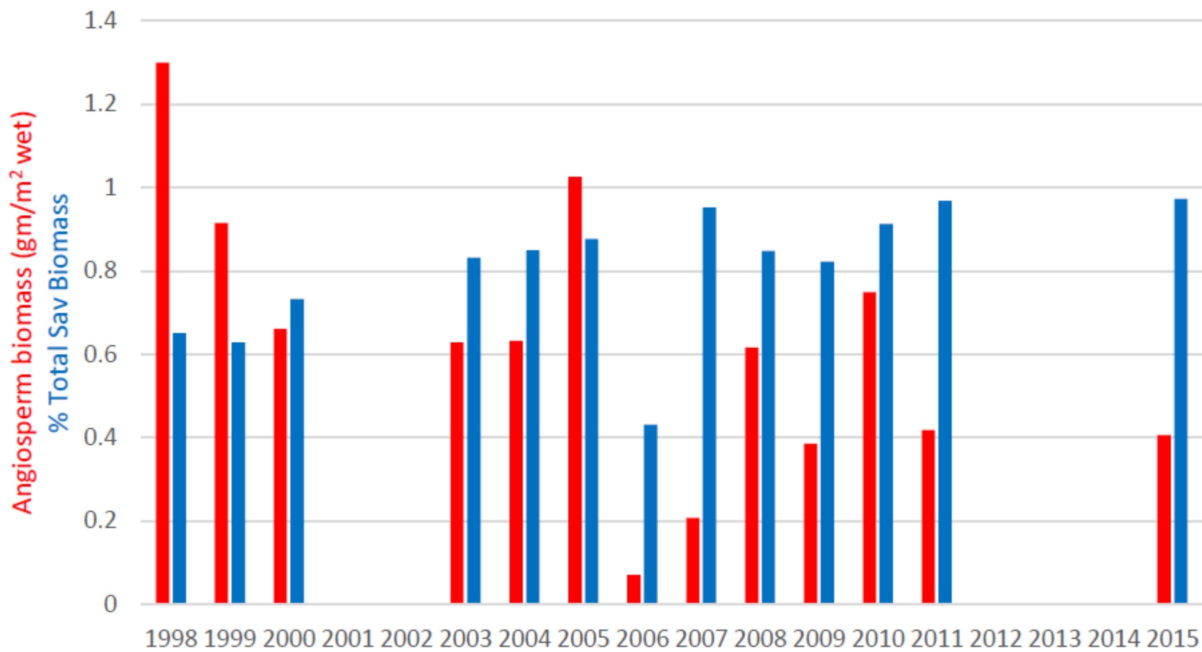
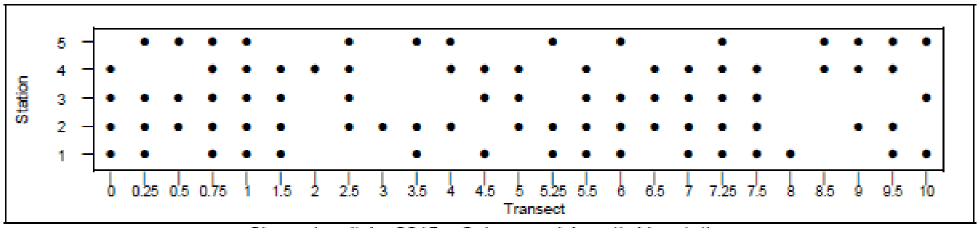


Figure 4-10. Total annual biomass of SAV in the Chassahowitzka River. Reproduced from Applied Technology and Management (2016).

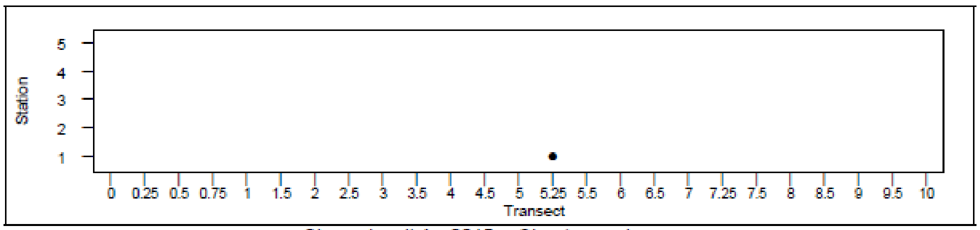
Table 4-2. Comparison of percent cover in 2015 with previous years.

2003-2011 Total SAV % Cover	2015 Total SAV % Cover	Difference: 2003-2011 minus 2015	% Increase/Decrease
30.34*	25.67*	4.67	-38.90%

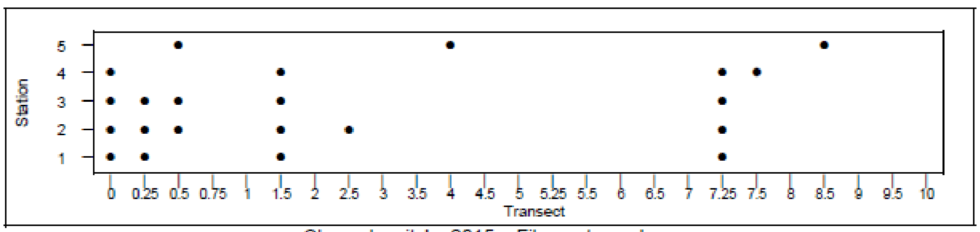
* statistically significant difference with at least 95% confidence



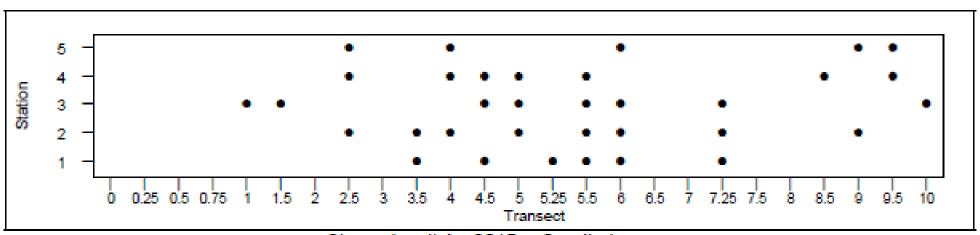
Chassahowitzka 2015 – Submerged Aquatic Vegetation



Chassahowitzka 2015 – *Chaetomorpha* sp.

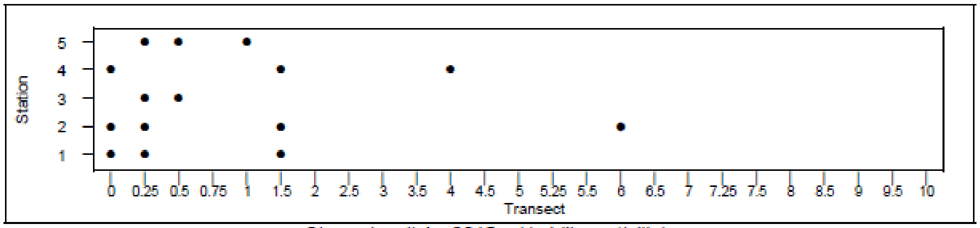


Chassahowitzka 2015 – Filamentous algae

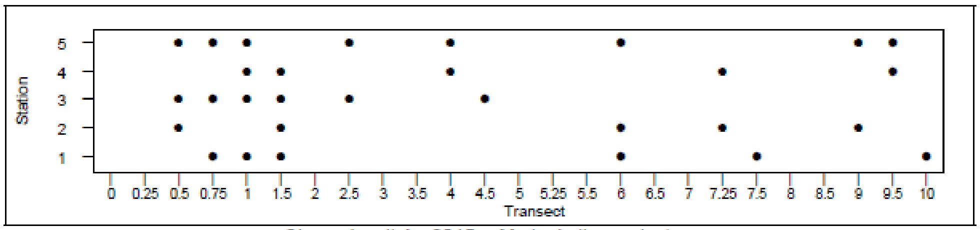


Chassahowitzka 2015 – *Gracilaria* sp.

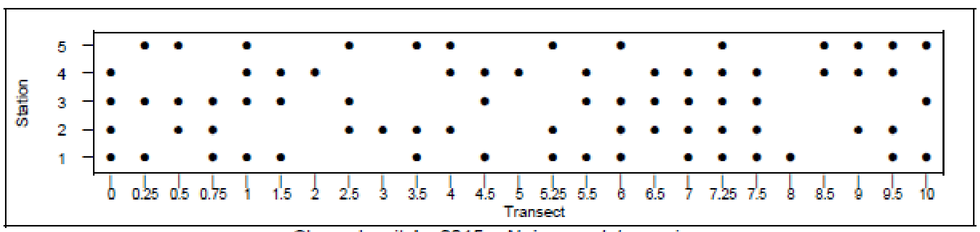
Figure 4-11. Part 1, SAV in Chassahowitzka in 2015. Transect 10 is downstream at approximately at Rkm 5, transect 7.5 at Rkm 6, transect 5.5 at Rkm 7, transect 3.5 at Rkm 8, and transect 0 is furthest upstream at Rkm 9. Points show presence.



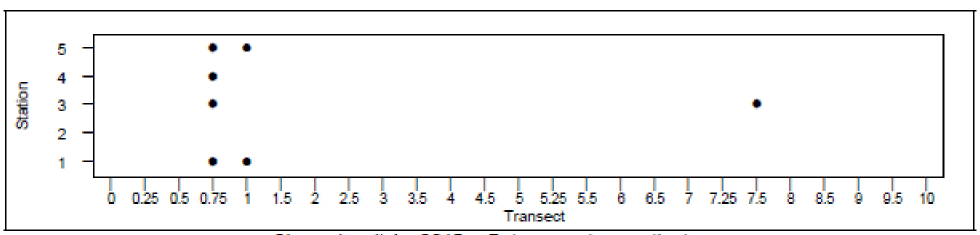
Chassahowitzka 2015 – *Hydrilla verticillata*



Chassahowitzka 2015 – *Myriophyllum spicatum*

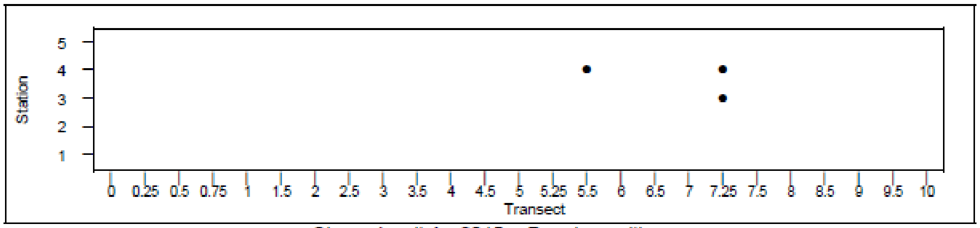


Chassahowitzka 2015 – *Najas guadalupensis*

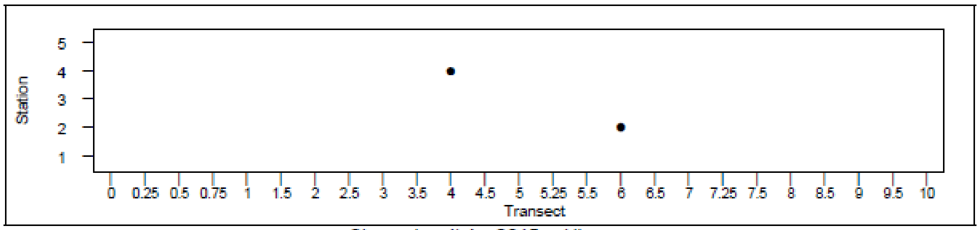


Chassahowitzka 2015 – *Potamogenton pectinatus*

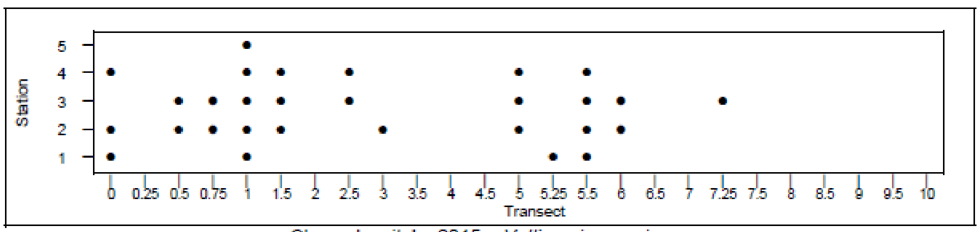
Figure 4-12. Part 2, SAV in Chassahowitzka in 2015. Transect 10 is downstream at approximately at Rkm 5, transect 7.5 at Rkm 6, transect 5.5 at Rkm 7, transect 3.5 at Rkm 8, and transect 0 is furthest upstream at Rkm 9. Points show presence.



Chassahowitzka 2015 – *Ruppia maritima*



Chassahowitzka 2015 – *Ulva* sp.



Chassahowitzka 2015 – *Vallisnaria americana*

Figure 4-13. Part 3, SAV in Chassahowitzka in 2015. Transect 10 is downstream at approximately at Rkm 5, transect 7.5 at Rkm 6, transect 5.5 at Rkm 7, transect 3.5 at Rkm 8, and transect 0 is furthest upstream at Rkm 9. Points show presence.

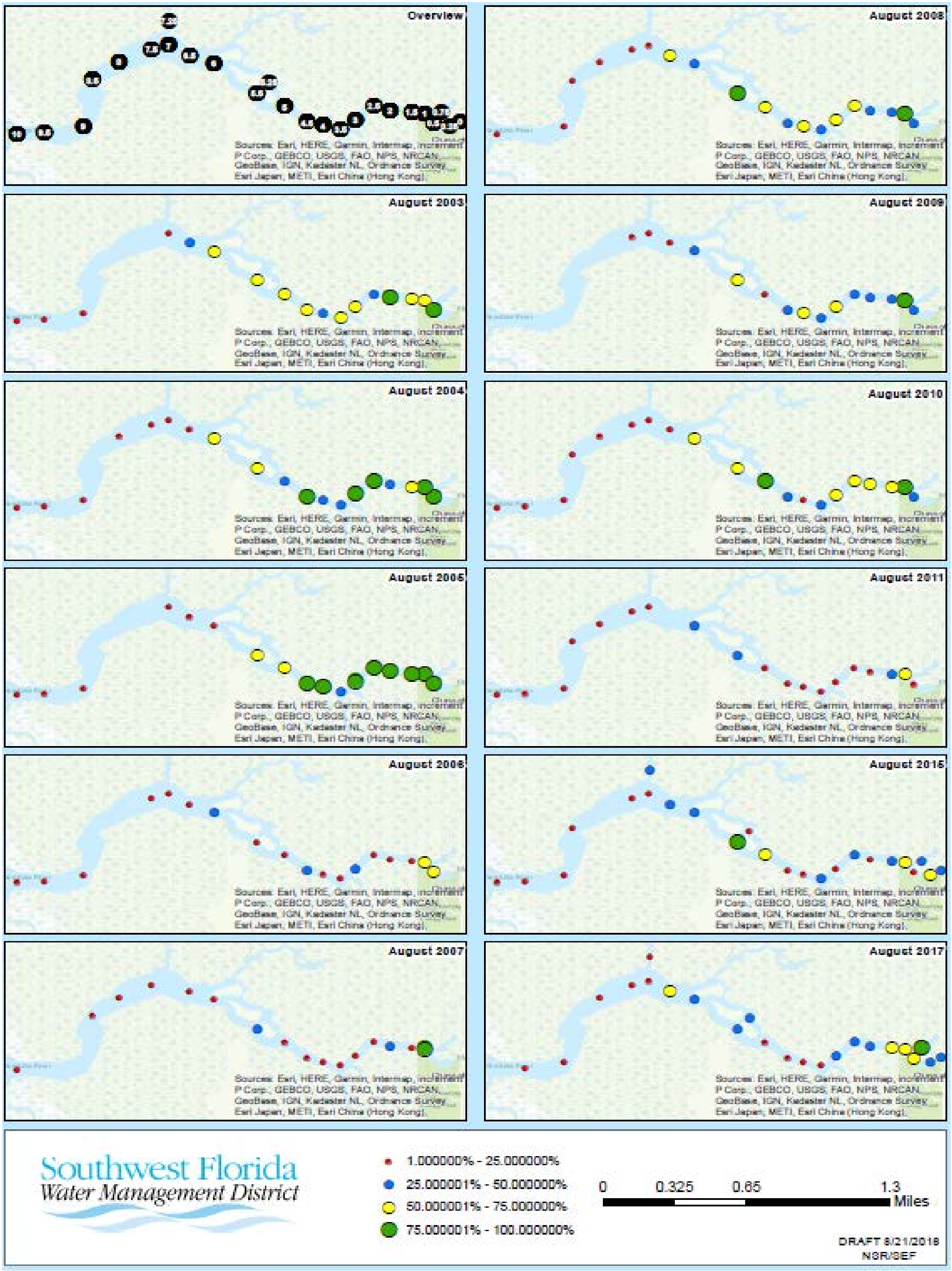


Figure 4-14. Percent cover of all SAV at 20 transects in the Chassahowitzka River following sampling design of Frazer et al. (2001). Data includes all samples from Frazer et al. (2001, 2006), ATM (2016), and additional data collected in 2017 and 2018.

4.1.4 Effects of Salinity and Sea Level on Vegetation

Shoreline and emergent plant species distributions are limited by a combination of salt stress tolerance and competition (Crain et al. 2004). Both saltwater plants and freshwater plants tend to flourish when grown alone in fresh water. However, freshwater plants outcompete saltwater plants when in combination. Saltwater plants are able to tolerate salt stress better than freshwater plants. Therefore, aquatic and semi-aquatic plant zonation in many coastal rivers is caused by a combination of competitive displacement in freshwater reaches and stress tolerance in saltwater reaches.

In seven Florida river estuaries, distribution of shoreline vegetation is linked to salinity (Clewell et al. 2002). Plants with increasing salt tolerance are seen closer to river mouths. There is a consistent pattern of transitions from less salt tolerant species to more salt tolerant species as one travels toward the Gulf of Mexico on these coastal rivers. However, salinity is not the only driver of community composition. Competition and disturbance also play roles in determination of which species are found in any location. Moreover, salinity varies in time over tidal periods, over years, with rainy years resulting in lower salinities, and with storms which drive higher salinities landward during storm surges. These factors combine to affect the zonation apparent in shoreline vegetation.

Freshwater hardwoods in the Chassahowitzka River System are restricted to the upper reaches where exposure to higher salinities is limited by elevation and freshwater input (Figure 4-2.). Salt tolerant species are limited to saltier reaches where their stress tolerance allows them to proliferate without competition from less tolerant species (Figure 4-3.). Thus, it is important to manage salinity habitat for emergent and shoreline species, as shifts in salinity habitat are predicted to result in salt stress at the individual level and alter shoreline habitats at the community level.

Sea level rise has led to the invasion of marsh grasses into the lower parts of the hammock islands that dot salt marshes on the Gulf coast of Florida. The presence of former islands is marked by groups of trunks of dead cabbage palms (the most salt tolerant of the upland trees) standing in the middle of what is now salt marsh (Williams et al. 1999). Die-offs of cabbage palm and red cedar in coastal hydric hammocks near Waccasassa Bay have been attributed to sea level rise and storm events. Sea level rise causes chronic stress and limits regeneration, while storm events produce acute stress and kill adult trees (Williams et al. 2003).

Sea level rise has resulted in expansion of marshes and decrease in area of forested wetlands in Gulf coast of Florida, with forest retreat reduced in areas with greater freshwater input (Raabe and Stumpf 2015). Sea level rise and drought are responsible for declines in coastal hydric hammocks, in particular *Sabal palmetto* and *Juniperus virginiana* distribution and abundance (DeSantis et al. 2007). Continued sea level rise is expected to result in continued loss of habitat and declines in spatial abundance of species and the communities they form. Castaneda and Putz (2007) documented a 17.5% decrease in coastal forest area in the Waccasassa Bay State Preserve between 1973 and 2003; these forests were replaced by salt marsh. Sea level rise is expected to continue this trend of forest loss and conversion to salt marsh (Doyle et al. 2010).

The effect of sea level rise on SAV will likely result in the upstream migration of species. Sea level rise will result in increased salinity as salinity increases towards the springs. If SAV are limited to locations less than 3.5 ppt as indicated by Hoyer et al. (2004), then SAV distribution will move to match the lower salinity waters as they move these waters become restricted to the upstream portions of the rivers. Increased sea level and salinity will also affect depth and clarity, which affect light attenuation. Hoyer et al. (2004) found that SAV was located only where greater than 10% of light reaches the bottom. Therefore, sea level rise will affect SAV through increased salinity and decreased light penetration.

4.1.5 Vegetation Summary

Natural communities surrounding the Chassahowitzka River System include upland forests, freshwater forested wetlands, salt marshes, and coastal forests. These communities, and their constituent species are constrained by their tolerance for abiotic factors including frequency and duration of inundation and exposure to salinity. The vegetative species occupying the shoreline of this system were mapped in 1989-1990, and this mapping was repeated in greater detail and extent in 2018. These species each have ranges of salinity tolerance that dictate where they are found. Changes to the salinity regime are expected to shift the composition of species bordering the Chassahowitzka River and its tributaries.

Submerged aquatic vegetation in the Chassahowitzka River shows annual fluctuations in biomass and coverage. SAV also shifts seasonally, thus the SAV community may respond to and recover from disturbance more readily than terrestrial plant communities.

Sea level rise has caused die-off of *Sabal palmetto*, *Juniperus virginiana*, and their coastal hydric hammock community along Florida's Gulf coast and elsewhere. Net loss of coastal forests in the region and conversion of forests to salt marsh are expected to continue with sea level rise, but some of these changes may be mitigated by continued freshwater input to the system.

4.2 <u>Benthic Macroinvertebrates</u>

4.2.1 Oysters

The District contracted Water and Air Research Inc. (2018b [Appendix 11]) to survey oysters in the Chassahowitzka River in 2018. The sampling protocol was focused on assessing oyster condition at representative sites along the river with the goal of determining physical, chemical, and biological determinants of oyster distribution, abundance and health (Water and Air Research, Inc. 2018b). A condition index, which is a relative measure based on the ratio of tissue mass to internal volume was used to assess oyster health (Water and Air Research, Inc. 2018b and references therein). The oyster sampling effort was not a comprehensive mapping survey. Rather, oyster bars were identified and mapped using aerial photographic interpretation that was complemented with visual field surveys and ground-truthing (Water and Air Research, Inc. 2018b).

Oyster bars were found from Rkm 0 to Rm 5 and grouped into three sampling groups or zones for condition index determinations (Figure 4-15.). Oysters in sampled bars averaged 21 alive out of 25 sampled (86 percent), with 561 per 10 x 10 cm quadrat. There were no statistically significant differences in oyster density or percent living between the three sampling zones. However, oyster condition index differed among groups, with a median zone C index value (7.6) significantly greater than those determined for zones B (6.6) and A (6.8). Zones A and B did not have significantly different condition indices. Zone C was the most downstream oyster sampling area with the highest salinity. This suggests that oyster condition is greatest at salinities higher than those found throughout most of the Chassahowitzka River.

4.2.2 Barnacles

Similar to the oyster effort, barnacles were surveyed to find representative sites along the river but were not comprehensively mapped. Barnacles were searched for on existing hard substrates within every Rkm and sampled if they were present on suitable substrate. Areas with suitable substrate, but with no or few barnacles present were located and recorded with a GPS. Only intertidal or shallow subtidal areas were searched visually from the boat or by walking along the shoreline.

Examples of locations surveyed include navigation aids, signs, docks, seawalls, and trees. At 8 sample collection sites, 25 barnacles within a 10 by 10 cm quadrat were measured and assessed as live or dead (Figure 4-16.). All barnacles within the quadrat were then collected for laboratory measurement. The number of barnacles at each location ranged from 9 to 40. Three upstream sites were considered oligohaline and 3 downstream sites were mesohaline. There were no statistical differences in number, percent alive, diameter, dry weight, and percent organic matter between oligohaline and mesohaline sites. There was an average of 20 barnacles per 100 cm^2, 77 percent of which were alive, with a mean diameter of 6.5 mm.

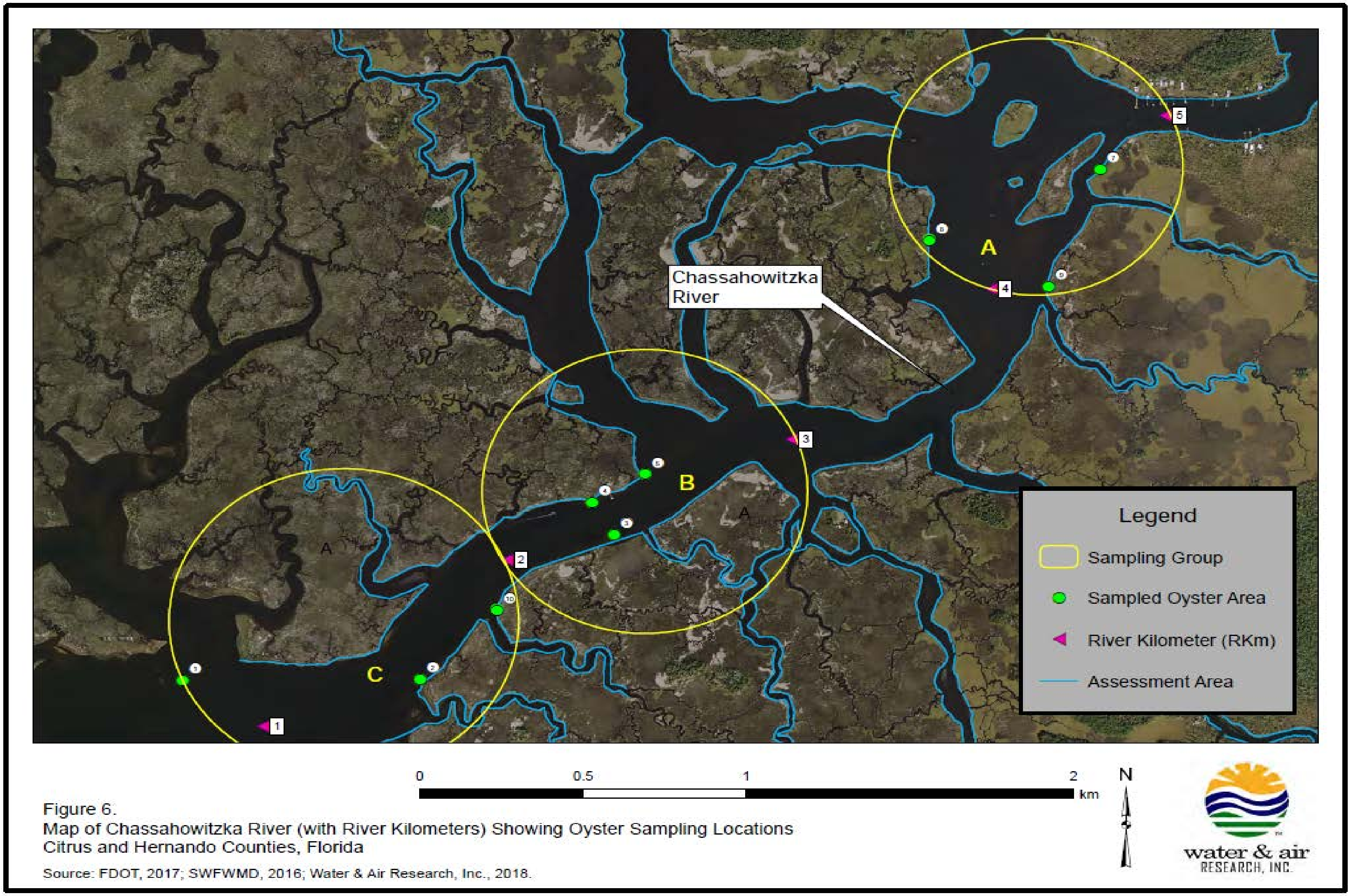


Figure 4-15. Oyster bar locations in the Chassahowitzka River and sampling groups used for condition index assessments.

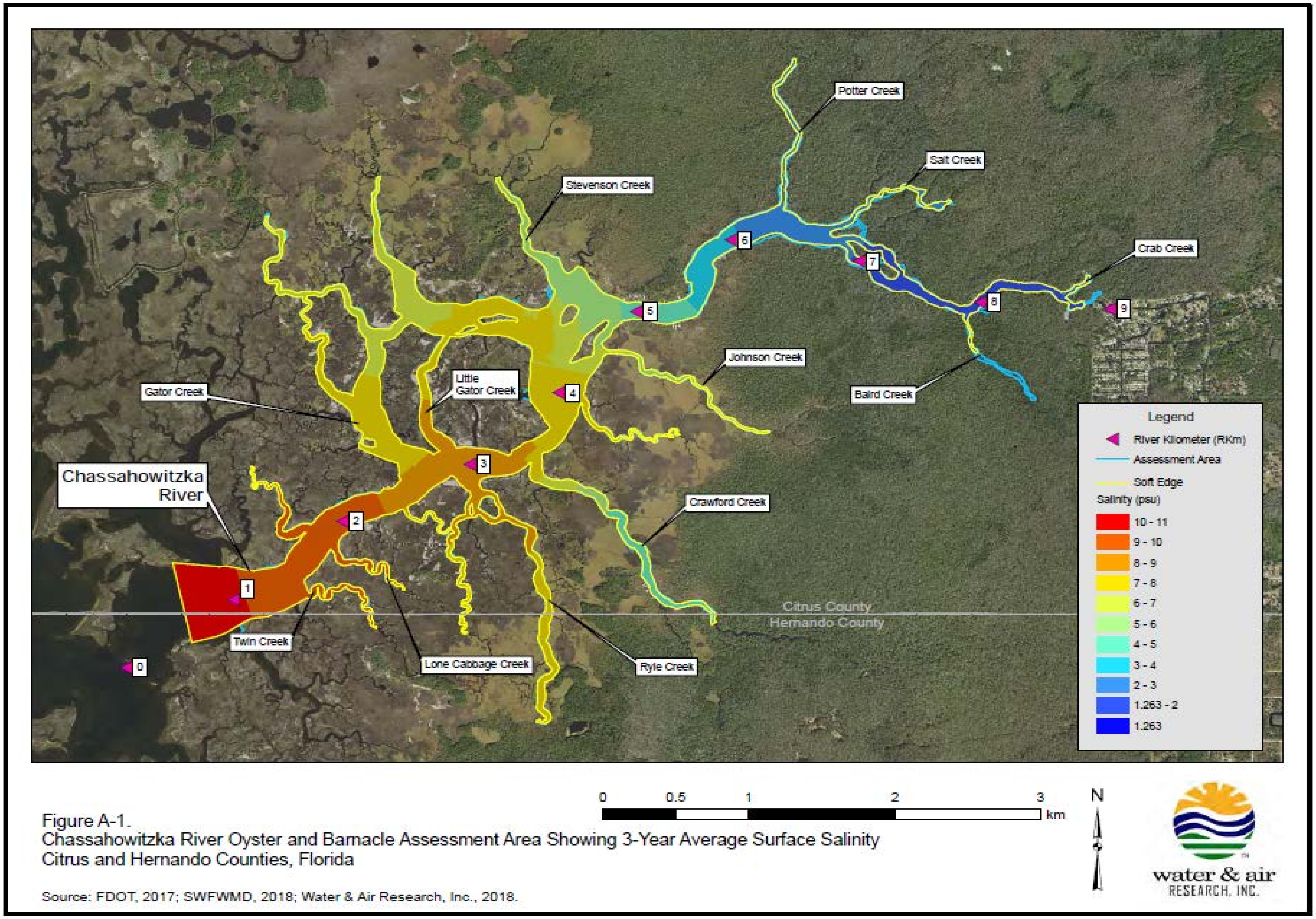


Figure 4-16. Barnacle sampling locations in the Chassahowitzka River.

4.2.3 Blue Crab

The Blue Crab, *Callinectes sapidus*, is an ecologically and economically valuable estuarine-dependent species that can be found from the waters of Argentina in the southern hemisphere to Massachusetts in the northern hemisphere. Blue Crabs use a wide range of habitats depending on the physiological requirements of each stage of their life cycle. Their life cycle includes planktonic, nektonic, and benthic stages. Mating occurs inshore, in low-salinity waters (<15 psu), where juvenile females undergo their pubertal molt, mate with mature males, and then migrate offshore (higher salinities; >30 psu) to spawn (Gandy et al. 2011). In Florida, Blue Crab mating occurs during spring and summer; although mating has been recorded in fall and winter months with spawning delayed until the following spring or when water temperatures rise to 19°C. March to November are also the months when Blue Crab megalopae (one of their planktonic stages) return from oceanic waters into the estuaries through tidally-related vertical migration. Once in the estuary, they settle in marshes and SAV for their metamorphosis into first-crab stage. Although early juveniles can be found in lower bay sites, large juveniles have been reported in lower-salinity waters, which suggests an upstream migration into oligohaline marshes and SAV beds (Gandy et al. 2011).

The FWC is the authority responsible for managing Blue Crab harvesting in Florida. Female Blue Crabs may be harvested lawfully if they are not bearing eggs. Since female Blue Crabs can only mate once, releasing them unharmed will help support the Blue Crab population (visit myFWC.com for fisheries regulations). Although fishing rates and Blue Crab landings in the state of Florida have been on a general downward trend since the 1990s, the predicted stock status does not suggest either coast of Florida to be overfished or undergoing overfishing (Cooper et al. 2013). Fisheries-independent studies also report steady trends in juvenile and adult stocks (FWRI-FIM 2016). It has been noted that Blue Crab stocks in the Eastern Gulf of Mexico (i.e., Florida) generally peak in years following high rainfall (GDAR 2013, FWRI-FIM 2016).

Over the course of several decades, FWC and the University of South Florida have conducted numerous studies relating abundance, location, and community dynamics to freshwater inflow. Gandy et al. (2011) summarized the results and discussed the limitations of these and other regional studies. No consistent direct relationships between Blue Crabs and quantity of freshwater flow have been found. Of particular concern is the fact that in the Chassahowitzka River, Blue Crab nekton decreased with increasing flow, while the opposite response was detected in the Homosassa River system (Peebles et al. 2009). Results from 12 years of fish and invertebrate sampling in the Alafia River showed that an abundance/flow regression approach with 2-5 years of data is insufficient to quantify a consistent predicable response (Wessel 2012). Wessel (2012) evaluated a moving 2-year window of sampling results for several taxa commonly found in west Florida tidal rivers. This report found that for a given taxa there was little consistency in the predicted number of organisms as a function of flow and response reversed often. Wessel (2012) notes that “only with at least 4 years of data collection did the slope estimates tend to stabilize toward a particular direction, and in several instances, 4 years of data was not enough to achieve statistical significance.” Wessel (2012) added that “together, these issues regarding the existing analytical methods to establish the fish-flow relationship revealed that more work was needed to describe the effects of freshwater inflows on fish abundance in tidal rivers”. Similarly, a literature review by the Gulf States Marine Fisheries Commission (GDAR 2013) suggests that studies showing positive relations to freshwater inflows used long-term, life-history based data, over a larger spatial component, while results with negative relations were generated when using data from an individual river.

The endangered Whooping Crane (*Grus americana*) overwinters in the southeastern United States, including the Chassahowitzka National Wildlife refuge in Florida (WCEP 2016). Recognizing that the Blue Crab is an important food source for these endangered birds, the District contracted with FWC to review the local relationships between Blue Crab and freshwater inflows (Gandy et al. 2011). Blue Crab population dynamics are dependent on many factors including nutrient loading, productivity, pollution, predator displacements, and their effects on habitat (Gandy et al. 2011). Alterations in freshwater inflows have the potential to impact available habitat for Blue Crab life stages, through alterations to salinity zonation (Gandy et al. 2011). Therefore, ensuring there are no significant changes to salinity habitats will protect Blue Crab populations from adverse effects of reduced flows on salinity.

4.2.4 Historical Surveys of Macroinvertebrates

The invertebrate fauna of the Chassahowitzka and other nearby rivers has been sampled on numerous occasions by various research groups. These studies have shown that there is a diverse assemblage of macroinvertebrates including crustaceans, mollusks, and insects in the river. Studies have also shown that benthic macroinvertebrate taxa are sensitive indicators of salinity.

4.2.4.1 Other Rivers

In the nearby Homosassa River, Sloan (1956) collected insects using dip net sampling every six weeks from November 1952 to February 1954. Representative species of the orders Diptera (flies), Ephemeroptera (mayflies), Trichoptera (caddisflies), Hemiptera (true bugs), Coleoptera (beetles), Lepidoptera (butterflies and moths), and Odonata (dragonflies). Species richness (number of species) and abundance (total number of insects) were low at the pool – correlating with low dissolved oxygen concentration, increased in the run immediately downstream of the pool, and decreased downstream toward the estuary – which correlates with the longitudinal salinity gradient.

Janicki Environmental Inc. (JEI 2007) conducted a meta-analysis of invertebrate sampling efforts in 12 rivers on the gulf coast of Florida: Peace River, Shell Creek, Myakka River, Manatee River, Little Manatee River, Alafia River, Tampa Bypass Canal, Lower Hillsborough River, Weeki Wachee River, Crystal River, Withlacoochee River, and the Waccasassa River. They found the polychaete *Laeonereis culver* and the isopod *Edotea triloba* in greater than 90 percent of these rivers, and the amphipod *Grandidierella bonnieroides*, the polychaete worms *Streblospio gynobranchiata* and *Paraprionospio pinnata*, and the bivalve *Amygdalum papyrium* in more than 80 percent of the rivers. Communities were able to be grouped by geographical locations. Communities were also grouped by salinity classes, with midges of the family Chironomidae and worms of the class Polychaeta and of the subclass Oligochaeta common at salinities less than 8 ppt. Community structure appeared to be influenced by salinity and sediment type. The authors concluded that complex models that deal with issues of high-level interactions and non-linearity tend to yield complex solutions which do not yield straightforward management actions. In other words, when simple linear relationships between organisms and flow are not found, searching for more complex analytical relationships will not yield the simple linear trends that were originally sought.

Montagna et al. (2008) conducted a meta-analysis of data on salinity and mollusks in 10 southwest Florida rivers. They parameterized nonlinear regressions to predict mollusk abundance from salinity. Results indicate that all rivers had different communities of mollusks due to differing salinity regimes. The authors assert that freshwater inflow, which controls salinity, is an important determining factor for species presence and abundance. Species demonstrated strong preferences for salinity ranges, allowing for grouping into oligohaline, mesohaline, and polyhaline zones. The invasive bivalve *Corbicula fluminea* was the best indicator of freshwater habitat. They conclude that mollusk assemblages will change in response to changing salinity regimes as a result of alterations to freshwater inflow.

4.2.4.2 Chassahowitzka Benthos

Estevez (2007) conducted a mollusk survey of the Chassahowitzka River using rapid survey techniques. The mollusk fauna in the river is similar to that of other area systems, in terms of species composition, but is reduced in diversity because marine influences do not extend from the Gulf of Mexico into the river. In terms of species abundance, the American oyster, *Crassostrea virginica*, was the most common native species.

Frazer et al. (2011) sampled at five stations each on 3 reaches in the Chassahowitzka and Homosassa rivers in 2007, 2008, 2009, and 2010. The density and biomass of invertebrates associated with SAV was greatest during winter sampling periods when filamentous algae biomass was high (Figure 4-17.). Many taxa demonstrated a higher abundance during periods with high biomass of filamentous algae, with the exception of insect larvae and pupae. Insect density and biomass was similar across all sampling periods in the Chassahowitzka River; however, Frazer et al. (2011) observed a relatively high biomass of insects in the Homosassa River during February 2008 when filamentous algae mats were prevalent. Insects, particularly chironomids, were abundant in both filamentous algae and macrophyte samples, which may explain why density and biomass remained high during summer periods in the Chassahowitzka River which provides year-round SAV habitat. Of the taxa measured in invertebrate samples, amphipods and blue crabs demonstrated the greatest biomass, with peak biomass occurring during winter periods (Figure 4-18.). Additionally, blue crabs demonstrated an increase in biomass during May and June, coincident with large-scale production of filamentous algae in the Homosassa River. One surprising result was the observed increase in density and biomass of gastropods associated with filamentous algae in the Homosassa River.

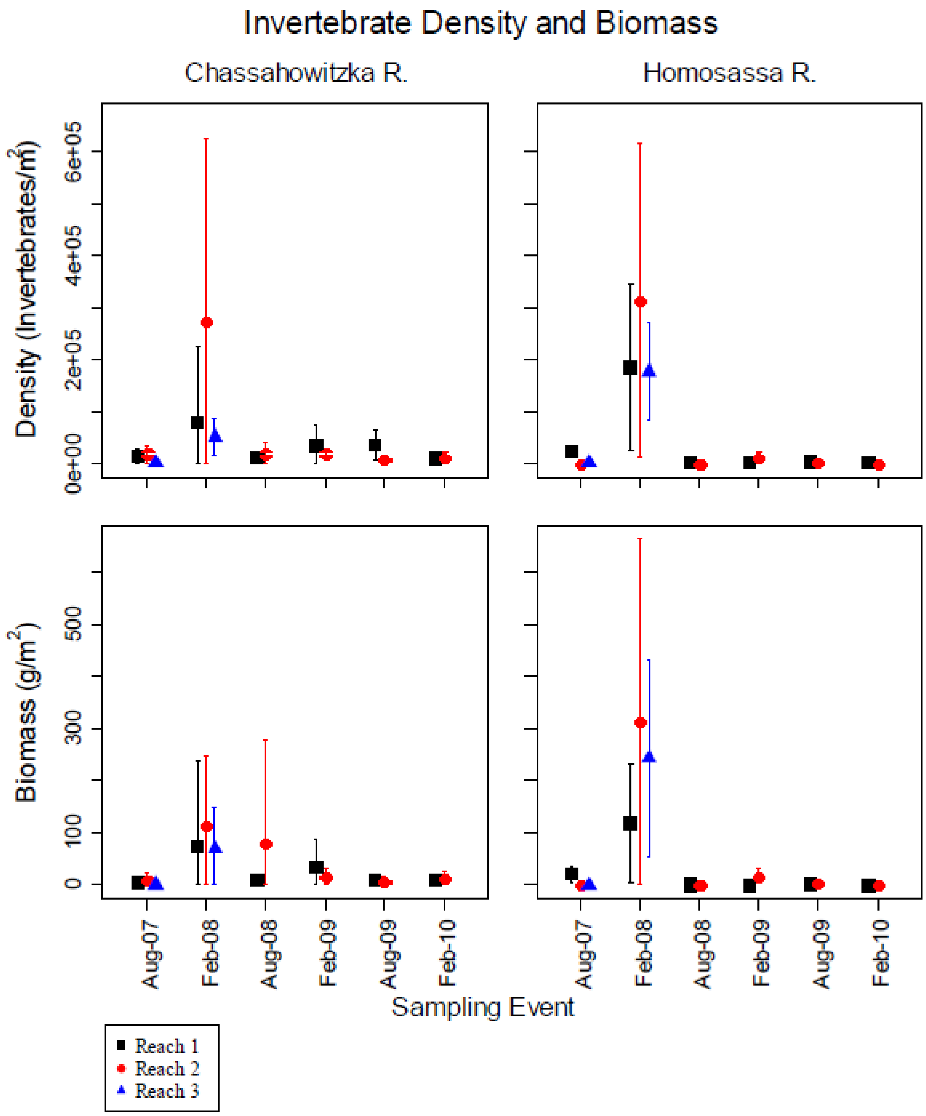


Figure 4-17. Biomass and density of invertebrates in the Chassahowitzka and Homosassa rivers from Frazer et al. (2011).

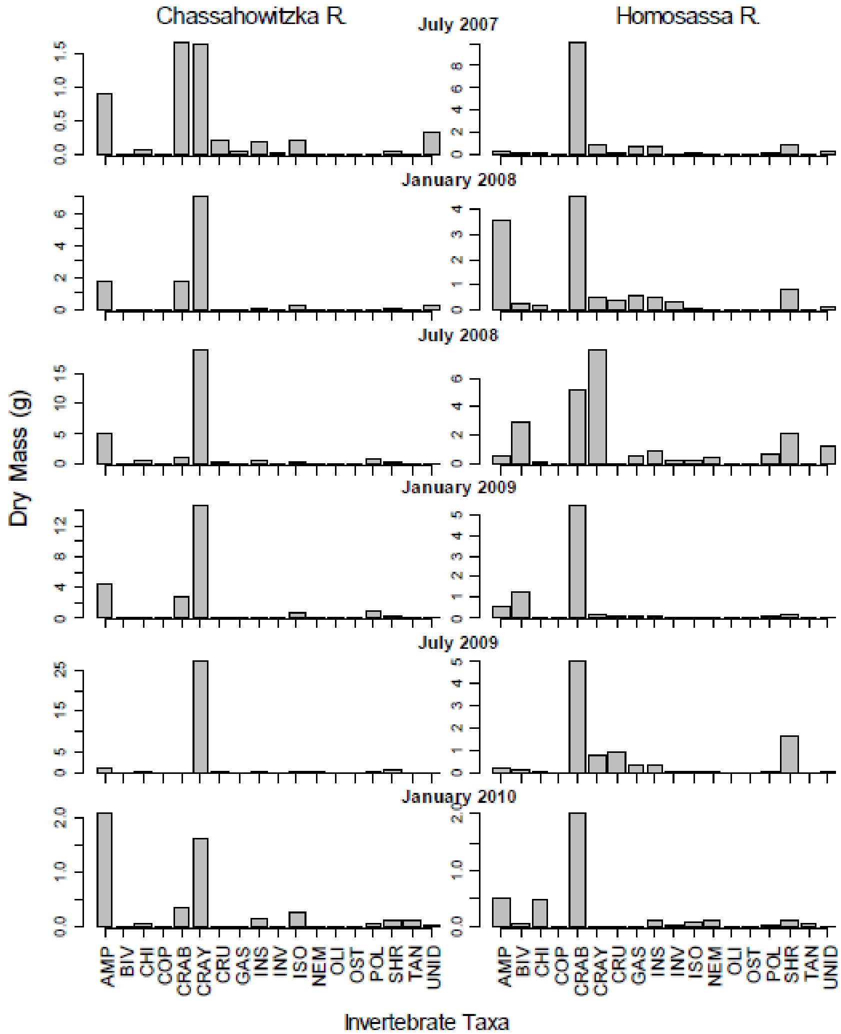


Figure 4-18. Invertebrate taxa in the Chassahowitzka and Homosassa rivers reported by Frazer et al. 2011. AMP=Amphipods, BIV=Bivalve, CHI=Chironomid Larvae, COP=Copepod, CRAB=Crabs, CRAY=Crayfish, CRU=Unidentified Crustacean, GAS=Gastropod, INS=Other Insect Larvae, INV=Other Invertebrate, ISO=Isopod, NEM=Nematode, OLI=Oligochaete, OST=Ostracod, POL=Polychaete, SHR=Shrimp, TAN=Tanaid, UNID=Unidentified Invertebrate.

4.2.5 2016 Coastal Rivers Invertebrate Analysis

Amec Foster Wheeler Environment & Infrastructure, Inc. (2016 [Appendix 1]) sampled macroinvertebrates in the Chassahowitzka River in 2015. The river was divided into sampling zones based on salinity gradients and hydrologic contributions to the mainstem of the river (Figure 4-19.). The six mainstem zones were delineated with three upstream of Salt and Potter Creek tributary inflows and three downstream of the aforementioned inflows. At each of the sampling sites within the zones, above-sediment SAV, rock, snag, and macroalgae samples were collected with a D-Frame dipnet. Each macroinvertebrate sample was collected by sweeping the D-frame net a total of four times (0.125 m^2 each), for a total sample area of 0.5 m^2 for each habitat. Petite ponar (0.023 m^2) was used to collect a quantitative sample of macroinvertebrates from bare sediment.

Amec Foster Wheeler Environment & Infrastructure, Inc. (2016) identified the 15 macroinvertebrate taxa with the highest dominance scores. Of these 15 taxa, 3 were annelid worms, 7 were crustaceans, 4 were midges, and 1 was a gastropod. The tanaid *Leptocheliidae spp*.; the amphipods *Gammarus* spp., *Grandidierella bonnieroides,* and *Apocorophium louisianum*; and the polychaete worm *Laeonereis culveri* were the most dominant taxa. These five taxa made up 56% of the collected organisms.

Habitat type was used as a factor to evaluate trends in invertebrate community structure among macroalgae, rock, sediment, SAV and snag habitats in the Weeki Wachee, Homosassa, and Chassahowitzka rivers (Amec Foster Wheeler Environment & Infrastructure, Inc. 2016). Dominance scores were calculated for the taxa within each habitat for all samples. Snag habitat displayed the highest total species richness of 142 taxa, followed by SAV and macroalgae (which had the same species richness of 118 taxa). Sediment and rock habitat had similar taxa richness with 86 and 84 taxa, respectively. The dominant taxon found in the macroalgae samples was the amphipod *Hyalella azteca* sp. complex making up 49% of the organisms found in macroalgae samples. Hydrobiidae snails are the second most dominant taxon in the macroalgae samples. Dominant taxa found in the rock samples were the Leptocheliidae tanaids, followed by the amphipod *G. bonnieroides*. Dominant taxa found in the SAV samples were the midges *Tanytarsus* spp. and *Cricotopus/Orthocladius* spp. making up 22% and 12% of the organisms found in all of the SAV samples, respectively. Dominant taxa found in the sediment samples were the amphipod *G. bonnieroides* and Tubificinae worms making up 20% and 15% of the total organisms found in all of the sediment samples, respectively. Dominant taxa found in snag samples were Leptochellidae tanaids, followed by the amphipod *A. louisianum,* making up 30% and 22% of the total organisms found in all snag samples, respectively. Invertebrate species richness and diversity indices were correlated with water temperature, salinity, turbidity, canopy cover, and habitat diversity (Table 4-3.). This result links macroinvertebrate community structure to salinity and temperature habitats modeled by LAMFE. Insect taxa were more common in fresher water, while annelid worms were more abundant in saltier water (Table 4-4.).

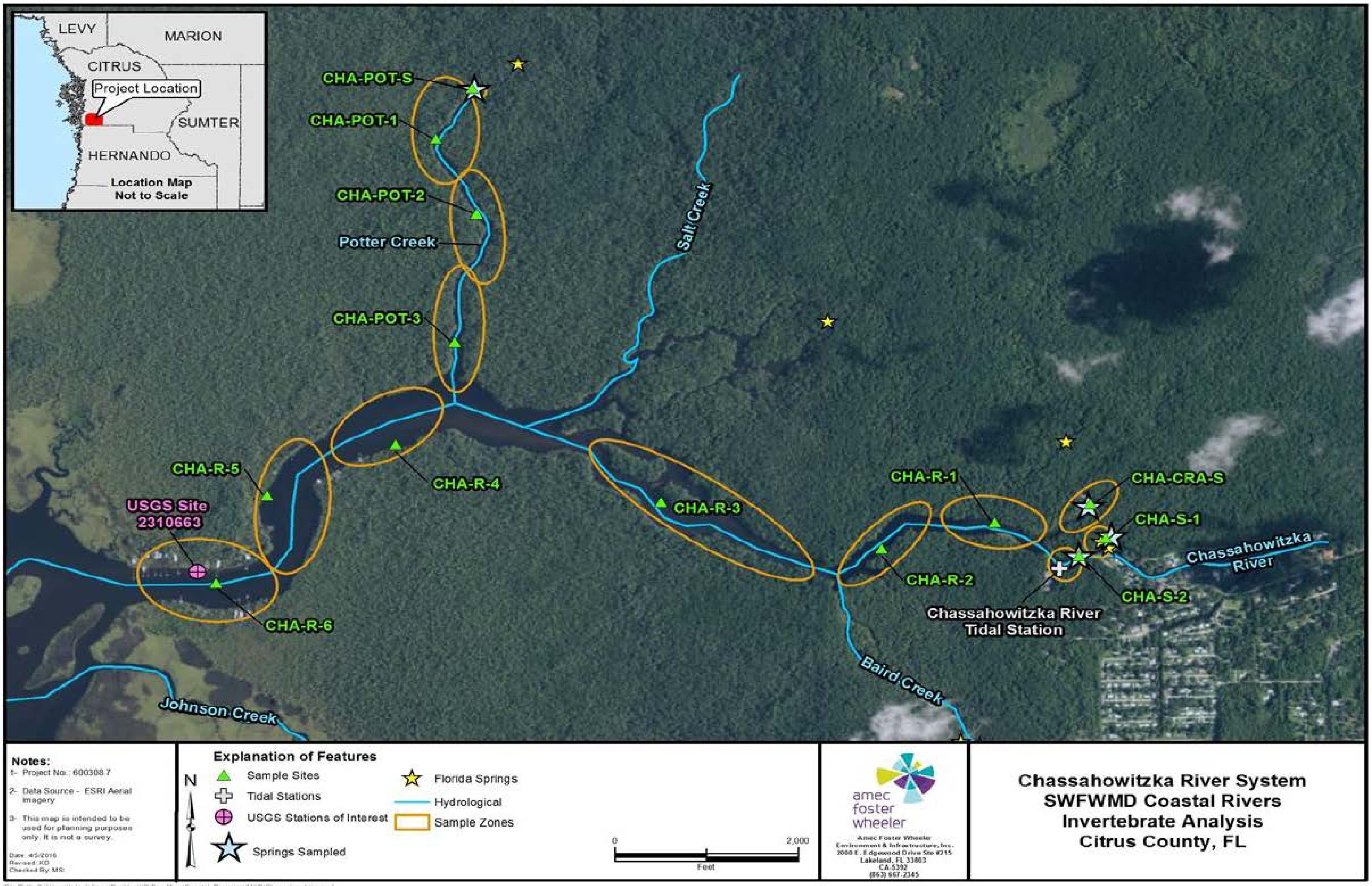


Figure 4-19. Invertebrate sampling sites used in 2015 by Amec Foster Wheeler Environment & Infrastructure, Inc. (2016).

Table 4-3. Spearman's rank correlation results for macroinvertebrate community metrics and habitat characteristics in the Weeki Wachee, Homosassa, and Chassahowitzka rivers reproduced from Amec Foster Wheeler Environment & Infrastructure, Inc. (2016).

Physical-Chemical Parameters	Richness (# of taxa)	Abundance (total # of individuals/m^2)	Margalef's Richness Index (d)	Pielou's Evenness Index (J')	Shannon's Diversity Index (H'(loge))	Simpson's Diversity Index (1-Lambda')
Water Temperature (°C)	Rho = -0.287 p = 0.112	Rho = -0.071 p = 0.688	**Rho = -0.404 p = 0.022**	Rho = 0.0148 p = 0.418	Rho = -0.125 p = 0.495	Rho = -0.029 p = 0.877
Dissolved Oxygen (mg/L)	Rho = 0.056 p = 0.763	Rho = 0.008 p = 0.967	Rho = -0.073 p = 0.691	Rho = -0.054 p = 0.767	Rho = 0.052 p = 0.779	Rho = 0.012 p = 0.949
Dissolved Oxygen (%)	Rho = 0.024 p = 0.896	Rho = -0.001 p = 0.995	Rho = -0.109 p = 0.554	Rho = -0.038 p = 0.834	Rho = 0.034 p = 0.854	Rho = -0.002 p = 0.991
Salinity (ppt)	**Rho = -0.354 p = 0.047**	Rho = -0.071 p = 0.700	**Rho = -0.410, p = 0.020**	Rho = 0.299 p = 0.097	Rho = -0.036 p = 0.846	Rho = 0.155 p = 0.398
Conductivity (µS/cm)	**Rho = -0.421 p = 0.016**	Rho = -0.020 p = 0.914	**Rho = -0.494 p = 0.004**	Rho = 0.303 p = 0.092	Rho = -0.064 p = 0.726	Rho = 0.155 p = 0.397
pH (SU)	Rho = 0.035 p = 0.851	Rho = 0.002 p = 0.991	Rho = -0.061 p = 0.741	Rho = -0.112 p = 0.540	Rho = 0.001 p = 0.995	Rho = -0.042 p = 0.818
Turbidity (NTU)	**Rho = -0.351 p = 0.049**	Rho = -0.133 p = 0.467	**Rho = -0.422 p = 0.016**	Rho = 0.157 p = 0.392	Rho = -0.099 p = 0.590	Rho = -0.005 p = 0.978
Canopy Cover (%)	**Rho = 0.383 p = 0.031**	Rho = -0.228 p = 0.209	**Rho = 0.625 p = 0.000**	Rho = 0.031 p = 0.865	Rho = 0.307 p = 0.088	Rho = 0.187 p = 0.306
Habitat Diversity	**Rho = 0.420 p = 0.017**	Rho = 0.207 p = 0.255	**Rho = 0.501 p = 0.004**	Rho = -0.316 p = 0.078	Rho = 0.151 p = 0.409	Rho = -0.030 p = 0.869

Note: Rho is the correlation coefficient, bolded cells are considered to be statistically significant at p<0.05.

Table 4-4. Spearman's rank correlations for major taxonomic groups for Weeki Wachee, Homosassa, and Chassahowitzka rivers reproduced from Amec Foster Wheeler Environment & Infrastructure, Inc. (2016).

Percentage of Major Taxonomic Group by Zone	Salinity ppt	Conductivity µS/cm	Water Temperature °C	Turbidity NTU	Dissolved Oxygen %
Acari	**-0.530**	**-0.505**	**-**	**-**	**-**
	0.002	*0.003*	*NS*	*NS*	*NS*
Annelida	**0.421**	**0.368**	**-**	**0.354**	**-**
	0.017	*0.038*	*NS*	*0.047*	*NS*
Coleoptera	**-0.609**	**-0.612**	**-0.480**	**-0.575**	**-**
	0.000	*0.000*	*0.005*	*0.001*	*NS*
Diptera	**-**	**-0.349**	**-0.384**	**-0.509**	**-**
	NS	*0.050*	*0.030*	*0.003*	*NS*
Ephemeroptera	**-0.613**	**-0.659**	**-0.491**	**-0.688**	**-**
	0.000	*0.000*	*0.004*	*0.000*	*NS*
Heteroptera	**-0.377**	**-0.376**	**-**	**-**	**-**
	0.033	*0.034*	*NS*	*NS*	*NS*
Lepidoptera	**-0.519**	**-0.531**	**-0.453**	**-0.560**	**-**
	0.002	*0.002*	*0.009*	*0.001*	*NS*
Trichoptera	**-0.701**	**-0.732**	**-0.637**	**-0.740**	**-0.362**
	0.000	*0.000*	*0.000*	*0.000*	*0.042*
Odonata	**-0.546**	**-0.542**	**-**	**-0.473**	**-**
	0.001	*0.001*	*NS*	*0.006*	*NS*

Note: The top bolded value in each cell is Rho, the correlation coefficient. The bottom value in italics is the p-value. All results reported in this table are considered to be statistically significant at $p<0.05$

4.3 Fish and Invertebrate Plankton and Nekton

4.3.1 Electrofishing from Jan. 2014 to Dec. 2017

Under contract with the District, the FWC sampled the fish community in the Chassahowitzka River on 40 dates during 11 events from January 2014 through June 2018 (Table 4-5.) (Johnson et al. 2017 [Appendix 9]). The FWC divided the Chassahowitzka into three salinity zones with a total of 123 transects measuring 100 m each and running parallel to the shoreline (Johnson et al. 2017, Figure 4-20.).

A total of 53 fish species were caught (Table 4-6.). The nineteen most abundant species made up 95% of the total catch (Figure 4-21.). Eleven of the nineteen most common fish are saltwater fish; eight are freshwater fish. The six most common species account for 74% of the catch, and these consist of three saltwater fish: Tidewater Mojarra (20%), Gray Snapper (18%), and Pinfish (10%); and three freshwater fish: Rainwater Killifish (12%), Spotted Sunfish (8%), and Largemouth Bass (6%).

Table 4-5. Fish sampling effort in the Chassahowitzka River by FWC (Johnson et al. 2017).

Event	Start	Finish	Season	Distance (m)	Sites
1	2014-01-07	2014-01-09	Winter	2000	20
2	2014-06-24	2014-06-26	Summer	3000	30
3	2014-11-17	2014-11-20	Winter	2800	28
4	2015-06-15	2015-06-18	Summer	3000	30
5	2016-01-04	2016-01-07	Winter	2800	28
6	2016-06-27	2015-06-30	Summer	3000	30
7	2016-08-08	2016-08-11	Summer	3000	30
8	2017-01-23	2017-01-26	Winter	2900	29
9	2017-08-15	2017-08-18	Summer	3000	30
10	2017-12-11	2017-12-13	Winter	2900	29
11	2018-06-25	2018-06-28	Summer	3000	30

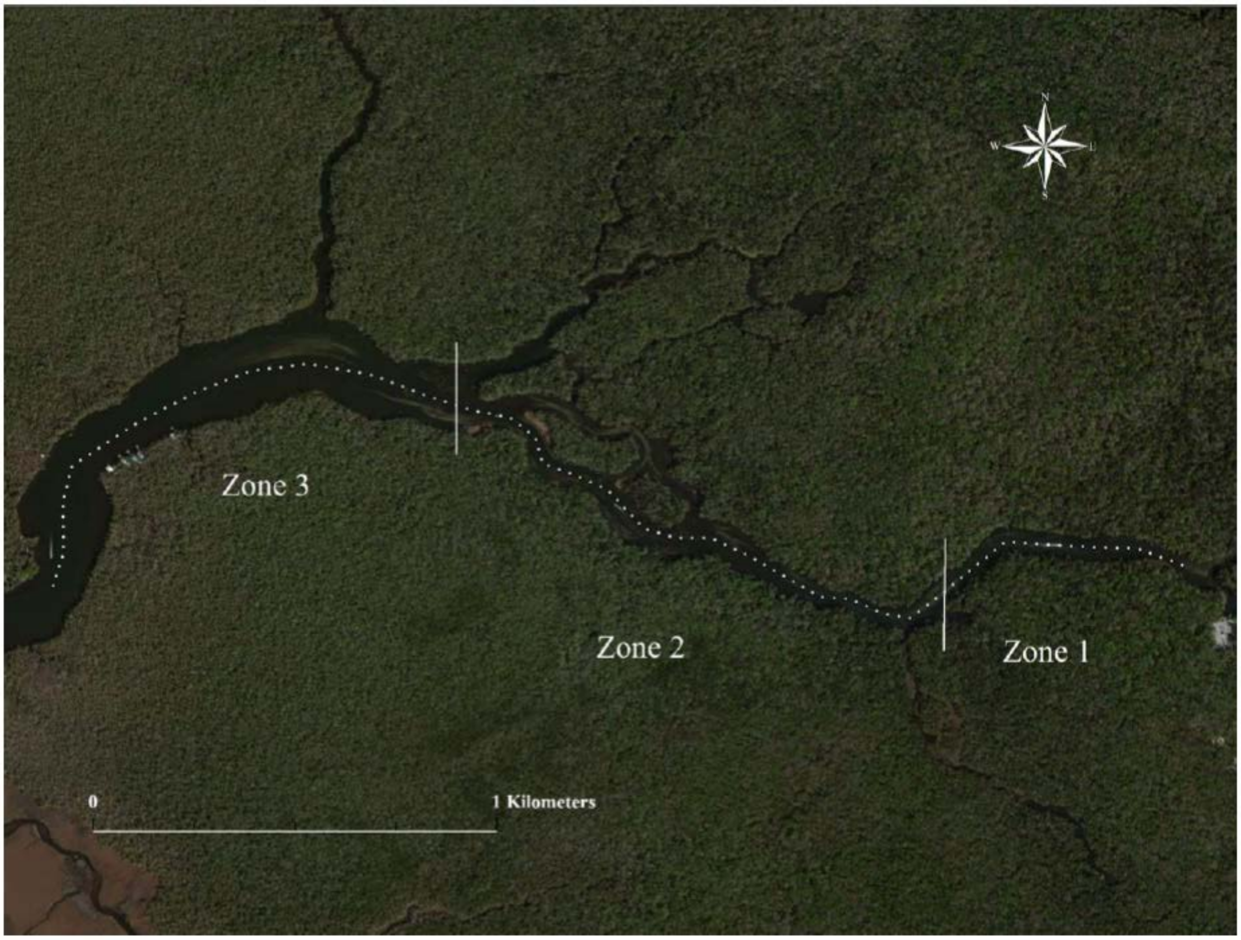


Figure 4-20. Zones for fish sampling in the Chassahowitzka River from Johnson et al. (2017).

Table 4-6. Species list with abundance in Chassahowitzka River from Jan. 2014 to June 2018 from Johnson et al. (2017). N = number caught, % = percent of total abundance, C.% = cumulative percent of catch.

Scientific	Common	Family	Habitat	N	%	C.%	Rank
Eucinostomus harengulus	Tidewater Mojarra	Gerreidae	Salt	3566	19.8	19.8	1
Lutjanus griseus	Gray Snapper	Lutjanidae	Salt	3287	18.2	38	2
Lucania parva	Rainwater Killifish	Fundulidae	Fresh	2153	11.9	50	3
Lagodon rhomboides	Pinfish	Sparidae	Salt	1893	10.5	60.5	4
Lepomis punctatus	Spotted Sunfish	Centrarchidae	Fresh	1457	8.1	68.5	5
Micropterus salmoides	Largemouth Bass	Centrarchidae	Fresh	1010	5.6	74.1	6
Erimyzon sucetta	Lake Chubsucker	Catostomidae	Fresh	706	3.9	78.1	7
Centropomus undecimalis	Common Snook	Centropomidae	Salt	622	3.4	81.5	8
Menidia beryllina	Inland Silverside	Atherinopsidae	Fresh	385	2.1	83.6	9
Brevoortia sp.	Menhaden	Clupeidae	Salt	376	2.1	85.7	10
Anchoa mitchilli	Bay Anchovy	Engraulidae	Salt	350	1.9	87.7	11
Mugil cephalus	Striped Mullet	Mugilidae	Salt	281	1.6	89.2	12
Lucania goodei	Bluefin Killifish	Fundulidae	Fresh	254	1.4	90.6	13
Fundulus grandis	Gulf Killifish	Fundulidae	Salt	191	1.1	91.7	14
Leiostomus xanthurus	Spot	Sciaenidae	Salt	188	1	92.7	15
Trinectes maculatus	Hogchoker	Achiridae	Salt	117	0.6	93.4	16
Lepomis microlophus	Redear Sunfish	Centrarchidae	Fresh	103	0.6	94	17
Archosargus probatocephalus	Sheepshead	Sparidae	Salt	100	0.6	94.5	18
Notropis chalybaeus	Ironcolor Shiner	Cyprinidae	Fresh	84	0.5	95	19
Gambusia holbrooki	Eastern Mosquitofish	Poeciliidae	Fresh	72	0.4	95.4	20
Harengula jaguana	Scaled Sardine	Clupeidae	Salt	68	0.4	95.8	21
Arius felis	Hardhead Catfish	Ariidae	Salt	65	0.4	96.1	22
Anguilla rostrata	American Eel	Anguillidae	Fresh	64	0.4	96.5	23
Fundulus seminolis	Seminole Killifish	Fundulidae	Fresh	60	0.3	96.8	24
Notropis petersoni	Coastal Shiner	Cyprinidae	Fresh	59	0.3	97.1	25
Notropis harperi	Redeye Chub	Cyprinidae	Fresh	58	0.3	97.4	26
Cyprinodon variegatus	Sheepshead Minnow	Cyprinodontidae	Salt	54	0.3	97.7	27
Poecilia latipinna	Sailfin Molly	Poeciliidae	Fresh	54	0.3	98	28
Notemigonus crysoleucas	Golden Shiner	Cyprinidae	Fresh	50	0.3	98.3	29
Microgobius gulosus	Clown Goby	Gobiidae	Salt	42	0.2	98.6	30
Strongylura marina	Atlantic Needlefish	Belonidae	Salt	41	0.2	98.8	31
Strongylura timucu	Timucu	Belonidae	Salt	28	0.2	98.9	32
Lepomis macrochirus	Bluegill	Centrarchidae	Fresh	27	0.1	99.1	33
Fundulus confluentus	Marsh Killifish	Fundulidae	Salt	23	0.1	99.2	34
Syngnathus scovelli	Gulf Pipefish	Syngnathidae	Salt	21	0.1	99.3	35

Mugil curema	White Mullet	Mugilidae	Salt	18	0.1	99.4	36
Oligoplites saurus	Leatherjacket	Carangidae	Salt	15	0.1	99.5	37
Lepomis sp.	Sunfish	Centrarchidae	Fresh	14	0.1	99.6	38
Cynoscion nebulosus	Spotted Seatrout	Sciaenidae	Salt	12	0.1	99.7	39
Myrophis punctatus	Speckled Worm Eel	Ophichthidae	Salt	9	0	99.7	40
Sciaenops ocellatus	Red Drum	Sciaenidae	Salt	8	0	99.8	41
Caranx hippos	Crevalle Jack	Carangidae	Salt	6	0	99.8	42
Heterandria formosa	Least Killifish	Poeciliidae	Fresh	6	0	99.8	43
Lepisosteus osseus	Longnose Gar	Lepisosteidae	Fresh	6	0	99.9	44
Opsanus beta	Gulf Toadfish	Batrachoididae	Salt	6	0	99.9	45
Strongylura notata	Redfin Needlefish	Belonidae	Salt	5	0	99.9	46
Gobiosoma bosc	Naked Goby	Gobiidae	Salt	4	0	99.9	47
Lepisosteus platyrhincus	Florida Gar	Lepisosteidae	Fresh	4	0	100	48
Remora sp.	Remora	Echeneidae	Salt	3	0	100	49
Ameiurus natalis	Yellow Bullhead	Ictaluridae	Fresh	1	0	100	50
Bagre marinus	Gafftopsail Catfish	Ariidae	Salt	1	0	100	51
Dasyatis sabina	Atlantic Stingray	Dasyatidae	Salt	1	0	100	52
Elops saurus	Ladyfish	Elopidae	Salt	1	0	100	53

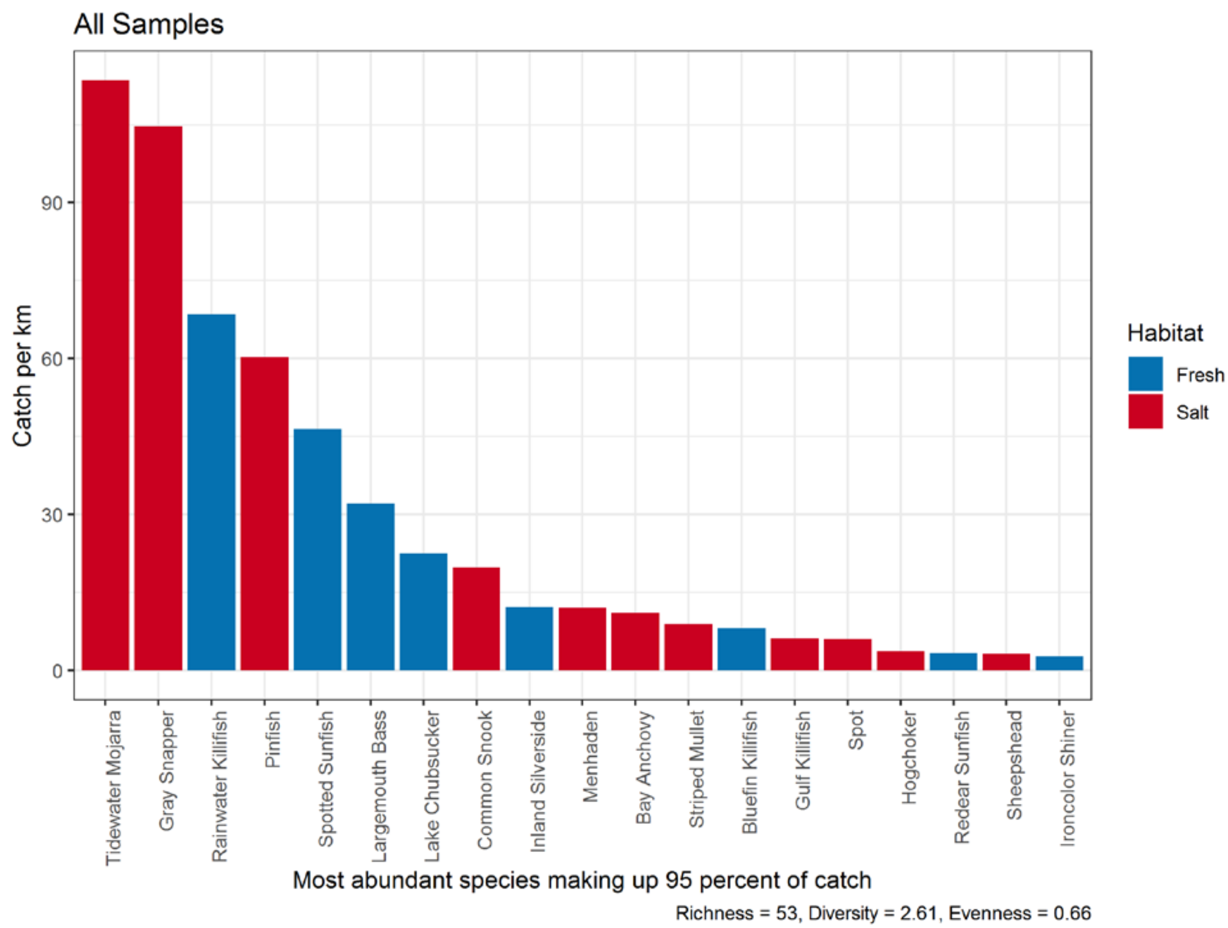


Figure 4-21. Nineteen species account for more than 95 percent of the total catch in the Chassahowitzka River from Jan. 2014 to Jun. 2018 reported by Johnson et al. (2017).

4.3.1.1 Seasonal differences

Fish in the Chassahowitzka River were sampled by the FWC over five winters and six summers (Table 4-5.). In the summer, Rainwater Killifish, Tidewater Mojarra, Pinfish, and Spotted Sunfish were the four most common species (Figure 4-22.). In the winter, Gray Snapper and Tidewater Mojarra account for more than 70% of the total catch (Figure 4-23.).

The summer fish community had greater richness, diversity, and evenness than the winter fish community (Table 4-7.). The differences in summer and winter communities can be seen by comparing abundance of the most common species (Figure 4-24.). The difference between summer and winter communities is significant (Table 4-8.). Changes in abundance of Gray Snapper, Tidewater Mojarra, Rainwater Killifish, and Spotted Sunfish contribute most strongly to seasonal differences (Table 4-9.). In the winter, saltwater Tidewater Mojarra and Gray Snapper become much more common. While these saltwater fish are more common in winter, freshwater fish become less common, and we see reductions in Rainwater Killifish, Largemouth Bass, and Spotted Sunfish. Thus, the assemblage appears to shift from a mix of salt and freshwater species in the summer, to being dominated by saltwater species in the winter.

Common Snook are slightly more abundant in summer (22/km) than in winter (17/km) in the Chassahowitzka River (Figure 4-24).

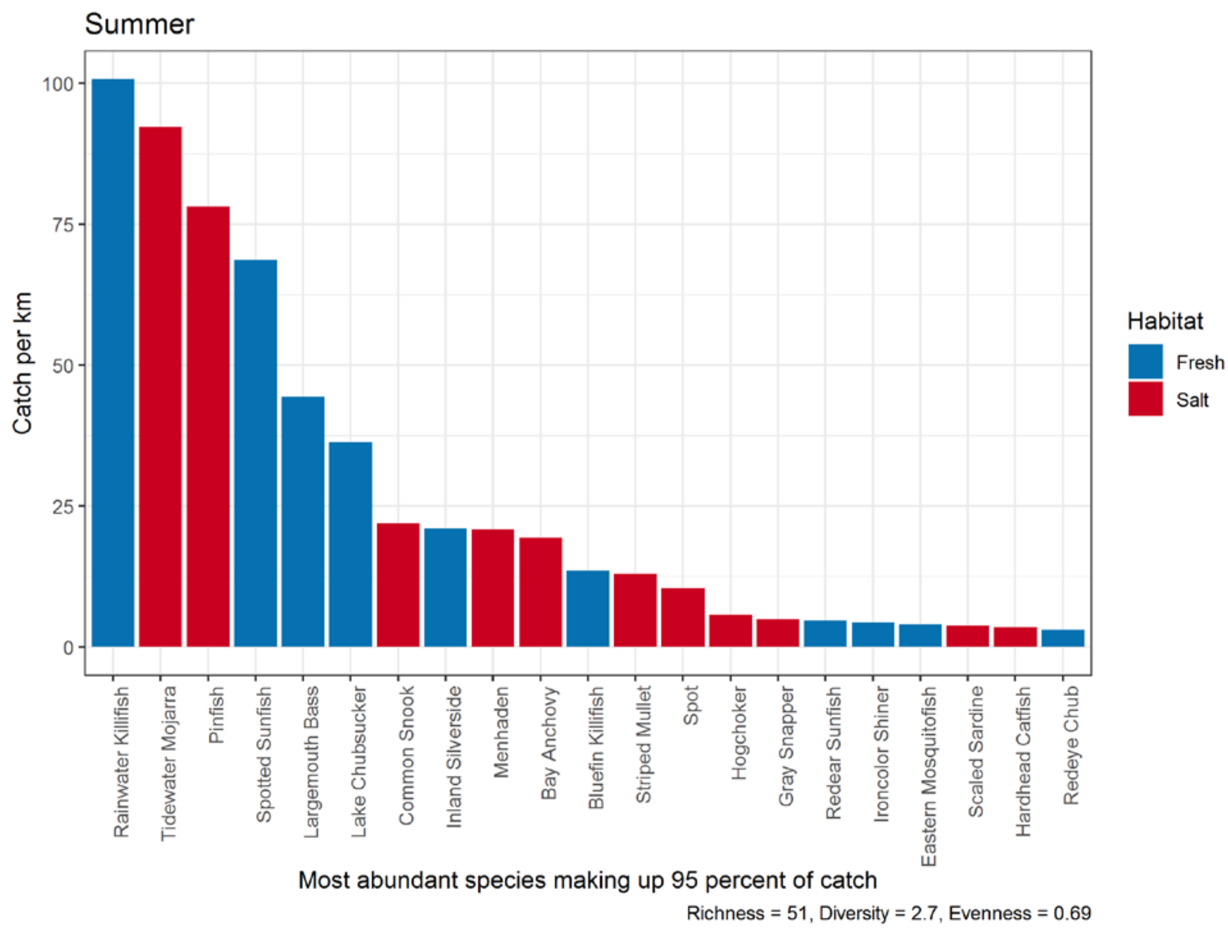


Figure 4-22. Twenty-one fish species account for greater than 95 percent of the total catch in summer sampling events in the Chassahowitzka River reported by Johnson et al. (2017).

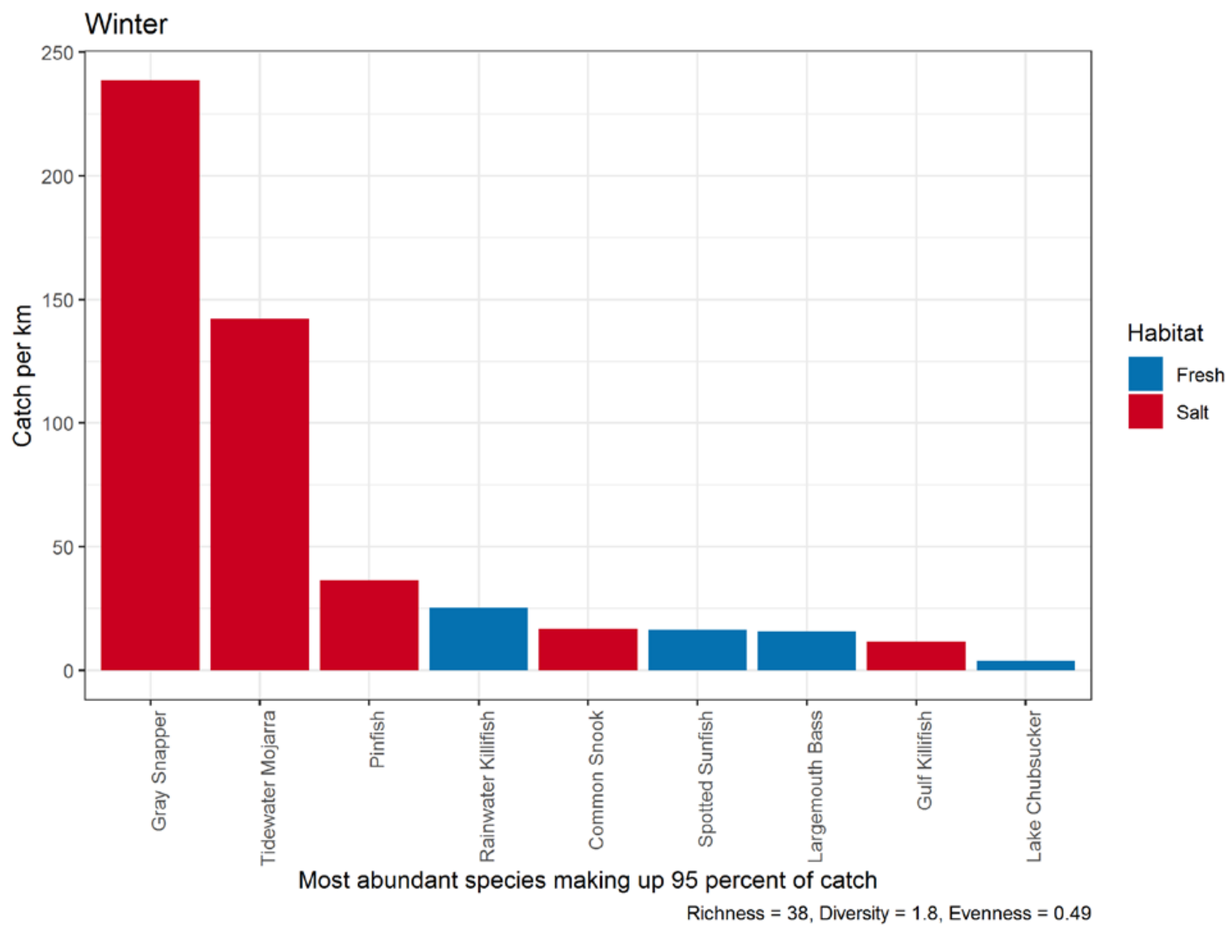


Figure 4-23. Nine fish species account for over 95 percent of the winter catch in the Chassahowitzka River reported by Johnson et al. (2017).

Table 4-7. Fish species richness, diversity, and evenness in summer and winter catch in the Chassahowitzka River reported by Johnson et al. (2017).

Season	Richness	Shannon Diversity	Evenness
Summer	51	2.7	0.69
Winter	38	1.8	0.49

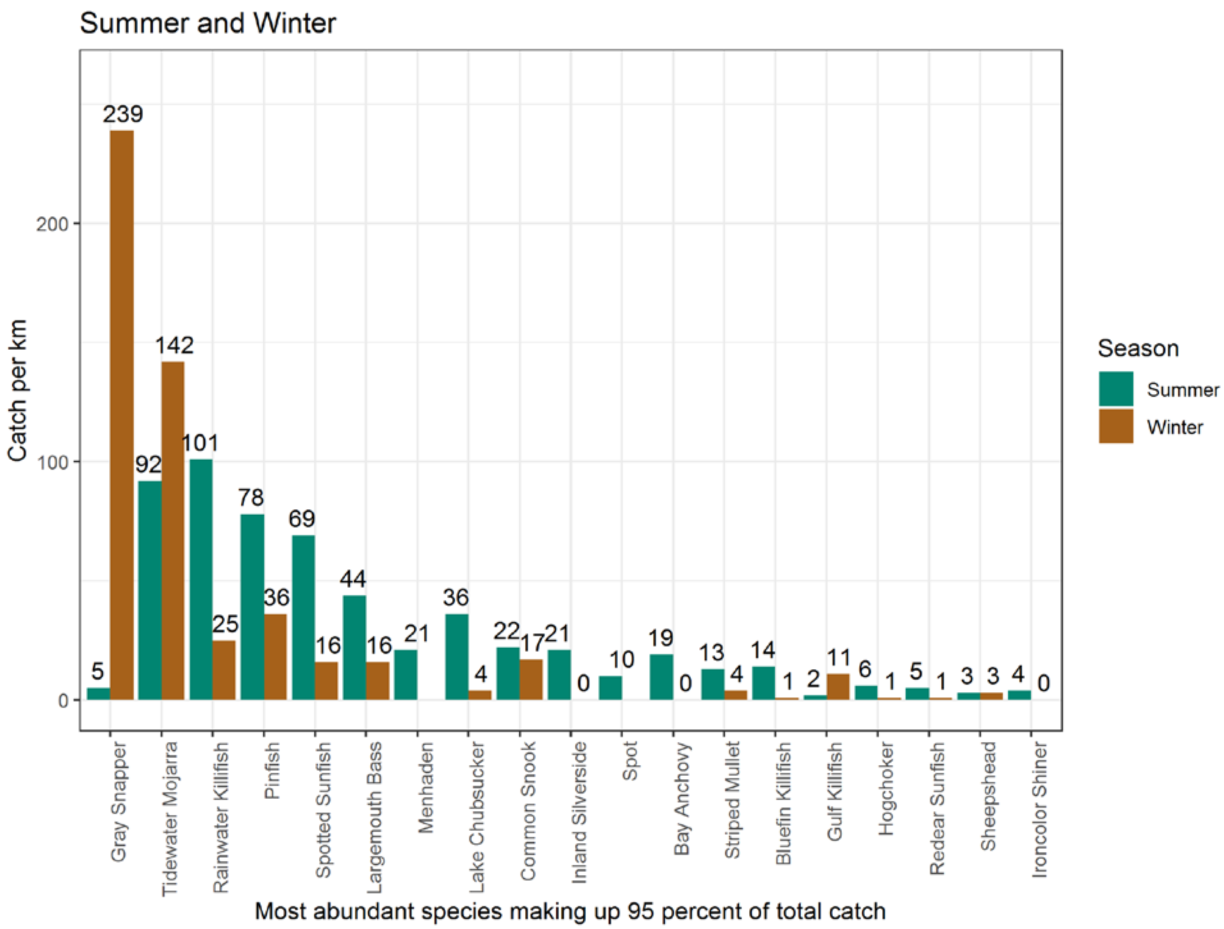


Figure 4-24. Most abundant fish species in the Chassahowitzka River by season based on sampling reported by Johnson et al. (2017).

Table 4-8. Results of test for similarity between summer and winter fish communities in the Chassahowitzka River based on sampling reported by Johnson et al. (2017). Significance level of sample statistic = 0.3%, indicating that there is a significant statistical difference between summer and winter.

One-Way - A
Resemblance worksheet Name: Resem6 Data type: Similarity Selection: All
Factors Place Name Type Levels A Season Unordered 2
Season levels Summer Winter
Tests for differences between unordered Season groups *Global Test* Sample statistic (R): 0.221 Significance level of sample statistic: 0.3% Number of permutations: 999 (Random sample from 1037158320) Number of permuted statistics greater than or equal to R: 2

Table 4-9. Similarity percentages (SIMPER) for individual species between summer and winter fish communities in the Chassahowitzka River based on sampling reported by Johnson et al. (2017). Analysis based on log transformed catch per unit effort and Bray-Curtis similarity using Primer. The average dissimilarity is 55.39.

Species	Summer Av. Abund	Winter Av. Abund	Av. Diss	Diss/SD	Contrib%	Cum.%
Lutjanus griseus	1.02	2.98	5.88	1.67	10.61	10.61
Eucinostomus harengulus	2.38	2.46	3.67	1.27	6.63	17.24
Lucania parva	2.30	1.42	3.23	1.44	5.83	23.07
Lepomis punctatus	1.93	1.25	3.22	1.49	5.81	28.88
Lagodon rhomboides	2.33	1.35	3.05	1.38	5.52	34.39
Centropomus undecimalis	1.22	1.05	2.66	1.27	4.79	39.19
Erimyzon sucetta	1.04	0.57	2.65	1.12	4.79	43.97
Micropterus salmoides	1.70	1.41	2.54	1.47	4.58	48.56
Mugil cephalus	0.95	0.49	2.10	1.11	3.79	52.34
Menidia beryllina	0.89	0.24	2.08	1.02	3.76	56.11
Fundulus grandis	0.24	0.66	1.86	0.76	3.36	59.47
Lucania goodei	0.61	0.32	1.69	0.89	3.05	62.52
Brevoortia sp.	0.35	0.41	1.46	0.60	2.63	65.15
Trinectes maculatus	0.65	0.21	1.39	1.13	2.52	67.67
Archosargus probatocephalus	0.37	0.43	1.27	0.99	2.30	69.97
Leiostomus xanthurus	0.36	0.23	1.15	0.65	2.07	72.04

4.3.1.2 Location Differences

Three spatial zones were identified for the Chassahowitzka River fish sampling, numbered in order going downstream, so that zone 1 is the most upstream and zone 3 is the most downstream (Figure 4-20.). Fish species richness increases in the downstream direction, while diversity and evenness were higher at the edges and lower in the middle (Table 4-10.). The upstream zone 1 experiences abundant saltwater Gray Snapper, Tidewater Mojarra, and Pinfish, but also has abundant and diverse freshwater species dominated by Spotted Sunfish and Largemouth Bass (Figure 4-25.). Zone 2 shows more dominance by saltwater species making up the three most common fish, but also has common Rainwater Killifish, Spotted Sunfish, Largemouth Bass, and Lake Chubsucker (Figure 4-26.). Zone 3 has the most abundance of saltwater species (Figure 4-27.). The saltwater assemblage in zone 3 looks different from the other zones, with Bay Anchovy, Common Snook, and Menhaden among the most common species.

Table 4-10. Fish species richness (n), Shannon diversity, and Pielou's evenness by location zone (see Figure 4-20) identified by Johnson et al. (2017) for sampling in the Chassahowitzka River.

Zone	Richness	Diversity	Evenness
1	36	2.4	0.68
2	43	2.3	0.61
3	48	2.6	0.67

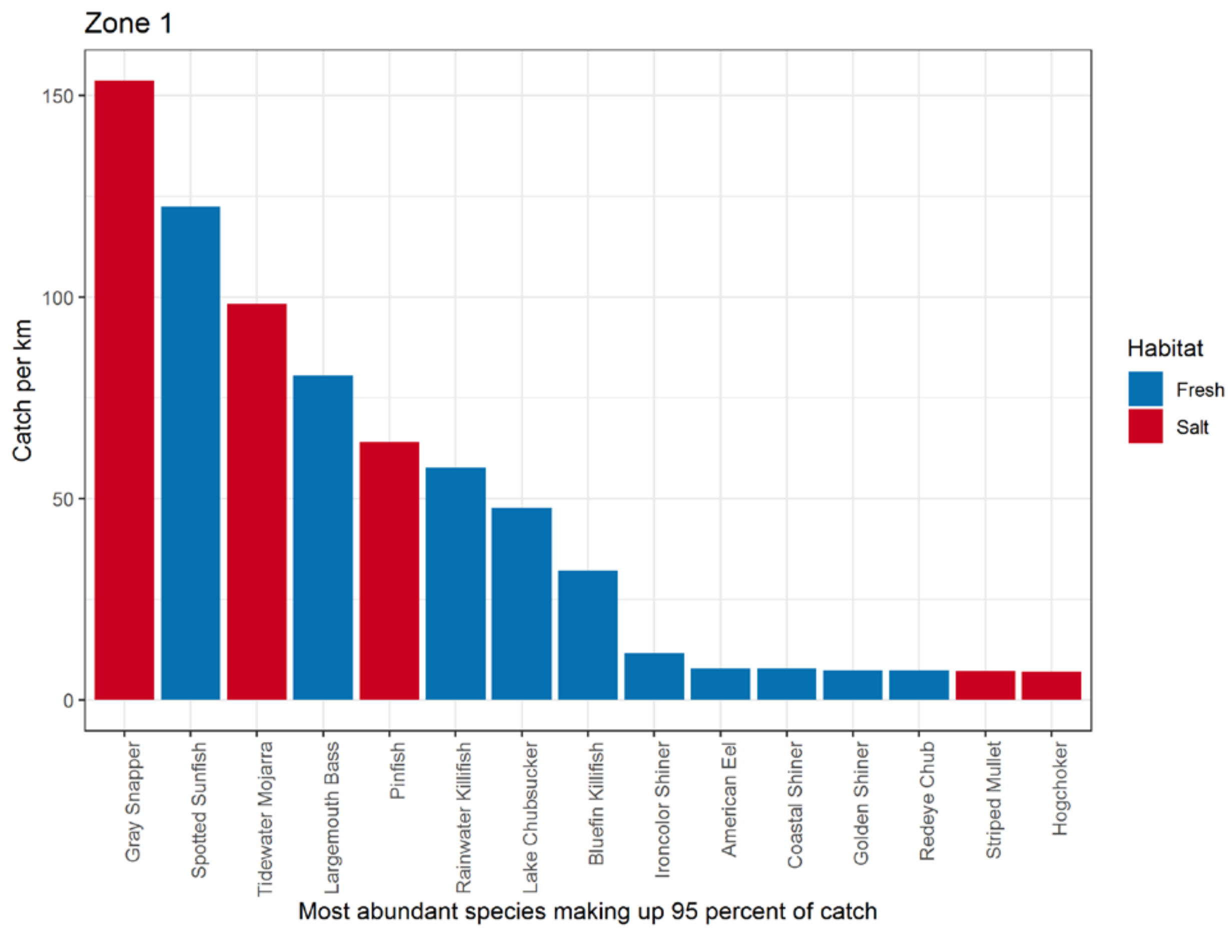


Figure 4-25. Most abundant fish species making up 95% of catch in zone 1 of the Chassahowitzka River (Johnson et al. 2017).

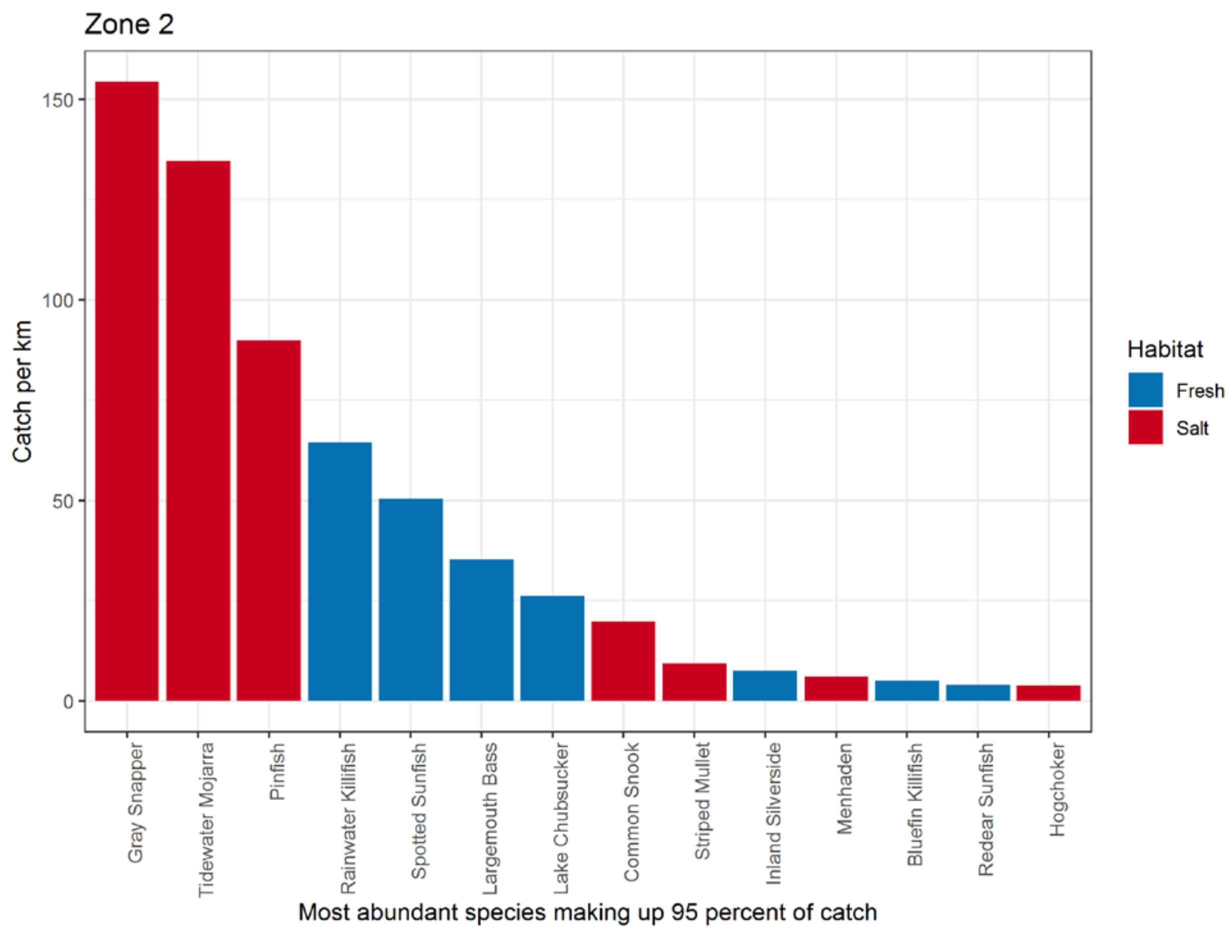


Figure 4-26. Most abundant fish species making up 95% of catch in zone 2 of the Chassahowitzka River (Johnson et al. 2017).

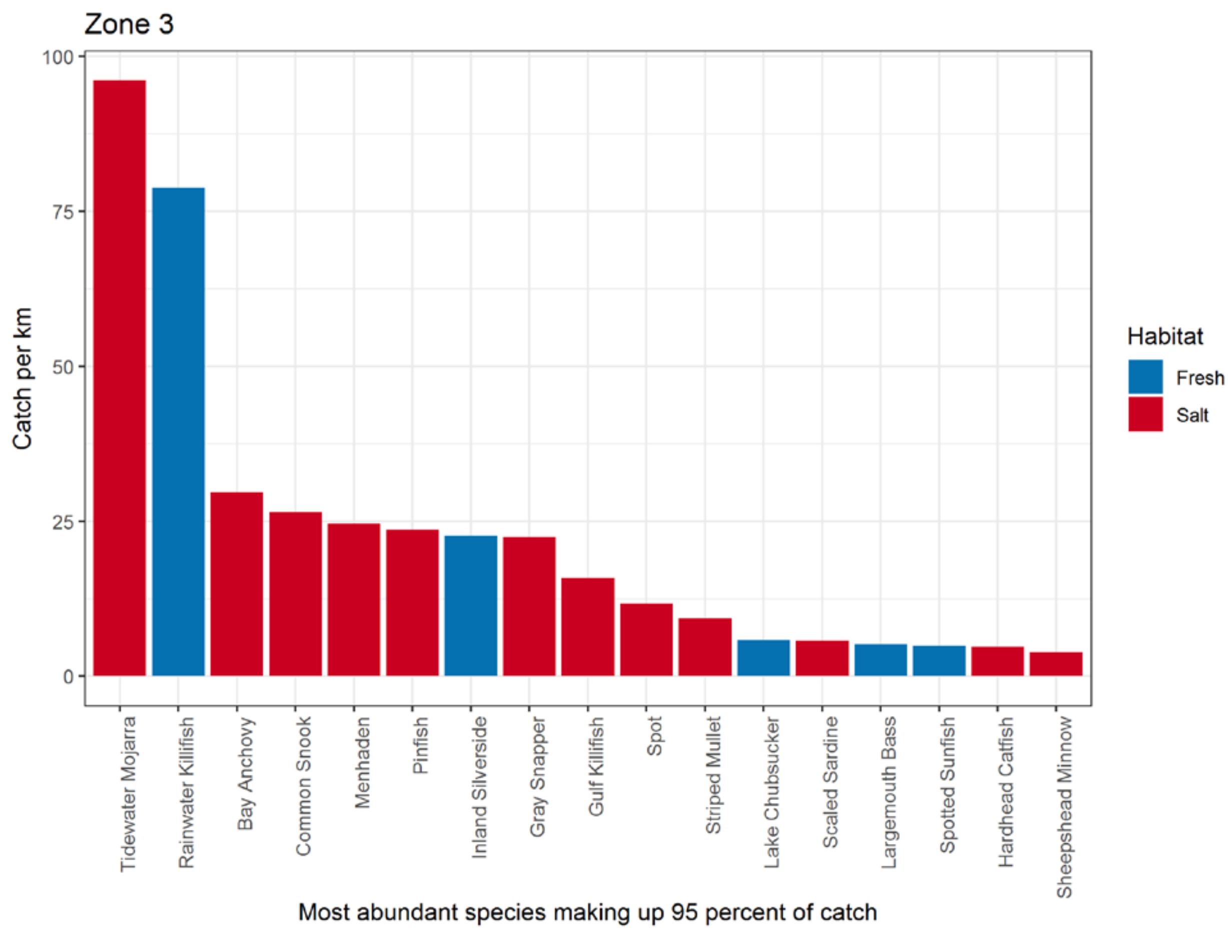


Figure 4-27. Most abundant fish species making up 95% of catch in zone 3 of the Chassahowitzka River (Johnson et al. 2017).

4.3.1.3 Electrofishing Summary

The fish community in the Chassahowitzka River changes from summer to winter. In summer, freshwater fish are common, and include Rainwater Killifish, Spotted Sunfish, and Largemouth Bass. In winter, saltwater fish swim upriver from the Gulf of Mexico and dominate catch. Tidewater Mojarra are numerous in both seasons, but are more abundant in winter, whereas Gray Snapper show a much more seasonal pattern, nearly disappearing in the summer and becoming the most abundant winter species (Figure 4-24.). Saltwater fish can be numerous in the upstream zone 1, but they are more abundant further downstream (Figure 4-25., Figure 4-26., Figure 4-27.).

The Chassahowitzka River fish community is rich with species (n= 53) and diverse (Shannon Index = 2.61), with a mixture of freshwater and saltwater species. Saltwater species are common throughout the river but are more numerous closer to the Gulf of Mexico. Likewise, saltwater fish can be caught at any time of year but are more common in winter.

4.3.2 Historical surveys

Fish species presence from 2013 through 2017 can be compared to previous sampling efforts (Table 4-11.). Most species were caught multiple times, but some were unique to particular sampling efforts (Johnson et al. 2017).

Frazer et al. 2011 conducted electrofishing and seining for three days each during four periods (summer 2007, winter 2008, summer 2008, and winter 2009). They found small-bodied fish density and biomass were lower in winters of 2008 and 2009 compared with summers of 2007 and 2008. They attributed this partly to reduced numbers of freshwater fish in winters. Seine sampling within the Chassahowitzka River during August primarily captured Rainwater Killifish (*Lucania parva*), followed by Inland Silverside (*Menidia beryllina*), Tidewater Mojarra (*Eucinostomus harengulus*), Bluefin Killifish (*Lucania goodei*), and young-of-the-year spotted Sunfish (*Lepomis punctatus*). February sampling within the Chassahowitzka River predominantly captured Rainwater Killifish, Tidewater Mojarra, Pinfish (*Lagodon rhomboides*), Needlefish (*Strongylura* spp.) and Gray Snapper (*Lutjanus griseus).* Freshwater and saltwater densities of large bodied fish were greatest upstream with lower densities observed in downstream reaches. Frazer et al. (2011) measured a large increase in the densities of *Lepomis* spp. (primarily *Lepomis punctatus*) and Lake Chubsucker (*Erimyzon sucetta*) between January 2008 and July 2009 within the river, corresponding with relatively strong cohorts of young-of-the-year captured during summer 2008 and subsequent sampling events. They documented high densities and biomass of saltwater, large-bodied fishes during January of 2008 and 2009. These results corroborate the major findings of Johnson et al. (2017), who reported a shift from high abundance of freshwater fish in summer to saltwater fish in the winter.

Greenwood et al. (2008) sampled the Chassahowitzka River with plankton net, seine net and trawl samples in 5 zones. Sampling was conducted on a monthly basis for the first year of the study (August 2005 to July 2006) and every six weeks for the remainder of the study (August 2006 to July 2007). Larval gobies and anchovies dominated the plankton net's larval fish catch. *Gobiosoma* spp. and *Microgobius* spp. were the dominant goby taxa, and the anchovies were strongly dominated by the Bay Anchovy (*Anchoa mitchilli*). Other abundant larval fishes included Silversides (*Menidia* spp.), Rainwater Killifish (*Lucania parva*), eucinostomus mojarras (*Eucinostomus* spp.), and blennies. Over 90 percent of the seine catch was comprised of Rainwater Killifish, menidia silversides, Bay Anchovy, Coastal Shiner (*Notropis petersoni*), eucinostomus mojarras, Pinfish (*Lagodon rhomboides*), Bluefin Killifish (*Lucania goodei*), Tidewater Mojarra (*Eucinostomus harengulus*), and Sheepshead Minnow (*Cyprinodon variegatus*). Fish collections from deeper, trawled areas were dominated by Pinfish and eucinostomus mojarras. These taxa comprised over 58 percent of total trawl catch of fishes.

Greenwood et al. (2008) developed regressions for invertebrates relating distribution and abundance to flow in the Chassahowitzka River. These regressions were screened based on number of organisms caught and coefficient of determination (R^2) values and used as criteria for minimum flows development in the original minimum flows evaluation for the Chassahowitzka River System (Heyl et al. 2012). The regressions that passed screening were not limiting: they indicated a minimum flow as a reduction of 13.7% from unimpacted (i.e., no withdrawal) condition. These regressions have not been updated and were therefore not used in the current minimum flow reevaluation.

Table 4-11. Sources of historical fish data for the Chassahowitzka River and number of species identified (richness) from Table 8 in Johnson et al. (2017).

Citation	Years	Richness
Frazer et al. 2011	2007 - 2010	52
Pine 2011	2008 – 2011	24
Johnson et al. 2017	2013 - 2017	53

4.4 Manatee Status and Habitat Definition

The Florida manatee, *Trichechus manatus latirostris*, is a subspecies of the West Indian manatee and is a high profile, threatened species whose geographic range is restricted to the southeastern U.S. (predominantly Florida) because of its limited tolerance to cold temperatures (< 20°C) (Bossart et al. 2003, Laist and Reynolds 2005, Laist et al. 2013). Due to population declines associated with hunting pressures during the 1500s to 1800s, the Florida manatee was designated as an endangered species under the Endangered Species Act; however, owing to the partial recovery of the manatee's population, this subspecies was recently downlisted from endangered to threatened (U.S. Fish and Wildlife Service 2017). Part of the manatee's successful population increase is a result of protection of their habitat, boating restrictions, and limitations on human interactions with the animals, which are all set forth by the Florida Manatee Sanctuary Act (as implemented in Rule 68C-22, F.A.C). As of 2018, synoptic aerial surveys estimate a minimum of 6,131 manatees in the waters of Florida of which a minimum of 2,400 are found along Florida's west coast. Aerial surveys of manatees in the Chassahowitzka River conducted from 2011 to 2018 have identified a maximum of 38 manatee (Joyce Kleen, personal communication) (Table 4-12.). Although their populations are rebounding, manatees are still highly susceptible to die-offs associated with watercraft, water control structures, marine debris, red tide, cold stress, and other factors (Runge et al. 2017).

Because manatees have low metabolic rates and consume a relatively poor-quality food source (Irvine 1983), they must seek out warm water refuges when air temperatures begin to drop (Bossart et al. 2003). In Florida, these warmer waters primarily consist of discharge from natural springs, discharge from power plants, and/or passive thermal basins (Laist et al. 2013). Based on synoptic aerial counts during winter months, Laist et al. (2013) estimate that 88.6% of the state's subpopulation of manatees seeking refuge in Northwest Florida rely on warmer waters being discharged from springs. For example, during the record low temperatures in 2010, a minimum of 645 manatees were observed in that coastal area. In addition to providing thermal refugia, freshwater discharge from artesian springs is positively correlated with the development of stratified salinity differences (haloclines) in water bodies, and such stratification can be important because it might also lead to the formation of temperature inversions (Stith et al. 2011). These temperature inverted haloclines can create passive thermal refugia (PTR) where a bottom layer of warm, salty water forms and can be sought out by manatees (Stith et al. 2011). Stith et al. (2011) also indicate that reduced freshwater discharge is strongly associated with the loss of these haloclines, and subsequently, a loss of the PTRs. Furthermore, as power plants (warm effluent utilized by 48.5% of all of Florida's manatees) are retired, a large amount of these subpopulations will likely have to begin relying on the warmer waters that are associated with springs (Laist et al. 2013). Based on these direct and indirect thermal benefits of spring discharge, it is imperative that that an appropriate discharge be maintained to support growing manatee populations.

When manatees are exposed to prolonged cold temperatures (< 20°C for several days), they experience cold stress syndrome (CSS) which can ultimately result in death; CSS is caused by nutritional, metabolic, and/or immunological disturbances that often result diseases caused by opportunistic pathogens (Bossart et al. 2003). Reported and confirmed manatee death data indicate that from 1974-2018, 8.9% of the 12,114 total deaths was cold stress-induced (Figure 4-28.) (FWC 2018). This number is likely to be underestimated because approximately 27% of the deaths reported by FWC are labeled as 'undetermined' which may also be linked to cold stress; of the 'undetermined' deaths, approximately 50% occurred during the typical cold months (November- March). During the three largest cold stress die-offs in 2010, 2011, and 2018 (Figure 4-29.), only 6 manatees were reported to have died due to cold stress in the Citrus County area; this indicates that manatees along the Citrus County coast are less likely to die from cold stress than at other Florida locations. This unusually low death rate from cold stress is kept low because of the springs feeding the Crystal River/Kings Bay, Homosassa River, and Chassahowitzka River systems, all of which are located in Citrus County. These low mortality rates are further reverberated by Laist et al. (2013), who concluded that relative to power plant discharge and natural passive thermal refugia, springs offer the best source of protection against cold stress. It should be noted that available data on manatee deaths in 2017 and 2018 are preliminary and reflect conditions only through August 2018. Furthermore, in some years, cold stress mortality counts were combined with natural mortality counts, which could also underestimate the cold stress deaths.

For the reevaluation of minimum flows for the Chassahowitzka River System and previous minimum flow assessments for several District rivers, thermal criteria were established for the Florida manatee based on Rouhani et al. (2007). For the Chassahowitzka River System reevaluation, we defined adequate thermal refuge based on chronic and acute cold stress conditions. To meet adequate thermal habitat for chronic conditions, the water must not be ≤ 20°C for > 3 days; for acute conditions, the water must not be ≤ 15°C for > 4 hrs. Additionally, we estimate that each manatee requires an area of 28.5 square feet and a total volume of 108 cubic feet with a minimum water depth of 3.8 feet (Figure 4-30.). These spatial requirements were originally adopted for Blue Spring with the St. Johns Water Management District, but they used a minimum depth of 5 ft (Rouhani et al. 2007). These criteria, including the minimum depth of 3.8 ft were used for prior minimum flows analyses completed and peer-reviewed for the Chassahowitzka River, Homosassa River, Weeki Wachee River, and Crystal River / Kings Bay systems.

Table 4-12. Manatee aerial survey counts for the Chassahowitzka River from the U.S. Fish and Wildlife Service (Joyce Kleen, personal communication).

Year	Maximum Count
2011	17
2012	27
2013	3
2014	6
2015	38
2016	16
2017	35
2018	23

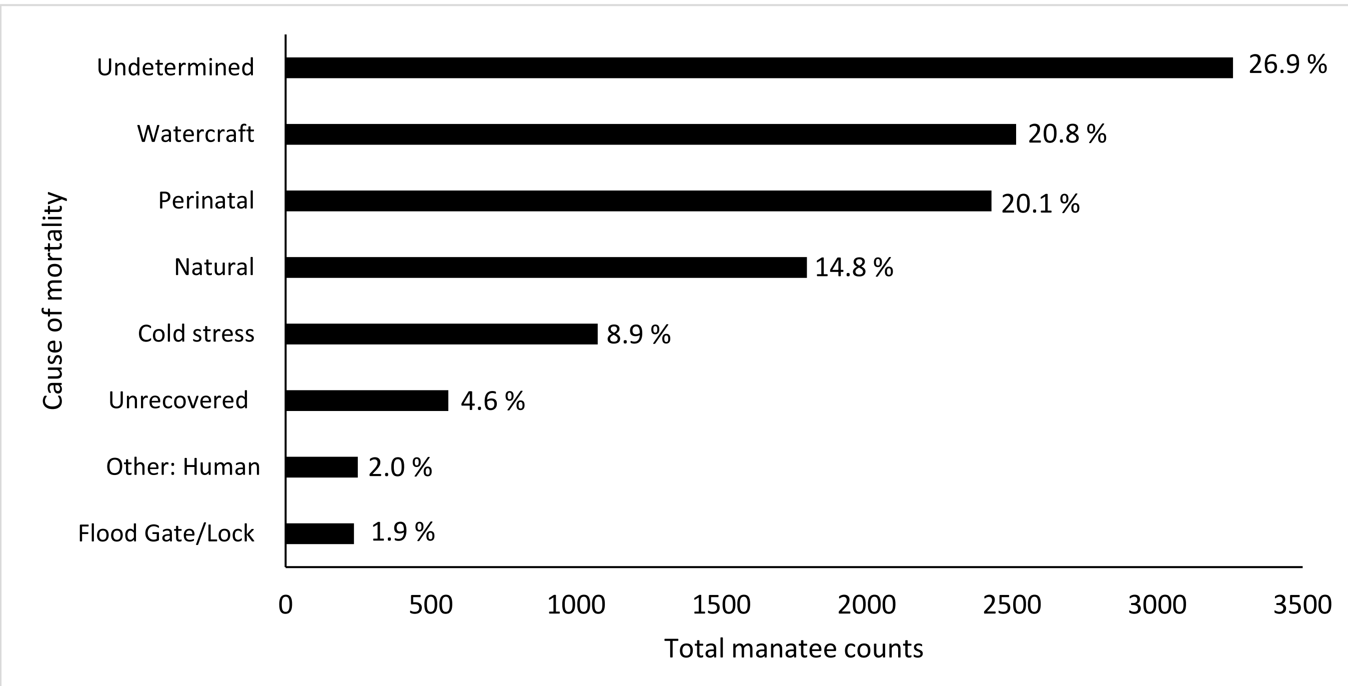


Figure 4-28. Total manatee deaths in Florida by category from 1974-2018 (from FWC 2018). Percentages indicate categorical contribution to overall reported deaths.

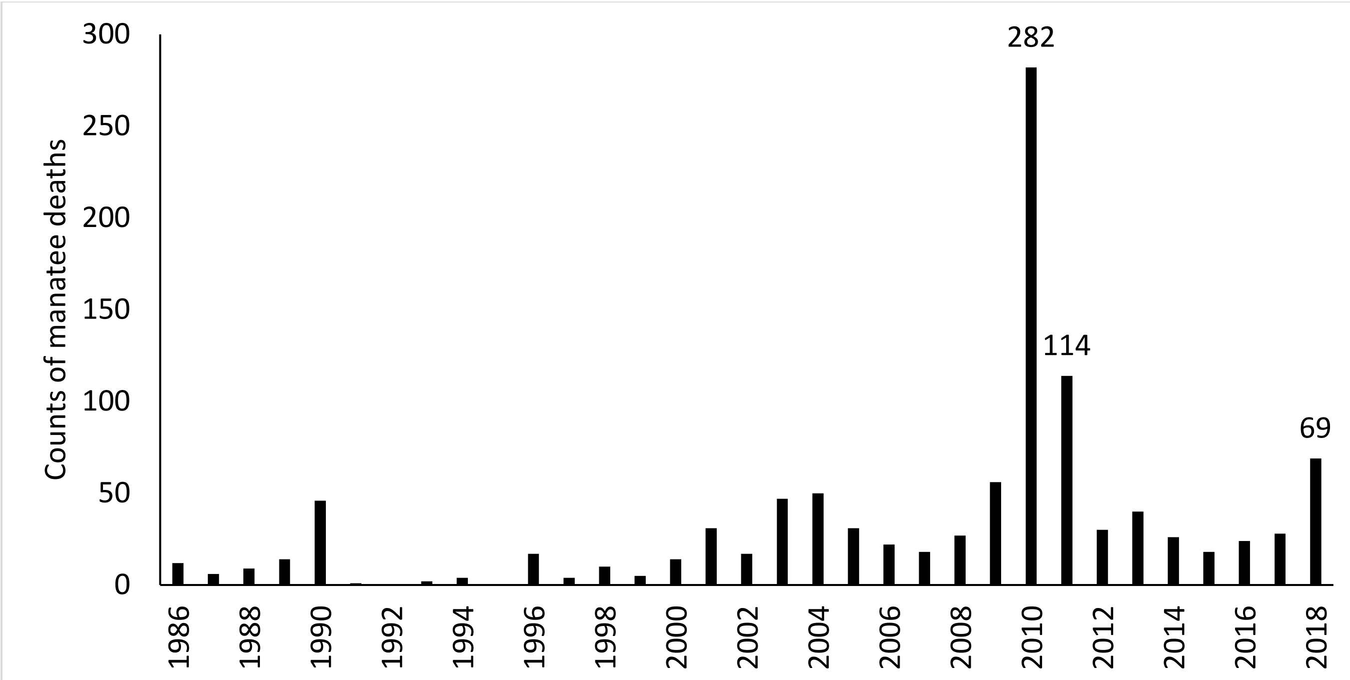


Figure 4-29. Counts of manatee deaths due to cold stress from 1974-2018 (from FWC 2018). No reports of cold stress-induced deaths were reported prior to 1986. According to data accessed within the FWC database at the time of analyses for this report, the 2017 and 2018 data were considered to be preliminary.

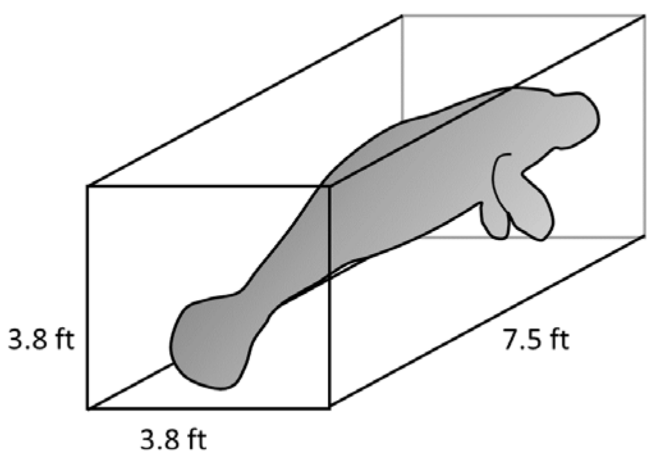


Figure 4-30. Dimensional criteria adopted for suitable manatee thermal space during cold stress events. Manatee space requirements are reproduced from Rouhani et al. (2007).

4.5 Common Snook Habitat

Common Snook (*Centropomus undecimalis*) is one of Florida's most popular gamefish and were the third most commonly targeted gamefish on the Florida Gulf Coast in 2014 (Muller et al. 2015). Common Snook were the eighth most abundant fish caught in the Chassahowitzka River from Dec. 2013 to June 2018, constituting 3 percent of the total catch (Table 4-6.) (Johnson et al. 2017). Snook were more common in summer than winter.

Studies of Common Snook have demonstrated temperature-based habitat requirements associated with a 10-15°C threshold. The geographical distribution of Common Snook is restricted by temperature with their northern range limited by the 15°C winter isotherm (Adams et al. 2012, Blewett and Stevens 2014); they stop feeding completely at 14.2(±2.1)°C, lose equilibrium at 12.7°C, and die at 12.5°C (Schafland and Foote 1983). However, some populations of Common Snook may be less sensitive to temperature (Howells et al. 1990).

Cold events in winters, and particularly in winter 2010, have negative impacts on Common Snook populations along the south-western coast of Florida. Common Snook in this region of Florida are located at the northern extent of their geographical distribution and can experience thermal stress when water temperatures decline in winter months (Muller et al. 2015). Lethal effects of cold were responsible for decline in Common Snook populations in the region following winter 2010 (Adams et al. 2012; Stevens et al. 2016). As a result of mortality caused by cold stress in 2010, the Common Snook fishery was closed in the Gulf from 2010 to 2013 (Muller et al. 2015). Common Snook responded differently in different estuaries in Florida (Stevens et al. 2016), underlying the importance of spring-fed estuaries that provide consistent temperature refuge from cold waters in the Gulf of Mexico. Unlike the Florida Manatee, Common Snook appear to have no upper limit to their useable winter warm-water habitat.

Common Snook have the ability to recognize relatively short short-term changes in weather patterns and seek warm warm-water habitat. Therefore, reductions in the volume and area of water greater than 15°C have the potential to adversely impact Common Snook populations. Electrofishing surveys and seine-haul data from the Charlotte Harbor area suggest that Common Snook may move to sites that are warmer or more stable during cold fronts (Blewett et al. 2009). At a broader scale, hydrology and temperature drive seasonal patterns of river use by the species along a latitudinal gradient (Stevens et al. 2018). In rivers of southwestern Florida (those in Everglades and Charlotte Harbor), Common Snook abundances increased three-fold during the time of year when surface waters inundating floodplains recede and force prey into the main stems of rivers. In spring-fed rivers north of Tampa Bay, Common Snook abundances generally double during winter compared to those of summer; stable water temperatures are thought to provide thermal refuge at the northernmost range of the species. Therefore, it should be expected that reductions in the volume and area of these warmer aquatic habitats (i.e. springs and spring-fed rivers/streams) has the potential to adversely impact Common Snook populations.

Common Snook are slightly more abundant in summer (22/km) than in winter (17/km) in the Chassahowitzka River (Figure 4-24).

CHAPTER 5 - HYDROLOGIC EVALUATION OF THE CHASSAHOWITZKA RIVER WATERSHED

This chapter provides a description of the Chassahowitzka River watershed, Chassahowitzka springshed, and surrounding area that includes information on the geology, hydrology, rainfall, water use, springflow, and groundwater withdrawal impacts to the Chassahowitzka River. Prior to the development of a minimum flow, the District evaluates hydrologic changes in the vicinity of the system and determines the impact on flow from existing groundwater withdrawals.

5.1 Hydrologic Setting

The Chassahowitzka River watershed boundary is delineated by the USGS) (see Figures 2-3 and 2-7). It is important to note that much of the watershed is internally-drained – so while the surface water runoff contributing area has been identified – there is very little runoff that actually occurs to the Chassahowitzka River. It is primarily a baseflow-dominated or spring-fed system.

The groundwater contributing area to the Chassahowitzka Spring Group is named a springshed. The springshed covers an area of about 105 square miles in northern Hernando and southern Citrus Counties (Figure 5-1; see also Figure 2-1 and 2-3). Springsheds are generally based on the groundwater flow field of the Upper Floridan aquifer (UFA). They may change slightly from year to year based on the measured elevation of the water levels within the UFA and availability of measured water level data. However, for the most part, they are semi-permanent areas that contribute flow to a spring.

The land area within the Chassahowitzka Springshed has high rolling sand hills with pine forest, pastureland, and developed areas. The hydrogeologic framework in this area includes a surficial aquifer, a discontinuous intermediate confining unit, 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 sand just above the contact with limestone. A thin, sometimes absent, sandy clay layer forms the intermediate confining unit (ICU) and overlies the limestone units of the UFA. In general, a regionally extensive surficial aquifer is not present because the clay confining unit is thin, discontinuous, and breeched by numerous karst features (Figure 5-2). Because of this geology, the UFA is unconfined over most of the northern Hernando and southern Citrus County area. In this unconfined setting, high infiltration soils and generally deep-water table conditions exist with UFA water levels varying from 10 to more than 50 feet below land surface except west of US 19 near the coast or near the Withlacoochee River to the east (Figure 5-3).

The geologic units, in descending order, that form the freshwater portion of the UFA include the upper Eocene age Ocala Limestone and the middle Eocene age Avon Park Formation (Table 5-1). In northern Hernando and southern Citrus Counties, the Ocala 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 500 feet in southwest Marion County to 1,000 feet in central Pasco 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 sub-Floridan confining unit forms the bottom of the Floridan aquifer system and is found in the top part of the Cedar Keys Formation at an elevation of -1,700 feet NGVD29 (FGS 2009).

The Chassahowitzka springshed is located within the 4,600 square mile Northern West-Central Florida Groundwater Basin (Southwest Florida Water Management District 1987), which is one of seven regional groundwater basins located on the Florida peninsula (Figure 5-4). Similar to topographic divides that separate surface water drainage basins, groundwater basins are delineated by divides formed by high and low elevations in groundwater levels. Groundwater does not flow laterally between basins. Each basin also generally contains similar geology regarding the confinement of the UFA. In well-confined basins, water level declines due to pumping are greatest and most widespread. In leaky or unconfined basins, regional pumping impacts are confined to within each basin or along their boundaries. These effects are more localized and near major pumping centers due to leakage from the overlying surficial aquifer or high storage within the UFA. This limits regional pumping impacts. This can be seen in the UFA water level change from 1970 to 2010 from the USGS (Figure 5-5). The greatest lowering of water levels in the UFA occurs in well-confined areas of southeast Georgia, Northeast Florida, and Southwest Florida, where there is large groundwater extraction (Williams et al. 2011). In the unconfined regions, water level changes are small. Changes in UFA water levels largely occur due to rainfall variation. In this region, pumping impacts are more localized and groundwater extraction is low.

In the Chassahowitzka springshed, the UFA is regionally unconfined and is located within a highly karst-dominated region. Dissolution of limestone is an active process via infiltration of rainwater because the limestone units of the UFA are close to land surface and poorly confined. Numerous sinkholes, internal drainage, and undulating topography that is typical of karst geology dominates the landscape. These active karst processes lead to enhanced permeability within the Floridan aquifer. The mean transmissivity value of the UFA based on seven aquifer performance tests in Citrus, Levy, and western Marion Counties is 1,070,000 $feet^2$/day (Southwest Florida Water Management District 1999). There are five additional first-magnitude springs (flow greater than 100 cfs discharge) found within the Northern West-Central Florida Groundwater Basin: the Kings Bay group, Homosassa group, Rainbow group, Weeki Wachee group, and Silver Springs. In addition, the highest recharge rates to the UFA in the state occur in West-Central Hernando and Citrus Counties with values ranging between 10 and 25 inches per year (Sepulveda 2002).

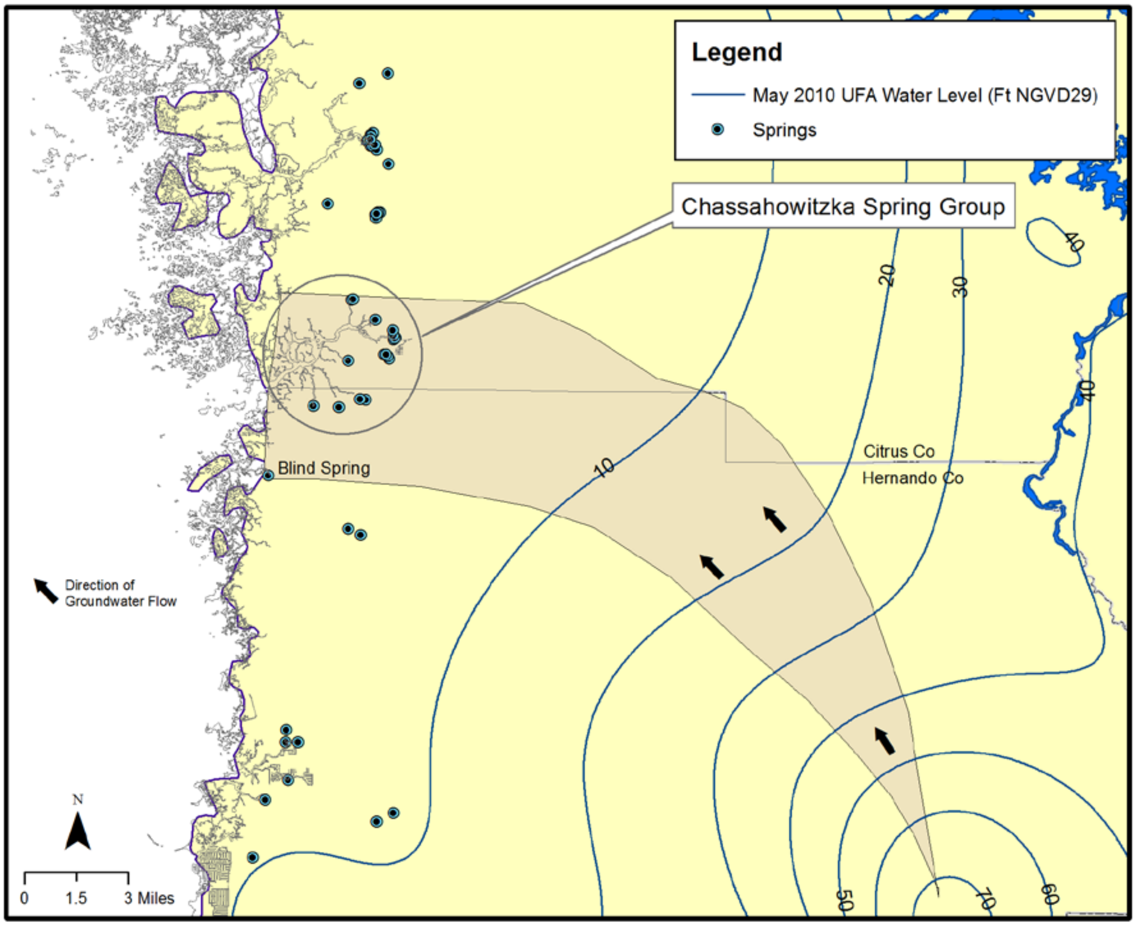


Figure 5-1. Location of Chassahowitzka springshed.

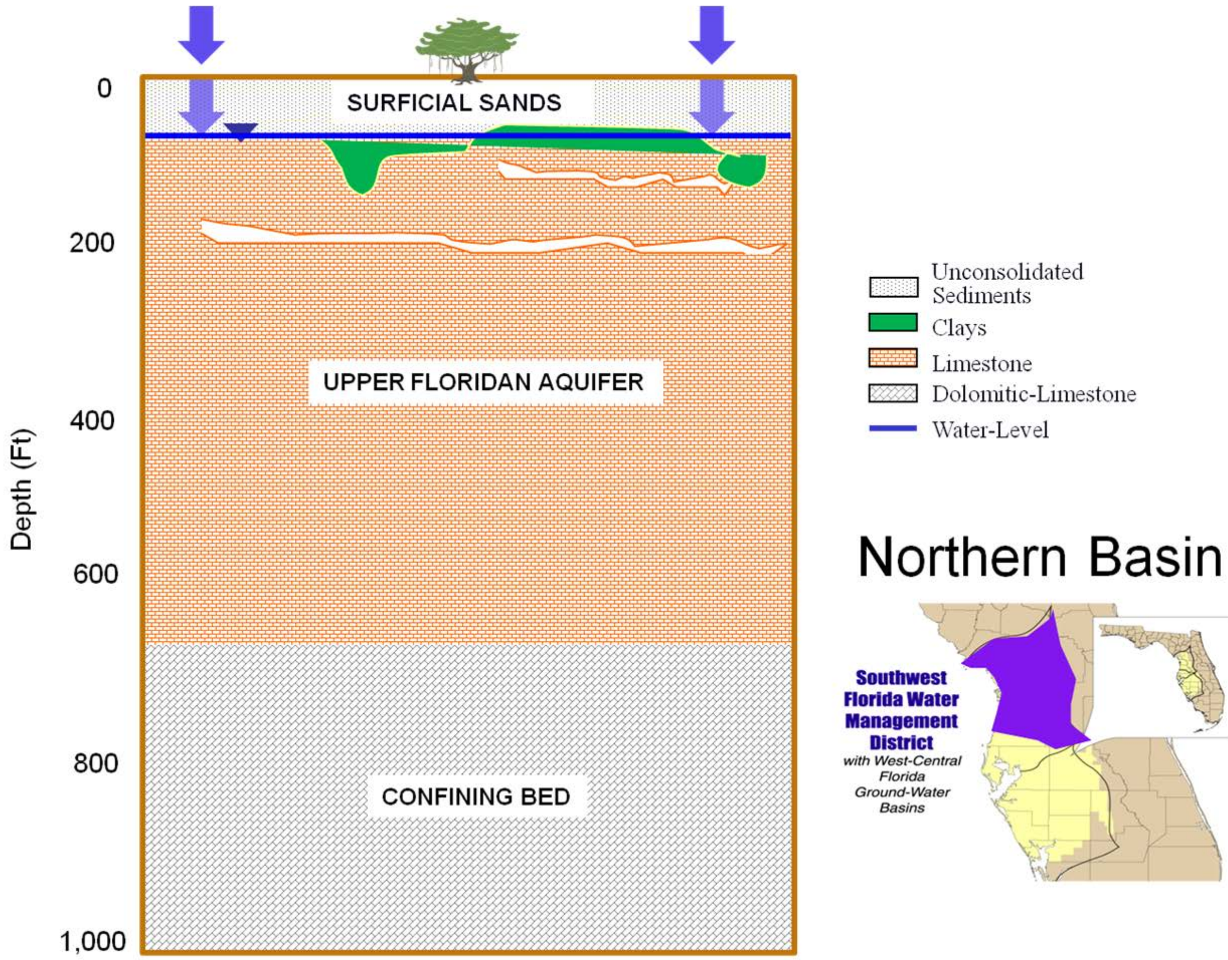


Figure 5-2. Generalized hydrogeology within the Chassahowitzka springshed.

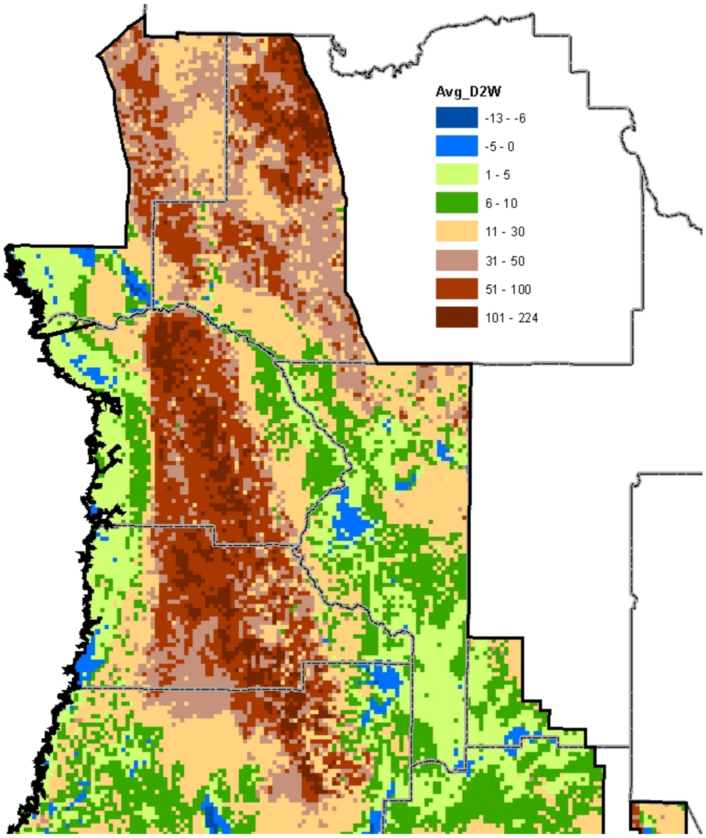


Figure 5-3. Depth below land surface (feet) to the water level in the Upper Floridan aquifer based on the average of May and September USGS potentiometric surface maps (average 2002 conditions).

Table 5-1. Hydrogeology of the Chassahowitzka Springshed area (modified from Miller 1986, Sacks and Tihansky 1996).

Series	Stratigraphic Unit	Hydrogeologic Unit		Lithology
Holocene to Pliocene	Undifferentiated Surficial Deposits	Unsaturated Zone, Surficial Aquifer or locally perched Surficial Aquifer		Sand, silty sand, clayey sand, sandy clay, peat, and shell
Eocene	Ocala Limestone	Upper Permeable Zone	Upper Floridan Aquifer	Limestone, white to tan, friable to micritic, fine-grained, soft, abundant foraminifera
	Avon Park Formation	Middle Confining Unit 2		Dolomite is brown, fractured, sucrosic, hard. Interstitial gypsum in Middle Confining Unit 2
	Oldsmar Formation	Lower Permeable Zone	Lower Floridan Aquifer	Limestone and dolomite. Limestone is tan, recrystallized. Anhydrite and gypsum inclusions.
Paleocene	Cedar Keys Formation	Basal Confining Unit		Massive anhydrites

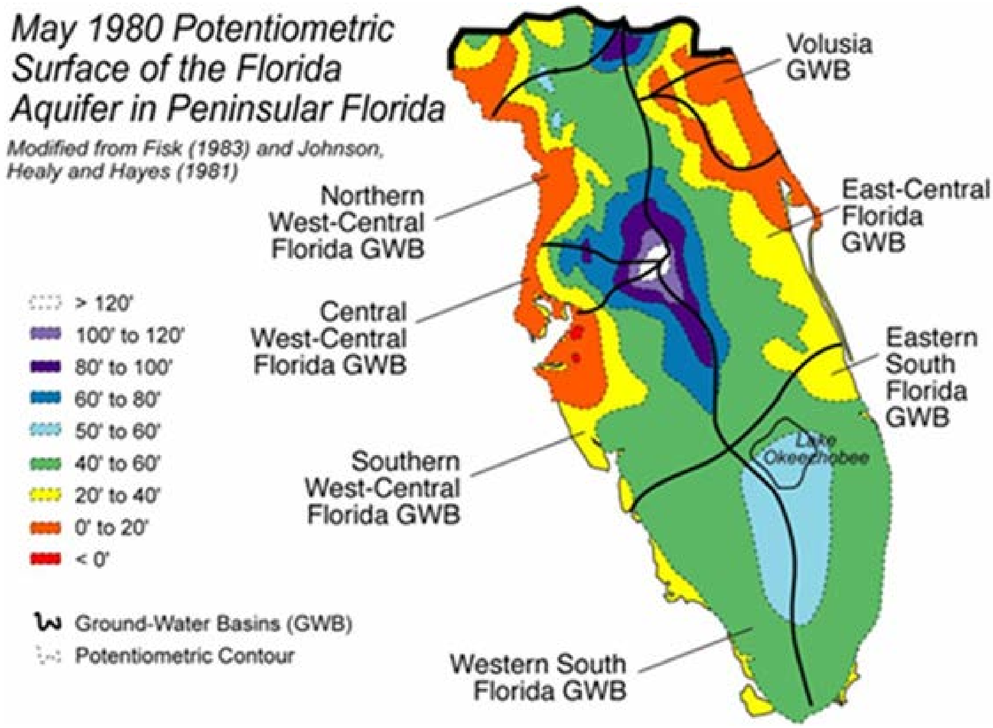
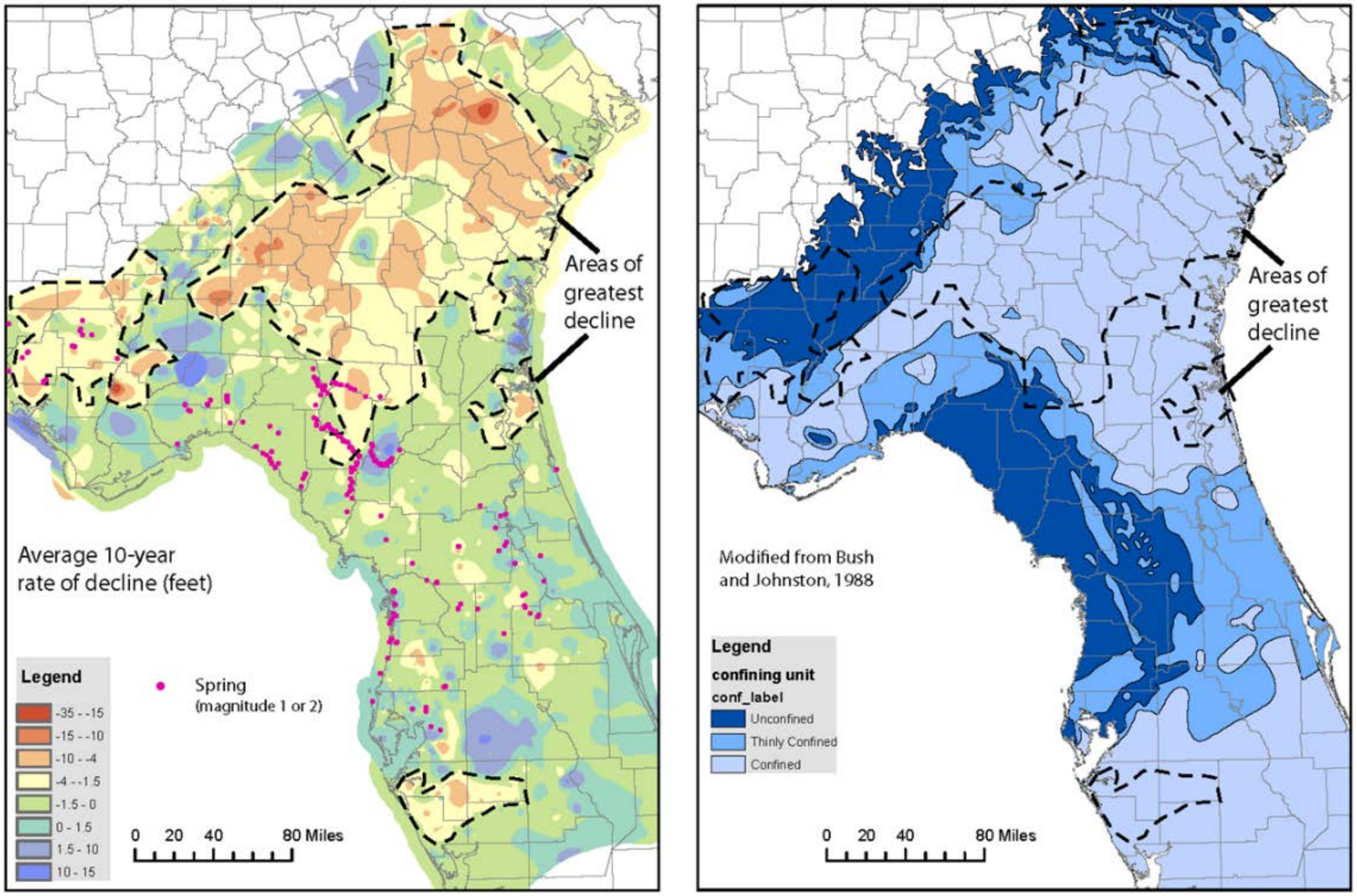


Figure 5-4. Location of regional groundwater basins in the Upper Floridan aquifer.



A. Composite 10-year rate of decline map for 1970 to 2010. Reds and yellows indicate declining trends; blues indicate increasing trends; greens indicates slightly increasing or decreasing trends in water levels.

B. Relative confinment of the Floridan Aquifer System Light blue indicates confined areas and darker blues indicate thinly confined and unconfined areas respectively.

Figure 5-5. Water level change in the Upper Floridan aquifer from 1970 through 2010 and the degree of confinement for the Upper Floridan aquifer (from Williams et al. 2011).

5.2 Climate and Rainfall

The Chassahowitzka springshed 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^{o} F (21^{o} C). Mean summer temperatures are in the low 80s (^{o}F), and the mean winter temperatures are in the upper 50s (^{o}F).

Average rainfall is approximately 54 inches per year but varies widely from season to season and year to year. About 60 percent of annual rainfall occurs in 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. An analysis of median decadal rainfall and 20-year moving average rainfall accumulated from the Ocala, Inverness, and Brooksville National Weather Service (NWS) stations from 1901 through 2017 shows an increasing trend up until the mid-1960s and then a declining trend thereafter (Figures 5-6 and 5-7). 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 bottom 10th percentile (P90) for most of the averages post-2000 (Figure 5-6). Recent 20-year periods (1996-2015, 1997-2016, and 1998-2017) have increased and lie between the P90 and P50 percentiles.

The departure in annual rainfall from the mean shows that 21 out of 29 years since 1989 have recorded below average rainfall (Figure 5-8). Therefore, the recent quarter century has been extremely dry; it is the driest in 117 years of recorded rainfall history as averaged from these three stations. Over the last six years since 2012, however, rainfall has been near average to slightly above average (54.9 in/yr averaged from the three stations).

Much of the lower rainfall experienced over the last 25 years is related to below average landfalling hurricanes and reductions in dry season rainfall associated with increasing La Niña events (Cameron et al. 2018). The state of Florida saw 11 consecutive years – from 2005 (Wilma) until 2016 (Hermine) – without a single landfalling hurricane. This represents the longest hurricane drought for the state in more than 150 years. Cameron et al. (2018) also found that an increase in La Niña months and a simultaneous decrease in El Niño months has led to lower dry season rainfall at most stations in the District. In the northern portion of the District, these ENSO-driven dry season decreases have completely cancelled out AMO-related wet season increases – such that the current warm phase has experienced lower annual rainfall than the preceding cool phase. This reduced dry season rainfall in the northern District largely explains more recent low aquifer water levels, river, and spring flows that haven’t recovered to those of the preceding warm AMO period prior to 1970.

In addition to the rainfall recorded at Brooksville, Inverness, and Ocala stations, radar-estimated rainfall became available to the District in 1995 at a 2-kilometer (km) grid scale. Radar-estimated rainfall was averaged for the entire springshed each year from 1995 through 2017 using the 105 square-mile May 2010 springshed boundary (Figure 5-9). Similar to the NWS station data, 14 out of 23 years of radar estimated rainfall were below average since 1995 (Basso 2019a [Appendix

5]). The cumulative departure from the mean annual rainfall for the 23-year period was -39.3 inches.

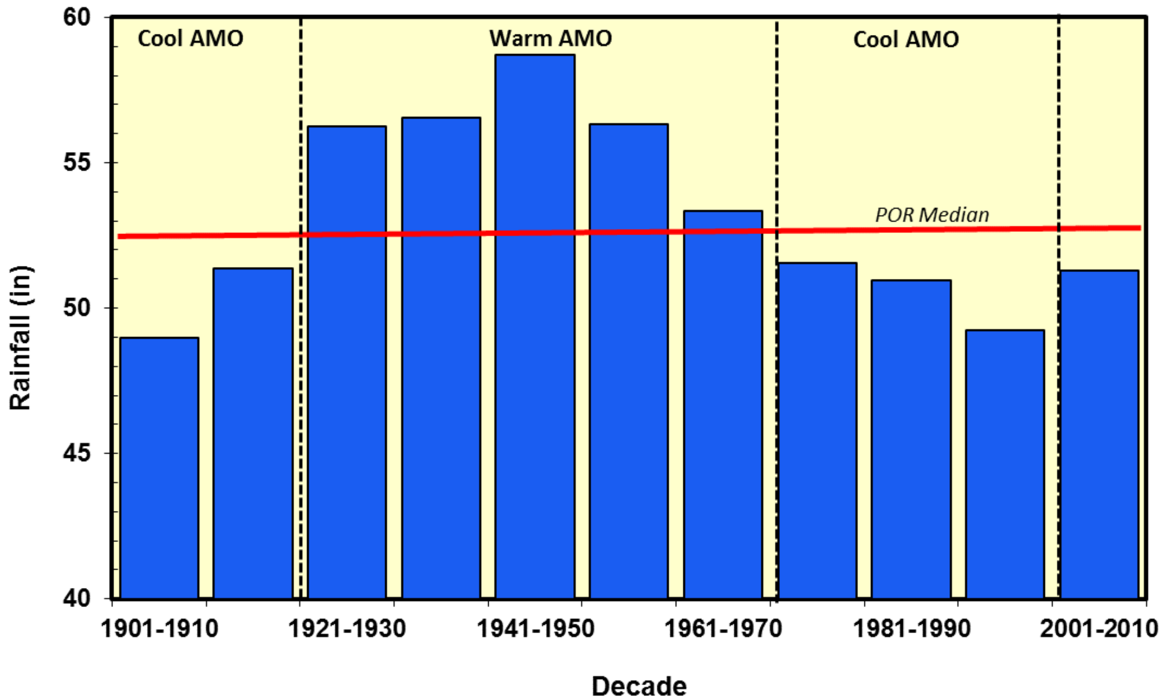


Figure 5-6. AMO periods and median decadal rainfall from the Brooksville, Inverness, and Ocala National Weather Service stations from 1901 through 2010. Red line indicates median rainfall for the entire period of record (POR).

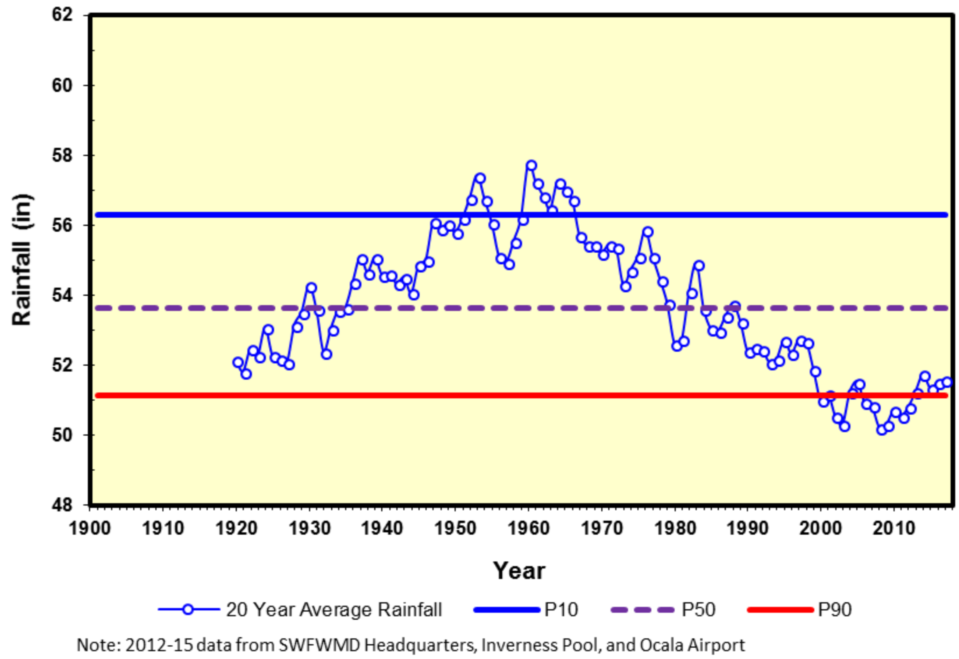


Figure 5-7. Twenty-year moving average rainfall from the Brooksville, Inverness, and Ocala National Weather Service stations from 1901 through 2017.

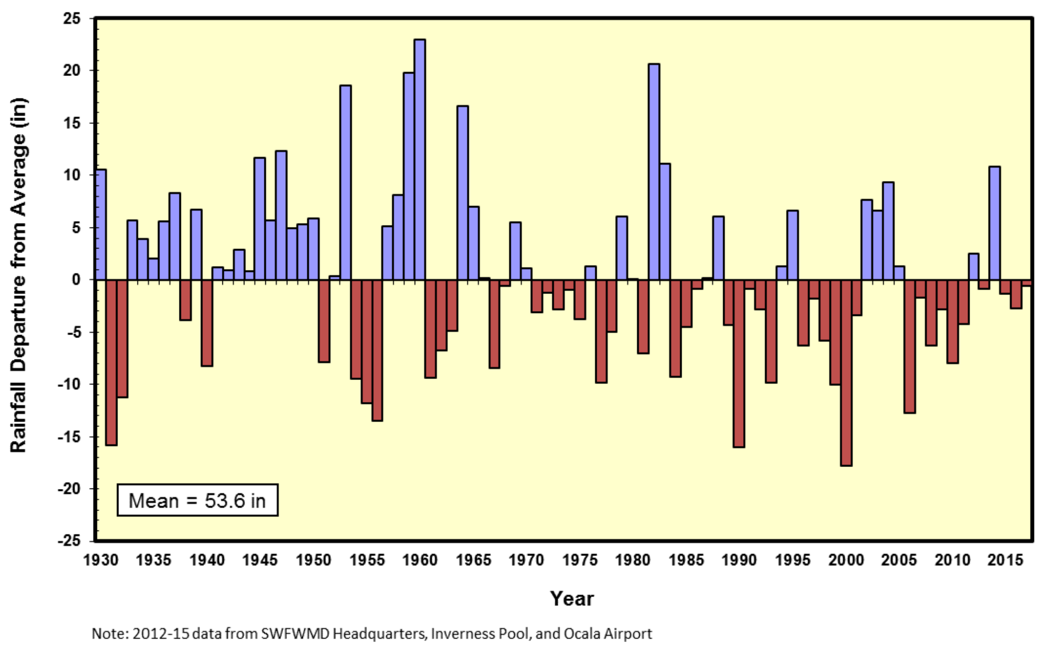


Figure 5-8. Departure in annual rainfall from the Brooksville, Inverness, and Ocala National Weather Service stations from 1930 through 2017.

5.3 Chassahowitzka Main Spring Discharge and Upper Floridan Aquifer Water Levels

The Chassahowitzka Spring group is located in southwest Citrus County. The spring complex forms the headwaters of the Chassahowitzka River, which flows west to the Gulf of Mexico approximately six miles through low coastal hardwood hammock and marsh. There are as many as five springs that flow into the upper part of the river and many more springs are known to exist in the lower portion (Rosenau et al. 1977). The entire river is tidally influenced (Scott et al., 2004).

The Chassahowitzka Spring Group consists of a collection of springs that discharge to the Chassahowitzka River or its tributaries. It includes Chassahowitzka Main, Crab Creek, Ruth/Potter, Salt Creek, Baird, Beteejay, Ryle Creek, Blue Run, Hernando Unnamed 10, Hernando Unnamed 8, and Blind Springs. All the springs are tidally influenced. Chassahowitzka Main Spring is 360 feet (ft) northeast of the boat ramp and is in the middle of the run. This spring is at the head of a large pool that measures 147 ft north to south and 135 ft east to west (Scott et al. 2004).

The Chassahowitzka Main Spring discharge has been continuously recorded by the USGS (Figure 5-10) from the Chassahowitzka River near Homosassa, FL Gage (No. 02310650). Continuous daily flow observations based on a regression equation were initiated in early 1997. The USGS has used rating curve relations between water levels in the Weeki Wachee well and measured flow on the Chassahowitzka River to calculate continuous flow at 15-minute intervals at this station. Index velocity flow measurements, a newer method of measuring flow, was initiated in 2012 at this station by the USGS.

The mean flow from the Chassahowitzka Main Spring is 59.9 cfs or 38.7 million gallons per day (mgd), based on the period from February 1997 through June 2018 (Figure 5-10). In 2017, the average yearly flow was 62.4 cfs, which is slightly above the long-term mean value for the spring. Total estimated spring group flow was 205 cfs for 2010 conditions based on simulated rates in the Northern District Model Version 5 (HGL and Dynamic Solutions, 2016).

The Chassahowitzka No.1 Deep Well, which monitors water levels within the UFA, is located about one mile east of the main spring vent. Data from this well was first recorded in late 1965, and its water level history is shown in Figure 5-11. Aquifer water levels have generally fluctuated between 5 and 10 feet NGVD29 over the last 50 years.

Simple linear regression of the daily water levels since 1965 shows a statistically significant downward trend ($p \leq 0.05$) of about 0.6 feet for the period October 1965 through June 2018 (Figure 5-12). However, applying linear regression to the daily water levels from January 1990 through June 2018 indicates slightly rising water levels that are also statistically significant. Table 5-2 shows linear water level trends since 1965 and 1990 and their significance levels. Based on this analysis, much of the long-term water level decline at this well occurred prior to 1990. This decline was due predominately to higher rainfall during the pre-1990 period compared to the last 25 years.

In addition to the Chassahowitzka No. 1 well, other long-term monitor water levels were examined within or adjacent to the springshed that had data back to at least 1990. Individual well hydrographs since 1990 are shown in Figure 5-13 for seven wells within the Chassahowitzka and adjacent Homosassa springsheds. Linear regression of the seven Upper Floridan aquifer monitor well water levels from 1990 through July 2018 showed that six of seven had increasing trends varying from 0.1 to 1 foot (Figure 5-14). Four of the six were statistically significant (Table 5-3). One well, the Romp 109 UFA well displayed a slight downward trend of 0.22 ft that was statistically significant. This data is generally consistent with water level trends evidenced in the Chassahowitzka No. 1 well over the last nearly three decades – that water levels vary from year to year due to annual variation in rainfall, but the overall trend is generally flat since the early-1990s.

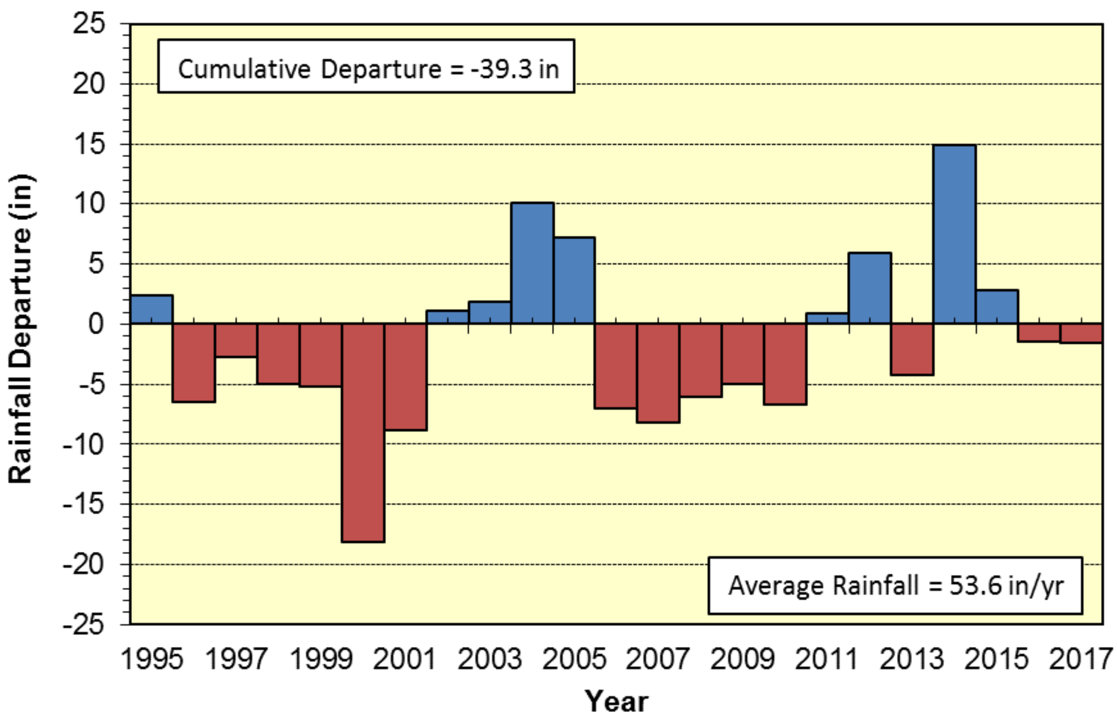


Figure 5-9. Annual departure in radar-estimated rainfall in the Chassahowitzka Springshed from 1995 through 2017.

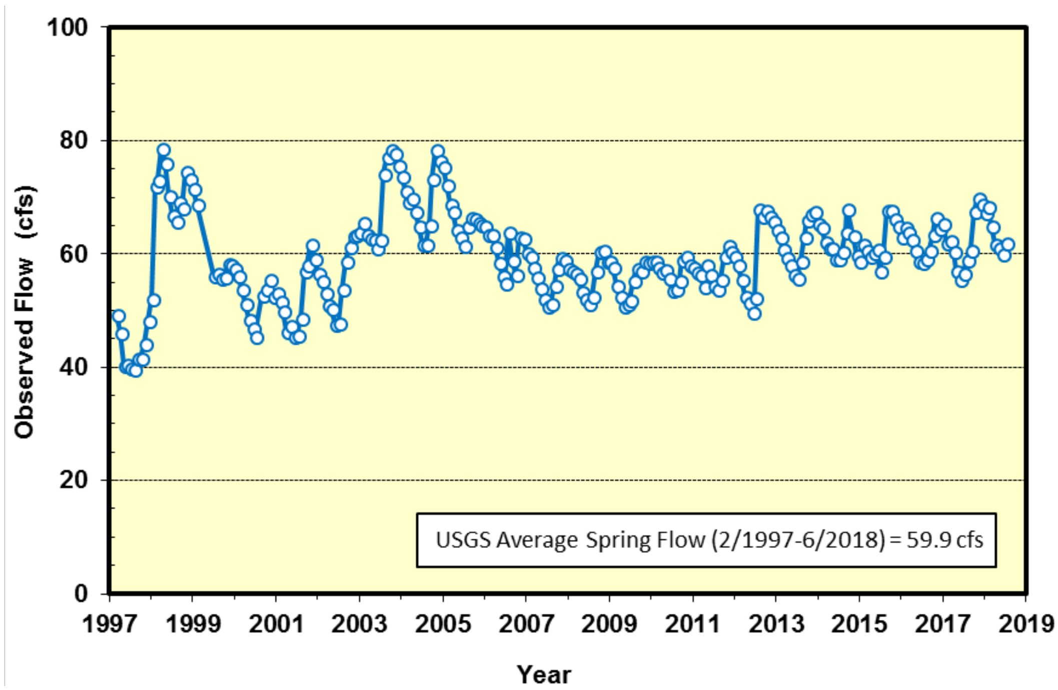


Figure 5-10. Average monthly flow at Chassahowitzka Main Spring from February 1997 to June 2018 (Source: USGS Chassahowitzka River near Homosassa - Gage No. 02310650).

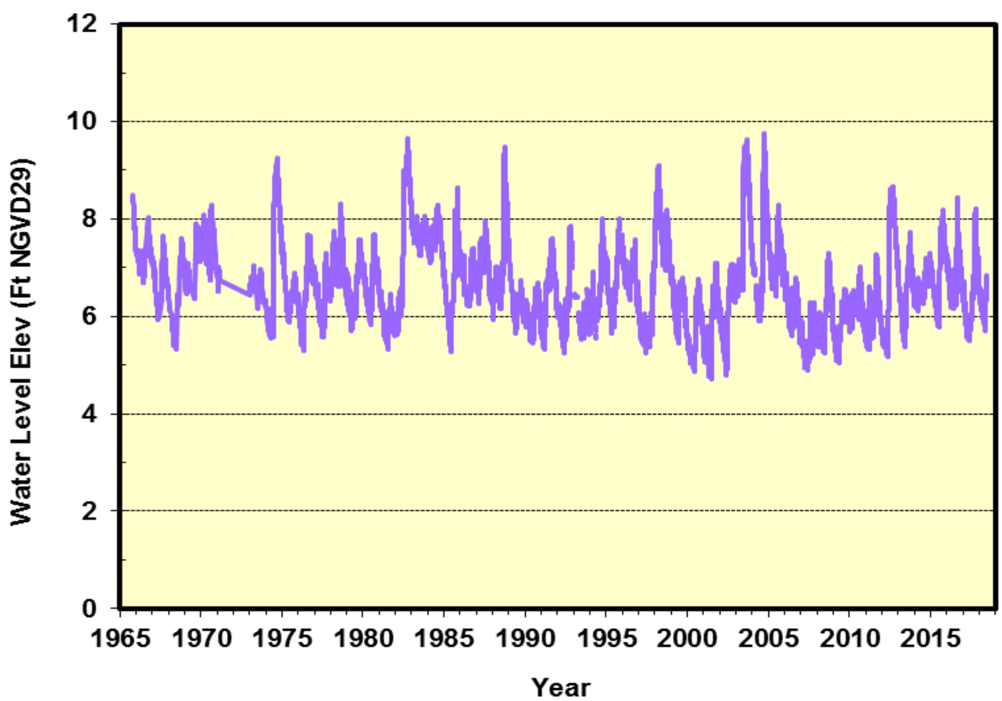


Figure 5-11. Water level history of the Chassahowitzka No. 1 Deep Well (October 1965 – June 2018).

Table 5-2. Linear trend and statistical significance level of Chassahowitzka No. 1 Deep Well water levels from 1965-2018 and 1990-2018.

Period of Record	Regression Equation	Slope (feet)	Total Water Level Change (feet)	Statistical Significance (p value≤0.05)
1965-2018	y = -0.0108x + 28.14	-0.0108	-0.56	<0.01
1990-2018	Y = 0.004x – 1.19	+0.004	+0.11	<0.01

Note: Statistical significance based on an alpha (p value) less than or equal to 0.05.

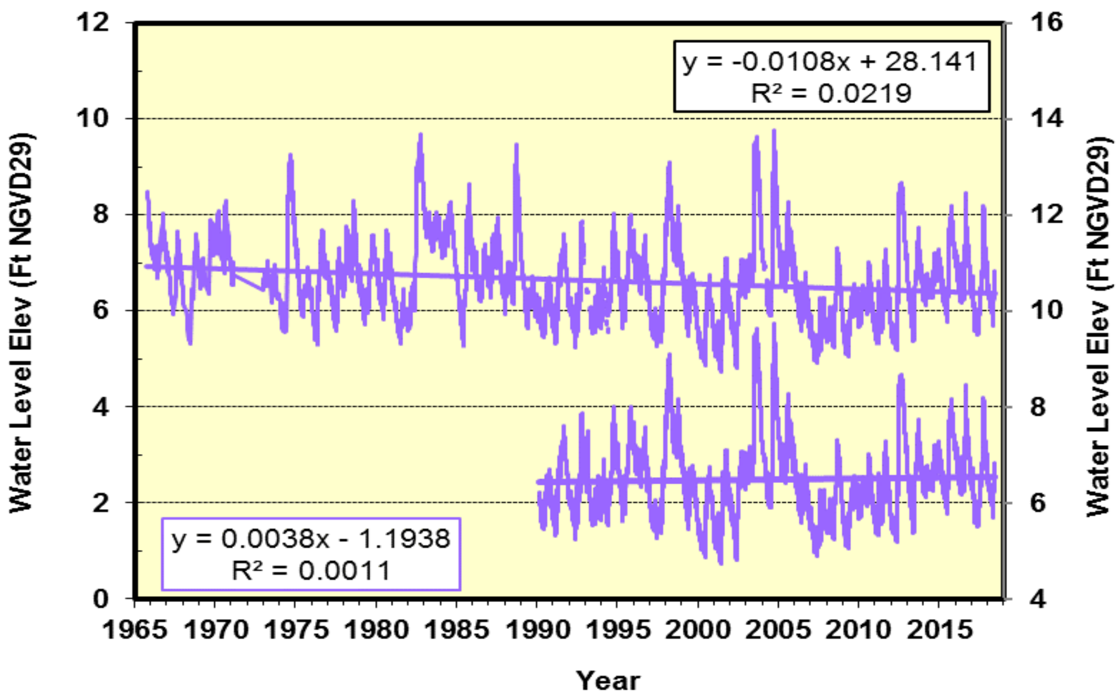


Figure 5-12. Simple linear regression of the Chassahowitzka No. 1 Deep Well water level trend from 1965-2018 and 1990-2018 (Note: Hydrograph from 1990-2018 assigned to secondary y-axis for viewing purposes).

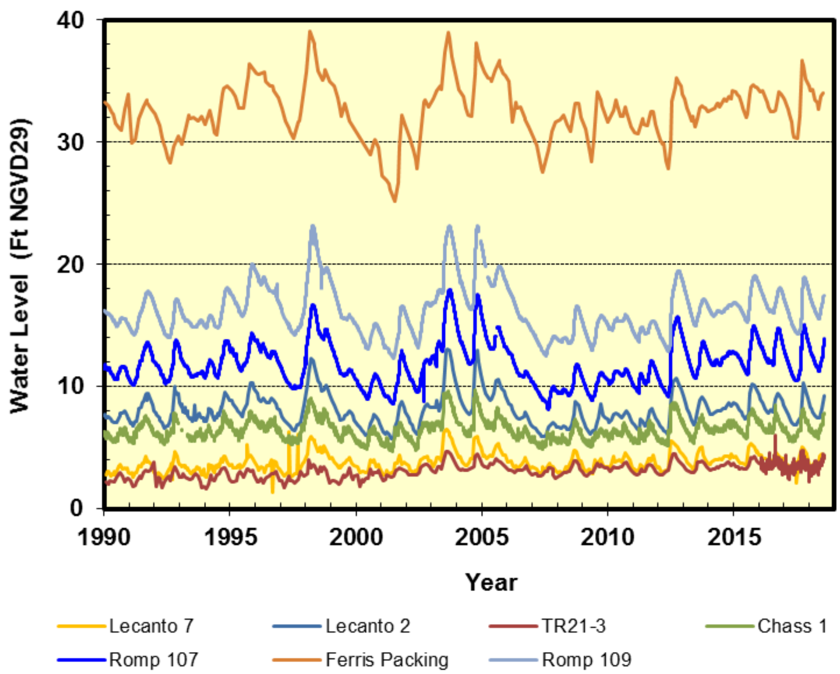


Figure 5-13. Water level history from 1990-2018 for seven UFA monitor wells within or near the Chassahowitzka and Homosassa springsheds.

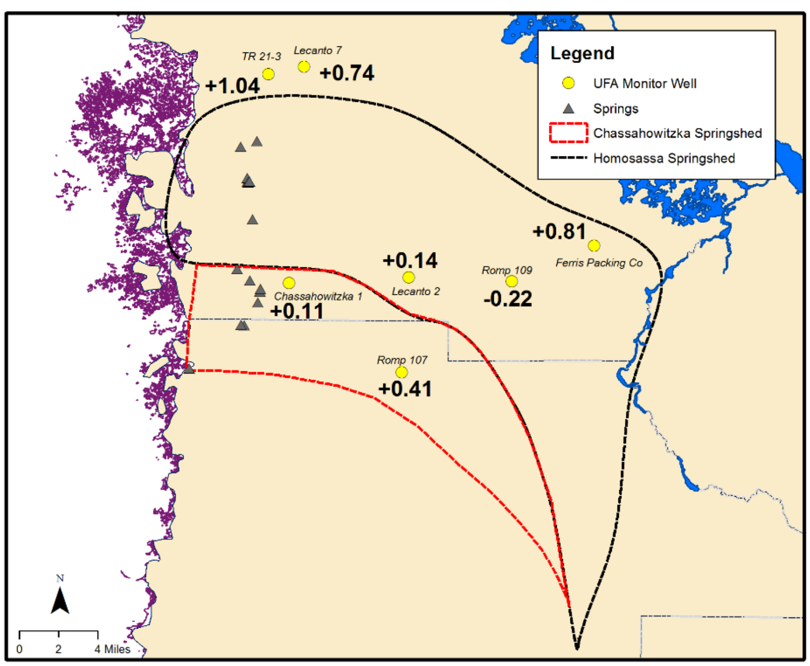


Figure 5-14. Water level change (ft) from 1990 to 2018 based on linear regressions of seven UFA monitor wells within or near the Chassahowitzka and Homosassa springsheds.

Table 5-3. Linear trend and statistical significance level of seven UFA monitor well water levels from 1990-2018 within or near the Chassahowitzka and Homosassa springsheds.

Well Name	Regression Equation	Slope (feet)	Total Water Level Change (feet)	Statistical Significance (p value≤0.05)
Chassahowitzka 1	y = 0.0038x - 1.19	0.0038	0.11	< 0.01
Romp 107	y = 0.0147x - 17.57	0.0147	0.41	< 0.01
Lecanto 2	y = 0.0049x -1.79	0.0049	0.14	0.52
Ferris Packing Co.	y = 0.029x - 25.98	0.029	0.81	0.08
Romp 109	y = -0.0077x + 31.78	-0.0077	-0.22	< 0.01
TR21-3	y = 0.037x - 71.15	0.037	1.04	< 0.01
Lecanto 7	y = 0.0266x - 49.47	0.0266	0.74	< 0.01

Note: Statistical significance based on an alpha (p value) less than or equal to 0.05.

5.3.1 Rainfall and Upper Floridan Aquifer Water Levels

A cumulative sum analysis of annual rainfall averaged from the Brooksville, Inverness, and Ocala NWS stations and average annual water levels at the Chassahowitzka No. 1 Deep well from 1965 through 2017 indicates no significant change in slope for the period (Figures 5-15 and 5-16). In the cumulative sum analysis, any major deviation in slope that occurs for more than five years would indicate an influence other than rainfall affecting water levels in the well. This suggests that water levels in the UFA are fluctuating largely due to the natural variability of rainfall in the area.

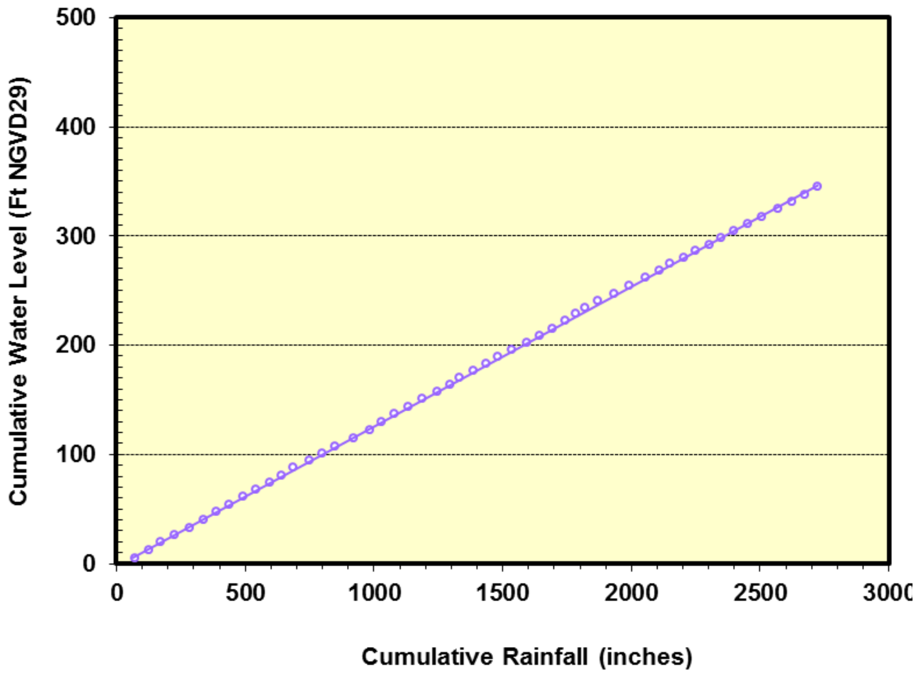


Figure 5-15. Cumulative sum of annual water levels at the Chassahowitzka No. 1 Deep well and average annual rainfall from the Brooksville, Inverness, and Ocala NWS stations from 1965-2017.

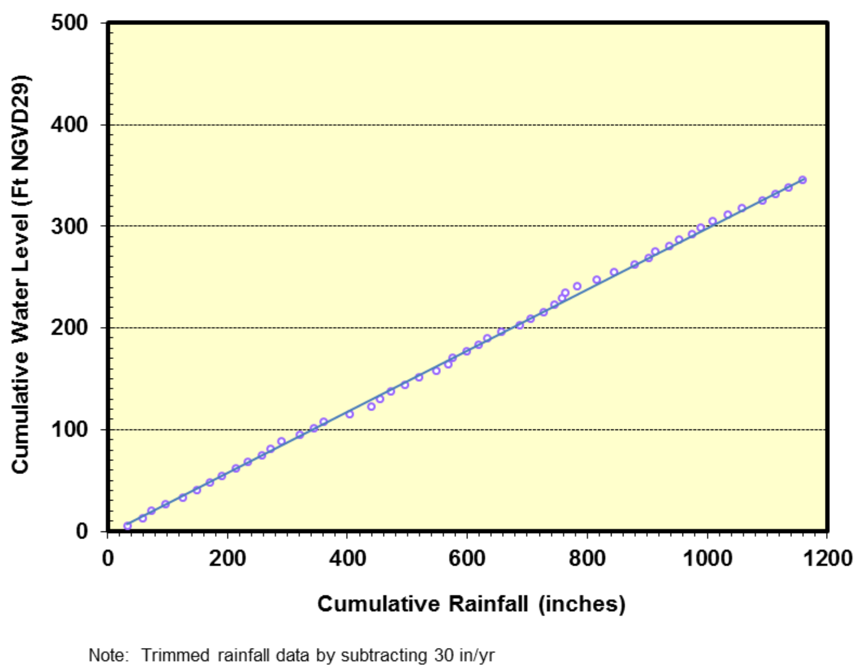


Figure 5-16. Cumulative sum of annual water levels at the Chassahowitzka No. 1 Deep well and average annual rainfall from the Brooksville, Inverness, and Ocala NWS stations from 1965-2017.

5.4 <u>Impacts of Groundwater Withdrawals on the Chassahowitzka River System</u>

The Northern District groundwater flow model (NDM) was used to predict the impacts of groundwater withdrawals on flow of the Chassahowitzka Spring Group. A water budget was also developed for the springshed to serve as a verification of model results.

5.4.1 Predicting Groundwater Withdrawal Impacts Using the Northern District Model

The Northern District Model (NDM) was originally developed in 2008 by Hydrogeologic, Inc. (HGL) (Hydrogeologic, 2008). Since that time, there have been several refinements to the original model, with subsequent Version 2.0 in 2010 and Version 3.0 in 2011. In 2013, Version 4.0 was completed by expanding the model grid slightly northward and east to the St. Johns River. This was done as a cooperative effort between the District (SWFWMD), St. Johns River Water Management District (SJRWMD), Marion County, and the Withlacoochee River Regional Water Supply Authority (Hydrogeologic, 2013). The domain of the NDM includes portions of the SWFWMD, the SJRWMD, and the Suwannee River Water Management District. The flow model encompasses the entire extent of the Central West-Central Florida Groundwater Basin (CWCFGWB) and the Northern West-Central Florida Groundwater Basin (NWCFGWB) and portions of the Northern East-Central Florida Groundwater Basin. The eastern boundary of the regional groundwater flow model extends to the St. Johns River, while the western boundary of the model domain extends approximately five miles offshore in the Gulf of Mexico (Figure 5-17). Version 5.0 was completed in August 2016 (Hydrogeologic, Inc. and Dynamic Solutions, 2016). Versions 4.0 and 5.0 were peer reviewed by Dr. Mark Stewart, P.G. and Dr. Pete Anderson, P.E.in a cooperatively-funded project for SJRWMD and SWFWMD (Anderson and Stewart, 2016). Dr. Stewart indicated in his most recent peer review that the *"NDM, Version 5.0, is the best numerical groundwater flow model currently available for assessing the effects of withdrawals in the central (Florida) springs region*."

The regional model grid consists of 212 columns and 275 rows with uniform grid spacing of 2,500 feet. The active model grid covers about 8,000 square miles in North-Central Florida. Seven active layers in the model represent the primary geologic and hydrogeologic units including: 1) Surficial Sand, 2) ICU, 3) Suwannee Limestone, 4) Ocala Limestone, 5) Upper Avon Park Formation, 6) MCU I and MCU II, and 7) Lower Avon Park Formation or Oldsmar Formation. The UFA is composed mainly of Suwannee Limestone, Ocala Limestone, and Upper Avon Park Formation. The LFA is composed of the permeable parts of both the Lower Avon Park and the Oldsmar Formations. Because of the permeability contrast between the units, each unit is simulated as a discrete layer rather than using a single layer to represent a thick sequence of permeable formations within the UFA. This model is unique for West-Central Florida in that it is the first regional flow model that represents the groundwater system as fully three-dimensional. Prior modeling efforts, notably Ryder (1982, 1985), Sepulveda (2002), Knowles et al. (2002), and Motz and Dogan (2004), represented the groundwater system as quasi-three dimensional.

A tremendous amount of hydrologic and geologic data was utilized to construct and calibrate the NDM. The SWFWMD utilized hydraulic and geologic information from more than 50 Regional Observation and Monitoring-Well Program (ROMP) sites in the SWFWMD model area. At nearly every site, coring of the earth materials occurred from land surface to more than 1,000 feet below land surface. Aquifer permeability was tested via slug tests and packer tests at specified intervals within each aquifer. Monitor wells were installed in each aquifer to measure water levels through time. The SWFWMD installs continuous recorders or manually measures these monitor well water levels every month. This data is stored within a water management information database at SWFWMD with some of the wells having a water level history of 30 to 50 years. Aquifer performance tests were conducted at some of the sites to measure water level response in the UFA from temporarily pumping it at high rates. All this information assists District scientist's in understanding how the aquifer system responds to groundwater withdrawn and helps us build better models that represent the real world.

The NDM Version 5.0 was calibrated to steady-state 1995 calendar year conditions and transient conditions from 1996 through 2006 using monthly stress periods. The model was also verified for 2010 steady-state conditions. The calibration process simply involves modifying aquifer parameters within a reasonable range in the model to best match measured aquifer water levels at wells and springflows recorded by the USGS. This process accounts for some of the uncertainty in aquifer parameters between data points.

If a model can closely replicate aquifer water levels and flow through time, then it is deemed well-calibrated. This in turn provides confidence that it is an effective tool to make predictions. In 2010, water levels from over 384 observation wells in the Upper Floridan aquifer were compared with simulated water levels at each well location within the model domain (Figure 5-18).

The groundwater flow and solute transport modeling computer code MODHMS was used for the groundwater flow modeling (Hydrogeologic, 2011). MODHMS is an enhanced version of the USGS modular, three-dimensional groundwater flow code (McDonald and Harbaugh 1988). This code was selected because of its powerful ability to simulate variably saturated conditions in Layer 1 coupled with its ability to model saltwater intrusion as a solute transport model in the northern region of the District.

In NDM Version 5.0, mean water level error (simulated minus observed) in the UFA for 1995 and the 1996-2006 average transient period was +0.17 feet and +0.41 feet, respectively (Hydrogeologic, Inc. and Dynamic Solutions, 2016). The mean absolute error varied from 3.77 to 3.61 feet for both periods, respectively, based on 137 wells in 1995 and 157 wells from 1996-2006. These statistics were for wells within the 4,600-square mile NWCFGWB. The mean error for Chassahowitzka Main Spring flows (simulated minus observed) for 1995 was minus one percent and for the 1996-2006 period was plus one percent. Mean error during the 2010 verification period was minus two percent.

To determine potential impacts to Chassahowitzka Spring group flow, 2010, 2015, and projected 2040 groundwater withdrawals with and without conservation/reuse were simulated in the NDM under long term transient conditions (five years) and compared to pre-pumping conditions (zero withdrawals) by running the model one year under transient conditions. Groundwater withdrawals include both water use permitted and domestic self-supply withdrawals. The UFA heads and springflows generated at the end of each period were subtracted from UFA heads and springflows at the end of the pre-pumping simulation to determine aquifer water level drawdown and flow changes. The model predicts UFA drawdown of approximately 0.1 feet from pre-pumping to 2015 conditions at Chassahowitzka Springs. The predicted reduction in Chassahowitzka Spring group flow from pumping in each period is shown in Table 5-4. Springs for the Chassahowitzka spring group simulated in the NDM5 include Potters Creek, Salt Creek, Crab Creek, Chassahowitzka Main, Baird, Beteejay, Ryle Creek, Blue Run, Hernando Unnamed 10, Hernando Unnamed 8, and Blind Springs. Predicted flow changes range from 1.4 percent due to 2015 pumping to 1.9 percent due to projected 2040 withdrawals without conservation and reuse. Predicted flow impacts are reduced to 1.7 percent in 2040 with planned conservation and reuse projects.

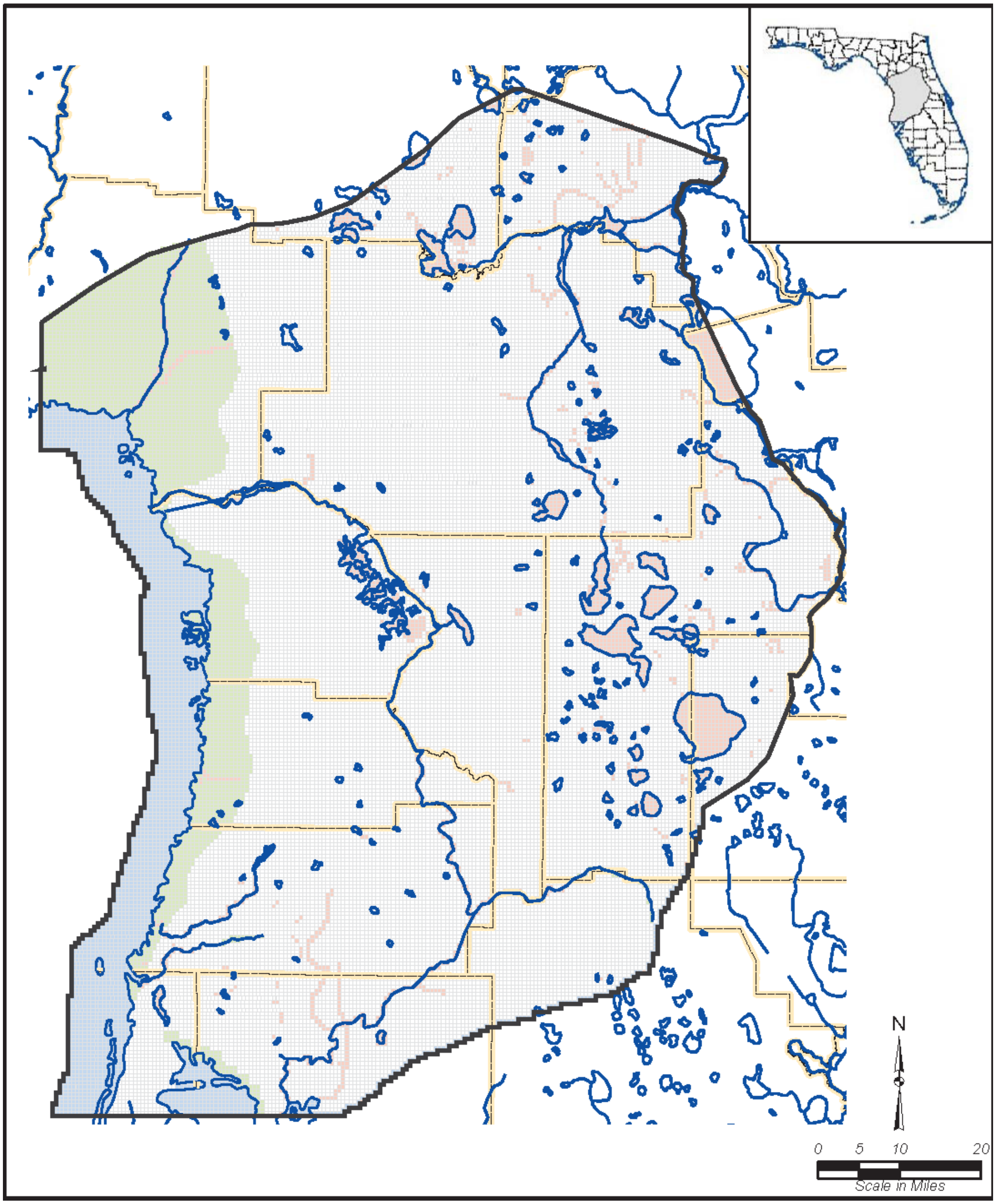


Figure 5-17. Northern District groundwater flow model, Version 5.0, model grid.

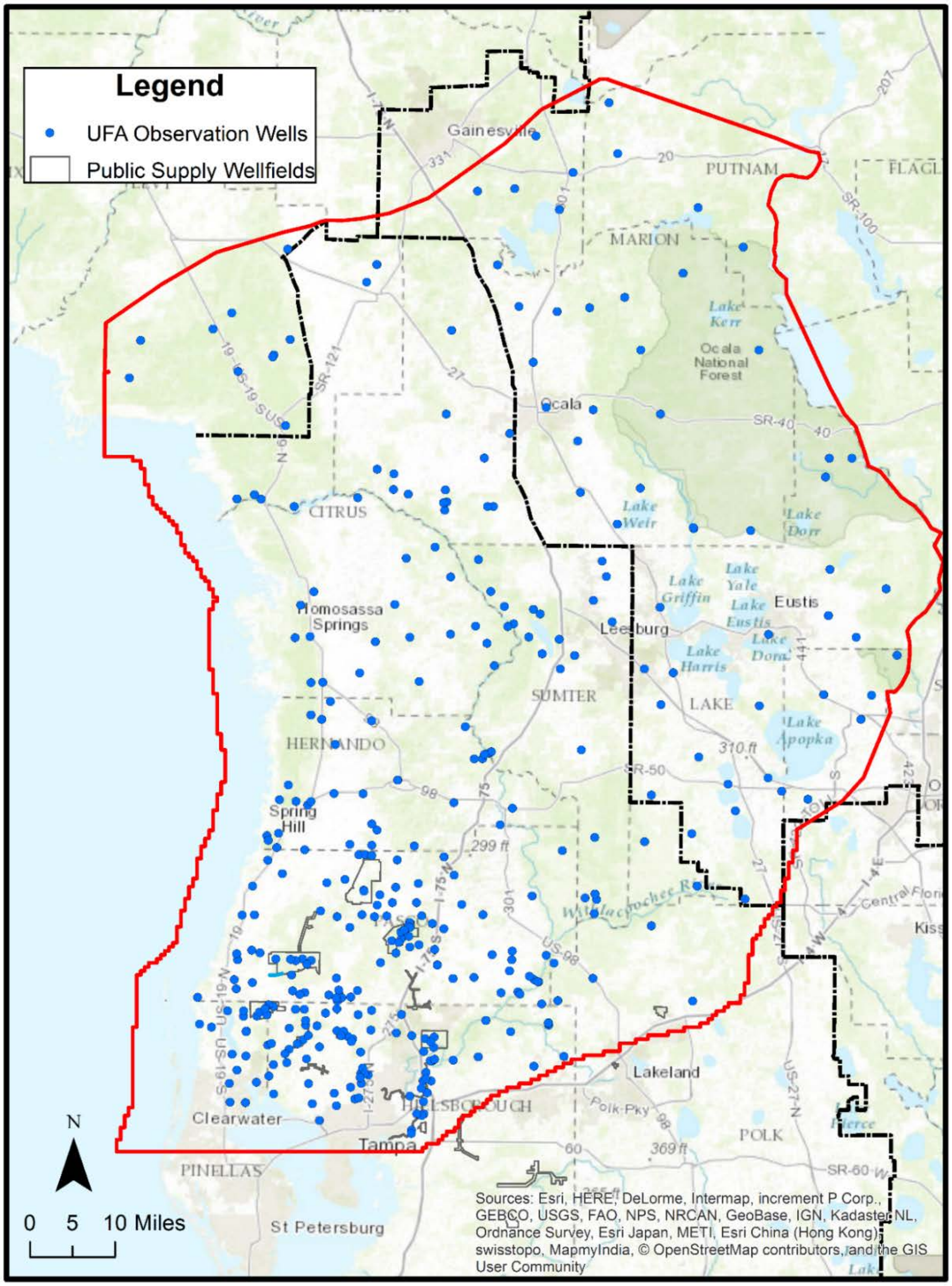


Figure 5-18. Location of Upper Floridan aquifer target wells used in the Northern District groundwater flow model for 2010.

Table 5-4. Predicted flow changes for Chassahowitzka Spring Group from the Northern District groundwater model, Version 5.0, due to groundwater withdrawals in 2010, 2015, and 2035.

Year	Model-wide Groundwater Withdrawals (mgd)	Non-pumping springflow (cfs)	Pumping Springflow (cfs)	Difference (cfs)	Difference (percent)
2010	479.1	208	205.23	2.77	-1.3
2015	446.4	208	205.14	2.86	-1.4
2040	596.2	208	203.96	4.04	-1.9
2040 with Conservation & Reuse	540.8	208	204.51	3.49	-1.7

5.4.2 Water Budget and Groundwater Withdrawals in the Chassahowitzka Springshed

A water budget for the Chassahowitzka springshed (105 sq. miles) was developed using the mean annual discharge from the springs based on no change in storage. Long-term average flow for the Chassahowitzka Spring group is estimated at 132.5 mgd (205 cfs) based on simulated flow rates within the NDM 5 model for 2015. During the same time period (2015), groundwater withdrawals (from both metered and estimated water use) were 4.5 mgd (7.0 cfs). Estimated water use includes domestic self-supply.

A water budget analysis uses mass balance to estimate the impacts of withdrawals on springflow. For example, imagine a tiny hypothetical springshed that discharges 10 gallons per year from its only spring. If 1 gallon is withdrawn from its springshed, we might expect for springflow to be reduced by that same 1 gallon, so impacts would be 1/10 = 10% in this hypothetical scenario. However, some proportion, for example 50%, of every gallon withdrawn will be returned to the springshed as non-consumptive use. Therefore, in this hypothetical example, the 1 gallon withdrawn would result in a 0.5 gallon reduction in springflow, equating to a (0.5/10 = 0.05) 5% impact. Additional factors make this an overestimate of impacts because 1 gallon of consumptively withdrawn water will result in less than 1 gallon of reduction to springflow since water can be derived from other sources besides springflow. The actual numbers for this Chassahowitzka springshed budget analysis are detailed below.

The 2015 estimate of withdrawals for the springshed were 4.5 mgd, which amount to 3.4 percent of the 132.5 mgd average flow for the spring group in 2015 (4.5/132.5 = 0.034). The USGS, however, estimates that on average only 45% of water withdrawn is consumptively-used (Marella 2008). This means that for every 100 gallons withdrawn, 55 gallons make their way back into the groundwater system in the springshed. Applying this factor to the total groundwater withdrawn in the springshed, and conservatively assuming every gallon of consumptively-used water results in a gallon decline in springflow, this would equate to a flow decline of 1.5 percent due to withdrawals in the springshed (4.5 mgd * 0.45 = 2.0 mgd; 2.0 mgd/132.5 mgd = 1.5%). This is a conservatively high assumption because groundwater withdrawal impacts are offset by changes in storage (water level decline); induced leakage from the surficial aquifer, lakes and wetlands; reductions in evapotranspiration (ET), runoff, and lateral groundwater outflow to the coast; and reductions in groundwater seepage to lakes and rivers. Therefore 100% of consumptively-used water cannot all be subtracted from springflow. For example, just a three percent reduction in 32 in/yr of evapotranspiration (150 mgd), would account for all groundwater withdrawn in the springshed (150 mgd * 0.03 = 4.5 mgd).

The state-wide average consumptive use percentage of 45% from the USGS was checked against estimates for the 4,600 square mile groundwater basin (NWCFGWB) which includes the Chassahowitzka springshed. In 2013, the total groundwater withdrawn in the basin was estimated at 163 mgd (0.75 inches), while the total estimate of return water from septic tanks, reclaimed water facilities, and irrigation was 94 mgd (0.43 inches). This yielded a consumptive use ratio of 42 percent (163 – 94 = 69; 69/163 = 0.42). Thus, the 45% consumptive use ratio from the USGS is slightly more conservative than the estimate for the larger groundwater basin because it assumes less water is returned to the springshed following withdrawals.

In 2015, water use permitted groundwater withdrawals based on estimated and metered use were 4.1 mgd with another 0.4 mgd estimated for domestic self-supply. The District maintains a metered and estimated water use database with the spatial distribution of withdrawals from 1992 through 2016 that includes both permitted and estimated domestic self-supply. Maps of the spatial distribution of groundwater withdrawals within the springshed each year from 1992 through 2016 are contained in Basso (2019b [Appendix 6]). Individual permitted groundwater withdrawals typically show withdrawal rates less than 0.5 mgd and are scattered throughout the springshed (Figure 5-19). Domestic self-supply well withdrawals are estimated per square mile within the springshed (Figure 5-20). Groundwater withdrawals have declined since reaching their peak of 15 mgd in 1999 and since 2010 the trend in springshed groundwater use has essentially remained flat (Figure 5-21).

The trend in springshed groundwater use is similar to the overall trend within the SWFWMD Northern Planning region which includes all or parts of Citrus, Hernando, Lake, Levy, Marion, and Sumter Counties. Groundwater use in the planning region in 2015 was 114.2 mgd, down from its peak in 2006 of 161.4 mgd (Figure 5-22). Groundwater withdrawn in the District’s six northern counties represented only 15 percent of 785 mgd of groundwater withdrawn in the SWFWMD in 2015.

In the 4,600 square-mile NWCFGWB, which includes the District’s northern six counties plus portions of Marion and Lake Counties within the SJRWMD, groundwater withdrawals in 2015 (0.83 in) made up just six percent of annual recharge (14.2 in) based on average rainfall conditions. Consumptively-used withdrawals were a little less than three percent of average recharge in the groundwater basin.

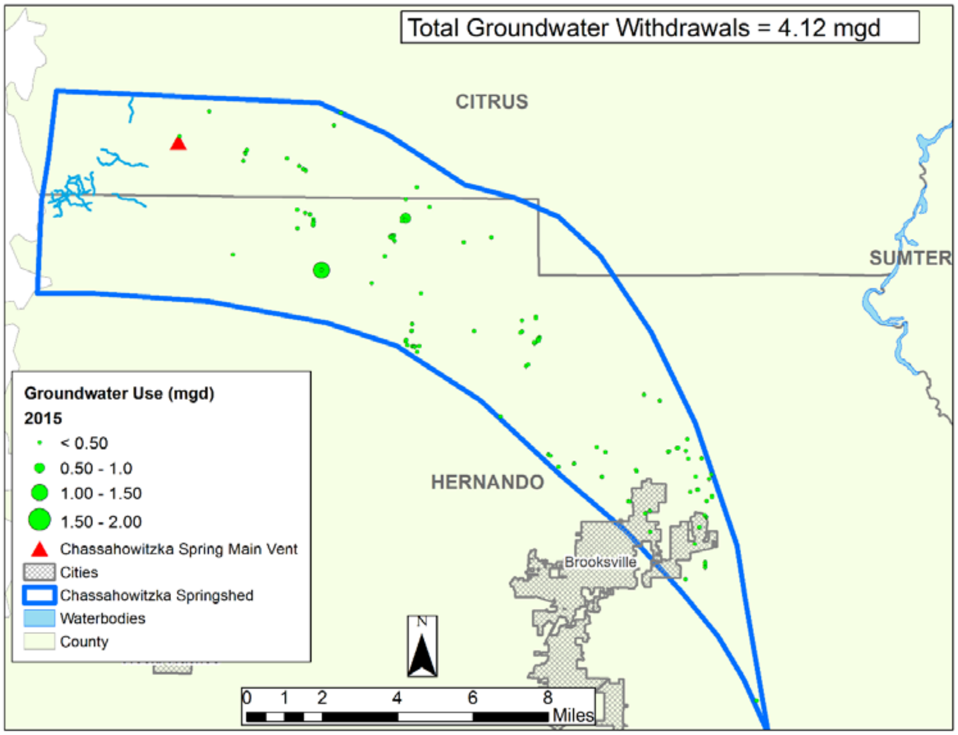


Figure 5-19. Water use permitted groundwater use in the Chassahowitzka Springshed in 2015.

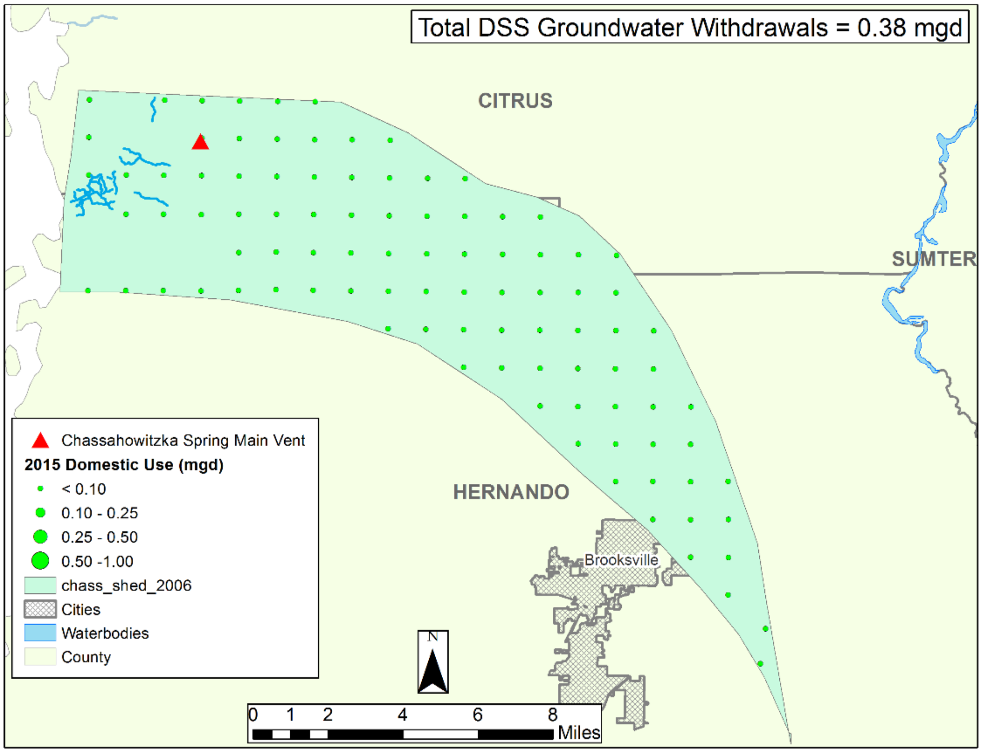


Figure 5-20. Estimated Domestic self-supply groundwater use in the Chassahowitzka Springshed in 2015.

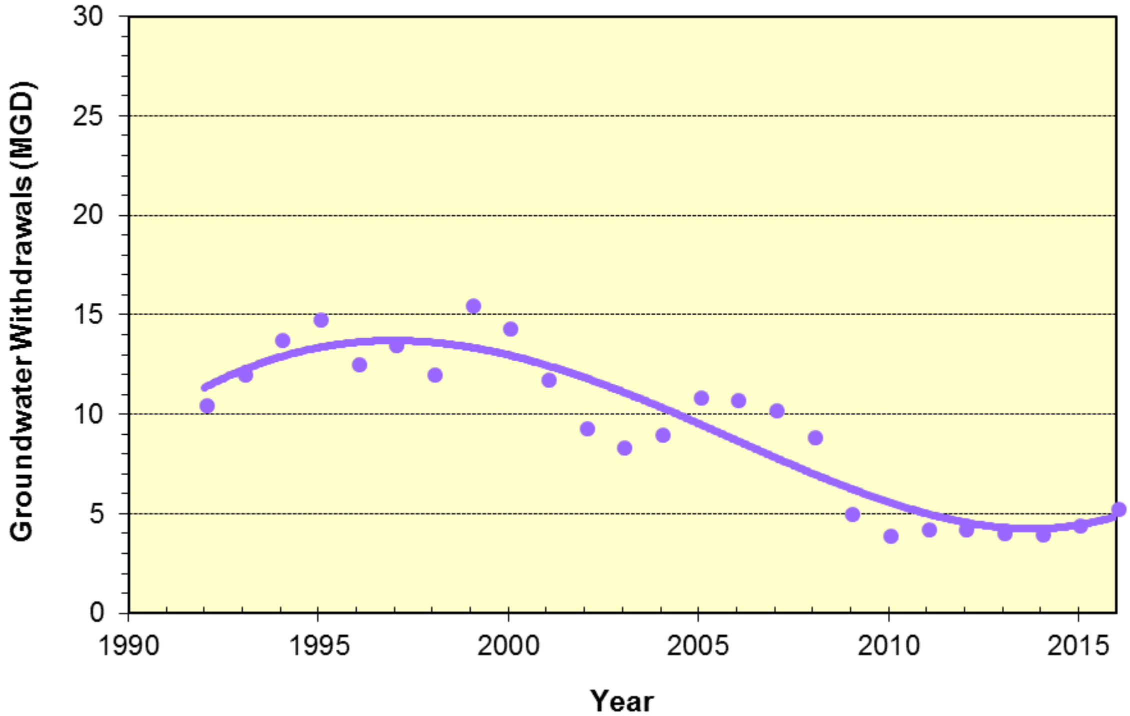


Figure 5-21. Estimated and metered groundwater use history within the Chassahowitzka Springshed from 1992 through 2016, includes estimates for domestic-self supply (Solid line is a 4th order polynomial fit to annual data).

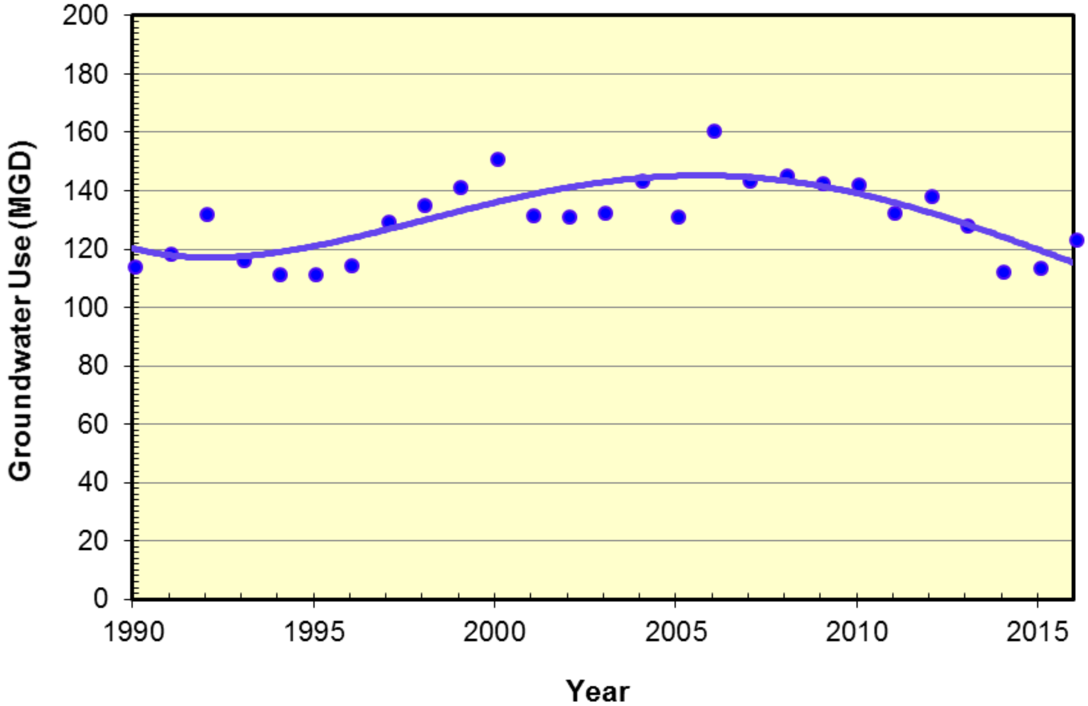


Figure 5-22. Estimated and metered groundwater withdrawal history within all or the portions of the six counties within the SWFWMD Northern Planning Region; including Citrus, Hernando, Lake, Levy, Marion, and Sumter counties; from 1992 through 2015. (Solid line is a 4th-order polynomial fit to the annual data).

5.4.3 Permitted Groundwater Withdrawals in the Northern Planning Area

In addition to estimated and metered water use, the magnitude of permitted groundwater and the number of permits existing per year were examined in the Northern Planning area of the District to note any trends. This area includes all or portions of the six counties: Citrus, Hernando, Lake, Levy, Marion and Sumter.

The total permitted groundwater use in 2017 was 190.6 mgd for the District's six northern counties. This has declined slightly since reaching its peak of 199.9 mgd in 2008 (Figure 5-23). In Citrus and Hernando Counties, permitted groundwater use has declined from 99.3 mgd in 2008 to 78.3 mgd in 2017. The number of permits in the northern six counties has also dropped from 714 in 2011 to 676 in 2017 (Table 5-5).

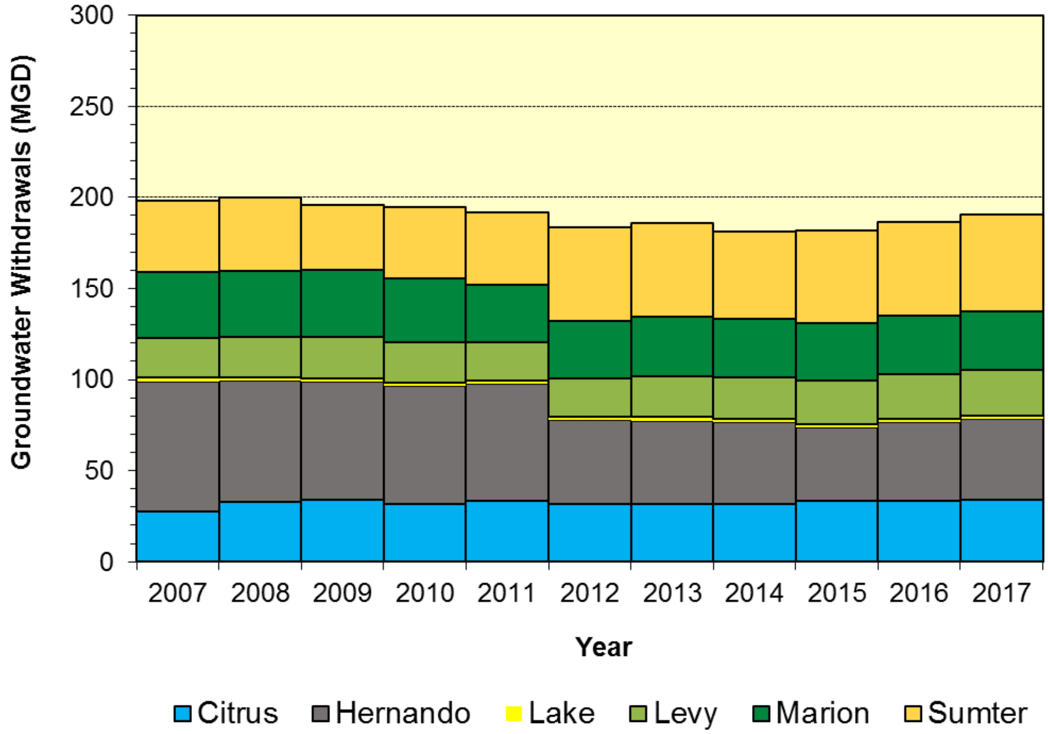


Figure 5-23. Permitted groundwater quantities in the six counties of the District's Northern Planning Region (2007-2017).

Table 5-5. Number of Water Use Permits existing in each of the six counties in the District's Northern Planning Region (2011-2017).

Year	Citrus	Hernando	Lake*	Levy*	Marion*	Sumter	Total
2011	121	135	20	96	146	196	714
2012	121	135	19	92	140	197	704
2013	121	136	19	92	140	192	700
2014	118	136	19	90	140	190	693
2015	122	124	16	92	135	189	678
2016	121	129	17	90	132	187	676
2017	121	127	17	93	131	187	676

*SWFWMD portion only

CHAPTER 6 - MODEL RESULTS AND MINIMUM FLOWS

6.1 Groundwater modeling

Northern District Model version 5 (NDM5) simulations indicate current (2015) withdrawals have reduced unimpacted flows by 1.4% (See Chapter 5).

6.2 Habitat Impacts

How much have groundwater withdrawals affected habitats in the system? How much might further incremental reductions in flow affect habitats? Answering these questions is the function of hydrodynamic modeling using the LAMFE. These questions are quantitative (e.g., how much?), meaning we want numeric estimates of habitat loss corresponding to numeric reductions in flow. The LAMFE model was selected by District staff as the best tool available for predicting quantitative changes to salinity and temperature-based habitats in response to incremental reductions in flow.

6.3 LAMFE Modeling

The LAMFE model (Chen 2011) was used to predict salinity and temperature throughout the Chassahowitzka River System (Figure 6-1.). Details about the application of the LAMFE model to the Chassahowitzka River System are reported in Chen (2019a [Appendix 7]). During the calibration process, model parameters including bottom roughness, ambient vertical eddy viscosity and diffusivity were adjusted to achieve the best fit between model results and measured data at three USGS gage sites for a 3 year, 1 month calibration period (Table 6-2.). Once the model was calibrated, the model predictions of water levels, salinities, and temperatures were compared against measured data during a 1 year, 2 month verification period without further tuning parameters. Verification results indicated the model was able to predict measured values with average Willmott skill of 0.982 for temperature, 0.964 for water level, and 0.910 for salinity (Table 6-3.). Coefficients of determination and skill values associated with comparison of modeled and observed water levels at three USGS gage sites, salinity and temperature were high for all assessed gage sites. This finding strongly supports our use of model output for development and use of criteria supporting the reevaluation of minimum flows for the Chassahowitzka River System.

Groundwater inputs to the system were estimated from data collected at the USGS Chassahowitzka near Homosassa, FL gage (No. 02310650) and from short-term measurements at Crab Creek, Baird Creek, Potter Creek, and Crawford Creek. Short term measurements at these four tributaries were used to develop regressions which predict tributary flows from gaged flows. Regression with the Weeki Wachee well was used to fill gaps in and hindcast long-term discharge data at the Chassahowitzka near Homosassa, FL gage (No. 02310650). Additional ungaged flows were added based on difference between measured flows at the Chassahowitzka River near Chassahowitzka, FL gage (No. 02310663) and upstream flows from the four tributaries and the main springs gage.

Boundary conditions at the river mouth were measured water levels, salinities, and temperatures at the USGS Chassahowitzka River at Mouth near Chassahowitzka station (No. 02310674). In addition, changes to salinity at the downstream boundary due to modeled flow reductions were accounted for. Meteorological data used were from the Lecanto High UF/IFAS FAWN station for the period from 2013-07-02 to 2018-03-12. Earlier meteorological data from the Inglis Dam station (WMIS ID No. 22960) maintained by the District were also used.

Scenario runs (simulations) were conducted over the period from 10/11/2007 to 02/15/2018 (10 years, 4 months). Model scenarios included unimpacted flows, existing (impacted) flows, and reductions from unimpacted flows (Table 6-4.).

Salinity-based habitats were considered three ways: as total volume of water, as bottom area, and as shoreline length. These were all calculated as the total habitat within salinity range zones. Salinity was partitioned into zones with salinities less than or equal to 1, 2, 3, 5, 10, 15, and 20 psu. For each flow reduction scenario, the quantity of habitat was compared with habitat present under the unimpacted flow scenario. Linear interpolation was used to find the exact flow reduction corresponding to a 15% decrease in habitat when flow reduction scenarios bracketed this value. For example, a 10% flow reduction may reduce shoreline habitat by 14%, while a 12.5% flow reduction may reduce shoreline habitat by 16%; linear interpolation is needed to find flow reduction corresponding to exactly 15% loss of habitat. The results of this analysis, with flow percentage reductions rounded to the nearest whole percent, show that the most sensitive response occurs with volume and bottom area of water less than 1 psu at a flow reduction of 8% (Table 6-5.).

Temperature-based habitats were considered specifically to avoid stress in Florida Manatee (*Trichechus manatus latirostris*) and Common Snook (*Centropomus undecimalis*). Stressful conditions for manatees occur if they are exposed to water less than 20°C for 72 hours (Chronic stress) or 15°C for 4 hours (Acute stress). The most stressful times for manatees were found by identifying the coldest average 72- hour and 4-hour time periods in the simulation. During these most stressful periods, flow reduction scenarios were compared with the unimpacted scenario. Habitat was considered in terms of volume of water and total area of habitat. Waters less than 3.8 feet deep were excluded from habitat because manatee typically inhabit deeper water. Results show that a 15% reduction in volume and area of suitable habitat (> 15°C) during the coldest 4 hours occurred when flows were reduced by 10% (Table 6-6.).

A fifteen percent reduction in manatee habitat is considered “presumptive” in this and previous minimum flows evaluations for the Chassahowitzka River, Homosassa River, Weeki Wachee River, and Crystal River / Kings Bay. It is possible for available warm water habitat to exceed the quantity of useable habitat based on the number of manatees expected to visit the site. For the Chassahowitzka River, a maximum of 38 manatees has been observed at one time. The overall habitat available when acute habitat is most sensitive to reductions in flow is 1,994,240 square feet (185,271 square meters). Recall from chapter 4 that each manatee requires 28.5 square feet. Thus, when flows are reduced by 10%, and habitat is reduced by 15% there is still room for 69,973 manatees. Therefore, the presumptive 15% reduction in habitat will not constitute a significant harm to the manatee population.

Stressful conditions for Common Snook occur when temperatures drop below 15°C for 24 hours or more, as discussed in Chapter 4. The most sensitive volume reduction during the simulation period occurred on January 4, 2014, when an 8% reduction in flow would have reduced habitat by 15% (Table 6-6.). Unlike the manatee, Common Snook do not appear to have an upper limit to their useable habitat. One line of evidence in support of the thesis that temperature habitat is limiting for Common Snook populations comes from the population level response following the cold event in 2010, which resulted in severe decline and closed the fishery from 2010 to 2013 (Muller et al. 2015). Contrast this response with the manatee, which did not demonstrate. We did not see a comparable decline in manatee following this same December 2010 event (Table 6-1).

Table 6-1. Total counts of manatees from synoptic surveys by the Florida Fish and Wildlife Conservation Commission.

Year	West Coast Total
January 19-23, 2009	1654
January 12-15, 2010	2,297
January 20 and 24, 2011	2,402

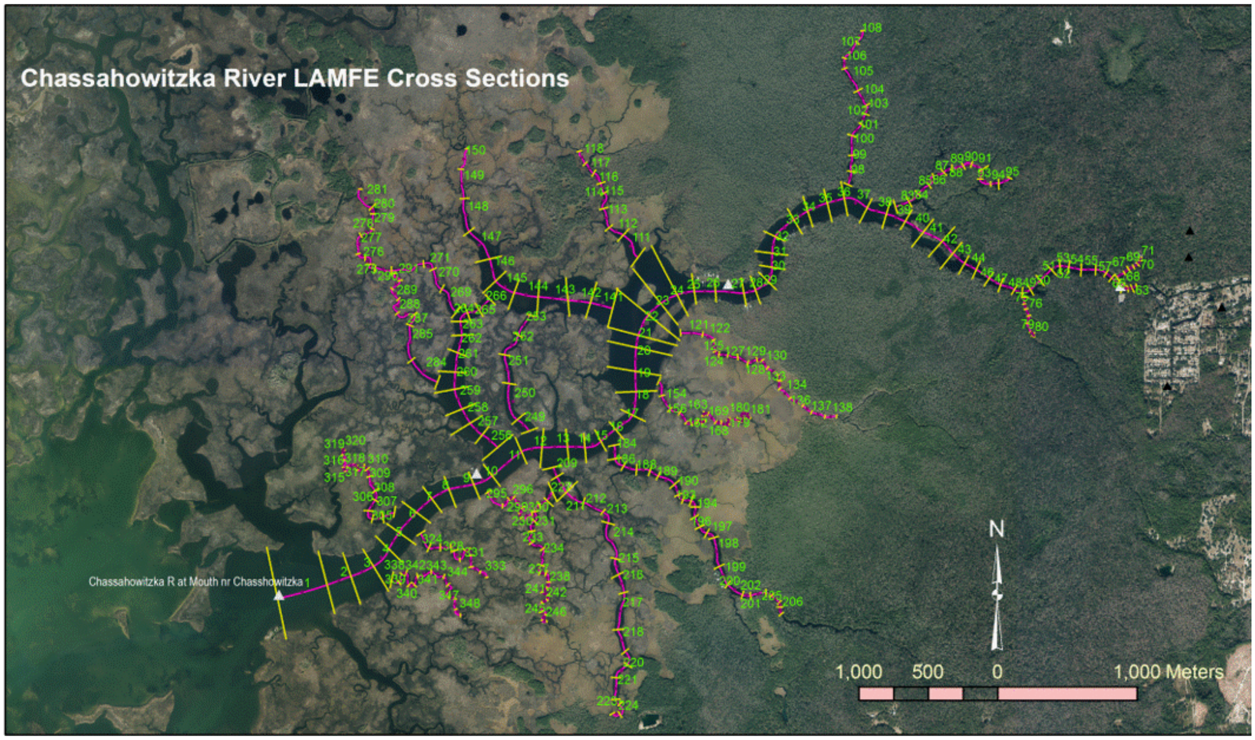


Figure 6-1. Chassahowitzka River System LAMFE model cross sections discretize 348 grids over main stem of the river and 19 branches or tributaries.

Table 6-2. LAMFE model calibration, verification, and simulation periods.

Calibration	Verification	Simulation
11/18/2012 to 12/31/2015	01/01/2016 to 3/28/2017	10/11/2007 to 02/15/2018

Table 6-3. Skill assessment metrics for the LAMFE model for USGS gage station data in the Chassahowitzka River.

Parameter	USGS Station	Mean Error	Mean Abs. Error	R^2	Skill
Water Level (cm)	Chass R nr Homosassa	-4.649	7.019	0.82	0.931
	Chass R nr Chassahowitzka	-3.425	6.425	0.923	0.974
	Chass R at Dog Island	-1.532	4.878	0.955	0.987
	Average	**-3.199**	**6.107**	**0.899**	**0.964**
Salinity (psu)	Chass R nr Homosassa	0.079	0.366	0.747	0.894
	Chass R nr Chassahowitzka	0.329	1.279	0.648	0.892
	Chass R at Dog Island (top)	-0.564	1.279	0.795	0.927
	Chass R at Dog Island (bottom)	-0.145	1.299	0.765	0.928
	Average	**-0.075**	**1.056**	**0.739**	**0.910**
Temperature (°C)	Chass R nr Homosassa	0.155	0.255	0.913	0.963
	Chass R nr Chassahowitzka	-0.372	0.973	0.943	0.976
	Chass R at Dog Island (top)	0.082	0.519	0.981	0.995
	Chass R at Dog Island (bottom)	0.070	0.543	0.980	0.995
	Average	**-0.016**	**0.573**	**0.954**	**0.982**

Table 6-4. LAMFE model run scenarios for the Chassahowitzka River System. Unimpacted flows calculated using withdrawal impact of 1.4% from NDM5

Flow scenarios
Unimpacted (Existing / 0.986)
Existing (impacted)
Unimpacted - 2.5%
Unimpacted - 5%
Unimpacted – 7.5%
Unimpacted - 10%
Unimpacted - 12.5%
Unimpacted - 15%
Unimpacted - 17.5%
Unimpacted - 20%
Unimpacted - 22.5%
Unimpacted - 25%
Unimpacted - 27.5%
Unimpacted - 30%

Table 6-5. Salinity-based habitat impacts: Flow reductions (as percent reduction from unimpacted scenario) corresponding to 15% decrease in available habitat are listed for 7 salinity zones. An 8% decrease in flow from unimpacted flow corresponds to a 15% decrease in the volume and bottom area of habitat exposed to average salinities less than or equal to 1 psu. A minimum flow based on this criterion would be 92% of unimpacted flows.

Salinity Habitat	Salinity (≤ psu)						
	1	2	3	5	10	15	20
Volume	8%	22%	23%	23%	>30%	>30%	>30%
Bottom Area	8%	24%	26%	25%	>30%	>30%	>30%
Shoreline Length (Altered)	10%	20%	>25%	>30%	>30%	>30%	>30%
Shoreline Length (Natural and Vegetated)	10%	>30%	>30%	29%	>30%	>30%	>30%

Table 6-6. Temperature-based habitat Impacts. Flow reductions (as percent reduction from unimpacted scenario) corresponding to 15% decrease in available habitat are listed for chronic and acute Florida manatee thermal habitat and Common Snook thermal habitat. An 8% decrease in flow from unimpacted flow corresponds to a 15% decrease in the volume of Common Snook habitat exposed with temperatures greater than 15°C during the most sensitive 24 hour period.

Temperature-Based Habitat	Florida Manatee Temperature Stress and Habitat Change (%)		Common Snook Temperature Stress and Habitat Change (%)
	Chronic: Water > 20°C over coldest 72h	Acute: Water > 15°C over coldest 4h	Most sensitive 24 h > 15°C
Volume	24%	12%	8%
Area	24%	10%	11%

CHAPTER 7 - MINIMUM FLOWS RECOMMENDATION FOR CHASSAHOWITZKA RIVER SYSTEM

7.1 Basis of Minimum Flow Recommendation

Minimum flows are designed to predict environmental effects of withdrawal impacts and determine the point at which further withdrawal-related reductions in flow would cause significant harm. We identified, developed and used four primary components for identifying numeric minimum flows recommendations for a reevaluation of minimum flows established for the Chassahowitzka River System. The four components included: 1) a groundwater flow model which predicts effects of existing and projected future withdrawals on flows – see Chapter 5; 2) a hydrodynamic model which predicts effects of reduced flows on surface water levels, salinity and temperature – see Chapter 6; 3) environmental values considerations of potential impacts of flow reductions on water quality (Chapter 3); and 4) environmental values considerations of biological components of the system (Chapter 4).

Present-day groundwater impacts are estimated at 1.4% reduction from unimpacted based on Northern District Model predictions. The most sensitive response of salinity and temperature-based habitats predicts that flow reductions of 8% will reduce salinity-based and temperature-based habitats by 15%, according to LAMFE model predictions (Table 6-5, Table 6-6).

Review of the data resulting from extensive monitoring and analysis of water quality and biological aspects of the system indicate that flow reductions up to 8% will not have disproportionate, adverse effects on the system. Minimal effects on chlorophyll concentrations were identified, based on our assessment of risks associated with exceeding a defined 3.9 ug/L concentration. However, the identified risk of chlorophyll concentration change is not analogous to a 15% loss of habitat or resource, and cannot be used to determine significant harm. Nonetheless, after determining significant harm based on 15% loss of salinity-based habitats as associated with an 8% reduction in flows, we can predict the effects this flow reduction will have on chlorophyll concentrations in the system. The results of water quality analysis show that flow reductions of 8% will increase the risk of exceeding the 3.9 µg/L chlorophyll threshold by 9 percent according to BLUPs and by 13.5 percent according to BLUEs (Figure 3-35).

Biological components of the system, including fish communities (Johnson et al. 2017), vegetation (Water and Air Research, Inc. 2018a), and oysters (Water and Air Research, Inc. 2018b) have been extensively surveyed by the District and will continue to be monitored in the future. Attempts to directly quantify effects of flow reductions on fish and invertebrates have not been successful (Leeper et al. 2012, Heyl et al. 2012).

The hydrodynamic modeling results presented here and detailed in Chapter 6, as well as in Chen (2011, 2019a) were used to develop the primary criteria used to for the reevaluation of minimum flows for the Chassahowitzka River System. These criteria included salinity and temperature based habitats. Confidence in the ability of the hydrodynamic modeling application to predict changes in salinity and temperature can be assessed through the verification statistics shown in Table 6-3. This hydrodynamic modeling application to this system represents the best information available for determination of minimum flows in this system.

In addition to the criteria used for establishing flows, much of the data and analysis presented in this report is treated as environmental values considerations that support the reevaluation of minimum flows for the Chassahowitzka River System. For example, shoreline vegetation mapping, fish community surveys, and oyster health assessments are all directly related to environmental values for the system. It would be inappropriate to assume that because the biological, chemical, and physical components of this system described in the preceding chapters do not have direct quantifications of significant harm resulting from reduced flows, that they were not fully considered. However, the best available information does not currently include methods for direct estimation of impacts to these biological factors as a consequence of changing flows. What is known is that salinity and temperature have far-reaching effects on biological, chemical and physical components of this system. Thus, all environmental values are considered and protected under the salinity- and temperature-based criteria that were used for our reevaluation of minimum flows for the Chassahowitzka River System.

7.2 Environmental Values

Rule 62-40.473, F.A.C. within the Water Resource Implementation Ruel dictates consideration of a suite of 10 environmental values when establishing minimum flows and minimum water levels. The District's Minimum Flows and Levels Program addresses this requirement and all other relevant requirements expressed in the Water Resource Implementation Rule as well as those included in the Water Resources Act of 1972 that pertain to minimum flows and minimum levels establishment. Environmental values assessments of the Rainbow River (HSW 2009) and for Blue Spring and Blue Spring Run (WSI 2006) provide case studies in addressing environmental values through minimum flows evaluations and serve as a basis for the following summary of the consideration of environmental values in our reevaluation of minimum flows for the Chassahowitzka River System.

7.2.1 Recreation in and on the Water

Recreation in and on the water was considered through assessment of potential changes in water levels, salinity and temperature. Recreational swimming, boating, and tubing requires adequate water depth (HSW 2009). Fishing and wildlife observation are also common recreational activities (WSI 2006). Other environmental values, including fish and wildlife habitats and the passage of fish, estuarine resources, aesthetic and scenic attributes, water quality and navigation contribute to recreational use. Water levels in the Chassahowitzka River System are tidally influenced, and reductions of up to 8%, based on the most sensitive response among the criteria used in our minimum flow reevaluation are not expected to decrease water levels. There recreation associated with water depths is not expected to be impacted with implementation of the minimum flows for the river system. Recreation associated with water salinities and temperatures includes fishing, wildlife observation, and swimming. These recreational activities will be protected by the salinity and temperature habitats modeled with the LAMFE described in Chapter 6.

7.2.2 Fish and Wildlife Habitat and the Passage of Fish

Fish passage is driven by water depth, which, in the Chassahowitzka River System, is primarily a function of tides. Water depth is strongly affected by tidal, seasonal, and long-term sea level trends and variation, and is not therefore expected to substantially vary based on changes in spring flow. The fish community is characterized by a combination of freshwater and saltwater assemblages (Johnson et al. 2017). The spatial and temporal patterns of salinity and freshwater in the system are critical to maintaining this diverse fish community. Shoreline vegetation also provides fish habitat. Shoreline vegetation is healthy throughout the system (Water and Air Research, Inc. 2018a). Hydrodynamic (LAMFE) modeling of impacts on salinity habitats will protect fish habitat through maintenance of the natural salinity regime and the natural vegetated shoreline. Temperature-based habitats targeted Common Snook and Florida Manatee habitat requirements. Common Snook (*Centropomus undecimalis*) is one of Florida's most popular gamefish and were the third most commonly targeted gamefish on the Florida Gulf Coast in 2014 (Muller et al. 2015). The Florida Manatee is a native species classified as threatened under the federal Endangered Species Act. Manatee habitat use is determined by warm water availability during winter. Temperatures and adequate water depths for manatee during these coldest times were directly assessed using the hydrodynamic model (LAMFE) and not expected to be adversely affected through implementation of the reevaluated minimum flow.

7.2.3 Estuarine Resources

Estuarine resources are maintained through preservation of salinity fluctuations in an estuary (HSW 2009). The Chassahowitzka River System is tidal throughout, and thus all of the resources assessed for reevaluation of minimum flows established for the system are "estuarine resources". Bathymetry, river bottom substrates, shoreline vegetation mapping, oyster and barnacle surveys, benthic invertebrate surveys, fish community surveys, water quality analyses, and all other status and trends in physical, chemical, and biological characteristics of the system are aimed at ensuring estuarine resources are protected.

7.2.4 Transfer of Detrital Material

Transfer of detrital material is typically realized through floodplain inundation, when large quantities of material are suspended and moved downriver in surface water driven systems. Detrital material also includes all plant and animal materials, such as senescent stems and leaves and animal waste. These materials are transported by net downstream movement of water. Sediment analysis found greater quantities of silt and organic material further downstream, indicating that detrital material is moved downstream in the Chassahowitzka River System (Arcadis 2016). Minimum flows established based on salinity and temperature habitats are expected to preserve flows necessary for downstream transport of detrital material in this tidally driven system.

7.2.5 Maintenance of Freshwater Storage and Supply

Effects of current and projected water use are included in the Northern District Model predictions of withdrawal impacts on groundwater levels and spring flows that were used to support the minimum flow reevaluation. These predictions did not indicate that current or projected withdrawals would be limited by the reevaluated minimum flow. In addition, this environmental value is expected to be protected through inclusion of conditions in water use permits which stipulate that permitted withdrawals will not lead to violation of any adopted minimum flows and levels.

7.2.6 Aesthetic and Scenic Attributes

Aesthetic and scenic attributes of the river are inextricably tied to other values such as water quality, shoreline vegetation, fish communities, and Florida Manatee and Common Snook thermal refuge. All of these aspects have been directly monitored for status and trends. Effects of flow reductions on temperature and salinity were directly estimated as hydrodynamic (LAMFE) model output.

Prevention and reduction of filamentous algae blooms are recognized as desirable for scenic and aesthetic enjoyment of the Chassahowitzka River System. The presence of filamentous algae in the Chassahowitzka River is driven primarily by salinity and light availability (which in turn is driven by water levels) (Hoyer et al. 2004). Salinity and water levels are predicted by the hydrodynamic (LAMFE) model. There is not enough data on filamentous algae to test for direct statistical relationships between flows and filamentous algae, because algae surveys have been intermittent and infrequent. Although there is also a strong link between algal growth and nitrate concentration, results of water quality data show that nutrient concentrations, particularly nitrates and total nitrogen, will not increase as a consequence of decreasing flows (see Chapter 3). However, we know from Hoyer et al. (2004) that algae grow in areas of low salinity and high light availability. Salinity is directly predicted by hydrodynamic modeling, and light availability is related to water level and clarity. Because we applied the hydrodynamic LAMFE model to predict changes to water level, salinity, and temperature, and these three factors are the most strongly affected by flow reductions and the most likely of factors impacted by flow reductions to impact filamentous algae growth, these minimum flows will prevent filamentous algal growth that might occur as a result of further flow reductions.

While filamentous algae are a nuisance and partially the basis for water quality criteria, there are insufficient data for direct calculation of trends between filamentous algae and flows. However, knowledge of the factors affecting filamentous algae growth can inform us as to whether the criteria analyzed are protective of the system with regard to filamentous algae. Water velocity, clarity, and salinity are the primary factors affecting filamentous algae growth. In the Chassahowitzka River system, water velocity is driven by tides, not springflow, and therefore withdrawal impacts will not affect filamentous algae growth by affecting water velocities. Filamentous algae have salinity habitat requirements similar to beneficial SAV, and therefore managing for salinity-based habitats cannot be used to promote beneficial SAV growth while limiting filamentous algae growth. Lastly, clarity is a composite of turbidity, color, and chlorophyll concentrations. Turbidity and color are not affected by flows in this system, while chlorophyll showed responses that were less sensitive to flows than the salinity-based and temperature-based habitats that provided the basis for the minimum flows recommendation made here.

7.2.7 Filtration and Absorption of Nutrients and Other Pollutants

Filtration and absorption of nutrients and other pollutants were considered by studying bathymetry, river bottom substrates and shoreline characterizations, water quality characterization (including impaired water body listings), water residence time, nitrate concentration, primary productivity, aquatic and semi-aquatic vegetation, thermally-based habitat for the water column, and salinity-based water column, river bottom and shoreline habitats.

Additionally, the factors used to evaluate fish and wildlife habitats and the passage of fish, estuarine resources, and water quality environmental values were considered applicable to the filtration and absorption of nutrients and other pollutants.

A water quality analysis focused on status and trends in critical water quality parameters. The majority of flow in the system comes from spring vents. Therefore, most nutrients and other pollutants enter the system as spring flow. Flow reductions of up to 8% are not predicted to alter concentrations of nutrients and other pollutants.

7.2.8 Sediment Loads

As with the transfer of detrital material, sediment loads are not expected to be reduced in this system. Sediment loads typically increase during flood events, when floodplains are inundated, and large flows transport large quantities of sediment during these infrequent events. Spring systems are more consistent than surface water systems, and do not exhibit floods or bursts of sediment loading in the same way. Thus, changes in sediment loads with implementation of the reevaluated minimum flow are expected to be negligible.

7.2.9 Water Quality

Water quality was considered by assessing status and trends in water quality parameters, including impaired water body listings, water residence time, nitrate concentration, temperature, salinity, river bottom, and shoreline habitats.

When interpreting water quality data, it is critical to consider context: where and when was data collected, what analytes were measured and what other data were collected in the same manner as part of a larger effort all matter for proper interpretation. For minimum flows evaluation, the most important aspect of water quality data is its trends with variation in flows: do water quality data “improve” with increased flows, where improvement is decreased likelihood of impairment or other harm? Nitrate concentrations have increased in spring vent waters over time, according to data collected by the District as part of Spring Vents Project P889 (Figure 3-22). This increase in concentrations is noteworthy, with levels well beyond the TMDL concentration of 0.23 mg/L established for several Chassahowitzka springs, a consistent trend dating back to the early nineties and continuing into the most recent data collection events (Table 3-1).

Implementation of minimum flows does not, however appear to be an effective tool for addressing increasing nitrate concentrations in spring vents within the District. There are seven spring vents monitored in the Spring Vents Project P889 in the Chassahowitzka River System. Nitrate is measured at all of them. Data collected at two of these vents, Beteejay and Crab Creek, showed significant linear relationships between flow and nitrate concentrations (Table 3-7). At Beteejay spring, nitrate concentrations tended to decrease when flows increased. However, at Crab Creek spring, nitrate concentrations tended to increase when flows increased. At the five remaining springs, there were no relationships between nitrate and flows. The synthesis of this information is that decreased flows associated with withdrawal impacts will not cause harm by increasing nitrate concentrations in spring vent discharges.

In the river mainstem, nitrate concentrations steadily decline with downstream location according to both Coastal Rivers Project P108 data and the University of Florida 5 Rivers Project data

(Figure 3-9). While nitrates are managed in spring vents, surface water quality criteria focus on total nitrogen (Table 3-1). Although total nitrogen concentrations are often above the NNC for WBID 1361 (the Chassahowitzka River Estuary), these concentrations have not increased over time on average (Figure 3-19), and at downstream locations are decreasing with time (Figure 3-20). There were no significant linear relationships found in the Coastal Rivers Project P889 or University of Florida 5 Rivers Project data between flow and total nitrogen (Janicki Environmental, Inc. and WSP, Inc. 2018). Therefore, this is further evidence that withdrawal impacts will not cause harm by affecting total nitrogen concentrations.

Although withdrawals and decreased flows will not affect total nitrogen based on the information summarized above, there was some evidence from the University of Florida 5 Rivers Project data that chlorophyll concentrations will be increased by decreasing flows. This potential relationship served as the basis for a “post-hoc” analysis in which we asked: how will setting minimum flows based on hydrodynamic modeling of salinity-based and temperature-based habitats affect chlorophyll concentrations expressed as the risk of exceeding a threshold value of 3.9 µg/L in individual samples? We found that at a minimum flow equivalent to an 8% reduction from unimpacted flows, the relative risk of exceeding this 3.9 µg/L threshold increases by 9 to 13.5 percent, depending on the statistical method (Figure 3-35). The identified risk of chlorophyll concentration change is not analogous to a 15% loss of habitat or resource, and cannot be used to determine significant harm. However, the relative risks of exceedance do show that flow has some effect on chlorophyll concentrations, and that those effects are not substantial enough to establish significant harm at flow reductions less than the 8% flow reduction recommended as the minimum flow through analysis of salinity-based and temperature-based habitats.

In summary, relevant water quality constituents have been thoroughly monitored and assessed for this minimum flows reevaluation. The recommended minimum flow expressed as an 8% reduction from unimpacted flows is protective of the water quality of the Chassahowitzka River System.

7.2.10 Navigation

Navigation was considered by mapping water depth and physical characteristics of the system. Water depth necessary for navigation in the Chassahowitzka River System is strongly affected by tidal, seasonal, and long-term sea level trends and variation, and is not therefore expected to substantially vary based on changes in spring flow. Thus, navigation is not expected to be affected by the allowable reduction in flow associated with the reevaluated minimum flow.

7.3 Minimum Flows

Minimum flows are defined as the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area. For the current reevaluation of minimum flows established for the Chassahowitzka River System, existing groundwater withdrawal impacts to flows in the system were assessed with the Northern District Model, version 5 (NDM5), and determined to be a 1.4 percent reduction from the unimpacted flows (see Chapter 5). Additional flow reduction impact scenarios were modeled with a hydrodynamic (LAMFE) model, which was used to predict impacts to salinity-based and temperature-based habitats from reduced flows. Protection of salinity-based habitats constitutes protection for a wide variety of species including submerged aquatic vegetation, shoreline vegetation, blue crabs, oysters, other invertebrates, and fish. Temperature-based habitats were modeled specifically for manatee and Common Snook. Physical and chemical processes that are affected or driven by salinity are similarly protected through protection of salinity habitats. Risk of exceeding a chlorophyll threshold was modeled as a function of flow reductions. These effects of flow on chlorophyll were considered as an environmental value assessment supporting the minimum flow determination.

The most sensitive salinity habitats were the bottom area and volume of water less than or equal to 1 psu (Table 6-5.). The most sensitive temperature habitat was Common Snook habitat by volume of water (Table 6-6.). Fifteen percent reductions in these three habitats corresponded with an 8% reduction in flows from an unimpacted flows scenario. This flow reduction is within the recommended maximum presumptive 10% reduction due to groundwater pumping suggested by Gleeson and Richter (2017), who suggest that “high levels of ecological protection will be provided if groundwater pumping decreases monthly natural baseflow by less than 10% through time.”

Results from this current reevaluation of the Chassahowitzka River System therefore indicate an appropriate minimum flow could be established at 92% of unimpacted flows; allowing up to an 8% reduction from unimpacted flows. Withdrawal impacts were based on Northern District Model (NDM) results (Table 5-4). From Jan. 1, 1975 to Jan. 1, 2005, the impact was linearly increased daily from 0 to 1% because the 2005 withdrawal impact estimated with the NDM was 1%. For all dates from Jan. 1, 2005 to Jan1, 2010, the impact was linearly increased daily from 1% to 1.3% based on the 1.3% withdrawal impact for 2010 estimated with the NDM. For all dates from Jan. 1, 2010 to Jan. 1, 2015, the impact was linearly increased daily from 1.3% to 1.4% because the 2015 impact estimated with the NDM was 1.4%. For all dates from Jan. 1, 2015 onward, the impact was considered to be 1.4%. Daily unimpacted flows were calculated as impacted flows / (1- impact).

Using the general flow record as described in section 2.5.2, minimum flows were calculated as unimpacted flows * 0.92 (Figure 7-1). Based on these data and calculations, the median gaged (impacted) flow was 59 cfs, the median unimpacted flow was 60 cfs, and the median minimum flow was 55 cfs (Table 7-1).

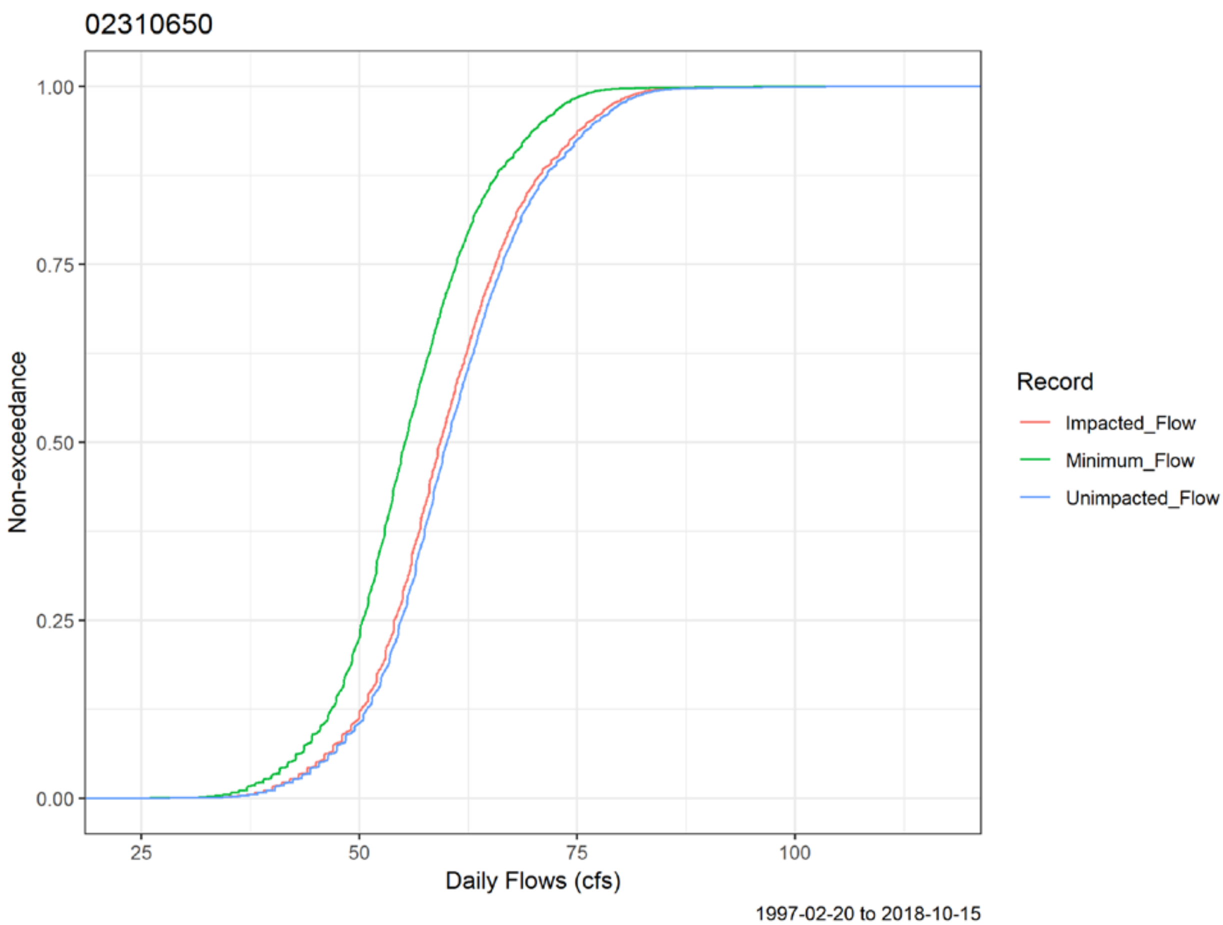


Figure 7-1. Empirical cumulative distribution curves for flow scenarios at the USGS Chassahowitzka River near Homosassa FL gage (No. 02310650). Data consists of 6,912 observations over 7,908 days from 1997-02-20 to 2018-10-15.

Table 7-1. Flow statistics for gaged flows (Impacted), Unimpacted flows, and Minimum flows at the USGS Chassahowitzka River near Homosassa FL gage (No. 02310650). Data consists of 6,912 observations over 7,908 days from 1997-02-20 to 2018-10-15. Values in cubic feet per second (cfs).

Record	min	10th	25th	mean	median	75th	90th	max
Unimpacted	25	49	55	61	60	66	73	117
Impacted	25	49	54	60	59	66	73	115
Minimum	23	45	50	56	55	61	68	107

7.4 Minimum Flow Status Assessment and Future Reevaluation

District staff evaluated the current status of the flow regime of the Chassahowitzka River System, numerical modeling results, and other supporting information to assess whether flows in the river are currently and are projected over the next 20 years to remain above limits associated with the currently proposed minimum flows. These assessments were completed because the Florida Water Resources Act of 1972 stipulates that If, at the time a minimum flow or minimum water level is initially established for a water body or is revised, 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 the 1.4 percent impact from recent groundwater withdrawals on flows in the Chassahowitzka River System modeled with the NDM5; District staff conclude the minimum flow proposed as a result of the current minimum flow reevaluation is being met. Similarly, based on a predicted impact of 1.9 percent associated with projected 2040 withdrawals, and a predicted 1.7 percent flow impact associated with projected 2040 withdrawals and planned conservation and reuse projects, the proposed minimum flow for the Chassahowitzka River System is also expected to be met during the coming 20 years. Development and adoption of a recovery strategy or specific prevention strategy in association with adoption of the proposed minimum flows is, therefore, not necessary at this time.

Because climate change, structural alterations and other changes in the watershed and groundwater basin contributing flows to the Chassahowitzka River System may affect flows in the system, and because additional information relevant to minimum flows development may become available, the District is committed to periodic reevaluation and if necessary, revision of the recommended minimum flows for this priority water body that will presumably be incorporated into Chapter 40D-8, F.A.C.

In support of this commitment, the District, in cooperation with the USGS, will continue to monitor and assess the status of flows in the river system and continue to work with others on refinement of tools such as the NDM5 that were used for development and assessment of the proposed minimum flow. Minimum flow status assessments for the Chassahowitzka River System 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 permit and project activities.

The District protocol for addressing sea level change when establishing minimum flows and levels states that information on sea level rise (SLR) should be used as a tool to determine if system reevaluation may be warranted (Southwest Florida Water Management District 2015). Sea level rises are calculated from the middle of the simulation period (in this case 2012) until the end of the current District planning horizon in 2035.

The United States Army Corps of Engineers (USACE) provides SLR estimates at their web site, http://www.corpsclimate.us/ccaceslcurves.cfm, where three types of the SLR can be obtained at several NOAA (2018) stations along the Florida Gulf coast: a low estimate, an intermediate estimate, and a high estimate. The closest NOAA stations to the mouth of the Homosassa River are Stations #8726724 (Clearwater Beach FL) and #8727520 (Cedar Key FL). The Clearwater Beach station is about 89,693 m south - southwest of mouth of the Chassahowitzka River and the Cedar Key station is about 61,996 m northwest of the Chassahowitzka River mouth. The St. Petersburg station is further south from the mouth of the Homosassa River with a distance of about 103,794 m but has a longer period of record of water level data than the Clearwater Beach station does. As such, the St. Petersburg station is considered as a better station for the SLR estimation than the Clearwater Beach station. Based on this consideration, the low, intermediate, and high sea level rise estimates at the mouth of the Chassahowitzka River from 2012 to 2035 were calculated from those at the St. Petersburg and Cedar Key stations using an inverse distance weighting interpolation (Table 7-2.). Over the 23-year period, estimated low, intermediate, and high SLRs at the mouth of the Homosassa River are 4.8, 8.7, and 21.1 cm, respectively.

These sea level rise values were added onto boundary conditions at the mouth of the Chassahowitzka River and scenario runs were repeated under minimum flows and unimpacted conditions. The minimum flows scenario was based on an 8% reduction from unimpacted flows based on results of salinity-based habitats and Common Snook temperature-based habitat analysis, which showed a 15% reduction in these habitats indicative of significant harm (see Table 6-5. and Table 6-6.). These simulations showed that at low, intermediate, and high rates of SLR, salinity-based habitats will be decreased by as much as 18%. Effects of an 8% reduction in flows on manatee temperature-based habitats will decrease habitat by maximum of 8% (Chen 2019a). This indicates manatee temperature-based habitats will not prompt a reevaluation before 2035. Common Snook temperature-based habitat associated with an 8% reduction in flow will be reduced by as much as 23% on a volume basis with the USACE intermediate rate of sea level rise (Chen 2019a). These increases in salinity and temperature-based habitat loss with sea level rise argue for reevaluation prior to the end of the planning period in 2035.

Table 7-2. Sea level rise projections (cm) from 2012 to 2035 for three U.S. Army Corps of Engineers sea level rise projections at two National Oceanic and Atmospheric Agency stations and estimated at the mouth of the Chassahowitzka River based on the NOAA (2018) data.

USACE Projection	St. Petersburg NOAA Station	Cedar Key NOAA Station	Chassahowitzka Mouth (estimated)
Low	5.8	4.3	4.8
Med	10.1	7.9	8.7
High	22.3	20.4	21.1

CHAPTER 8 - LITERATURE CITED

Adams, A.J., J.E. Hill, B.N. Kurth and A.B. Barbour. 2012. Effects of a Severe Cold Event on the Subtropical, Estuarine-Dependent Common Snook, *Centropomus undecimalis*. *Gulf and Caribbean Research* 24 (1): 13-21.

Amec Foster Wheeler Environment & Infrastructure, Inc. 2016. *Coastal Rivers Invertebrate Analysis*. Prepared for Southwest Florida Water Management District, Brooksville, FL

Anderson, P. and M. Stewart. 2016. *Peer Review of the Northern District Model Version 5 and Predictive Simulations, October 10, 2016*. Final Report. In files of SJRWMD and SWFWMD, Palatka and Brooksville, FL.

Annear, T., Chisolm, I., Beecher, H., Locke, A., Aarestad, P., Coomer, C., Estes, C., Hunt, J., Jacobson, R., Jobsis, G., Kauffman, J., Marshall, J., Mayes, K., Smith, G., Wentworth, R. and Stalnaker, C. 2004. *Instream flows for riverine resource stewardship, revised Edition.* Published by the Instream Flow Council. Cheyenne, Wyoming.

Applied Technology and Management. 2015. Coastal Rivers Submerged Aquatic Vegetation Analysis Technical Memorandum Chassahowitzka River Data Analysis. Prepared for Southwest Florida Water Management District.

Applied Technology and Management. 2016. Coastal Rivers Submerged Aquatic Vegetation Analysis. Prepared for Southwest Florida Water Management District.

Arcadis 2016. Sediment Assessment Report. Coastal Rivers: Homosassa, Chassahowitzka, and Weeki Wachee. Prepared for Southwest Florida Water Management District.

Basso, Ron. 2019a. Radar-estimated Rainfall in the Chassahowitzka Springshed from 1995-2017. Southwest Florida Water Management District. Brooksville, FL

Basso, Ron. 2019b. Estimated and Metered Groundwater Use in the Chassahowitzka Springshed from 1992-2016 (includes Domestic self-supply). Southwest Florida Water Management District. Brooksville, FL

Bianchi, T.S. 2013. Estuarine Chemistry. In *Estuarine Ecology*, ed. J.W.J. Day, Byron C. Crump, W. Michael Kemp, and Alejandro Yanez-Arancibia. Hoboken, N.J.: John Wiley, & Sons, Inc.

Blewett, D.A., Stevens, P.W., Champeau, T.R. and Taylor, R.G., 2009. Use of rivers by common snook *Centropomus undecimalis* in southwest Florida: a first step in addressing the overwintering paradigm. Florida Scientist, pp.310-324.

Blewett, D.A. and Stevens, P.W., 2014. Temperature variability in a subtropical estuary and implications for common snook Centropomus undecimalis, a cold-sensitive fish. Gulf of Mexico Science, 32(1), p.4.

Bossart, Gregory D., René A. Meisner, S. A. Rommel, Shin-je Ghim, and A. Bennett Jenson. (2003). Pathological features of the Florida manatee cold stress syndrome. *Aquatic Mammals*. 29. 9-17. 10.1578/016754203101024031.

Bukaveckas, P.A., L.E. Barry, M.J. Beckwith, V. David, and B. Lederer. 2011. Factors Determining the Location of the Chlorophyll Maximum and the Fate of Algal Production within the Tidal Freshwater James River. *Estuaries and Coasts* 34: 569–582.

Cameron, Cortney, Marty Kelly, and Ron Basso. 2018. Summary Statistics of Rainfall Data for Sites in West-Central Florida. Southwest Florida Water Management District. Brooksville, FL.

Castaneda, H. and Putz, F.E. 2007. Predicting sea-level rise effects on a nature preserve on the Gulf Coast of Florida: a landscape perspective. Florida Scientist 70: 166-175.

Champion, K.M. and Starks, R. 2001. The hydrology and water quality of springs in west-central Florida. Southwest Florida Water Management District. Brooksville, Florida.

Chen, XinJian. 2011. User's manual for Laterally Averaged Model for Estuaries. Southwest Florida Water Management District. Brooksville, FL.

Chen, XinJian. 2019a. A modeling study of flow reduction on salinity and thermal habitats in the Chassahowitzka River. Southwest Florida Water Management District. Brooksville, FL.

Chen, XinJian. 2019b. Will A Reduction of Submarine Groundwater Discharge Cause Salinity in SGD to Increase in the Chassahowitzka and Homosassa Rivers? Southwest Florida Water Management District. Brooksville, FL.

Chislock, M.F., E. Doster, R. A. Zitomer, and A. E. Wilson. 2013. Eutrophication is a leading cause of impairment of many freshwater and coastal marine ecosystems in the world. Why should we worry about eutrophication and how is this problem managed? *Nature Education Knowledge* 4: 7.

Clewell, A.F., Flannery, M.S., Janicki, S.S., Eisenwerth, R.D. and Montgomery, R.T. 2002. An analysis of vegetation-salinity relationships in seven tidal rivers on the coast of west-central Florida (draft). Southwest Florida Water Management District. Brooksville, Florida.

Cooper, W., Gandy, R. L., and Crowley, C. E. 2013. A stock assessment for Blue Crab, *Callinectes sapidus*, in Florida waters through 2011. Prepared for the Florida Fish and Wildlife Commission, Division of Marine Fisheries Management. In-House Report 2013-xxx. 127 pp. Accessed from http://myfwc.com/media/4309892/bc-2012.pdf on September 6, 2018.

Crain, Caitlin Mullan, Brian R. Silliman, Sarah L. Bertness, and Mark D. Bertness. 2004. Physical and biotic drivers of plant distribution across estuarine salinity gradients. *Ecology* 85: 2539–2549.

De Cicco, L.A., Hirsch, R.M., Lorenz, D., and Watkins, W.D., 2018, dataRetrieval: R packages for discovering and retrieving water data available from Federal hydrologic web services,<doi:10.5066/P9X4L3GE>

Delaney, M.L. 1998. Phosphorous accumulation in marine sediments and the oceanic phosphorous cycle. *Global Biogeochemical Cycles* 12: 563-572.

DeSantis, L.R.G., Bhotika, S., Williams, K. and Putz, F.E. 2007. Sea-level rise and drought interactions accelerate forest decline on the Gulf coast of Florida, USA. Global Change Biology 13: 2349-2360.

Dixon, L.K. and E.D. Estevez. 1997. Biogeochemical indicators of trophic status in a relatively undisturbed shallow water estuary. Mote Marine Laboratory Technical Report Number 518 Prepared for U.S. Fish and Wildlife Service. Denver, Colorado. (Revised April 21, 1998.)

Dixon, L.K. and E.D. Estevez. 1998. Chassahowitzka National Wildlife Refuge status and trends. Mote Marine Laboratory Technical Report Number 579. Sarasota, Florida. Prepared for the United States Fish and Wildlife Service Air Quality Branch. Denver, Colorado

Dixon, L.K. and E.D. Estevez. 2001. Summary of information: water quality and submerged aquatic vegetation in the Chassahowitzka National Wildlife Refuge 1996-2001. Mote Marine Laboratory Technical Report Number 759. Prepared for U.S. Fish and Wildlife Service July 6, 2001. Denver, Colorado

Dodson, J., K. Bridger, and G. Maddox. 2014. Final TMDL Report: Nutrient TMDLs for Chassahowitzka Springs Group, Crab Creek Spring, Chassahowitzka River–Baird Creek, Baird Springs, Ruth Spring, and Beteejay Springs (WBIDs 1348Z, 1348D, and 1361B), 105. September 2014: Florida Department of Environmental Protection.

Doyle, T.W., Krauss, K.W., Conner, W.H. and From, A.S., 2010. Predicting the retreat and migration of tidal forests along the northern Gulf of Mexico under sea-level rise. *Forest Ecology and Management*, *259*(4), pp.770-777.

Dunbar, M.J., Gustard, A., Acreman, M.C. and Elliott, C.R. 1998. *Overseas approaches to setting river flow objectives*. Institute of Hydrology. R&D Technical Report W6-161. Oxon, England.

Dynamic Solutions, LLC. 2009. Impacts of withdrawals on the Chassahowitzka River System. Prepared for Southwest Florida Water Management District. Brooksville, Florida.

Enfield, D.B., A.M. Mestas-Nunez, and P.J. Trimble, 2001: The Atlantic Multidecadal Oscillation and its relationship to rainfall and river flows in the continental U.S., Geophys. Res. Lett., 28: 2077-2080.

Estevez, E.D. 2007 Chassahowitzka River mollusk survey. April 16, 2007 letter report prepared by Mote Marine Laboratory for the Southwest Florida Water Management District. Brooksville, Florida.

Flannery, M.S., X. Chen, M.G. Heyl, A. Munson, and M. Dachsteiner. 2008. The determination of minimum flows for the lower Alafia River estuary. Brooksville, FL: Southwest Florida Water Management District.

Flannery, M.S., Peebles, E.B. and Montgomery, R.T. 2002. A percent-of-flow approach to managing reductions in freshwater inflows from unimpounded rivers to Southwest Florida estuaries. Estuaries 25: 1318-1332.

Florida Department of Environmental Protection. 2009. State of Florida Numeric Nutrient Criteria Development Plan. Tallahassee, FL.

Florida Department of Environmental Protection. 2013. Numeric Nutrient Criteria for Springs Coast. Tallahassee, FL.

Florida Department of Environmental Protection. 2018. Final Integrated Water Quality Assessment for Florida: 2018 Sections 303(d), 305(b), and 314 Report and Listing Update. Tallahassee, FL.

Florida Department of Transportation. 1999. Florida Land Use, Cover and Forms Classification System. Florida Department of Transportation Surveying and Mapping Office Geographic Mapping Section.

Florida Natural Areas Inventory. 2010. Guide to the natural communities of Florida: 2010 edition. Florida Natural Areas Inventory, Tallahassee, FL.

Frazer, T.K., Hoyer, M.V., Notestein, S.K., Hale, J.A. and Canfield, D.E., Jr. 2001. Physical, chemical and vegetative characteristics of five Gulf coast rivers. University of Florida Institute of Food and Agricultural Sciences, Department of Fisheries and Aquatic Sciences. Gainesville, Florida. Prepared for the Southwest Florida Water Management District. Brooksville, Florida

Frazer, T.K., Notestein, S.K. and Pine, W.E., Jr. 2006. Changes in the physical, chemical and vegetative characteristics of the Homosassa, Chassahowitzka and Weeki Wachee Rivers. University of Florida Institute of Food and Agricultural Sciences, Department of Fisheries and Aquatic Sciences. Gainesville, Florida. Prepared for the Southwest Florida Water Management District. Brooksville, Florida.

Frazer, T.K., Lauretta, M.V., Pine, W.E., III, Nagid, E.J., Strong, W., Tuten, T and Warren, G. 2011. Increased nutrient loading of spring-fed coastal rivers: effects on habitat and faunal communities. University of Florida Institute of Food and Agricultural Sciences and Fish and Wildlife Institute, Florida Fish and Wildlife Conservation Commission. Gainesville, Florida.

Frazer, T.K, E.J. Philips, S.K. Notestein, and C. Jett. 2002. Nutrient Limiting Status of Phytoplankton in Five Gulf Coast Rivers and Their Associated Estuaries, 21. Gainesville, FL: University of Florida.

FWRI-FIM. 2016. Fisheries-Independent Monitoring Program 2016 Annual Data Summary Report. Prepared by the Florida Fish and Wildlife Conservation Commission, Florida Fish and Wildlife Research Institute, Fisheries-Independent Monitoring program. 366 pp.

FGS, Florida Geological Survey. 2009. Hydrogeological Units of Florida, FGS Special Publication No. 28 (revised), 32 pp.

Florida Fish and Wildlife Conservation Commission. 2007. The cradle of the ocean – estuaries. St. Petersburg, Florida.

FWC. Florida Fish and Wildlife Conservation Commission. 2018. Manatee Mortality Statistics. http://myfwc.com/research/manatee/rescue-mortality-response/mortality-statistics/. Accessed Sep. 17, 2018.

Gandy, R. L., Crowley, C. E., Machniak, A. M., and Crawford, C. R. 2011. Review of the biology and population dynamics of the Blue Crab, *Callinectes sapidus*, in relation to salinity and freshwater inflow. Prepared for the Southwest Florida Water Management District. 54 pp.

GDAR. 2013. GDAR01 – Gulf of Mexico Blue Crab stock assessment report. Gulf Data Assessment and Review (GDAR), Gulf States Marine Fisheries Commission, Ocean Springs, MS. GSMFC Pub No. 215. 291 pp.

Gleeson, T. and Richter, B., 2017. How much groundwater can we pump and protect environmental flows through time? Presumptive standards for conjunctive management of aquifers and rivers. River Research and Applications, 34(1), pp.83-92

Gore, J.A., Dahm, C. and Klimas, C. 2002. A review of "Upper Peace River: an analysis of minimum flows and levels" August 25, 2002 draft. Published by the Southwest Florida Water Management District. Brooksville, Florida.

Greenwood, M.F.D, E.B. Peebles, S.E. Burghart, T.C. MacDonald, R.E. Matheson, Jr., and R.H. McMichael, Jr. 2008. Freshwater inflow effects on fishes and invertebrates in the Chassahowitzka River and estuary. University of South Florida and Florida Fish and Wildlife Conservation Commission. St. Petersburg, Florida. Prepared for Southwest Florida Water Management District. Brooksville, Florida.

Hancock, Michael C., Douglas A. Leeper, Mark D. Barcelo, and Marty H. Kelly. 2010. Minimum Flows and Levels Development, Compliance, and Reporting in the Southwest Florida Water Management District. Brooksville, FL

Hem, J.D. 1986. Study and Interpretation of the Chemical Characteristics of Natural Water, ed. U.S.G. Survey, 263. Alexandria, VA: USGS.

Herrick, Gabe, XinJian Chen, Ron Basso, Mike Heyl, and Doug Leeper. 2017. Recommended Minimum Flow for the Crystal River/Kings Bay System -Revised Final Report. Southwest Florida Water Management District. Brooksville, Florida

Heyl, M.G. 2008. Weeki Wachee River recommended minimum flows and levels. Southwest Florida Water Management District. Brooksville, Florida.

Heyl, M. G., A. B. Munson, Jason Hood, Johnathan Morales, and Marty Kelly. 2010. *Anclote River System Recommended Minimum Flows and Levels*. Southwest Florida Water Management District.

Heyl, M.G., Doug Leeper, and Ron Basso. 2012. Recommended Minimum Flows for the Chassahowitzka River System. Southwest Florida Water Management District. Brooksville, FL

Hill, M.T., Platts, W.S. and Beschta, R.L., 1991. Ecological and geomorphological concepts for instream and out-of-channel flow requirements. *Rivers*, *2*(3), pp.198-210.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. Techniques of trend analysis for monthly water-quality data. *Water Resources Research* 18: 107-121.

Hirsch, R.M., and J.R. Slack. 1984. A nonparametric trend test for seasonal data with serial dependence. *Water Resources Research* 20: 727-732.

Howells, R.G., Sonski, A.J., Schafland, P.L. and Hilton, B.D., 1990. Lower temperature tolerance of snook, Centropomus undecimalis. Gulf of Mexico Science, 11(2), p.8.

Hoyer, M.V., Frazer, T.K., Notestein, S.K. and Canfield, D.E. 2004. Vegetative characteristics of three low-lying Florida coastal rivers in relation to flow, light, salinity and nutrients. Hydrobiologia 528: 31-43.

HSW 2009. Water Resource and Human Use Assessment of the Rainbow River in Marion County, Florida. Prepared for the Southwest Florida Water Management District. HSW Engineering, Inc. 3820 Northdale Boulevard, Suite 210B, Tampa FL

Hydrogeologic Inc. 2008, Computer Flow and Saltwater Intrusion Model for the Northern District Water Resources Assessment Project.

Hydrogeologic Inc., 2011, MODHMS Software (Version 3.0) Documentation, Volume I: Groundwater Flow Modules.

Hydrogeologic Inc., 2013, Northern District Groundwater Flow Model, Version 4.0.

Hydrogeologic Inc. and Dynamic Solutions, 2016, Northern District Groundwater Flow Model, Version 5.0

Irvine, Blair A. 1983. Manatee metabolism and its influence on distribution in Florida. *Biological Conservation*. 25. 315-334.

Jacoby, C.A., T.K. Frazer, D.D. Saindon, and S.K. Notestein. 2012. Water quality characteristics of the nearshore Gulf coast waters adjacent to Citrus, Hernando and Levy Counties Project COAST 1997–2010. Gainesville, FL: University of Florida.

Jacoby, C.A., T.K. Frazer, M.A. Edwards, and J.R. Frost. 2015. Water quality characteristics of the nearshore Gulf coast waters adjacent to Hernando, Citrus and Levy Counties Project COAST 1997–2014, 24. Gainesville, FL: University of Florida.

Janicki Environmental, Inc. 2007. Development of analytical tools for quantifying minimum flows in Southwest Florida tidal rivers based upon benthic macroinvertebrate communities. St. Petersburg, Florida. Prepared for Southwest Florida Water Management District. Brooksville, Florida.

Janicki Environmental, Inc. and WSP, Inc. 2018. Exploratory evaluation of water quality and flow relationships for the Chassahowitzka River in support of minimum flows reevaluation. Prepared for Southwest Florida Water Management District. Brooksville, Florida.

Johnson, E.R., Stanfill, A.P., Taylor, A.E., Simonton, L.B., and Marosi, T.B. 2017. Springs Coast Fish Community Assessment. Prepared for the Southwest Florida Water Management District by the Florida Fish and Wildlife Conservation Commission

Jones, Gregg W., Sam B. Upchurch, Kyle M. Champion, and David J. Dewitt. 2011. Water-Quality and Hydrology of the Homosassa, Chassahowitzka, Weeki Wachee, and Aripeka Spring Complexes, Citrus and Hernando Counties, Florida. Southwest Florida Water Management District.

Jowett, I.G. 1993. *Minimum flow requirements for instream habitat in Wellington rivers*. NZ Freshwater Miscellaneous Report No. 63. National Institute of Water and Atmospheric Research. Christchurch, New Zealand.

Kelly, M. and Gore, J., 2008, Florida River Flow Patterns and the Atlantic Multidecadal Oscillation, River Research and Applications 24:598-616 (2008), published online at www.interscience.wiley.com.

Kimrey, Joel Otto and Warren Anderson. 1987. Reconnaissance of geohydrologic areas and 1981 low-flow conditions, Withlacoochee River basin, Southwest Florida Water Management District. US Geological Survey.

Kimmerer, W.J. 2002. Physical, biological, and management responses to variable freshwater inflow into the San Francisco Estuary. *Estuaries* 25: 1275-1290.

Kirk, J.T. 1994. *Light and photosynthesis in aquatic ecosystems*. Cambridge: Cambridge University Press.

Kleen, Joyce. 2018. Personal Communication. Email dated July 18, 2018. Aerial survey data on manatee.

Kleppel, G.S., Christie, D.R., Milon, W., Smith, N.P. and Vargo, G.A. 1996. The state of Florida's estuaries and future needs in estuarine research. Part 1. A synopsis of Florida's estuarine resources with recommendations for their conservation and management. The Florida Sea Grant College Program, University of Florida. Gainesville, Florida.

Knochenmus, Lari A., and Dann K. Yobbi. 2001. Hydrology of the coastal springs ground-water basin and adjacent parts of Pasco, Hernando, and Citrus Counties, Florida. Water-Resources Investigations Report (WRIR 01-4230). U.S. Geological Survey.

Knowles, Leel, Jr., O'Reilly, Andrew M., and Adamski, James C., 2002, Hydrogeology and Simulated Effects of Ground-Water Withdrawals from the Floridan Aquifer System in Lake County and in the Ocala National Forest and Vicinity, North-Central Florida: Water-Resources Investigations Report 02-4207, 140 p.

Laist, David W., and John E. Reynolds. 2005. Florida manatees, warm-water refuges, and an uncertain future. *Coastal Management* 33: 279–295.

Laist, David W., Cynthia Taylor, and John E. Reynolds. 2013. Winter Habitat Preferences for Florida Manatees and Vulnerability to Cold. *PLoS ONE* 8. doi:10.1371/journal.pone. 0058978.

Lee, G. Fred, Anne Jones-Lee, and Water Rast. 1995. Secchi Depth as a Water Quality Parameter. Report of G. Fred Lee and Associates. El Macero, CA

Leeper, Douglas A. 2016. Incorporating Elevation Data Referenced to the North American Vertical Datum of 1988 (NAVD 88) into Minimum Flows and Levels Data Collection, Summarization, Reporting and Rule Development. Southwest Florida Water Management District.

Leeper, Douglas A., Michael S. Flannery, Michael G. Heyl, Ron Basso, and Marty Kelly. 2012. *Recommended Minimum Flows for the Homosassa River System*. Southwest Florida Water Management District.

Leverone, J.R. 2006. Collection, enumeration and analysis of invertebrate community and substrate in the Chassahowitzka River, Florida: Methodology and data report. Mote Marine Laboratory. Sarasota, Florida. Prepared for Southwest Florida Water Management District. Brooksville, Florida.

Lewis, E.L. 1980. The Practical Salinity Scale 1978 and its antecedents. IEEE Journal of Oceanic Engineering OE-5(1):3-8.

Lloyd, Natalie, Gerry Quinn, Martin Thoms, Angela Arthington, Ben Gawne, Paul Humphries, and Keith Walker. 2004. Does flow modification cause geomorphological and ecological response in rivers. *A literature review from an Australian perspective. CRC for Freshwater Ecology* 57.

Mace, J.W. 2007. Minimum flows and levels determination: St. Johns River at State Road 50, Orange and Brevard Counties, Florida. Technical Publication SJ2007-01. St. Johns River Water Management District. Palatka, Florida.

Marella, R., 2008, Water Use in Florida 2005, and Trends 1950-2005, United States Geological Survey Fact Sheet 2008-3080.

McDonald, M.G. and A.W. Harbaugh, 1988, A modular three-dimensional finite-difference groundwater flow model, U.S. Geological Survey Techniques of Water-Resources Investigations Book 6, Chapter A1.

Miller, J.A. 1986. Hydrogeologic framework of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Caroline: U.S. Geological Survey Water-Resources Investigations Report 84-4135, 69 p.

Montagna, P.A., Estevez, E.D., Palmer, T.A. and Flannery, M.S., 2008. Meta-analysis of the relationship between salinity and molluscs in tidal river estuaries of southwest Florida, USA. *American Malacological Bulletin*, *24*(1)

Motz, L. and Dogan, A., 2004, North-Central Florida Active Water-Table Regional Groundwater Flow Model, St. Johns River Water Management District, 141 p.

Muller, R.G., A.A. Trotter, and P.W. Stevens. 2015. The 2015 stock assessment of common snook, Centropomus undecimalis. Florida Fish and Wildlife Conservation Commission, Florida Fish and Wildlife Research Institute. St. Petersburg, FL

Neubauer, C.P., Hall, G.B., Lowe, E.F., Robison, C.P., Hupalo, R.B. and Keenan, L.B. 2008. Minimum flows and levels method of the St. Johns River Water Management District. Environmental Management 42: 1101-1114.

NOAA 2018. National Centers for Environmental Information. www.ncdc.noaa.gov.

Olsen, S.B. and Richter, B.D. 2006. Managing freshwater inflows to estuaries - a methods guide. U.S. Agency for International Development. Washington, D.C.

Overton, I. C., M. J. Colloff, T. M. Doody, Brent Henderson, and S. M. Cuddy. 2009. Ecological outcomes of flow regimes in the Murray-Darling Basin. *Report prepared for the National Water Commission by CSIRO Water for a Healthy Country Flagship, Canberra. 422p*.

Peebles, E.B., T.C. MacDonald, S.E. Burghart, C. Guenther, R.E. Matheson Jr, and R.H. McMichael Jr. 2009. Freshwater inflow effects on fish and invertebrate use of the Homosassa River estuary. Southwest Florida Water Management District. Brooksville, Florida.

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E. and Stromberg, J.C., 1997. The natural flow regime. *BioScience*, *47*(11), pp.769-784.

Poff, N. LeRoy, and Julie KH Zimmerman. 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. *Freshwater Biology* 55: 194–205.

Postel, S. and Richter, B. 2012. Rivers for life: Managing water for people and nature. Island Press. Washington, D.C.

Powell, G.L., Matsumoto, J. and Brock, D.A. 2002. Methods for determining minimum freshwater inflow needs of Texas bays and estuaries. *Estuaries*. 25: 1262-1274.

Powell, G.L., Johnson, B.H. and Hackney C.T. 2010. Scientific review of the Chassahowitzka River System recommended minimum flows and levels. Scientific Peer Review Report. June 30, 2010. Prepared for Southwest Florida Water Management District. Brooksville, Florida

Raabe, Ellen A. and Richard P. Stumpf. 2015. Expansion of Tidal Marsh in Response to Sea-Level Rise: Gulf Coast of Florida, USA. Estuaries and Coasts.

Richter, B.D., Baumgartner, J.V., Powell, J. and Braun, D.P., 1996. A method for assessing hydrologic alteration within ecosystems. *Conservation biology*, *10*(4), pp.1163-1174.

Richter, B.D., Davis, M.M., Apse, C. and Konrad, C. 2011. A presumptive standard for environmental flow protection. River Research and Applications

Rosenau, J.C., Faulkner, G.L., Hendry, C.W., Jr., and Hull, R.W., 1977, Springs of Florida: Florida Geological Survey Bulletin 31 Revised, 461 p

Rouhani, Shahrokh, Peter Sucsy, Greeneville Hall, William Osburn, and Michael Wild. 2007. *Analysis of Blue Spring Discharge Data to Determine a Minimum Flow Regime*. St. Johns River Water Management District.

Runge, Michael C., Carol A. Sanders-Reed, Catherine A. Langtimm, Jeffrey A. Hostetler, Julien Martin, Charles J. Deutsch, Leslie I. Ward-Geiger, and Gary L. Mahon. 2017. Status and threats analysis for the Florida manatee *(Trichechus manatus latirostris),* 2016. Scientific Investigations Report 2017–5030. U.S. Geological Survey.

Ryder, Paul. 1982. Digital Model of Predevelopment Flow in the Tertiary limestone (Floridan) Aquifer System in West-Central Florida, U.S. Geological Survey Water-Resources Investigations Report 81-54

Ryder, Paul. 1985. Hydrology of the Floridan aquifer system in west-central Florida. US Geological Survey Professional Paper.

Sacks, L. A. and A.B. Tihansky, 1996, Geochemical and isotopic composition of ground water with emphasis on sources of sulfate in the upper Floridan Aquifer and intermediate aquifer system in southwest Florida, U.S. Geological Survey WRI Report 96-4146, 54 p.

Schemel, Larry. 2001. Simplified Conversions Between Specific Conductance and Salinity Units for Use with Data from Monitoring Stations. IEP Newsletter. Interagency Ecological Program for the San Francisco Estuary. Vo. 14, No. 1.

Shafland, P.L. and Foote, K. J. 1983. A lower lethal temperature for fingerling snook, *Centropomus undecimalis*. *Gulf of Mexico Science.* 6 (2). 12.

Scott, Thomas M., Guy H. Means, Rebecca P. Meegan, Ryan C. Means, Sam Upchurch, R. E. Copeland, James Jones, Tina Roberts, and Alan Willet. 2004. Springs of Florida. Bulletin 66. Tallahassee, FL: Florida Geological Survey.

Sepulveda, N. 2002. Simulation of Ground-Water Flow in the Intermediate and Floridan Aquifer Systems in Peninsular Florida, U.S. Geological Survey WRI Report 02-4009, 130 p.

Sloan, W.C. 1956. The distribution of aquatic insects in two Florida springs. Ecology 37: 81-98.

South Florida Water Management District. 2002. Final draft – technical documentation to support development of minimum flows and levels for the northwest Fork of the Loxahatchee River. West Palm Beach, Florida.

South Florida Water Management District. 2018. Technical Document to Support Reevaluation of the Minimum Flow Criteria for the Caloosahatchee River Estuary. West Palm Beach, FL.

Southwest Florida Water Management District, 1987, Ground-water Resource Availability Inventory: Citrus County, Florida, 166 p.

Southwest Florida Water Management District, 1999, Aquifer Characteristics within the Southwest Florida Water Management District, 111 p.

Southwest Florida Water Management District. 2015. Protocol for addressing sea level change when establishing minimum flows and levels and recovery assessments. Memorandum. March 17, 2015.

Southwest Florida Water Management District. 2017. Chassahowitzka River Surface Water Improvement and Management (SWIM) Plan. Brooksville, FL.

Stevens, P.W., Fox, S.L. and Montague, C.L., 2006. The interplay between mangroves and saltmarshes at the transition between temperate and subtropical climate in Florida. *Wetlands Ecology and Management*, *14*(5), pp.435-444.

Stevens, P.W., Blewett, D.A., Boucek, R.E., Rehage, J.S., Winner, B.L., Young, J.M., Whittington, J.A. and Paperno, R., 2016. Resilience of a tropical sport fish population to a severe cold event varies across five estuaries in southern Florida. Ecosphere, 7(8).

Stevens, P.W., R.E. Boucek, A.A. Trotter, J.L. Ritch, E.R. Johnson, C.P. Shea, D.A. Blewett, and J.S. Rehage. 2018. Illustrating the value of cross-site comparisons: Habitat use by a large, euryhaline fish differs along a latitudinal gradient. Fisheries Research 208: 42-48.

Stevenson, R.J., A. Pinowska, and Y.K. Yang. 2004. Ecological condition of algae and nutrients in Florida springs.

Stevenson, R.J., A. Pinowska, A. Albertin and J.O. Sickman. 2007. Ecological condition of algae and nutrients in Florida Springs. The Synthesis Report WM 858 Florida Department of Environmental Protection, Tallahassee, Florida. 58 pp. plus appendices.

Stith, Bradley M., James P. Reid, Catherine A. Langtimm, Eric D. Swain, Terry J. Doyle, Daniel H. Slone, Jeremy D. Decker, and Lars E. Soderqvist. 2011. Temperature inverted haloclines provide winter warm-water refugia for manatees in Southwest Florida. *Estuaries and Coasts*. 34: 106-119.

Strickland, J.D.H., and T.R. Parsons. 1972. *A practical handbook of seawater analysis*. Ottawa, Ontario, Canada: Fisheries Research Board of Canada.

Toutant, T., J.S. Perry, and L. K. Dixon. 2004. Change analysis of submerged aquatic vegetation in the Chassahowitzka National Wildlife Refuge 1996-2000. Mote Marine Laboratory Technical Report Number 972. Sarasota, Florida. Prepared for the United States Fish and Wildlife Service Air Quality Branch. Denver, Colorado.

Upchurch, S.B., J. Chen, and C.R. Cain. 2008. Relationships of Nitrate to Flow in Springs of the Suwannee River Water Management District, Florida, 38. Live Oak, FL: Suwannee River Water Management District.

U.S. Fish and Wildlife Service, 2017. Endangered and Threatened Wildlife and Plants; Reclassification of the West Indian Manatee from Endangered to Threatened, Rule FWS-R4-ES-2015-0178-3905. https://www.federalregister.gov/documents/2017/04/05/2017-06657/endangered-and-threatened-wildlife-and-plants-reclassification-of-the-west-indian-manatee-from

U.S. Geological Survey. 2018. National Water Information System (NWIS). https://waterdata.usgs.gov/nwis

Water and Air Research, Inc. 2018a. Shoreline Vegetation Assessment of Chassahowitzka and Homosassa River Systems. Prepared for the Southwest Florida Water Management District. Brooksville, Florida.

Water and Air Research, Inc. 2018b. Assessment of Oysters and Barnacles along the Chassahowitzka, Homosassa, and Lower Withlacoochee River Systems. Prepared for the Southwest Florida Water Management District. Brooksville, Florida.

Water Resource Associates, Inc., SD II Global Corporation and Janicki Environmental, Inc. 2005. Suwannee River Water Management District technical report – MFL establishment for the lower Suwannee River & estuary, Little Fanning, Fanning & Manatee Springs. Tampa and St. Petersburg, Florida. Prepared for the Suwannee River Water Management District. Live Oak, Florida

WCEP 2016. Whooping Crane Eastern Partnership 2016 Annual Report. Prepared by Jo-Anne Bellemer. 26 pp.

Wessel, M. 2012. Defining the fish-flow relationship in support of establishing minimum flows and levels for Southwest Florida tidal rivers: building on the toolbox of analytical techniques. Janicki Environmental, Inc. St. Petersburg, Florida. Prepared for the Southwest Florida Water Management District.

White, William A. 1970. *The Geomorphology of the Florida Peninsula*. Geological Bulletin No. 51. Florida Department of Natural Resources.

Williams, B. K., R. C. Szaro, and C. D. Shapiro. 2009. Adaptive Management: The U.S. Department of the Interior Technical Guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington, DC.

Williams, B.K. and E.D. Brown. 2014. Adaptive management: from more talk to real action. *Environmental Management.* 53: 465-479.

Williams, K., Ewel, K.C., Stumpf, R.P., Putz, F.E. and Workman, T.W., 1999. Sea-level rise and coastal forest retreat on the west coast of Florida, USA. *Ecology*, *80*(6), p.2045.

Williams, K., MacDonald, M. and Sternberg, L.D.S.L., 2003. Interactions of storm, drought, and sea-level rise on coastal forest: a case study. *Journal of Coastal Research*, pp.1116-1121.

Williams, L.J., Dausman, A.D., and Bellino, J.C. 2011, Relation of aquifer confinement and long-term groundwater-level decline in the Floridan aquifer system: Proceedings of the 2011 Georgia Water Resources Conference, April 11-13, 2011, Athens, Georgia.

WSI 2006. Human Use and Ecological Evaluation of the Recommended Minimum Flow Regime for Blue Spring and Blue Spring Run, Volusia County, Florida. Prepared for the St. Johns River Water Management District. Wetland Solutions, Inc.

Yobbi, D.K., and L.A. Knochenmus. 1989. Salinity and Flow Relations and Effects of Reduced Flow in the Chassahowitzka River and Homosassa River Estuaries, Southwest Florida: U.S. Geological Survey Water-Resources Investigations Report 88-4044: United State Geological Survey, Southwest Florida Water Management District.

CHAPTER 9 - APPENDICES (BOUND SEPARATELY)