Recommended Minimum Flows for Charlie Creek
Final Draft Report

November 8, 2023

Southwest Florida Water Management District

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Acronym List Table

Acronym	Definition
AMO	Atlantic Multidecadal Oscillation
AWS	Area Weighted Suitability
BLUJ	Juvenile Bluegill
BMAP	Basin Management Plan
CCSP	Spawning Channel Catfish
cfs or (ft^3/s)	cubic feet per second
CLIP	Critical Lands and Waters Identification Project
CWCFGWB	Central West-Central Florida Groundwater Basin
DEM	Digital Elevation Model
DEP	Florida Department of Environmental Protection
District	Southwest Florida Water Management District
DPSL	Deep Slow Habitat Guild
DPFA	Deep Fast Habitat Guild
EDP	Environmental Data Portal (of the District)
ENSO	El Niño-Southern Oscillation
F.A.C	Florida Administrative Code
FDACS	Florida Department of Agriculture and Consumer Services
FDOT	Florida Department of Transportation
FEGN	Florida Ecological Greenways Network
FLUCCS	Florida Land Use, Cover, and Forms Classification System
FNAI	Florida Natural Areas Inventory
F.S.	Florida Statutes
FSAID	Florida Statewide Agricultural Irrigation Demand
FWC	Florida Fish and Wildlife Conservation Commission
GIS	Geographic Information System
GLMM	Generalized Linear Mixed Model
HA	Habitat Assessment
HEC-RAS	Hydrologic Engineering Center River Analysis System
HUC	Hydrologic Unit Code
HYDR	Hydropsychidae
IA	Intermediate Aquifer
IAS	Intermediate Aquifer System
ICU	Intermediate Confining Unit
IWR	Impaired Waters Rule
LDI	Landscape Development Index
LFA	Lower Floridan Aquifer
LWPIP	Lowest Wetted Perimeter Inflection Point
MFL	Minimum Flow and/or Minimum Water Level (as defined in Section 373.042, F.S.)
mgd	million gallons per day
n	Number, count data
NAVD88	North American Vertical Datum of 1988

Acronym	Definition
NGVD29	National Geodetic Vertical Datum of 1929
No.	Number, for USGS gage designations
NWCFGWB	Northern West-Central Florida Groundwater Basin
NWI	National Wetland Inventory
PHABSIM	Physical Habitat Simulation System
PRIM	Peace River Integrated Model
R^2	Coefficient of determination (for statistical analyses)
ROMP	Regional Observation and Monitor-well Program
SA	Surficial Aquifer
SCI	Stream Condition Index
SEFA	System for Environmental Flow Analysis
SIMPER	Similarity Percentages
SR	State Road
SST	Sea Surface Temperature
SWCFGWB	Southern West-Central Florida Groundwater Basin
SWFWMD	Southwest Florida Water Management District
TDS	Total Dissolved Solids
TINV	Total Invertebrates
TMDL	Total Maximum Daily Load
TVET	*Tvetenia vitracies*
UF	University of Florida
UFA	Upper Floridan Aquifer
USGS	United States Geological Survey / Department of Interior.
WBID	Waterbody Identification Numbers (of the DEP)

Conversion Unit Table

Metric to U.S. Customary		
Multiply	By	To Obtain
cubic meters per second (m^3/s)	35.31	cubic feet per second (cfs)
cubic meters per second (m^3/s)	23	million gallons per day (mgd)
millimeters (mm)	0.03937	inches (in)
centimeter (cm)	0.3937	inches (in)
meters (m)	3.281	feet (feet)
kilometers (km)	0.6214	statute miles (mi)
square meters (m^2)	10.76	square feet (ft^2)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.315	cubic feet (ft^3)
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
Celsius degrees (^oC)	1.8*(^oC) + 32	Fahrenheit (^oF)
U.S. Customary to Metric		
Multiply	By	To Obtain
inches (in)	25.40	millimeters (mm)
inches (in)	2.54	centimeters (cm)
feet (feet)	0.3048	meters (m)
statute miles (mi)	1.609	kilometers (km)
square feet (ft^2)	0.0929	square meters (m^2)
square miles (mi^2)	2.590	square kilometers (km^2)
acres	0.4047	hectares (ha)
gallons (gal)	3.785	liters (l)
cubic feet (ft^3)	0.02831	cubic meters (m^3)
acre-feet	1233.0	cubic meters (m^3)
Fahrenheit (^oF)	0.5556*(^oF-32)	Celsius degrees (^oC)
U.S. Customary to U.S. Customary		
Multiply	By	To Obtain
acre	43560	square feet (ft^2)
square miles (mi^2)	640	acres
cubic feet per second (cfs)	0.646	million gallons per day (mgd)

EXECUTIVE SUMMARY

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

This report summarizes minimum flows for Charlie Creek developed by the District. Charlie Creek originates north of East County Line Road in Polk County and flows to the Peace River in Hardee County, south of Zolfo Springs. Charlie Creek is one of six major tributaries to the Peace River that provides a large volume of freshwater inflow to the Charlotte Harbor estuary, which opens to the Gulf of Mexico.

The recommended minimum flows for Charlie Creek were based upon the best available information, as required by Florida Statute, and were based on all relevant environmental values identified in the Florida Water Resource Implementation Rule. The District’s approach for developing these minimum flows was habitat-based. Resource management goals for the development of minimum flows for Charlie Creek included the following:

- Determination of a low flow threshold to provide protection for ecological resources and recreational use of Charlie Creek during critical low-flow periods.
- Maintenance of seasonal hydrologic connections between the Charlie Creek channel and floodplain to ensure persistence of floodplain structure and function.
- Maintenance of available instream habitat for fish and invertebrates.
- Maintenance of inundation of instream woody habitat.
- Maintenance of water quality.

The baseline flow record used for the minimum flow analyses was developed for Charlie Creek to account for decreases and increases (from excess agricultural runoff) in gaged flows associated with surface and groundwater withdrawals. The Charlie Creek baseline flow record extended from May 1, 1950, through December 31, 2021. Flow-based blocks, defined below, were developed from analysis of the minimum flow requirement for fish passage and the sensitivity of floodplain inundation to flow reduction at the United States Geological Survey (USGS) Charlie Creek near Gardner, FL (No. 02296500) gage.

- Block 1 – Flows less than or equal to 27 cubic feet per second (cfs)
- Block 2 – Flows greater than 27 cfs and less than or equal to 120 cfs
- Block 3a – Flows greater than 120 cfs and less than or equal to 316 cfs
- Block 3b – Flows greater than 316 cfs and less than or equal to 945 cfs
- Block 3c – Flows greater than 945 cfs

A percent-of-flow approach was used with several block-specific criteria to develop minimum flows for Charlie Creek that ensure maintenance of 85% of the most sensitive criteria, and by default, all criteria associated with the resource management goals. In addition, a low flow threshold was identified to protect flow continuity. Assessments were conducted to ensure all relevant environmental values identified by the Florida Water Resources Implementation Rule would be protected by the minimum flows proposed for Charlie Creek.

For Charlie Creek, the recommended minimum flows for Block 1 and Block 2 maintain available instream habitat and the recommended minimum flows for Blocks 3a, Block 3b, and Block 3c maintain floodplain inundation. All proposed minimum flows are derived from baseline flows for the previous day at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage that have been adjusted for withdrawal impacts.

Flow-Based Block	If Previous Day's Flow, Adjusted for Withdrawals, is:	Recommended Minimum Flow is:	Potential Allowable Flow Reduction is:
1	≤ 27 cfs	Flow on the previous day	0 cfs
2	> 27 cfs and ≤ 120 cfs	27 cfs or 86% of the flow on the previous day, whichever is greater	14% of flow on the previous day
3a	> 120 cfs and ≤ 316 cfs	88% of the flow on the previous day	12% of flow on the previous day
3b	> 316 cfs and ≤ 945 cfs	91% of the flow on the previous day	9% of flow on the previous day
3c	> 945 cfs	93% of the flow on the previous day	7% of flow on the previous day

The recommended minimum flows for Charlie Creek are currently being met and are expected to be met over the next 20 years. Therefore, development of a recovery or prevention strategy is not necessary.

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

CHAPTER 1 - INTRODUCTION

This report documents the development of new, recommended minimum flows for Charlie Creek, which were formulated by the Southwest Florida Water Management District (District) using the best available information. This chapter provides an overview of the rationale for developing these minimum flows and the legal directives and approaches used by the District. Chapter two provides a description of the Charlie Creek watershed, including the location, soils, climate, streamflow, hydrogeology, and aquifer levels. Factors that affect streamflow with some emphasis on larger scale climatic oscillations, are also summarized in this chapter. Chapter three presents water quality trends and relationships with historic flow patterns. Chapter four identifies and discusses the ecological resources of concern. Chapter five outlines the technical approaches for establishing minimum flows associated with resources of concern. Chapter six presents the results of staff analyses, with minimum flow recommendations for Charlie Creek.

1.1. Rationale for Minimum Flows Development

Flowing surface waters provide numerous benefits to society and are an integral part of the natural functioning of ecosystems within Florida. Surface water withdrawals can directly affect the water volume or rate of flow in rivers of the area. Similarly, groundwater withdrawals have the potential to alter groundwater levels and thereby reduce the water volume or flow. These cause-and-effect relationships between water withdrawals and reduced surface water flows have been recognized by the Florida State Legislature in the Florida Water Resources Act of 1972 (Chapter 373, Florida Statutes (F.S.)). As a result of this legislation, the District has the responsibility for establishing minimum flows for all surface watercourses within its boundaries. A minimum flow is defined in Section 373.042(1)(a), F.S., as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area."

Based on its importance to the state and region and the existence of withdrawal-related impacts, the District has prioritized the establishment of minimum flows for Charlie Creek, a 42-mile watercourse that originates north of East County Line Road in Polk County and flows to the Peace River in Hardee County, south of Zolfo Springs. Charlie Creek is one of the six major tributaries to the Peace River that provides a large volume of freshwater inflow to Charlotte Harbor estuary, which opens to the Gulf of Mexico. The creek and its floodplain provide critical habitat for numerous fish, macroinvertebrate, and plant species, which in turn provide food and habitat for various birds, mammals, and other organisms. The District initiated work supporting development of minimum flows for Charlie Creek in

2007 and has completed extensive physical, hydrologic and ecological data collection and analysis for the effort over the past sixteen years.

Based on comprehensive analyses, the District has developed recommended minimum flows for Charlie Creek. These minimum flows were developed with consideration of and are protective of all relevant environmental values identified for consideration in the Water Resource Implementation Rule (see Rule 62-40.473, Florida Administrative Code, or F.A.C.). If adopted by the District's Governing Board, the recommended minimum flows for Charlie Creek will be included in the District's Water Levels and Rates of Flow Rules (Chapter 40D-8, F.A.C.). Once effective, the minimum flow rules will support District water-use permitting, environmental resource permitting, water-supply planning and other management activities that afford protection for the creek.

1.2. Legal Directives and Use of Minimum Flows

1.2.1. Relevant Florida Statues and Rules

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

1. Section 373.042 of The Florida Water Resources Act of 1972 (Chapter 373, F.S.) directs the 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 District Governing Board. Section 373.042 also allows for the establishment of an independent scientific peer review panel and use of a final report prepared by a peer review panel when establishing minimum flows and minimum water levels.

2. Section 373.0421, F.S., allows for considerations and exclusions concerning minimum flows or minimum water level establishment, including changes and structural alterations to watersheds, surface waters and aquifers and their effects. 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 requires that recovery and prevention strategies must be adopted and implemented if flows in a water body are not currently meeting or are projected to not meet an applicable minimum flow within the next 20 years. In addition, the periodic and as needed, revision of established minimum flows and minimum water levels is required.

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 minimum water levels. This rule identifies the ten environmental values described in section 1.2.2 below that are to be considered when establishing minimum flows and minimum water levels. In recognition of the fact that flows naturally vary, this rule also states that minimum flows should be expressed as multiple flows defining a minimum hydrological regime to the extent practical and necessary.

4. Chapter 40D-8, F.A.C., the District's Water Levels and Rates of Flow Rules, describes the minimum flows established for surface watercourses in the District. Minimum Flows are specifically included in Rule 40D-8.041, F.A.C.

5. Chapter 40D-80, F.A.C., the District's Recovery and Prevention Strategies for Minimum Flows and Levels Rules, sets forth the regulatory portions of the recovery or prevention strategies to achieve or protect, as applicable, the minimum flows and minimum water levels established by the District.

6. Rule 62-41.204(2), F.A.C., the Central Florida Water Initiative Area Uniform Process for Setting Minimum Flows and Minimum Water Levels and Water Reservations Rule, within the Regulation of the Consumptive Use of Water Rules of the DEP (Chapter 62-41, F.A.C.) identifies additional requirements for minimum flow and level prioritization, establishment, and status assessments for certain waterbodies. These water bodies include those within the Central Florida Water Initiative (CFWI) Area, which as defined in Section 373.0465, F.S., includes all of Orange, Osceola, Polk and Seminole counties and southern Lake County. The CFWI is a collaborative water supply planning effort among the St. Johns River, South Florida and Southwest Florida water management districts, the Florida DEP, the Florida Department of Agriculture

and Consumer Services, regional utilities, business organizations, environmental groups, agricultural interests, and other stakeholders (CFWI 2020). Rule 62-41.204(2) (F.A.C.) requires coordination between the DEP, St. Johns River Water Management District, Southwest Florida Water Management District, and the South Florida Water Management District for discussion of water body prioritization for minimum flow, minimum water level and reservation development, and the sharing of information between the three water management districts when seeking to establish or reevaluate minimum flows and levels.

The District's Minimum Flows and Levels Program addresses all relevant requirements expressed in the Water Resources Act of 1972, District rules, and those of the DEP. The District has developed specific methods for establishing minimum flows or minimum water levels for lakes, wetlands, rivers, springs, and aquifers, subjected the methods to independent, scientific peer-review, and in some cases, adopted the methods into its Water Level and Rates of Flow rules. 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 rules (Chapter 40D-80, F.A.C.) and in the District's Consumptive Use of Water rules (Chapter 40D-2, F.A.C.).

A summary of efforts completed for the District's Minimum Flows and Levels Program is provided by Hancock et al. (2010) and SWFWMD (2023b). Additional information pertaining to the establishment and implementation of minimum flows and other related issues is available from the District's Minimum Flows and Levels (Environmental Flows) Program web page at https://www.swfwmd.state.fl.us/projects/mfls, and in CFWI (2020), DEP (2021), SWFWMD (2020b, 2021a,b,c, 2022 and 2023a, b).

1.2.2. Environmental Values

The Florida Water Resource Implementation Rule, specifically Rule 62-40.473, F.A.C., provides additional guidance for the minimum flows and levels establishment, requiring 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 were considered for development of proposed minimum flows for Charlie Creek are discussed in Chapter 6.

1.3. Development of Minimum Flows and Levels

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

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. Relationships between some of these altered variables can be quantified and used to develop significant harm thresholds or criteria that are useful for establishing minimum flows and levels.

3. Alternative hydrologic regimes may exist that differ from non-withdrawal impacted conditions but are sufficient to protect water resources and the ecology of these resources from significant harm.

Support for these assumptions is provided by a large body of published scientific work addressing relationships between hydrology, ecology and human-use values associated with water resources (e.g., see reviews and syntheses by Pastor et al. 2014, Poff et al. 1997, Poff and Zimmerman 2010, Postel and Richer 2003, Wantzen et al. 2008). This information has been used by the District and other water management districts within the state to identify significant harm thresholds or criteria supporting development of minimum flows and minimum water levels for over 400 water bodies (DEP 2022), as summarized in publications associated with these efforts (Flannery et al. 2002, Neubauer et al. 2008) and in minimum flows reports, which may be found at the links provided in Table 1-1.

Table 1-1. Hyperlinks to minimum flows and levels (MFL) documents, including technical reports, from each of the water management districts (WMD) within the state of Florida.

WMD	Hyperlink to MFL Documents
Northwest Florida WMD	https://nwfwater.com/water-resources/minimum-flows-minimum-water-levels/
South Florida WMD	https://www.sfwmd.gov/our-work/mfl
St. Johns River WMD	https://www.sjrwmd.com/documents/mfl/
Suwanee River WMD	https://www.mysuwanneeriver.com/55/Minimum-Flows-and-Minimum-Water-Levels
Southwest Florida WMD	https://www.swfwmd.state.fl.us/projects/mfl/documents-and-reports

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

1.3.1. Flow Definitions and Concepts

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

- Flow or streamflow refers to discharge, i.e., the rate a specified volume of water flows past a point for some unit of time. For minimum flow purposes, flow is typically expressed in cubic feet per second (cfs).

- Long-term, as defined in Rule 40D-8.021, F.A.C., “means an evaluation period used to establish Minimum Flows and Minimum Water Levels, and assess withdrawal impacts on established Minimum Flows and Minimum Water Levels that represents a period which spans the range of hydrologic conditions which can be expected to occur based upon historical records, ranging from high water levels to low water levels." Also, for minimum flow and level purposes, "historic" means a Long-term period when there are no measurable impacts due to withdrawals and Structural Alterations are similar to current conditions."

- Reported flows are directly measured or estimated by a relationship developed using measured flows and water depth or velocity. Examples include measured and estimated flows reported by the United States Geological Survey (USGS) and those available through the District's Environmental Data Portal (EDP). Most reported flows are estimated using velocity and water-depth measurements or regressions or other models developed from empirical measurements. For example, reported flows are typically estimated from measured water levels using rating curves. Reported flows are alternatively referred to as *observed* or *gaged* flows.

- Modeled flows are flows that are derived using a variety of modeling approaches. Examples include flows predicted using numerical groundwater flow models, flows predicted with statistical models derived from either observed or other modeled hydrologic data, and impacted flows adjusted for withdrawal-related flow increases or decreases.

- Impacted flows are flows that include withdrawal-related impacts. Impacted flows can be *reported flows*, and they can also be *modeled flows* based on simulated groundwater withdrawal scenarios.

- Baseline flows are flows that have occurred or are expected in the absence of withdrawal impacts. Baseline flows may be *reported flows* if data exists prior to any withdrawal impacts. More typically, baseline flows are *modeled flows*. Baseline flows are alternatively referred to as *natural, unimpacted, unimpaired* or *historic* flows.

- Minimum flow is defined by the Florida Water Resources Act of 1972 as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area."

- A flow regime is a hydrologic regime characterized by the quantity, timing, and variation of flows in a river. Rule 62-40.473, F.A.C., dictates that "minimum flows and levels should be expressed as multiple flows or levels defining a minimum hydrologic regime, to the extent practical and necessary to establish the limit beyond which further withdrawals would be significantly harmful to the water resources or the ecology of the area as provided in Section 373.042(1), F.S."

1.3.2. Baseline Flow Conditions

Use of significant harm criteria for minimum flows development is predicated upon identification of a baseline flow record or records that characterize environmental conditions expected in the absence of withdrawals. For river segments or entire rivers where flows are currently or have not historically been affected by water withdrawals, reported flows for the period without withdrawal effects or, respectively, for the entire period of record can be used as baseline flows. More typically, reported flows are impacted flows that incorporate withdrawal effects, or are available for a limited period, and baseline flows must be modeled.

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

1.3.3. Building-Block Approach

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

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

For some baseflow-dominated systems, for example, short, coastal rivers where discharge from spring vents accounts for much of the flow, use of a seasonal, building block approach may not be necessary.

In addition, association of blocks with specific flow ranges, which typically, but not always correspond with seasonal periods, may be appropriate for establishing minimum flows for some systems.

In the past, the building block approach for characterizing flow regimes was based on fixed dates. However, the fixed-date approach for block definition is not currently considered appropriate for representing seasonal flow regimes for a system in years when the annual flows remain high or low relative to historical conditions. To address this issue, the District has begun using flow-based blocks that correspond with typical low (Block 1), medium (Block 2), and high (Block 3) flows to develop minimum flows. This approach was successfully used for the reevaluation of minimum flows for the Lower Peace River (Ghile et al. 2021) and was strongly supported by findings of the independent peer review panel that contributed to that effort (Bedinger et al. 2020). The approach is also being used for the recommended minimum flows for the Little Manatee River (Holzwart et al. 2023). As described in Section 5.2 of this report, flow-based blocks were used for the development of minimum flows for Charlie Creek.

1.3.4. Low Flow Threshold

Criteria used to establish low flow thresholds in freshwater rivers include fish passage depths or potential changes in wetted perimeter (i.e., the width of the stream bottom and banks in contact with water for a stream channel cross-section). A low flow threshold associated with maintaining adequate freshwater flows to protect numerous environmental values is proposed for Charlie Creek.

1.3.5. Significant Harm and 15 Percent Change Criteria

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

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

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

When natural breakpoints, inflections, or thresholds are not available, the District has used a presumptive 15% habitat or resource-reduction standard as a criterion for significant harm. The basis for the management decision to equate a 15% 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% 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. More than twenty peer review panels have evaluated the District’s use of the 15% standard for significant harm (review reports are available at https://www.swfwmd.state.fl.us/projects/mfl/documents-and-reports). Although they have questioned its use, these panels have generally been supportive of the use of a 15% change criterion for evaluating effects of potential flow reductions on habitats or resources when determining minimum flows.

Potential loss of habitats and resources in other systems has been managed using methods other than the 15% resource reduction standard. In some cases, resources have been protected less conservatively: habitat loss > 30% compared with historical flows (Jowett 1993) and preventing > 20% 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% habitat exceedance percentile,” which is equivalent to an allowable 20% decrease from baseline conditions. More recently, the Nature Conservancy proposed that in cases where harm to habitat and resources is not quantified, presumptive standards of 10% to 20% reduction in natural flows will provide high to moderate levels of protection, respectively (Richter et al. 2011).

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 available information 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.

1.3.6. Percent-of-flow Method

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

The District has successfully used a percent-of-flow method, often in combination with a low flow threshold, to establish minimum flows for numerous flowing systems including the Upper and Lower Alafia River, Upper and Lower Anclote River, Upper Braden River, Chassahowitzka River/Chassahowitzka Spring Group, Crystal River/Kings Bay Spring Group, Gum Slough Spring Run, Homosassa River/Homosassa Spring Group, Upper Hillsborough River, Upper and Lower Myakka River, Middle and Lower Peace River, Upper and Lower Pithlachascotee River, Upper and Lower Little Manatee River, Lower Shell Creek, Rainbow River/Rainbow Spring Group and Weeki Wachee River/Weeki Wachee Spring Group.

Minimum flows developed using the percent-of-flow method allow permitted surface-water users to withdraw a percentage of streamflow at the time of the withdrawal and permitted groundwater users to potentially reduce baseline flows by prescribed percentages on a longer-term basis. By proportionally scaling water withdrawals to the rate of flow, the percent-of-flow method minimizes adverse impacts that could result from withdrawal of large volumes of water during low flow periods, especially when river systems may be vulnerable to flow reductions. Similarly, larger volumes may not be available for withdrawal during periods of higher flows to protect floodplain inundation.

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

1.3.7. Adaptive Management

Adaptive management is a standard approach for reducing the inherent uncertainty associated with natural resource management (Williams and Brown 2014) and is recommended by the 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 (Herrick et al. 2019).

Continued adaptive management will require: ongoing monitoring of water quality, water flows and levels, biological communities and land use changes in the watershed; status assessments of the current minimum flows and evaluation of compliance of with permitted withdrawal requirements; and periodic reevaluation of all minimum flows that are ultimately adopted for Charlie Creek.

1.4. Vertical Datums

The District has recently converted from use of the National Geodetic Vertical Datum of 1929 (NGVD 29) to use of the North American Vertical Datum of 1988 (NAVD 88) for measuring and reporting vertical elevations. In some circumstances within this document, elevation data that were collected or reported relative to mean sea level or relative to

NGVD 29 are converted to elevations relative to NAVD 88. All datum conversions were derived using the Corpscon 6.0 software distributed by the United States Army Corps of Engineers.

CHAPTER 2 - PHYSICAL AND HYDROLOGIC DESCRIPTION

This chapter describes the Charlie Creek watershed including the location, land use, soils, climate, streamflow, hydrogeology, and aquifer levels relevant to the development of minimum flows for Charlie Creek.

2.1. Description of the Watershed

The Charlie Creek watershed (Figure 2-1), as defined by the USGS Hydrologic Unit Codes (HUC) 0310010105 and 0310010106, encompasses approximately 333.92 square miles (864.86 square kilometers). The majority of Charlie Creek is in Eastern Hardee County, with portions extending into Polk, Highlands, and DeSoto County (Figure 2-1).

The physiographic setting of the watershed is primarily described by the DeSoto Plain, with portions of Polk Uplands in the northeastern section and Lake Wales Group on the eastern side (Figure 2-2). Elevations in the Charlie Creek basin (excluding the creek channel) range from 80 feet north of State Road 64 to 30 feet NGVD at the confluence with the Peace River. Extensive wetlands throughout the watershed have an average elevation of less than 60 feet (PBS&J 2007). In general, the basin is described by low, flat topography with slow water movement to streams and wetlands (HSW 2012).

The USGS National Hydrography Dataset identifies seven tributaries to Charlie Creek in the Geographic Names Information System, listed from upstream to downstream in the watershed at the point of junction with Charlie Creek: Old Town Creek, Bee Branch, Little Charley Bowlegs Creek, Buckhorn Creek, Mineral Creek, Oak Creek, and Fish Branch. The Charlie Creek channel is approximately 42 miles (67 kilometers) long, originating north of north of East County Line Road in Polk County and flows to the Peace River in Hardee County, south of Zolfo Springs, with a mean daily discharge of 262 cfs as measured from May 1950 to December 2021 at the USGS Charlie Creek near Gardner, FL (Number (No.) 02296500) gage. Charlie Creek is a significant tributary to the Peace River, contributing over half of the intermediate annual inflow to the river reach between Zolfo Springs and Arcadia (PBS&J 2007).

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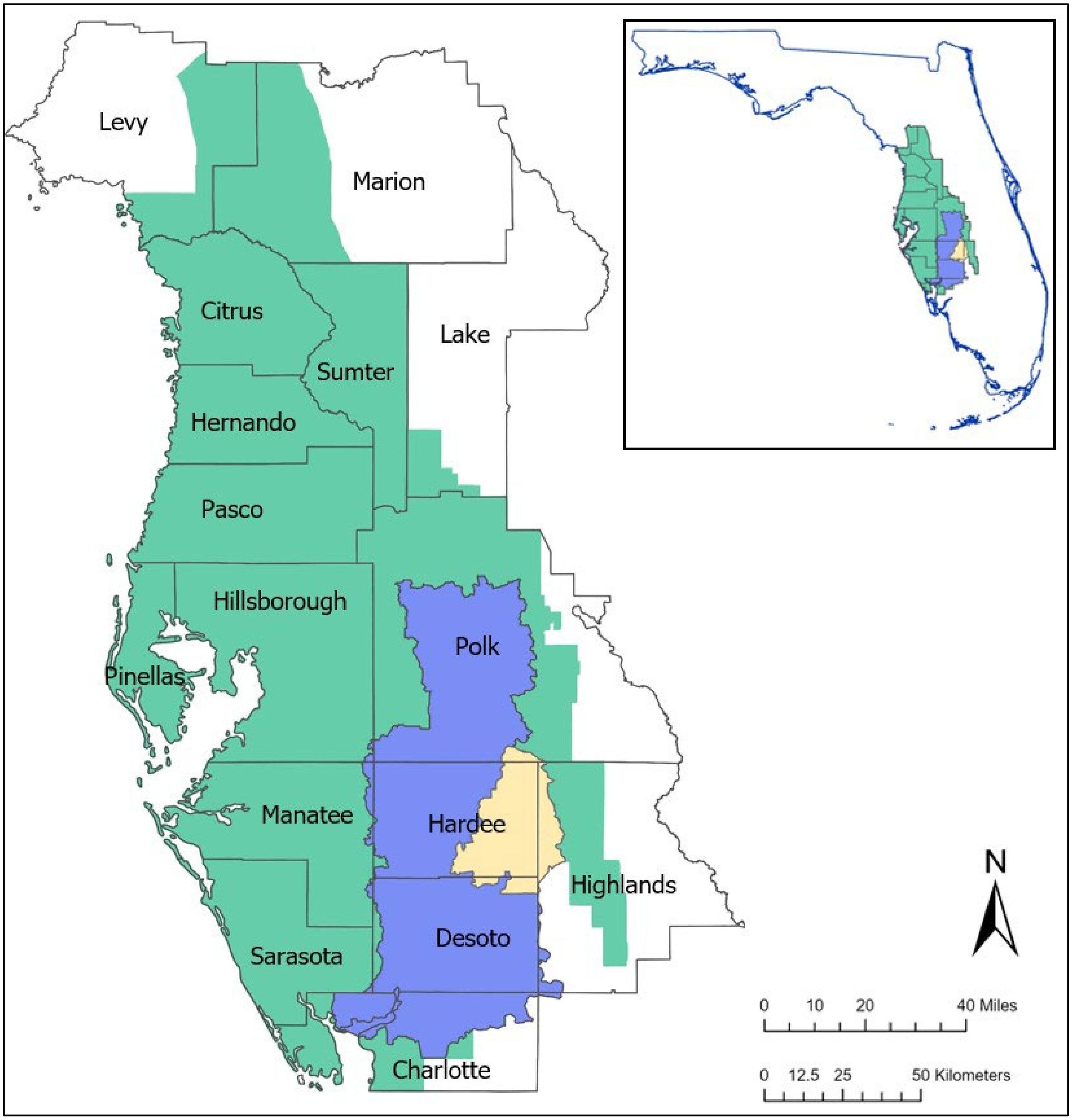

Figure 2-1. Location of the Charlie Creek watershed (yellow) within the Peace River watershed (blue), the District boundary (green), and the state of Florida (inset map).

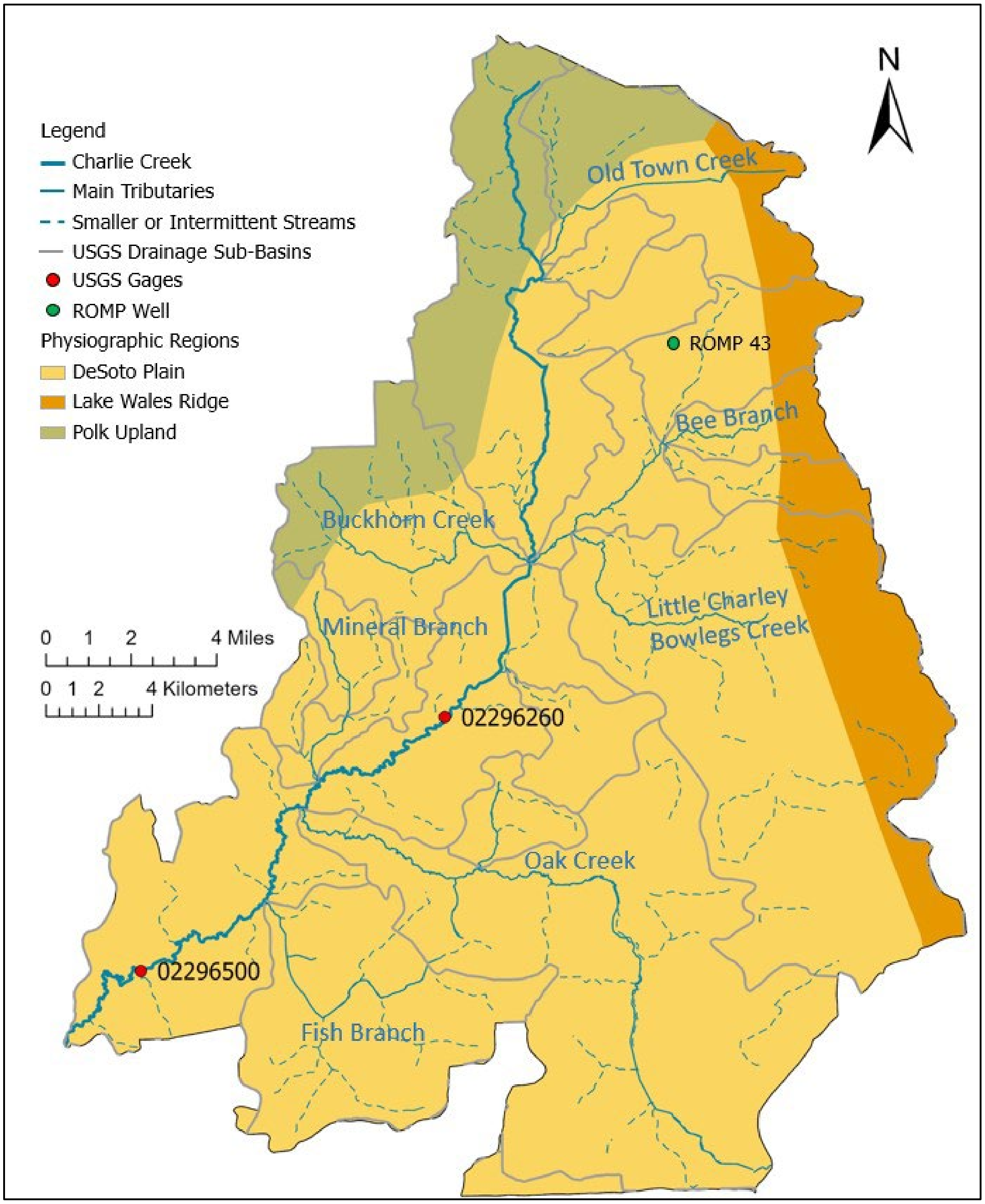

Figure 2-2. Map of the Charlie Creek watershed showing the Charlie Creek mainstem, named tributaries, smaller and intermittent streams, lakes, USGS drainage sub-basins, USGS gage stations, a SWFWMD Regional Observation and Monitor-well Program (ROMP) well, and physiographic regions (source: GIS layer files maintained by the District (SWFWMD 2019b, d).

2.2. Land Use and Cover

The Florida Land Use, Cover and Forms Classification System (FLUCCS) is a hierarchical method for classifying land information with increasing levels of specificity, derived from photointerpretation of aerial data (FDOT 1999). Level 1 codes divide land use into eight broad categories, including industrial, agricultural, and wetlands. Level 4 codes are more specific and contain subcategories such as extractive mining (within the Level 1 industrial classification) or row crops (under the Level 1 agricultural designation). Since the adoption of FLUCCS by the Florida Department of Transportation (FDOT), different state water management districts have modified their codes slightly, particularly at finer-scale designations. Details of the classifications used by the District can be found in the Photo Interpretation Key for Land Use Classification (SWFWMD 2014).

In this chapter, FLUCCS Level 1 data are used to coarsely describe the watershed and Level 4 data are used to calculate the Landscape Development Index (LDI). A small portion (3.81 mi^2; 9.86 sq. km.) of the Charlie Creek watershed extends into the South Florida Water Management District (SFWMD). Therefore, corresponding years of SWFWMD and SFWMD FLUCCS data were compiled to describe land use throughout the watershed. In this chapter, the 2020 land use data includes the SWFWMD 2020 land use and cover data and the SFWMD 2017-2019 land use and cover data within the Charlie Creek watershed.

2.2.1. Changes in Land Use Over Time

Agricultural land covered 55.57% of the watershed in 2020 (Figure 2-3, Table 2-1). Much of this agricultural land is either rangeland used for cattle, hay, or sod production, or citrus groves, particularly orange groves (Figure 2-4; USDA 2022). Other crops grown in the watershed include peaches, peppers, sweet corn, and blueberries (USDA 2022). Urban or built-up land covers 6.89% of the watershed (Figure 2-3, Table 2-1). As of 2020, this built sector was primarily composed of low-density residential dwellings, of less than two houses per acre. The remainder of the watershed is primarily described as natural lands including wetlands (24.43%) and upland forests (7.33%; Figure 2-3; Table 2-1). There have not been significant changes in land use between 1995 and 2020 (Table 2-1, Figure 2-5).

In 2023, the Eastern Extension of Mosaic's South Fort Meade mine was approved by the Hardee County Board of County Commissioners. The mine boundary contains 3,170 acres, including 2,203 acres to be mined to the east of Charlie Creek from 2025 through 2030 (Figure 2-6). An access and infrastructure corridor will cross Charlie Creek and Old

Town Creek (a tributary to Charlie). A permit for a new NPDES discharge to Old Town Creek has been submitted to the DEP, however, it has not yet been approved. Water use permits for these mining activities have been issued by the District.

The Florida Department of Agriculture and Consumer Services (FDACS) Office of Agricultural Water Policy has developed the Florida Statewide Agricultural Irrigation Demand (FSAID) Geodatabase as a repository for agricultural water use projections through 2045 (Balmorial Group 2022, FDACS 2022). Approximately 62.10 square miles of agricultural land were irrigated in 2020, primarily to produce citrus, hay, vegetables, and for greenhouses or nurseries (Figure 2-7). In 2045, this irrigated area is projected to decrease by 8.3% (Figure 2-6). The amount of water used in irrigated areas is projected to decrease by 1.47 million gallons per day (mgd) from 35.09 mgd in 2020 to 33.62 mgd in 2045.

As of 2023, the SWFWMD had approved 353 active permits for agricultural irrigation in the Charlie Creek watershed. The majority of water use permits for irrigated areas (n = 295) included citrus, irrigated by low volume spray. Most of the fruit and vegetable crops (melons, tomatoes, strawberries, squash, peppers, and cucumbers) were irrigated by drip with plastic, the exception being blueberries, (76% of their requested irrigation was to be delivered by drip without plastic). Permits for the irrigation of pasture and sod primarily requested irrigated by seepage.

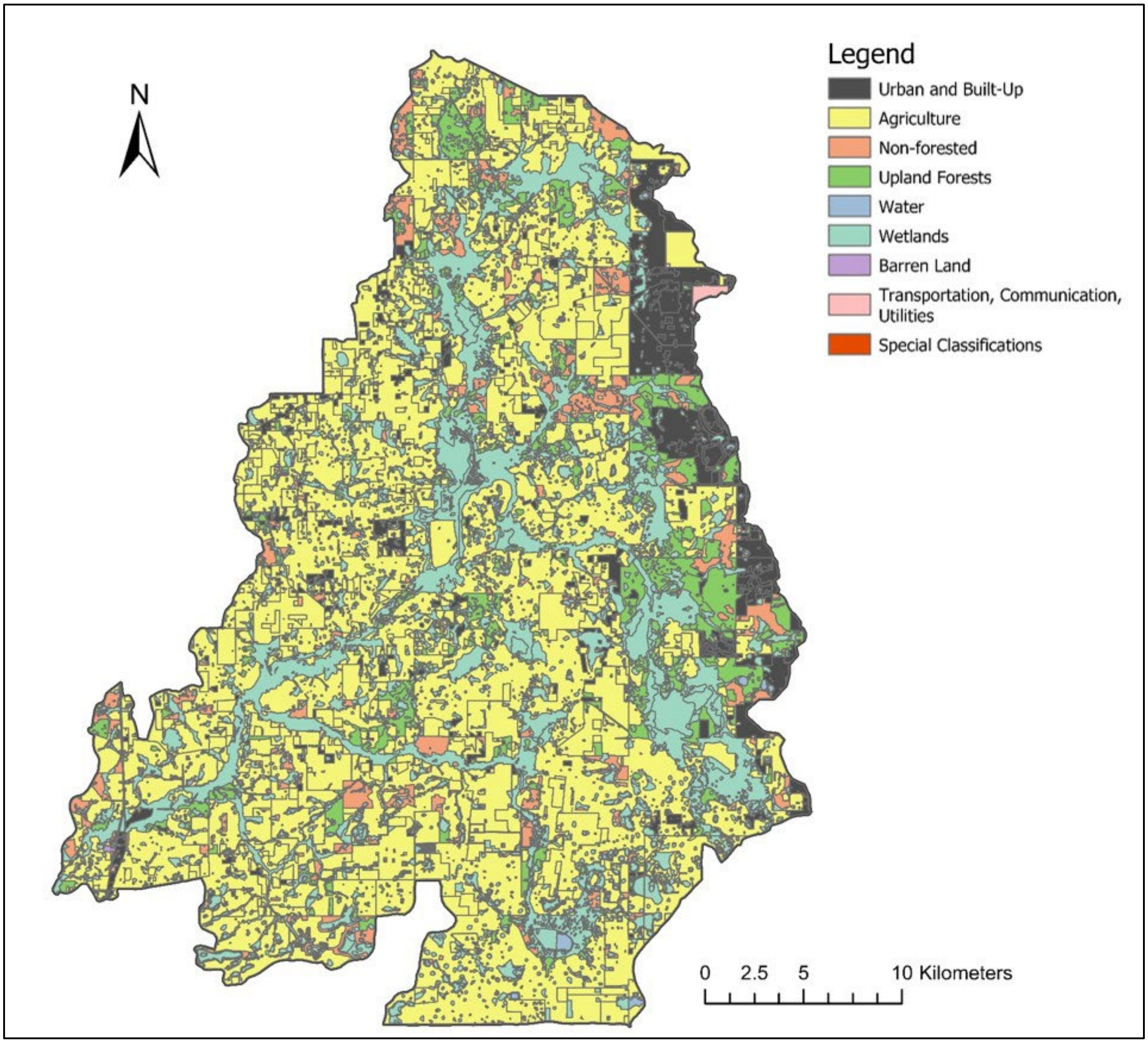

Figure 2-3. The Florida Land Use, Cover and Forms Classification System (Level 1) designated land within the Charlie Creek Watershed (source: GIS layer files maintained by SWFWMD (2021d) and SFWMD (2018)).

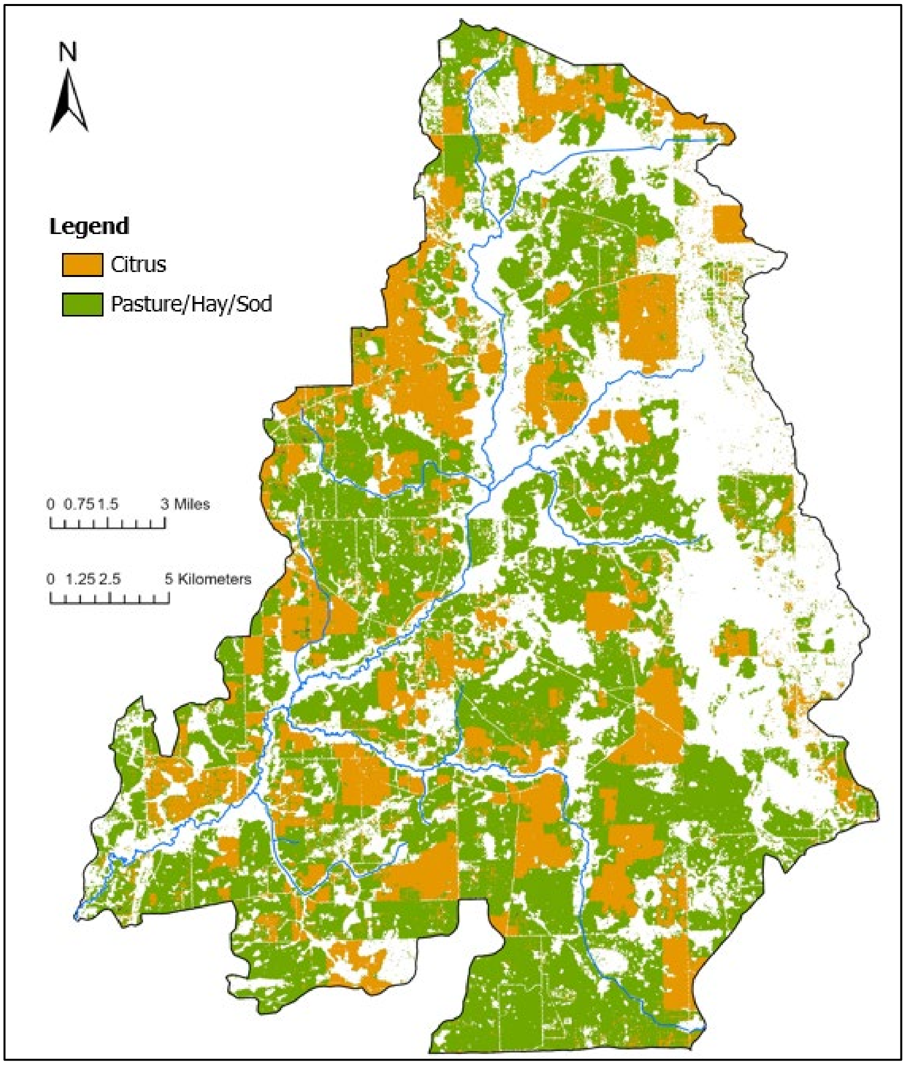

Figure 2-4. Primary agricultural use in the Charlie Creek watershed includes pastures for cattle grazing, hay, and sod production (green) and citrus groves (orange; source: GIS layer files maintained by the United States Department of Agriculture (2022)).

Table 2-1. Land use change in the Charlie Creek watershed from 1995 to 2020 by Florida Land Use, Cover and Forms Classification System (Level 1) designations in terms of area (in square miles (mi^2)) and as a percentage of the total area, from GIS layers maintained by SWFWMD (2003, 2009, 2021) and SFWMD (2003, 2009, 2018).

Land Use and Cover Level 1	1995		2008		2020	
	Area (mi^2)	Percent of Total (%)	Area (mi^2)	Percent of Total (%)	Area (mi^2)	Percent of Total (%)
Urban and built-up	17.59	5.27	22.75	6.81	23.01	6.89
Agricultural	187.03	56.00	185.69	55.61	185.57	55.57
Rangeland	25.48	7.63	15.39	4.61	16.27	4.87
Upland forest	37.85	11.34	25.98	7.78	24.49	7.33
Water	1.09	0.33	1.15	0.34	1.64	0.49
Wetlands	64.37	19.28	82.30	24.65	81.59	24.43
Barren land	0.07	0.02	0.10	0.03	0.03	0.01
Transportation, utilities, communication	0.44	0.13	0.57	0.17	1.32	0.40

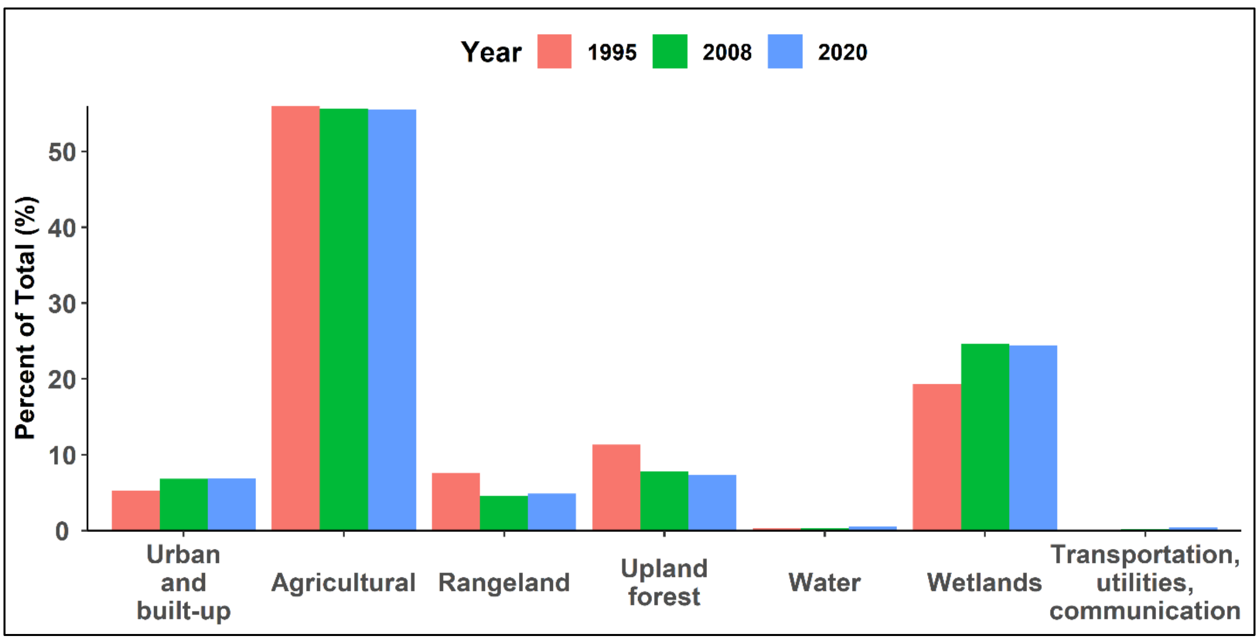

Figure 2-5. Visualization of land use change in the Charlie Creek watershed from 1995 to 2020, as classified by the Florida Land Use, Cover and Forms Classification System (Level 1) in GIS layers maintained by SWFWMD (2003, 2009, 2021) and SFWMD (2003, 2009, 2018).

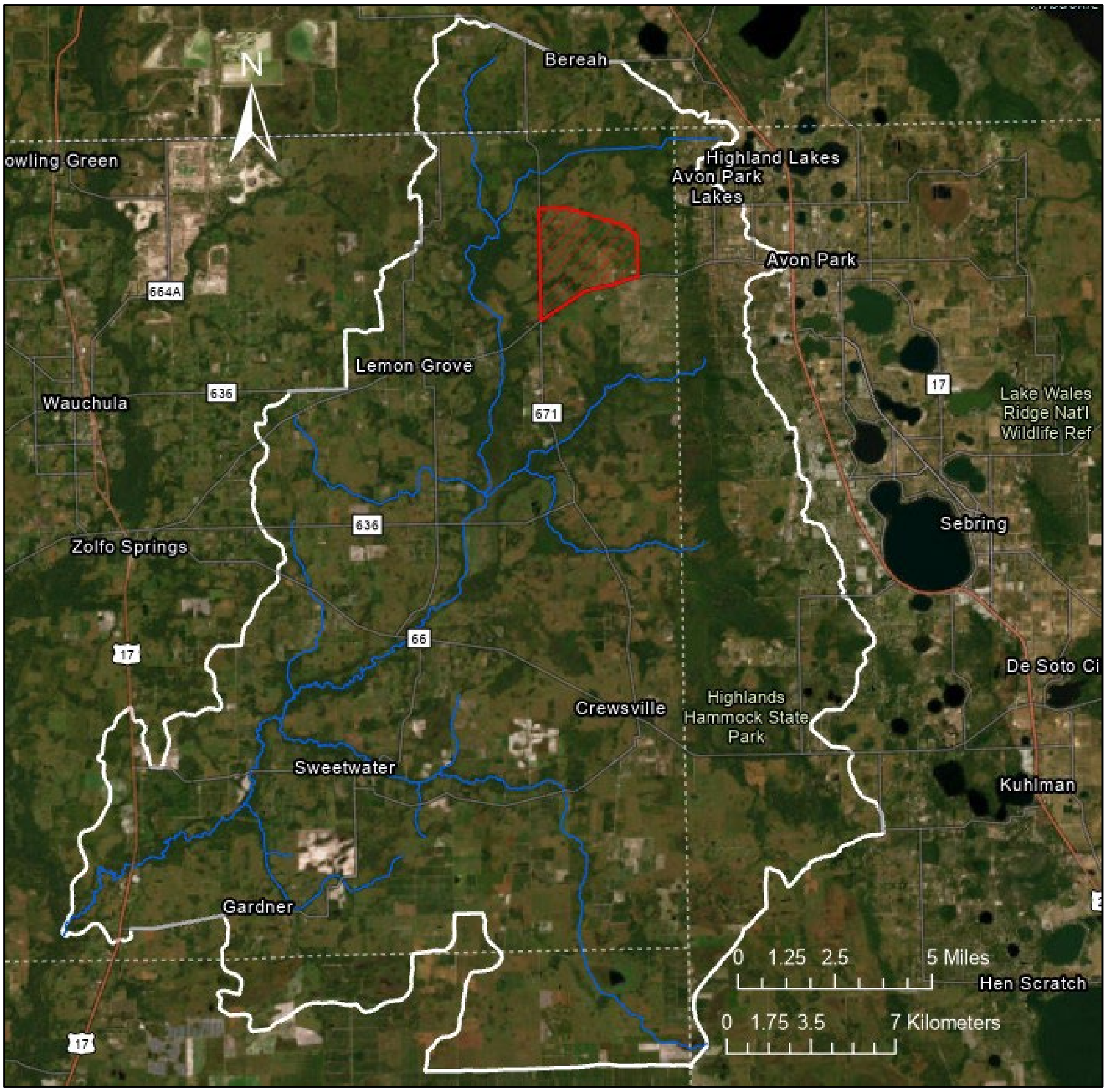

Figure 2-6. Location of the South Fort Meade Mine Eastern Extension (red hatched polygon) in relation to the Charlie Creek watershed (white outline), and the Charlie Creek mainstem and primary tributaries (blue lines).

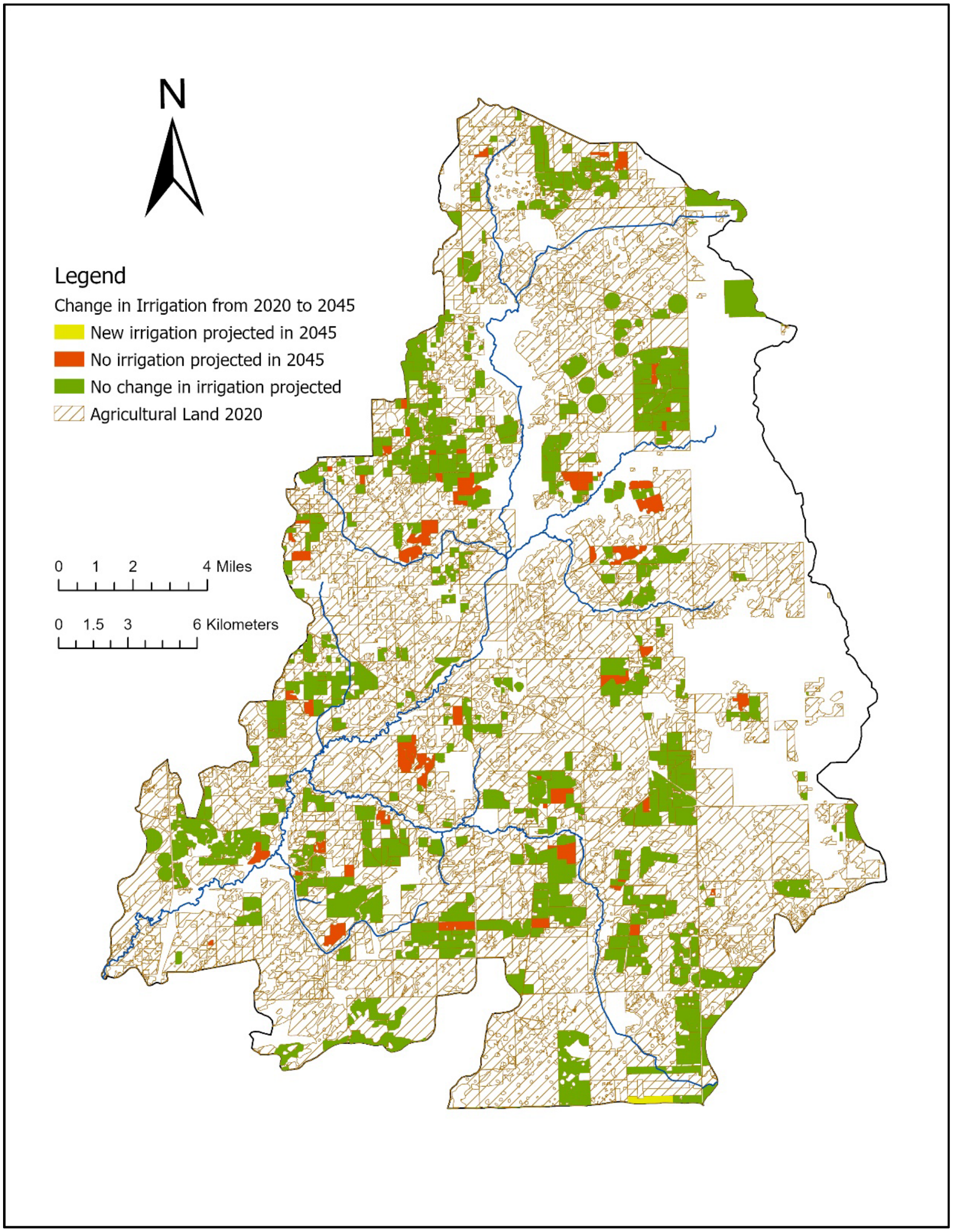

Figure 2-7. Projected changes in irrigated agricultural lands from 2020 to 2045. Irrigated lands identified by the Florida Department of Agriculture and Consumer Services (FDACS) are contained in the yellow, red, and green polygons. The color of these polygons indicates the projected change in irrigation status in 2045 as compared to 2020. All agricultural lands identified by FDACS are shown within the brown hatched polygons (source: GIS files maintained by FDACS (2022)).

2.2.2. Landscape Development Index

The LDI of the DEP Bioassessment Program (see information available at https://floridadep.gov/program-content/DEAR/Bioassessment) is a method to quantify levels of anthropogenic disturbance on ecological systems within a watershed and can be applied at many scales. Generally, the more intensive the human activity, the greater the negative impact on ecological processes. Many landscapes are patchy, with a mixture of developed and natural lands. In such cases, natural lands and their associated ecosystems can experience secondary impacts originating from areas with higher human disturbance, such as the runoff of nutrients through surface or groundwater. To calculate the LDI of an area, areas of a particular land use classification are multiplied by an LDI energy coefficient and the resulting values for all land use classifications are summed in the evaluated catchment. The energy coefficients consider the amount of non-renewable energy used per unit area, including the consumption of electricity, fuels, fertilizers, pesticides, public water supply, and water used for irrigation (Brown and Vivas 2005).

The LDI was calculated at two scales within the Charlie Creek watershed: for the entire watershed and for the 100-meter buffer around the main channel and main tributaries. Land use land cover data were obtained from 2020 Level 4 FLUCCS codes, available from the District and 2017-2019 codes obtained from the SFWMD (SWFWMD 2021, SFWMD 2019). Where FLUCCS descriptions did not exactly match those described by Brown and Vivas 2005, a best approximation was made by either averaging LDI coefficients for similarly classified areas, or by assigning the value associated with the most intensive probable use. The LDI for the buffered main stem and tributaries of Charlie Creek was calculated as 1.52, indicative of a minimally disturbed watershed (Brown and Vivas 2005). This is largely due to natural land classifications, such as stream bottomlands, hardwoods, and marshes accounting for 83% of the area within the 100-meter buffer surrounding the creek channel. When the LDI was instead calculated for the entire watershed, the LDI score was 2.88, indicative of a basin primarily dominated by agricultural use (Brown and Vivas 2005).

2.2.2. Conservation Land

There are several conservation lands and conservation easements throughout the northern and eastern portions of the watershed, primarily managed by the DEP. A conservation easement managed by the Florida Department of Agriculture and Consumer Services (FDACS) and the United States Department of Agriculture National Conservation Services surrounds a portions of the creek mainstem. The Florida Forever

Board of Trustees has acquired lands within the watershed and have many planned acquisitions (Figure 2-8).

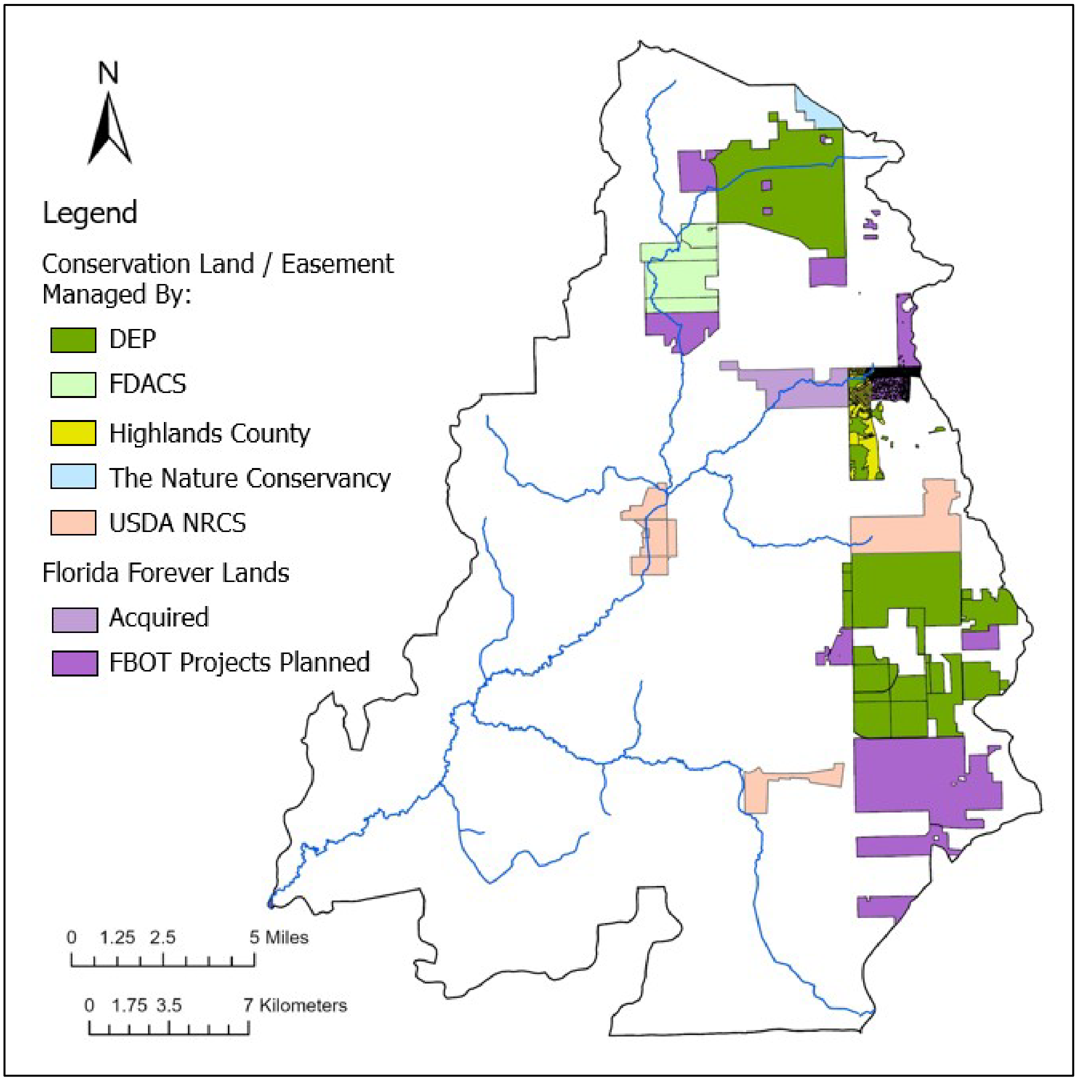

Figure 2-8. Conservation land, conservation easements, and Florida Forever lands within the Charlie Creek watershed, with their managing agency (including the Florida Department of Environmental Protection (DEP), the Florida Department of Agriculture and Consumer Services (FDACS), the United States Department of Agriculture National Conservation Services (USDA NRCS), and the Florida Forever Board of Trustees (FBOT)). Sources include GIS layers from the Florida Natural Areas Inventory (FNAI) including Florida Conservation Lands (2022a), Florida Forever Acquisitions (2022b), Florida Forever Board of Trustees Projects (2022c), and Florida Managed Areas (2022d) and layers from the DEP including FL-SOLARIS/CLEAR Conservation Easements (2018a) and FL-SOLARIS/CLEAR Conservation Owned Lands (2018b).

2.3. Soils

Soils in the United States can be assigned to one of four main hydrologic groups (A, B, C, and D) based upon estimated runoff potential. Group A soils have a low runoff potential when thoroughly saturated and have a high infiltration rate. This includes well-drained sands or gravelly sands. Group B soils have a moderate infiltration rate when thoroughly wet and include moderately well-drained soils with a moderately fine to coarse texture. Group C soils have a slow infiltration rate and higher runoff potential when thoroughly wet and include soils with an underlying layer that hinders water transmission. Group D soils have very high runoff potential when thoroughly wet and low infiltration. This group includes clays, soils with a high water table, and shallow soils overlying impervious materials. Soils can also be classified into one of three dual classes (A/D, B/D, or C/D) based on their saturated hydraulic conductivity and water table depth when drained. In such instances, the first letter indicates the properties of drained areas and the second describes undrained areas (USDA 2016).

The Charlie Creek watershed is primarily composed of relatively poorly drained, acidic, sandy soils with a low, flat topography, over which water movement to natural streams is very slow (HSW 2012). Approximately 55.59% of land classified as soil type A/D and 26.62% classified as B/D (SWFWMD 2019c, USDA 2020; Figure 2-9). Most soils in the watershed are described as fine sands (61%), sands (18%), or muck (4%). The frequently flooded sandy and loamy Bradenton-Felda-Chobee association soils are common along the Charlie Creek corridor and account for 7% of soils in the watershed (HSW 2012, SWFWMD 2019c). Soil saturation is common and infiltration to the SA is low throughout much of the watershed (SWFWMD 2000).

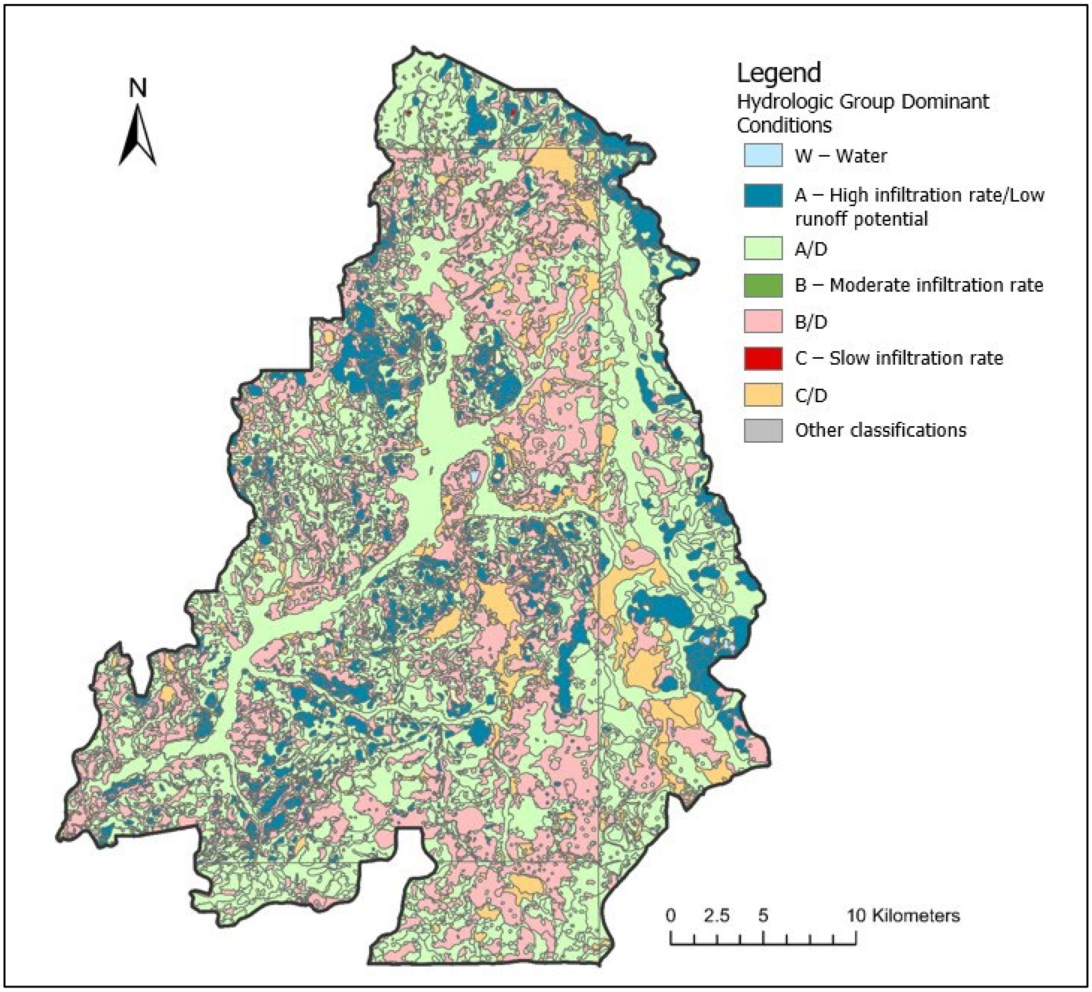

Figure 2-9. Hydrologic soil groups in the Charlie Creek watershed. If soil is assigned to a dual hydrologic group, the first letter describes conditions in drained areas and the second described undrained area (source: GIS layer files maintained by SWFWMD (2019c) and USDA (2020)).

2.4. Climate

The climate of central Florida is classified as humid subtropical and is characterized by warm, relatively wet summers and mild dry winters. The mean annual temperature in the region ranges from 91°F in July and August to a low of 49°F in January. The average annual rainfall at the Sunshine Foliage World station (District Station No. 25195) in Zolfo Springs is approximately 44 inches and more than 60% of the annual rainfall occurs during the months of June, July, August, and September (Figure 2-10). Rainfall is unevenly distributed during the summer months because most of the summer rainfall is derived from local showers or thunderstorms. The passing of tropical storms and hurricanes can sometimes result in higher rainfall, usually in late summer months. The dry season extends from mid-October through mid-June, with the lowest average rainfall in November. Winter rainfall slightly increases from January through March due to the passing of cold fronts that bring rain in advance of high pressure by dry air (Kelly et al. 2004; Hood et al. 2011). Winter rainfall tends to be more evenly distributed than summer rainfall, since it generally results from large frontal systems as cold air masses from the north move south through the area (Kelly and Gore 2008). The rainfall to runoff conversion on average ranges from 4% in May to 39% in October.

The Sunshine Foliage World station has a rainfall record from 1986 through 2022 (Figure 2-11). Annual rainfall totals of less than the long-term average (44 inches) were recorded for 15 years during the period of record from 1986 through 2022. The highest three yearly rainfall totals occurred in 2003, 2017 and 2001 with 73, 64 and 60 inches respectively (Figure 2-11). These high rainfalls are attributable to tropical depressions and hurricanes that can move through the area in the late summer and early fall. A detailed trend analysis for rainfall is provided in Section 2.5.3.

Within this general seasonal cycle, rainfall intensities and frequencies are controlled by the effects of larger scale oscillations, notably the Atlantic Multidecadal Oscillation (AMO) and El Niño-Southern Oscillation (ENSO) (Kelly 2004; Kelly and Gore 2008). These oscillations are often thought to be driven by natural variability in the climate system, although some recent studies (e.g., Mann et al. 2021, Qu et al. 2021) claim oscillations are driven by episodes of high amplitude volcanic activities that happened in past centuries. The AMO is an index of Sea Surface Temperature (SST) anomalies averaged over the North Atlantic from 0–70°N and has a strong influence on summer rainfall over the conterminous United States (McCabe et al. 2004). The ENSO, a naturally occurring phenomenon associated with an irregular cycle of warming and cooling of SSTs in the tropical Pacific Ocean (5°N to 5°S, 150° to 90°W) is also known as a dominant force causing climate variations over the United States. and much of the globe (Hansen et al. 1997; Schmidt and Luther 2002).

To better understand how these climate indices are related to the temporal variability of streamflow in Charlie Creek, the mean annual SST patterns tracked by these two indices and USGS Charlie Creek near Gardner, FL (No. 02296500) gaged flows were normalized. Plots of 5- and 10-year moving averages of the normalized values of AMO and Charlie Creek flows are shown in Figure 2-12. A similar pattern is evident in the two data sets, with higher flows occurring during warmer AMO phases and lower flows occurring during cooler AMO phases. The Pearson's coefficient between 5-year running means of AMO and Charlie Creek flows is 0.65, while the Pearson's coefficient between 10-year running means of AMO and Charlie Creek flows is 0.75. This is consistent with

Kelly's (2004) previous findings in the region. Superimposed within the AMO cycle, the ENSO anomalies were also related to the year-to-year streamflow variability in Charlie Creek as shown in Figure 2-13. El Niño years are wetter than La Niña years in the region. However, El Niño effects during the summer wet season are somewhat attenuated by the seasonal occurrence of thunderstorms (Kelly and Gore 2008).

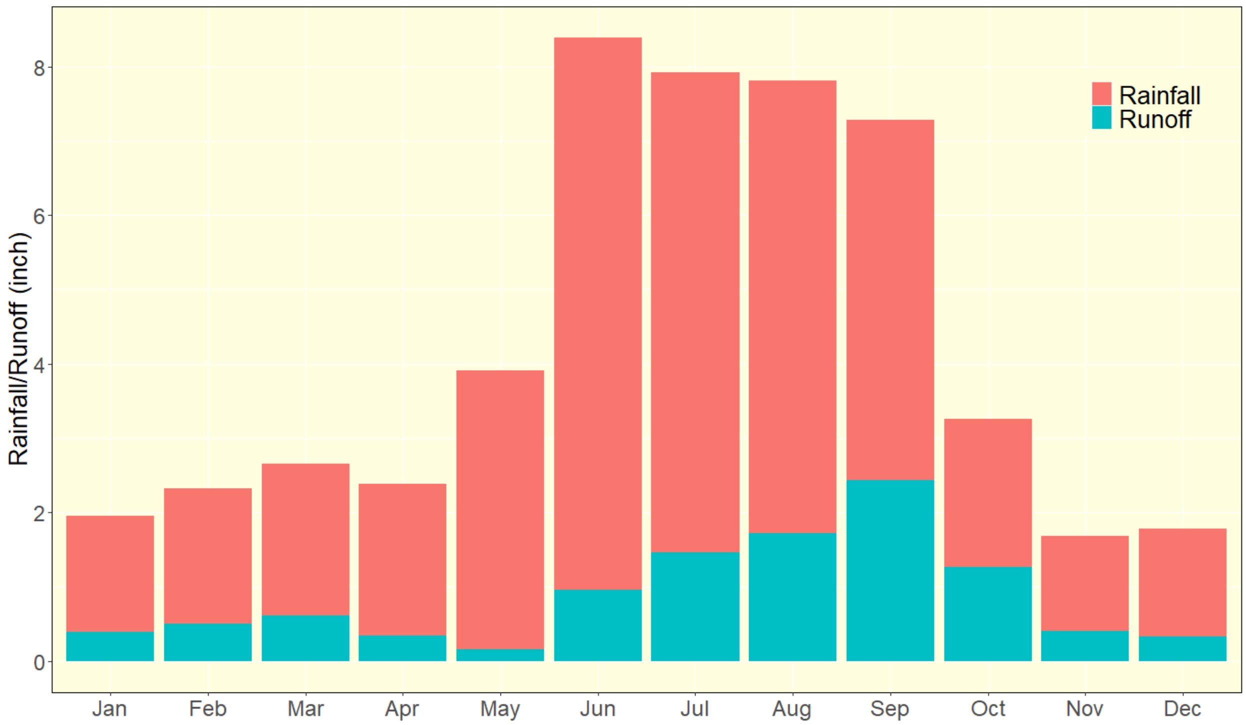

Figure 2-10. Average total monthly rainfall at the Sunshine Foliage World station (District Station No. 25195) for the period of record from 1986 through 2022, and average monthly runoff at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage for the period of record from 1950 through 2021

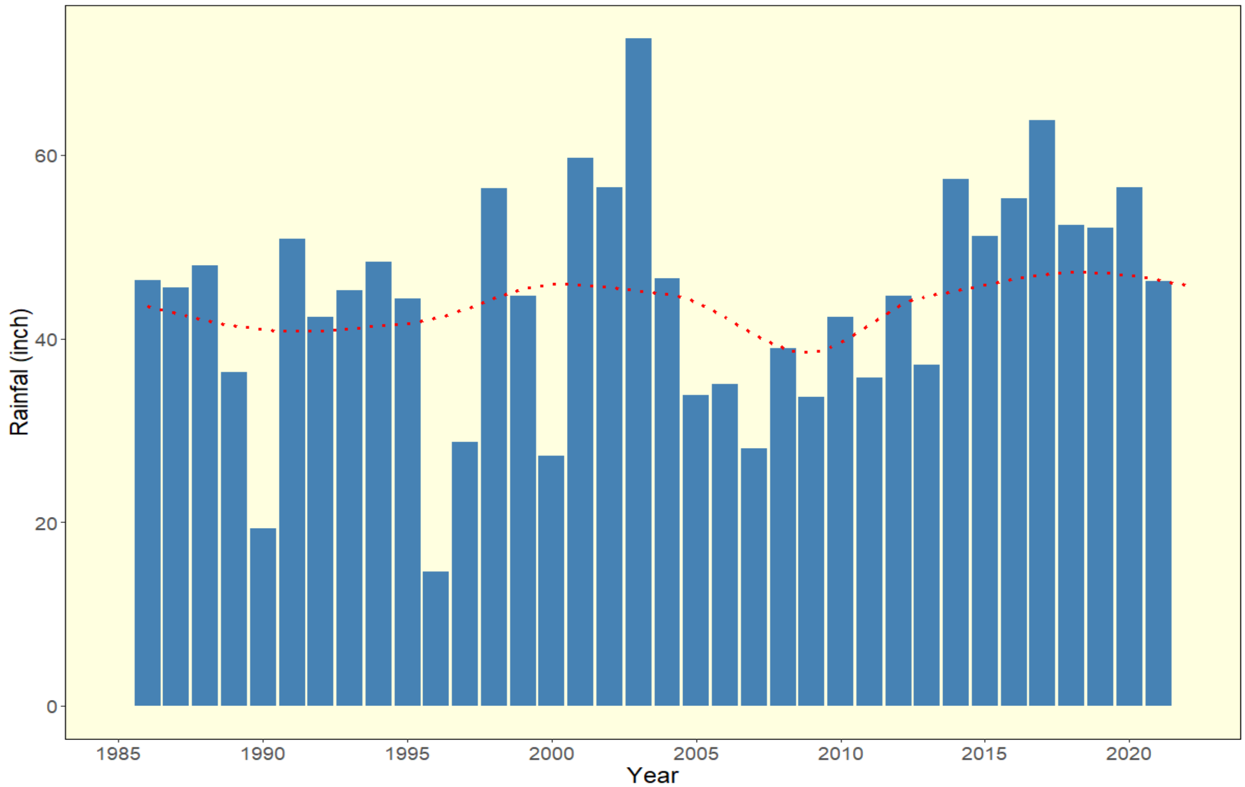

Figure 2-11. Annual rainfall totals (inch) at the Sunshine Foliage World station (District Station No. 25195) from 1986 through 2022. The dashed line indicates the overall trend derived using locally estimated scatterplot smoothing (LOESS).

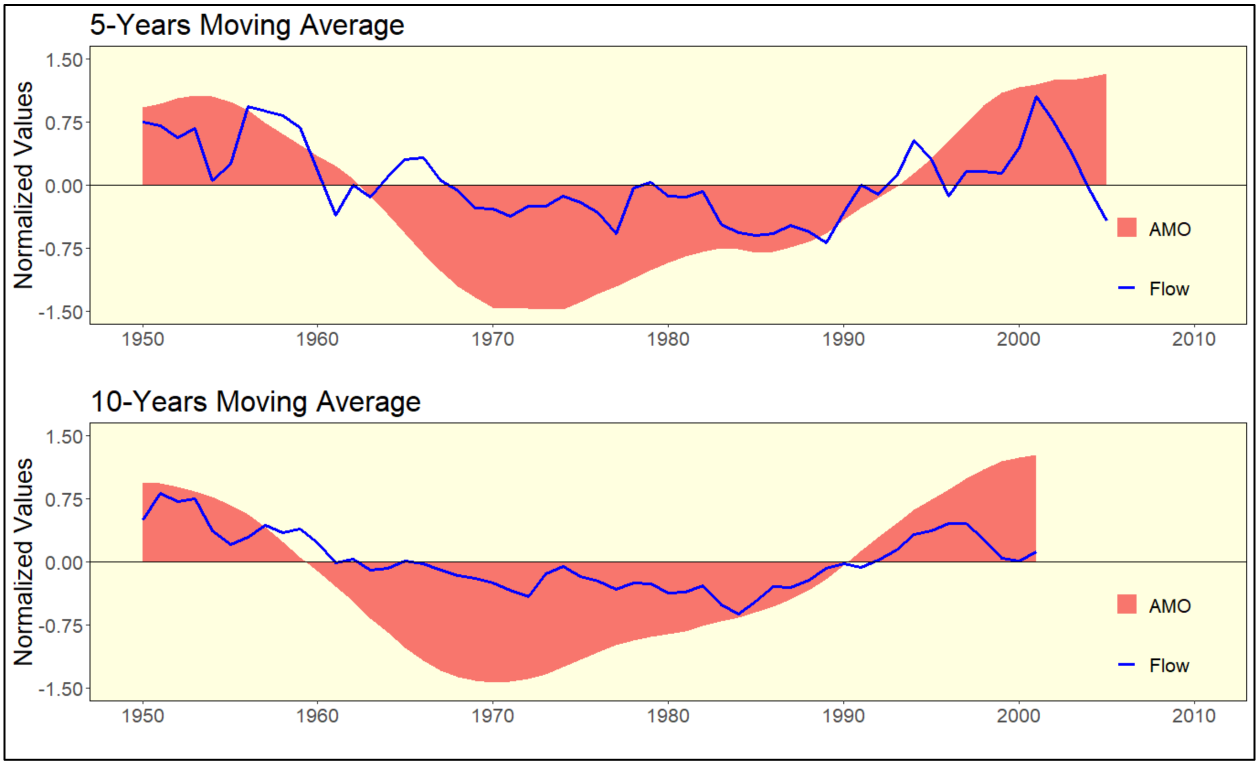

Figure 2-12. Normalized values of 5- and 10-year moving averages of annual AMO anomalies and flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage for the period from 1951 through 2008.

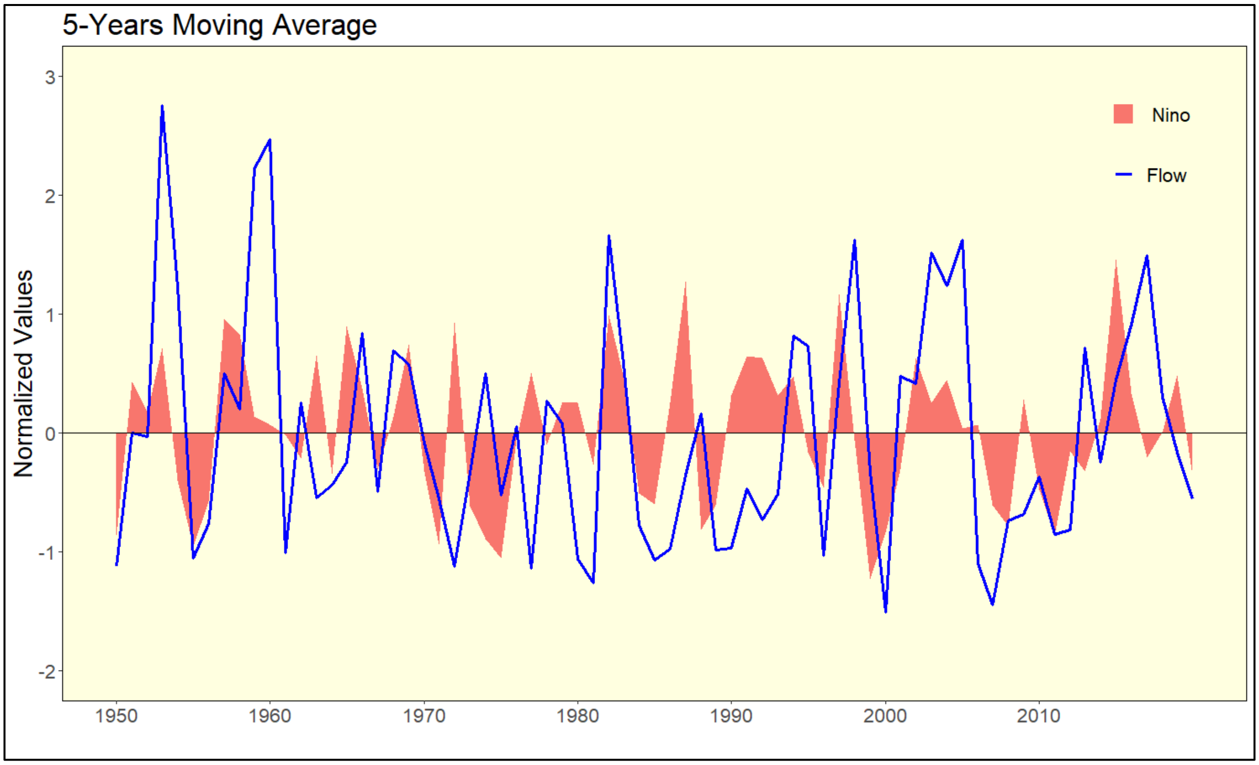

Figure 2-13. Normalized values of annual ENSO anomalies (°C) and flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage for the period from 1951 through 2020.

2.5. Streamflow

Streamflow represents the sum of contributions from groundwater, runoff, direct rainfall, and anthropogenic discharges (e.g., wastewater), minus the volume of water that is lost due to evapotranspiration, losses to groundwater, and withdrawals. The physical, chemical, and biological properties of aquatic ecosystems can be affected by the hydrologic regime (Poff and Ward 1989, 1990), so substantial ecological changes can be associated with long-term changes in flows.

Streamflow is measured at two locations within the Charlie Creek watershed. Figure 2-2 illustrates the location of the USGS Charlie Creek near Crewsville, FL (No. 02296260) gage and the USGS Charlie Creek near Gardner, FL (No. 02296500) gage. The USGS Charlie Creek near Crewsville, FL (No. 02296260) gage is located in Hardee County at latitude 27°27'33" and longitude 81°40'43" NAD27 and has a drainage area of 192 square miles. The USGS Charlie Creek near Gardner, FL (No. 02296500) gage is located at latitude 27°22'29" and longitude 81°47'48" NAD27 and has the drainage area is 330 square miles. There are no notable tributaries or dams that could cause backwater in the immediate vicinity of these gages.

2.5.1. Mean Annual Flows

Charlie Creek flows have been measured at the USGS Charlie Creek near Crewsville, FL (No. 02296260) gage since 2004. For the period from 2004 through 2021, themean daily flows ranged from a minimum of 0 cfs to a maximum of 6,670 cfs in 2017, with a long-term average of 141 cfs. Measured flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage are available from 1950 to the present. For the period from 1950 to 2021, mean daily flows ranged from a minimum of 0.06 cfs in 2000 to a maximum of 9,160 cfs in 2017. The long-term mean (1950-2021) annual flow at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage is 262 cfs (Figure 2-14). The downtrend from 1950s through 1980s is associated with reduced rainfalls during cooler AMO phases in North Atlantic ocean, as described in section 2.4.

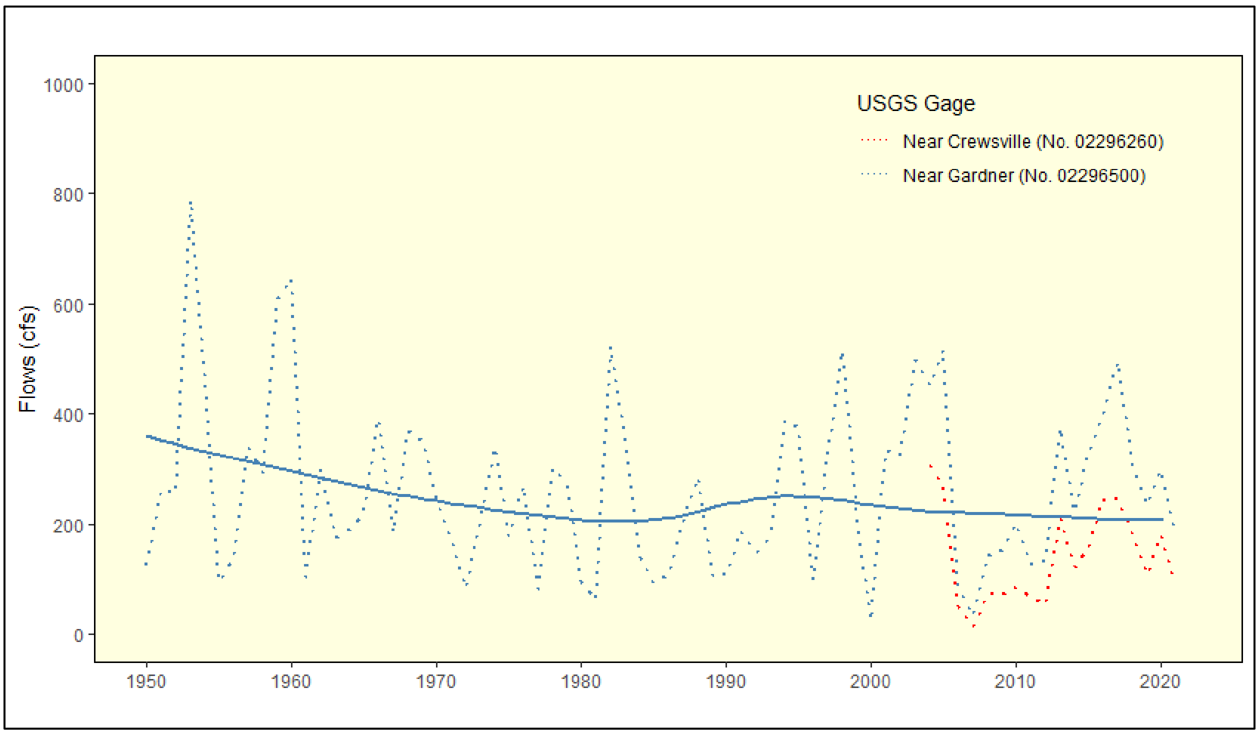

Figure 2-14. Time series of Charlie Creek mean annual flows (cfs) at the USGS Charlie Creek near Crewsville, FL (No. 02296260) gage for the period 2004 through 2021 and the USGS Charlie Creek near Gardner, FL (No. 02296500) gage for the period 1950 through 2021, with the solid blue line showing trend over time.

2.5.2. Seasonal Flows

Box and whisker plots of the daily flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage are presented in Figure 2-15. The typical seasonal distribution of flows in Charlie Creek follows the seasonal pattern of rainfall in west-central Florida, with high flows occurring during a four-month wet season (mid-June to mid-October) followed by medium and low flow periods associated with the dry season that extends from mid-October to mid-June. Streamflow reaches its lowest values in May and June, when potential evapotranspiration rates are high, groundwater levels are low, and surface water storages available in sinks, depressions, soils, and wetlands are high. In the late summer and fall, surface and ground-water levels are higher, soils are more saturated, and there is much greater streamflow production per unit of rainfall, with peak flows typically occurring in August and September.

Flows in Charlie Creek have been less affected by mining, drainage alterations, and water withdrawals when compared to other sub-watersheds of the Peace River (PB&J 1997). A recent study conducted by HydroGeoLogic, Inc. (2023; Appendix A) indicates that groundwater withdrawals have relatively less impact on flows in the lower vs. the upper portion of the Peace River basin. The lessened impact in the lower Peace River basin, which includes Horse Creek, can be attributed to the much tighter confinement of the Upper Floridan aquifer (UFA) underlying the middle and lower portions of the basin. Additional information pertaining to anthropogenic impacts on flows in the Horse Creek is provided in Section 5.1.

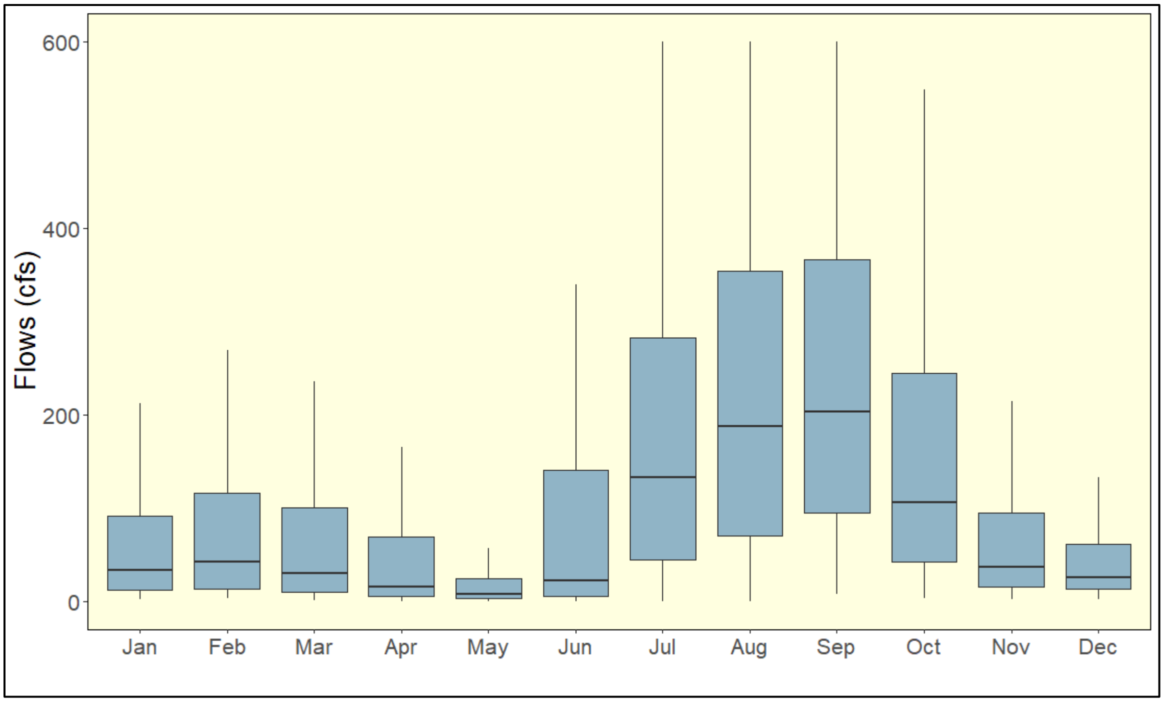

Figure 2-15. Box and whisker plots of daily flows (cfs) by calendar month at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage. Boxes represent the inter-quartile range; whiskers represent lowest and highest observations.

2.5.3. Flow Trends

Flow data collected from May 1950 through December 2018 for the USGS Charlie Creek near Gardner, FL (No. 02296500) gage and NWS rainfall data (District Station No. 24570) were analyzed for trend analysis. Using the nonparametric Mann-Kendall's trend test on monthly time-step, trend analysis for rainfall identified a significant decreasing trend at alpha level of 0.05 for February and October. Charlie Creek flows exhibited no significant trend pattern for all months, suggesting that land use and anthropogenic influences on flows in the creek have not significantly changed over time (Table 2-2). A study conducted by INTERA (2018) also indicated that monthly flows in Charlie Creek exhibited no significant trends over the period from 1950 through 2013.

Trend analysis conducted by PBS&J (2007) indicated that the historic flows in nearby Charlie Creek are consistent with the timing of the wet and dry climate periods in southwest Florida. Based on land use change analysis for the period from 1940 to 1999, they found that, among the nine watersheds in the Peace River Basin, Charlie Creek remains relatively stable land use, with no phosphate mining at that time and limited urbanization. A comparison of median daily flows per unit area for three periods for Charlie and Horse Creek is presented in Figure 2-16. If climate is the major controlling factor, one should expect similar flow patterns in these neighboring two watersheds. The top panel of Figure 2-16 suggests that the 1950-1969 flow patterns for Horse and Charlie Creeks were similar for most of the year with the exception that Horse Creek flows during May-June (from approximately the 121st day of the year to the 181st day) were relatively lower than the flows in Charlie Creek. During the periods of 1970-1995 and 1996-2021, however, the May through June flows in Horse Creek increased over time (see the middle and lower panels of Figure 2-16). This increased flow in Horse Creek is most likely due to changes to more intensive agricultural land uses and discharges of mineralized groundwater into the creek in the past 50 years. These increases are consistent with the timing of the growing season where return flows from irrigated fields are expected to contribute to streamflow.

Table 2-2. Trend analysis for rainfall near Arcadia (District Station No. 24570) and flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage.

Month	Rainfall near Arcadia		Flows at USGS Charlie Creek near Gardner, FL gage	
	p-value	Trend Direction	p-value	Trend Direction
Jan	0.52	No trend	0.65	No trend
Feb	0.05*	Decreasing	0.42	No trend
Mar	0.88	No trend	0.22	No trend
Apr	0.98	No trend	0.56	No trend
May	0.97	No trend	0.82	No trend
Jun	0.27	No trend	0.85	No trend
Jul	0.97	No trend	0.60	No trend
Aug	0.08	No trend	0.91	No trend
Sep	0.72	No trend	0.61	No trend
Oct	0.02*	Decreasing	0.74	No trend
Nov	0.11	No trend	0.91	No trend
Dec	0.14	No trend	0.42	No trend

* p-values significant at an alpha level of 0.05

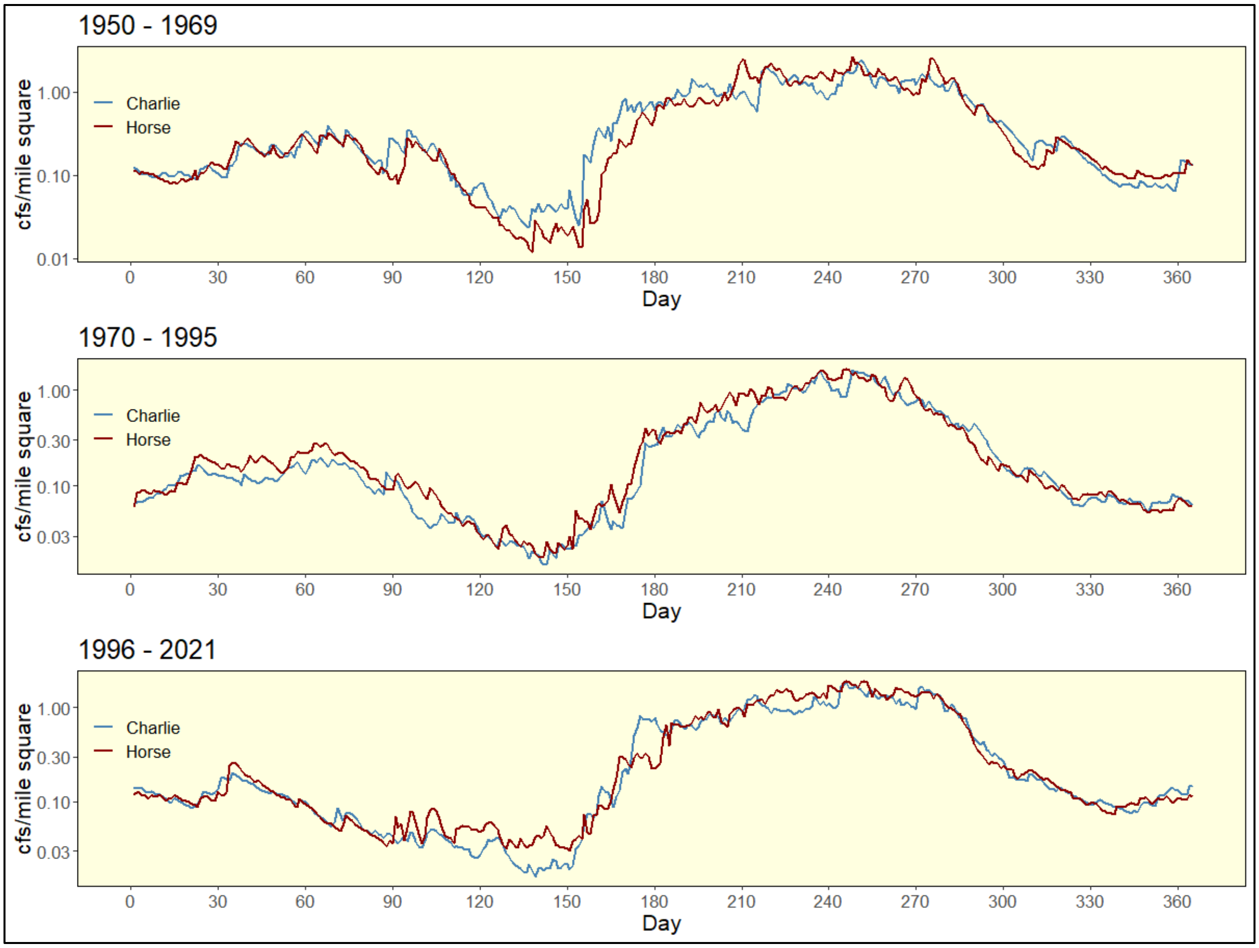

Figure 2-16. Comparison of median daily flows (logarithmic scale) for three time periods at the USGS Charlie Creek near Gardner, FL (No. 02296500) and USGS Horse Creek at SR72 near Arcadia, FL (No. 02297155) gages. Data from 1950 begin on May 1st.

2.6. Hydrogeology and Aquifer Levels

The hydrogeology of the District can generally be divided into three broad regions that correspond to major groundwater basins within the UFA (Figure 2-17). Within the District, from upstream to downstream, are the Northern West-Central Florida Groundwater Basin (NWCFGWB), the Central West-Central Florida Groundwater Basin (CWCFGWB), and the Southern West-Central Florida Groundwater Basin (SWCFGWB). In general, the UFA is mostly unconfined in the NWCFGWB, semi-confined in the CWCFGWB, and well-confined in the SWCFGWB as the intermediate confining unit (ICU) thickens from upstream to downstream (Basso 2019).

Three principal hydrogeologic units underly most of the Charlie Creek watershed: the surficial aquifer (SA), the Hawthorn aquifer system (HAS), and the Floridan aquifer system (FAS). The uppermost system is the SA composed primarily of unconsolidated fine to medium sand, becoming increasingly clayey and phosphatic with depth (SWFWMD 2004, Gates 2009). The SA thickness in Charlie Creek can be up to 150 feet and is mainly recharged by rainfall and the irrigation of agricultural land or landscape areas (Weber 1999, Spechler and Kroening 2007, Zydek 2021). Because of low water quality, SA use is limited for lawn and garden irrigation, and for stock watering (Duerr and Enos 1991), and it is important for recharging deeper aquifers or discharges into streams, wetlands, and lakes (Lee et al 2010). Clay and the phosphate-rich beds form a confining unit between the SA and HAS in Charlie Creek. The SA horizontal hydraulic conductivity ranges from 1 to 34 feet per day. The SA transmissivity in Charlie Creek ranges from around 10 to 1,000 square feet per day (Lee et al 2010).

Underlying the SA is the confined HAS consisting of water-bearing and confining beds between the overlying SA and the underlying FAS (Gates 2009, HydroGeoLogic, Inc. 2009, Lee et al 2010). The water-bearing units are confined above and below by less permeable materials such as sandy clay, clay, and marl (Duerr and Enos 1991, SWFWMD 2001). The confining units hinder the vertical movement of groundwater between the overlying SA and the underlying FAS, but it is a leaky aquifer system (Duerr and Enos 1991, Spechler and Kroening 2007, HydroGeoLogic, Inc. 2009). The HAS is relatively thin in the upper reaches of the Peace River basin and thickens to the south (SWFWMD 2001). The elevation of the top of the HAS ranges from about 25 feet below sea level in northeastern DeSoto County to about 100 feet above sea level in northwestern Hardee County (Duerr and Enos 1991, Gates 2009).

Underlying the HAS, the confined FAS exists as a major source of fresh groundwater for most of southwest Florida. The FAS is composed primarily of limestone and dolostone that are hydraulically highly permeable (Duerr and Enos 1991, Weber 1999, Gates 2009). The FAS is subdivided into the UFA and Lower Floridan aquifer (LFA) which are separated by a confining unit. The UFA deepens from upstream to downstream in the Charlie Creek basin and it thickens from 148 to 370 ft below NAVD88 (Lee et al 2010). About 85% to 90% of all groundwater is derived from the UFA. The LFA is generally brine-saturated (SWFWMD 2004).

As part of the Regional Observation and Monitor-Well Program (ROMP), the District has installed many monitoring wells at several locations, but the available data is limited by the short length of record. The longest record is available at ROMP 43 for the period from 1986 to the present. The location of this well is provided in Figure 2-2. Water levels measured at District Station No. 23956 and 23958 to monitor water levels in the SA and the UFA, respectively, are shown in Figure 2-18. The hydrographs show larger fluctuations caused by seasonal rainfall variability and groundwater withdrawals. The SA water levels at the site have generally fluctuated between 77.6 and 97.7 feet NAVD88 during the period from 2007 through August 2022, while the UFA water levels at the site fluctuated between 52.5 and 87.9 feet NAVD88 during the same period. Both the SA and UFA water levels exhibited a positive trend from 2007 through 2015 but the increasing trend is more evident in the UFA water levels. Since 2016 the water levels for both aquifers generally remained steady with no significant change over time.

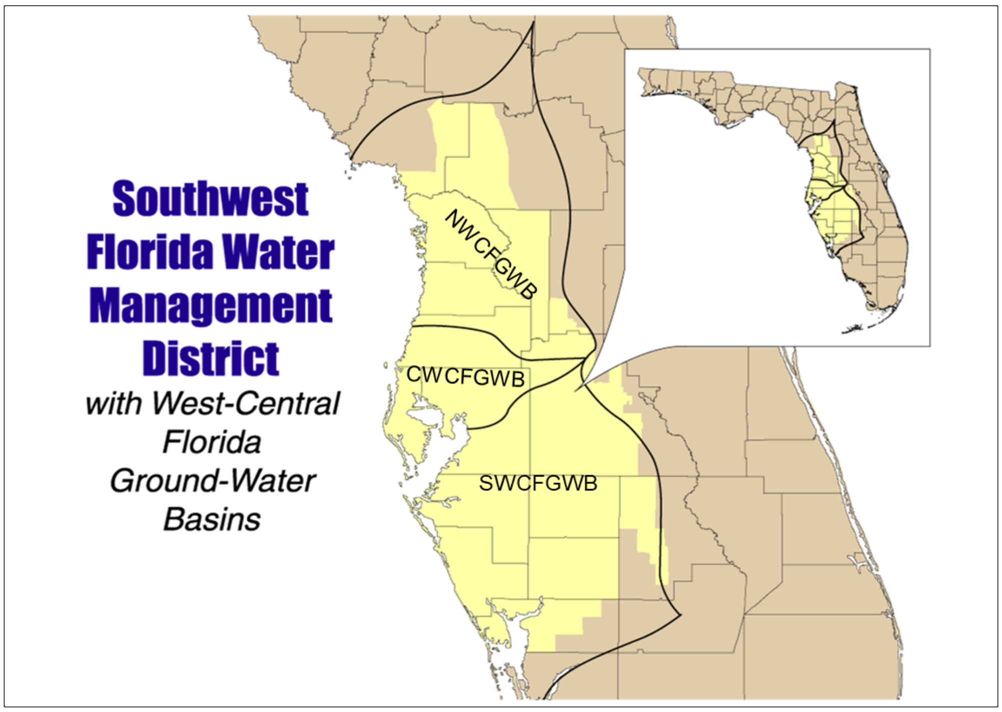

Figure 2-17. Location of regional groundwater basins within the District boundary including the Northern West-Central Florida Groundwater Basin (NWCFGWB), the Central West-Central Florida Groundwater Basin (CWCFGWB), and the Southern West-Central Florida Groundwater Basin (SWCFGWB).

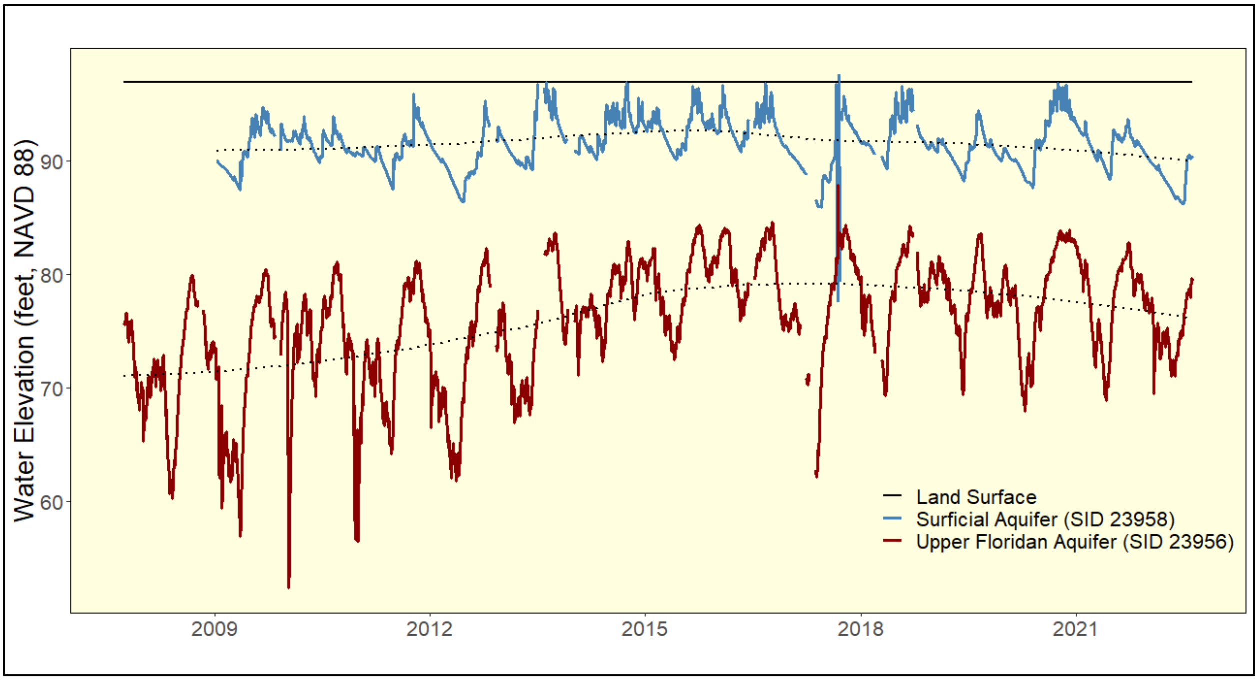

Figure 2-18. Water levels (feet) from monitor wells installed into the surficial and Upper Floridan aquifers at the District Regional Observation and Monitor-Well Program 43 site from 2007 through August 2022. The dashed lines indicate the overall trend using LOESS.

CHAPTER 3 - WATER QUALITY CHARACTERISTICS

Water quality is one of the ten "Environmental Values" defined in the State Water Resource Implementation Rule for consideration when establishing minimum flows. This chapter provides an overview of trends for water quality parameters measured in Charlie Creek, including exploratory evaluations of water quality and flow relationships prepared for the District ATM and JEI 2021a; Appendix B). The inclusion of any information pertaining to adopted water quality standards in this chapter is for informational purposes only and not intended to be a determination of impairment by the District.

3.1. Designated Use and Impaired Waters Rule

Under Rule 62-302.200, F.A.C., Florida's surface water quality standards consist of four components: 1) the designated use of 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. Surface water bodies in Florida are classified according to their present and future most beneficial use, referred to as designated use, with class-specific water quality criteria for select physical and chemical parameters (Chapter 62-302, F.A.C.).

The DEP assigns waterbody identification numbers (WBIDS) to portions of watersheds, rivers, and other water bodies with homogenous water quality. Used as an assessment unit, each WBID is accompanied by a GIS polygon layer that delineates the drainage basin surrounding it. The Charlie Creek watershed contains twenty WBIDs, all listed as class III, meaning their designated use is for fish consumption, recreation, propagation, and maintenance of a healthy and well-balanced population of fish and wildlife (Rule 62-302.400, F.A.C.; Figure 3-1).

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 comply with this requirement, the DEP has traditionally assessed waterbodies on a five-year cycle, although the department is changing this to a biennial schedule under the Impaired Waters Rule (IWR; Chapter 62-303, F.A.C.). During assessments, the Watershed Assessment Section utilizes the best available data to determine if WBIDs are meeting applicable water quality standards (Chapter 62-302, F.A.C.) and their designated use (Chapter 62-303, F.A.C.). If a waterbody does not meet the applicable water quality criteria, it is no longer considered to support its designated use. It is then added to the

DEP's Verified List for subsequent total maximum daily load (TMDL) development and is reported to the United States Environmental Protection Agency.

The most recently adopted Verified List for Charlie Creek was approved on July 15, 2022, based upon the IWR Run 60 Database which contains data through 2020. Charlie Creek above Peace River (WBID 1763A) is impaired for macrophytes (determined by linear vegetation surveys) and total phosphorus (frequent exceedances of the annual geometric mean threshold) and is a medium priority for TMDL development. The WBID has biological evidence indicating non-attainment of its designated use. Charlie Creek above Old Town Creek (WBID 1763D) is impaired for fecal coliform. Charlie Creek above Oak Creek (WBID 1763B), Little Charlie Bowlegs (WBID 1857), and Fish Branch (WBID 1928) are on the Study List for dissolved oxygen percent saturation exceedances without a known causative pollutant. The DEP has not established a TMDL or basin management plan (BMAP) specific to any waterbody within Charlie Creek. A statewide mercury TMDL has been developed due to widespread atmospheric deposition (DEP 2013).

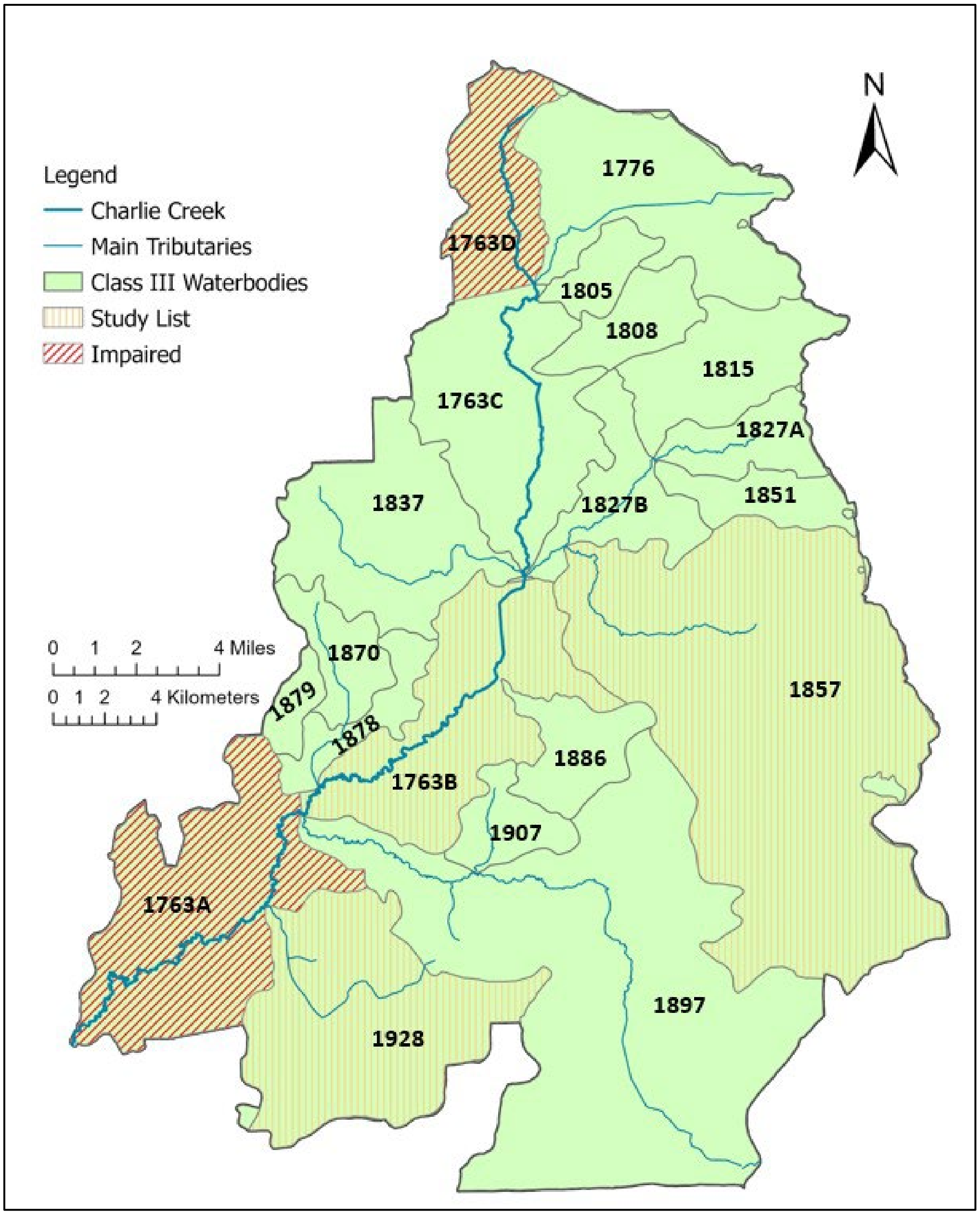

Figure 3-1. The location of waterbodies by waterbody identification number (DEP 2005) within the Charlie Creek watershed, colored according to designated use classification and shaded by their impairment status, according to the DEP's Impaired Waters Rule Run 60 and the Verified List adopted in 2022.

3.2. Water Quality Analysis

3.2.1. Data

To assess the relationship between water quality and flow, Janicki Environmental, Inc. (JEI) through Applied Technology & Management, Inc. (ATM), conducted regression and time series trend analysis on select water quality parameters (ATM and JEI 2021a). Long-term flow data were obtained from two USGS gaging stations: USGS Charlie Creek near Crewsville, FL (No. 02296260) and USGS Charlie Creek near Gardner, FL (No. 02296500; Figure 3-2). Flow data has been measured at the upstream site near Crewsville since 2004 and at the downstream site near Gardner since 1950. Water quality data were obtained from the DEP (IWR Run 59), the District, and the USGS (Table 3-1, Figure 3-2). Station data were retained for each constituent if they met minimum sample requirements of 30 observations. Outlier analysis was performed to identify and remove potentially erroneous data.

From the available data, water quality constituents were grouped based upon their relevance to one another and their likely impact on water quality (Table 3-2). The constituent groups included Nitrogen, Phosphorus, Chlorophyll, Physio-Chemical, Minerals and Metals, and Indicators of Water Clarity. Further details about each constituent group and their results are provided in Section 3.2.3.

In this system, all water quality stations were co-located with a USGS discharge gage (Figure 3-2). Therefore, to develop relationships between water quality and flow, each water quality station was assigned the discharge record from the USGS station it was co-located with. Due to the proximity of all water quality stations to USGS gages, antecedent flow conditions were not considered in the analysis.

Table 3-1. Water quality sampling stations in Charlie Creek meeting the criterion of at least 30 observations and the general period of record (POR) used for analysis in ATM and JEI (2021a).

Source	Station ID	POR Start	POR End
DEP	21FLGW 3561	10/08/1998	12/05/2017
SWFWMD	23969	05/16/2007	03/05/2019
USGS	02296500	01/26/1965	9/28/1999

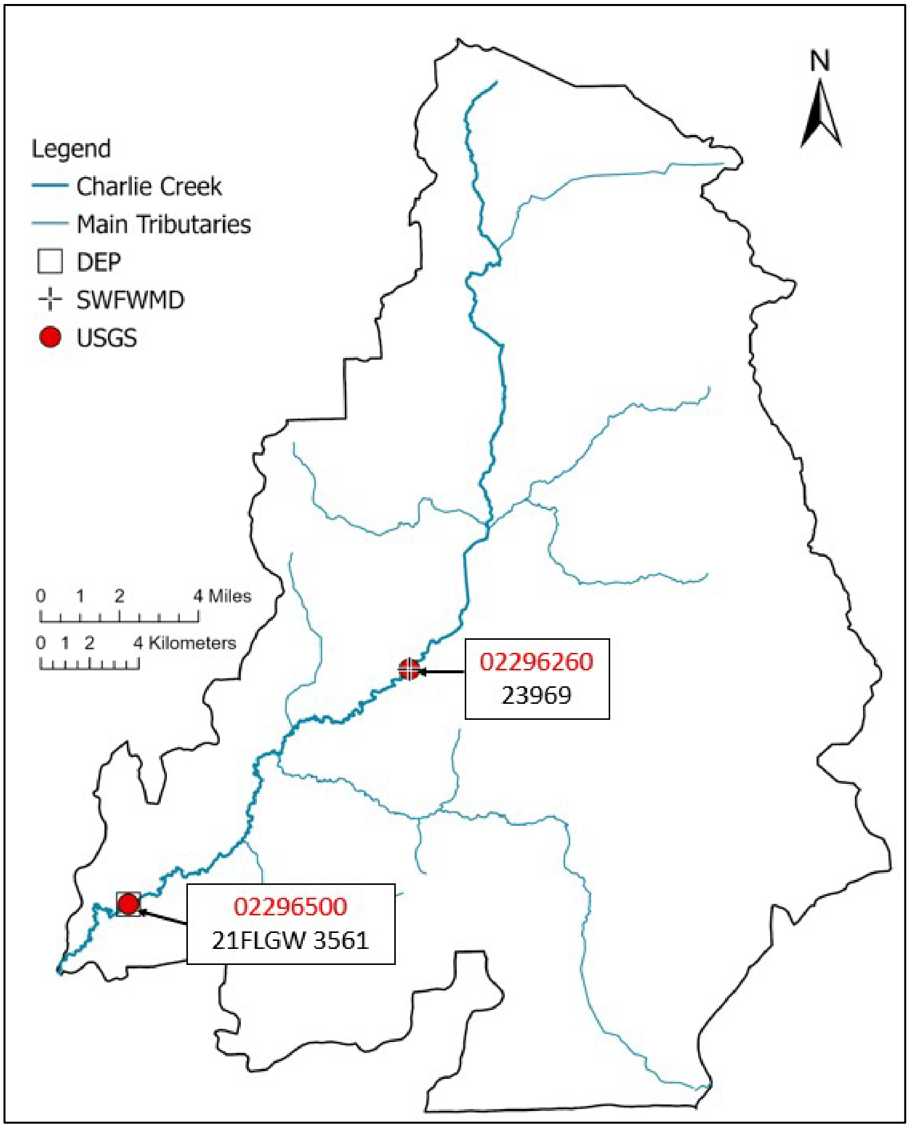

Figure 3-2. Locations of the water quality and quantity sampling sites that met criteria for inclusion in analysis by ATM and JEI (2021a). The USGS stations labeled with red text provided water quantity data. Stations 23949, 21FLGW 3561, and 02296500 provided water quality data.

Table 3-2. Water quality constituent groups used for analysis by ATM and JEI (2021a) with their associated constituents.

Group	Constituent
Nitrogen	Ammonia
	Ammonium
	Nitrate
	Nitrate-Nitrite
	Nitrite
	Organic Nitrogen
	Total Kjeldahl Nitrogen
	Total Nitrogen
	Unionized Ammonium
Phosphorus	Dissolved Orthophosphate
	Orthophosphate
	Phosphorus in Total Orthophosphate
	Total Phosphorus
Chlorophyll	Chlorophyll *a*
Physio-Chemical	Biological or Chemical Oxygen Demand
	Conductivity
	Dissolved Oxygen
	Hardness
	pH
	Temperature
Minerals and Metals	Calcium
	Chloride
	Fluoride
	Iron
	Magnesium
	Radium 226
	Radium 228
	Radium Total
	Sulfate
Water Clarity	Color
	Total Dissolved Solids
	Total Organic Carbon
	Total Suspended Solids
	Turbidity

3.2.2. Analytical Methods

To characterize the relationship between water quality and flows, trend tests, linear regression, and logistic regression were used. Trend tests were used to assess whether flow and water quality data have increased or decreased over time and whether the trend in either direction was significant. For flow trend analysis, a Mann Kendall trend test was performed using monthly median flow values at a corresponding USGS gage. Seasonal Mann Kendall was used, with a correction for serial dependence (Hirsh and Stack 1984) for water quality trend analysis. While this methods test can screen for monotonic trends over time, they do not account for the effects of other explanatory factors affecting trends, and therefore do not provide inferences as to the cause of detectable change. Inclusion criteria for these tests consist of having recent data (within the past five years), and for the seasonal Mann Kendall, at least five years of data and 60 observations were required (Reckhow et al., 1993; ATM and JEI 2021a).

To investigate relationships between water quality and flow, linear regressions were performed on natural log transformed flow and water quality parameter data. Linear regression is a common statistical method for relating predictor variables to response variables under strict assumptions. A seasonal classification term was added to the model to evaluate how different months may have affected the response between flows and water quality parameters. To evaluate model fit and potential utility in assessing water quality relationships, the sign of the slope statistic, the p value indicating the statistical significance of the slope statistic, and the coefficient of determination (R^2) defining the proportion of variation explained by the model were reported. For example, an R^2 value of 0.4 would indicate that 40% of the variation in a constituent is explained by the model (flow). Only regressions with an R^2 value of 0.2 or more are included in this chapter. Importantly, even when linear regressions suggested significant relationships, this did not imply causation. Results of linear regressions were reported for “primary sites,” which had at least 100 observations for a constituent of interest, and “secondary sites,” which had fewer observations. Analyses performed on “secondary sites” with smaller sample sizes should be interpreted with caution (ATM and JEI 2021a).

Logistic regression was also used to examine the probability of exceeding ecologically relevant water quality thresholds as a function of flows. This analysis was restricted to stations and constituents with 100 or more observations which had more than 10% of observations exceeding thresholds. Based on these requirements, analysis was limited to total phosphorus at DEP station 21FLGW 3561. Threshold values associated with DEP water quality standards (based on annual geometric means) were used, including the maximum total phosphorus concentration for freshwater streams (annual geometric mean of 0.49 mg/L, per Rule 62-302.531, F.A.C.). The use of these threshold values is not intended to suggest that variation in flow would lead to impairment according to state standards, but rather to identify constituents for further investigation, should reductions in flow lead to an increased probability of exceeding the state-established thresholds. Evaluation of the logistic regression model fits included calculating a generalized R^2, which was rescaled to conform to the typical inference regarding R^2, in which the maximum value is 1 (ATM and JEI 2021a). As with linear regression results, only those regressions with an R^2 greater than 0.2 are included in this chapter.

3.2.3. Results

3.2.3.1 Nitrogen

Nitrogen is an essential nutrient for plants; however, an overabundance can have a deleterious effect on aquatic life by causing overgrowth of phytoplankton and nuisance vegetation. Several nitrogen species have been monitored throughout Charlie Creek (Table 3-2). There were no statistically significant ($p < 0.05$) results of the seasonal Mann Kendall trend test, indicating no change in trends in nitrogen species over time, given available data.

When relationships with flow were considered by linear regression analysis, statistically significant positive relationships with an R^2 value of 0.2 or greater were observed for several nitrogen species including: ammonium ($p < 0.001$), nitrate-nitrite ($p < 0.001$), total nitrogen ($p < 0.001$) and total Kjeldahl nitrogen ($p < 0.001$) at DEP station 21FLGW 3561; nitrite ($p < 0.001$) at SWFWMD station 23969; and organic nitrogen ($p < 0.001$), total Kjeldahl nitrogen ($p < 0.001$), and total nitrogen ($p < 0.001$) at USGS station 0229650 (Table 3-3). The positive relationship between many nitrogen species and flow is comparable to findings from other Florida rivers (ATM and JEI 2020, ATM and JEI 2021b), and generally results from increased flushing of decomposing organic matter and agricultural runoff that can increase nitrogen loads to the system during the wet season (ATM and JEI 2021b). Statistically significant ($p < 0.05$) seasonal terms were observed for all nitrogen species measured at DEP station 21FLGW 3561, which has a more robust period of record and sampling schedule than other stations. An example of the seasonal trend for total nitrogen is provided in Figure 3-3, demonstrating higher values of the constituent during the summer rainy season.

Although total nitrogen data in Charlie Creek did not meet the requirements for logistic regression analysis, the annual geometric mean was calculated by the District to visualize individual yearly threshold exceedances of state water quality criteria for Class III waters (an annual geometric mean of <1.65 mg/L, not to be exceeded more than once in any three-calendar year period). Due to a long, continuous period of record, data from DEP station 21FLGW 3561 were utilized, from 1999-2017. A calculated annual geometric mean above the State water quality threshold occurred once, in 2001 (Figure 3-4).

Table 3-3. Summary of statistically significant ($p < 0.05$) linear regression relationships between nitrogen group constituents and flow with R^2 values greater than or equal to 0.20. The positive (Pos.) or negative (Neg.) slope designation refers to the relationship between constituent and flow at the corresponding USGS gage. Non-significant monthly p-values are listed as "ns" (modified from ATM and JEI 2021a).

Constituent	Station	Samples (n)	Period of Record	Month p-value	Flow p-value	R^2	Slope
Ammonium	21FLGW 3561	222	10/1998-12/2017	<0.001	<0.001	0.39	Pos.
Nitrate-Nitrite	21FLGW 3561	216	10/1998-12/2017	<0.001	<0.001	0.29	Pos.
Nitrite	23969	70	10/2009-3/2019	ns	<0.001	0.22	Pos.
Organic Nitrogen	02296500	76	5/1970-9/1999	ns	<0.001	0.39	Pos.
Total Kjeldahl Nitrogen	21FLGW 3561	220	10/1998-12/2017	<0.001	<0.001	0.67	Pos.
	02296500	73	7/1970-9/1999	ns	<0.001	0.39	Pos.
Total Nitrogen	21FLGW 3561	225	10/1998-12/2017	<0.001	<0.001	0.67	Pos.
	02296500	73	7/1989-9/1999	ns	<0.001	0.26	Pos.

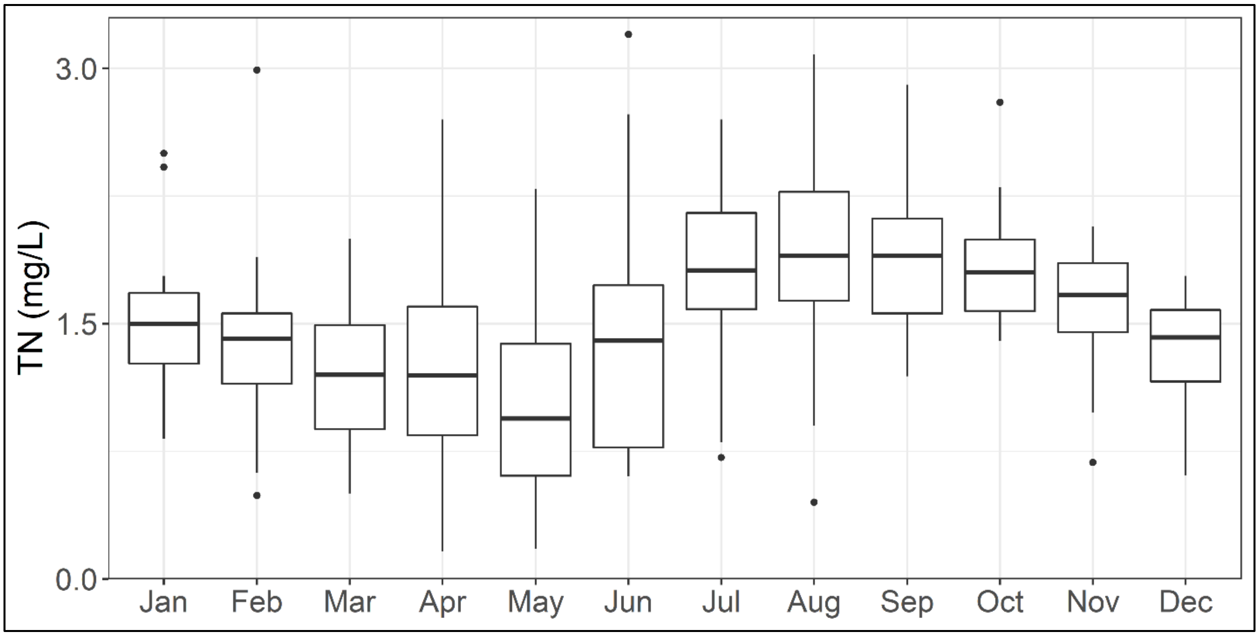

Figure 3-3. Total nitrogen (TN) concentrations at DEP station 21FLGW 3561 from 1998 through 2017. Boxed values indicate the 25th to 75th percentiles with centerline reflecting the 50th percentile value. Dots represent outliers, indicative of values outside of the 1.5*interquartile range.

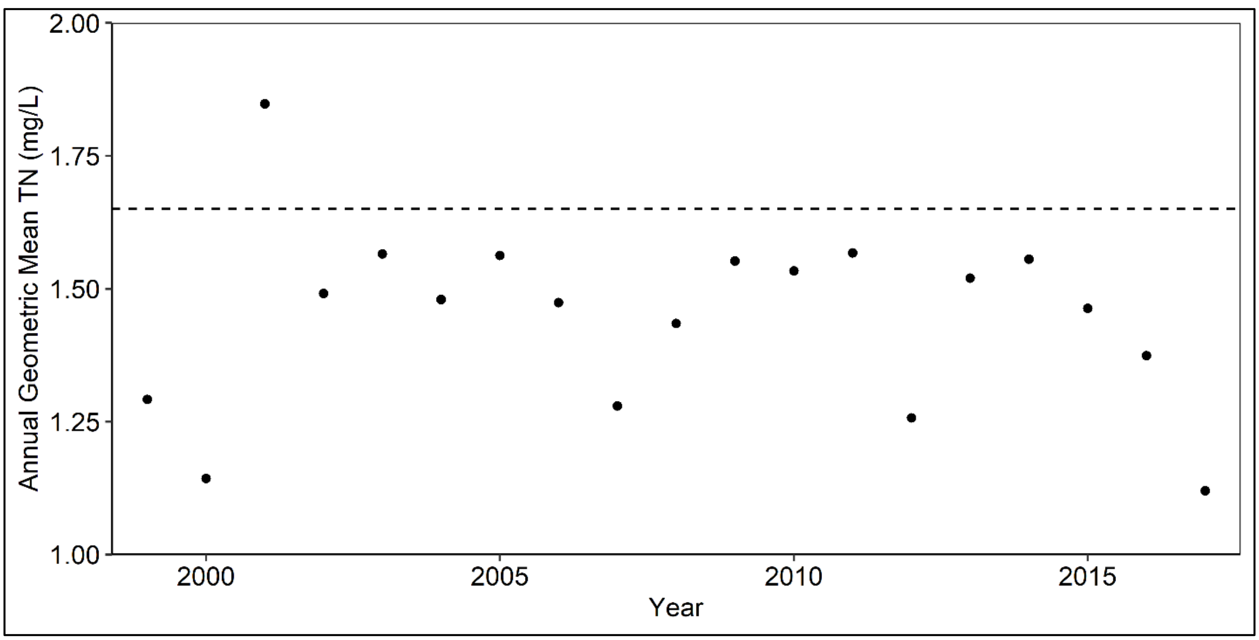

Figure 3-4: Annual geometric mean of total nitrogen (TN) at DEP station 21FLGW 3561, from 1999 through 2017. The State water quality threshold for TN in Class III waters (an annual geometric mean of 1.65 mg/L) is indicated by the dashed line.

3.2.3.2. Phosphorus

Phosphorus is another nutrient essential for plant growth that can lead to ecological degradation at high concentrations. Orthophosphate and total phosphorus have been measured in Charlie Creek at DEP, USGS, and SWFWMD stations. There were no statistically significant ($p < 0.05$) results of the seasonal Mann Kendall trend test, indicating no change in trends in phosphorus species over time, given available data.

Linear regressions at DEP station 21FLGW 3561, which had the greatest number of samples, indicated statistically significant negative relationships with flow for both orthophosphate ($p = 0.032$) and total phosphorus ($p < 0.001$; Table 3-4). There was a statistically significant ($p < 0.001$) seasonal term for both relationships. An example of the seasonal trend for total phosphorus is provided in Figure 3-5. When stations with fewer than 100 samples were considered, the relationship with flow was significant for both orthophosphate ($p < 0.001$) and total phosphorus ($p = 0.008$), but positive, with significant seasonal terms (Table 3-4). The difference in slope direction between the DEP and District station was likely due to sampling frequency. The District station was sampled once every two months beginning in 2012. The DEP station was sampled more frequently over the POR and therefore, the negative relationship between flow and phosphorus species observed there is more likely to reflect actual trends in the system.

As mentioned above, the WBID in which DEP station 21FLGW 3561 is located (WBID 1763A) is impaired for total phosphorus. This impairment is determined by the annual geometric mean exceeding the state water quality total phosphorus threshold for class III waters (0.49 mg/L) more than once in a three-year period. For this station, the annual geometric mean was exceeded in 16 of the 19 available study years (Figure 3-6). Logistic regression analysis indicated a statistically significant negative relationship with flow ($p = 0.017$, $R^2 = 0.28$) and a significant seasonal term ($p < 0.001$; Table 3-5).

Table 3-4. Summary of statistically significant ($p < 0.05$) linear regression relationships between phosphorus group constituents and flow with R^2 values greater than or equal to 0.20. The positive (Pos.) or negative (Neg.) slope designation refers to the relationship between constituent and flow at the corresponding USGS gage (modified from ATM and JEI 2021a).

Constituent	Station	Number of Samples	Period of Record	Month p-value	Flow p-value	R^2	Slope
Ortho-phosphate	23969	74	10/2009-3/2019	0.021	<0.001	0.59	Pos.
	21FLGW 3561	111	10/1998-9/2008	<0.001	0.032	0.33	Neg.
Total Phosphorus	23969	71	10/2009-3/2019	0.006	0.008	0.58	Pos.
	21FLGW 3561	217	10/1998-12/2017	<0.001	<0.001	0.32	Neg.

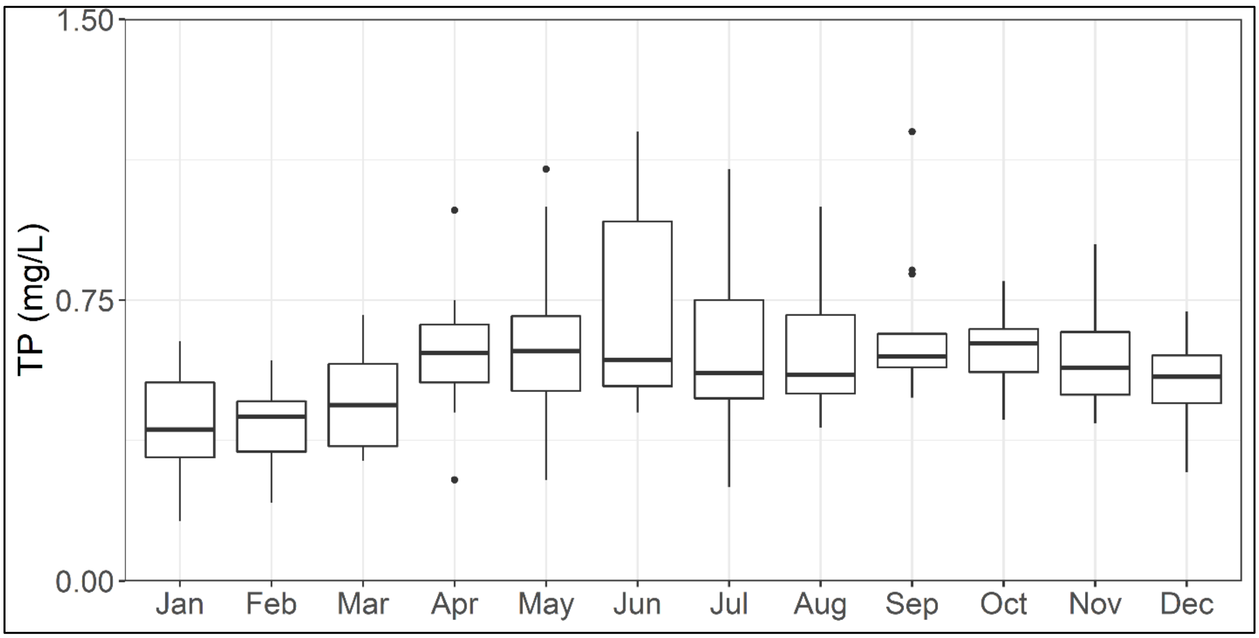

Figure 3-5. Monthly total phosphorus (TP) concentrations at the DEP station 21FLGW 3561 from 1998 through 2017. Boxed values indicate the 25th to 75th percentiles with centerline reflecting the 50th percentile value. Dots represent outliers, indicative of values outside of the 1.5*interquartile range.

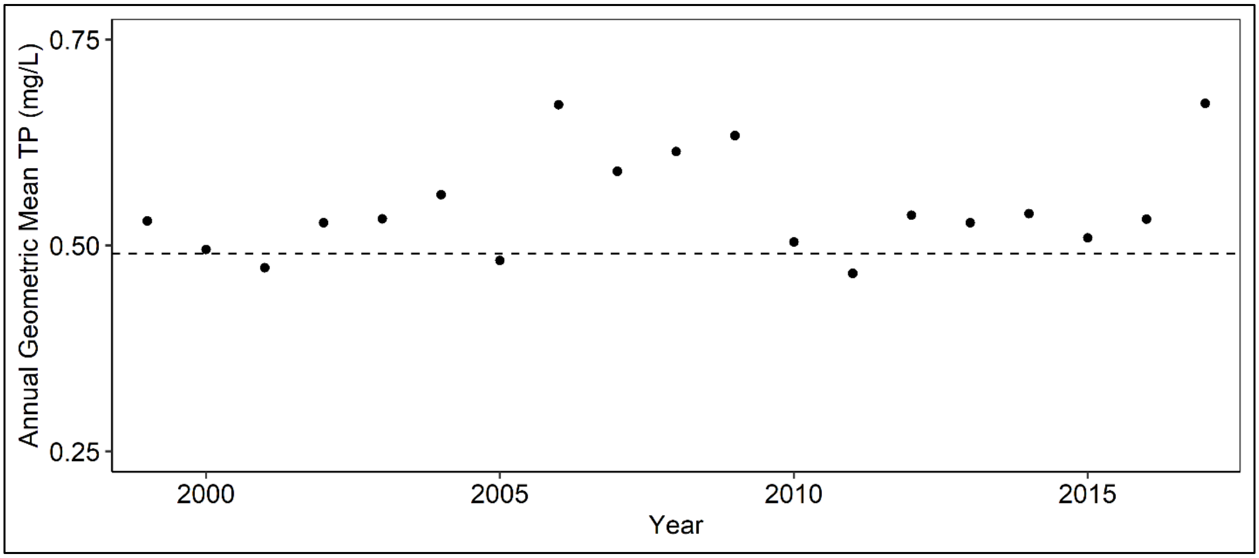

Figure 3-6. Annual geometric mean of total phosphorus (TP) at the DEP station 21FLGW 3561 from 1999 through 2017. The State water quality threshold for TP in Class III waters (0.49 mg/L) is indicated by the dashed line.

3.2.3.3. Chlorophyll *a*

Excess nutrients in a system can stimulate phytoplankton growth, whose biomass can be approximated by measurement of chlorophyll concentrations. With reduced flushing and increased residence time, eutrophication can occur leading to oxygen depletion and ecological stress. Although there are many types of chlorophyll, chlorophyll *a* is commonly assessed for aquatic ecosystems studies. Uncorrected chlorophyll *a* at station 23949 had a significant negative relationship with flow ($p < 0.001$), although these results may be interpreted with caution as there were fewer than 100 samples collected (Table 3-5). The DEP station 21FLGW 3561 measured both uncorrected chlorophyll *a* ($n = 119$) and corrected chlorophyll *a* ($n = 214$) but no statistically significant relationship with flow was observed in these data. All corrected chlorophyll *a* measurements from the POR (1998-2017) were below the State water quality threshold of 20 µg/L for freshwater streams (per Rule 62-303.651, F.A.C.).

Table 3-5. Summary of statistically significant ($p < 0.05$) linear regression relationships between phosphorus group constituents and flow with R^2 values greater than or equal to 0.20. The Negative (Neg.) slope designation refers to the relationship between constituent and flow at the corresponding USGS gage (modified from ATM and JEI 2021a).

Constituent	Station	Samples (n)	Period of Record	Month p-value	Flow p-value	R^2	Slope
Chlorophyll a (Uncorrected)	23969	73	10/2009-3/2019	ns	<0.001	0.42	Neg.

3.2.3.4. Physio-Chemical Constituents

Physio-chemical parameters analyzed in Charlie Creek included: dissolved oxygen, pH, alkalinity, conductivity, hardness, and temperature. Dissolved oxygen levels have been reported in this system as both concentration and percent saturation, the latter of which approximates the amount of oxygen the water can hold as a function of temperature. Dissolved oxygen can increase through physical processes, atmospheric interaction, and photosynthesis and decrease as it is used by organisms and through decomposition of organic materials. The pH of a waterbody is important since different chemical species become soluble and bioavailable at different pH levels and as such many aquatic organisms have evolved to survive within certain pH ranges. The alkalinity of a system refers to the buffering capacity of the water against rapid fluctuations in pH. Limestone-dominated systems tend to have higher alkalinity overall. Conductivity refers to the ability of water to pass an electrical current and can increase with increasing levels of dissolved salts and other inorganic chemicals or rising temperature. In addition to previously mentioned roles, temperature is critical both for the types and life stages of biological organisms a river can support and the rate of chemical and biological reactions that happen within a liquid medium.

When statistically significant ($p < 0.05$), hardness, pH, and temperature were decreasing over time by Seasonal Kendall Tau analysis at water quality stations co-located with USGS Charlie Creek near Gardner, FL (No. 02296500; Table 3-6, Figures 3-7, 3-8, 3-9) gage. Conductivity was increasing over time from 1965 to 1999 at the USGS Charlie Creek near Garner, FL (No. 02296500) gage but decreasing at the upstream District station 23969 over a more recent period of record, from 2000 through 2017 (Figure 3-10). In a 2010 report, dissolved minerals from agricultural runoff were linked to increasing conductivity in various creeks in the Charlie Creek basin (Lee et al., 2010). As discussed in Chapter 2, land use has not changed significantly in Charlie Creek over time, however different agricultural practices and rainfall between sampling periods may influence the observed trends (ATM and JEI 2021a).

All statistically significant ($p < 0.05$) relationships between physio-chemical water quality constituents and flow were negative, which was expected when compared to relationships seen in other southwest Florida streams (Table 3-7; ATM and JEI 2021a, ATM and JEI 2021b). Seasonal relationships were evident for conductivity, dissolved oxygen (both mg/L and percent saturation) and temperature. Dissolved oxygen tends to decrease in the warmer summer months, since warm water holds less oxygen and phytoplankton production is increased (Figure 3-11). Conductivity declines during the rainy season with additional freshwater input.

The state has a minimum threshold for dissolved oxygen percent saturation in Class III waters, according to which no more than 10% of daily values may be below 38% Rule (62-302.533, F.A.C.). Over the available period of record, 43% of samples at District station 23969 were below this threshold (Figure 3-12). This station is located within WBID 1763B (Charlie Creek above Oak Creek) and downstream from WBID 1857 (Little Charlie Bowlegs) two water bodies on the DEP Study List due to dissolved oxygen percent saturation impairment.

Hypoxic conditions can occur in waters with dissolved oxygen concentrations below 3 mg/L. Over the POR, hypoxic conditions were most common at District station 23949, occurring in 35% of samples (Figure 3-13). At DEP station 21FLGW 3561, hypoxic conditions occurred in 1% of samples.

Table 3-6. Results of seasonal Mann Kendall tests for trend for those constituent/station combinations with statistically significant (p < 0.05) results (modified from ATM and JEI 2021a).

Constituent	Station	Samples (n)	Period of Record	Adjusted p-value	Theil Sen Slope (Change/year)	Trend Direction
Conductivity	23969	74	5/200-3/2019	0.017	-6.833	Decreasing
	02296500	132	1/1965-9/1999	0.001	4.3765	Increasing
Hardness	21FLGW 3651	68	10/1998-12/2017	0.003	-5.625	Decreasing
pH	02296500	98	1/1965-9/1999	0.017	-0.02	Decreasing
Temperature	02296500	122	1/1965-9/1999	0.003	-0.114	Decreasing

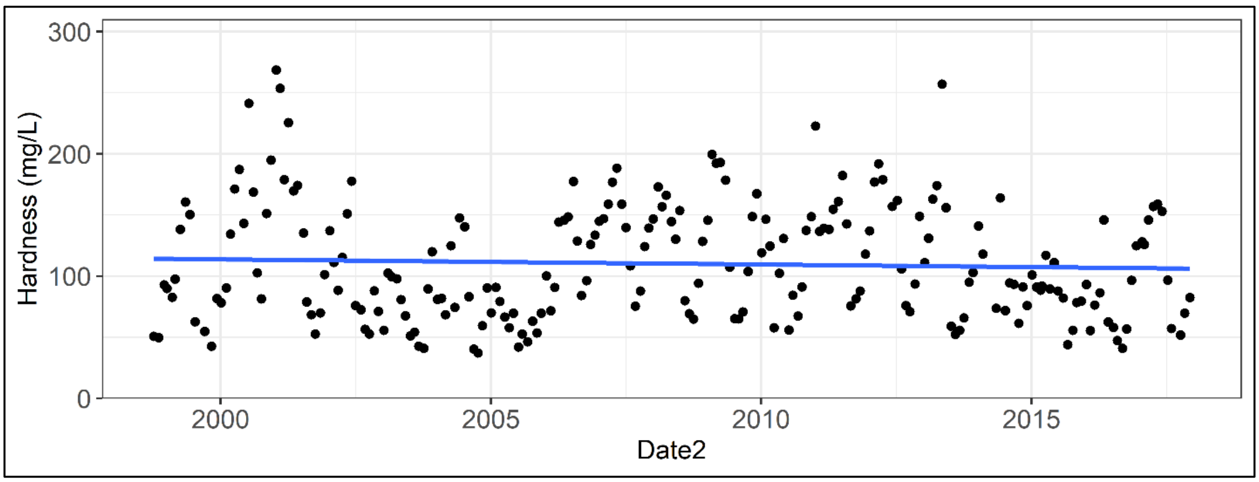

Figure 3-7. Sample distribution of water hardness (mg/L) at DEP station 21FLGW 3561 from 1998 through 2017. The blue line indicates a statistically significant (p = 0.003) decreasing trend.

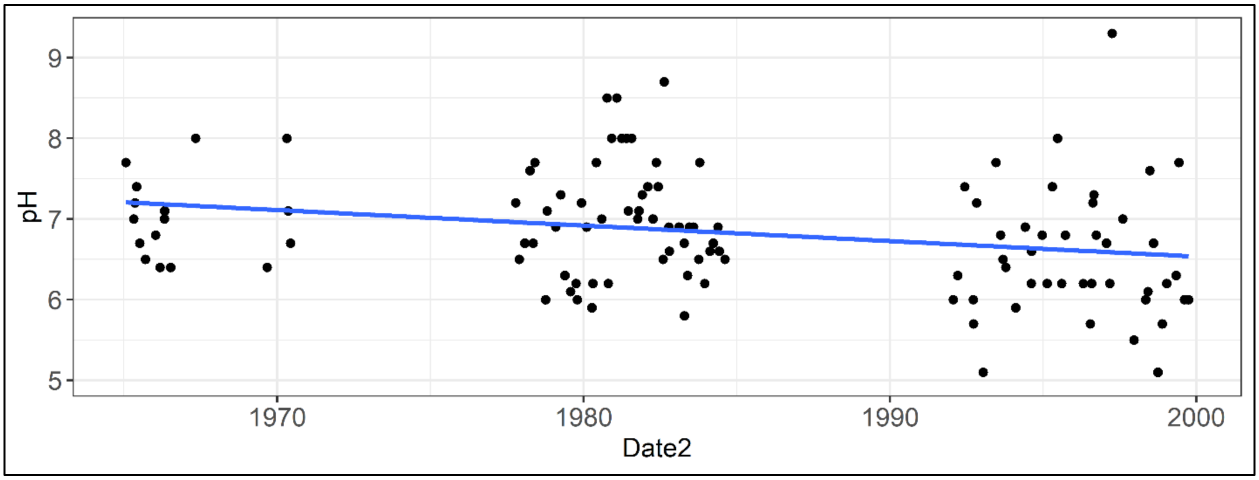

Figure 3-8. Sample distribution of water pH at USGS station 02296500 from 1965 through 1999. The blue line indicates a statistically significant (p = 0.017) decreasing trend.

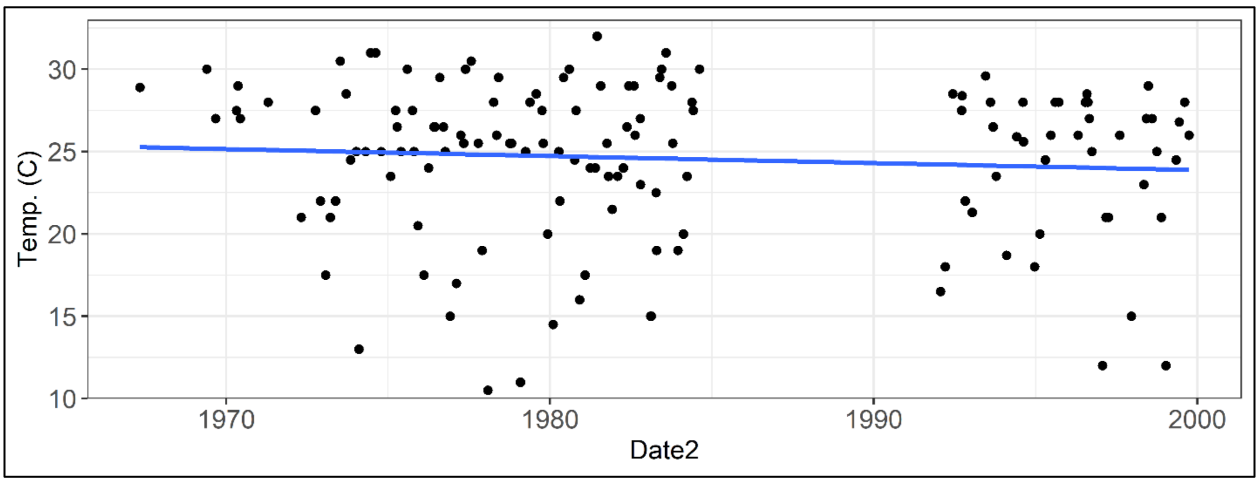

Figure 3-9. Sample distribution of water temperature (ºC) at USGS station 02296500 from 1965 through 1999. The blue line indicates a statistically significant (p = 0.003) decreasing trend.

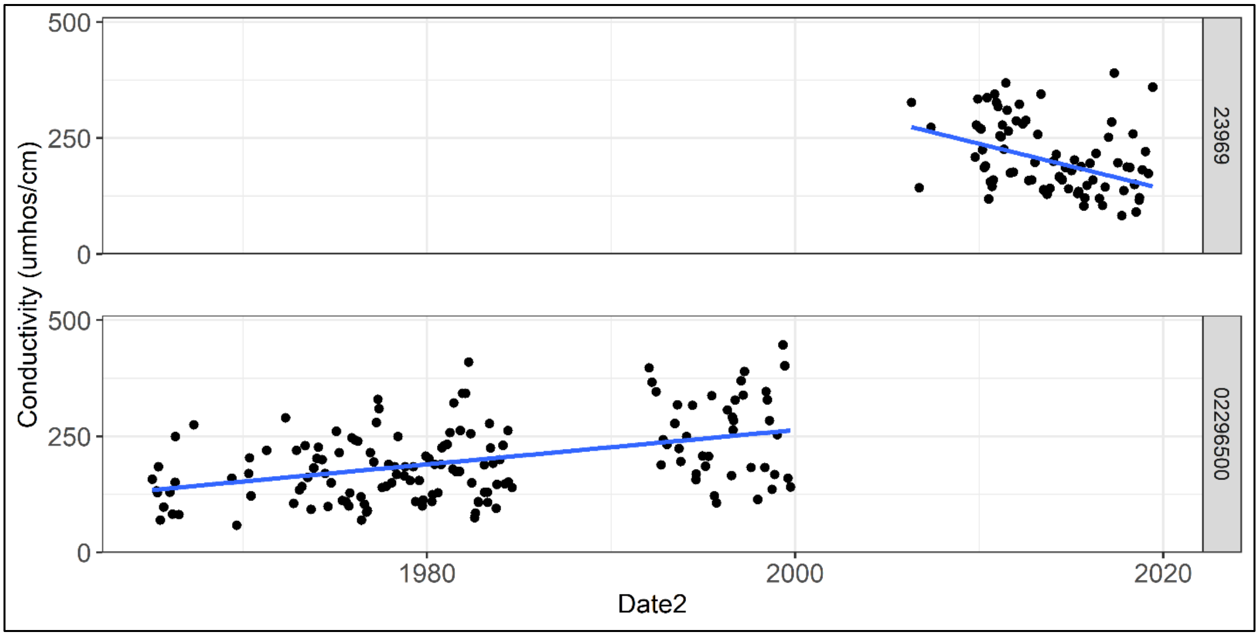

Figure 3-10: Sample distribution of specific conductance (μmhos/cm) at District station 23949 from 2007 through 2019 with the blue line indicating a statistically significant (p = 0.017) decreasing tend, and at USGS station 02296500 from 1965 through 1999 with the blue line indicating a statistically significant (p = 0.001) increasing trend.

Table 3-7. Summary of statistically significant ($p < 0.05$) linear regression relationships between physio-chemical group constituents and flow with R^2 values greater than or equal to 0.20. The negative (Neg.) slope designation refers to the relationship between constituent and flow at the corresponding USGS gage (modified from ATM and JEI 2021a).

Constituent	Station	Samples (n)	Period of Record	Month p-value	Flow p-value	R^2	Slope
Alkalinity	23969	69	10/2009-3/2019	ns	<0.001	0.74	Neg.
Conductivity	23969	76	5/2004-3/2019	0.001	<0.001	0.75	Neg.
	21FLGW 3561	223	10/1998-12/2017	<0.001	<0.001	0.74	Neg.
	02296500	149	1/1965-9/1999	0.021	<0.001	0.57	Neg.
Dissolved Oxygen	21FLGW 3561	217	10/1998-12/2017	<0.001	<0.001	0.52	Neg.
	02296500	133	5/1967-9/1999	<0.001	<0.001	0.51	Neg.
Dissolved Oxygen Percent Saturation	02296500	29	5/1967-4/1983	0.007	<0.001	0.87	Neg.
Hardness	21FLGW 3561	72	10/2011-12/2017	ns	<0.001	0.79	Neg.
pH	23969	76	5/2007-3/2019	ns	<0.001	0.66	Neg.
	21FLGW 3561	226	10/1998-12/2017	ns	<0.001	0.37	Neg.
	02296500	113	1/1965-9/1999	ns	<0.001	0.2	Neg.
Temperature	21FLGW 3561	225	10/1998-10/2017	<0.001	0.015	0.76	Neg.
	02296500	140	5/1967-9/1999	<0.001	0.042	0.71	Neg.

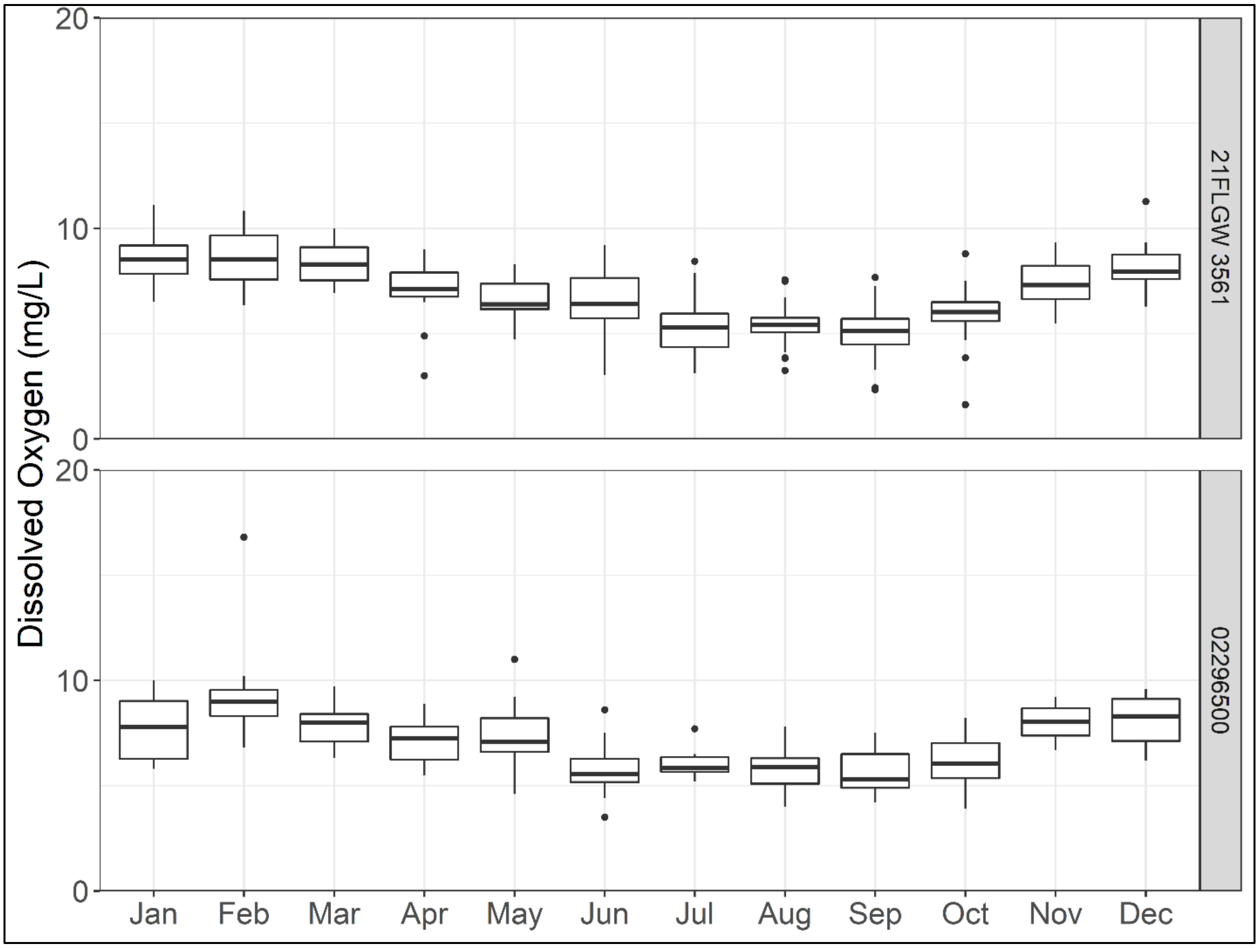

Figure 3-11: Monthly distribution of mean dissolved oxygen (mg/L) at DEP station 21FLGW 3561 from 1998-2017 and USGS station 02296500 from 1967 through 1999. Boxed values indicate the 25th to 75th percentiles with centerline reflecting the 50th percentile value. Dots represent outliers, indicative of values outside of the 1.5*interquartile range.

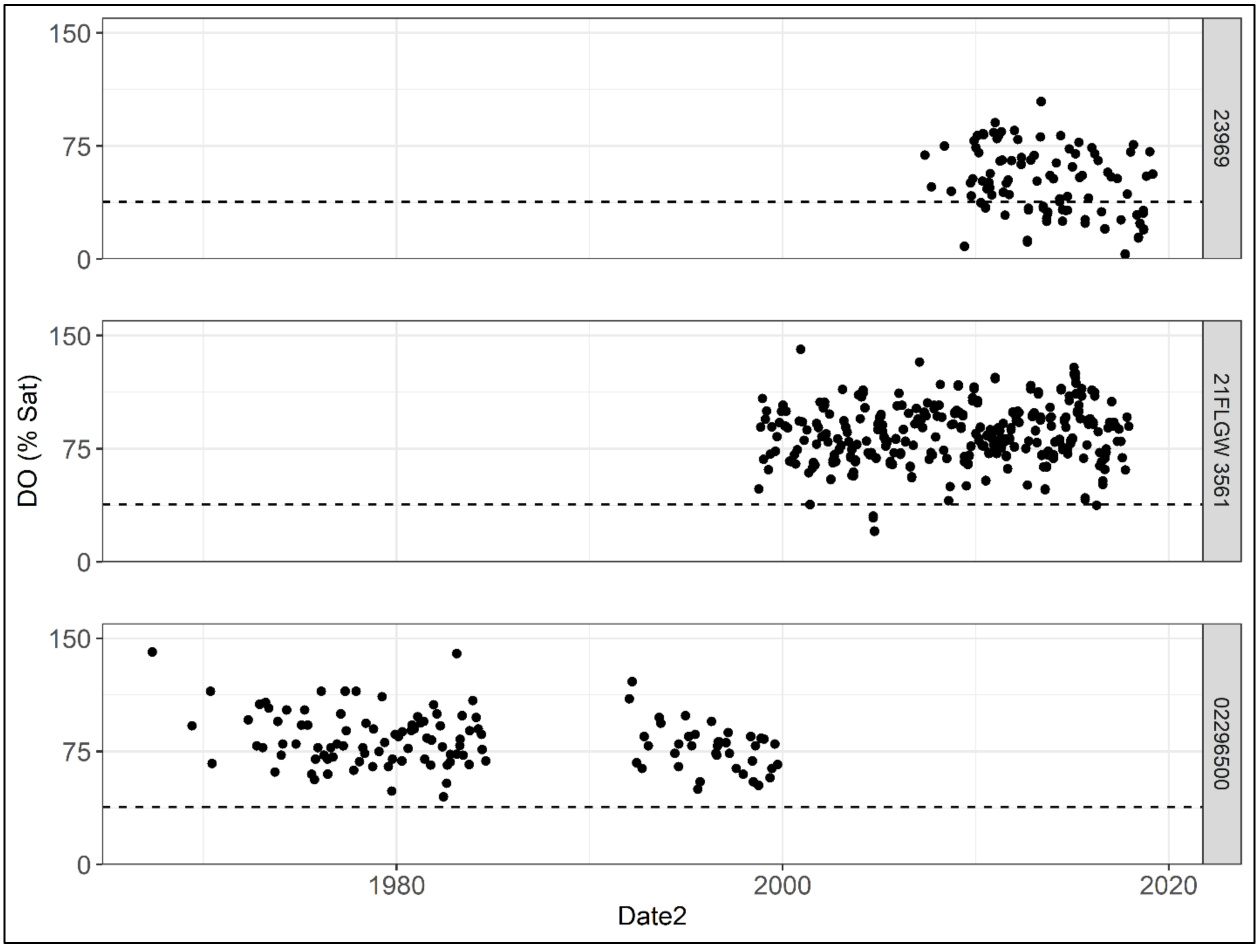

Figure 3-12: Sample distribution of dissolved oxygen (DO) percent saturation (% Sat) at District station 23969, DEP station 21FLGW 3561, and USGS station 02296500 over the available period of record. Stations are listed from upstream to downstream in the watershed. The State water quality threshold for DO (% Sat; 38%) is indicated by the dashed line.

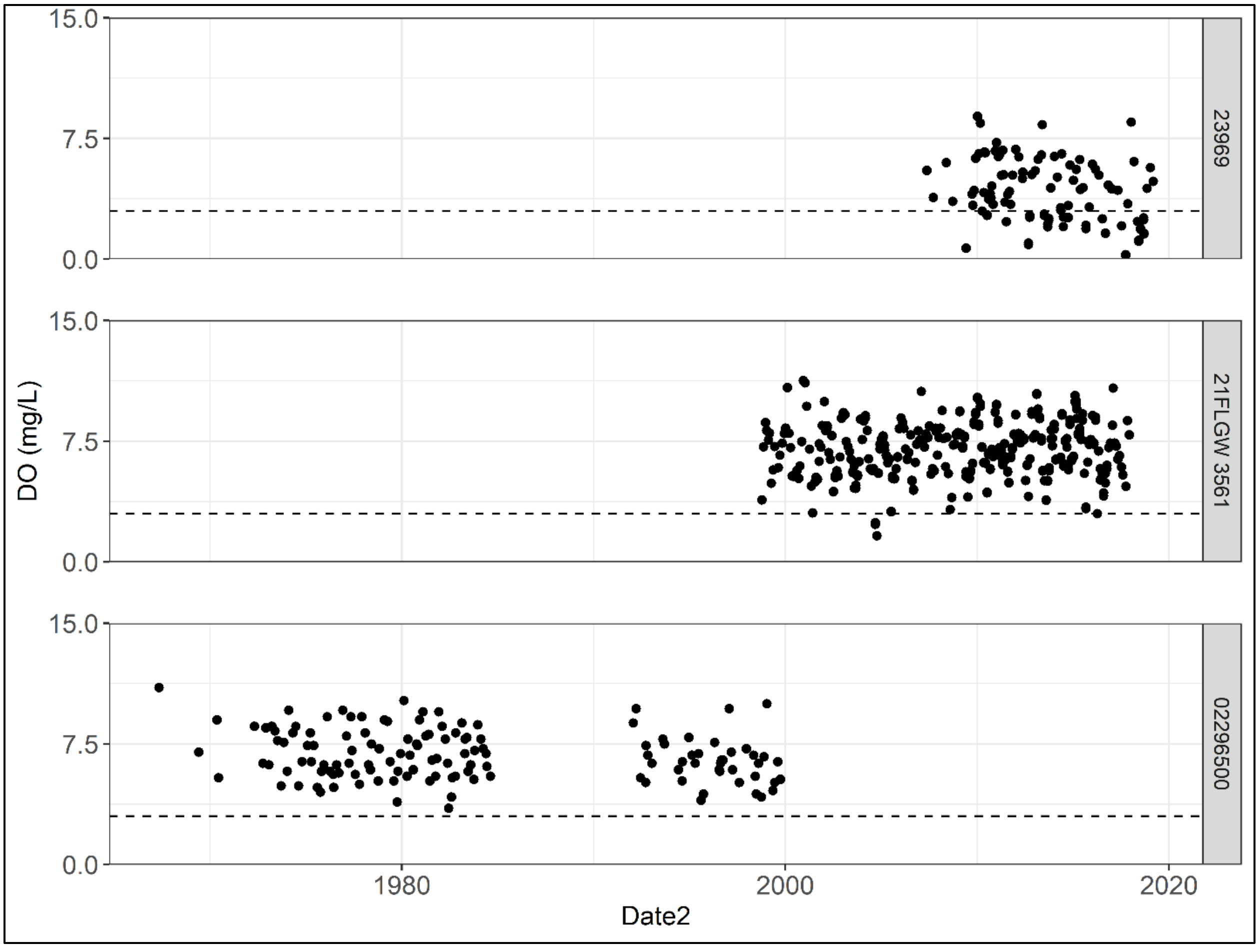

Figure 3-13. Sample distribution of dissolved oxygen (DO) concentration at District station 23969, DEP station 21FLGW 3561, and USGS station 02296500 over the available period of record. The dashed line indicates a generally accepted threshold for hypoxia in fresh waters (3 mg/L). Stations are listed from upstream to downstream in the watershed.

3.2.3.5. Minerals and Metals

The presence of minerals and metals in waterways is typically indicative of the geology of an area through which they or the groundwater flows. Charged particles like calcium, chloride, fluoride, iron, magnesium, and sulfate can affect the conductivity of water. Hardness is the concentration of dissolved minerals in water, particularly calcium and magnesium. Increased levels of these minerals could have negative implications for humans and environmental health.

No significant trends over time were observed for constituents in the minerals and metals group. Of the statistically significant linear regression relationships between constituents in this group and flow, all were negative and all with more than 100 observations had a significant seasonal relationship (Table 3-8), with lower values observed during the summer rainy season.

Table 3-8. Summary of statistically significant ($p < 0.05$) linear regression relationships between minerals and metals group constituents and flow with R^2 values greater than or equal to 0.20. The negative (Neg.) slope designation refers to the relationship between constituent and flow at the corresponding USGS gage (modified from ATM and JEI 2021a).

Constituent	Station	Samples (n)	Period of Record	Month p-value	Flow p-value	R^2	Slope
Dissolved Calcium	23969	74	10/2009-3/2019	ns	<0.001	0.7	Neg.
Total Calcium	21FLGW 3561	226	10/1998-12/2017	0.002	<0.001	0.77	Neg.
Chloride	21FLGW 3561	227	10/1998-12/2017	<0.001	<0.001	0.72	Neg.
Fluoride	23969	63	10/2009-1/2019	0.034	<0.001	0.7	Neg.
	21FLGW 3561	226	10/1998-12/2017	0.004	<0.001	0.85	Neg.
	0229650 0	30	10/1998-9/2005	ns	<0.001	0.54	Neg.
Dissolved Magnesium	23969	74	10/2009-3/2019	0.045	<0.001	0.73	Neg.
Dissolved Sulfate	23969	73	10/2009-11/2015	0.003	<0.001	0.61	Neg.
Total Sulfate	21FLGW 3561	221	10/1998-5/2017	<0.001	<0.001	0.69	Neg.
	0229650 0	30	10/1998-9/2005	ns	0.005	0.25	Neg.

3.2.3.6. Indicators of Water Clarity

Water clarity is a measure of light penetration in the water column, which impacts the diversity of aquatic life within a system. Water clarity can naturally be affected by the presence of tannins, resulting from the decomposition of organic materials, sediment loads, influxes of organic and inorganic matter and increased algae or plankton biomass.

Higher flows are generally related to increases in turbidity and decreases in water clarity, as water carries soil off into a system and increasing suspend materials. Total organic carbon (TOC) is included in this section as it can represent the contribution of both anthropogenic and natural sources of carbon into a river (ATM and Janicki 2021).

No significant trends over time were observed for water clarity constituents. When statistically significant ($p < 0.005$), color, total organic carbon, and turbidity had increasing relationships with flow (Table 3-9). This correlates with the seasonal flow patterns in southwest Florida, as tannins from surrounding wetlands and nutrients from agricultural runoff enter the system during periods of high flow (JEI 2019) and has been observed in other systems (ATM and JEI 2021b). All statistically significant linear regressions with greater than 100 observations had significant seasonal effects, with p-values less than 0.05 (Table 3-9). An example of the seasonal effect trends is provided with color data from DEP station 21FLGW 3561 (Figure 3-14).

Table 3-9. Summary of statistically significant ($p < 0.05$) linear regression relationships between water clarity constituents and flow with R^2 values greater than or equal to 0.20. The positive (Pos.) slope designation refers to the relationship between constituent and flow at the corresponding USGS gage (modified from ATM and JEI 2021a).

Constituent	Station	Samples (n)	Period of Record	Month p-value	Flow p-value	R^2	Slope
Color	23969	72	10/2009-3/2019	ns	<0.001	0.51	Pos.
	21FLGW 3561	226	10/1998-12/2017	<0.001	<0.001	0.71	Pos.
Total Organic Carbon	23969	73	10/2009-3/2019	ns	<0.001	0.29	Pos.
	21FLGW 3561	223	10/1998-12/2017	0.007	<0.001	0.65	Pos.
Turbidity	21FLGW 3561	226	10/1998-12/2017	0.02	<0.001	0.29	Pos.

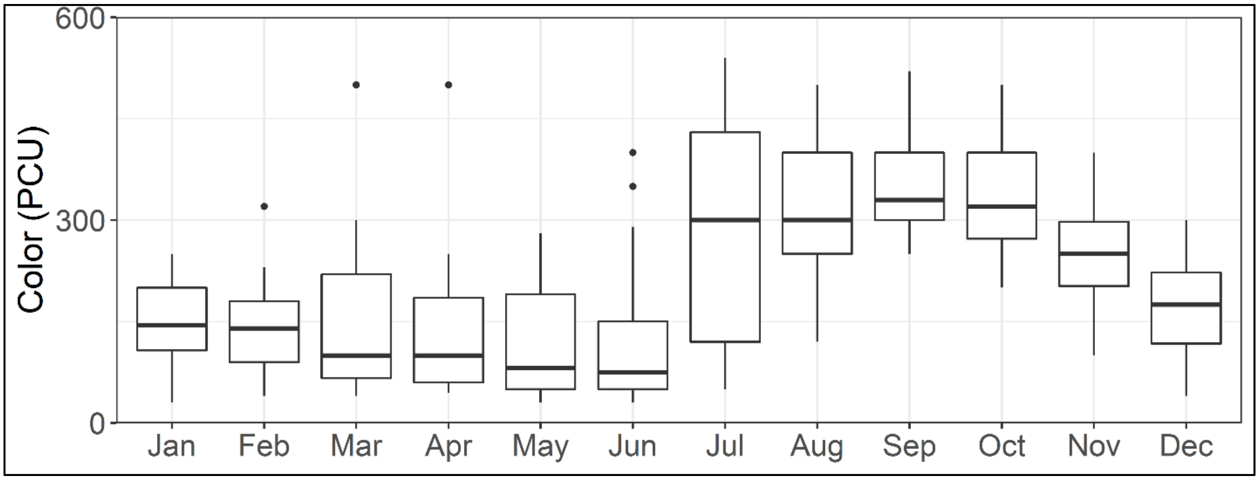

Figure 3-14: Monthly distribution of mean color at DEP station 21FLGW 3561 from 1998-2017. Boxed values indicate the 25th to 75th percentiles with centerline reflecting the 50th percentile value. Dots represent outliers, indicative of values outside of the 1.5*interquartile range.

3.3. Summary

Temporal trends in water quality parameters and their relationships with flow in Charlie Creek generally met the expectations for Florida streams and rivers under the influence of agricultural use. Time series trend tests suggested that most constituents were stable over the evaluated period of record, with few exceptions (ATM and JEI 2021a).

CHAPTER 4 – ECOLOGICAL RESOURCES

As the least disturbed sub-basin within the Peace River watershed, Charlie Creek provides important palustrine and riverine habitat for diverse wildlife and plant species. The description of existing flora and fauna and consideration of their habitat requirements is essential when establishing minimum flows. A primary objective of the analysis is to protect the natural flow regime for which aquatic life has adapted along the river corridor and floodplains. This chapter summarizes data collection efforts and studies performed by the Florida Fish and Wildlife Conservation Commission (FWC), DEP, University of Florida (UF), and consultants hired by the District, that best describe the ecological resources within the watershed. The focus is on taxa diversity and distribution within the river corridor and surrounding floodplain.

4.1 Macroinvertebrates

The DEP has conducted sporadic macroinvertebrate sampling within Charlie Creek during 32 events since 1993 using their Stream Habitat Assessment (HA) and Stream Condition Index (SCI) assessment methods (Figure 4-1). The HA method quantified the overall habitat quality by considering eight attributes known to impact stream biota, including: substrate diversity, substrate availability, water velocity, habitat smothering, artificial channelization, bank stability, riparian buffer zone width, and riparian zone vegetation quality. The values assigned for each parameter are then averaged and a rating is developed for the habitat on a scale from poor to optimal. The SCI captures the capacity for flowing freshwater systems to support a balanced community, by classifying and quantifying benthic macroinvertebrates and identifying impairment relative to what may be expected with minimally disturbed conditions. Dipnet sweeps are used to sample a 100-meter stretch of stream and collected macroinvertebrates are used to calculate ten biological metrics: total number of taxa, number of long-lived taxa, number of Mayfly (Ephemeroptera) taxa, number of Caddisfly (Trichoptera) taxa, number of sensitive taxa, number of clinger taxa, percent dominant taxon, percent Tanytarsini, percent very tolerant taxa, and percent filterer individuals. These metrics predominantly respond negatively to anthropogenic disturbance, though two are expected to increase with human influence (percent dominant taxon and percent very tolerant taxon). Scores for each metric are aggregated into an overall score of ecosystem health.

Data from 23 sampling events taken since the most recent SCI methodology update in 2012 suggests the upstream stations have “exceptional” biological health and the downstream site is “healthy.” The accompanying HA scores, however, suggest suboptimal to marginal habitat at all sampled sites, with lowest scores for bank stability, substrate availability and habitat smothering. Available taxa from the DEP describes individuals from 122 taxa in their exploration of four stations in Charlie Creek over nine sampling dates from 1993 to 2006 (Table 4-1).

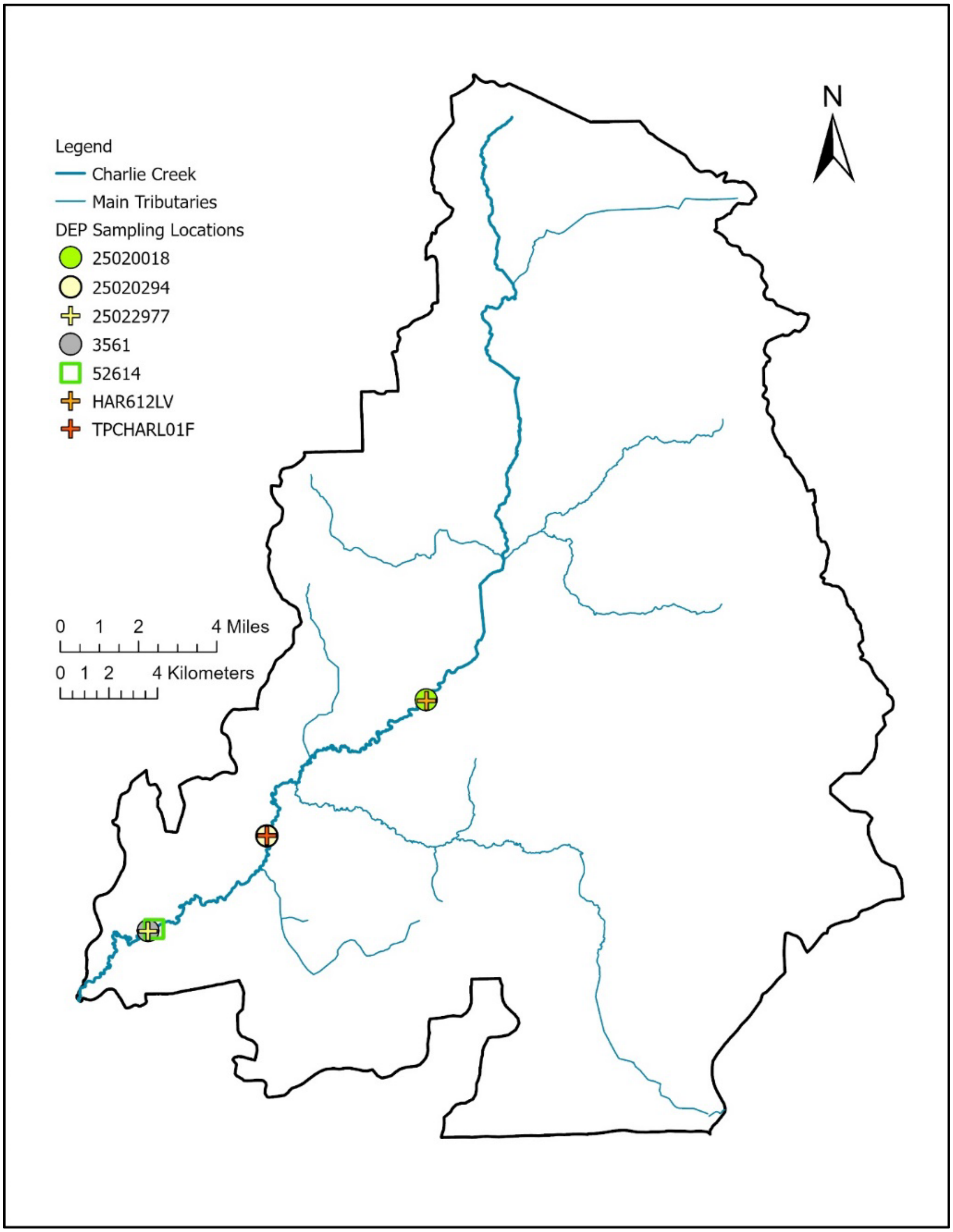

Figure 4-1. Benthic macroinvertebrate sampling locations by the DEP along Charlie Creek from 1993 to 2006.

Table 4-1. Macroinvertebrates that account for at least 1% of catch from available DEP data from 1993 to 2006.

Common Name	Taxa	Count (n)	Percent Composition (%)
Amphipod	*Hyalella azteca*	201	20.12
Non-biting Midge	*Polypedilum illinoense* grp.	88	8.81
Freshwater Snail	*Micromenetus dilatatus*	36	3.60
Mayfly	Baetidae	35	3.50
Mayfly	*Caenis diminuta*	27	2.70
Freshwater Clam	*Corbicula fluminea*	27	2.70
Non-biting Midge	*Tanytarsus* sp. *c epler*	27	2.70
Non-biting Midge	*Cladotanytarsus cf. daviesi*	22	2.20
Leech	*Helobdella stagnalis*	22	2.20
Mayfly	*Pseudocloeon*	22	2.20
Non-biting Midge	*Polypedilum scalaenum* grp.	19	1.90
Dero Worm	*Dero vaga*	18	1.80
Black Fly	*Simulium*	18	1.80
Serrate Crownsnail	*Pyrgophorus platyrachis*	15	1.50
Non-biting Midge	*Rheotanytarsus exiguus* grp.	15	1.50
Non-biting Midge	*Polypedilum beckae*	14	1.40
Net-spinning Caddisfly	*Cheumatopsyche*	13	1.30
Non-biting Midge	*Polypedilum flavum*	13	1.30
Non-biting Midge	*Ablabesmyia mallochi*	12	1.20
Midge	*Goeldichironomus*	12	1.20
Non-biting Midge	*Phaenopsectra*	12	1.20
Damselfly	*Enallagma*	11	1.10
Mud Snail	Hydrobiidae	11	1.10
Red Worm	*Limnodrilus hoffmeisteri*	11	1.10
Non-biting Midge	*Polypedilum convictum* grp.	11	1.10
Mayfly	*Tricorythodes albilineatus*	11	1.10
Mayfly	*Caenis amica*	10	1.00

4.2. Fish

The FWC has conducted two sampling events within Chalie Creek. The first consisted of 100-m electrofishing transects over three events: April 2008 (n = 7 transects), August 2009 (n = 9), and March 2010 (n = 13; Call et al., 2011). Transects were randomly selected during each event to include all available habitat, such as: woody debris, root wads, bare shorelines, pools, runs, and shoals. Sampling took place from the confluence of Charlie Creek with the Peace River to approximately 1.44 miles (2.32 kilometers) upstream (Figure 4-2). A total of 627 fish were caught in Charlie Creek, representing 25 species common to streams in Southwest Florida. The most frequently encountered fish in this study were Shiners (*Notropis sp.*, 27.43% of catch), Spotted Sunfish (*Lepomis punctatus*, 21.53%), and Brook Silversides (*Labidesthes sicculus,* 10.53%; Table 4-2). The largest contributors to total biomass were Florida Gar (*Lepisosteus platyrhincus*, 28.63%), Common Snook (*Centropomus undecimalis*, 19.85%) and Largemouth Bass (*Micropterus salmoides*, 19.30%; Table 4-2).

The lower portion of Charlie Creek was also fished by the FWC during five electrofishing sampling events from Summer 2010 through Fall 2011, as part of an effort to understand four tributaries to the Peace River (Schworm et al. 2013). Sampling occurred in in summer 2010 (n = 25 transects), winter 2011 (n = 20), spring 2011 (n = 26), summer 2011 (n = 100), and fall 2011 (n = 27). The most abundant fish from these data were: Eastern Mosquitofish (*Gambusia holbrooki*, 22.28% of total catch), Coastal Shiner (*Notropis petersoni*, 19.22%), and Spotted Sunfish (14.80%; Table 4-3). The largest contributors to total biomass were Florida Gar (21.032%), Largemouth Bass (17.65%), and Blue Tilapia (14.94%; Table 4-3).

Schworm et al. (2013) concluded that Charlie Creek and Horse Creek contained similar fish assemblages, with distinction form the assemblages observed in Prairie Creek and Shell Creek. Other salient findings for Charlie Creek include the high densities of species that prefer shallow areas with elevated current velocities (identified by principal component analysis) and those that are known to thrive under a variety of stream flow conditions, important for a system with variable hydrology. As an example of the latter, Coastal Shiner (*Notropis petersoni*), which experience ontogenetic shifts in depth and velocity requirements, were common in the creek. Spotted Sunfish were more common in the system than in Prairie and Shell Creeks (contributing 12% to dissimilarity by similarity percentages (SIMPER) analysis), which was attributed to their preference for the complex woody habitat available in Charlie Creek (Schworm et al., 2013). Eastern Mosquitofish were thought to be abundant in Charlie Creek due to their ability to thrive in inundated floodplains and their preference for complex habitats dominated by woody debris (Schworm et al., 2013).

Historical collections were made in Charlie Creek in 1890, 1952, 1964, 1972, 1986, and 1973 (Fraser et al., 2007). Species that occurred in more than one of these collections which were not found by the FWC in more recent studies include: Golden Topminnow (*Fundulus chrysotus*), Redface Topminnow (*Fundulus rubifrons*), Florida Flagfish (*Jordanella floridae*), Golden Shiner (*Notemigonus crysoleuca*), and Black Crappie (*Pomoxis nigromaculatus*).

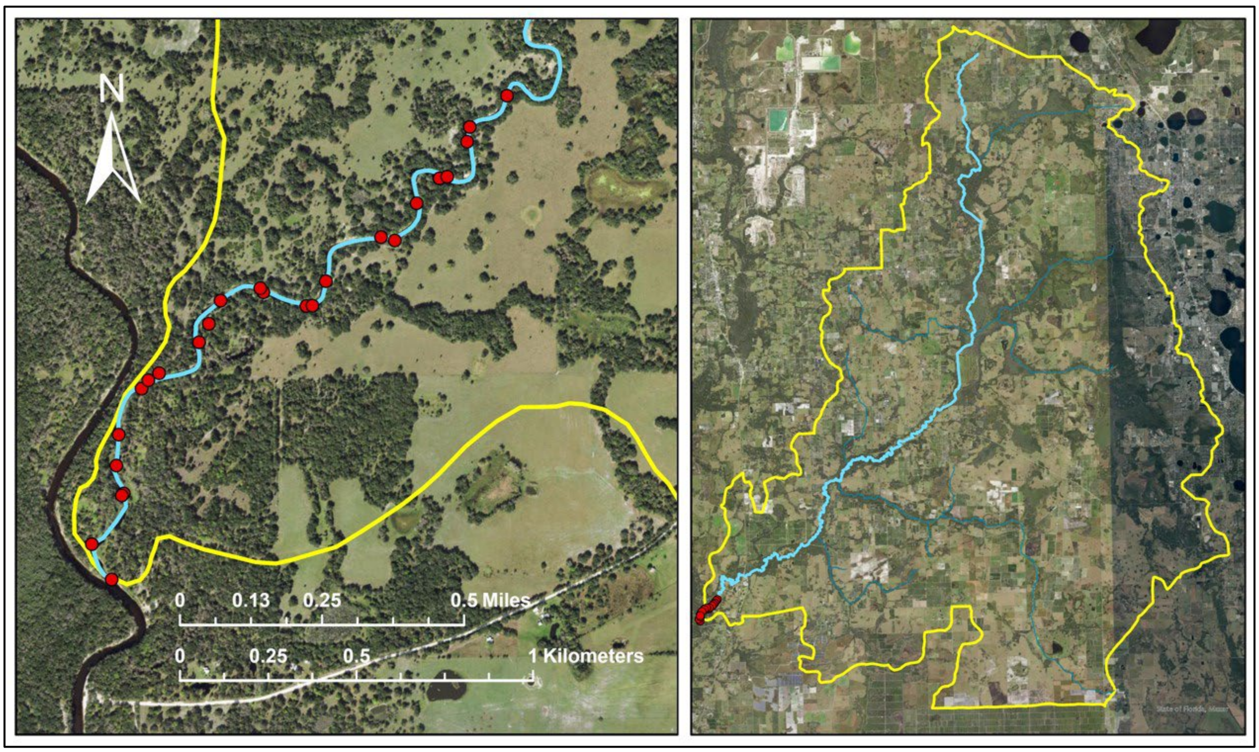

Figure 4-2. Electrofishing sample locations by the FWC (Call et al. 2011; left) with their location relative to the entire Charlie Creek system and watershed (yellow outline; right).

Table 4-2. Summary of species collected by the FWC (Call et al., 2011) in Charlie Creek from 2008 to 2010.

Common Name	Scientific Name	Total Count		Total Biomass	
		Count (n)	Percent Composition (%)	Weight (g)	Percent Composition (%)
African Jewelfish	*Hemichromis bimaculatus*	1	0.16	14	0.02
American Eel	*Anguilla rostrata*	1	0.16	361	0.57
Atlantic Needlefish	*Strongylura marina*	3	0.48	156	0.25
Blue Tilapia	*Oreochromis aureus*	7	1.12	5424	8.53
Bluefin Killifish	*Lucania goodei*	2	0.32	2	0.00
Bluegill	*Lepomis macrochirus*	16	2.55	888	1.40
Bowfin	*Amia calva*	1	0.16	2667	4.19
Brook Silverside	*Lapdesthes sicculus*	66	10.53	74	0.12
Brown Bullhead	*Ameiurus nebulosus*	1	0.16	94	0.15
Brown Hoplo	*Hoplosternum littorale*	1	0.16	197	0.31
Channel Catfish	*Ictalurus punctatus*	4	0.64	4312	6.78
Common Snook	*Centropomus undecimalis*	7	1.12	12625	19.85
Eastern Mosquitofish	*Gambusia holbrooki*	35	5.58	4	0.01
Florida Gar	*Lepisosteus platyrhincus*	37	5.90	18213	28.63
Hogchoker	*Trinectes maculatus*	5	0.80	10	0.02
Inland Silverside	*Menidia berylina*	2	0.32	2	0.00
Largemouth Bass	*Micropterus salmoides*	62	9.89	12275	19.30
Longnose Gar	*Lepisosteus osseus*	2	0.32	263	0.41

Common Name	Scientific Name	Total Count		Total Biomass	
		Count (n)	Percent Composition (%)	Weight (g)	Percent Composition (%)
Shiners	*Notropis sp.*	172	27.43	142	0.22
Armored Catfish	*Pterygoplichthyes sp.*	4	0.64	816	1.28
Redear Sunfish	*Lepomis microlophus*	23	3.67	842	1.32
Seminole Killifish	*Fundulus seminolis*	38	6.06	220	0.35
Spotted Sunfish	*Lepomis punctatus*	135	21.53	3013	4.74
White Catfish	*Ameirus catus*	1	0.16	772	1.21
Yellow Bullhead	*Ameirus natalis*	1	0.16	223	0.35

Table 4-3. Summary of species collected by the FWC (Schworm et al. 2013) from 2010 to 2011.

Common Name	Scientific Name	Total Count		Total Biomass	
		Count (n)	Percent Composition (%)	Weight (g)	Percent Composition (%)
African Jewelfish	*Hemichromis bimaculatus*	23	0.87	53	0.06
Armored Catfish	*Pterygoplichthys sp.*	1	0.04	610	0.69
Blue Tilapia	*Oreochromis aureus*	69	2.61	13280	14.94
Bluefin Killifish	*Lucania goodei*	31	1.17	9	0.01
Bluegill	*Lepomis macrochirus*	171	6.46	2878	3.24
Brook Silverside	*Labidesthes sicculus*	162	6.12	112	0.13
Brown Bullhead	*Ameiurus nebulosus*	1	0.04	26	0.03
Brown Hoplo	*Hoplosternum littorale*	3	0.11	642	0.72
Channel Catfish	*Ictalurus punctatus*	13	0.49	8281	9.32
Chinese Weather Loach	*Misgurnus anguillicaudatus*	2	0.08	2	0.00
Coastal Shiner	*Notropis petersoni*	509	19.22	456	0.51
Common Snook	*Centropomus undecimalis*	11	0.42	12569	14.14
Eastern Mosquitofish	*Gambusia holbrooki*	590	22.28	109	0.12
Flagfish	*Jordanella floridae*	19	0.72	7	0.01
Florida Gar	*Lepisosteus platyrhincus*	33	1.25	18695	21.03
Hogchoker	*Trinects maculatus*	32	1.21	44	0.05

Common Name	Scientific Name	Total Count		Total Biomass	
		Count (n)	Percent Composition (%)	Weight (g)	Percent Composition (%)
Ironcolor Shiner	*Notropis chalybaeus*	13	0.49	5	0.01
Lake Chubsucker	*Erimyzon sucetta*	10	0.38	54	0.06
Largemouth Bass	*Micropterus salmoides*	99	3.74	15686	17.65
Least Killifish	*Heterandria formosa*	13	0.49	0	0.00
Longnose Gar	*Lepisosteus osseus*	2	0.08	97	0.11
Pirate Perch	*Aphredoderus sayanus*	6	0.23	11	0.01
Pugnose Minnow	*Opsopoeodus emiliaea*	31	1.17	112	0.13
Redear Sunfish	*Lepomis microlophus*	72	2.72	3708	4.17
Sailfin Molly	*Poecilia latipinna*	34	1.28	225	0.25
Seminole Killifish	*Fundulus seminolis*	185	6.99	383	0.43
Shiners	*Notropis sp.*	4	0.15	0	0.00
Spotted Sunfish	*Lepomis punctatus*	392	14.80	6538	7.36
Striped Mullet	*Mugil cephalus*	10	0.38	2785	3.13
Sunfish	*Lepomis sp.*	10	0.38	2	0.00
Swamp Darter	*Etheostoma fusiforme*	1	0.04	0	0.00
Tadpole Madtom	*Noturus gyrinus*	6	0.23	5	0.01
Taillight Shiner	*Notropis maculatus*	26	0.98	4	0.00
Warmouth	*Lepomis gulosus*	57	2.15	334	0.38
White Catfish	*Ameiurus catus*	7	0.26	1161	1.31

4.3. Avian Wildlife

The Peninsular Florida Landscape Conservation Cooperative identified approximately 37.82% of the Horse Creek watershed as potential Florida Sandhill Crane (*Antigone canadensis pratensis*) habitat (PFLC 2021; Figure 4-3). Florida Sandhill Cranes are a non-migratory species designated as threatened by the state, with a current population estimate of 4,000 to 5,000 birds (FWC 2020). Their preferred locales include freshwater marshes and wetlands for nesting, particularly those with pastures, prairies, or other grasslands nearby (Downs et al., 2020). Approximately 25,000 migratory Greater Sandhill Cranes (*Antigone canadensis tabida*) travel through Florida each year, which also rely upon well-connected and shallowly inundated riparian and palustrine habitats for foraging and roosting (FWC 2020, Donnelly et al., 2021). According to 2017 National Wetland Inventory (NWI) data, compiled by the District in 2019, the Charlie Creek watershed contains 77.50 square miles (200.73 square kilometers) of palustrine habitat, much of which occurs around Charlie Creek and its tributaries. A map of NWI data is included in Figure 4-6, accompanying a description of vegetation sampling.

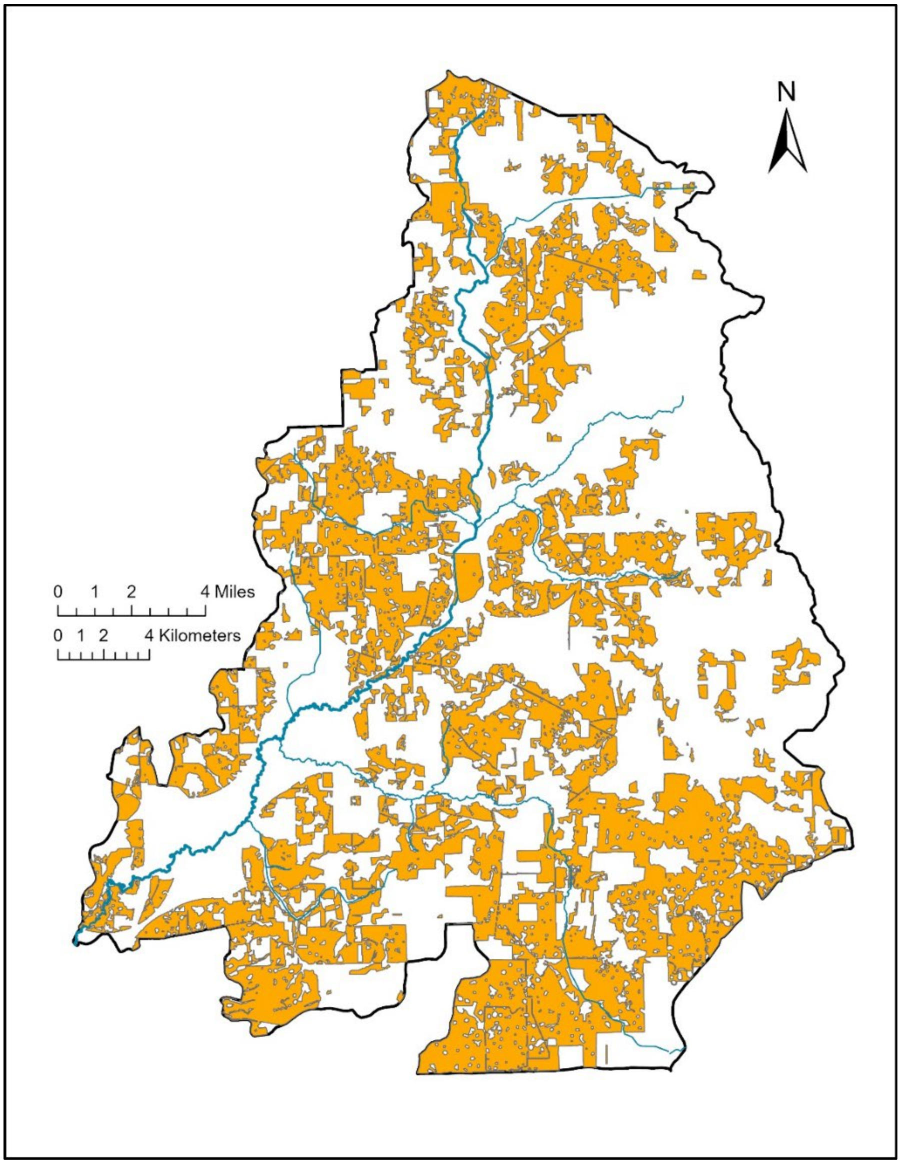

Figure 4-4. Golden areas reflect the potential distribution of Florida Sandhill Cranes throughout the Charlie Creek watershed (source: Peninsular Florida Landscape Conservation Cooperative (2021) Sandhill Crane Habitat GIS layer).

4.4. Watershed and Floodplain Vegetation

Approximately 35.9% of the Charlie Creek watershed is classified as vegetated, according to 2020 land use and cover data from SWFWMD and 2017-2019 data from SFWMD. Vegetation classes identified by FLUCCS level four codes and covering at least 1 square kilometer (0.38 square miles) are shown in Figure 4-5 and detailed in Table 4-4. Dominant vegetative lands include swamps (13.25%), freshwater marshes (5.91%), pine flatwoods (4.83%), and shrubs or brush (4.07%; Table 4-4).

HSW Engineering, Inc. conducted a study of the Charlie Creek riparian corridor in 2012 (Appendix C), to better describe the composition and distribution of plant communities and hydrologic indicators across seven floodplain transects (Figure 4-6). Elevated lichen lines and water stains were the predominant hydrologic indicator in Charlie Creek, representing the approximate high-water elevation. Along the sampled transect, all hydrologic indicators occurred 10.14 to 13.64 feet above channel bottom and their vegetative communities were classified as either floodplain swamp or bottomland forest, according to the FNAI ecological community classification system (HSW 2012).

Vegetation sampling of trees, shrubs, and ground cover along floodplain transects was performed using a modified point-centered quarter methodology. Within quadrats, the data recorded included species presence, distance to the nearest tree or shrub, the diameter of the nearest tree at breast height, and the dominant types of shrub vegetation and ground cover. The basal area and frequency of trees were then used to calculate the relative importance value of trees (HSW 2012).

Four wetland communities were identified along sampled transects: floodplain swamp, bottomland forest, hydric hammock, and a drier upland hammock community. Within these areas, fifteen tree species were identified and assigned importance values (Table 4-5).

The floodplain swamp communities were located close to the river channel or within nearby deep depressions and contained nine tree species. Species with the highest importance values (IV) included Pop Ash (*Fraxinus caroliniania*, IV = 121.81), Bald Cypress (*Taxodium distichum*, IV = 75.89), and Cabbage Palm (*Sabal palmetto,* IV = 60.43), which are all either obligate or facultative wetland indicators (HSW 2012).

Eleven tree species were described in the bottomland forest community of sampled transects along Charlie Creek. Species with the highest IV included: Cabbage Palm (IV = 132.76), Laurel Oak (*Quercus lariflora*, IV = 114.14), and Live Oak (*Quercus virginiana*, IV = 61.89). Trees within this community had obligatory to facultative upland plus wetand indicator status, where “plus” indicates greater frequency towards the wetter end of the category (HSW 2012).

The hydric community was composed of six tree species and was described as a well-developed hardwood and cabbage palm forests with an understory of palms and ferns. The Cabbage Palm (IV = 121.83) and Live Oak (IV = 93.28) had the highest importance values within this community, whose wetland indicator statuses are facultative and facultative upland plus, respectively (HSW 2012).

Six tree species occurred in the upland hammock community, with facultative wetland to facultative upland wetland indicator statuses. The dominant species included Laurel Oak (IV = 85.40), Sweetgum (*Liquidambar styraciflua*, IV= 58.32), and Cabbage Palm (IV = 43.86, HSW 2012).

Table 4-4. Summary of vegetation within the Charlie Creek watershed using Level 4 Florida Land Use and Cover Classification System (FLUCCS) codes from GIS layers maintained by the water management districts (SWFWMD (2021d) and SFWMD (2019)).

FLUCCS Level 4 Description	Area (mi^2)	Area (Acres)	Percent of Watershed (%)
Swamps - Stream and lake bottomland	44.26	28323.37	13.25
Freshwater marshes	19.73	12630.11	5.91
Pine flatwoods	16.11	10312.32	4.83
Shrubs and brushland	13.58	8692.94	4.07
Wet prairies	9.48	6066.36	2.84
Upland hardwood - coniferous mix	7.60	4861.06	2.27
Cypress	5.53	3536.38	1.65
Vegetated non-forested wetlands	2.30	1472.00	0.69
Upland hardwood forests	0.42	267.49	0.13
Wetland forested mix	0.40	254.15	0.12

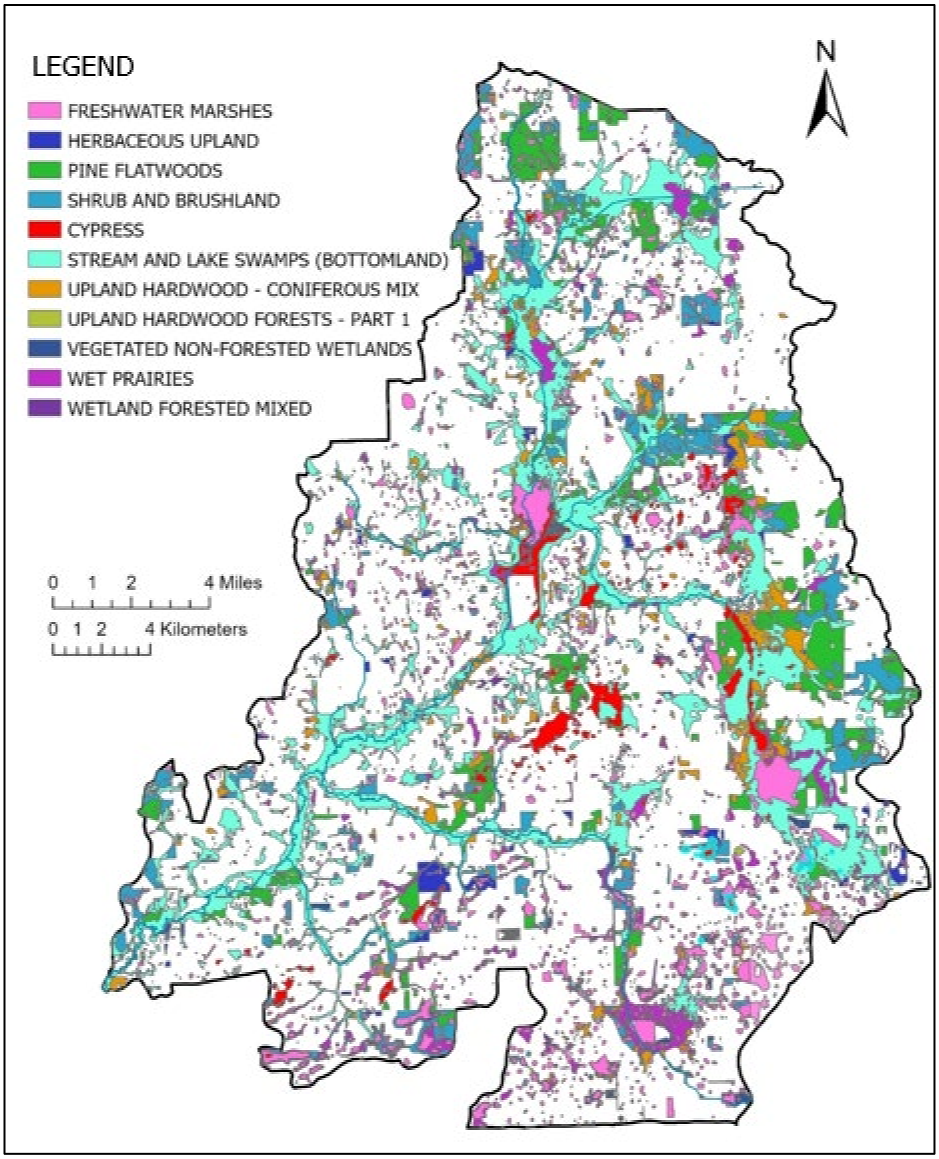

Figure 4-5. Vegetation groups within the Charlie Creek watershed according to recent Level 4 Florida Land Use and Cover Classification Systems (FLUCCS) designations (source: GIS layer files maintained by SWFWMD (2021d) and SFWMD (2019)).

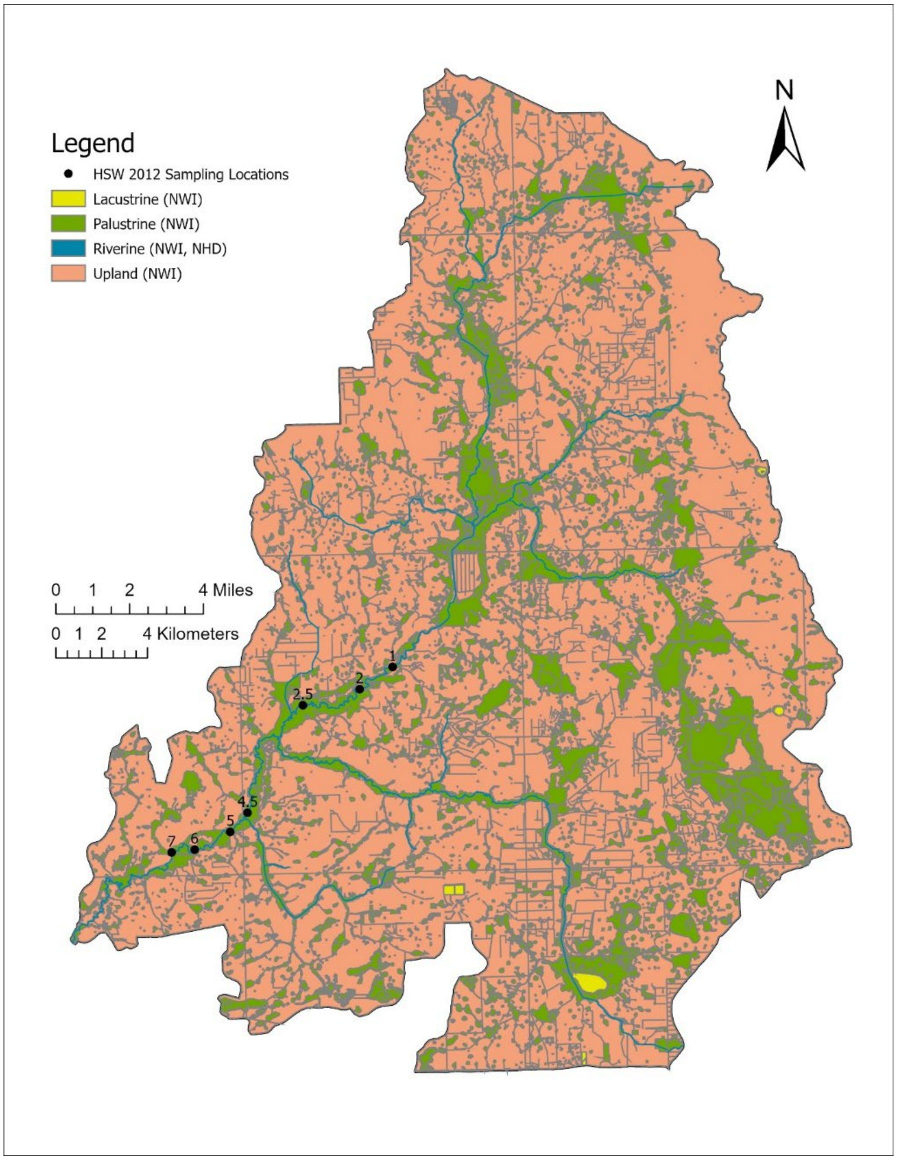

Figure 4-6. Floodplain transect locations sampled by HSW Engineering, Inc. along Charlie Creek in 2012, in relation to National Wetland Inventory (NWI) and National Hydrography Dataset (NHD) habitat designations (source: GIS layer files maintained by SWFWMD (2019a, 2019b)).

Table 4-5. Tree species with their importance values within each vegetative community: floodplain swamp (FS), bottomland forest (BF), hydric hammock (HH), and upland hammock (UH). Cells labeled "NA" indicate species were not present within the community (adapted from HSW 2012).

Common Name	Scientific Name	Importance Value			
		FS	BF	HH	UH
Bald Cypress	*Taxodium distichum*	75.89	11.76	NA	NA
Bay	*Persea* sp.	NA	NA	NA	7.34
Buttonbush	*Cephalanthus occidentalis*	4.67	NA	NA	NA
Cabbage Palm	*Sabal palmetto*	60.43	132.76	121.83	43.86
Carolina Willow	*Salix caroliniana*	NA	7.23	NA	NA
Laurel Oak	*Quercus lauriflolia*	12.24	114.14	47.59	85.40
Live Oak	*Quercus virginiana*	10.17	61.89	93.28	34.85
Pignut Hickory	*Carya glabra*	NA	3.51	NA	NA
Pop Ash	*Fraxinus caroliniana*	121.81	31.38	NA	NA
Possumhaw	*Viburnum nudum*	4.58	3.47	11.24	15.68
Red Maple	*Acer rubrum*	NA	3.68	NA	NA
Sweetgum	*Liquidambar styraciflua*	4.72	20.56	17.50	58.32
Water Locust	*Gleditsia aquatica*	5.5	NA	NA	NA
Wild Orange	*Citrus x aurantium*	NA	NA	8.56	NA
Viburnum	*Viburnum nudum*	NA	5.07	NA	NA

4.5. Ecological Integrity of Lands

The Florida Ecological Greenways Network (FEGN) is a database maintained by the UF Center for Landscape Conservation Planning that identifies and ranks connected public and private lands in terms of ecological benefit on a scale from 1 (highest priority) to 5 (lowest priority). It is intended to inform land acquisition programs about the most important ecological corridors within a given region, to best preserve wildlife and ecosystem services and promote resiliency. Lands currently protected by the state were shown in Figure 2-7. As of the 2021 update, 76% of the Charlie Creek watershed was prioritized as part of the Florida Ecological Greenways Network (FEGN; Figure 4-7). Approximately 29% of the watershed was designated with the highest priority as it provides critical linkages or ecological hubs for wildlife. In 2021, the Florida Legislature classified lands within FEGN priority levels 1, 2, and 3 as part of the Florida Wildlife

Corridor. Approximately 75.38% of the Charlie Creek watershed can be considered part of this corridor.

The UF Center for Landscape Conservation Planning also developed a Critical Lands and Waters Identification Project (CLIP; Oeeting et al. 2016). This effort compiled natural resource data from the Florida Natural Areas Inventory (FNAI), the University of Florida GeoPlan center, and the FWC and worked with a variety of advisors to develop models to better prioritize areas for conservation. One of the resource categories considered is Biodiversity, which combines the following data layers: strategic habitat conservation areas (FWC), potential habitat richness (FWC), rare species habitat conservation priorities (FNAI), and priority natural communities (FNAI).

The most recent CLIP analysis (version 4.0, 2016) indicates that roughly half of the Charlie Creek watershed is of low priority in terms of biodiversity resources, with a score of either 4 (40.47% of area) or 5 (6.02% of area; Figure 4-8). High priority lands account for 29.86% of the watershed (2.49% Priority 1 and 27.37% Priority 2). Much of the high priority lands occur in the southeastern portion of the watershed and contain the lower portion of Charlie Creek and its southern tributaries.

The CLIP also produces a landscape integrity index, based on data from the UF Geoplan Center and Center for Landscape Conservation Planning. Within this index, areas with large expanses of remote, intact, predominantly natural lands are considered to have high ecological integrity. Lower values are reserved for fragmented landscapes with intensive land uses including agriculture and urban development. Using data from 2010-2015, approximately 26.54% of the Charlie Creek watershed is considered to have high ecological integrity and approximately 42.33% of the watershed has moderate ecological integrity (Figure 4-9). Much of Charlie Creek and its tributaries are in areas of high to moderate integrity. Approximately 31.13% of the watershed was classified as having little to no ecological integrity, likely due to heavy agricultural use or habitat fragmentation (Figure 4-9).

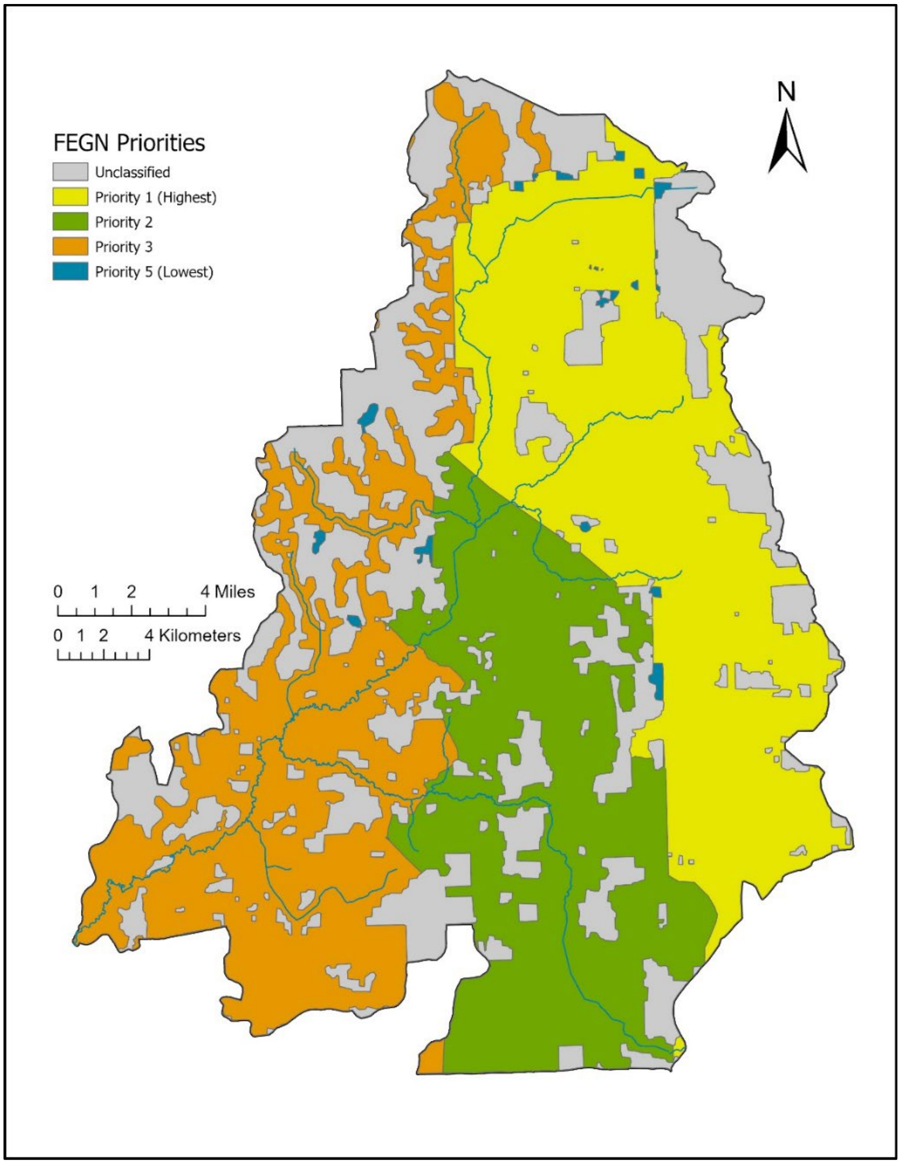

Figure 4-7. Florida Ecological Greenways Network (FEGN) 2021 priorities within the Charlie Creek watershed (source: GIS layer maintained by the University of Florida Center for Landscape Conservation Planning (2021)).

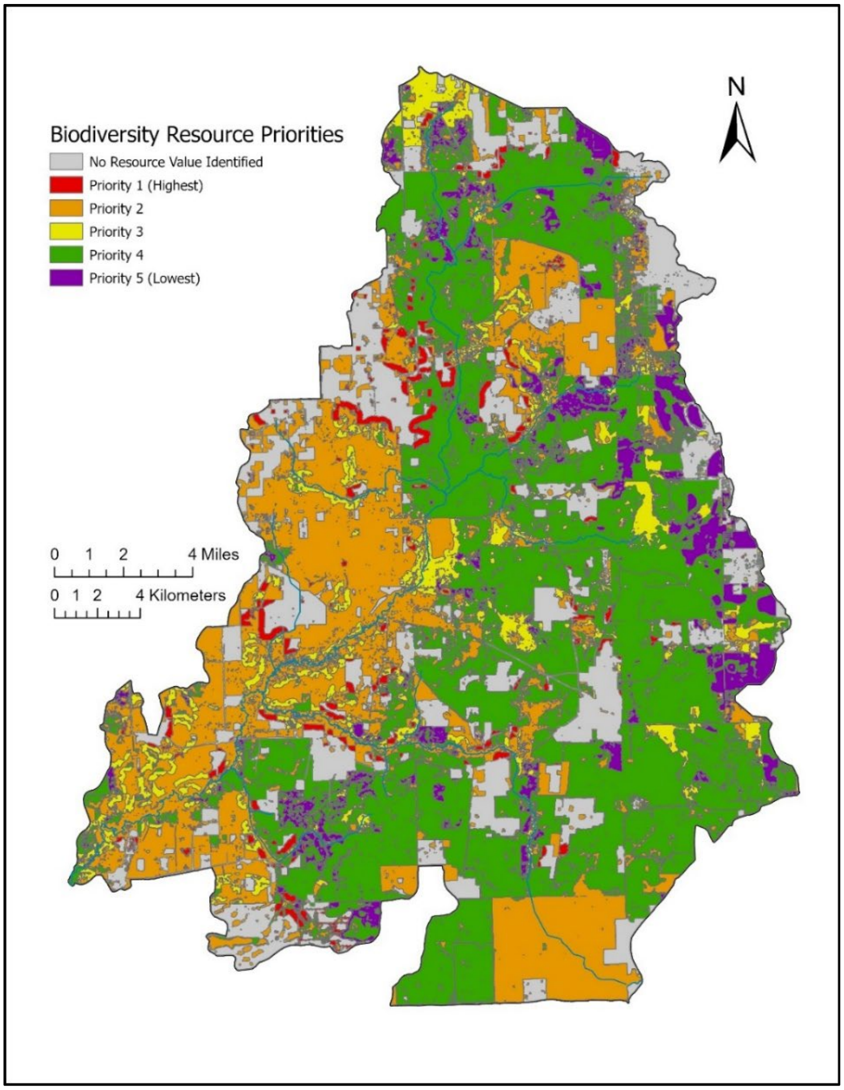

Figure 4-8. Biodiversity resource priority areas within the Charlie Creek Watershed, as designated by the Critical Lands and Waters Identification Project, version 4.0 (source: GIS layer maintained by the University of Florida Center for Landscape Conservation Planning (2016a)).

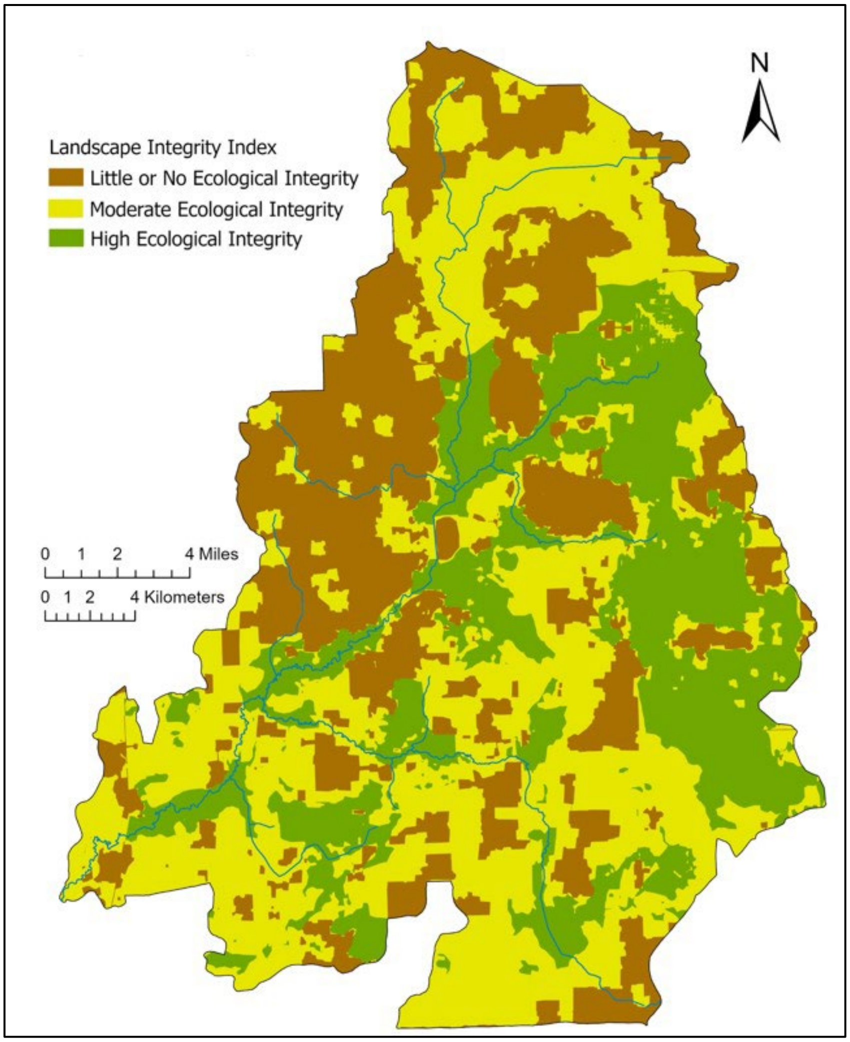

Figure 4-9. Landscape integrity values within the Charlie Creek Watershed, as designated by the Critical Lands and Waters Identification Project, version 4.0 (source: GIS layer maintained by the University of Florida Center for Landscape Conservation Planning (2016b)).

CHAPTER 5 – TECHNICAL APPROACHES FOR ESTABLISHING MINIMUM FLOWS

This chapter describes the methods used to determine minimum flow requirements for Charlie Creek. A variety of hydrologic and ecological analyses and modeling approaches were used to develop baseline flows and flow-based blocks, identify low flow threshold, and develop allowable flow reductions for low (Block 1), medium (Block 2), and high (Block 3) flow ranges. The low flow threshold is used to identify a minimum flow condition and is expected to be applicable to flows throughout the year. The allowable flow reductions are based on limiting potential changes in aquatic and wetland habitat availability that may be associated with changes in river flow during each flow-based block.

5.1. Baseline Flow Development

Assessment of anthropogenic impacts on Charlie Creek flow records, in particular those associated with water use, was considered essential for the determination of minimum flows. To assist in this effort and other water management activities, the District developed and subsequently updated the Peace River Integrated Model (PRIM2) to investigate the effects of climate variability, groundwater pumping, land use changes, and other factors on flows in the Peace River and its tributaries. Detailed information on model components, required inputs, calibration and validation results, and results of simulated scenarios are documented in HydroGeoLogic, Inc. (2023).

The PRIM2 was used with measured groundwater withdrawals to simulate flows for a 15-year period, from 2003 through 2018. The daily flows produced by PRIM2 agreed reasonably well with the observed streamflow in the Peace River and some tributaries. Correlations were strong for streamflow measured at the USGS Horse Creek at SR72 near Arcadia, FL (No. 02297310) gage (R^2 = 0.82), the USGS Peace River at SR70 at Arcadia, FL (No. 02296750) gage (R^2 = 0.77), the USGS Peace River at US 17 at Zolfo Springs, FL (No. 02295637) gage (R^2 = 0.82), the USGS Peace River at Fort Meade, FL (No. 02294898) gage (R^2 = 0.80), the USGS Peace River at SR60 at Bartow, FL (No. 02294650) gage (R^2 = 0.76) and the USGS Peace Creek Drainage Canal near Wahneta, FL (No. 02293987) gage (R^2 = 0.72). Correlation results for streamflow at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage (R^2 = 0.57) and the USGS Joshua Creek at Nocatee, FL (No. 02297100) gage (R^2 = 0.52) were slightly less than the goal of 0.6 or greater. Groundwater head calibration statistics indicated that predicted water levels at individual wells in the SA, HAS, and UFA met the calibration target. Coefficients of determination (R^2) values for 24 wells (57%) in the SA, 21 wells (75%) in the HAS, and 34 wells (94%) in the UFA were greater than or equal to 0.6. The accurate simulations of seasonal and pumping-induced head changes in the HAS and UFA indicated the model performed reasonably well in quantifying impacts of groundwater pumping on streamflow in the Peace River and its tributaries.

After calibration with measured flows that presumably integrate withdrawal-related effects, PRIM2 was run for 25% and 50% reductions in groundwater pumping to assess the effects of reducing pumping on streamflow in the Peace River and its tributaries. Results from the PRIM2 simulations indicated a strong linear response for the 25% and 50% reductions in groundwater pumping scenarios. Impacts for zero groundwater withdrawals were therefore simply estimated by doubling the impacts estimated under the 50% pumping reduction scenario.

Given that PRIM2 was designed to simulate long-term groundwater pumping or rainfall impacts on regional hydrology, daily flows generated using PRIM2 were not used. Rather, the simulation results were aggregated into monthly average values to establish a reasonable cause-and-effect relationship between baseline and impacted flows.

The specific steps undertaken to develop Charlie Creek's daily baseline flows were as follows:

(1) The daily simulated flows for both the actual and 50% pumping reduction scenarios were each averaged into monthly flows and differences in flows between the two scenarios were calculated for each month.
(2) The monthly average percentage differences in flows calculated in step 1 were multiplied by two to estimate the effects of no, i.e., zero, groundwater -pumping on flows.
(3) The daily gaged flows measured at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage for the period from May 1, 1950, through December 31, 2021, were corrected for the effects of groundwater withdrawals calculated for each month in step 2. Because the effects of groundwater withdrawals were found to increase flows in the creek, the corrections involved subtracting excess groundwater flow from the gaged flow to yield the baseline flow record.

Changes expected in the absence of groundwater withdrawals for monthly flows in Charlie Creek at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage are presented in Table 5-1. The effects of reduced groundwater withdrawals were positive, with 1.4 to 8.7 cfs decreases in flows associated with the 50% groundwater withdrawal reductions. This result is due primarily to reduction of groundwater runoff associated with agriculture.

Median daily baseline and gaged flows for the period May 1, 1950, through December 31, 2021, for the USGS Charlie Creek near Gardner, FL (No. 02296500) gage are shown in Figure 5-1. The contribution from excess irrigation flow ranged from 3 cfs in May and November to 17 cfs in August (see Table 5-1).

There are uncertainties associated with inputs and simplified assumptions and approximations of complex hydrologic interactions in the PRIM2 model that may induce errors in the baseline flow development. Some of the sources of uncertainty include:

- The quality of meteorological forcing datasets, particularly rainfall and evapotranspiration are a large source of uncertainty.
- Uncertainty associated with interpolation of gridded input data could affect the accuracy of the model.
- The PRIM2 model solves groundwater water levels and flows at center of a grid cell but is calibrated against observed data measured at locations not the center of grid cells.
- The effects of groundwater withdrawals were assumed the same over the period of record from May 1, 1950, through December 31, 2021.

Given these uncertainties, the daily flows generated using PRIM2 were not considered appropriate for use. Rather, the simulation results were aggregated into a longer timescale (e.g., monthly) and the relative difference between baseline and impacted flows were used for establishing a reasonable cause-and-effect relationship.

Table 5-1. Estimated changes in flows at the USGS Charlie Creek near Gardner, FL (No. 0226500) gage in the absence of groundwater withdrawals (and associated runoff).

Month	Average Gaged Flows (cfs)	Average Simulated Flows under 50% Pumping Reduction (cfs)	Difference (cfs)	Groundwater Withdrawal Impact (cfs)*	Average Adjusted Flows (cfs)
Jan	114.0	110.8	-3.2	-6.4	107.6
Feb	118.1	113.9	-4.2	-8.4	109.7
Mar	97.2	93.6	-3.6	-7.2	90
Apr	43.3	41.0	-2.3	-4.6	38.7
May	25.2	23.8	-1.4	-2.8	22.4
Jun	144.4	138.7	-5.7	-11.4	133
Jul	205.1	199.1	-6.0	-12	193.1
Aug	312.0	303.3	-8.7	-17.4	294.6
Sep	583.6	576.5	-7.1	-14.2	569.4
Oct	333.6	327.1	-6.5	-13	320.6
Nov	109.1	107.3	-1.7	-3.4	105.7
Dec	77.9	75.8	-2.2	-4.4	73.5

* Groundwater withdrawal impacts were estimated by doubling the difference between the average gaged flows and average simulated flows under the 50% pumping reduction scenario.

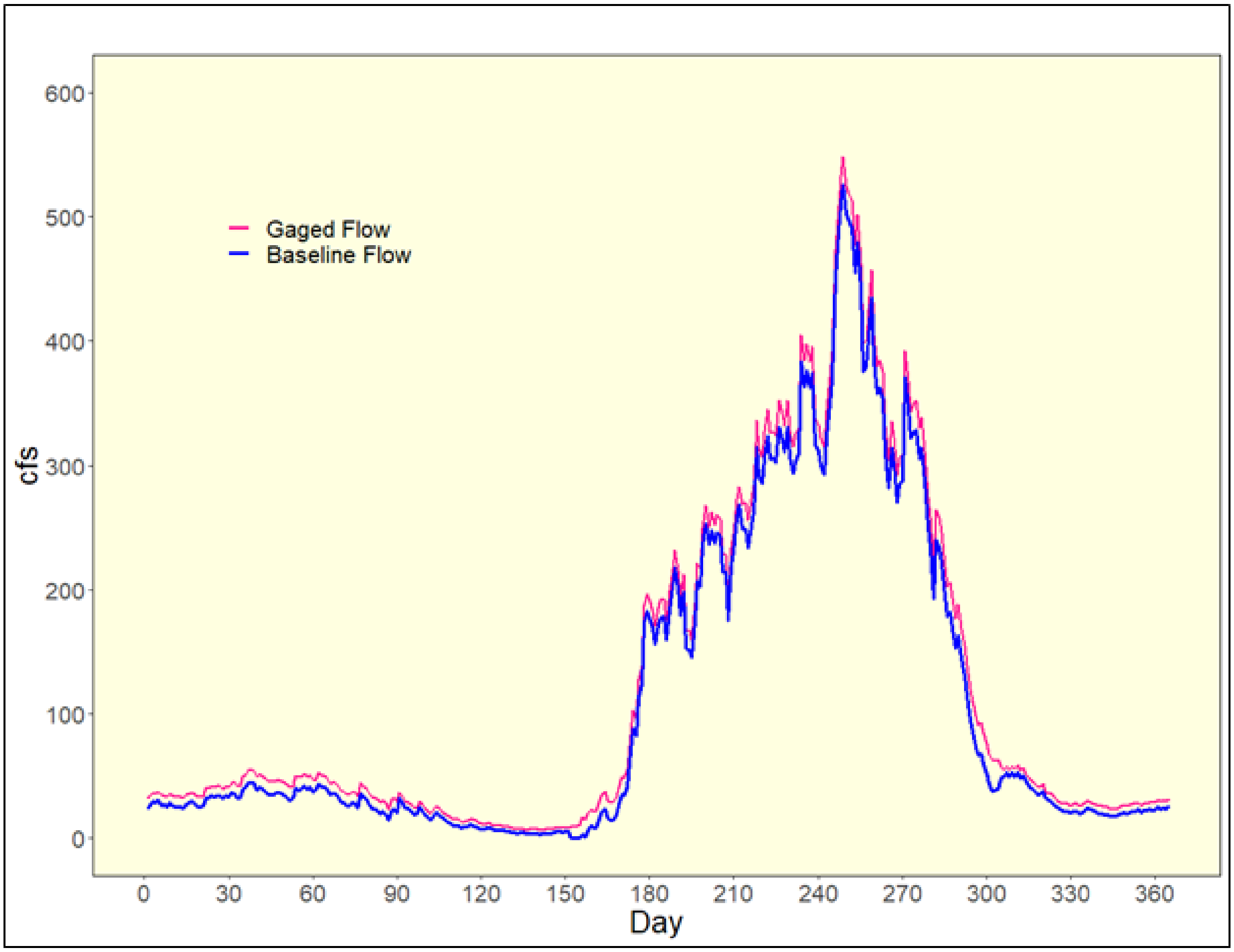

Figure 5-1. Median daily baseline and gaged flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage for the period from 1950 through 2021.

5.2. Development of Flow Blocks

For most rivers in the District, there is an average annual flow regime that can be divided into three periods. These three periods are characterized by low, medium, and high flows and for the purpose of developing minimum flows, are termed Block 1, Block 2, and Block 3, respectively (Kelly et al. 2005a). This approach was originally proposed during the independent peer review of the recommended minimum flows for the Upper Peace River with the intent of appropriately representing hydrologic and hydroperiodic conditions in the river (Gore et al. 2002). The identification of flow blocks accounts for flow requirements associated with ecosystem functions, biological populations, and communities, and the assembly of flow blocks form a minimum flow prescription (Postel and Richter 2003). As noted by the Upper Peace River minimum flows peer review panel, the assumptions behind block techniques are based upon basic ecological theory–

organisms and communities occurring in a river have evolved and adapted their life cycles to flow conditions over a long period of pre-development history (Stanford et al. 1996). Since the development of the Upper Peace River minimum flows, the District has typically used calendar-based blocks developed by analyzing flow records for long-term USGS gage sites (Kelly et al. 2005a, b, c, 2007, Leeper et al. 2018, Munson et al. 2007). The calendar-based block approach uses the median flow for days of the year to identify dates when flows typically are above or below the 25th and 50th percentiles. Calendar-based Block 1 begins when median flows fall below and stay below the 25th percentile, calendar-based Block 3 begins on the day of year when median flows exceed and stay above the 50th percentile, and calendar-based Block 2 extends from the end of Block 3 to the beginning of Block 1.

To help reduce unintended negative impacts on biological communities in years where flows are not well-matched to the fixed start and end dates of the calendar-based blocks, flow-based blocks were recently introduced by the District to re-evaluate the minimum flows for the Lower Peace River and develop recommended minimum flows for Lower Shell Creek (Ghile et al. 2021) and Little Manatee River (Holzwart et al. 2023). For the same reason, the flow blocks were also applied for Charlie Creek.

For Charlie Creek, flow-based blocks were developed from analysis of fish passage and floodplain inundation criteria (e.g., developed based on resources of concern; Figure 5-2). The threshold for fish passage was determined to be 27 cfs; this is the cutoff between the low-flow Block 1 and medium-flow Block 2. The threshold for floodplain inundation was determined to be 120 cfs; this is the boundary between the medium flow Block 2 and high flow Block 3. Based on the sensitivity of the floodplain inundation, the high flow Block 3 is divided into three subblocks (Block 3a, Block 3b and Block 3c) at flow thresholds of 316 cfs and 945 cfs. For reference, 27 cfs is the 27th non-exceedance percentile, 120 cfs is the 58th non-exceedance percentile, 316 cfs is the 75th non-exceedance percentile and 945 cfs is the 93rd non-exceedance percentile. These blocks are defined using the flow record from May1, 1950 through December 31, 2021, at the USGS Charlie Creek near Gardner, FL (No. 02300500) gage. Days are assigned to the following blocks based on daily average flow, regardless of calendar date:

- Block 1 – Flows less than or equal to 27 cfs
- Block 2 – Flows greater than 27 cfs and less than or equal to 120 cfs
- Block 3a – Flows greater than 120 cfs and less than or equal to 316 cfs
- Block 3b – Flows greater than 316 cfs and less than or equal to 945 cfs
- Block 3c – Flows greater than 945 cfs

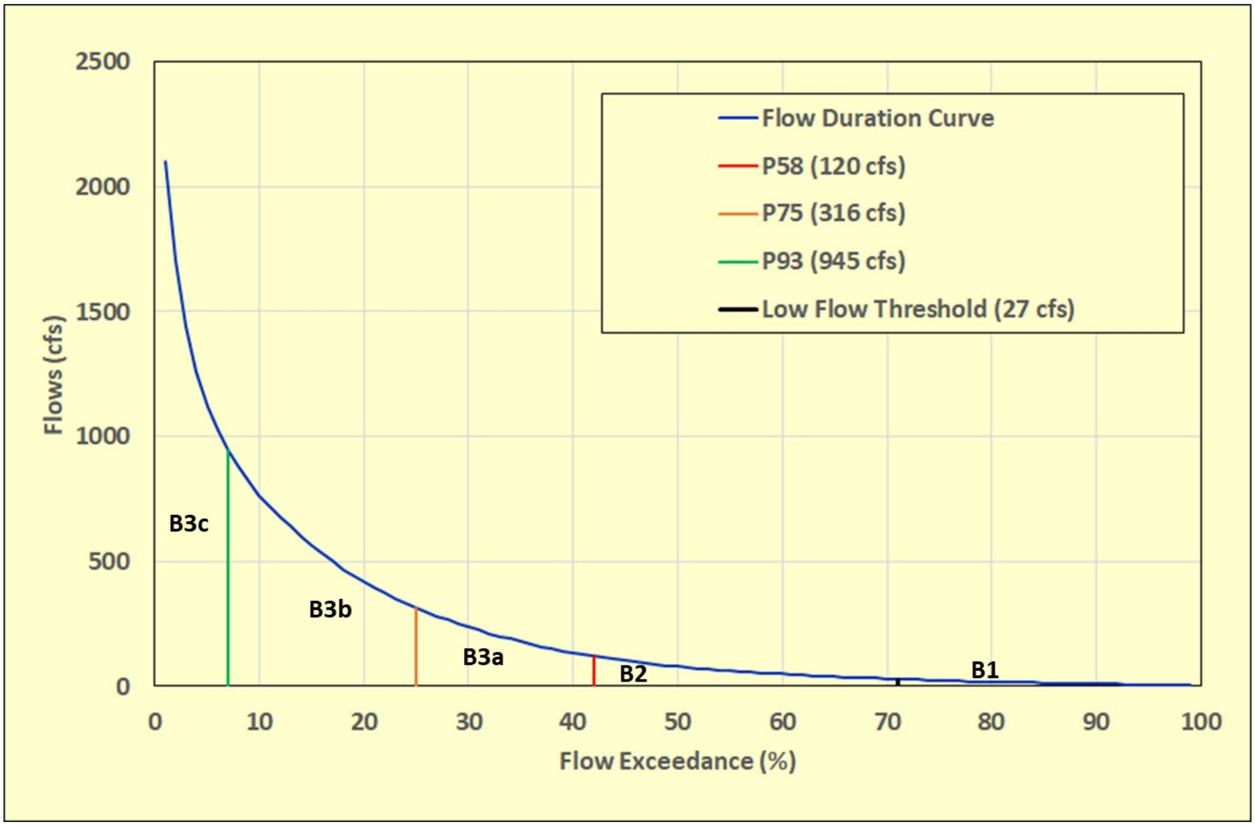

Figure 5-2. Flow blocks superimposed on a flow duration curve (solid blue line) at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage. The high flow Block 3 is divided into three sub-blocks as shown by green and orange vertical lines. The boundary between the high-flow Block 3 and medium-flow Block 2 is shown as a red vertical line. The boundary between medium-flow Block 2 and low-flow Block 1 is shown as a black vertical line. The flow duration curve is shown here for reference; blocks were determined based on fish passage and floodplain inundation criteria, not on the median flows.

5.3. Resources of Concern

The District's approach for developing minimum flows is habitat-based. Because river systems include of aquatic and wetland habitats that support diverse biological communities, it is necessary to identify key ecological resources for consideration, and when possible, determine hydrologic requirements for specific habitats associated with the resources. It is assumed that protecting the resources of concern will also provide protection for other ecological aspects or functions of the river system that are more difficult to quantify, such as transfer of detrital material and the maintenance of river channel geomorphology.

Resource management goals that were the focus of the technical analyses for the development of minimum flows for Charlie Creek and the relevant environmental values associated with each of these goals are listed below.

- Determination of a low flow threshold to provide protection for ecological resources and human uses of Charlie Creek by prohibiting withdrawal impacts during critical low-flow periods. This supports maintenance of a minimum depth for fish passage, which also promotes natural flow continuity, and maintains water depths above inflection points in the wetted perimeter of the river channel to maximize aquatic habitat with the last amount of flow. Relevant environmental values include:
    - Recreation in and on the water
    - Fish and wildlife habitats and the passage of fish
    - Transfer of detrital material
    - Maintenance of freshwater storage and supply
    - Aesthetic and scenic attributes
    - Filtration and absorption of nutrients and other pollutants
    - Water quality
    - Navigation
- Maintenance of the inundation of instream woody habitat, including snags and exposed roots in the river channel. Relevant environmental values include:
    - Fish and wildlife habitats and the passage of fish
    - Transfer of detrital material
    - Sediment loads
- Maintenance of seasonal hydrologic connections between Charlie Creek and floodplain to ensure the persistence of floodplain structure and function. Relevant environmental values include:
    - Recreation in and on the water
    - Fish and wildlife habitats and the passage of fish
    - Transfer of detrital material
    - Aesthetic and scenic attributes
    - Filtration and absorption of nutrients and other pollutants
    - Sediment loads
    - Water quality
    - Navigation
- Maintenance of available instream habitat for fish and macroinvertebrate taxa throughout Charlie Creek. Relevant environmental values include:
    - Recreation in and on the water
    - Fish and wildlife habitats and the passage of fish
    - Transfer of detrital materials

- Aesthetic and scenic attributes
- Filtration and absorption of nutrients and other pollutants
- Sediment loads
- Water quality

The primary approach used for minimum flows development in Charlie Creek focused on the maintenance of 85% of the most sensitive criterion associated with the resource management goals. In addition, a low flow threshold was identified to ensure flow continuity for environmental and human use values.

5.3.1. Low Flow Threshold

Development of minimum flows for Charlie Creek included the identification of a low flow threshold. This is a flow rate below which no surface withdrawals would be permissible, and it is developed for some rivers because environmental values may exhibit high sensitivity to impacts at very low rates of flow. A low flow threshold has been included in minimum flows established for many District rivers, including portions of the Alafia, Anclote, Braden, Hillsborough, Myakka, Pithlachascotee rivers, the middle and lower sections of the Peace river, and Gum Slough Spring Run, and is currently proposed for the Little Manatee River.

Two metrics are typically associated with the development of a low flow threshold. One is based on maintaining fish passage along the river corridor. The other is based upon the lowest wetted perimeter inflection point, a measure of gain in available habitat per unit of flow. The low flow threshold is then established at the higher of the two metrics, if comparison of that criterion with historical flow records indicates that it is reasonable. Although flows less than the low flow threshold may occur during anytime of the year, they typically occur during the dry season, when Block 1 flows are most common.

5.3.1.1. Fish Passage

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

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

Output from multiple runs of a Charlie Creek HEC-RAS model created to support minimum flow development was used to assess flow-related water depths at each of the 36 HEC-RAS cross-sections on the mainstem of the river (see Section 6.1.1). Flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage were associated with flows at each cross-section that resulted in at least 0.6-ft (0.18-m) of water in the deepest part of the channel were identified. The highest flow at the USGS gage required to maintain this depth at the most sensitive cross-section was calculated for use as a fish passage metric to be considered for development of the low flow threshold.

5.3.1.2. Lowest Wetted Perimeter

Wetted perimeter is defined as the distance along the stream bed and banks at a cross-section where there is contact with water. Evaluation of the “wetted perimeter” of the stream bottom is useful for assessing relationships between flow and the quantity of stream-bottom habitat. Wetted perimeter methods for evaluating streamflow requirements assume that there is a direct relationship between wetted perimeter and fish habitat (Annear and Conder 1984), and with aquatic habitat, in general. Studies on streams in the Southeast United States have demonstrated that the greatest amount of macroinvertebrate biomass per unit reach of stream occurs on the stream bottom (Benke et al. 1985). Although production on a unit area basis may be greater on snag and root habitats, the greater the area of stream bottom along a reach makes it the most productive habitat under low flow conditions (Heinz and Woodard 2013).

By plotting the response of wetted perimeter to incremental changes in discharge, an inflection or inflections can be identified in the resulting curve where small decreases in flow result in increasingly greater decreases in wetted perimeter. This inflection point or points represent flows at which the water surface recedes from stream banks and habitat (particularly for benthic macroinvertebrates and other bottom-dwelling organisms) is lost at an accelerated rate. Stalnaker et al. (1995) describe the wetted perimeter approach as a technique for using the “break” or inflection point in the stream’s wetted perimeter versus discharge relation as a surrogate for minimally acceptable habitat. They note that when this approach is applied to riffle (shoal) areas, “the assumption is that minimum flow satisfies the needs for food production, fish passage, and spawning.” The District refers to the lowest breakpoint on the wetted perimeter-discharge curve as the LWPIP. Identification of this point permits evaluation of flows that provide the greatest amount of inundated bottom habitat in the river channel on a per-unit flow basis.

Output from multiple runs of the HEC-RAS model was used to generate a wetted perimeter versus discharge plot for each of the 36 HEC-RAS cross-sections included in the model for Charlie Creek. Plots were visually examined for the LWPIP at each cross-section and used along with calculated changes in wetted perimeter on a per unit of flow basis to identify flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage that were associated with relatively large changes in wetted perimeter within the river channel. For cross-sections that displayed no distinct inflection point, or where the majority of in-channel wetted perimeter was inundated at the lowest modeled flow, the LWPIP was established at the lowest modeled flow. The LWPIP flows at each HEC-RAS cross-section were used as a metric for consideration when developing the low flow threshold.

5.3.2. Floodplain Inundation

Floodplains are valuable ecosystems that support high levels of biodiversity, enhance habitat heterogeneity, and serve as hotspots for primary production, while providing important ecosystem services like the filtration of surface water and groundwater recharge (Opperman et al. 2010). Their periodic inundation strongly influences overall biological productivity of riverine systems (Junk et el. 1989). Flooding can result in areas of shallow water that are less turbid than that of the main river channel, and thus can stimulate high rates of primary production from aquatic plants and algae (Ahearn et al. 2006). Furthermore, during inundation, different prey items and habitats become available to instream organisms, which can have positive impacts on the condition and abundance of large, predatory fish (Blewett et al. 2017). High velocity flood events can disperse organic materials throughout the river and affect the geomorphology of the river channel.

The duration and depth of floodplain inundation, along with the frequency of floods, are primary drivers of plant community composition and distribution in these ecosystems (Light et al., 2002, Whitlow and Harris 1979). In areas with longer hydroperiods, the decomposition of organic materials can be slow, with the development of anaerobic mucky or peaty soils (Tate 1980, Brown et al. 1990). Plants growing in flooded areas are tolerant to these anoxic conditions and the physical structure of saturated soils (Hook and Brown 1973, McKevlin et al. 1998). Spatial gradients in vegetative communities are frequently observed in floodplains with increasing distance from the river channel, as changes in the depth and frequency of inundation impact soil saturation and anoxia (Capon 2005, Junk et al., 1989). Changes to floodplain inundation can therefore affect the distribution of these soils and the plants that grow within them (Light et al., 2002).

Floodplain vegetation, soil, and hydrologic indicator data collection and analysis for Charlie Creek were completed by HSW Engineering, Inc. (2012), included as Appendix B to this report, for six representative cross-sections perpendicular to the river channel (Figure 4-6). Floodplain cross-sections were selected based upon review of the District's available soils and vegetation mapping data and inspection of previously established physical habitat simulation sites along the creek. Representative wetland communities that best represented the floodplain of the targeted corridor were selected.

To characterize forested vegetation communities along each cross-section, changes in dominant vegetation communities were located and used to delineate boundaries between vegetation zones. Trees, rather than shrubs and herbaceous species, were used to define vegetation communities, because relatively long-lived tree species are better integrators of long-term hydrologic conditions. Trees with obligate or facultative wetland indicator status dominated the floodplain swamp and bottomland forest communities, with facultative species in the hydric hammock community.

Soils along the floodplain cross-sections were evaluated for the presence of hydric or flooding indicators, as well as saturation and inundation condition. Key physical indicators of historical inundation were identified, including lichen or moss lines, trunk buttresses, and water marks, with lichen and moss lines being the most prevalent. Elevations were surveyed along transects to characterize conspicuous changes and heights of hydrologic indicators were recorded. As expected, hydric soils occurred at lower elevations and non-hydric soils occurred at the ends of transects or higher than the boundary of transition bottomland hardwood to hydric hammock or upland hammock community with a significant difference in median elevation between hydric and non-hydric soils. Based on the occurrence of wetlands throughout Charlie Creek, a floodplain inundation criterion was developed.

The HEC-RAS model was used to evaluate the extent of floodplain inundation as a function of flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage. Then HEC-GeoRAS, a geo-processing accessory to HEC-RAS that incorporates a digital elevation layer, was used to import the HEC-RAS model water surface profile simulation data into ArcGIS for spatial mapping of the extent of the floodplain inundation for the baseline flow scenario. A prescriptive standard allowing up to 15% change in floodplain inundation from the baseline condition was adopted to define the limit beyond which further withdrawals would result in significant harm. Inundation of the floodplain by river flows occurs predominantly during Block 3, which has a wide range of flows. To protect the various floodplain habitats, three percent-of-flow reductions were identified: Block 3a for out-of-bank floodplain inundation (swamps), Block 3b for inundation of lowland floodplains and Block 3c for infrequent and extreme high pulse flooding events (leading to inundation of upland floodplains). Both total area of inundation and duration of inundation were considered.

5.3.3. Instream Habitat

Maintaining instream habitat is critical for proper ecosystem function. Geomorphically distinct substrate patches (sand, mud, or woody debris) can benefit different microbial, macroinvertebrate, and fish assemblages. Changes in community composition and function occurring along the river continuum are in part a consequence of the relative abundance of different habitat patches, which are under the control of channel geomorphology and flow. The District quantified instream habitat in Charlie Creek using System for Environmental Flow Analysis (SEFA) modeling to predict habitat suitability for aquatic biota and by modeling flows required for woody habitat inundation.

5.3.3.1 Habitat Suitability for Aquatic Biota

One of ten environmental values in the water resource implementation rule is “fish and wildlife habitats and the passage of fish.” Fish, including game fish, non-game fish, and the invertebrates that support the ecosystem have specific requirements for water depth, velocity, substrate, and cover. Instream habitat modeling combines field measurements of channel geometry, water depth and velocity with substrate and cover characteristics.

Aquatic biota, including fish and benthic macroinvertebrates, need sufficient habitat to obtain resources, avoid predation, and reproduce in a flowing water environment. This habitat can be quantified in terms of depth and velocity which vary with the quantity of discharge. In addition, qualitative habitat variables include substrate types, presence of organic detritus, nearby structural elements such as overhanging banks or logs, and other characteristics. As the total quantity of discharge varies in a stream, these habitat elements will vary as well, affecting the amount and quality of habitat available.

Predicting changes to depth and velocity with changing flow requires hydraulic modeling. The SEFA software package offers a flexible modeling framework for quantifying changes to the habitat of aquatic biota in response to changing flow regimes (Jowett et al. 2020, Aquatic Habitat Analysts, Inc. 2021). The SEFA software is capable of analysis identical to PHABSIM, which was commonly used in past minimum flows analysis by the District and offers options for analysis in addition to PHABSIM methods.

The SEFA modeling software (Jowett et al. 2020) was used to quantify changes in available instream habitat with flow in Charlie Creek. HSW Engineering, Inc. collected habitat, stage, and flow data at five locations along Charlie Creek (HSW 2021, included as Appendix D to this report). To support use of the best available information for minimum flow development, the District conducted an analysis of instream habitat using SEFA based on data collected by HSW and an updated baseline flow record (Herrick 2022, included as Appendix E to this report). For the analysis, taxa were evaluated for a 15% change in their area weighted suitability under flow reduction scenarios.

5.3.3.2 Woody Habitat Inundation

Woody habitats are important instream features that can be influenced by flow conditions (Benke and Wallace 1990). Wood provides a relatively stable, structurally complex medium that serves as cover for a variety of invertebrates, fish, and other organisms. As physical impediments to flow, woody structures enhance the formation of leaf packs and debris dams that further improve instream habitat diversity and complexity. With sustained inundation, microbial conditioning and periphyton growth can occur on woody materials, leading to successful macroinvertebrate colonization and subsequent support for aquatic food webs.

Mean elevation of exposed root and snag woody habitats were obtained at seven locations in Charlie Creek, corresponding to the floodplain vegetation work performed by HSW Engineering, Inc. (2012; included as Appendix C to this document). The Charlie Creek HEC-RAS model was run to identify flow-stage relationships at these instream habitat sites. Based on these relationships, corresponding flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage necessary to inundate mean elevations of exposed roots and snags were determined. The maximum percent-of-flow reduction that would result in 15% fewer days of 1-day, 7-day, and 30-day periods of inundation of the mean elevation of woody habitat was then calculated, relative to baseline conditions.

5.4. Modeling Tools and Technical Approaches for Addressing Resources of Concern

This section describes the modeling tools and technical approaches used determine the minimum flow requirements for Charlie Creek between two USGS gaging stations, Charlie Creek near Crewsville (No. 02296260; upstream) and Charlie Creek near Gardner, FL (No. 02296500; downstream). The HEC-RAS model was developed to characterize stages as a function of flow, and their relationships ecological criteria, including wetted perimeter, fish passage, navigation, sediment loads, transfer of detrital material, floodplain inundation, and woody habitat. The HEC-GeoRAS software was used to process geospatial data and support hydraulic model development, and to import the HEC-RAS model water surface profile simulation data into ArcGIS for spatial mapping of the extent of floodplain inundation. The SEFA modeling was used to characterize potential changes in the availability of fish habitat and macroinvertebrate habitat.

5.4.1. HEC-RAS Modeling

The HEC-RAS model allows users to perform a one-dimensional steady flow and unsteady flow calculations, as well as two-dimensional unsteady flow calculations. It has been used by the District as one of the major modeling tools in support of minimum flows development for flowing systems.

A one-dimension HEC-RAS model was initially developed for Charlie Creek in 2016 by INTERA to analyze and characterize water levels and flows throughout the Charlie Creek. After initial model construction, the District identified the need for improved model accuracy, improved flow apportionment by reach along the Creek, and inclusion of overbank bathymetry/topography for floodplain inundation analysis. With these goals in mind, the District contracted with INTERA to incorporate additional cross-sections into the model, collect additional flow and stage data, re-calibrate the model, and perform predictive simulations, including floodplain inundation mapping (INTERA 2018, Appendix F).

The updated HEC-RAS model was constructed for approximately 16 miles between the USGS Charlie Creek near Crewsville, FL (No. 02296260) gage and the USGS Charlie Creek near Gardner, FL (No. 02296500) gage, flowing southwesterly to its confluence with Peace River (Figure 5-3). Geometric data used for the analyses consisted of surveyed transects and bathymetric/topographic data (point data) collected by the District. A field survey was conducted by District professional land surveyors at eight locations, including seven vegetative transects and one bridge (Figure 5-3). Additionally, Digital Elevation Model (DEM) data (5-foot by 5-foot cells) from the District’s GIS and Mapping Department was used to develop new HEC-RAS cross-sections. The DEM is based on aerial LiDAR data collected in 2005 by 3001 Northrop Grumman (Appendix G). Both the surveyed and DEM-based cross-sections were extended to the outer boundary of the river-corridor wetlands to incorporate the range floodplain elevations more fully. A total of

41 cross-sections are defined in the updated HEC-RAS model, including 13 surveyed cross-sections and 28 digitized cross-sections from DEM (Figure 5-3).

Hydraulic data input required by the model includes flow data and stage data for the boundary conditions. Daily flow and stage data for the USGS Charlie Creek near Crewsville, FL (No. 02296260) gage and the USGS Charlie Creek near Gardner, FL (No. 02296500) gage were obtained from the USGS. However, additional flow and stage data were required to develop and run the HEC-RAS model for Charlie Creek. Field engineers from INTERA collected additional flow data at six locations during three discrete events in October 2017 and May and June 2018 that represented medium, low, and high flow conditions respectively. To improve model calibration, additional stage data was collected at two locations (Platt residence and Sweetwater Road Bridge) continuously from December 11, 2017, through August 19, 2018, Locations of the additional flow data collection sites, which were evenly distributed along the creek, are shown in Figure 5-3.

Required steady-flow data included the USGS gage records and the flow measurements collected by INTERA at six locations. Based on these data, eight cross-sections (out of 93 cross-sections) were assigned with a flow relationship between the cross-section and the USGS Charlie Creek near Gardner, FL (No. 02296500) gage located at the US 17 bridge, and a linear interpolation approach was used to generate flow values at each cross-section (Table 5-2).

A known water surface elevation was used as the downstream boundary condition at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage, where a USGS stage-flow rating curve was available. To ensure the model accurately simulated a low, medium and high flows, five flow and stage profiles were developed using the flow data collected at six locations, stage data collected continuously at three locations from December 11, 2017, through August 19, 2018, as well as the stage and flows measured at the USGS Charlie Creek near Crewsville, FL (No. 02296260) gage and the USGS Charlie Creek near Gardner, FL (No. 02296500) gage. All these data were used for model calibration or validation purposes.

he HEC-RAS model was run for steady flow analysis and was considered well-calibrated when calculated water surface elevations were within plus or minus 0.5 foot of observed stage value, in keeping with standard USGS practices where this range of error is based on the potential error associated with using data collected to a 1-foot contour interval aerial mapping standard for model development (Lewelling 2004). The model was able to capture the hydrologic response to all flow conditions at the calibration sites, with stage residuals of less than or equal to 0.5 feet (Table 5.3). Model validation was conducted at two sites where the observed stage data was not utilized for model calibration. Review of the model validation results for eight flow profiles indicated that all stage residuals fell within a range of plus or minus 0.5 feet (Table 5-4).

The HEC-RAS model was then run for fifteen flow rate profile scenarios to establish flow vs stage rating curves for each cross-section. Each profile represents a non-exceedance percentile ranging from 5 to 99 percent at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage for the period from May 1, 1950, to December 31, 2021.

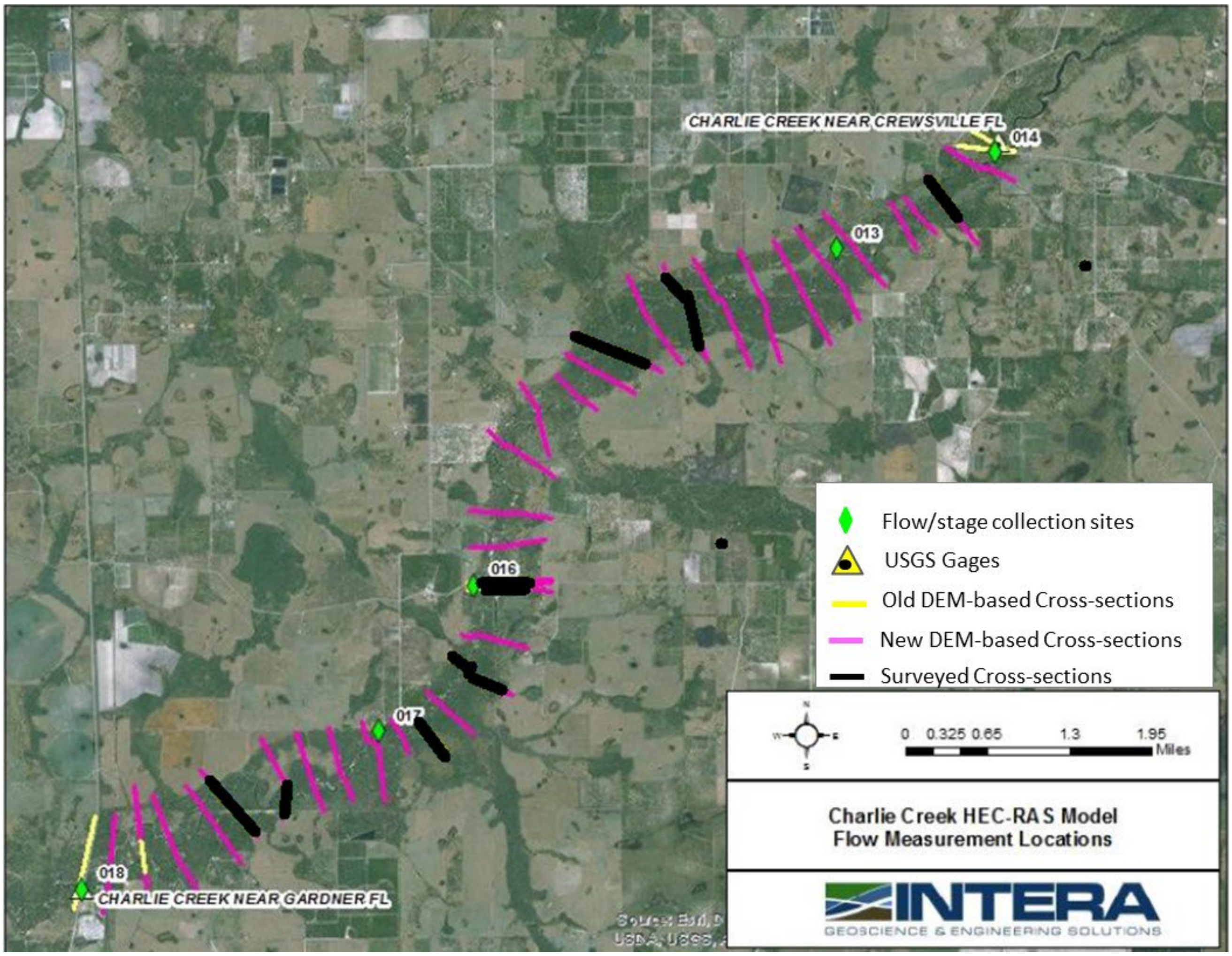

Figure 5-3. Locations of the USGS gages, data collection sites, and surveyed and DEM-based cross-sections of Charlie Creek used for development of the HEC-RAS model.

Table 5-2. Summary of the channel flow apportionment percentage for eight cross-sections used for the Charlie Creek HEC-RAS model.

Reach Name	Station Name	HEC-RAS River Station	Flow Apportionment Percentage (%)
Main Reach	Near Crewsville Gage	86227.02	36.0
Main Reach	-	74495.30	65.5
Main Reach	-	62280.21	67.5
Main Reach	-	48607.62	70.0
Main Reach	-	45497.82	93.0
Main Reach	Sweetwater Road Bridge	33205.22	96.1
Main Reach	-	23459.81	99.7
Main Reach	US 17 Bridge		100.0

Table 5-3. Summary of Charlie Creek HEC-RAS model calibration results; all stages in feet NAVD88 (Table 27 from INTERA 2018).

Calibration Site		Flow Profiles					
		PF1	PF2	PF3	PF4	PF5	PF6
Near Crewsville	Observed	47.02	47.9	48.79	49.53	52.79	53.44
	Simulated	47.52	48.1	48.64	49.13	52.51	53.12
	Residual	0.5	0.2	-0.15	-0.4	-0.28	-0.32
Platt Residence	Observed	44.86	45.73	46.54	47.36	50.42	51.25
	Simulated	44.55	45.43	46.27	46.96	50.7	51.59
	Residual	-0.31	-0.3	-0.27	-0.4	0.28	0.34
Sweetwater Road Bridge	Observed	32.37	33.49	35.53	36.65	40.52	42.57
	Simulated	32.72	33.38	35.86	36.8	40.03	42.11
	Residual	0.35	-0.11	0.34	0.14	-0.49	-0.45

Table 5-4. Summary of Charlie Creek HEC-RAS model validation results; all stages in feet NAVD88 (Table 29 from INTERA 2018).

Flow Profile	USGS Crewsville			Transect T2.5		
	Observed	Simulated	Residual	Observed	Simulated	Residual
PF1	47.22	47.74	0.52	38.45	38.83	0.38
PF2	47.83	48.23	0.4	39.01	39.13	0.12
PF3	48.09	48.28	0.19	39.1	39.44	0.34
PF4	49.41	49.2	-0.21	40.38	40.22	-0.16
PF5	50.3	49.93	-0.37	41.52	41.17	-0.35
PF6	51.26	50.8	-0.46	42.89	42.47	-0.42
PF7	52.25	51.94	-0.31	44.29	44.01	-0.28
PF8	53.58	53.08	-0.5	45.43	45.55	0.12

5.4.2. Low Flow Threshold Evaluation

The protection of aquatic resources associated with low flows is an important goal for minimum flow establishment and implementation. To support this goal, the District develops a low flow threshold, through use of two criteria. One is based on maintaining fish passage along the river corridor; the other involves evaluating the relationship between the quantity of stream habitat and the rate of flow for maximizing wetted perimeter for the least amount of flow. The low flow threshold is established at the higher of the two low-flow criteria, if comparison of that criterion with historic flow records indicates that the criterion is reasonable.

5.4.2.1. Evaluation of Fish Passage

For development of minimum flows, it is desirable to maintain longitudinal connectivity along a river corridor, to the extent that this connectivity has historically occurred. The HEC-RAS model output was used to assess flows necessary for fish passage at each of the HEC-RAS cross-sections by adding a 0.6-ft (0.18-m) fish-passage depth to the elevation of the lowest spot in the channel cross-section. This fish-passage depth is routinely used by the District for minimum flow and level development and was found to be acceptable by review panels that evaluated proposed minimum flows for more than 20 flowing systems.

Flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage were associated with flows at each cross-section that resulted in at least 0.6-ft (0.18-m) of water in the deepest part of the channel. These cross-section specific, fish-passage depths were then evaluated to identify the most sensitive cross-sections to support development of a minimum low flow threshold for Charlie Creek.

5.4.2.2. Evaluation of Wetted Perimeter

A useful technique for evaluating the relation between the quantity of stream habitat and the rate of flow is an evaluation of the "wetted perimeter." Wetted perimeter is defined as the distance along the stream bed and banks at a cross-section where there is contact with water. Output from the twelve flow profile scenarios of the HEC-RAS model were used to generate a wetted perimeter versus flow plot for each modeled cross-section of Charlie Creek. Plots were visually examined for inflection points, which identify flow ranges that are associated with relatively large changes in wetted perimeter. The lowest wetted perimeter inflection point (LWPIP) for flows up to 50 cfs was identified for each cross-section.

Many cross-section plots displayed no apparent inflection points between the lowest modeled flow and 50 cfs. Inflection points for flows higher than 50 cfs were disregarded since the goal was to identify the LWPIP for flows contained within the stream channel. For cross-sections that displayed no distinct inflection point or where most of the wetted perimeter is inundated below the lowest modeled flow, the LWPIP was established at the lowest modeled flow. Flows associated with the LWPIP at each cross-section were converted to flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage using relationships from the HEC-RAS model output. These cross-sections specific, LWPIPs were then evaluated to identify the most sensitive cross-sections to support development of a minimum low flow threshold for Charlie Creek.

5.4.3. Evaluation of Floodplain Inundation

Floodplain inundation criteria were developed to protect intermittent high flows that supply requirements for wetland vegetation and the biogeochemical processes and habitat values associated with the floodplain in Charlie Creek. A prescriptive standard allowing up to a 15% change in floodplain inundation from the baseline condition was adopted to define the limit beyond which further withdrawals would result in significant harm. Charlie Creek is relatively deep with extensive low lying floodplain areas and evaluation of floodplain inundation is an appropriate criterion for establishing minimum high flows for the creek.

The updated HEC-RAS model was used to evaluate the extent of floodplain inundation as a function of flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage.

The HEC-GeoRAS, a geo-processing accessory to HEC-RAS that incorporates a digital elevation layer, was used to import water surface profile simulation data from the HEC-RAS model into ArcGIS for spatial mapping of the extent of floodplain inundation. The steps involved in the floodplain inundation modeling were as follows:

1. Water elevations for the 5th, 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 90th, 95th, and 99th percentile flows were converted to triangulated irregular networks (TINs) using HEC-GeoRAS in ArcGIS for the representation of water surfaces.
2. The water-elevation TINs were rasterized in ArcGIS 10.6 at the spatial resolution of the DEM.
3. The rasterized water surface profiles and DEM data were overlain to determine the extent and depths of inundation. Inundated area was defined as the area encompassed by the intersection of the water surface and land surface.
4. The inundated area for each percentile were then intersected with the 2021 Cooperative Land Cover Map Version 3.5 (FWC 2021), which was used to characterize the extent of floodplain wetland vegetation within the floodplain of the model domain.
5. To quantify the daily inundated wetland area, a flow-inundated area rating curve was developed using flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage.
6. Using the rating curve, a daily time series of inundated floodplain wetland area for the baseline condition was generated for the period from May 1, 1950, through December 31, 2021, using the baseline flow record described in Section 5.1 and an interpolation function in an Excel spreadsheet.
7. A total available inundated floodplain area was calculated for the baseline condition by summing the daily time-series area values.
8. Steps 6 and 7 were repeated for 30 scenarios associated with 1% to 30% reductions in the daily baseline flows.
9. Decreases in the inundated floodplain wetland habitat availability for each reduced flow scenario were calculated to identify the flow reduction scenario that resulted in no more than a 15 percent reduction in available habitat relative to the baseline condition.

Multiple sources of uncertainty can be associated with our floodplain inundation modeling for Charlie Creek. These sources can be ascribed to cross-section data and data-processing errors associated with DEM development, wetland mapping in the available land cover dataset that was used, and estimation of inundation from rating curves.

The model domain and the existing wetland vegetation within the model domain are shown in Figure 5-4, along with floodplain wetland vegetations in the watershed that were not included in the model domain. Additional information on the methods used for assessment of floodplain inundation in the river is provided in INTERA (2018, Appendix F).

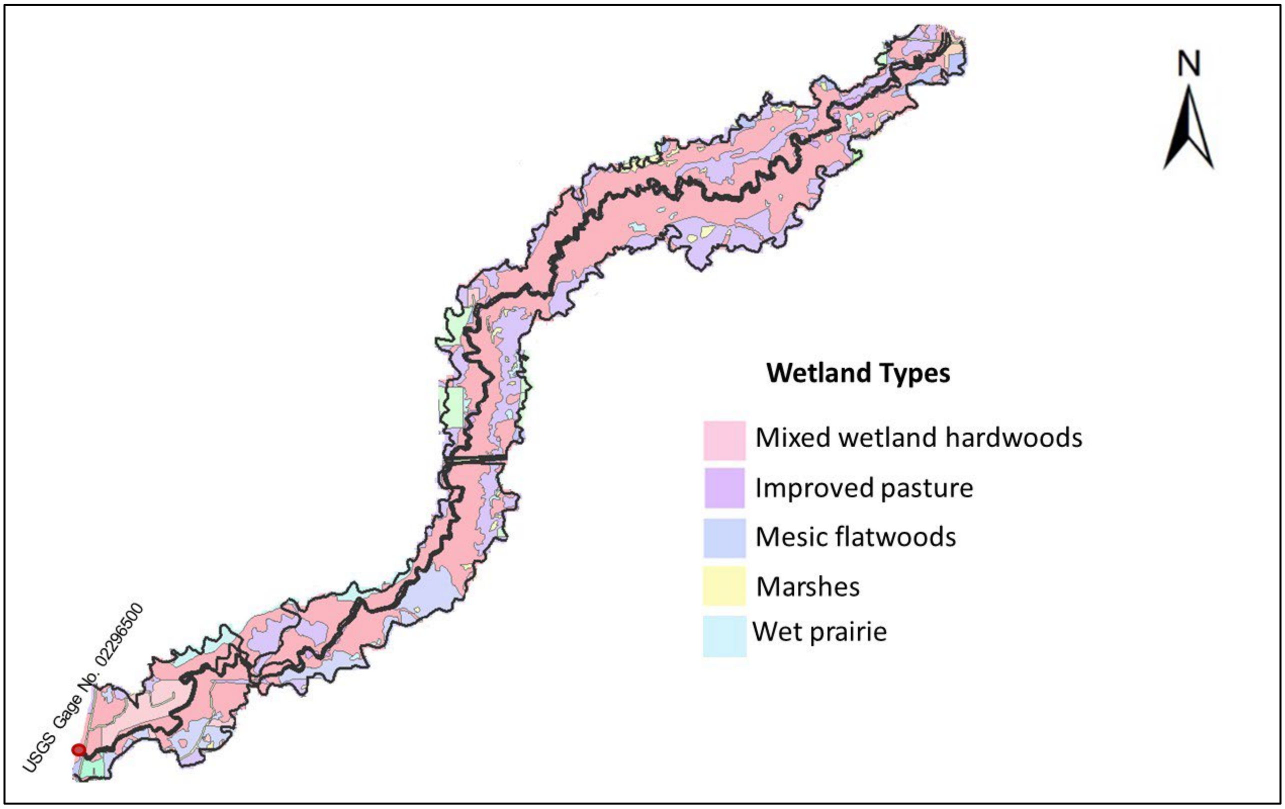

Figure 5-4. The HEC-RAS model boundary and channel for Charlie Creek and floodplain wetland vegetation within the model domain (source: GIS layer maintained by the FWC (2021)).

5.4.4. Evaluation of Instream Habitat

The District evaluated the effects of flow reductions on instream habitat by using SEFA modeling to quantify the impacts to fish and macroinvertebrate taxa and HEC-RAS to predict changes to woody habitat inundation.

5.4.4.1. Habitat Suitability Modeling Methods

SEFA habitat modeling uses cross-sectional elevation profiles, water surface elevation, velocity, and qualitative habitat characteristics at specific locations across the channel to characterize habitat (Figure 5-5). In addition to these environmental cross-section data, SEFA uses habitat suitability curves which relate water depth, water velocity, and an index of qualitative habitat characteristics including substrate and cover to habitat suitability for fish and aquatic macroinvertebrates (Figure 5-6). These habitat suitability curves can represent species, life history stages such as juveniles and adults, and habitat guilds, which include all organisms with similar habitat requirements such as deep, fast-moving water. Suitability is scaled on an index from zero (unsuitable) to one (maximally suitable), with intermediate values between zero and one. The history and development of the habitat suitability curves used by the District is described in Nagid (2022).

For a given flow, SEFA calculates the depth and velocity at each point along a cross-section and uses the depth and velocity habitat suitability curves to quantify the suitability of each of these physical variables. In addition, field observations of qualitative habitat characteristics are converted to suitability using their habitat suitability curves. These three suitability values are averaged and weighted by the total quantity of the cross-section represented to create a dimensionless index called the area weighted suitability (AWS).

The AWS is a combined index of habitat quality and quantity. The AWS can be modeled for an individual cross-section, or in aggregate for any number of cross-sections. The SEFA model output for AWS is a curve relating flow to AWS, with each value of flow having a single corresponding AWS value. Therefore, a time series of daily flow values can be converted into a daily time series of AWS values for each habitat suitability group. Alternative scenarios, for example time series of flows under baseline (unimpacted) conditions, can be compared to flow reduction scenarios to determine loss of habitat associated with decreases in flows. As a result, the patterns of flow variation across time scales can be modeled under differing flow scenarios.

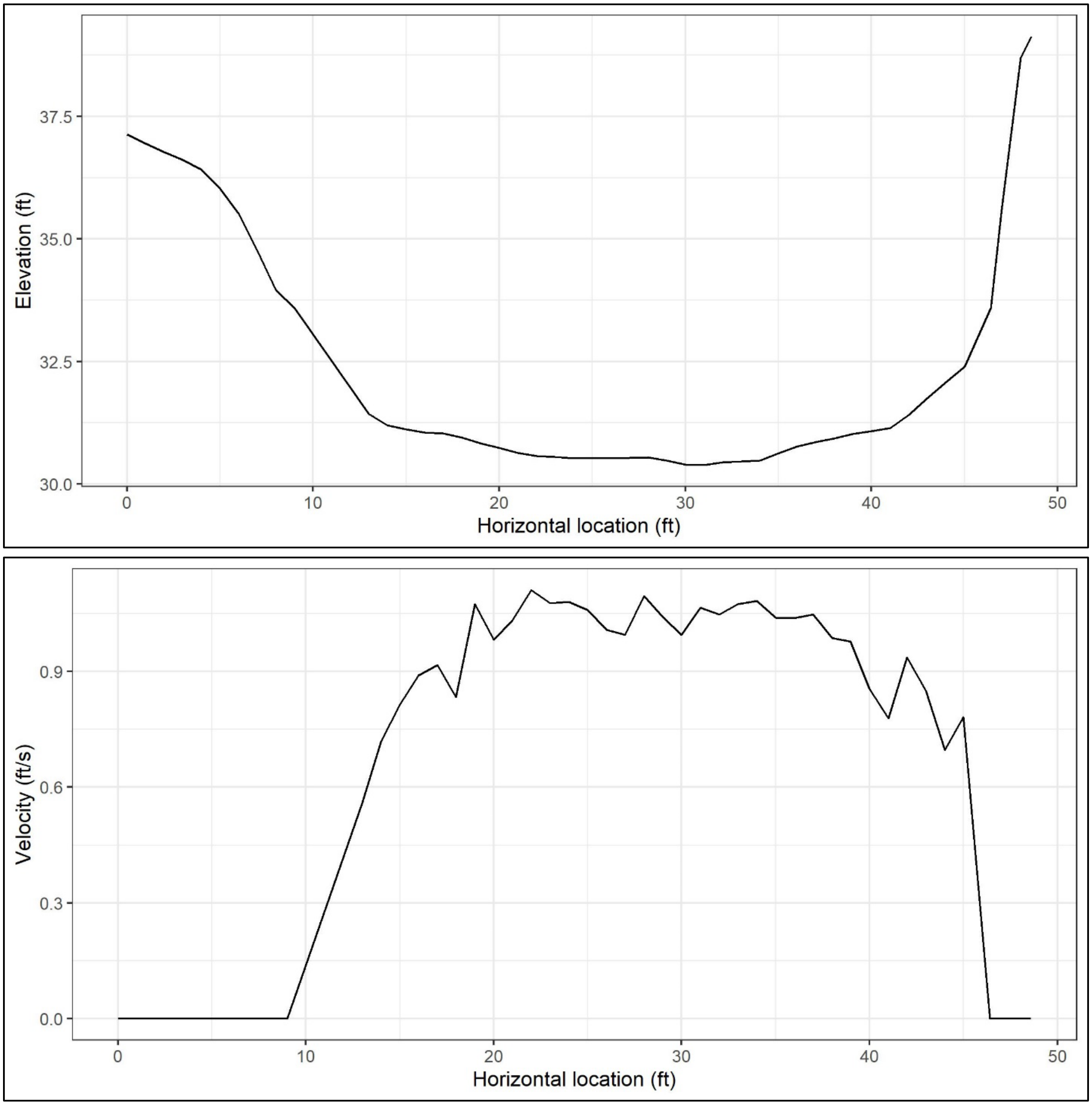

Figure 5-5. Example cross-section profile of water surface elevation (ft) and velocity (ft/s) from field observations.

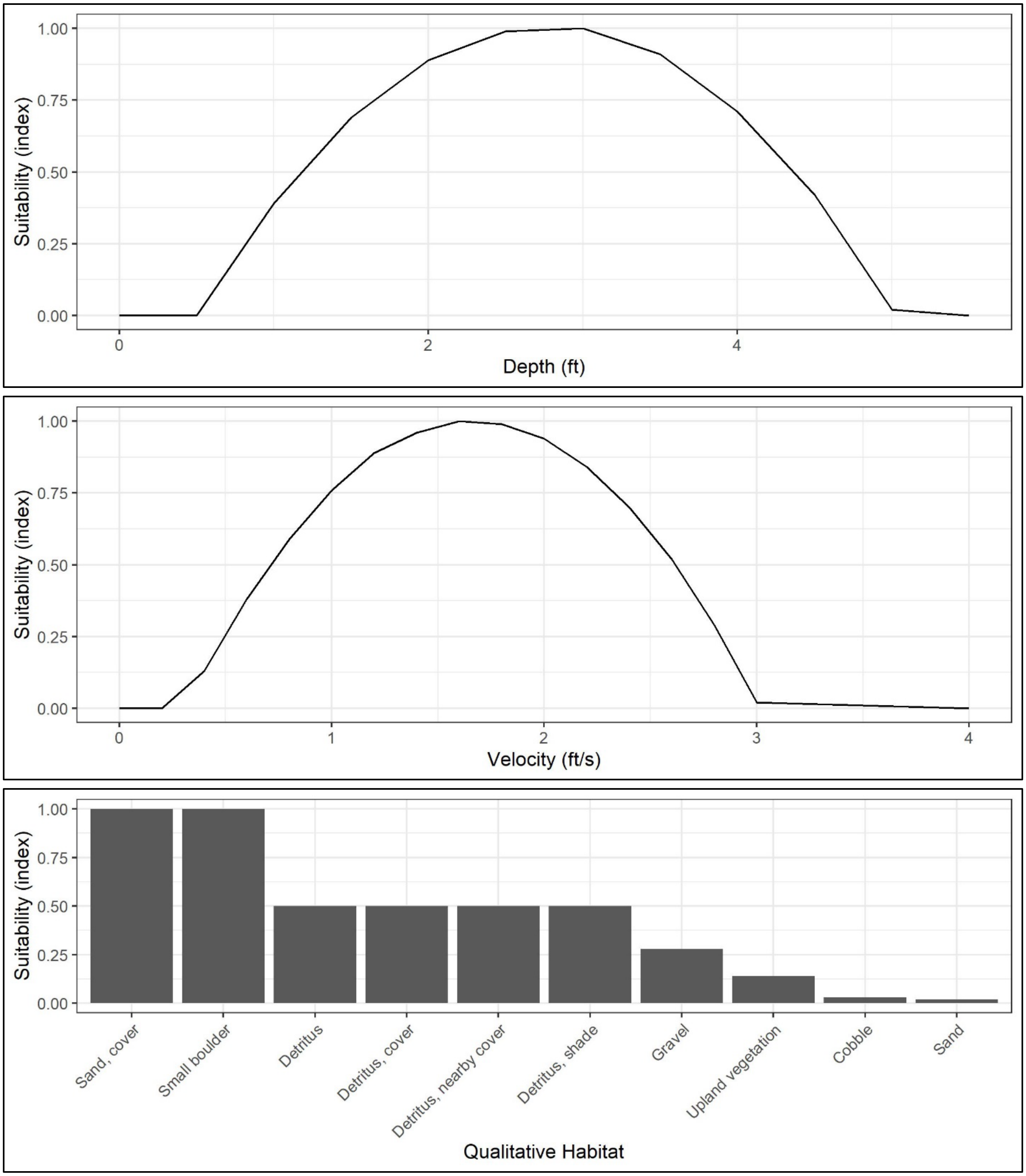

Figure 5-6. Example habitat suitability curves for net-spinning caddisflies (Hydropsychidae).

5.4.4.2. SEFA Site Descriptions

Elevation profiles, depth, velocity, substrate, and cover data was collected at five sites with three transects each, yielding a total of 15 sampled cross-sections (Figure 5-7, Table 5-5; HSW 2021). From upstream to downstream, these sites are Grass Valley Ranch (GVR), White Marsh A (WMA), White Marsh B (WMB), White Marsh C (WMC), and Hog Heaven (HH). These sites lie between the USGS Charlie Creek near Crewsville, FL (No. 02296260; upstream) and the USGS Charlie Creek near Gardner, FL (No. 02296500; downstream) gages. Detailed descriptions of site characteristics can be found in HSW (2021) and its appendix A.

This sampling design follows the habitat mapping approach which is a type of stratified sampling (Jowett et al. 2008). The first step is to identify different mesohabitat types with different hydraulic characteristics (depth and velocity). We identified pools as deeper areas, shoals as shallower areas, and runs as intermediate in depth between pools and shoals. The second step is to divide the river into these mesohabitat types. We clustered these mesohabitats into sites and spread sites throughout the study reach of the river as much as access would allow. Sites are located first by the presence of a shallow shoal. Next, a nearby pool is identified as the deepest area within approximately 150 ft of the shoal. Last, a run is identified as an area intermediate in depth between the pool and the shoal. These three habitats may occur in any upstream-downstream order within a site. In this way, each site is a representative subsample of the available habitat heterogeneity that exists within a reach of the river.

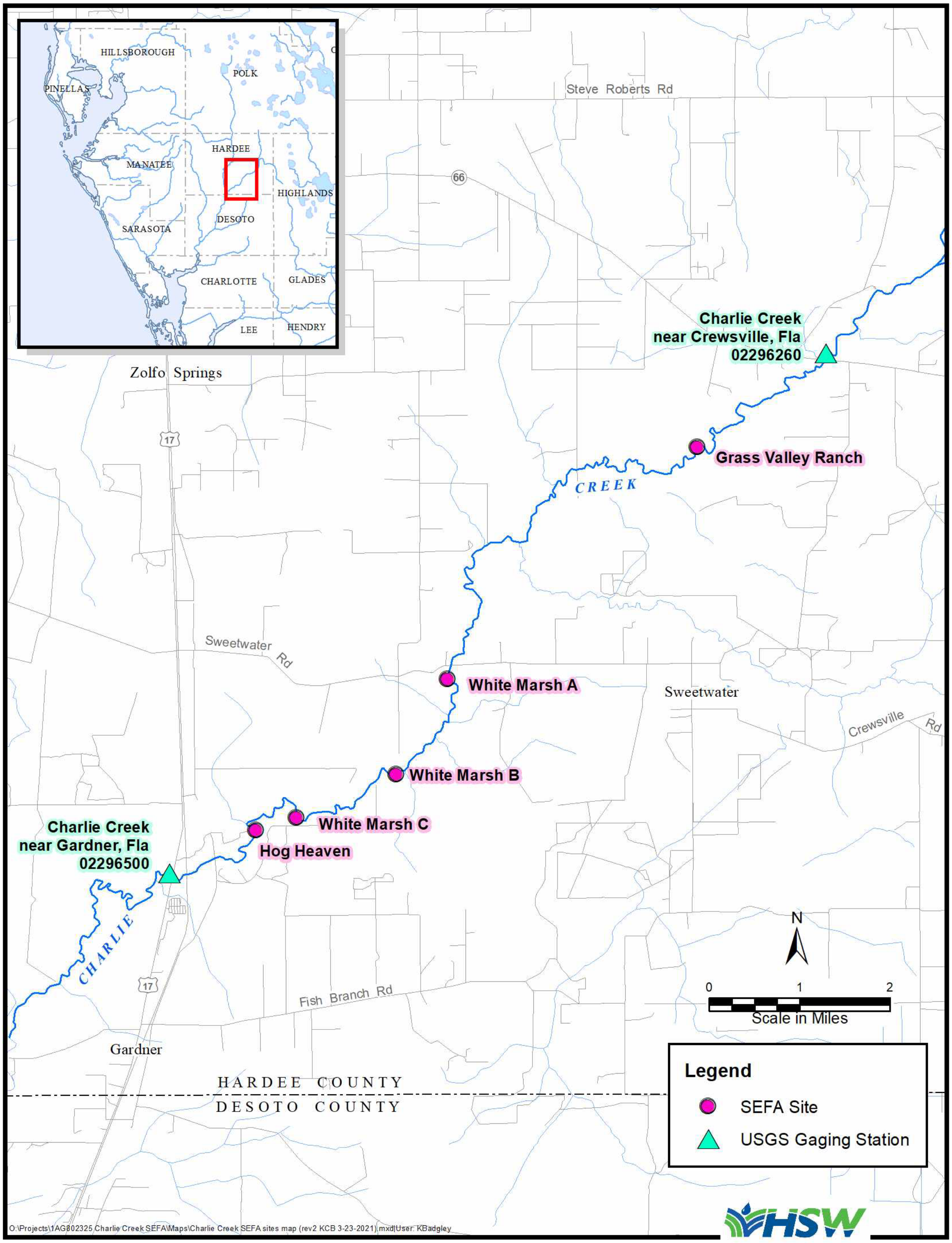

Figure 5-7. Locations of the five SEFA sampling sites in Charlie Creek (HSW 2021).

Table 5-5. Stage and flow at low, medium, and high data collection events at five sites. Reproduced from HSW (2021). Both sites and the transect types at each site are listed from upstream to downstream.

Site ID (Latitude Longitude)	Transect Type	Low flow		Medium flow		High flow	
		Flow (cfs)	Stage (NAVD88 ft)	Flow (cfs)	Stage (NAVD88 ft)	Flow (cfs)	Stage (NAVD88 ft)
Grass Valley Ranch (27.44498, -81.7016)	Pool	0.32	42.22	37	43.65	166.3	46.63
	Run	0.37	42.22	39.5	43.66	171.1	46.63
	Shoal	0.38	42.23	39.4	43.67	174.8	46.57
White Marsh A (24.40761, -81. 7467)	Pool	1.34	31.55	91.4	33.61	299.6	36.18
	Run	2.57	31.54	93.3	33.60	303.3	36.12
	Shoal	2.98	31.51	94.3	33.57	310.8	36.12
White Marsh B (27.39188, -81.7558)	Pool	2.94	28.14	107.5	30.30	321.6	32.99
	Run	3.10	28.13	109.5	30.30	323	32.98
	Shoal	3.53	28.11	109.6	30.30	317	32.94
White Marsh C (27.38525, -81.7742)	Run	3.53	26.17	34.9	27.16	290.4	30.05
	Pool	2.08	26.14	36.6	27.02	287	30.04
	Shoal	3.54	26.10	34.4	26.89	299.5	29.99
Hog Heaven (27.38233, -81.7815)	Run	3.07	25.81	33.2	26.71	305.4	29.24
	Shoal	3.30	25.80	34.1	26.70	302.6	29.23
	Pool	4.47	25.78	35.9	26.69	305.1	29.23

5.4.4.3. Updates to SEFA Model

HSW (2021, included as Appendix D to this report) collected SEFA data and performed a preliminary modeling analysis. Subsequently, District staff performed a separate modeling analysis of the data collected by HSW, which used different methods and produced different results from the original HSW analysis (see Appendix D). Consequently, different conclusions were reached, reflecting the differences in methods and results which are described below.

The HSW (2021) methods have the following characteristics:

- Use of median flow as the survey flow.
- SEFA default rating curves that force the curve through the survey flow (see section 12.2.1 of Jowett et al. 2020).
- Beta for velocity distribution value of -0.3, as specified in section 14.3 of Jowett et al. (2020).
- No adjustment to velocity distribution factors at elevations above the survey flow.
- Use of older habitat suitability curves developed by James Gore (Nagid 2022).
- The Grass Valley Ranch site was apportioned flows equal to the upstream USGS Charlie Creek near Crewsville, FL (No. 02296260) gage, while the four downstream sites were apportioned flows equal to the downstream USGS Charlie Creek near Gardner, FL (No. 02296500) gage.
- Flows are divided into blocks based on 75th and 50th exceedance, where Block 1 is less than 24 cfs and Block 2 is between 24 cfs and 79 cfs at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage.

These model files were modified in the following manner:

- The stage at Hog Heaven Run cross-section at low flow was modified from 26.21 ft NAVD88 to 25.8 ft NAVD88 to which matches field sheet and improves rating curve (Table 5-5).
- Adjustment to velocity distribution factors at points above survey flow water surface to near 1 as specified in section 14.5 of Jowett et al. (2020).
- Flows were apportioned based on regression with USGS gaging sites as described in sub-section 5.4.4.5.
- Flows were analyzed in a single block from zero to 120 cfs at the gage, corresponding to the boundary between instream and overbank flows. This was determined by HEC-RAS analysis described in section 6.2.
- Adjustments to White Marsh A shoal elevations based on field data sheets.

5.4.4.4. SEFA Rating Curves

Rating curves were developed for each site. Stage at zero flow was iteratively calculated by SEFA and modified in input files to get the best fit to observed data. This is appropriate when there is no known nearby hydraulic control point. Rating curves demonstrate a good fit to data based on correlation coefficients (R^2) and Mean Error of Q (Discharge; Table 5-6).

Table 5-6. Rating curve equations. Transects are listed from upstream to downstream.

Site ID	Transect Type	Rating Curve
Grass Valley Ranch	Pool	Flow = 24.903 * (Stage - 42.204) ^1.074 Mean error of Q = 11.405%
	Run	Flow = 23.663 * (Stage - 42.179) ^1.305 Mean error of Q = 1.303%
	Shoal	Flow = 22.167 * (Stage - 42.172) ^1.423 Mean error of Q = 1.931%
White Marsh A	Pool	Flow = 27.294 * (Stage - 31.450) ^1.579 Mean error of Q = 2.842%
	Run	Flow = 23.129 * (Stage - 31.240) ^1.624 Mean error of Q = 1.237%
	Shoal	Flow = 21.502 * (Stage - 31.191) ^1.681 Mean error of Q = 0.193%
White Marsh B	Pool	Flow = 32.451 * (Stage - 27.959) ^1.408 Mean error of Q = 0.797%
	Run	Flow = 29.197 * (Stage - 27.901) ^1.511 Mean error of Q = 2.292%
	Shoal	Flow = 29.441 * (Stage - 27.870) ^1.480 Mean error of Q = 1.182%
White Marsh C	Run	Flow = 18.338 * (Stage - 25.754) ^1.889 Mean error of Q = 0.601%
	Pool	Flow = 34.200 * (Stage - 25.975) ^1.541 Mean error of Q = 1.940%
	Shoal	Flow = 33.420 * (Stage - 25.871) ^1.535 Mean error of Q = 1.243%
Hog Heaven	Run	Flow = 25.241 * (Stage - 25.540) ^1.746 Mean error of Q = 11.753%
	Shoal	Flow = 18.795 * (Stage - 25.366) ^2.067 Mean error of Q = 0.992%
	Pool	Flow = 15.776 * (Stage - 25.222) ^2.142 Mean error of Q = 0.767%

5.4.4.5. SEFA Flow Apportionment

Sites were combined to develop a single set of reach habitat curves that combines the area weighted suitability at all 15 transects. Modeling reach habitat curves requires specification of the range and increment of flows to be modeled. This is to ensure that upstream sites are modeled as receiving appropriately lower flows than downstream sites, simulating the natural accumulation of increasing flows with downstream distance. Flow apportionment for the SEFA analysis was based on linear regression of flows at each site with the gaged flow on same date (Table 5-7). Linear modeling was done with a fixed intercept at zero to avoid negative flows that may be predicted if the intercept is allowed to vary at low gaged flows. The upstream Grass Valley Ranch site was selected as the reference reach and other reaches were assigned the maxima and incremental values shown in Table 5-6.

Instream flow habitat was calculated for flows from zero to 120 cfs in the baseline flow record at the gage, which includes all instream habitat value below the point at which floodplain inundation metrics apply.

Table 5-7. Linear model results, including flow max and increment for apportioning flows based on comparison of flows measured at individual sites compared with flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage.

Site	Residual Standard Error	Adjusted R^2	Slope	p-value	Max	Increment
Grass Valley Ranch	4.75	1.00	0.58	0.00074	100	1.00
White Marsh A	7.26	1.00	0.88	0.00052	152	1.52
White Marsh B	15.10	0.99	0.94	0.00199	161	1.61
White Marsh C	0.91	1.00	0.93	0.00001	159	1.59
Hog Heaven	1.01	1.00	0.96	0.00001	166	1.66

5.4.4.6. Reach Habitat Curves

Habitat suitability curves relate physical features of the environment to suitability for occupation, feeding, reproduction, refuge, and other uses to meet habitat needs. A suite of habitat suitability curves representing a range of species, life history stages, and habitat guilds appropriate for lotic Florida waterbodies (Nagid 2022) was used for our Charlie Creek analyses. Plots of these habitat suitability curves are provided in HSW (2021, included as Appendix D to this report). For results presented in this report, names for each assessed group were abbreviated into four-letter codes (Table 5-9).

Reach habitat curves are the key modeling result of a SEFA analysis and relate flow to AWS as a measure of habitat availability. The reach habitat curves for flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage exhibit a variety of patterns or responses (Figure 5-8). Some, such as the curve for Black Banded Darter adults (BBDA), exhibit high sensitivity over very low flow ranges, with subsequent tapering or leveling-off of AWS at higher flows. These types of responses are frequently relatively insensitive to modeled flow reductions because of the relatively flat response or change in AWS at higher flows. Others, such as the juvenile Bluegill (BLUJ) curve, rise to a peak then decrease with higher flows (Figure 5-8). These peaked responses are also often relatively insensitive to flow reductions because losses in habitat at low flows are offset by increases in habitat at high flows.

Other reach habitat curves are J-shaped, such as those for *Tvetenia vitracies* larvae (TVET), where habitat suitability is insensitive to increases in flow at low flows but rises with higher flows (Figure 5-8). These types of curves can be among the most sensitive to modeled flow reductions because losses in flow near the median flow value tend to reduce habitat to zero. Others, such as Hydropsychidae (HYDR), exhibited nearly linear responses across the entire range of flows (Figure 5-8). These linear responses are among the most sensitive to flow reductions because they directly result in a loss in habitat with a reduction in flows.

Table 1-9. Habitat suitability curves used in this analysis with their four-letter abbreviations (Code).

Code	Species	Stage
REDA	Redbreast Sunfish	Adult
REDJ	Redbreast Sunfish	Juvenile
REDS	Redbreast Sunfish	Spawning
REDF	Redbreast Sunfish	Fry
SHSL	Shallow	Slow
SHFA	Shallow	Fast
DPSL	Deep	Slow
DPFA	Deep	Fast
DART	Darters	Adult
PHEM	Ephemeroptera	Larvae
PLEC	Plecoptera	Larvae
TRIC	Tricoptera	Larvae
TINV	Total Invertebrates	Larvae
PSEU	Pseudocloeon ephippiatum	Larvae
HYDR	Hydropsychidae	Total
TVET	Tvetenia vitracies	Larvae
LMBA	Largemouth Bass	Adult
LMBJ	Largemouth Bass	Juvenile
LMBS	Largemouth Bass	Spawning
LMBF	Largemouth Bass	Fry
BLUA	Bluegill	Adult
BLUJ	Bluegill	Juvenile
BLUS	Bluegill	Spawning
BLUF	Bluegill	Fry
SPOA	Spotted Sunfish	Adult
SPOJ	Spotted Sunfish	Juvenile
SPOS	Spotted Sunfish	Spawning
SPOF	Spotted Sunfish	Fry
CYPA	Cyprinidae	Adult
CCAD	Channel Catfish	Adult
CCJU	Channel Catfish	Juvenile
CCSP	Channel Catfish	Spawning
CCFR	Channel Catfish	Fry
CCJP	Channel Catfish	Juvenile (Spring)
CCJS	Channel Catfish	Juvenile (Summer)
CCJF	Channel Catfish	Juvenile (Fall)

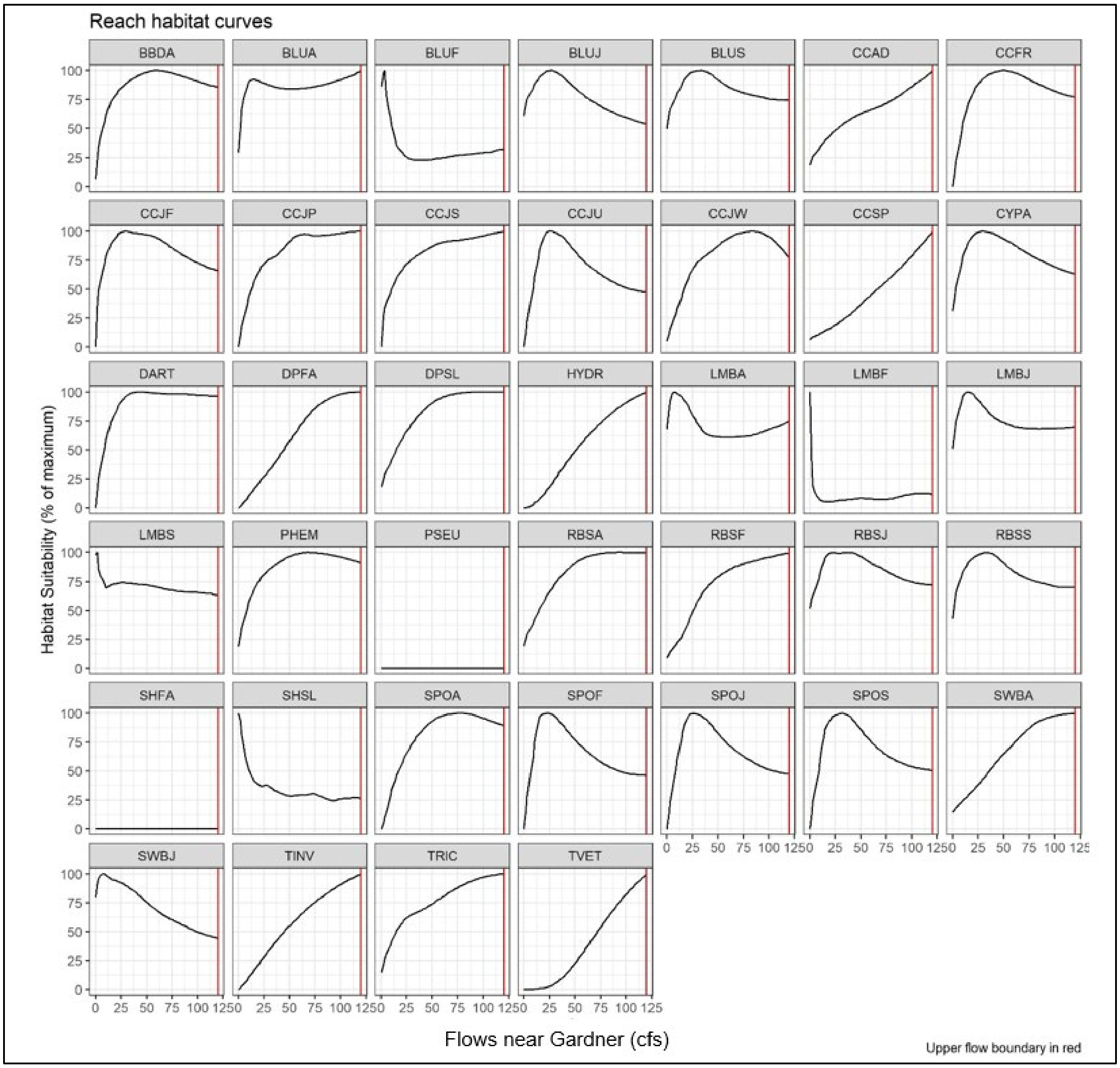

Figure 5-8. Reach habitat curves for species/life history stages/niche guilds. The red line 120 cfs at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage which is the boundary between instream flows and floodplain inundation.

5.4.4.7. Filtering of Species Based on AWS-Flow Relationships

The percent-of-flow method for determining minimum flows assumes a consistent relationship between habitat and flow within a flow "block". For a percent-of-flow loss to result in the same percent of habitat loss across a range of flows, the slope of the line relating flow on the x-axis to habitat on the y-axis must be invariant. This means that the habitat-flow relationship must be linear to meet the implicit assumption in the percent-of-flow approach. J-shaped curves violate this assumption, and result in a situation where at flows corresponding to the initial insensitive part of the curve, further losses in flow do not result in losses of habitat. We do not think it is necessary that the linearity pass a formal statistical test, but it is possible to screen out relationships between AWS and flow that are not consistent across the flow range of interest.

For Charlie Creek, the flow range from 0 cfs to 120 cfs at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage is of interest based on the flows that are retained within creek banks. To eliminate species with curves that are overly concave or J-shaped, we included only those with at least 5% of their maximum AWS by the fish passage flow of 15 cfs. This resulted in the exclusion of PSEU, SHFA, and TVET reach habitat curves from further analysis.

5.4.4.8. Flow Reduction Scenarios

Using the reach habitat curves and the daily flow record of baseline flows, a daily habitat suitability is generated for each species. The average (mean) habitat suitability over this flow record is taken as a summary of the overall habitat provided by the flow record. Reduced flow scenarios are created by reducing each daily flow by a percentage, and recalculating habitat suitability based on each new reduced flow scenario. Reduced flow scenarios are then compared to the baseline flow scenario to calculate the percentage loss in habitat associated with percentage loss in flows (Figure 5-9). The most sensitive responses show a downward trend where habitat decreases with decreasing percent-of-flow.

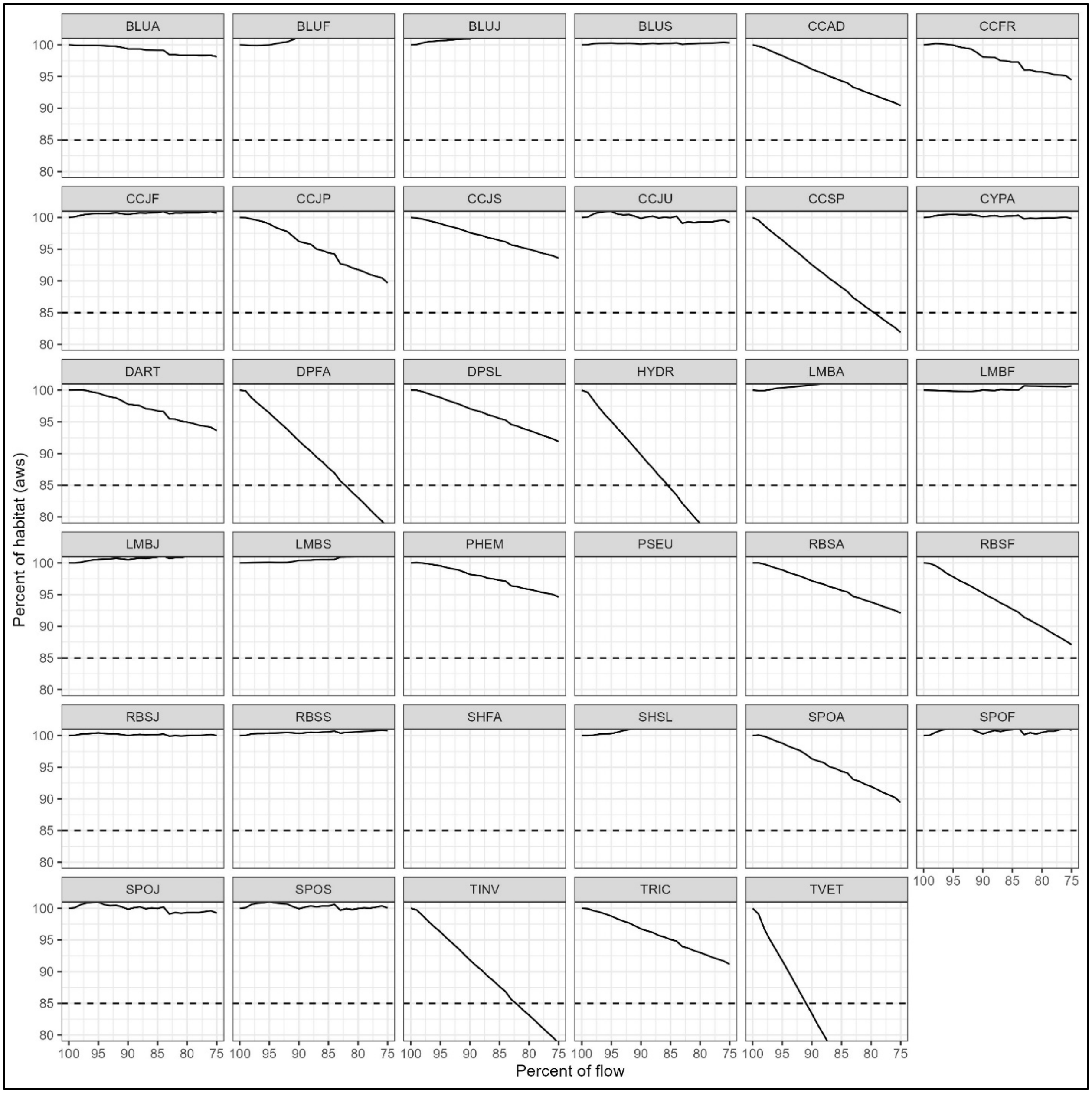

Figure 5-9. Loss of habitat associated with reduced flow scenarios from baseline conditions in Charlie Creek. Note the x-axis is reversed such that 100% of the baseline flow is on the left. The dashed line shows an 85% of habitat threshold.

5.4.4.9. Evaluation of Woody Habitat Inundation

Live (exposed roots) and dead (snags) instream woody habitats were assessed at seven sites on Charlie Creek (Figure 5-10). At each site, cross-sections from the top of bank on one side of the channel through the river and up to the top of bank on the opposite channel, were established. Minimum and maximum (e.g., top and bottom elevations relative to NAVD88) of up to 15 samples of exposed root and snag habitats in the vicinity of each cross-section were measured along each bank and averaged for each cross-section site. Flows at Charlie Creek near Gardner Gage that would result in inundation of the mean exposed root and snag habitat elevations at each cross-section were determined using the HEC-RAS model (Table 5-10).

Because flow requirement for snags at site T5 was less than the low flow threshold (27 cfs), flow reductions that would result in significant harm associated with snag habitats were not calculated. Similarly, exposed roots at all sites and snags at T1, T2, T2.5 and T4.5 were not considered in the woody habitat analysis since their flow requirement for inundation exceeded the 120 cfs flow associated with floodplain inundation. Of the seven sampling sites, only two sites for snags (T6 and T7) that were inundated at flows between 27 and 120 cfs were considered appropriate for the woody habitat analysis.

The two site-specific flow requirements and nine additional with-bank flows between 27 and 120 cfs were then used along with the baseline flow record and sequentially reduced flow records to identify the number of days during the historic period of record that the specified flows were equaled or exceeded.

Because sustained inundation prior to colonization by invertebrates is essential for microbial conditioning and periphyton development that enhances the woody habitat utility for many invertebrate species, we assessed 1-day, 7-day and 30-day durations of flows associated with the specified flows. Several days of inundation were evaluated because the rate of biofilm accumulation on instream woody habitat can vary widely in different streams and seasonally within a stream (Findlay 2010, Gulis et al. 2008).

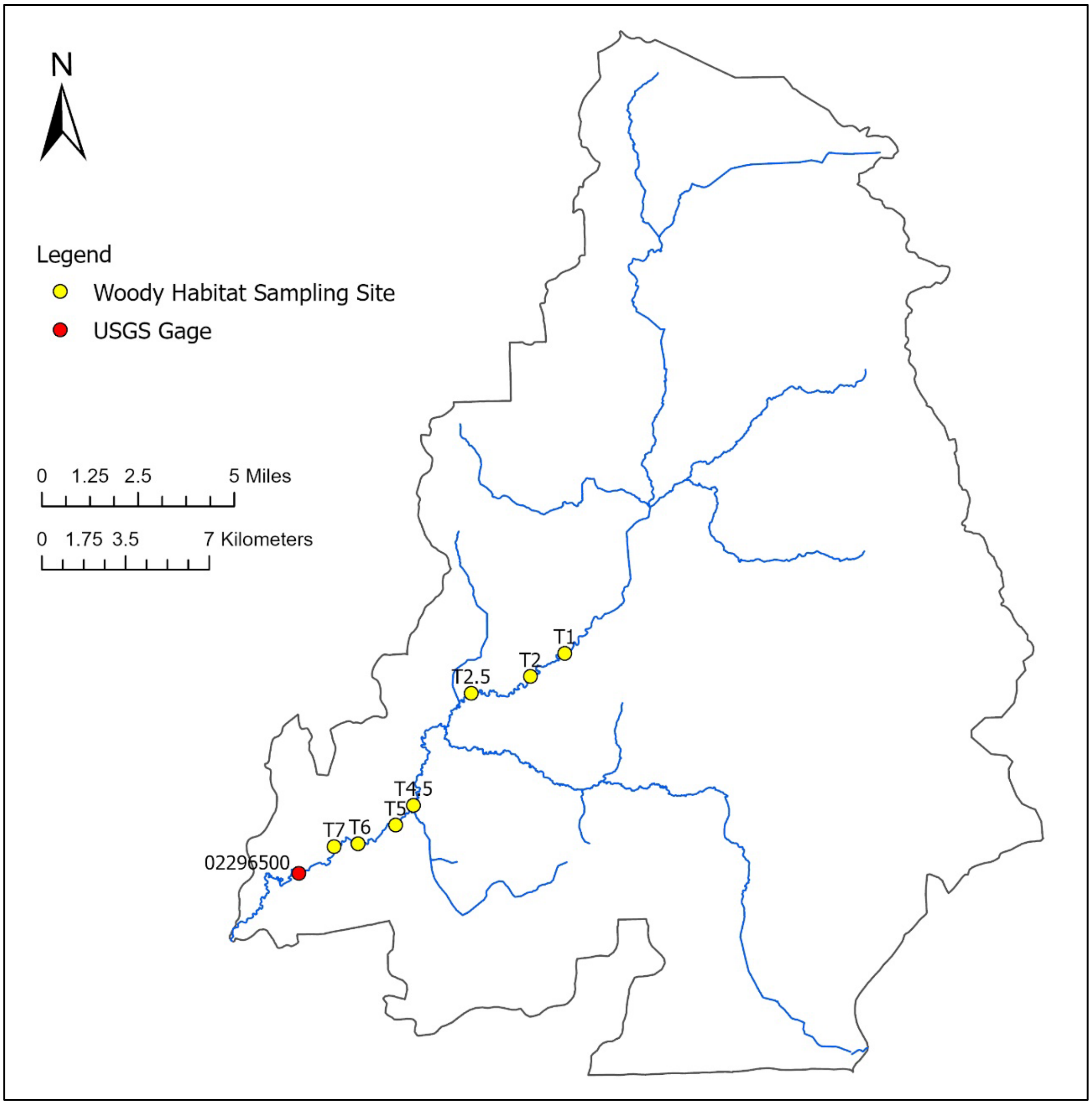

Figure 5-10. Locations of the woody habitat data collection sites and the USGS Charlie Creek near Gardner, FL (No. 02297500) gage used for analysis.

Table 5-10. Flows at the USGS Charlie Creek near Gardner (No. 02296500) gage required to inundate elevations of instream woody habitats (exposed roots and snags) at seven sites in Charlie Creek.

Site	Elevation (ft, NAVD88)		Charlie Creek Flows (cfs) near Gardner Gage	
	Snags	Exposed Roots	Snags	Exposed Roots
T1	50.8	49.8	598.1	392.7
T2	41.9	41.9	187.7	187.7
T2.5	43.0	42.0	582.5	417.0
T4.5	34.6	32.7	344.8	137.9
T5	28.7	32.8	8.0	260.4
T6	29.2	30.0	118.6	171.5
T7	27.3	29.0	63.9	173.2

CHAPTER 6 – RESULTS OF THE MINIMUM FLOW ANALYSES

The District approach for setting minimum flows is generally habitat-based and involves assessment of sensitive ecological resources that provide protection to all relevant environmental values identified in the Water Resource Implementation Rule for consideration when establishing minimum flows or levels. Results from modeling and field data for Charlie Creek were assessed to develop minimum flows and to ensure the ecological characteristics and functions associated with various flows and levels are protected from significant harm. A low flow threshold based on fish passage depth and wetted perimeter inflection points is recommended. Based on low flow threshold and 15% change in habitat criteria minimum flows are also identified for flow-based blocks corresponding with low (Block 1), medium (Block 2) and high (Block 3) flow ranges.

6.1. Low flow threshold

The low flow threshold defines flows that are to be protected in their entirety (i.e., flows that are not available for consumptive-use) throughout the year. The low flow threshold is established at the higher of two flow standards, which are based on maintaining fish passage and maximizing wetted perimeter for the least amount of flow in the river channel. Results of fish passage and wetted perimeter were used to develop a recommended low flow threshold for Charlie Creek.

6.1.1. Fish Passage Results

Flows necessary to reach a maximum water depth of 0.6-ft (0.18-m) to allow fish passage at each of the 36 cross-sections in the HEC-RAS model of Charlie Creek between the USGS Charlie Creek near Crewsville, FL (No. 02296260) gage and the USGS Charlie Creek near Gardner, FL (No. 02296500) gage were identified (Figure 6-1).

At most cross-sections, the minimum water surface elevation that would allow for fish passage was lower than the elevation associated with the lowest modeled flow. These cross-sections were located in pool or run areas, where fish passage would be possible during low flow periods. The analysis also indicated that to maintain fish passage depth at the most restrictive cross-section, a flow of 27 cfs is required at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage. A flow of 27 cfs was therefore used to define the fish passage criterion for the USGS Charlie Creek near Gardner, FL (No. 02296500) gage site on Charlie Creek. The standard flow is sufficient to maintain constant flow in the river and would minimize problems such as low dissolved oxygen levels that may be associated with low flow or stagnant conditions.

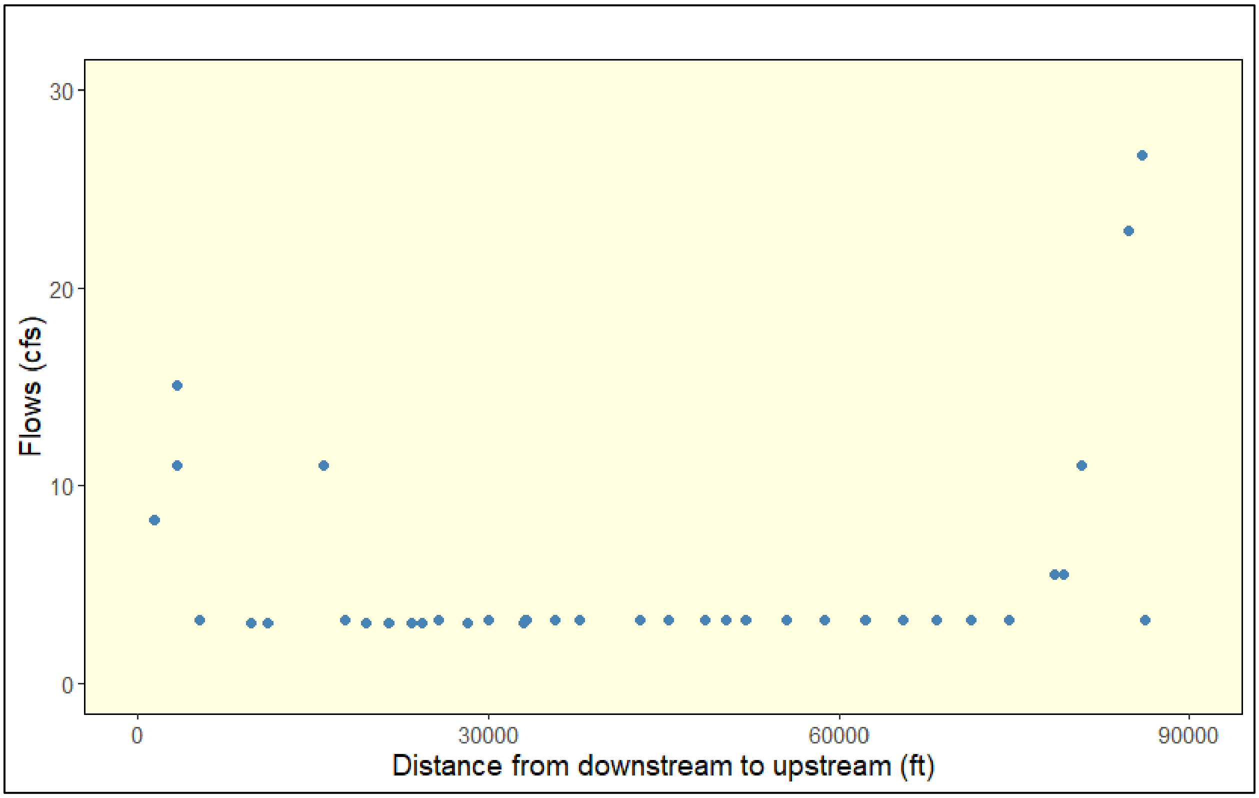

Figure 6-1. Flow required at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage to inundate the deepest part of the channel to a depth of 0.6 ft in the Horse Creek HEC-RAS model, arrayed by distance upstream of the gage.

6.1.2. Evaluation of Wetted Perimeter Results

Wetted perimeter plots (wetted perimeter versus local flow) were developed for each HEC-RAS cross-section of Charlie Creek to identify the LWPIP as potential low flow threshold protective of benthic macroinvertebrates and other benthic organisms and processes. Most cross-sections exhibited no LWPIP or LWPIPs associated with flows above 50 cfs at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage and for these cross-sections, the LWPIP was established at the lowest modeled flow, 0.9 cfs. The six cross-sections that exhibited an LWPIP for flows of less than 30 cfs at the USGS Horse Creek near Arcadia gage are shown in Figure 6-2.

A flow of 19.1 cfs at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage would, therefore, be sufficient to meet the local LWPIP flows at all assessed cross-sections in Charlie Creek (Table 6-1).

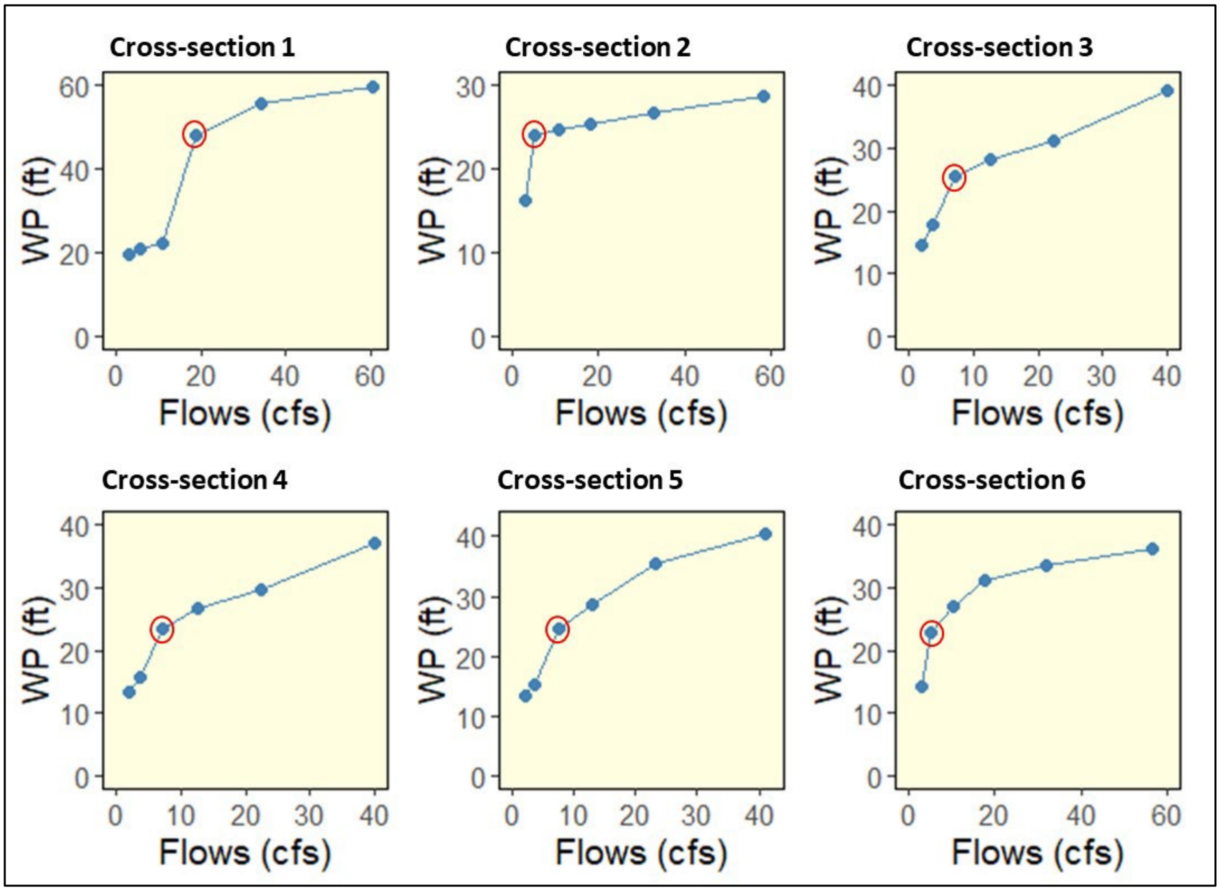

Figure 6-2. Plot of local flows versus wetted perimeter in Charlie Creek at 6 HEC-RAS model cross-sections that exhibited a lowest wetted perimeter inflection point (highlighted with red circles) at flows associated with less than a 50 cfs flow at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage.

Table 6-1. Summary of Lowest Wetted Perimeter Inflection Point (LWPIP) results for six HEC-RAS model cross-sections in Charlie Creek.

Transect	Wetted Perimeter at LWPIP (ft)	Flow (cfs) at Cross-section for LWPIP	Flow (cfs) at Gage for LWPIP
1	48.0	5.5	19.1
2	23.9	5.3	5.5
3	25.5	7.2	11.0
4	23.5	7.2	11.0
5	24.6	7.4	11.0
6	22.7	5.1	5.5

6.1.3. Recommended Low Flow Threshold

A low flow threshold of 27 cfs was identified for Charlie Creek at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage. The low flow threshold was established at the higher of the fish passage and wetted perimeter criteria and is therefore expected to provide protection for ecological values associated with both criteria. Although flows in the creek at the gage site may be expected to drop below the low flow threshold naturally, the threshold is defined to be a flow that serves as a limit to surface withdrawals throughout the year, with no withdrawals permitted from the river unless the threshold flow is exceeded.

6.2. Floodplain Inundation Results

The floodplain inundation analysis was conducted based on the flow-inundated area relationship at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage (Figure 6-3). Using the baseline flow record (May 1,1950 through December 31, 2021), flow reductions that would result in a 15% reduction of floodplain inundation area were identified.

Based on historic flow records, inundation of floodplain habitats in Charlie Creek is largely expected during Block 3 when flow exceeds the capacity of the creek channel and water spills over the creek banks into adjacent, low lying floodplain areas. However, some floodplain areas may also be inundated when flow is low and remains in the channel. This can occur when rainfall pools in low lying floodplain areas during low flow periods when there are no direct surface water connections between low areas and the creek channel. These depressional areas can be characterized as “ineffective” inundated areas when the creek flow is low. During high flow conditions, however, the depressional areas may be inundated when water overtops the creekbank.

For floodplain habitat assessments associated with minimum flows, inundated areas that have no direct connection to creek flows should be excluded. Manually checking for ineffective inundation areas through each cross-section is difficult and fraught with uncertainty regarding possible floodplain-channel connections between model cross-sections. A simpler approach for addressing this issue involves the use of sensitivity analysis to distinguish floodplain inundation associated with overbank flooding from inundation associated with ineffective flow areas.

Percent-of-flow reductions that would result in a 15% decrease in the amount of total inundated wetlands adjacent to Charlie Creek were assessed for flows at and above 1st percentile, 2nd percentile, and so on, up to 99th percentile. When plotted against flow percentiles, the percent-of-flow reductions exhibited three general sensitivity patterns (Figure 6-4). For low flow percentiles, percent-of flow reduction changes were relatively flat with no appreciable gradient. For mid to high flow percentile, the percent-of-flow reductions exhibited greater sensitivity, with sensitivity increasing with flows.

We numerically approximated changes in sensitivity, i.e., the slope of the flow percentiles and percent-of-flow reduction curve, by fitting four straight lines to the data (Figure 6.4) and finding a maximum combined coefficient of determination (R^2) for the four lines. The maximum combined R^2 was obtained at 58th, 75th and 93rd flow percentiles. It should be noted that the combined R^2 does not have a true statistical meaning–we simply used it as a quantitative indicator of best fit to divide the sensitivity curve into three parts based on slope changes. For flows between the 1st to 58th percentile, the 15% decrease in the total inundated wetlands exhibited minimal sensitivity to flow reductions. This lack of sensitivity to flow reductions for the lower flow percentiles suggests that overbank flooding does not occur until the flow is above the 58th percentile, which is approximately 120 cfs. This 120 cfs flow was, therefore, used to define the threshold between the medium-flow, Block 2, and the higher flow, Block 3.

In addition, to ensure protection of relatively infrequent higher flow pulses that are important for physical and ecological processes in the creek, Block 3 was split into three sub-blocks at the 75th flow percentile (approximately 316 cfs) and at the 93rd flow percentile (approximately 945 cfs), based on the sensitivity of total inundated wetland area to river flow reductions.

For flows between 120 and 316 cfs, percent-of-flow reductions between 12.3% and 11.2% would result in 15% or less reduction in the total inundated wetlands in Charlie Creek (Table 6-2). For flows between 316 cfs and 945 cfs, percent-of-flow reductions between 11.1% and 8.8% would result in 15% or less reduction in the total inundated wetlands (Table 6-3). For flows above 945 cfs, percent-of-flow reductions between 8.2% and 4.7% would result in 15% or less reduction in the total inundated wetlands (Table 6-4). Based on average allowable flow reductions for preventing significant harm to floodplain wetlands (see Tables 6-2, 6-3 and 6-4), 88% of the baseline flow for flows between 120 and 316 cfs and 91% of the baseline flow for flows between 316 and 945 cfs and 93% of the baseline flow for flows greater than 945 cfs at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage are recommended.

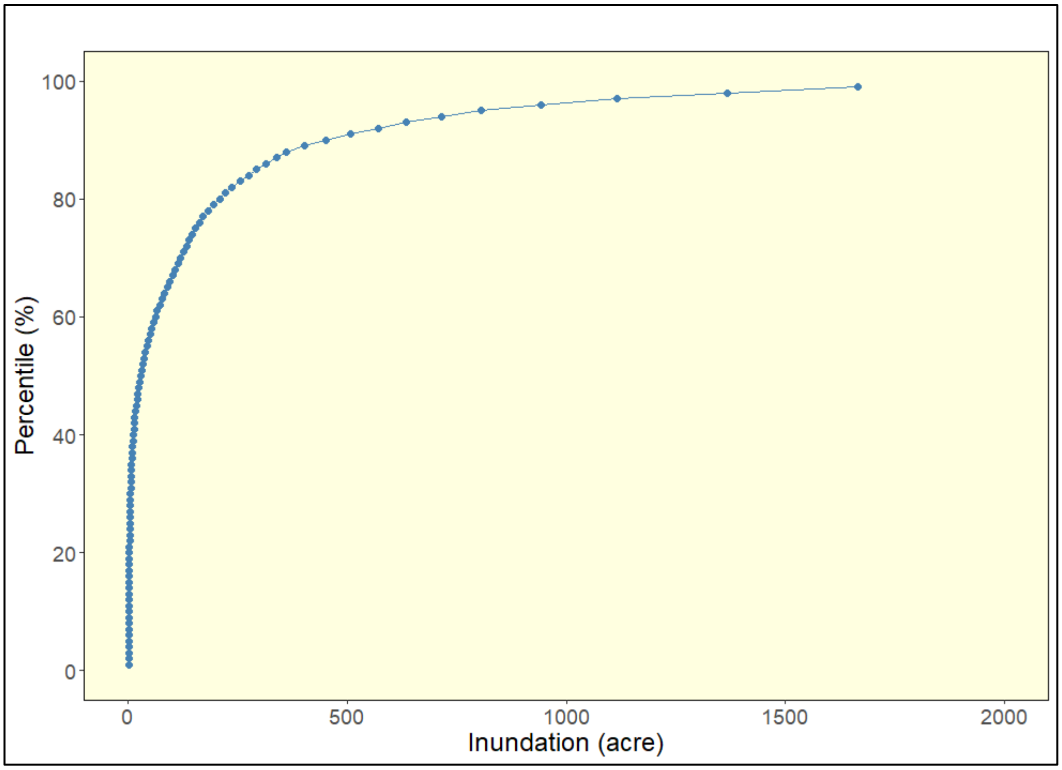

Figure 6-3. A flow percentile versus area of total inundated floodplains at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage.

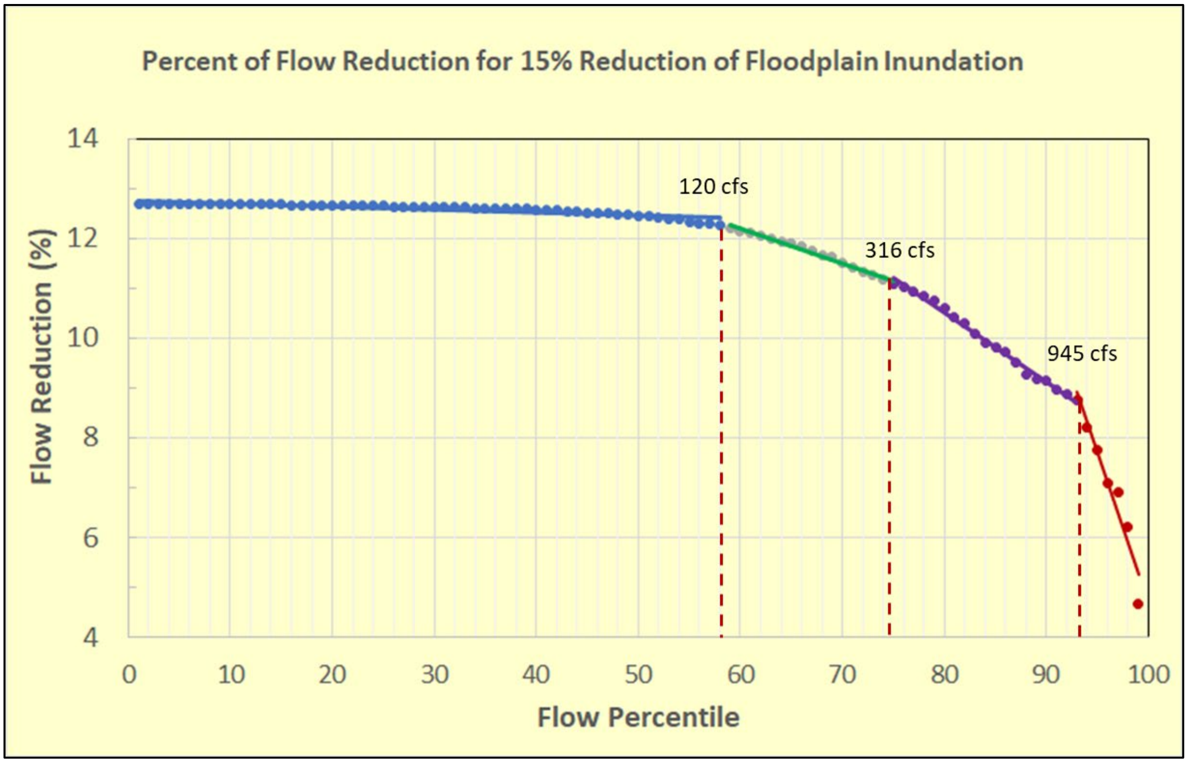

Figure 6-4. The sensitivity between the percent-of-flow reductions that would result in a 15 percent decrease in the amount of total inundated wetlands and river flow percentiles in Charlie Creek. Note the fitting of four lines for low, mid and high flow percentile portions of the sensitivity curve.

Table 6-2. Key results of Charlie Creek floodplain analysis for Block 3a, demonstrating percent-of-flow reductions at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage that result in a 15% decrease in the total inundated wetland area of Charlie Creek, based on baseline flow records from May 1, 1950, through December 31, 2021.

Flow Percentile (%)	Flow (cfs)	Inundation Area (acre)	Allowable flow reductions (%)
58	120.23	54.45	12.3
59	126.74	58.34	12.2
60	133.37	62.30	12.2
61	141.06	66.89	12.1
62	150.13	72.31	12.1
63	159.26	77.76	12.0
64	169.68	83.99	11.9
65	180.22	90.29	11.9
66	189.89	96.07	11.8
67	199.91	102.06	11.8
68	211.04	108.17	11.7
69	225.02	114.40	11.6
70	237.63	120.02	11.5
71	252.80	126.78	11.4
72	268.34	133.70	11.3
73	282.63	140.07	11.3
74	297.37	146.64	11.2
75	316.08	154.98	11.1
Allowable average withdrawal			**12**

Table 6-3. Key results of Charlie Creek floodplain analysis for Block 3b, demonstrating percent-of-flow reductions at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage that result in a 15% decrease in the total inundated wetland area of Charlie Creek, based on baseline flow records from May 1, 1950, through December 31, 2021.

Flow Percentile (%)	Flow (cfs)	Inundation Area (acre)	Allowable flow reductions (%)
76	334.51	163.19	11.1
77	352.37	171.16	10.9
78	373.07	182.57	10.8
79	395.23	195.48	10.8
80	418.33	208.92	10.6
81	441.13	222.20	10.4
82	467.55	237.58	10.3
83	501.63	257.42	10.1
84	531.71	274.93	9.9
85	564.31	293.92	9.9
86	600.52	315.01	9.8
87	640.22	338.14	9.5
88	677.79	360.59	9.3
89	719.84	403.80	9.2
90	766.82	452.08	9.2
91	822.08	508.86	8.9
92	882.13	570.57	8.9
93	945.41	635.07	8.8
Allowable average withdrawal			**9**

Table 6-4. Key results of Charlie Creek floodplain analysis for Block 3c, demonstrating percent-of-flow reductions at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage that result in a 15% decrease in the total inundated wetland area of Charlie Creek, based on baseline flow records from May 1, 1950, through December 31, 2021.

Flow Percentile (%)	Flow (cfs)	Inundation Area (acre)	Allowable flow reductions (%)
94	1028.51	715.63	8.3
95	1122.60	806.85	7.8
96	1261.12	941.14	7.2
97	1440.74	1115.29	7.0
98	1705.27	1366.59	6.2
99	2103.13	1665.91	4.6
Allowable average withdrawal			**7.0**

6.3. Instream habitat

This section describes the results from SEFA modeling to determine effects of flow reductions on habitat availability for fish and macroinvertebrates and HEC-RAS modeling to determine impacts of flow reductions on instream woody habitat inundation.

6.3.1. Habitat Suitability Modeling Results

Significant harm is defined as a loss of habitat greater than or equal to 15% of the total available under baseline flow conditions. Five species are predicted to experience instream habitat losses that occur at flow reductions less than or equal to 25% (Figure 6-6). The net-spinning caddisflies of the family Hydropsychidae (HYDR) are the most sensitive group with a 15% loss of habitat occurring at flow reductions greater than 14%, or at 86% of the baseline flows.

These results are consistent with known habitat preference information for HYDR. The average depth for all 15 assessed cross-sections increased with flow (Figure 6-7). These average depths increase from 0.66 ft at zero flow to 2.44 ft at 120 cfs. These depths correspond to the rising arm of the habitat suitability curve for HYDR (Figure 5-6). This means that over the range of flows evaluated, the relationship between flow and depth results in a positive relationship between flow and habitat suitability of HYDR. This relationship is based on the geometry and hydrology of the assessed cross-sections as well as the habitat suitability curves for HYDR (HSW 2021, included as Appendix D to this report; Nagid 2022).

The average velocity for all 15 cross-sections surveyed also increased with flow (Figure 6-8). These average velocities increased from 0.00 ft/s at zero flow to 0.933 ft/s at 120 cfs. These average velocities correspond to the rising arm of the habitat suitability curve for HYDR (Figure 5-5). This means that over the range of flows we are interested in, there was a steep increase in habitat suitability for velocity associated with an increase in flows, based on the geometry and hydrology of the assessed cross-sections.

The habitat suitability curves for HYDR (HSW 2021, included as Appendix D to this report; Nagid 2022) were based on data collected by Warren and Nagid (2008) in the northern Withlacoochee River, Florida. The curves for depth and velocity (Figure 5-6) are directly translated from the northern Withlacoochee data, converted from cm to ft (Figure 6-9). Substrate suitability was modified from the data collected on the northern Withlacoochee River (Figure 6-10) to match the categorization of other habitat suitability curves (Figure 5-6). Based on the depths, velocities, and substrate types found in the assessed portion of Charlie Creek, and their corresponding habitat suitability for HYDR, it makes sense that this taxonomic group was sensitive to reduced flows.

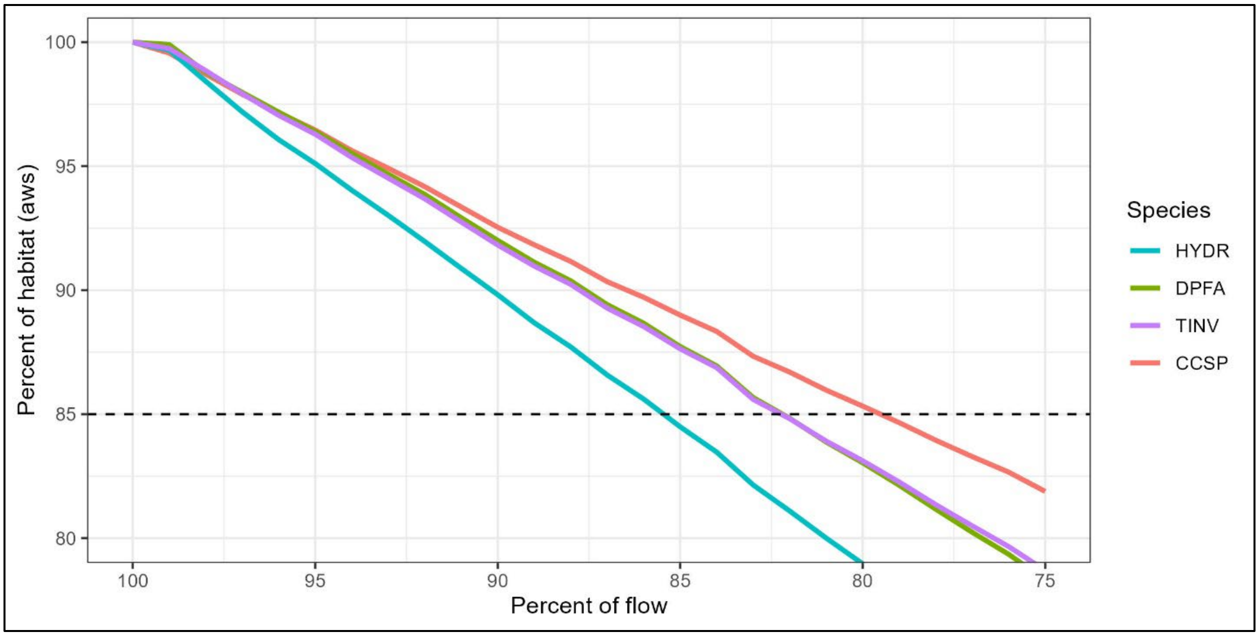

Figure 6-6. Habitat loss of the most sensitive species assessed for Charlie Creek. The significant harm threshold is shown as a dashed line at 85% of habitat that would occur under the baseline condition unimpacted by withdrawals. The minimum allowable percent-of-flow occurs where the line for each species crosses the dashed threshold line. Only species, groups, and species life stages that exhibit a 15% or greater loss in habitat with flow reductions of less than 25% are shown, and these include Hydropsychidae (HYDR), the deep fast habitat guild (DPFA), total invertebrates (TINV) and spawning Channel Catfish (CCSP)

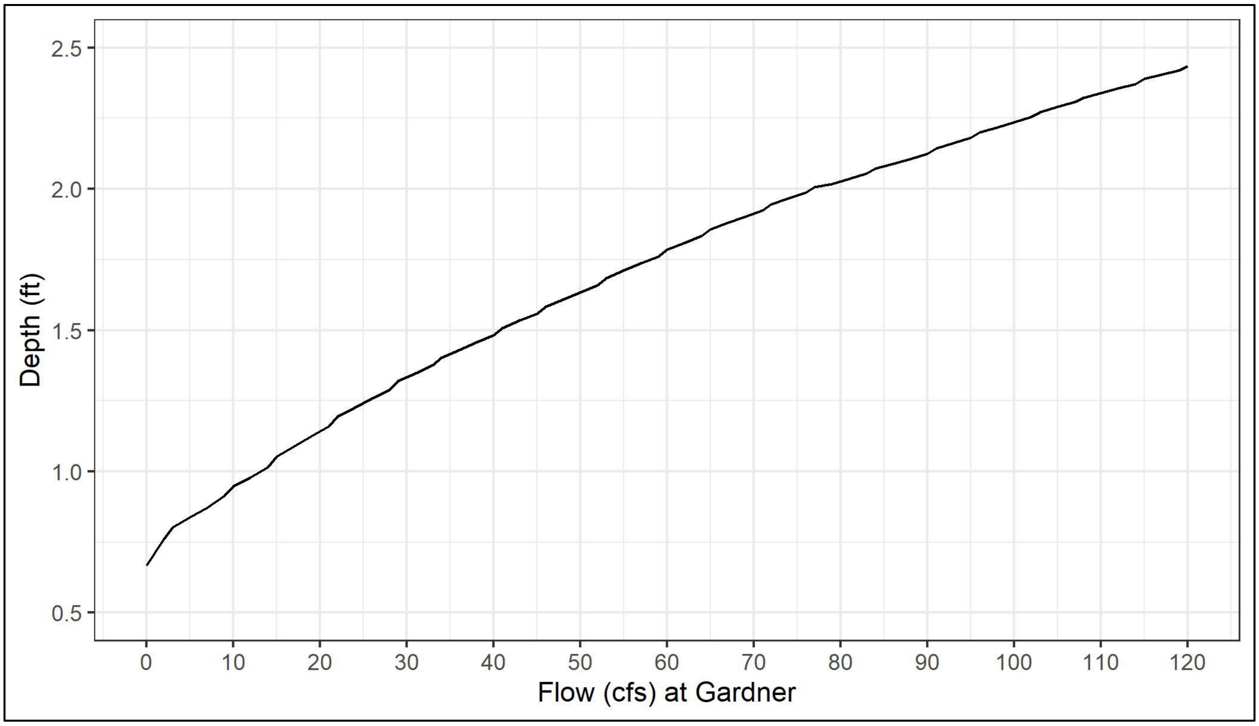

Figure 6-7. Average depth across all SEFA sites compared to flow at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage.

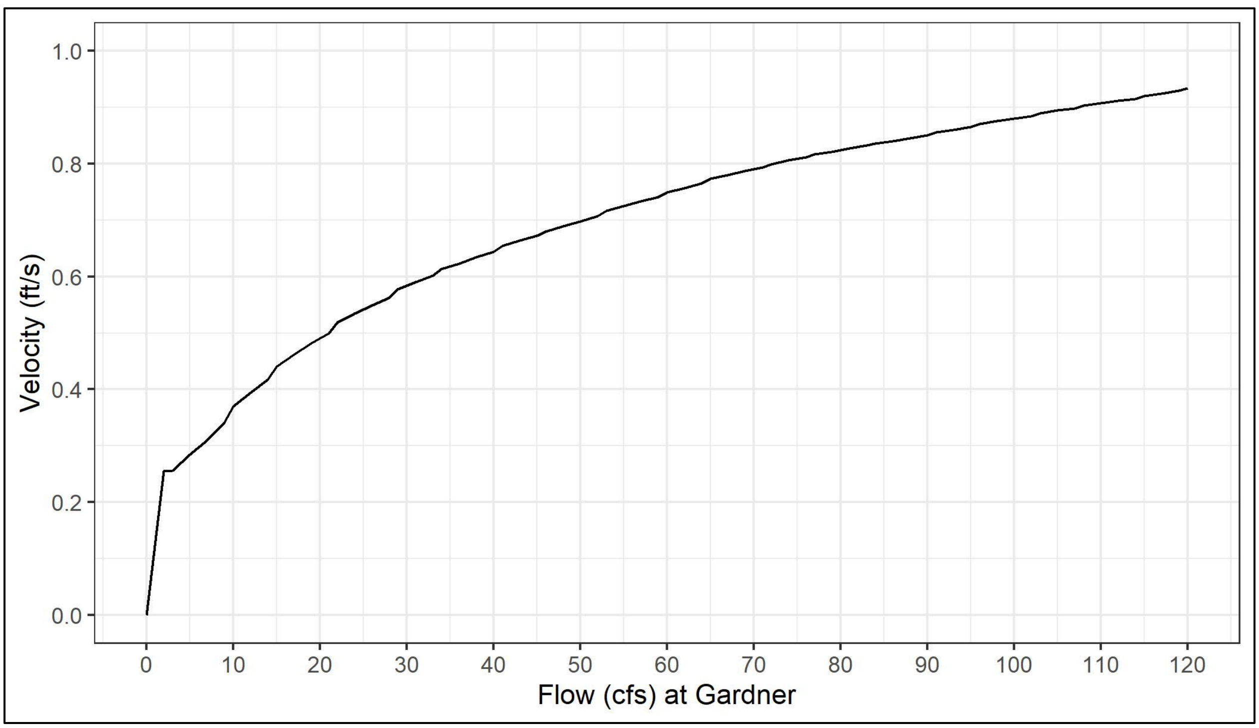

Figure 6-8. Average velocity across all SEFA sites compared to flow at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage.

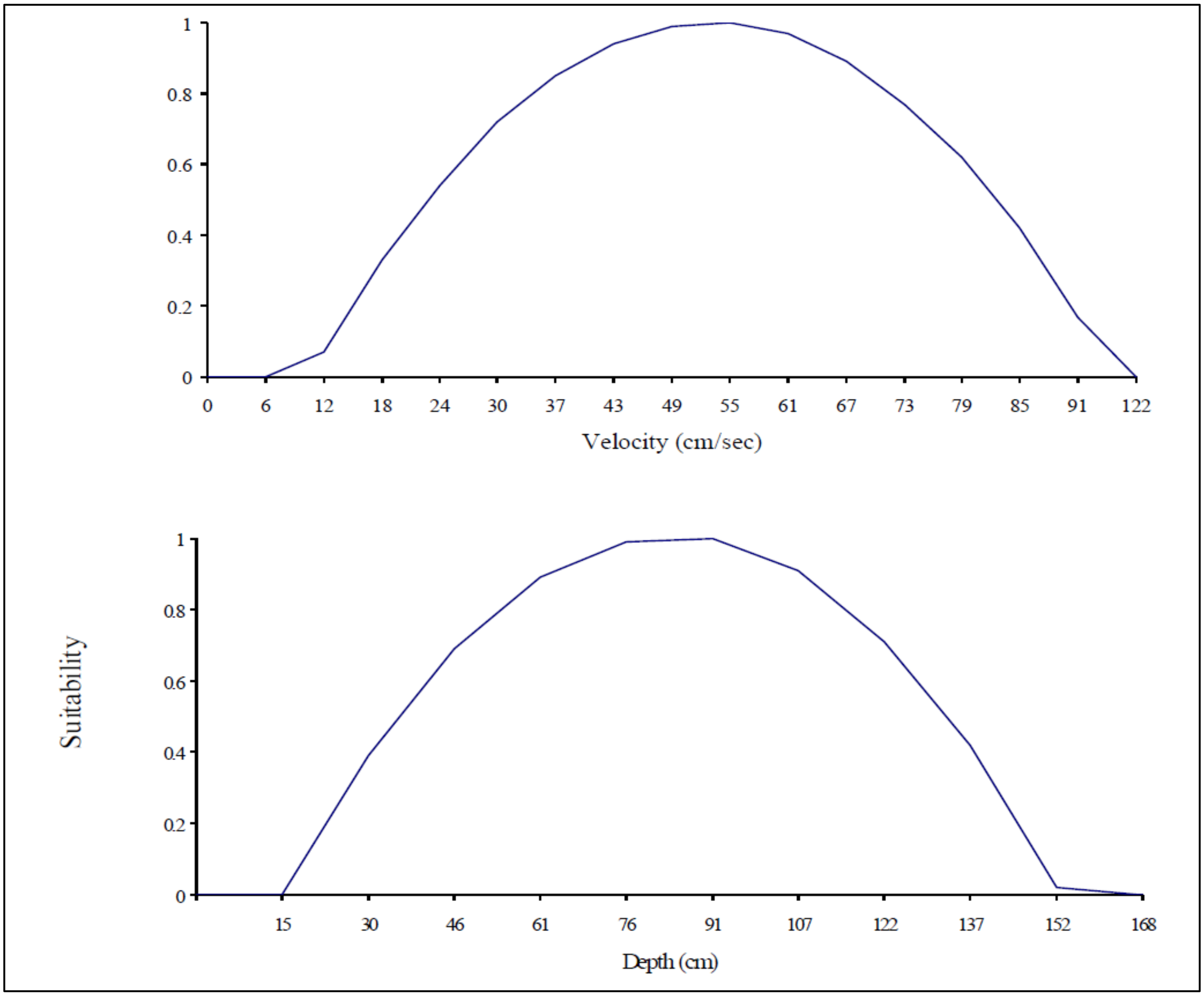

Figure 6-9. Depth and velocity habitat suitability curves for Hydropsychidae based on northern Withlacoochee River data (Warren and Nagid 2008).

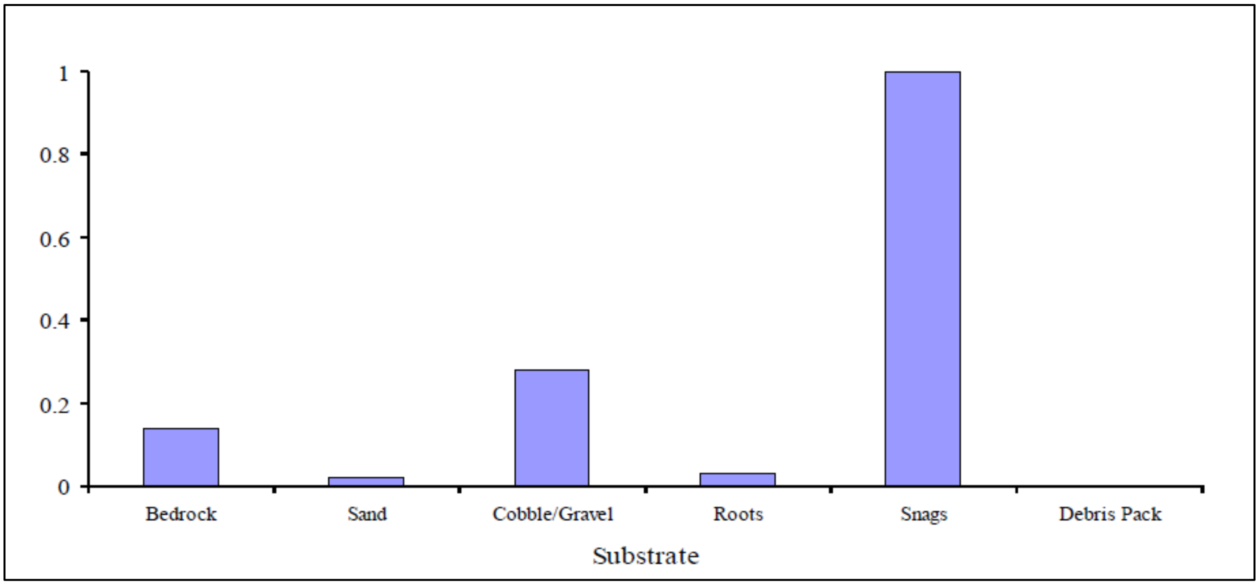

Figure 6-10. Substrate suitability for Hydropsychidae from northern Withlacoochee data from Warren and Nagid (2008).

6.3.2. Woody Habitat Inundation Results

Inundation patterns of exposed root and snag habitats were examined at two instream habitat cross-sections and nine selected flow targets between the 27 cfs low flow threshold and the 120 cfs overbank flow threshold in Charlie Creek. The number of days to which these flow targets were equaled or exceeded for 1-day, 7-day, 30-day duration were assessed using the baseline flow record from May 1,1950 through December 31, 2021. Percent-of-flow reductions that would result in greater than a 15% reduction in the number of days the specified duration-events occurred relative to those associated with baseline conditions were also calculated (Table 6-5).

The mean allowable flow reduction associated with the 1-day duration events was 39%, with a range of 31% to 50%. The mean allowable flow reduction for inundations of 7-day duration was 32%, with a range from 25% to 43%. Inundations for 30 days were relatively sensitive to reductions in flow, with a mean allowable flow reduction of 22%, with a range from 14% to 33% (Table 6-5). Based on these woody habitat inundation results, a 22% flow reduction from baseline conditions is considered protective of woody habitats in Charlie Creek.

Table 6-5. Selected instream woody habitats flow targets and allowable flow reductions associated with a 15% reduction from baseline conditions in the number of days of flow sufficient to inundate woody habitat for 1-day, 7-day, and 30-day durations at 3 sites in Charlie Creek.

Site	Target Flows at Gage near Gardner (cfs)	Maximum Allowable Flow Reduction (%)		
		1-Day	7-Day	30-Day
	27.0	50	43	33
	30.0	48	41	33
	40.0	45	38	27
	50.0	42	34	23
	63.9	39	31	20
	70.0	37	31	22
	80.0	35	30	20
	90.0	34	27	18
	100.0	32	26	16
T6 (Snags)*	110.0	32	26	14
T7 (Snags)*	118.6	31	25	17
Mean Allowable Reduction		**39**	**32**	**22**

*Measured elevations of woody habitat that require flows between 27 and 120 cfs

6.4. Proposed Minimum Flows

Resource management goals identified for the development of minimum flows for Charlie Creek included the following:

- Determination of a low flow threshold to provide protection for ecological resources and recreational use of Charlie Creek during critical low-flow periods.
- Maintenance of seasonal hydrologic connections between the Charlie Creek channel and floodplain to ensure persistence of floodplain structure and function.
- Maintenance of available instream habitat for fish and benthic macroinvertebrates.
- Maintenance of the inundation of instream woody habitat, including exposed roots and snags.
- Maintenance of water quality.

A percent-of-flow approach was used with several block-specific criteria to develop minimum flows for Charlie Creek that ensure maintenance of 85% of the most sensitive criterion, and by default all criteria associated with the resource management goals. A low flow threshold was also identified to ensure flow continuity for environmental and human use values. Assessments were conducted to ensure all relevant environmental values that must be considered when establishing minimum flows would be protected by the minimum flows proposed for Charlie Creek.

Based on the results of the analysis described in the previous sections, the proposed minimum flows for Charlie Creek are described in Table 6-6 and Figure 6-11. For Charlie Creek, the recommended minimum flows for Block 1 are based on fish passage, for Block 2 are based on maintaining available instream habitat and for Block 3 are based on maintaining floodplain inundation. The recommended minimum flows are based on flows for the previous day at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage that have been adjusted for withdrawal effects.

Table 6-6. Proposed minimum flows for Charlie Creek based on flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage that have been adjusted for withdrawal effects.

Flow-Based Block	If Previous Day's Flow, Adjusted for Withdrawals, is:	Recommended Minimum Flow is:	Potential Allowable Flow Reduction is:
1	≤ 27 cfs	Flow on the previous day	0 cfs
2	> 27 cfs and ≤ 120 cfs	27 cfs or 86% of the flow on the previous day, whichever is greater	14% of flow on the previous day
3a	> 120 cfs and ≤ 316 cfs	88% of the flow on the previous day	12% of flow on the previous day
3b	> 316 cfs and ≤ 945 cfs	91% of the flow on the previous day	9% of flow on the previous day
3c	> 945 cfs	93% of the flow on the previous day	7% of flow on the previous day

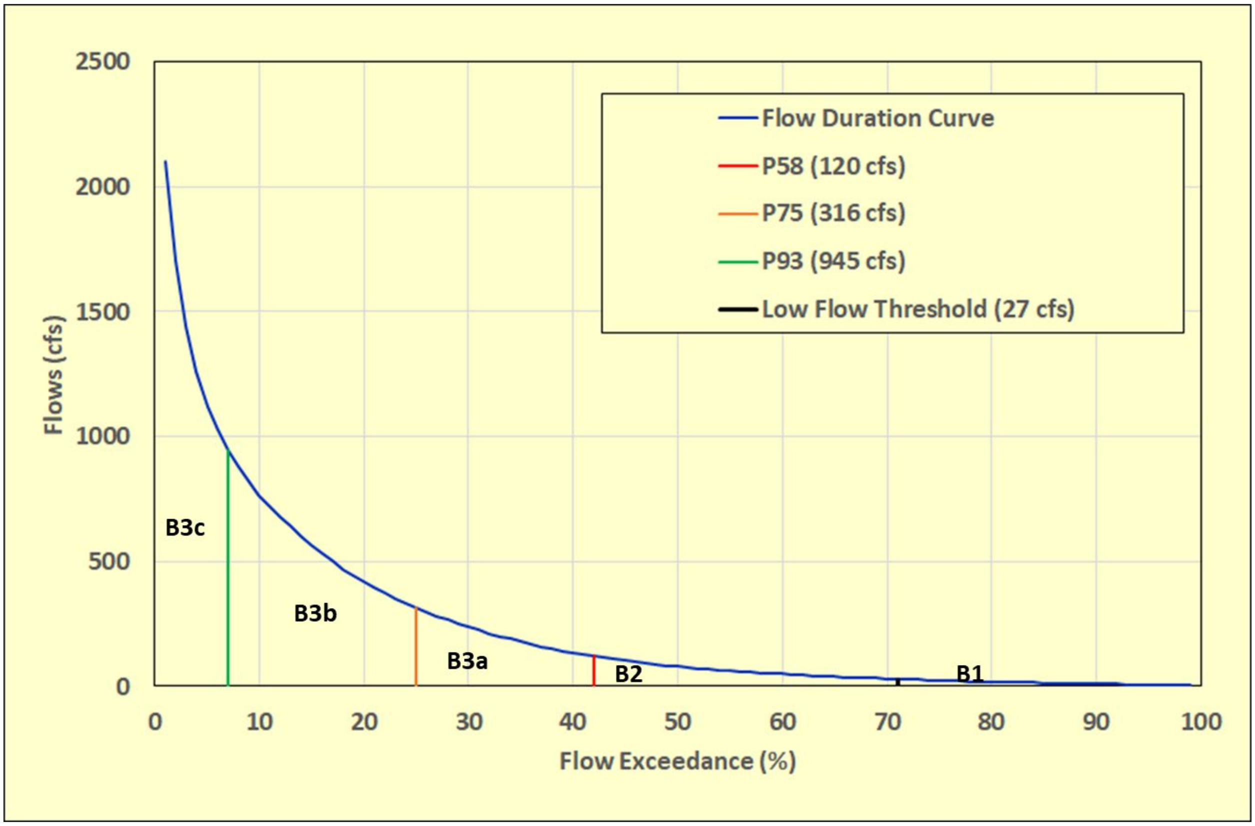

Figure 6-11. Block-based proposed minimum flows superimposed on a flow duration curve at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage.

6.5. Consideration of Environmental Values

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

Primary factors considered for development of the recommended minimum flows for Charlie Creek included potential, flow-related changes to fish passage, wetted perimeter along stream bed and banks, floodplain wetland inundation and instream habitat, and lower river fish habitat. Based on assessments associated with these factors, the recommended minimum flows are protective of all relevant environmental values identified for consideration in the Water Resource Implementation in Rule, as well as those included in the Water Resources Act of 1972 that pertain to the establishment of minimum flows.

6.5.1. Recreation In and On the Water

The Recreation in and on the Water Environmental Value for Charlie Creek was considered through characterization of water depths, and assessment of potential changes in floodplain inundation, fish, and invertebrate habitats.

Using the bathymetric information included in the HEC-RAS model, water levels were considered to ensure that the floodplain (5.3.2, 5.4.3, and 6.2) and instream habitat (Sections 5.3.3, 5.4.4, and 6.3), including the passage of fish (Sections 5.3.3.1, 5.4.2.1, and 6.1.1), were protected under the proposed minimum flows, which also protects recreation in Charlie Creek.

6.5.2. Fish and Wildlife Habitat and the Passage of Fish

To support consideration of the Fish and Wildlife Habitat and the Passage of Fish Environmental Value, information summarizing the fish, nekton, and benthic macroinvertebrate communities of Charlie Creek were summarized in Chapter 4.

Using the HEC-RAS model developed for Charlie Creek (Section 5.4.1), a low flow threshold of 15 cfs was developed (Sections 5.3.1, 5.4.2, and 6.1) and is proposed to protect the passage of fish in Charlie Creek.

A SEFA analysis was conducted to develop minimum flows for Charlie Creek that protect fish and wildlife instream habitat (Sections 5.3.3.1, 5.4.4, and 6.3.1). Flows and water levels were also evaluated during this investigation to ensure important fish and wildlife floodplain habitat was considered and protected in the creek (Sections 5.3.2, 5.4.3, and 6.2).

6.5.3. Estuarine Resources

Charlie Creek flows into the Lower Peace River. While the Peace River flows into the Gulf of Mexico, through the Charlotte Habor, Charlie Creek is not directly connected to estuarine resources. Therefore, this environmental value was not considered relevant for development of the minimum flow for Charlie Creek.

6.5.4. Transfer of Detrital Material

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

The Transfer of Detrital Material Environmental Value was considered for development of recommended minimum flows for Charlie Creek through use of a percent-of-flow approach intended to maintain characteristics of the baseline flow regime and patterns of Charlie Creek floodplain inundation (Sections 5.3.2, 5.4.3, and 6.2). Maintenance of the floodplain habitats in Charlie Creek is expected to support their structural and functional contributions to detrital transfer processes, including roles as sources or sinks for detritus generation, export, and use.

Transfer of detrital material was defined for the evaluation as the movement by water of loose organic material and debris and associated decomposing biota from the overbanks in the floodplain to the main channel. Based on the floodplain inundation analysis (Section 6.2), 120 cfs is a flow threshold in which water starts to overflow from the channel onto the adjacent floodplain. Events of 1-day and a 7-day duration with flows above 120 cfs were identified as primary indicators of detrital in Charlie Creek. These events were assumed to transfer detritus to the main channel, where it would be subsequently moved downstream. The extent to which the number of these events and their duration are expected to change as a function of the proposed minimum flows for Charlie Creek was also summarized.

Reducing the baseline conditions by the allowable percent-of-flow reductions associated with the recommended minimum flows in each block is predicted to result in a 1% decrease in the number of 1-day duration events and a 2% decrease in the number of 7-day duration events with flows continuously exceeding 120 cfs (Table 6-7). Based on these results, we conclude the recommended minimum flows for Charlie Creek will ensure that the transfer of detrital material is protected.

Table 6-7. Number (n) 1-day and 7-day events continuously exceeding 120 cfs Charlie Creek under the baseline and minimum flows scenarios evaluated based on flows at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage between May 1, 1950, and December 31, 2021.

Floodplain Inundation Threshold (cfs)	Number of 1-day Events above 120 cfs (average events per year)			Number of 7-day Events above 120 cfs (average events per year)		
	Baseline (n)	MFL (n)	Change (%)	Baseline (n)	MFL (n)	Change (%)
120	99	98	1	80	79	2

6.5.5. Maintenance of Freshwater Storage and Supply

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

The maintenance of freshwater storage and supply is specifically supported through development of minimum flows, such as those proposed for Charlie Creek, that include block-specific, allowable percent-of-flow reductions that can be easily used to develop permit conditions for existing and future surface water withdrawals. The low flow threshold proposed for Charlie Creek can also be directly linked with consideration of the maintenance of freshwater storage and supply.

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

6.5.6. Aesthetic and Scenic Attributes

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

6.5.7. Filtration and Absorption of Nutrients and Other Pollutants

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

6.5.8. Sediment Loads

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

Sediment transport modeling requires detailed understanding of processes involved in erosion and movement and deposition of sediments in the water column. In addition, measured bed and suspended loads are required for accurate model calibration and validation. Sediment loads were considered for development of recommended minimum flows for Charlie Creek using the Engelund-Hansen method (Engelund and Hansen 1972) which evaluates changes in sediment loads associated with implementation of the recommended minimum flows. However, the simulated sediment discharges do not represent the actual sediment loads, but rather the capacity of the system to transport sediment loads. The aim is to assess if the long-term sediment transport capacity of the creek will significantly be impacted by the implementation of the recommended minimum flows.

There are several empirical methods that can be applied to calculate sediment discharge capacity. The Engelund-Hansen method was selected because it is a relatively simple approach based on a stream power, and all inputs were derived from the already developed HEC-RAS model. It is also appropriate for sandy-bed rivers, which are common in Florida. Sediment loads are predicted based on mean flow velocity, bed level shear stress, particle size, specific gravity, and channel width. The specific steps undertaken to evaluate sediment loads in Charlie Creek were as follows:

1. Critical shear stress by particle size classification for sediment mobility was obtained from USGS scientific investigations report (USGS 2013; Table 6-8). Sediment mobility for a given particle size is assumed to occur when the bed shear stress exceeds these critical shear stress. The particle size distribution in Charlie Creek is generally in the range of medium to coarse sand. Using this grain size range and, an average shear stress of 0.006 pound per square foot (lb/ft^2) was identified as a critical shear stress for sediment transport in Charlie Creek.
2. The Charlie Creek HEC-RAS model was run for 12 flow profiles and provided 12 flow-bed shear-velocity relationships at each of the 41 HEC-RAS cross-sections in the model. The 12 flow profiles ranged from the five percent to 99 percent exceedance and were obtained through flow-duration analysis of the flow data at the USGS Charlie Creek near Gardner, FL (No. 02296500) gage for the period from May 1, 1950, to December 31, 2021.
3. A flow-sediment discharge rating curve was developed at each cross-section using the Engelund-Hansen method and the 12 flow-shear-stress scenarios.
4. A daily sediment discharge for the baseline condition was generated at each cross-section for the period from 1951 through 2021 using the rating curves and an interpolation function in an Excel spreadsheet.
5. Mean annual sediment transport capacity (tons/year) were calculated for the creek by adding the total sediment loads generated at each cross-section in the HEC-RAS model and dividing the sum by the number of years (71 years) in the time series.
6. Steps 4 and 5 were repeated for a minimum flows scenario by reducing the baseline flow record by the allowable percent-of-flow reductions associated with the recommended minimum flows for Blocks 1, 2, 3a, and 3b.
7. Relative changes in sediment transport capacity between the baseline and minimum flow conditions were calculated to ensure that the long-term sediment loads will not be significantly impacted by the recommended minimum flows for Charlie Creek.

The estimated sediment transport capacity under the baseline scenario was 190,176 tons/year and under the minimum flows scenario was 169,176 tons/ year (Table 6-10) assuming unlimited sediment availability in the creek. These transport capacities are over-predicted because gravel, pebbles, and non-sand materials (e.g., shells) that retard sediment mobility are neglected in the analysis. Nevertheless, the relative change between the baseline and minimum flow conditions allows us to assess the potential effects of the recommended minimum flows on sediment loads.

Reducing the baseline flow record by the allowable percent-of-flow reductions associated with the recommended minimum flows for Blocks 1, 2 and 3 is predicted to result in an 11% decrease of the mean baseline sediment transport capacity (Table 6-9). The recommended minimum flows for Charlie Creek are, therefore, not expected to negatively affect sediment loads.

Table 6-8. Critical shear stress by particle-size classification for determining approximate condition for sediment mobility at 20degrees Celsius (Source: USGS 2013).

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

Table 6-9. Sediment transport capacity (tons/year) in Charlie Creek under the baseline and minimum flows scenarios were evaluated using the Engelund-Hansen method.

Sediment Transport Capacity (tons/year)		Percentage Change (%)
Baseline	Minimum Flows	
190,137	169,176	11

6.5.9. Water Quality

Consideration of water quality was discussed in Chapter 3. To predict whether the proposed minimum flows would impact the probability of individual samples exceeding State water quality thresholds for Class III waters, generalized linear mixed models (GLMMs) were run (Deak 2023, Appendix H). A GLMM can be considered an extension of a linear mixed model, that allows for response variables to be from different distributions, including binary responses. Input data may be normal or non-parametric and either continuous or categorical. A GLMM allows for inclusion of fixed and random effects. Fixed effects include variables in the predictive equation for the model. Random effects allow for specific properties of a particular variable to be considered in the analysis.

A series of GLMMs were developed for total phosphorus and dissolved oxygen percent saturation using the glmer function in the lme4 package in R programming language (Bates et al. 2015, R Core Team 2021). Models were run for each analyte, considering combinations of the continuous variables (flow or river kilometer) and categorical variables (season, i.e. quarter of the year, beginning in January) and interaction terms among them. If the model failed to converge with raw flows, the log of flows was used in subsequent analyses. For each model, available analyte data was obtained from the DEP, SWFWMD, and USGS. Corresponding flow data for each sample on the day of sample collection were from the USGS Charlie Creek near Gardner, FL (No. 02296500) gage record. The successful model with the lowest Akaiki Information Criteria (AIC) score was selected for further analysis. The predict function in R was then applied to the selected model to predict the probability of State water quality threshold exceedance at a given flow and location. Flow reduction scenarios were run from 1-20% to determine if such reduction increased the 50% probability of State water quality threshold exceedance by more than 15% compared to baseline conditions. This 50% (or 0.5) probability threshold was selected based on its common use as a standard and its previous application during a similar analysis by Janicki Environmental, Inc. on water quality constituents in the Chassahowitzka River (JEI and WSP 2018).

The State water quality threshold for total phosphorus is based upon the annual geometric mean of samples frequently exceeding the threshold in a three-year period. The threshold for dissolved oxygen percent saturation is exceeded if more than 10% of the daily average dissolved oxygen percent saturation values are below 38%. Although the statistics we calculated were based on available sample data, and therefore, reflect the probability of exceedance of the threshold on a per sample basis, we assumed that if the number of samples exceeding the threshold was not substantially increased by flow reduction, the probability of exceeding the threshold once an annual geometric mean or 10% of daily averages is calculated would also not increase.

Based upon results from this analysis, the proposed minimum flows for Charlie Creek are not anticipated to increase the probability of exceeding the State water quality threshold for total phosphorus or dissolved oxygen percent saturation at the evaluated water quality stations. Under baseline conditions at District station 23969, four of 28 tested samples were predicted to surpass the 0.5 probability threshold for exceeding the State water quality threshold during Block 2. This was reduced to three samples under the proposed minimum flows. Similarly during Block 3a at this station, one fewer sample was predicted to surpass the 0.5 probability of exceedance threshold under the proposed minimum flows (Deak 2023). The likelihood of 0.5 probability threshold exceedance for dissolved oxygen percent saturation at station 23969 decreased during Block 3a under minimum flow conditions, with three of 17 samples expected to surpass the threshold as opposed to seven samples under baseline conditions (Deak 2023). Of note, water quality data in Charlie Creek are somewhat limited and there was little overlap in the period of record or sampling frequency in the available data. Robust sampling over a longer period of record with additional water quality stations along the length of the river would likely improve confidence in the model outputs.

Based upon analysis of available data, results from the GLMM analysis and trends with flow explored by ATM and JEI (2021a) water quality constituents in Charlie Creek are not expected to substantially change in response to flow reductions associated with implementation of the recommended minimum flows. The recommended minimum flows for Charlie Creek are, therefore, not expected to negatively affect water quality or impair the water designated use of either water body.

If water quality parameters are protected, many other environmental values that can be associated with water quality are also afforded protection. As discussed in previous sub-sections of the report, this protection can be extended to recreation in and on the water (Section 6.5.1), fish and wildlife habitat and the passage of fish (Section 6.5.2), transfer of detrital material (Section 6.5.4), maintenance of freshwater storage and supply (Section

6.6.5), aesthetic and scenic attributes (Section 6.5.6), and filtration and absorption of nutrients and other pollutants (Section 6.5.7).

6.5.10. Navigation

Charlie creek is too shallow for commercial and recreational boating; however, there are docks on Charlie Creek that can be used for canoeing, kayaking, and fossil hunting. A navigation criterion is defined as the flow corresponding to a water depth of 0.5-ft (0.15-m) at a cross-section in the minimum flow evaluation for the Lower Santa Fe River (HSW 2021) and the Little Manatee River (Holzwart et al. 2023). Since the critical depth needed for canoe and kayak navigation is shallower than that needed for fish passage, implementation of the minimum flows is not expected to adversely affect canoe and kayak navigation in Charlie Creek.

6.6. Minimum Flows Status Assessment

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

The minimum flow status assessment for Charlie Creek required an understanding of historic and current flow conditions and evaluation of the extent to which withdrawals or other anthropogenic factors have affected flows in the creek. As noted in Section 5.1, The District developed the PRIM2 for investigating the effects of climate variability, groundwater pumping, land use changes and other factors on flows in the Peace River and its tributaries. Results from the PRIM2 simulations indicated that the observed discharge in Charlie Creek has been increased by return flow and runoff associated with groundwater withdrawals. Estimated monthly flow increases due to withdrawal-related effects generally ranged from 3 cfs in May and November to 17 cfs in August (see Table 5-1) for a 16-year assessment period. In addition, the Florida Statewide Agricultural Irrigation Demand (FSAID) database (Balmorial Group 2022, FDACS 2022) indicates the volume of irrigation water in the Horse Creek watershed is projected to increase by less than 1 mgd by 2045 (refer to Section 2.2.1).

Collectively, this information indicates the recommended minimum flows for Charlie Creek are currently being met and are also expected to be met over the next 20 years and beyond. Therefore, development of a specific recovery or prevention strategy for the creek is not required.

An adaptive management approach will be used by the District to monitor and assess the status of minimum flows established for Charlie Creek. Because changes in the Charlie Creek watershed related to numerous factors, including climate change, could potentially affect flow characteristics and additional information relevant to minimum flows development may become available, the District is committed to periodic reevaluation, and, if necessary, revision of minimum flows established for Charlie Creek.

CHAPTER 7 – LITERATURE CITED

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