A Reevaluation of Minimum Flows for the Upper Peace River from Bartow to Zolfo Springs, Florida

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Environmental Flows and Levels Section
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Executive Summary

The Southwest Florida Water Management District (District) has been directed by the Florida Legislature to establish minimum flows for flowing watercourses within its jurisdiction. As defined in Section 373.042(1) of the Florida Statutes, minimum flows represent "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." Each water management district, or the Florida Department of Environmental Protection, identifies criteria for "significant harm" to guide the development of minimum flows. Once adopted into the District's Water Levels and Rates of Flow Rules within the Florida Administrative Code, minimum flows serve as regulatory benchmarks for water supply planning, water use permitting, and environmental resource regulation.

This report presents the District's recommended minimum flows for the Upper Peace River, based on a comprehensive reevaluation of previously established low-flow thresholds and the development of new minimum flows for medium and high flow conditions. The Upper Peace River is defined as the 37-mile stretch from Bartow (State Highway 60 bridge) to Zolfo Springs (US Highway 17 bridge). Originating at the confluence of Lower Saddle Creek and the Peace Creek Drainage Canal near Bartow in Polk County, the river flows south through Polk and Hardee counties for approximately 105 miles before entering the Charlotte Harbor near Punta Gorda in Charlotte County.

In developing Minimum Flows and Levels, the District utilized the best available information, as required by Florida Statues, and considered all relevant environmental values identified in the Florida Water Resources Implementation Rule. The District's habitat-based approach focuses on resource management goals including:

- Maintenance of minimum water depths in the river channel for fish passage and recreational use
- Maintenance of water depths above inflection points in the productive wetted perimeter of the river channel to maximize aquatic habitat
- Maintenance of instream habitat availability for selected fish species and macroinvertebrate assemblages
- Maintenance of inundation of instream woody habitats (e.g., snags and exposed roots)
- Maintenance of seasonal hydrologic connections between the river channel and floodplain to protect floodplain structure and function

To establish minimum flows, baseline flow data from January 1, 1975, through December 31, 2022, were developed at three USGS index gaging stations: Peace River at SR 60 at Bartow (02294650), Peace River at Fort Meade (02294898), and

Peace River at US 17 at Zolfo Springs (02295637). The baseline flows represent river flow conditions in the absence of groundwater withdrawals and serve as the basis for defining minimum flow regimes for the Upper, Middle, and Lower segments of the river. The selected gaging stations are consistent with those used in the existing minimum flow framework for the Upper Peace River.

Flow-based blocks were defined to represent low (Block 1), medium (Block 2), and high (Blocks 3A and 3B) flow conditions. For each river segment, these blocks are based on ecological criteria related to fish passage, wetted perimeters, and floodplain inundation. The table below summarizes the flow blocks, associated flow ranges, maximum allowable reductions, and recommended minimum flows, all derived from baseline flows at the three index gages.

River Segment	Index Gage Name (Site ID)	Flow Block	Flow Range	Maximum Allowable Reduction[a]	Minimum Flow[a]
Upper	Bartow	B1	≤ 30 cfs	0%	100%[b]
	(02294650)	B2	>30 cfs and ≤71 cfs	12%	30 cfs or 88%[c]
		B3A	>71 cfs and ≤483 cfs	15%	85%
		B3B	>483 cfs	7%	93%
Middle	Fort Meade	B1	≤21 cfs	0%	100%[b]
	(02294898)	B2	>21 cfs and ≤120 cfs	12%	21 cfs or 88%[c]
		B3A	>120 cfs and ≤529 cfs	10%	90%
		B3B	>529 cfs	7%	93%
Lower	Zolfo Springs	B1	≤40 cfs	0%	100%[b]
	(02295637)	B2	>40 cfs and ≤274 cfs	13%	40 cfs or 87%[c]
		B3A	>274 cfs and ≤1,047 cfs	9%	91%
		B3B	>1,047 cfs	7%	93%

Notes: [a] Based on previous day baseline flow. [b] A 95% annual exceedance is proposed to account for uncertainties related to annual rainfall variations, provisional USGS data, sinkhole losses, Lake Hancock water storage capacity, and structure maintenance, etc. [c] Whichever is greater.

For low-flow Block B1, thresholds were established to ensure flow continuity for both environmental and human use values. For medium and high flow Blocks B2, B3A, and B3B, a percent-of-flow approach was applied to ensure the maintenance of at least 85% of the most sensitive ecological metrics, thereby supporting all resource management goals. Assessments confirmed that the proposed minimum flows adequately protect all relevant environmental values identified in the Florida Water Resources Implementation Rule.

To protect low flows, thresholds of 30 cfs, 21 cfs, and 40 cfs are recommended at Bartow, Fort Meade and Zolfo Springs, respectively. A 95% annual exceedance criterion is also recommended as an operational target at the Lake Hancock P-11 structure to help maintain these thresholds. This criterion has been part of currently established minimum flows and has proven effective in improving low-flow conditions in the Upper Peace River since 2016.

The recommended minimum flows for medium flows (Block 2) are designed to preserve at least 85% of instream habitats, while those for high flows (Blocks 3A and Block 3B) aim to maintain at least 85% of floodplain inundation.

The recommended minimum flows for the Upper Peace River are currently being met and are projected to continue being met over the next 20 years. Therefore, development of a recovery or prevention strategy is not required in association with the adoption of the recommended minimum flows.

The District will apply an adaptive management approach to monitor and assess the status of the minimum flows. Recognizing the potential impacts of climate change, structural alternations, water withdrawals, and other changes within the watershed and contributing groundwater basin, the District remains committed to periodic reevaluation and, if necessary, revision of established minimum flows for the Upper Peace River.

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(To be finalized after peer review)

Acronyms and Abbreviations

AMO	Atlantic Multidecadal Oscillation
BMAPs	Basin Management Action Plans
cfs	Cubic feet per second
CFWI	Central Florida Water Initiative
DO	Dissolved oxygen
ENSO	El Nino Southern Oscillation
F.A.C.	Florida Administrative Code
FDACS	Florida Department of Agriculture and Consumer Services
FDEP	Florida Department of Environmental Protection
F.S.	Florida Statutes
FWC	Florida Fish and Wildlife Conservation Commission
FLUCCS	Florida Land Use, Cover and Forms Classification System
FNAI	Florida Natural Areas Inventory
GIS	Geographic Information Service
HEC-RAS	Hydrologic Engineering Center-River Analysis System
LFA	Lower Floridan aquifer
LWPIP	Lowest wetted perimeter inflection point
MFLs	Minimum Flows and Levels
mgd	Million gallons per day
mg/l	Milligrams per liter
NAVD88	National American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWI	National Wetlands Inventory
PHABSIM	Physical Habitat Simulation Model or System
PRIM	Peace River Integrated Modeling
SEFA	System for Environmental Flow Analysis
SWFWMD	Southwest Florida Water Management District
SWUCA	Southern Water Use Caution Area
TMDLs	Total Maximum Daily Loads
UFA	Upper Floridan aquifer
USDA	United States Department of Agriculture
U.S.	United States
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

TABLE OF CONTENTS

List of Figures

List of Tables

List of Appendices

CHAPTER 1 INTRODUCTION: BACKGROUND, CONTEXT, AND PURPOSE

The Southwest Florida Water Management District (SWFWMD or "the District") is responsible for establishing minimum flows and levels (MFLs) for prioritized waterbodies under its jurisdiction, as mandated by Section 373.042, Florida Statutes (F.S.). This legislative charge is tied directly to the District's role in regulating consumptive water use and its responsibility to prevent "significant harm" to the region's water resources. Under the oversight of the Florida Department of Environmental Protection (FDEP), the District manages the MFLs program to meet its statutory obligations pursuant to Sections 373.042 and 373.0421, F.S. Establishing MFLs is a cornerstone of the District's Strategic Plan (SWFWMD 2022a), ensuring adequate water supplies while preserving ecological integrity. Once adopted into the District's Water Levels and Rates of Flow Rules, MFLs serve as scientifically grounded hydrologic and ecological standards that guide water use permitting, water supply planning and environmental resource regulation decisions related to both surface and groundwater withdrawals.

1.1 Background for Reevaluation of the Upper Peace River Minimum Flows

The Peace River, one of the most complex hydrologic systems within the District, extends approximately 105 miles and is generally divided into upper, middle, and lower segments (Figure 1-1) for MFLs purposes. Among these, the Upper Peace River presents one of the most significant challenges in the Peace River watershed. Located in the northernmost portion of the Peace River watershed, the Upper Peace River drains over 800 square miles. It originates at the confluence of Saddle Creek and Peace Creek near Bartow and flows approximately 37 miles through Fort Meade to Zolfo Springs (Figure 1-1).

Over the past several decades, streamflow in the Upper Peace River has declined significantly, particularly during dry seasons. This decline is attributed to multiple contributing factors, including groundwater withdrawals, land-use change, drought and the presence of karst features. The river segment between Bartow and Fort Meade has been most affected, where numerous karst features have developed in the riverbed and across the adjacent floodplain areas. These karst formations created direct connections between the river channel and the underlying aquifer, resulting in substantial streamflow losses. Since the 1950s, the Upper Peace River upstream of Fort Meade has become a predominantly losing stream, with portions of the river drying out during extreme drought years.

The District established minimum low flows for the Upper Peace River in 2002 (SWFWMD 2002) at three United States Geological Survey (USGS) gaging stations: 17 cfs at Peace River at SR60 at Bartow, FL (No. 02294650), 27 cfs at Peace River at Fort

Meade, FL (No. 02294898), and 45 cfs at Peace River at US 17 at Zolfo Springs, FL (No. 02295637). The minimum low flows were approved by the District Governing Board in 2006 and formally adopted into the District's Water Levels and Rates of Flow Rule 40D-8.041(7), Florida Administrative Code (F.A.C.), which became effective in 2007.

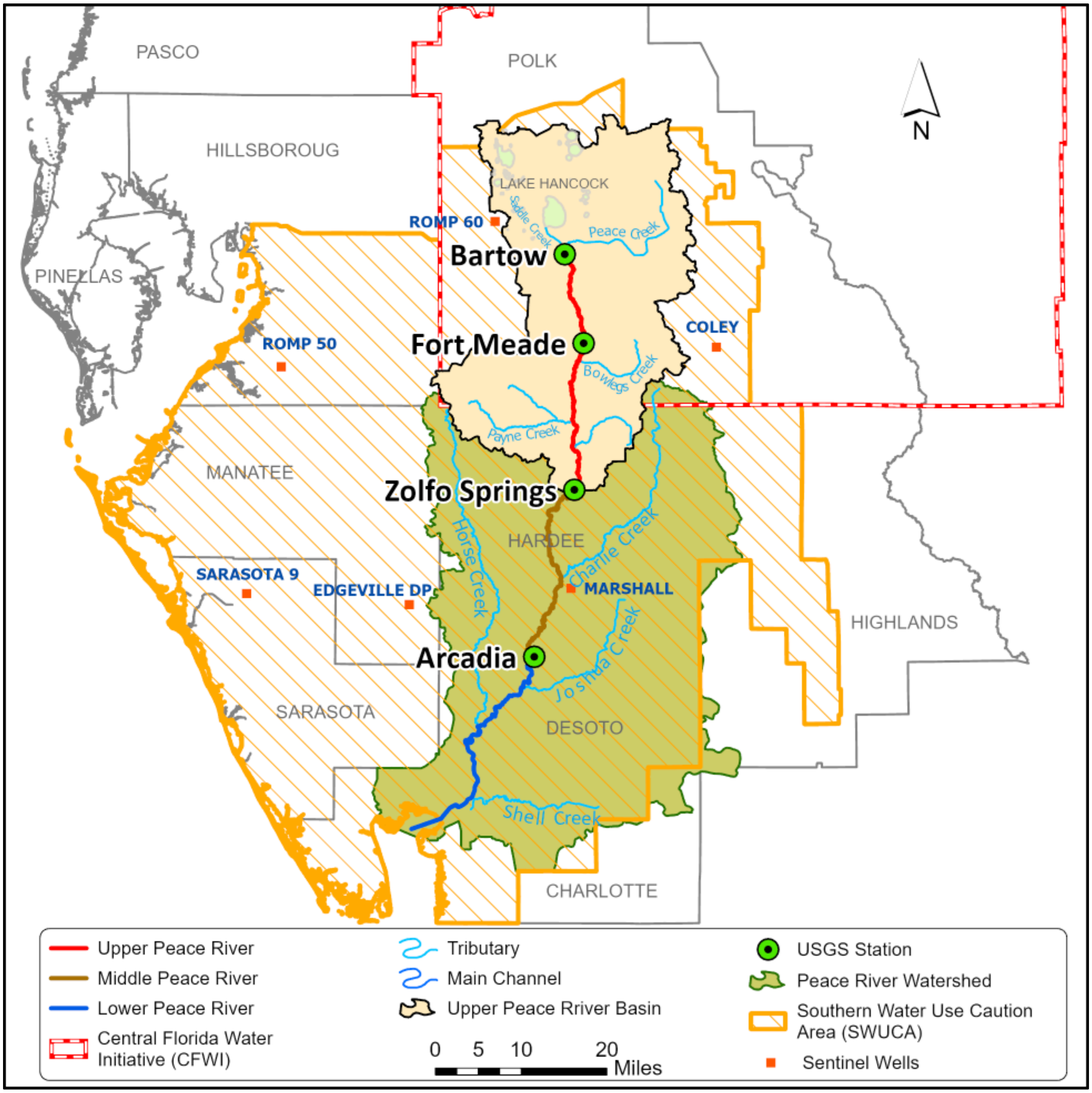

Figure 1-1. Map of the Peace River watershed and Upper Peace River basin, depicting the upper, middle, and lower river segments along the main channel, major tributaries, and key USGS gaging stations located at Bartow, Fort Meade, Zolfo Springs, and Arcadia. The map also delinates the boundaries of the Southern Water Use Caution Area (SWUCA) and Central Florida Water Initiative (CFWI) Planning Area, and six sentinel wells within the SWUCA.

In conjunction with adopting these minimum flows, the District also developed the Southern Water Use Caution Area (SWUCA) recovery strategy (SWFWMD 2006a) for a region covering about 5,100 square miles (Figure 1-1). One of the primary goals of this strategy is to restore the Upper Peace River's MFLs by 2025 through implementation of a suite of recovery projects. One key initiative under this strategy is the Lake Hancock Lake Levels Modification Project, which involved altering the P-11 control structure at Lake Hancock's outlet. By raising the structure's control elevation, the structure allows additional water to be stored during the wet season and released during the dry season to the Upper Peace River to help meet the river's minimum flows requirements. Since the District began operating the modified P-11 structure in 2016, the Upper Peace River has successfully met its MFLs from 2020 through 2024. The District continued compliance with MFLs in 2025 and beyond.

The Upper Peace River was the first river segment in the District for which minimum flows were developed. The initial evaluation, completed in 2002, underwent scientific peer review, resulting in constructive feedback that informed the development of subsequent MFLs. At that time, only low-flow thresholds were recommended, based on fish passage and wetted perimeter criteria (SWFWMD 2002). Minimum flows for medium and high flow regimes were not established, primarily due to limitations on separating the confounding effects of withdrawals and structural alterations on the hydrologic regime of the river (SWFWMD 2002).

Although the 2002 MFLs report described criteria for medium and high flows, such as the inundation of aquatic and woody habitats within the river channel and vegetative communities on the floodplain, these criteria were not used to develop recommended minimum flows for those regimes. This was primarily due to insufficient information to distinguish the effects of natural factors from anthropogenic influences (e.g., groundwater withdrawals, land-use change) on flow declines.

Now, more than 20 years later, advancements in data collection, modeling, analytical techniques, and MFLs methodologies, as outlined in the following chapters, support a comprehensive reevaluation. This study reevaluated the existing low flow thresholds and established new minimum flows for medium and high flow regimes, resulting in a full flow regime framework encompassing low, medium and high flows for the Upper Peace River between Bartow and Zolfo Springs (Figure 1-1). The proposed MFLs are scheduled for adoption in 2025 (SWFWMD 2024). This report documents the data, tools, methodology, and scientific basis that support the updated MFL recommendations.

1.2 Legislative Direction

The establishment of MFLs is mandated by the Florida Legislature under Subsection 373.042(2), F.S., as well as the State Comprehensive Plan (Chapter 187, F.S.) and the Water Resources Implementation Rule (Chapter 62-40.473, F.A.C.).

By virtue of its responsibility to permit the consumptive use of water and its legislative mandate to prevent "significant harm" to water resources, the District is directed to establish MFLs for surface watercourses, aquifers, and other surface waters within its jurisdiction (Section 373.042, F.S.). Specifically:

- Rivers, streams, estuaries, and springs require **minimum flows**
- Lakes, wetlands, and aquifers require **minimum levels**

As currently defined by statute:

- A **minimum flow** is defined as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area."
- A **minimum water level** is defined as "the level of groundwater in an aquifer and the level of surface water at which further withdrawal would be significantly harmful to the water resources or ecology of the area."

Once established, MFLs are adopted into the District's Water Levels and Rates of Flow Rule (Chapter 40D-8, F.A.C.) and serve as technical guidance to support the District's regulatory programs, including water use permitting, environmental resource permitting, and water resource planning, to ensure groundwater and surface water withdrawals do not cause significant harm to the water resources or ecology of the area. MFLs identify a range of water flow and or level conditions above which water may be permitted for consumptive use. In addition, MFLs protect nonconsumptive uses of water, including the water necessary for navigation and recreation, and for fish and wildlife habitat and other natural resources (Chapter 62-40, F.A.C.).

It's important to note that the mere development or adoption of MFLs does not guarantee protection of a water body from significant harm. However, once these standards are in place, a water use permit may not be issued for a proposed withdrawal if that withdrawal is inconsistent with an established MFL.

State law also requires periodic reevaluation and revision of established MFLs as necessary. In addition, Section 373.0421, F.S. mandates the development and implementation of a recovery or prevention strategy in the following cases:

(a) At the time of a minimum flow or minimum water level is initially established, or is revised, if the flow or water level is below or is projected to fall within 20 years below the initial or revised minimum flow or minimum water level, the District shall simultaneously adopt or modify the implementation of the recovery or prevention strategy required by Section 373.0421(2), F.S.

(b) If minimum flow or minimum water level has been established for a water body and the existing minimum flow or minimum water level is below, or is projected to fall within 20 years below the existing minimum flow or level, the District shall expeditiously adopt or modify a recovery or prevention strategy required by Section 373.0421(2), F.S.

These recovery or prevention strategies are adopted and implemented in accordance with Chapter 62-40.073, F.A.C., and the regulatory portions of recovery and prevention strategies are codified Chapter 40D-80, F.A.C., the District’s Recovery and Prevention strategies for Minimum Flows and Levels Rule.

Rule 62-41.304 of the Regulation of the Consumptive Uses of Water Rule (Chapter 62-41, F.A.C.) of the FDEP outlines the uniform process for setting MFLs and Water Reservations for the Central Florida Water Initiative (CFWI) Planning Area (see Figure 1-1). The CFWI Planning Area includes all of Orange, Osceola, Polk and Seminole counties, as well as southern Lake County, in the region of Central Florida where the boundaries of the St. Johns River, South Florida, and Southwest Florida Water Management Districts abut. The uniform process for establishing MFLs in the CFWI Planning Area includes directives concerning development of priority lists and schedules for the establishment of MFLs by the three water management districts, sharing of technical information supporting proposed MFLs, and status assessments for established MFLs.

Further guidance is provided by the Florida Water Resource Implementation Rule (Rule 62-40.473, F.A.C.) for MFLs 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”.

1.3 Flow Regime and Definitions

1.3.1 Flow Regime

The long-term temporal patterns of streamflow are collectively referred to as a river's flow regime (or hydrologic regime). The regime plays a key role in regulating geomorphological processes that shape river channels and floodplains, driving ecological functions that support the life cycles of aquatic organisms, and influencing the seasonality of lotic ecosystems. Flow regimes are commonly characterized by five components: magnitude, frequency, duration, timing, and rate of change or flashiness (Poff et al. 1997, 2006). A robust characterization of a river's flow regime generally requires many years of continuous streamflow data (Poff et al. 1997).

Hill et al. (1991) stated "multiple flow regimes are needed to maintain biotic and abiotic resources within a river ecosystem." The logic is that "maintenance of stream ecosystems rests on streamflow management practices that protect physical processes which, in turn, influence biological systems." Hill et al. (1991) identified four key flow types to consider in flow assessment:

- **Flood flows** that determine the boundaries and shape of floodplain and valley features;
- **Overbank flows** that maintain riparian habitats;
- **In-channel flows** that keep immediate streambanks and channels functioning; and
- **In-stream flows** that meet critical fish requirements.

These flow types underscore the importance of both in-stream and out-of-bank flows for ecosystem function, as well as the need to preserve seasonal variability.

As further noted by Hill et al. (1991), minimum flow methodologies should take into consideration "how stream flows affect channels, transport sediments, and influence vegetation." Similarly, Richer et al. (1996) argued that "the full range of natural intra- and inter-annual variation of hydrologic regimes is necessary to [fully] sustain the native biodiversity".

The concept of "minimum flows" has since evolved to encompass the broader idea of maintaining a "minimum flow regime." Many aquatic species require a range of flows to complete their life cycles successfully, and alterations to the flow regime may negatively impact these organisms by changing the physical, chemical and biological conditions that support them.

In addition to aquatic species within the channel, streamflow evaluation must account for the hydrologic requirements of adjacent floodplain ecosystems. These habitats support floodplain-dependent biota and contribute to important ecological interactions between floodplain and instream communities.

Reflecting the growing recognition of these relationships, updates to the F.A.C. in 2005 acknowledged the importance of retaining the hydrologic regime. Specifically, Chapter 62-40.473(2) of the State Water Resources Implementation Rule directs that "minimum flows and levels should be expressed as multiple flows or levels defining a minimum hydrologic regime". This revision was designed to protect the ecological functions supported by flow variability across the hydrologic continuum.

1.3.2 Flow Definitions and Concepts

To comply with legal directives concerning MFLs and to improve clarity throughout this report, District staff has provided the following definitions of key flow-related terms, specifically in the context of evaluating flow conditions in the Upper Peace River:

Flow: Refers to streamflow or discharge, i.e., the rate at which a specified volume of water passes a point for some unit of time. For MFLs purposes, flow is typically expressed in cfs.

Modeled or Simulated Flow: Flow estimates generated through various modeling approaches, including numerical groundwater models, hydraulic models, instream habitat models, statistical models based on observed or simulated hydrologic data, and adjusted flows reflecting water withdrawals and other impacts.

Impacted Flow: Refers to streamflow influenced by human activities, primarily through water withdrawals as considered in this study. These flows may be directly measured (e.g., USGS or District data) or derived from simulations incorporating withdrawal scenarios. Impacted flow is often synonymous with historical flow.

Exceedance Flow: Describes the streamflow value that is equaled or exceeded a specific percentage of the time over a defined period. It is commonly used to describe the frequency and magnitude of river or stream flows. A 90% exceedance flow indicates low flow conditions, meaning the flow is equal to or greater than this value 90% of the time. Conversely, a 10% exceedance flow reflects high flow conditions, occurring only 10% of the time. **Non-Exceedance Flow** is the inverse concept, referring to the streamflow value that is not exceeded a certain percentage of the time.

Baseline Period: A continuous, multiple decade time series that represents a range of climatological and hydrologic conditions. It may include all or a subset of available records and serves as the foundation for establishing MFLs based on historical hydrologic conditions.

Baseline Flow: An estimate of natural, unimpacted flow conditions, developed by adjusting historical data to remove the effects of water withdrawal. This includes correcting for loss due to withdrawals and gain from sources like irrigation or reuse. Note that not all human-related impacts may be removed from the historic record.

Minimum Flow: As defined by the Florida Water Resources Act of 1972, the "limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area."

Flow Profile: A one-dimensional, steady state representation of the water surface elevation along a river channel under specific discharge and boundary conditions. It accounts for factors such as channel geometry, roughness, and energy losses due to flow transitions.

Rating Curve: A relationship between river stage and discharge at a specific location. Developed from field measurements, it is influenced by the stream channel and floodplain characteristics and can also be modeled using tools such as the U.S. Army Corps of Engineers' Hydrologic Engineering Center River Analysis System (HEC-RAS).

While both flow profiles and rating curves describe aspects of river hydraulics, rating curves depict relationships at a single point, whereas flow profiles show how water surface elevations change throughout the channel for a given flow condition.

Gage: A structure equipped with instruments that continuously measure the water level, known as gage height or stage. Managed by USGS, a local District, or both through a partnership, it uses a site-specific relationship called a rating curve to calculate streamflow or discharge from the measured water levels. It is sometimes referred to as a streamflow gage or flow gage. As part of the national streamflow network, a gage provides real-time data essential for flood forecasting, water resources management, environmental research, and infrastructure planning. Major gages on the main stem and tributaries of the Upper Peace River are shown in Figure 2-27 and Figure 2-28 and summarized in Table 2-6 and Table 2-7.

Index Gaging Station: An index gaging station, as defined by the USGS, is a streamflow monitoring site used to represent flow conditions within a broader river segment or basin. In the context of minimum flow development, index gaging stations serve as anchor points for evaluating flow regimes across defined river segments. For the Upper Peace River, three index gaging stations were designated, as discussed in Section 2.1.

1.4 Ecosystem Integrity

Ecosystem integrity refers to the completeness and functionality of an ecosystem and its ecological processes, particularly in relation to its natural state. This concept lies at the heart of ecosystem management, which strives to sustain biodiversity and the ecological and evolutionary dynamics that support it. As Richter et al. (1996) emphasize:

"A goal of ecosystem management is to sustain ecosystem integrity by protecting native biodiversity and the ecological (and evolutionary) processes that create and maintain that diversity. Faced with the complexity inherent in natural systems, achieving that goal will require that resource managers explicitly describe desired ecosystem structure, function, and variability; characterize differences between current and desired conditions; define ecologically meaningful and measurable indicators that can mark progress toward ecosystem management and restoration goals; and incorporate adaptive strategies into resource management plans."

Despite the broad recognition that sustaining ecosystems, streams, riparian zones and valleys require multiple flow conditions, fundamental research needed to quantify the ecological links between instream and out of bank resources remains ongoing, largely due to the expense and complexity involved. This research is needed to develop more refined methodologies, and will require a multi-disciplinary approach involving hydrologists, geomorphologists, aquatic and terrestrial biologists, and botanists (Hill et al. 1991).

To justify a minimum flow aimed at sustaining ecological integrity, it is necessary to present site-specific evidence of the ecological impacts resulting from flow alterations, and to identify measurable thresholds that define significant harm.

Florida law mandates the development of minimum flows to prevent significant harm to the state's rivers and streams. To fulfill this requirement, the term "significant harm" must be clearly defined in quantifiable term for establishing MFLs. It is recognized that some hydrologic changes may occur before the thresholds are reached but are not expected to cause significant harm to water resources and the ecology of the area.

Therefore, the goal of a minimum flow would not be to preserve a hydrologic regime in its original form, but rather to establish the threshold(s) at which flow alterations begin to negatively affect aquatic ecosystems. If recent changes have already resulted in significant harm, or such harm is expected within the next twenty years, it will be necessary to develop a recovery or prevention plan.

1.5 District's Framework for Establishing Minimum Flows

In the decades following the mid-20th century's surge in reservoir construction and water development across North America, resource agencies increasingly recognized the widespread degradation of riverine fish and wildlife habitats, particularly in the arid western United States. In response, several western states began adopting rules aimed at protecting existing stream resources from further depletions. During the 1960s and early 1970s, a variety of methods assessing MFLs were introduced that incorporated hydrologic analysis of water supply, hydraulic evaluations of critical stream channel, and empirical observations of habitat quality and fish ecology (Stalnaker et al. 1995). Most applications resulted in a single threshold or 'minimum' flow value for a specified river segment.

In Florida, the concept of MFLs was established under the 1972 Water Resource Act, although the state's formal definition and implementation of MFLs was clarified much later in 1997 (Munson et al. 2005).

According to Section 373.042, F.S., MFLs shall be established based upon the best information available and shall be developed with consideration of "… changes and structural alterations to watersheds, surface waters, and aquifers and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of an affected watershed, surface water, or aquifer …"

Annear et al. (2004) recognized the inherent complexity of instream flow assessments and emphasized that "[t]here is no universally accepted method or combination of methods that is appropriate for establishing instream flow regimes on all rivers or streams. Rather, the combination or adaptation of methods should be determined on a case-by-case basis; . . . In a sense, there are few bad methods – only improper applications of methods. In fact, most . . . assessment tools . . . can afford adequate instream flow protection for all of a river's needs when they are used in conjunction with other techniques in ways that provide reasonable answers to specific questions asked for individual rivers and river segments. Therefore, whether a particular method 'works' is not based on its acceptance by all parties but whether it is based on sound science, basic ecological principles, and documented logic that address a specific need."

Therefore, the scientific basis, methodological assumptions, and policy context for each minimum flow recommendation must be clearly defined throughout the development process.

To comply with statutory requirements and ensure defensible implementation, the District has established comprehensive methodologies tailored to distinct water body types: rivers, estuaries, springs, lakes, wetlands, and aquifers. These methodologies have undergone independent scientific peer reviews, and many are codified within the Water Level and Rates of Flow Rule (Chapter 40D-8, F.A.C.) to guide water use permitting, environmental resource permitting, and water resource planning programs to ensure groundwater and surface water withdrawals do not cause significant harm.

In accordance with the District's broader resource management strategies, a habitat–based approach was employed to establish minimum flows for the Upper Peace River. This methodology accounts for both instream and floodplain habitats (see Figure 1-2), acknowledging their critical roles in supporting ecosystem functions and providing benefits to natural systems and human communities. The fundamental assumptions and specific technical components of this approach are discussed in subsequent sections.

Figure 1-2. Cross-sectional view of instream and floodplain zones in a flowing system, with features including pools, riparian vegetation, and floodplain features, emphasizing the connectivity between aquatic and terrestrial habitats.

1.5.1 Fundamental Assumptions

The implementation of the District's MFLs Program rests on three fundamental assumptions:

- Many water resource values and associated features are influenced by long-term hydrology and changes in hydrologic conditions.
- Relationships among hydrologic and ecological variables can be quantified to establish thresholds or criteria for identifying significant harm.
- Alternative hydrologic regimes may exist that differ from historical, unimpacted conditions but still adequately protect water resources and the ecology of the area from significant harm.

These assumptions are supported by a robust body of scientific literature examining the interplay between hydrology, ecology and human-use values tied to water resources (e.g., Postel and Richter 2003, Wantzen et al. 2008, Poff et al. 1997, Poff and Zimmerman 2010). Such findings have informed of the development of significant harm thresholds used to establish MFLs for hundreds of water bodies across the state, as summarized in the numerous publications associated with these efforts (e.g., SFWMD 2002, 2006, Flannery et al. 2002, SRWMD 2004 and 2005, Neubauer et al. 2008, Mace 2009).

Specifically, regarding alternative hydrologic regimes, consider a historically unaltered river or lake system without any local groundwater or surface water withdrawal impacts. As water use increases, each increment can potentially shift the hydrologic regime from minimal changes to substantial alternations. There may exist a threshold regime that, while reduced from the historical conditions, still protects water resources and ecosystem from significant harm. In this context, MFLs represent minimum acceptable rather than historical or potentially optimal hydrologic conditions.

1.5.2 Baseline Flow

Baseline flow refers to flow that is free from water withdrawal impacts as possible, otherwise known as unimpacted flow as defined in Section 1.3.2. Development of minimum flows is performed upon identification of a baseline flow record for characterization of environmental conditions expected in the absence of withdrawals.

For river segments or entire rivers that have not historically been affected by water withdrawals, existing flow records from those unaffected periods, or in some cases, the entire period of record may serve as baseline flows. More commonly, however, available flow data are influenced by human activities, such as withdrawals or discharge/augmentation effects, or are available for a limited period, and baseline flows must be estimated by corrections for flow lost (e.g., surface water or groundwater withdrawals), or gained (e.g., excess irrigation water derived from groundwater or reuse) because of human activities.

Once established, these corrected baseline flow records can be evaluated alongside significant harm criteria to identify acceptable flow reductions. This process supports the development of minimum flows that protect water resources and ecological integrity by ensuring flow reductions do not cause significant harm.

1.5.3 Flow-Based Building Block Approach

A peer review report on the proposed MFLs for the Upper Peace River (Gore et al. 2002) recommended adopting a "building block" approach to better replicate the basin’s original hydrologic and hydroperiodic conditions. The development of regulatory flow requirements using this approach typically involves describing the natural flow regime, identifying building blocks associated with flow needs for ecosystem specific functions, biological assemblages or populations, and assembling these blocks into a comprehensive flow prescription (Postel and Richter 2003).

Review panelists of the 2002 Upper Peace River MFLs emphasized that "assumptions behind building block techniques are based upon simple ecological theory: that organisms and communities occupying that river have evolved and adapted their life cycles to flow conditions over a long period of pre-development history (Stanford et al. 1996). Given the limited biological knowledge of flow requirements, the best alternative is to recreate the hydrographic conditions under which communities have existed prior to disturbance in the flow regime."

Although the District does not aim to fully restore pre-disturbance conditions through MFLs development and implementation, it recognizes the building block approach is a reasonable method for maintaining similar, although dampened, natural hydrographic conditions.

Following the establishment of minimum flows for the Upper Peace River (SWFWMD 2002), the District traditionally used a calendar-based block approach. This method, derived from analyses of long-term flow records at USGS gage sites (Kelly et al. 2005a, b, c, Munson et al. 2007, Heyl et al. 2010, Leeper et al. 2018, among others), categorized flow periods based on where median values typically fall relative to the 25th and 50th flow percentiles. Specifically, Block 1 (low flow) begins when median flows fall below and remain beneath the 25th percentile; Block 3 (high flow) commences when median flows exceed and stay above the 50th percentile; and Block 2 (medium flow) spans the period between Block 3 and Block 1.

To mitigate unintended adverse impacts on biological communities in years when fixed calendar-based dates do not align well with actual flow conditions, the District introduced a flow-based block approach in recent years. In this approach, thresholds for low and high flow are defined first, as outlined in Section 1.5.5. Flows at or below the low-flow threshold are assigned to the low-flow block; flow exceeding the high-flow threshold fall into the high-flow block; and flows between the two thresholds are designated as the medium-flow block. Figure 1-3 visually represents how these blocks relate to flow thresholds and the flow hydrograph.

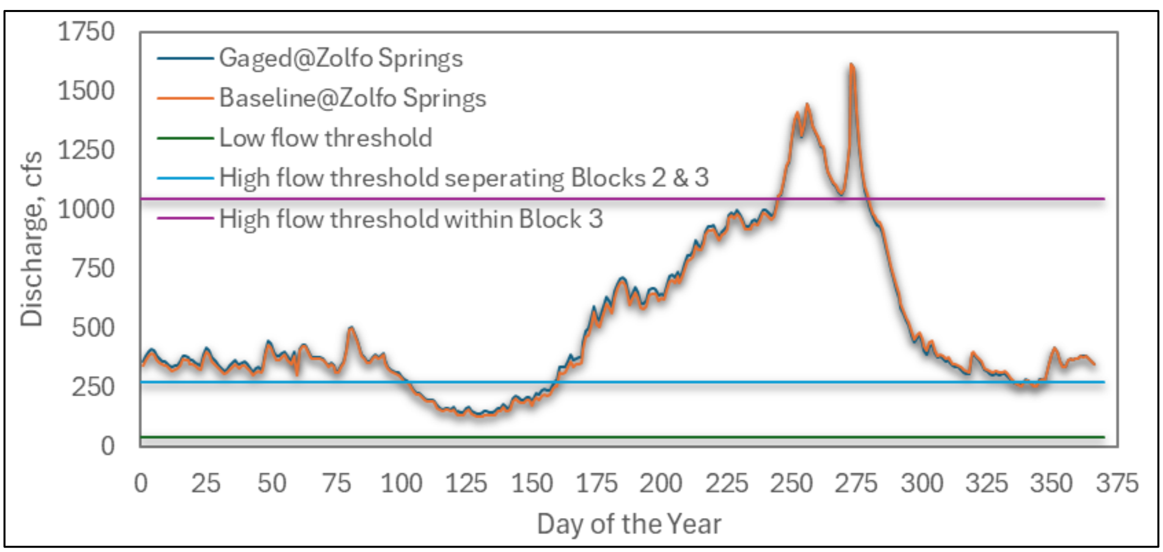

Figure 1-3. Flow blocks are superimposed on hydrographs displaying the mean observed daily flows (solid blue line) and mean baseline daily flows (solid gold line) at the USGS Peace River gaging station at US 17 at Zolfo Springs, FL (No. 02295637). High-flow Block 3 is subdivided into two sub-blocks, as indicated by a purple horizontal line. The boundary

between the high-flow (Block 3) and medium-flow (Block 2) blocks is shown by a blue line, while the boundary between the medium-flow (Block 2) and low-flow (Block 1) blocks is marked with a green line. Although the mean hydrographs are included for reference, the flow blocks were determined using criteria based on fish passage, wetted perimeter, and floodplain inundation rather than mean flows.

This more adaptive, flow-based building block method was applied for the Lower Peace River and Lower Shell Creek (Ghile et al. 2021), the Little Manatee River (Holzwart et al. 2023), Charlie Creek (Deak et al. 2023), and Horse Creek (Ghile et al. 2023) MFLs establishments. Notably, the panel who were convened to peer review the proposed minimum flows for Lower Peace River and Lower Shell Creek acknowledged that shifting from a calendar-based to a flow-based approach marked a major improvement (Appendix G-2, Ghile et al. 2021).

1.5.4 Significant Harm and 15% Change Criteria

The Florida Statutes broadly define minimum flow as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." However, "significant harm" was not explicitly defined in the Water Resource Act of 1972 or the Water Resource Implementation Rule. The literature offers little guidance, and definitions of “significant harm” often involves technical evaluations. With few exceptions (e.g., loss of fish passage or wetted perimeter inflection point), there are few definitive thresholds for identifying when “significant harm” occurs. Often, habitat loss happens gradually with declining flows, lacking a distinct tipping point.

Drawing from the recommendation of the peer review panel for the Upper Peace River MFLs (Gore et al. 2002), significant harm can be interpreted as quantifiable reductions in habitat. Gore et al. (2002) stated, “[i]n 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.” This threshold emerged from analyses using the Physical Habitat Simulation Model (PHABSIM), which evaluates flow, water depth, and substrate/cover preferences to characterize aquatic species habitats.

Following these insights, the District adopted the use of a 15% change in habitat availability as a measure of significant harm for MFLs development. This criterion has since been applied in numerous MFLs studies for both freshwater (e.g., Kelly et al. 2005a, 2005b, and 2005c, Munson et al. 2007, Heyl et al. 2010, Basso et al. 2011, Holzwart et al. 2016, Holzwart et al. 2017, Leeper et al. 2018) and estuarine (e.g., SWFWMD 2006b, Heyl 2008, Flannery et al. 2008, Herrick et al. 2019a and 2019b, Ghile et al. 2021) river segments. Its original endorsement by the Upper Peace River peer review panel has continued to receive support from subsequent reviews of District recommendations. Most instream flow analysts agree that changes greater than 15% in the duration or frequency of hydrologic events or a similar loss in habitat from baseline or current conditions can result in significant harm to ecological resources (Gore and Mead 2002, cited from HSW 2022).

Although the 15% threshold offers a practical standard, other studies have applied percentage thresholds ranging from 10% to 33%. For example, Dunbar et al. (1998), referring to PHABSIM, proposed, "an alternative approach is to select the flow giving 80% habitat exceedance percentile," equivalent to a 20% reduction. Jowett (1993) used a one-third habitat loss guideline during naturally low flows but acknowledged that, "[n]o methodology exists for the selection of a percentage loss of "natural" habitat which would be considered acceptable." The state of Texas utilized a target of less than 20% decrease from the historic average when setting MFLs for Matagorda Bay (Powell et al. 2002). With respect to allowable changes in flow, Richter et al. (2011) identified acceptable presumptive criteria for environmental flow protection, noting that allowing flow reductions up to 10% affords high protection, while reductions up to 20% offer moderate protection.

Building on these findings and peer review recommendations, the District continues to use the 15% habitat or resource change criterion in the development of recommended minimum flows for the Upper Peace River outlined in this report.

1.5.5 Minimum Flow Thresholds

The District's approach to developing minimum flows for the Upper Peace River involves identifying low-flow and high-flow thresholds. These thresholds are designed to protect selected environmental values from significant harm and define the transition points between low, medium, and high flow blocks, serving as regulatory benchmarks for minimum flows and maximum allowable withdrawals.

Low-flow thresholds are developed for river segments to limit when surface water withdrawals may occur and mark the upper flow boundary of the low-flow blocks. Criteria for developing these thresholds include fish passage depths and the lowest wetted perimeter inflection point, with the more protective value adopted as the low-flow threshold. Recommended low-flow thresholds across the three river segments of the Upper Peace River (see Figure 2-2) are elaborated in Chapters 5 and 6.

In contrast, high-flow thresholds are used to identify flow-based allowable percent-of-flow reductions and are developed separately for all three river segments of the Upper Peace River. Criteria for establishing these thresholds typically include floodplain inundation areas. For the Upper Peace River, the wetted perimeter inflection points in the medium- and high-flow ranges were also considered. The final threshold is a combination of these two criteria, designed to ensure that hydrological connectivity and ecological function are maintained during elevated flow periods. Recommendations for these high-flow thresholds for the Upper Peace River are also discussed in Chapters 4 and 5 of this document.

1.5.6 Percent-of-Flow Approach

In addition to identifying minimum flow thresholds, the District incorporates a percent-of-flow method as part of its building-block framework using a 15% reduction criterion tied to specific environmental values. The percent-of-flow method is considered as a “top-down” approach (Arthington et al. 1998, Brizga et al. 2002, Arthington 2012), in which modeled scenarios of incremental reductions to baseline flow and their associated ecological impacts are evaluated to identify flow thresholds that potentially lead to significant harm.

Although this approach begins with an analysis of the river’s flow regime, the ultimate determination of withdrawal limits depends on the relationship between flow and specific resources of concern. The main goal is to maintain the natural flow regime of the river as much as possible while allowing limited flow reductions for water supply. This goal is based on the current understanding of linkages between the natural flow regime and physical and biological processes affecting the ecological integrity of flowing water bodies (Poff et al. 1997, Instream Flow Council 2002, Postel and Richter 2003). These processes include sediment transport, channel maintenance, fish passage, the inundation of instream and floodplain habitats, and maintaining water levels and velocities that support aquatic life cycles.

Since its inception, this method has received international recognition as a progressive strategy for managing freshwater and estuarine environments (Alber 2002, Postel and Richter 2003, National Research Council 2005, Instream Flow Council 2002). Its utility has recently been recognized in the development of presumptive, risk-based environmental flow standards that are recommended for river systems where data-intensive approaches to flow protection have not been or are unlikely to be implemented (Richter et al. 2011).

Under this approach, minimum flows allow permitted surface water users to withdraw a percentage of streamflow at the time of the withdrawal, while permitted groundwater users may be authorized to reduce baseline flows by prescribed percentages on a long-term basis. By proportionally scaling water withdrawals to the rate of flow, the method minimizes adverse impacts associated with large extractions during low-flow periods, when river systems are especially vulnerable to flow reductions. Conversely, high flows may permit increased withdrawals without compromising ecological health.

The regulation of groundwater withdrawals under this method requires consideration of the gradual and more diffuse manner in which groundwater level changes influence streamflow. Despite these challenges, the District has successfully implemented the percent-of-flow method to manage groundwater withdrawals.

The District has successfully implemented the percent-of-flow method across a range of freshwater systems for permitted water withdrawals, including water-supply withdrawals from the Lower Peace River, Lower Alafia River and Little Manatee River, further validating its effectiveness as a regulatory tool.

1.6 Other Supporting Information

1.6.1 Horizontal and Vertical Datums

The horizontal datum for this reevaluation is referenced to the Florida State Plane Coordinate System, West Zone (0902), using U.S. Survey Feet, based on the North American Datum of 1983 (NAD83 HARN) with the current adjustment, including the most recent update from the National Spatial Reference System (NSRS). This standard is applied across all relevant activities involving data collection, GIS mapping, and modeling.

In alignment with federal agency requirements, the District has completed its upgrade from the National Geodetic Vertical Datum of 1929 (NGVD 29) to the National American Vertical Datum of 1988 (NAVD 88). Accordingly, all elevation related analyses in this report utilize NAVD88. This datum standard also applies to all associated and supporting project work discussed in Section 1.6.2.

1.6.2 Overview of Completed Supporting Projects

In response to the peer review panel's comments on the Upper Peace River MFLs study (Gore et al. 2002), specifically recommendation for "collection of more detailed data and adoption of a border perspective regarding options for ecosystem management and restoration" and in consideration of subsequent advancements in the development of MFLs methodologies within the District, a series of supporting projects have been completed. These projects, conducted through consulting services, are briefly summarized below in chronological order of completion.

- **Peace River Corridor LiDAR Hydrographic & Topographic Survey**

Ground elevation data were collected and delivered using aerial light detection and ranging (LiDAR) photogrammetric mapping systems by Aerial Cartographics of America, Inc. (ACA) and two other consultants in 2014. The survey encompassed approximately 150 square miles of the Peace River floodplain, spanning from Lake Hancock, Polk County to Sandhill Blvd, Charlotte County. Data collection consisted of 167 individual square tiles, each measuring 5,000 feet by 5,000 feet. The resulting dataset supported the development of digital elevation models for the Peace River Corridor. Additional information related to this survey is provided in Section 5.2.1.

- **Upper Peace River Bathymetric Survey**

Bathymetric data were collected at 90 transect locations along the main stem of the Upper Peace River by Pickett and Associates, LLC (Pickett 2020). Transect lengths were determined based on the distance required to extend approximately 100 feet beyond the water boundaries defined in the District-provided LiDAR dataset. This survey supplemented topographic coverage by addressing data gaps beyond the LiDAR limits and supported both HEC-RAS modeling and habitat characterization. Additional details regarding bathymetric data are provided in Section 5.2.2.

- **Review and Recommendation for HEC-RAS Unsteady Flow Modeling of the Upper Peace River**

Previous HEC-RAS modeling efforts for the Upper Peace River (SWFMMD 2002, Chen 2011) were limited to steady flow simulations. To support a comprehensive reevaluation of the river system, the District contracted with Barnes, Ferland, and Associates, Inc. (BFA) in 2020 to assess the feasibility of integrating unsteady flow simulations using HEC-RAS in conjunction with the steady state model. The consultant conducted a detailed review of earlier modeling work, with particular focus on the HEC-RAS model developed by Chen (2011). Their assessment concluded that a paired modeling approach, combining both steady and unsteady HEC-RAS simulations, offers a sound strategy to improve the model accuracy (BFA 2020). For complete findings, refer to Appendix A.

- **Peace River Integrated Modeling (PRIM) Project**

To better understand hydrologic dynamics within the basin, the Peace River Integrated Modeling Project version 1 (PRIM1) was initiated in 2008. This numerical model integrated surface water and groundwater simulations to evaluate the effects of past development and to support the District in achieving its recovery goals for the basin. Based on the data from 1994 to 2002, PRIM1 was completed in 2011 (HGL 2011).

In 2020, the District contracted with HydroGeoLogic, Inc. to update the PRIM1 to PRIM2 using data from 2003 to 2018, which was completed in 2022 (Appendix B). With this updated model, the District was able to simulate the impacts of groundwater withdrawals on the river's flow regime, isolating from the effects of structural alterations and long-term climatic changes.

- **Woody Habitat Data Collection**

To support instream habitat analysis within the overall MFLs methodology used in reevaluating minimum flows for the Upper Peace River, the District contracted with Environmental Science Associates (ESA 2023) to collect woody habitat data, primarily snags and exposed root elevations, during low-flow conditions. Data were gathered from 20 transects located along both river banks from Bartow to Zolfo Springs in the Upper Peace River. The resulting dataset was utilized by District staff for woody habitat analysis, as detailed in Sections 5.2.3.2, 5.5.5 and 6.2.3.2 and in Appendix D.

- **System for Environmental Flow Analysis Data Collection**

In parallel with the woody habitat analysis, an additional instream habitat analysis was conducted using the System for Environmental Flows Analysis (SEFA), as part of the overall MFLs methodology applied in the reevaluation of minimum flows for the Upper Peace River. To support this effort, the District contracted with HSW Engineering Inc. (now Verdantas) in 2021 to collect physical habitat data including depth, velocity, and substrate/cover at nine designated sites. Each site consists of three transects representing shoal, run, and pool habitats, sampled under low-, medium-, and high-flow conditions. Further details can be found in Sections 5.2.3.1, 5.5.4, and 6.2.3.1 and Appendix E.

- **Upper Peace River HEC-RAS Model Development**

To support the reevaluation of minimum flows for the Upper Peace River, Verdantas (2024, see Appendix H), under contract with the District, developed a HEC-RAS model covering the study reach from approximately two miles upstream of the USGS Peace River at SR 60 at Bartow, FL gage (No. 02294650; River Mile [RM] 104) to approximately 0.5 miles downstream of the USGS Peace River at US 17 at Zolfo Springs, FL gage (No. 02295637; RM 68.6), encompassing a total reach length of roughly 40 miles. Key modeling activities included review of existing site conditions, compilation of relevant data, evaluation of the utility of unsteady flow modeling, model construction, model calibration and validation, conversion of unsteady to steady flow model, and development of flow profiles and inundation mapping. Outputs from the HEC-RAS model serve as a critical foundation for the technical and analytical components of MFLs development for the Upper Peace River. For further details, refer to Sections 5.3.2 and Appendix H.

1.6.3 Organization of This Document

Chapter 1 outlines the regulatory framework and scientific rationale for establishing minimum flows in the Upper Peace River. It emphasizes the importance of protecting the flow regime rather than a single minimum flow threshold and introduces the District's approach to setting minimum flows for the Upper Peace River, including a brief overview of supporting projects.

Chapter 2 provides an overview of the Upper Peace River basin, along with an extended discussion of the broader Peace River watershed. It examines basin-wide characteristics, including climate, physiography, soil, land use, and water use, followed by an exploration of hydrogeology, streamflow and levels, key factors influencing flow conditions, and ecological resources.

Chapter 3 analyzes trends in water quality parameters within the Upper Peace River and includes exploratory evaluations of the relationships between flow and water quality.

Chapter 4 identifies the ecological resources of concern and highlights the key habitat indicators used in the development of minimum flow criteria.

Chapter 5 outlines the data sources, modeling tools, and analytical methodologies employed to evaluate minimum flows in relation to the identified resources of concern.

Chapter 6 presents the results of technical analyses and provides minimum flow recommendations for the Upper Peace River, with specific attention to the protection of ten environmental values.

Chapter 7 discusses the status assessment and implementation of minimum flows for the Upper Peace River and concludes with guidance for future evaluation and adaptive management.

CHAPTER 2 FROM PAST TO PRESENT: UNDERSTANDING THE UPPER PEACE RIVER BASIN

This chapter presents a comprehensive overview of the Upper Peace River basin and, where appropriate, extends the discussion to the broader Peace River watershed to provide context for understanding the Upper Peace River's historical and current conditions, as well as its hydrological and ecological connectivity within the larger watershed system.

Chapter 2 traces the environmental, geological, hydrological, and ecological evolution of the Upper Peace River basin to support the reevaluation of the minimum flow criteria. It begins with an overview of the watershed's physical and environmental characteristics, including climate, physiography, land use and land cover, soil, and water use - factors that shape the region's hydrologic behavior and ecological integrity.

The hydrogeology section examines subsurface water systems, detailing the surficial, intermediate, and Floridan aquifers. It also highlights groundwater flow and level conditions, and the presence of karst features and the hydraulic connectivity between groundwater and surface water systems.

The streamflow and levels section analyzes data for major gaging stations, offering insights into flow statistics, long-term trends in streamflow and surface water levels, and specific characteristics of the river between Bartow and Zolfo Springs.

Following this, the chapter presents a detailed assessment of factors influencing streamflow, including long-term changes in rainfall, groundwater withdrawals, phosphate mining, reductions in wastewater discharges, structural alterations, and the Lake Hancock Lake Level Modification Project.

The chapter concludes with the summary of the watershed's ecological resources, covering benthic macroinvertebrates, fish populations, other wildlife, vegetation communities, and designated conservation areas.

2.1 Description of Study Area

The Peace River watershed, also known as the Peace River Valley, spans approximately 2,350 square miles and stretches across central and southwestern Florida. It includes major portions of Polk, Hardee, Desoto, and Charlotte counties, with small sections of Hillsborough, Mantee, Sarasota, Highlands, and Glades counties. The Upper Peace River basin, upstream of the USGS Peace River at US 17 at Zolfo Springs, FL gage (No. 02295637), encompasses the uppermost 825 square miles, accounting for roughly 35% of the entire watershed (Figure 2-1 and Table 2-1).

The Peace River, the primary drainage system within the watershed, originates in the Green Swamp in northern Polk County and flows south through Lake Hancock and

Peace Creek watersheds. The river officially begins at the confluence of Lower Saddle Creek and the Peace Creek Drainage Canal near Bartow in Polk County. From the confluence, it travels approximately 105 miles southward, passing through Fort Meade in Polk, Zolfo Springs in Hardee, and Arcadia in Desoto, before eventually discharging into Charlotte Harbor near Punta Gorda in Charlotte County (Figure 2-1), where it merges with the Caloosahatchee and the Myakka rivers. The Peace River is crucial for maintaining the health and productivity of Charlotte Harbor's estuarine system.

Primarily a blackwater river, the Peace River carries a dark mixture of leaf detritus, organic matter, and tannin from surrounding peaty wetlands and forests. It flows freely for most of its course, except for two regulated tributaries: the P-11 flood control structure on Lower Saddle Creek and a dam on Shell Creek for Punta Gorda's water supply. From its headwaters to its mouth, the river drops more than 200 feet in elevation. Upstream of Arcadia, the channel is generally well defined, while downstream it becomes braided and widened substantially, exceeding a mile in width in some locations. Tidal influences have been observed during periods of low flow as far as five miles upstream from Fort Ogden, which is about 10 miles southwest of the USGS Peace River at SR70 in Arcadia, FL gage (No. 02296750; Hammett 1990). Major surface water withdrawals occur at the Peace River Manasota Regional Water Supply Authority (PRMRWSA) water plant located south of Arcadia.

For this minimum flow reevaluation, the Upper Peace River is defined as a 37-mile river segment between two USGS gaging stations (Figure 2-1): the USGS Peace River at SR60 at Bartow, FL gage (No. 02294650), located just downstream of the confluence of Lower Saddle Creek and the Peace Creek Drainage Canal, and the USGS Peace River at US17 at Zolfo Springs, FL (No. 02295637), situated in the approximate center of Hardee County.

The Peace River watershed includes ten subbasins (Figure 2-1 and Table 2-1). The five largest subbasins, i.e., Peace Creek, Peace River at Zolfo Springs, Charlie Creek, Shell Creek, and Coastal Lower Peace River, each account for between 10% and 16% of the watershed, collectively comprising 65% of the total area. The remaining five subbasins, i.e., Saddle Creek, Paynes Creek, Peace River at Arcadia, Horse Creek, and Joshua Creek, contribute between 5% and 9% each. These subbasins exhibit diverse hydrologic, geologic, vegetative and land-use characteristics, with varying levels of anthropogenic impacts affecting surface waters, groundwaters, wetlands, fisheries, aquatic habitats, and water supplies, etc.

For minimum flows development, these subbasins are grouped as follows:

- **Upper Basin**: Saddle Creek, Peace Creek, Paynes Creek, and Peace River at Zolfo Springs
- **Middle Basin**: Charlie Creek and Peace River at Arcadia

- **Lower Basin**: Joshua Creek, Horse Creek, Shell Creek and Costal Lower Peace.

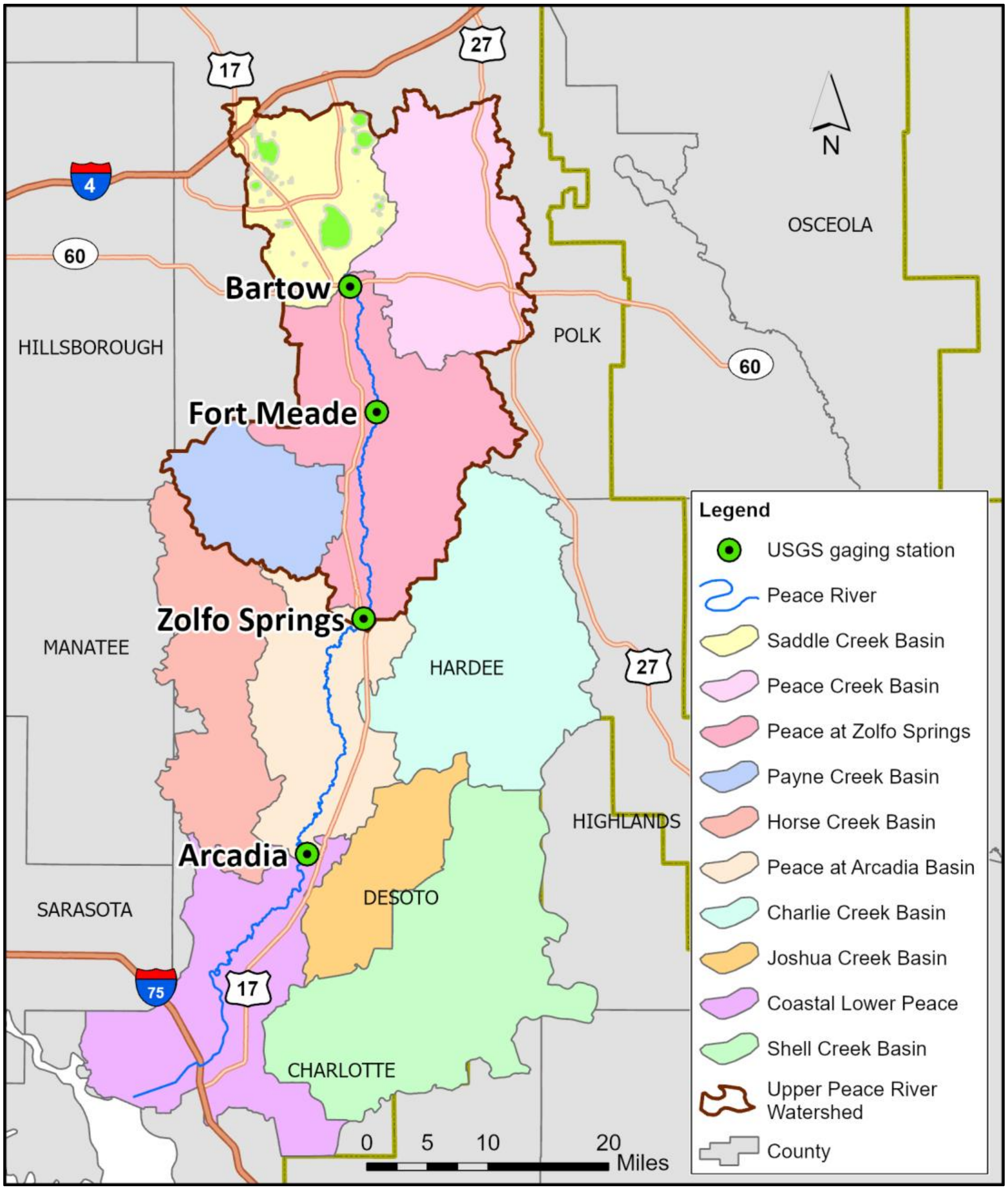

Figure 2-1. Overview of the Peace River watershed, including the Peace River, subbasins, major tributaries, key USGS gaging stations, and other pertinent locations. The Upper Peace River basin, defined as the area upstream of the USGS Zolfo Springs gage, is outlined in brown.

Between Bartow and Bowling Green (see Figure 2-2), surface water drainage into the Peace River is predominately from phosphate mine outfalls and reclaimed stream channels affected by past mining (Lewelling 2004). This area also contains numerous clay-settling areas, the dominant reclaimed landform type, spanning hundreds of acres along the river. South of Bowling Green, drainage transitions to naturally formed, well developed tributaries (Lewelling et al. 1998).

Aside from Saddle Creek and Peace Creek, the Upper Peace River receives inflows from several key tributaries: Bear Branch, Six Mile Creek, Camp Meeting Ground Branch, Sink Branch, Bowlegs Creek, McCullough Creek, Whidden Creek, Little Payne Creek, Payne Creek, Little Charlie Creek, Max Branch, and Thompson Branch. Among these, Bowlegs Creek and Payne Creek are notably significant. Several tributaries, such as Bear Ranch, Six Mile Creek, Camp Meeting Ground Branch, McCullough Creek, Whidden Creek, and Little Payne Creek, have been altered by historic phosphorate mining, while others like Sink Branch, Max Branch and Thompson Branch remain natural, flowing through agricultural lands. Downstream of the Upper Peace River, major natural tributaries feeding into the river include Charlie Creek, Joshua Creek, Horse Creek, and Shell Creek.

Table 2-1. Drainage subbasins contributing to the Upper, Middle and Lower Peace River segments.

MFL River Segment	Subbasin Name	$Miles^2$	Acres	Percentage of Watershed
Upper Peace River	Saddle Creek	159	101,689	7
	Peace Creek	229	146,658	10
	Payne Creek	124	79,310	5
	Peace River at Zolfo Springs	313	200,047	13
	Subtotal	**825**	**527,704**	**35**
Middle Peace River	Charlie Creek	328	209,866	14
	Peace River at Arcadia	207	132,243	9
	Subtotal	**535**	**342,109**	**23**
Lower Peace River	Joshua Creek	120	76,581	5
	Horse Creek	212	135,798	9
	Shell Creek	381	243,567	16
	Costal Lower Peace	275	175,999	12
	Subtotal	**988**	**631,946**	**42**
Entire Basin	**Total**	**2,348**	**1,501,759**	**100**

For the purpose of minimum flow development for the Upper Peace River, three river segments were defined and referenced throughout the later chapters of this document. These segments are as follows:

- **Upper segment**: Extend from Bartow to Fort Meade and is associated with the USGS index gaging station at Bartow.
- **Middle segment**: Covers the reach from Fort Meade to Bowling Green, corresponding to the USGS index gaging station at Fort Meade.
- **Lower segment**: Spans from Bowling Green to Zolfo Springs and is associated with the USGS index gaging station at Zolfo Springs

As shown in Figure 2-2, these segments serve as the basis for segment-specific minimum flows evaluations.

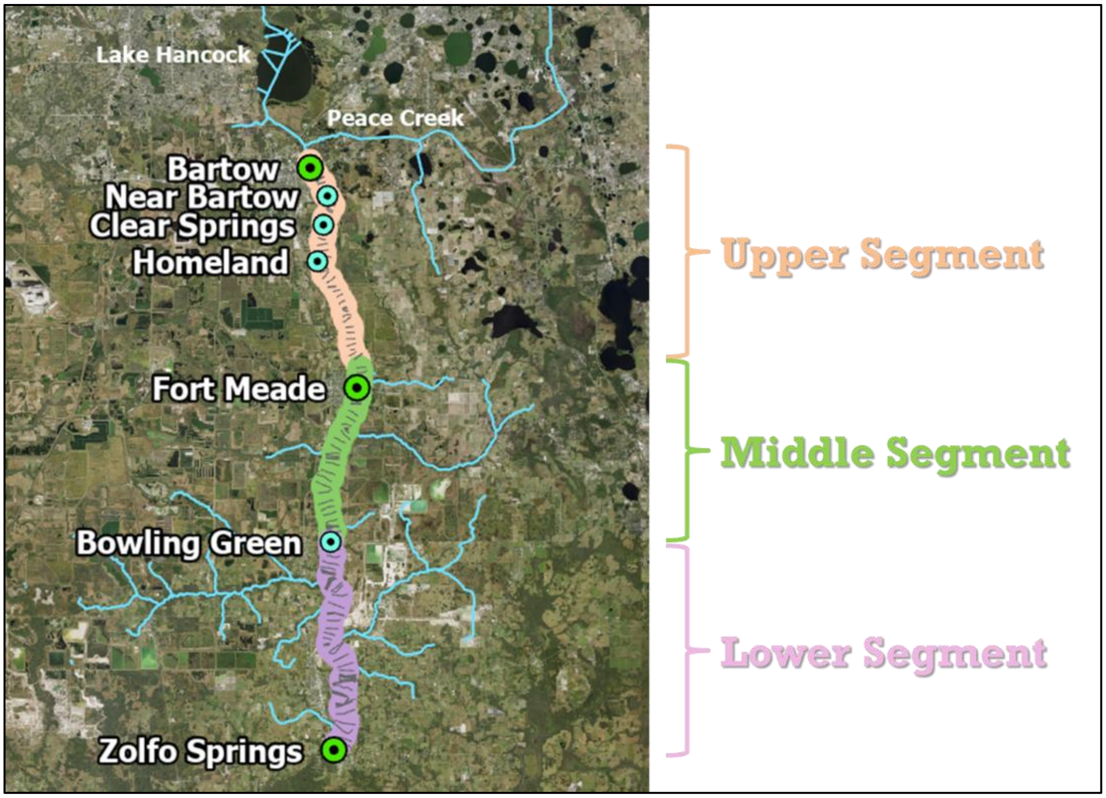

Figure 2-2. Color-coded river segments of the Upper Peace River and the seven mainstem USGS gaging stations, including the index gaging stations at Bartow, Fort Meade, and Zolfo Springs.

2.1.1 Climate

The Peace River watershed, located in West-Central Florida, experiences a humid subtropical climate, with mild, dry winters and hot, wet summers. The average annual temperature is approximately 72 °F (Hammett 1990, SWFWMD 2001). Long-term rainfall records from 1915 to 2022 indicate an average annual rainfall of around 52 inches (Figure 2-3), with historical extremes ranging from 31 inches in 2000 to 78 inches in 1947.

Rainfall is the primary freshwater source for the watershed, and seasonal variability drives its hydrologic dynamics. At the onset of the rainy season, rainfall contributes significantly to surface and groundwater storage (Basso and Schultz 2003). At the end of the rainy season, surface and groundwater levels are high and much of the rainfall goes directly to runoff (Ross et al. 2001). Rainfall is unevenly distributed throughout the year, with roughly 60% occurring during the wet season (June-September), mainly from local thunderstorms. In contrast, spring, winter, and fall participation typically comes from large frontal systems moving southward (Hammett 1990).

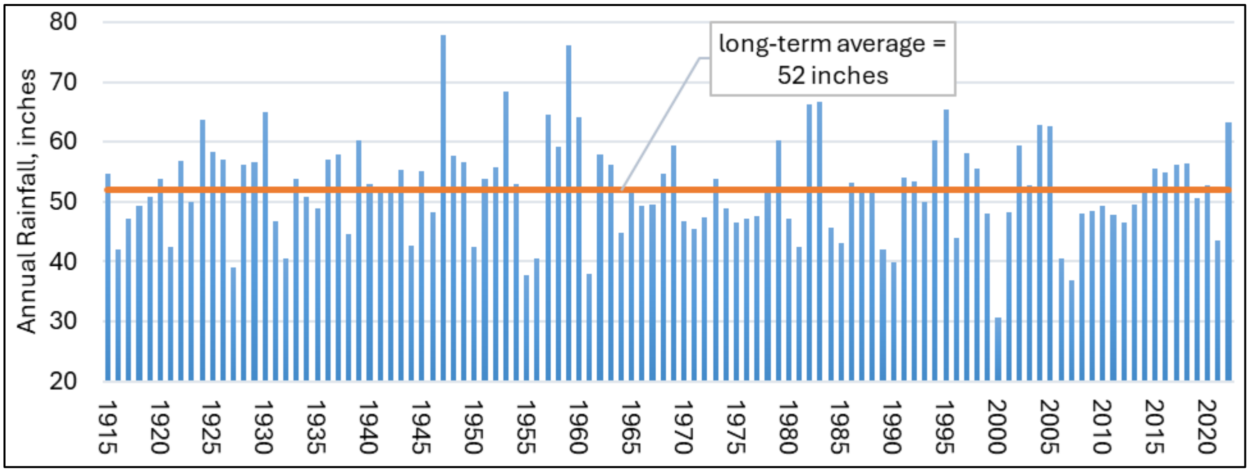

Figure 2-3. Distribution of annual rainfall for the period of record from 1915 through 2022 based on the rainfall data summary for the Peace River watershed published by the District.

Data from 1915 to 2022 (Figure 2-4) show that June is the wettest month, averaging 8.34 inches of rain, while November is the driest, averaging 1.77 inches. Most rainwater is lost through evapotranspiration (ET), with the remainder recharging groundwater and flowing as runoff into the Peace River system. Despite low rainfall in November and December (Figure 2-4), stream flows, lake stages and groundwater levels tend to bottom out in April and May due to a combination of prolonged low rainfall and high evaporation rates (Hammett 1990, SWFWMD 2001).

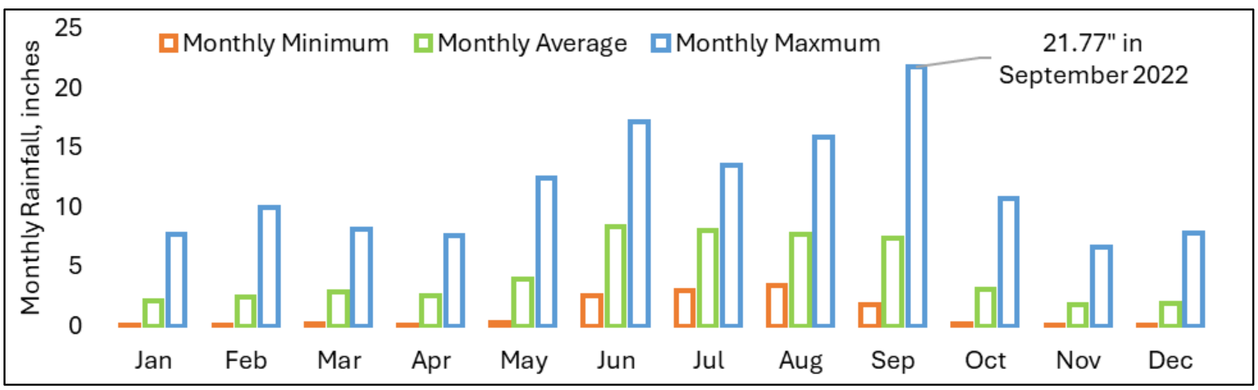

Figure 2-4. Distribution of average monthly rainfall for the period of record from 1915 through 2022 based on the rainfall data summary for the Peace River watershed published by the District.

Climatic conditions significantly influence watershed hydrology. Tropical storms and hurricanes cause the most severe weather, evident in stream flow hydrographs for all streams in Central Florida. For instance, Hurricane Donna brought 14.76 inches of rainfall in September 1960, nearly double the long-term monthly mean of 7.38 inches. This record was surpassed in September 2022, when Hurricane Ian resulted in 21.77 inches of rainfall, the highest monthly record for the Peace River watershed in the 108-year period (1915-2022).

The watershed has also experienced severe droughts, notably in 1999-2001 and 2006-2007. The droughts of 2001 and 2007 resulted in the lowest annual rainfall of 30.72 inches and 36.97 inches, respectively, indicating 40% and 30% below the long-term annual average. These droughts caused the Upper Peace River between Bartow and Fort Meade to dry up for extended periods, jeopardizing water supply due to water quality issues (FDEP 2007a).

Evaporation is another critical hydrologic factor. Florida's high solar radiation and warm water temperatures drive substantial evaporation rates. In the Upper Peace River, clay-settling areas from phosphate-mining have limited recharge capacity due to their clay-lined bottoms. Water in these ponds typically evaporates instead of recharging the groundwater system, representing a loss of water from the Upper Peace River basin that did not occur before mining operations began (Metz and Lewelling 2009).

In summary, annual rainfall patterns and extreme variations result from three interacting weather patterns: large frontal systems in winter, highly variable and spotty wet season rain events, and the potential for tropical depressions and hurricanes in late summer and early fall. The climate of the Peace River watershed significantly affects its water resources, habitats, ecology, and human activities.

2.1.2 Physiography[1]

The physiographic features of the Peace River watershed (Figure 2-5) have been shaped over geologic time by interactions between geologic units and both the surface water and groundwater systems. The physiographic boundaries generally correspond to paleoshorelines that separate marine plains or terraces, as originally recognized by Cooke (1945) and MacNeil (1950). These shorelines (Figure 2-5) have been mapped throughout the Peace River valley and its major tributaries (Wilson 1977).

The three major physiographic provinces present in the Peace River watershed are the Polk Upland, the DeSoto Plain, and the Gulf Coast Lowlands (White 1970). Brooks (1981) further subdivided these areas into the Bone Valley Uplands, DeSoto Slope, and Barrier Island Coastal Strip (see Figure 2-5). A paleoshoreline at the 100-foot elevation marks the boundary between the upland regions and the plain, while the 30-foot elevation separates the plain from the coastal lowlands, which include both the Barrier Island Costal Strip and the Gulf Coastal Lowlands near Charlotte Harbor.

Overall, the watershed's physiography transitions from an upland, internally drained lake district, dominated by several highland ridges in Polk County, through a poorly

[1] The physiographic details in this section are derived from the Physiographic Setting described in Lewelling et al. 1998.

drained upland in the northern half of Hardee County, to a broad, gently sloping plain with well-developed surface drainage in southern Hardee and most of DeSoto Counties (Lewelling et al. 1998). Several physiographic features reflect or influence the regional hydrologic regime, notably:

- The Bartow Embayment, extending from above Lake Hancock to directly north of Homeland (Brooks 1981), is an internally drained, local erosional basin partially infilled with phosphate-rich siliclastic deposits (Brooks 1981). In this area, the Peace River basin lies between several ridges to the east and west.

The Polk Upland, stretching south from Homeland to Zolfo Springs, corresponds to the Bone Valley Uplands and features land surface elevations above 130 feet above sea level. It is characterized by flatwoods, wetlands, and lakes atop a poorly drained plateau underlain by deeply weathered sand and clayey sand of the Bone Valley Member of the Peace River Formation (see).

- The Upper Peace River basin, especially upstream of Bowling Green, phosphate surface-mining has altered many natural drainage system characteristics. Reclaimed landforms adjacent to the floodplain from Bartow to Bowling Green, predominantly large clay-settling areas that impede natural ground-water recharge and surface water drainage into the Peace River.
- The DeSoto Slope, or the DeSoto Plain, is a combination of wet prairie, swamp, and flatwoods that contains the well-developed surface drainage system of the Peace River and its major tributaries.
- The Gulf Coastal Lowlands and the Barrier Islands Coastal Strip are below Arcadia where the Peace River ultimately discharges into the Charlotte Harbor estuary.

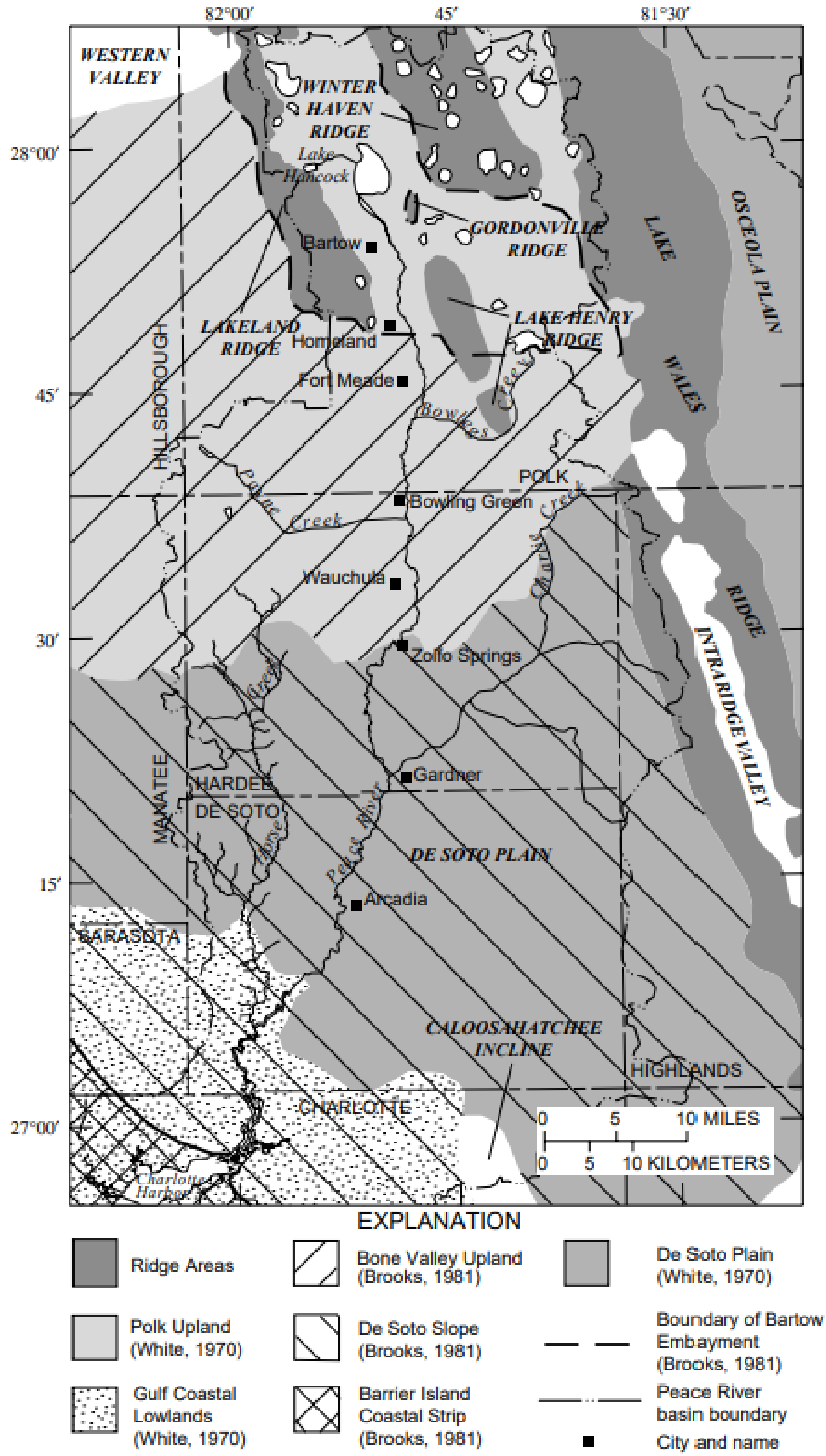

Figure 2-5. Regional physiographic features of the Peace River watershed (adapted from Lewelling et al. 1998, Figure 2; originally modified from White 1970 and Brooks 1981).

2.1.3 Land Use and Land Cover

2.1.3.1 Land Use and Land Cover Trends[2]

Development and population growth within the entire Peace River watershed, including the Upper, Middle, and Lower Basins, have led to substantial land-use changes that directly affect the quality and quantity of water entering the river system. Since the 1940s, the watershed has experienced marked transformations. The Peace River Cumulative Impact Study (PBSJ 2007) provides a comprehensive analysis of land-use trends from the 1940s through 1999 across nine subbasins. Notably, the study combines the Peace Creek and Saddle Creek subbasins under the designation “Peace River at Bartow” (see Figure 2-1).

In the 1940s, uplands and wetlands comprised approximately 59.7% and 25.4% of the watershed’s 1.4 million acres, totaling around 85% natural land cover (Table 2-2). By 1999, these figures declined sharply to 17.4% for uplands and 15.6% for wetlands. In contrast, developed land (improved pasture, intense agriculture, phosphate mining, and urban) increased from 12% to nearly 63% over the same time period (Table 2-2). Land-use percentages in 2020 remained generally consistent with those in 1999, though notable shifts occurred within specific land-use classes.

Improved pasture saw the largest expansion, increasing from about 40,000 acres (2.8%) in the 1940s to 379,000 acres (27.2%) in 1999. Intense agriculture more than doubled, from approximately 107,000 acres to 230,000 acres. By 1999, agriculture became the primary driver of native upland conversion, representing 43.7% of total land use. Both improved pasture and intensive agriculture declined slightly between 1999 and 2020 (Table 2-2).

Phosphate mining occupied less than 1% of land in the 1940s, but expanded to roughly 10% by 1999, with a slight increase through 2020 (Table 2-2). Mining activities were concentrated in five subbasins: Peace River at Bartow, Peace River at Zolfo Spring, Payne Creek, Peace River at Arcadia, and Horse Creek (Table 2-3). Over time, operations shifted southward from the northern Peace River at Bartow and Zolfo Springs subbasins to the Payne Creek and upper Horse Creek subbasins, driven by deeper ore deposits and declining ore quality in the north.

Urban land use increased from approximately 15,000 acres (1%) in the 1940s to 134,000 (9.6%) in 1999, removing approximately 73,000 acres of native upland habitat (Table 2-2). Between 1999 and 2020, urban land use expanded by more than 50%, rising to about 15% of total land use (Table 2-2). Urbanization was most

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[2] A comprehensive analysis of land use trends in the entire Peace River watershed and its subbasins is documented in the “Peace River Cumulative Impact Study” (PBSJ 2007), which covers the period from the 1940s through 1999. Land use data referenced in that time frame were drawn from this report. Additional information beyond 1999 has been gathered and analyzed as part of this current study to capture more recent developments.

pronounced in the northern Polk County (Peace Creek and Saddle Creek subbasins) and southern Charlotte County in the Costal Lower Peace River basin. Population growth trends corresponding to urban expansion are illustrated in Figure 2-6.

Table 2-2. Summary of land-use acres and percentages in the Peace River watershed (1940s–2020).

Land Use Class	1940 Acres	%	1979 Acres	%	1999 Acres	%	2020 Acres	%
Developed								
Improved Pasture	39,640	2.8	356,925	25.6	379,346	27.2	334,685	22.8
Intense Agriculture	107,115	7.7	191,496	13.7	229,832	16.5	204,173	13.9
Mined Lands	7,495	0.5	64,437	4.6	143,487	10.3	159,191	10.8
Urban Land Use	14,659	1.0	73,049	5.2	133,571	9.6	216,630	14.7
Subtotal	**168,909**	**12**	**685,907**	**49**	**886,236**	**63**	**914,679**	**62**
Undeveloped								
Native Uplands	834,311	59.7	419,449	30	242,849	17.4	208,785	14.2
Wetlands	354,674	25.4	249,255	17.8	218,232	15.6	286,830	19.5
Subtotal	**1,188,985**	**85**	**668,704**	**48**	**461,081**	**33**	**495,615**	**34**
Water								
Lakes	33,779	2.4	35,432	2.5	43,027	3.1	52,286	3.6
Other Waters	5,011	0.4	6,641	0.5	6,338	0.5	6,793	0.5
Subtotal	**38,790**	**3**	**42,073**	**3**	**49,365**	**4**	**59,079**	**4**

Note that the benchmark period for land use data was circa-1940s based on the availability of high-resolution aerial photography. Land use statistics from the 1940s through1999 were adapted from PBSJ (2007), while data for the year 2020 were derived from the District's 2020 Land Use Land Cover GIS layer.

Table 2-3. Mining area changes (acres) in subbasins within the Peace River watershed (1940-1999). Modified from PBSJ (2007).

Year	Mining Category	Peace River at Bartow	Peace River at Zolfo Springs	Payne Creek	Peace River at Arcadia	Horse Creek	Total
1940	Totally/Partially Reclaimed	0	0	0	0	0	0
	Mined Nonmandatory	6,572	5,207	1,256	0	0	13,035
	Mined Mandatory	0	0	0	0	0	0
	Active Clay Setting Areas	387	0	0	0	0	387
1979	Totally/Partially Reclaimed	8,180	4,752	2,490	0	0	15,422
	Mined Nonmandatory	11,952	10,957	4,362	0	0	27,270
	Mined Mandatory	6,623	0	3,899	0	0	10,522
	Active Clay Setting Areas	23,642	7,227	7,958	0	0	38,828
1999	Totally/Partially Reclaimed	28,363	11,486	16,152	0	574	56,575
	Mined Nonmandatory	9,616	8,641	3,458	0	0	21,715
	Mined Mandatory	1,528	232	11,032	0	2,398	15,191
	Active Clay Setting Areas	28,267	5,903	14,025	183	553	48,931

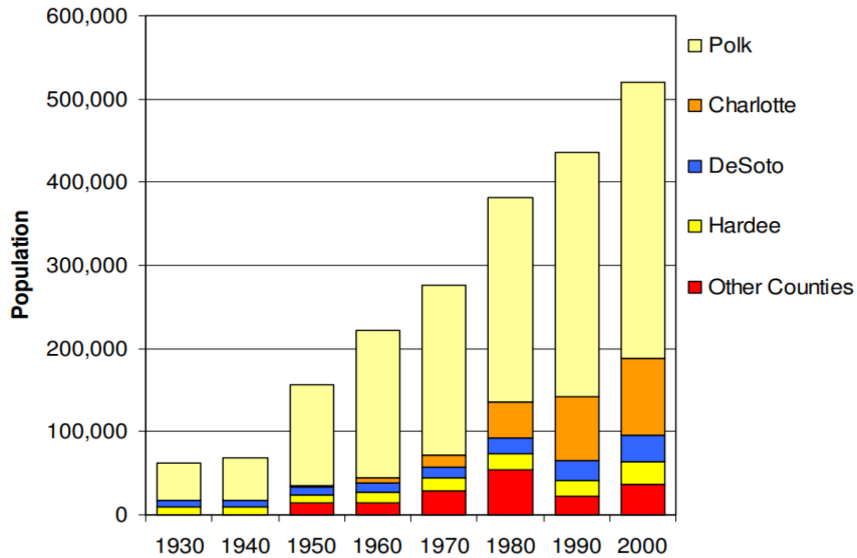


Figure 2-6. Population changes in the Peace River watershed (1930-2000). Modified from PBSJ (2007).

As development intensified, undeveloped lands (uplands, wetlands, streams and river channels, and lakes) declined sharply from covering 88% of the Peace River watershed in the 1940s to 51% in 1979, and further to 37% in 1999 (Table 2-2). Most land-use conversions occurred between the 1940s to 1979, primarily shifting uplands to improved pasture. Mining and urban development continued to expand between 1979 and 1999 (Table 2-2 and Table 2-3).

The Upper Peace River basin (Figure 2-1), which comprises approximately 35% of the entire Peace River watershed (Table 2-1), exhibited similar trends (Table 2-4). However, unlike the broader watershed, where improved pasture (22.8%) and intense agriculture (13.9%) were the dominant developed land-use classes in 2020, mined land (25.2%) represented the largest developed area in the Upper Peace River basin, followed by urban land use (22.3%) (Table 2-4, Figure 2-7).

Table 2-4. Summary of land-use acres and percentage in the Upper Peace River basin (1940s–2020).

Land Use Class	1940s Acres (%)	1979 Acres (%)	1999 Acres (%)	2020 Acres (%)
Developed				
Improved Pasture	16,504 (3.2)	97,333 (19.0)	83,941 (16.4)	65,068 (12.3)
Intense Agriculture	73,733 (14.4)	88,998 (17.4)	69,146 (13.5)	47,930 (9.0)
Mined Lands	7,458 (1.5)	64,437 (12.6)	135,539 (26.5)	133,851 (25.2)
Urban Land Use	10,339 (2.0)	37,405 (7.3)	76,466 (15.0)	118,296 (22.3)
Subtotal	**108,034 (21.1)**	**288,173 (56.4)**	**365,092 (71.4)**	**365,145 (68.8)**
Undeveloped				
Native Uplands	231,627 (45.3)	105,899 (20.7)	42,230 (8.3)	32,142 (6.1)

Land Use Class	1940s Acres (%)	1979 Acres (%)	1999 Acres (%)	2020 Acres (%)
Wetlands	137,550 (26.9)	82,413 (16.1)	64,711 (12.7)	87,364 (16.5)
Subtotal	**369,177 (72.2)**	**188,312 (36.9)**	**106,941 (20.9)**	**119,506 (22.5)**
Water				
Lakes and Open Water	33,362 (6.5)	34117 (6.7)	38,639 (7.6)	45,973 (8.7)
Stream and River Channels	414 (0.1)	387 (0.1)	318 (0.1)	367 (0.1)
Subtotal	**33,776 (6.6)**	**34,504 (6.8)**	**38,957 (7.6)**	**46,339 (8.7)**

Note that the benchmark period for land use data was circa-1940s based on the availability of high-resolution aerial photography. Land use statistics from the 1940s through1999 were adapted from PBSJ (2007), while data for the year 2020 were derived from the District's 2020 Land Use Land Cover GIS layer.

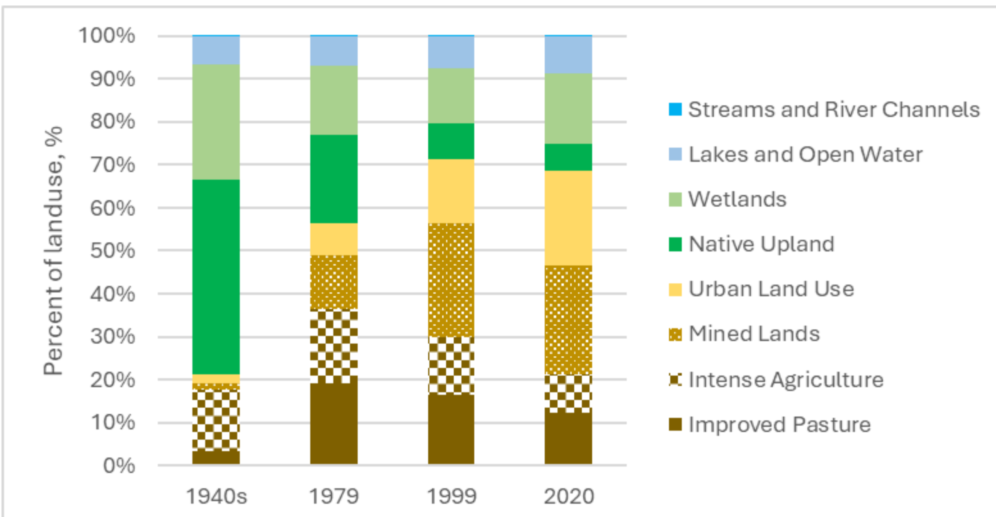


Figure 2-7. Changes in land use and land cover in the Upper Peace River basin among developed (gold), undeveloped (green) and water (blue) classifications, as described in Table 2-4.

Since 1975, Florida state law has required the reclamation of land mined for phosphate, including contouring, protecting water quality and quantity, revegetation of the area, and returning wetlands to their pre-mining state (Part II of Chapter 378, F.S., and Chapter 62C-16, F.A.C.). The FDEP maintains several geodatabases that track the status of mandatory phosphate units that must adhere to these reclamation laws.

Of the lands included in this database in the Upper Peace River basin, as of 2020, 34% of the lands were still actively mined, 38% were permanently shut down, and 29% were temporarily shut down (FDEP 2021a, Figure 2-8a). Reclamation work had been completed on 62% of the required lands, with 19% slated for future work and 4% considered work in progress (FDEP 2021b, Figure 2-8b). It is important to note that although the extent of mined lands changed only slightly between 1999 and 2002, as indicated by the percentages in Table 2-4, 60% of these lands had been reclaimed by 2020, as shown in Figure 2-9.

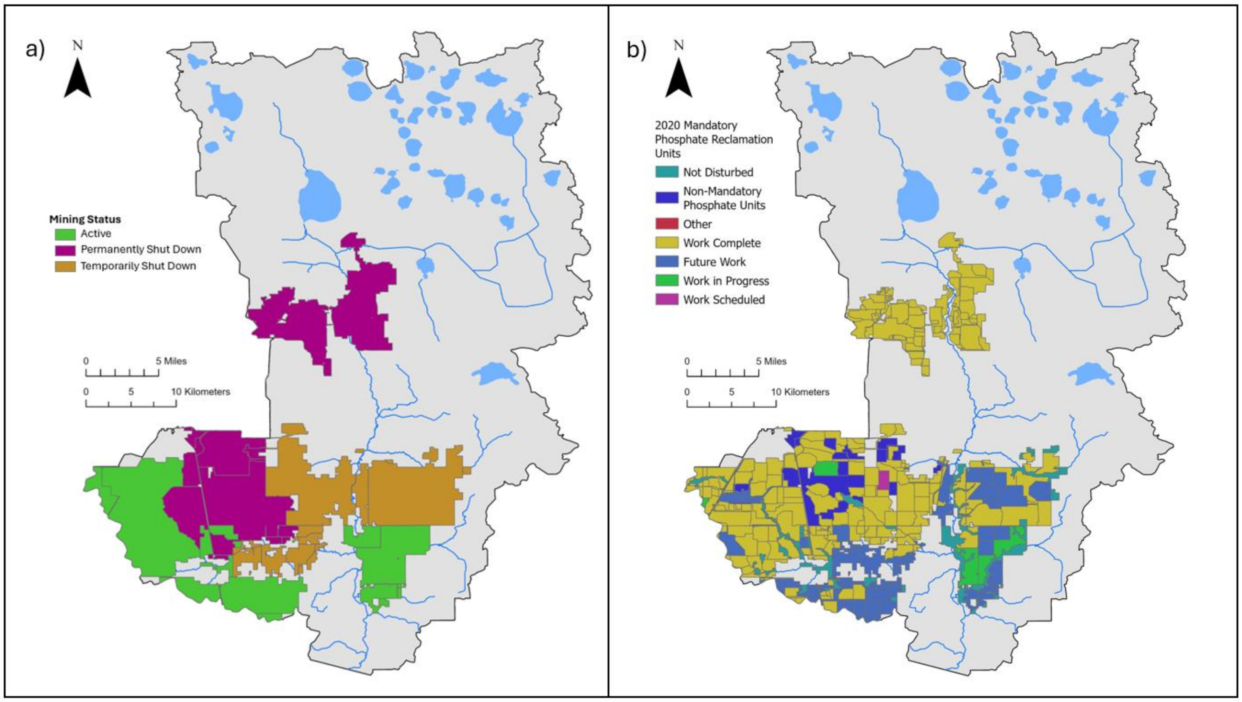


Figure 2-8. a) 2020 mining status of mandatory phosphate units within the Upper Peace River basin (Source: GIS layer maintained by FDEP (2021a). b) Areas mined for phosphate within the Upper Peace River basin as of 2020 (Source: GIS layer maintained by FDEP (2021b).

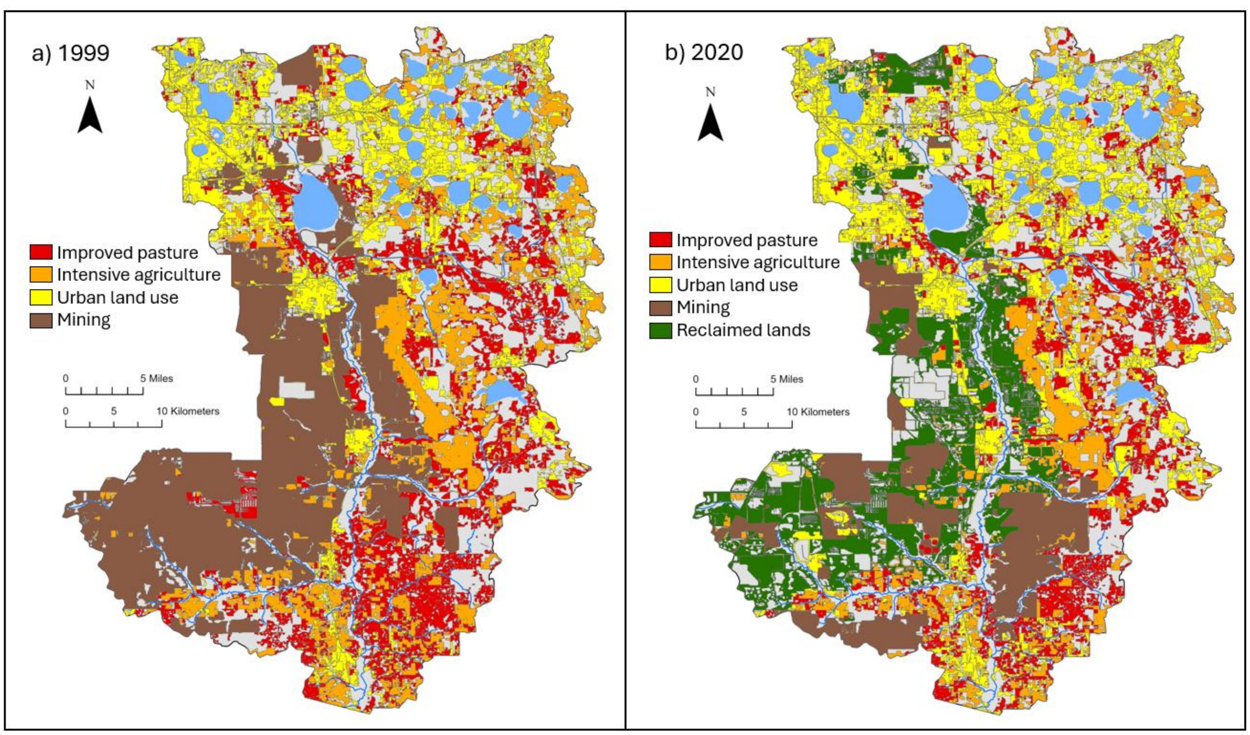


Figure 2-9. Developed land in the Upper Peace River basin between 1999 and 2020, based on FLUCCS categorizations delineated by PBS&J (2007) and GIS Land Use Land Cover files maintained by SWFWMD (2022b, 2022c).

Of the 156,153 acres of land classified as "agricultural" by the Florida Department of Agriculture and Consumer Services (FDACS), the vast majority (64%) are forms of grass or woodland pasture, rangeland, and fields for sod or hay. Approximately 19% of agricultural lands are active citrus orchards (FDACS 2023; Figure 2-10).

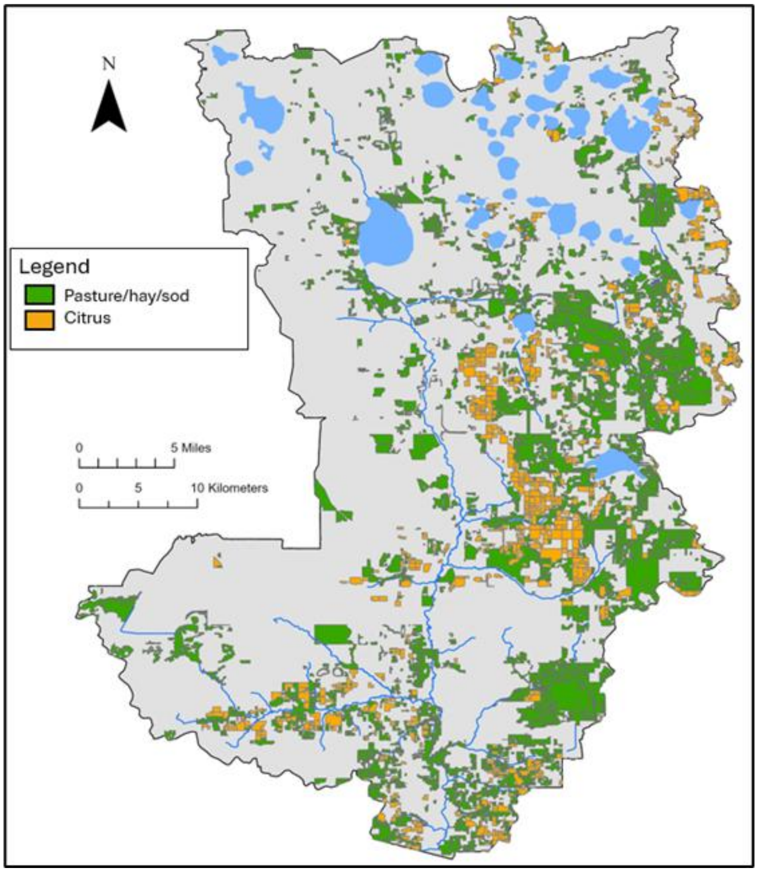


Figure 2-10. Primary agricultural land use in the Upper Peace River basin, includes various pasture classifications and citrus orchards (Source: GIS layer files maintained by the Florida Department of Agriculture and Consumer Services [FDACS], 2023).

In summary, these land-use changes have dramatically altered natural drainage patterns. Ditching and hydrologic manipulation connected poorly drained wet prairies and isolated wetlands to facilitate agricultural and urban development, increasing water conveyance and lowering water tables. Phosphate mining further reshaped topography and surface flow. Although reclamation practices now comply with regulatory standards, legacy impacts continue to affect watershed hydrology. As a result, the Peace River and its tributaries, along with the Charlotte Harbor Estuary have experienced significant shifts in volume, quality, and timing of surface runoff.

2.1.3.2 Landscape Development Intensity Index

The Landscape Development Intensity Index (LDI), developed by the FDEP's Bioassessment Program, quantifies the degree 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 mosaics 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 Upper Peace River basin: for the 100-meter buffer around the main channel of the Upper Peace River and for the 100-meter buffer around the main channel and primary tributaries. Land-use and land-cover data were obtained from 2023 Level 4 FLUCCS (Florida Land Cover Classification System) codes, available from the District (SWFWMD 2022c). Where FLUCCS descriptions did not exactly match those described by Brown and Vivas (2005), the 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 100-meter buffer around the main channel of the river was calculated as 1.35, indicative of a minimally disturbed watershed (Brown and Vivas, 2005). This is largely due to natural land classifications, such as stream bottomlands, wetlands, hardwoods, shrub and brushland, and marshes accounting for 93% of the area surrounding the river channel. When lands surrounding tributaries were included, the LDI was calculated as 2.46. The increased value was primarily driven by the presence of high intensity agriculture throughout 12% of the study area, extractive lands on 6% of the area, and reclaimed lands throughout 4% of the study area.

2.1.4 Soils

A Soil Survey Geographic (SSURGO) database for Florida, updated in October 2021, was obtained from the Florida Geographic Data Library in polygon feature class format. This dataset provides detailed information on soil types and their distribution across the state. To focus specifically on the Upper Basin of the Peace River watershed, the polygon feature class was clipped using ArcGIS Pro.

In 2002, the District (as cited in Metz and Lewelling, 2009) categorized soils within the Upper Basin of the Peace River watershed into five general types:

- Fine sands along the ridges and uplands
- Fine sands and loams along the riverine floodplain

- Mucky fine sand in depressional areas
- Altered soils in urban areas
- Sandy-clay soils in mined areas

Using these categories, the percentage and spatial distribution of each soil type were recalculated based on the 2021 SSURGO dataset, as illustrated in Figure 2-11.

Approximately 57% of the basin is covered by upland soils, which are moderately sloping and excessively to moderately well drained, allowing for rapid infiltration. The most dominant natural soil type in the region is flatwoods soil, typically nearly level with 0 to 2% slopes, poorly drained, sandy, and characterized by a high-water table. Common soil series include Candler, Myakka, Smyrna, and Immokalee.

Soils within riverine floodplain and depressional areas, making up roughly 12% of the basin, are frequently flooded, have little to no slope, moderately to poorly drained with high water table, providing moderate infiltration. Along the Upper Peace River, soils often belong to the Chobee series and are intermixed with other wetland types. Soils in the Chobee series are deep, with nearly level slopes of 0-1%, very poorly drained, and occur in depressions with high water tables. They typically include mucky or loamy components, in contrast with the sandier flatwoods soils. In Polk County, soil series, such as Nittaw-Kaliga-Chobee and Bradenton-Felda-Chobee, contain organic substrates of marshes and swamps underlain by clayey marine sediments. In Hardee County, similar series, such as Bradenton-Felda-Myakka, occur on loamy marine sediments typical of flatwoods but not marshes and swamps.

Mined soils, which border both sides of the Upper Peace River floodplain, comprise approximately 22% of the basin (Figure 2-11). The sandy-clay soils of mined sites, or arents, are less pervious because of the increase in clay content at the surface horizons that tends to limit surface infiltration (Lewelling and Wylie 1993). Postmining areas contain a large amount of clay waste byproducts, occupying around 40 to 60% of the postmined landscape (Yon 1983). Arent soil types include haplaquents, hydraquents, udorthents, gypsum-land complex, and urban-land complex. Due to the low hydraulic conductivity of clay, groundwater recharge and movement through a clay-settling area can be substantially reduced compared to natural conditions (Metz and Lewelling 2009).

Some sections of the floodplain, particularly near the confluence of Saddle Creek and the Peace Creek Drainage Canal, and within the Clear Springs Mine area, were mined prior to the establishment of mandatory reclamation in 1975. Field observations indicate that during low to moderate rainfall events, water ponds on these impervious soils primarily dissipate through evaporation. Additionally, shrinkage of the consolidating clays can cause depressional surface features to form, subsequently reducing runoff by increasing ponding and evaporation (Lewelling and Wylie 1993). Under heavier rainfall, runoff increases and occurs mostly as sheet flow.

Hydrological Soil Groups (HSGs), as defined by the Natural Resources Conservation Services (NRCS), classify soils based on their runoff potential during prolonged rainfall events (Figure 2-12). The four major soil groups (A, B, C and D) range from Group A (lowest runoff potential) to Group D (highest runoff potential) (Table 2-5). These classifications are determined by infiltration rates, which are influenced by soil texture and structure, depth to restrictive layers, and depth to the water table. Dual HSGs (A/D, B/D, and C/D) represent soils that are naturally in Group D but can be artificially drained. In these cases, the first letter represents the drained conditions while the second reflects the undrained conditions.

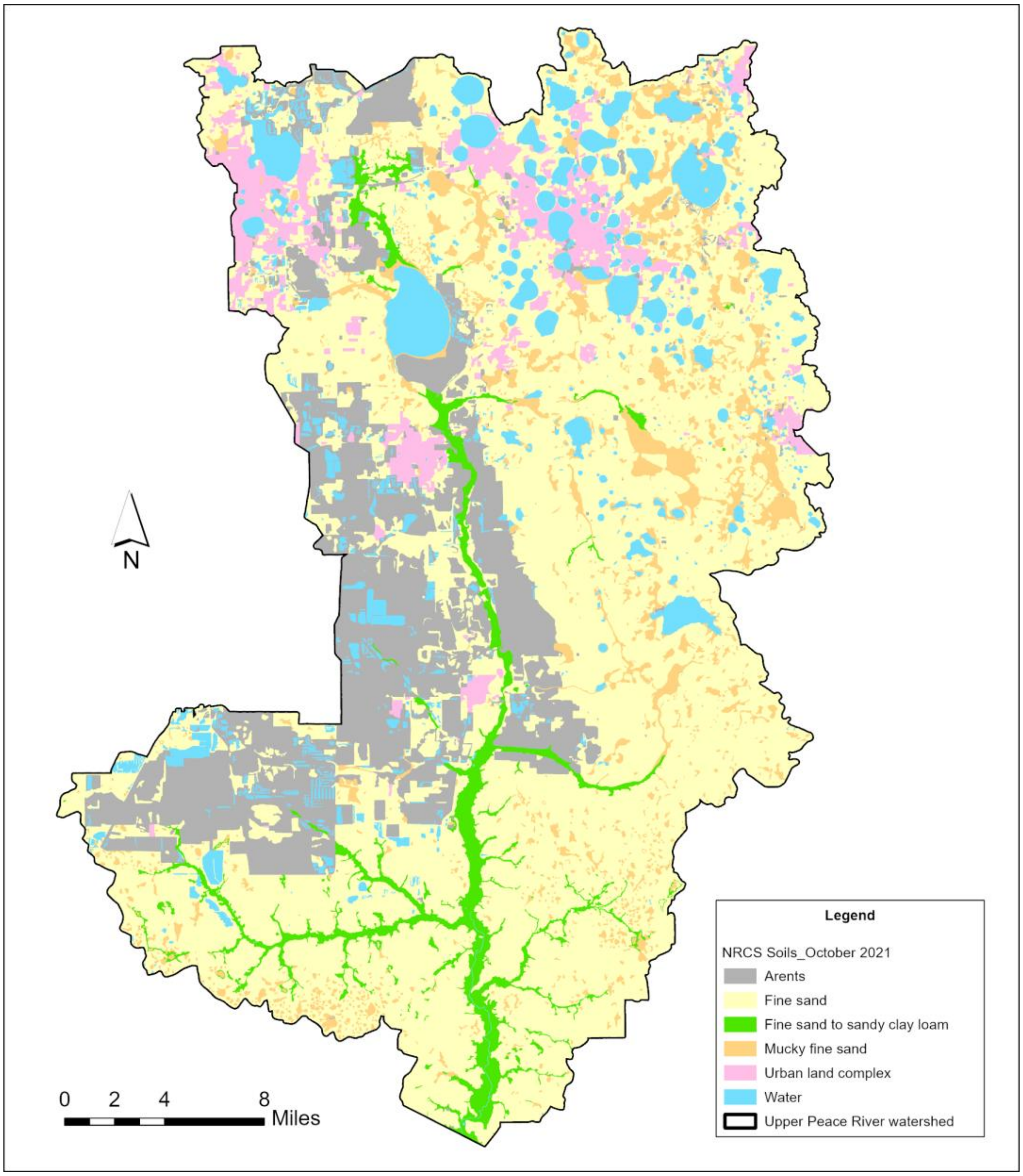


Figure 2-11. Generalied soil types in the Upper Peace River basin. Map generated from the USDA Natural Resource Conservation Service Soil Survey Geographic Database for Florida of October 2021.

Figure 2-12 illustrates the distribution of HSGs within the Upper Peace River basin. Group A soils dominate, covering about 36% of the area. Group A/D soils follow closely, comprising approximately 32% of the watershed. Groups B/D, D, and C/D soils account for roughly 10%, 7%, and 5% of the watershed, respectively. Groups C and B are nearly negligible (Table 2-5).

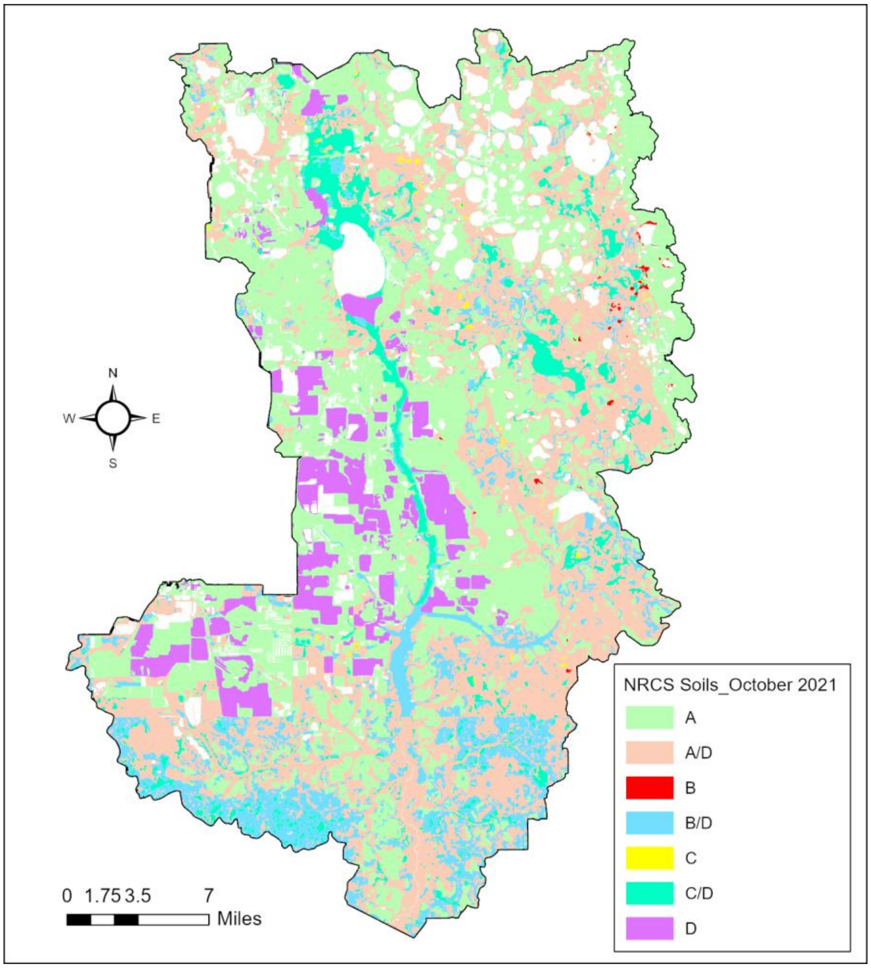


Figure 2-12. Hydrologic soil group designations for the Upper Peace River basin. The map was generated based on the October 2021 USDA NRCS Soil Survey Geographic Database for Florida.

Table 2-5. Hydrologic soil groups in the Upper Peace River basin.

Soil Group	Acres	%	Infiltrate Rate	Runoff Potential	Typical Soil Characteristics
A	189,680	36%	High	Low	Deep, well-drained sands or gravelly sands. High permeability.
A/D	168,633	32%	High (if drained/Very Low (if undrained)	Low/High	Naturally Group D but can behave like Group A when artificially drained.

Soil Group	Acres	%	Infiltrate Rate	Runoff Potential	Typical Soil Characteristics
B/D	52,351	10%	Moderate (if drained/Very Low (if undrained)	Moderate /High	Naturally Group D but function like Group B when drained.
D	36,192	6.8%	Very Slow	Very High	Clays with high shrink-swell potential, shallow soils over impervious layers, or high-water tables. Poor drainage.
C/D	28,126	5.3%	Slow (if drained/Very Low (if undrained)	High/Very High	Group D soils that behave like Group C when drained
C	908	0.2%	Slow	High	Soil with a layer that impedes water movement. Fine textures like clay loam.
B	630	0.1%	Moderate	Moderate	Moderately deep, well-drained loams. Moderate permeability.

2.1.5 Water Use

Water use in the Peace River watershed closely reflects changes in land use. Urban expansion drives increased municipal demand, while the conversion of natural lands to cropland heightens irrigation needs. Both surface water and groundwater are vital to the region, with the Peace River itself serving as a critical source for human consumption and maintaining the ecological integrity of the Charlotte Harbor estuary. However, agriculture, phosphate mining, and urban development have significantly altered the watershed's hydrology and water quality.

Historically, groundwater has been the primary source for municipal, industrial, and agricultural water needs throughout the watershed. In the upper basin, phosphate mining dominated groundwater use from the 1940s to the 1970s. By the late 1970s, the mining industry began implementing water conservation practices, including capturing and recycling surface waters from mining operations. By the late 1990s, agriculture constituted roughly 40% of Polk County's annual groundwater use, while domestic and industrial uses each accounted for slightly less than 30% (SWFWMD 2004). In the southern portion of the watershed, agricultural irrigation remains the predominant driver of groundwater withdrawals.

The FDACS Office of Agricultural Water Policy has developed the Florida Statewide Agricultural Irrigation Demand Geodatabase, a repository for agricultural water use projections through 2050 (Balmoral Group 2025). In 2025, approximately 33,811 acres of the Upper Peace River basin were irrigated, primarily to support citrus production (FDACS 2023). This figure is projected to decline to 32,543 acres by 2045 (Figure 2-13). Correspondingly, water use in irrigated agricultural areas is projected to decrease from 30.07 mgd in 2025 to 28.48 mgd by 2045.

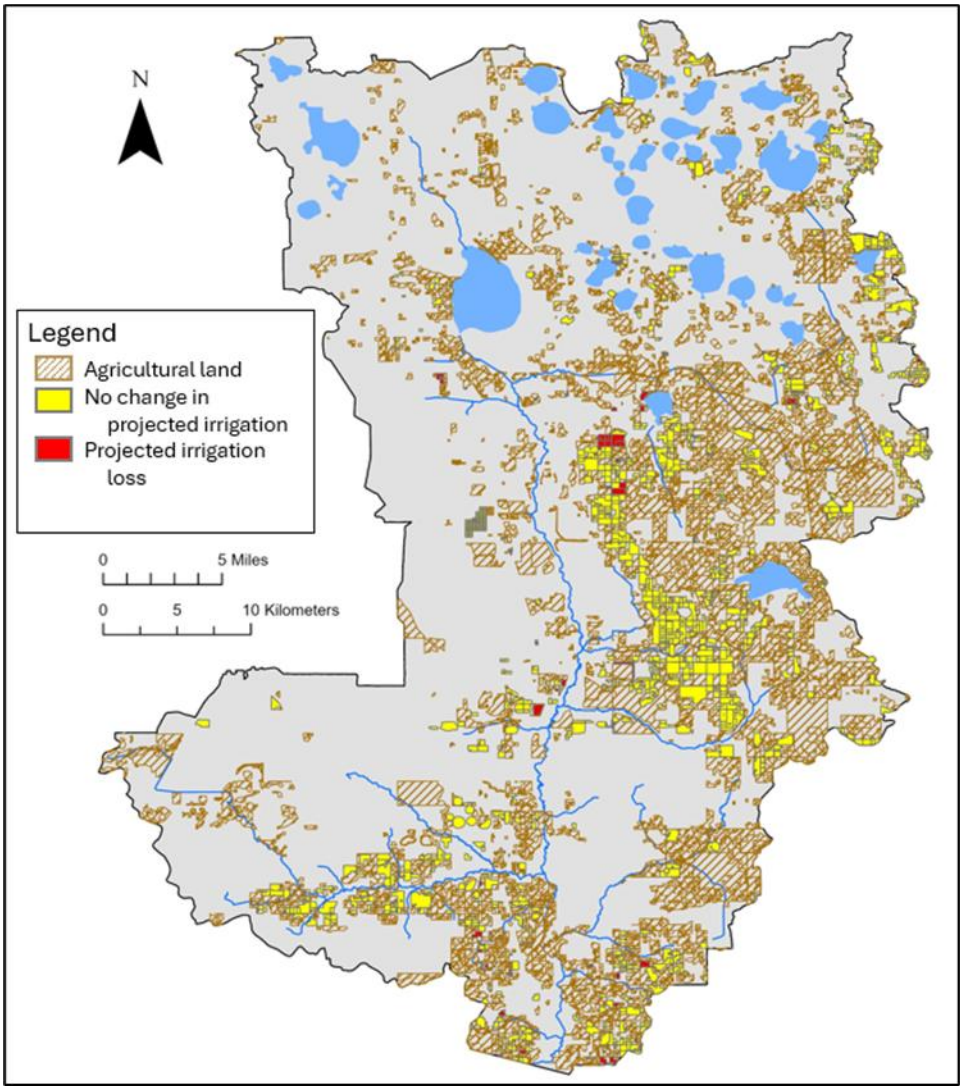


Figure 2-13. Projected changes in irrigated agricultural lands from 2025 to 2045 (Source: GIS files maintained by the Florida Department of Agriculture and Consumer Services (FDACS 2023).

Phosphate mining has also significantly impacted streamflow in the Peace River. Peek (1951) estimated that annual groundwater withdrawals in Southwest Polk County at 22 mgd in 1940, rising to 90 mgd by 1950, with 70% attributed to phosphate mining. The phosphate mining industry use peaked at about 257 mgd in 1975 and declined to 114 mgd in 1996.

In contrast to groundwater withdrawals, surface water withdrawals have been minimal and relatively stable over time. The largest withdrawal occurs on the lower Peace River in southern DeSoto County, where the Peace River Manasota Regional Water Supply Authority (PRMRWSA) provides potable water to DeSoto, Charlotte, and Sarasota Counties. Additionally, the City of Punta Gorda operates a water treatment facility at the Hendrickson Dam on Shell Creek. Smaller surface water withdrawals also occur in Polk County, serving various permittees for diverse purposes.

The Upper Peace River basin's reliance on groundwater has been extensively documented. Since 1983, the District has produced annual water use reports based on metered and estimated data (Ferguson and Hampton, 2022). Well pumping data has been systematically compiled since 1992, including monthly records for permitted wells and domestic self-supply (DSS) estimates within 2 km grids. Additionally, the USGS archived county-level water use data by use type for Florida from 1950 to 1990 (Marella 1995), offering insights into Polk and Hardee Counties' withdrawals for selected years (1965, 1970, 1975), as well as annual data from 1977 to 1983. Older estimates from Stewart (1966) and Kaufman (1967) extend the historical record back to 1934.

Figure 2-14 shows the long-term trends in groundwater use in Polk County, highlighting shifts in the proportions of different use types over time based on compiled historical records. Total groundwater withdrawals in Polk County reached 230 mgd in 1960 and peaked at over 410 mgd by 1975 (Peek 1951, Steward 1966, Hammett 1990, Basso 2003).

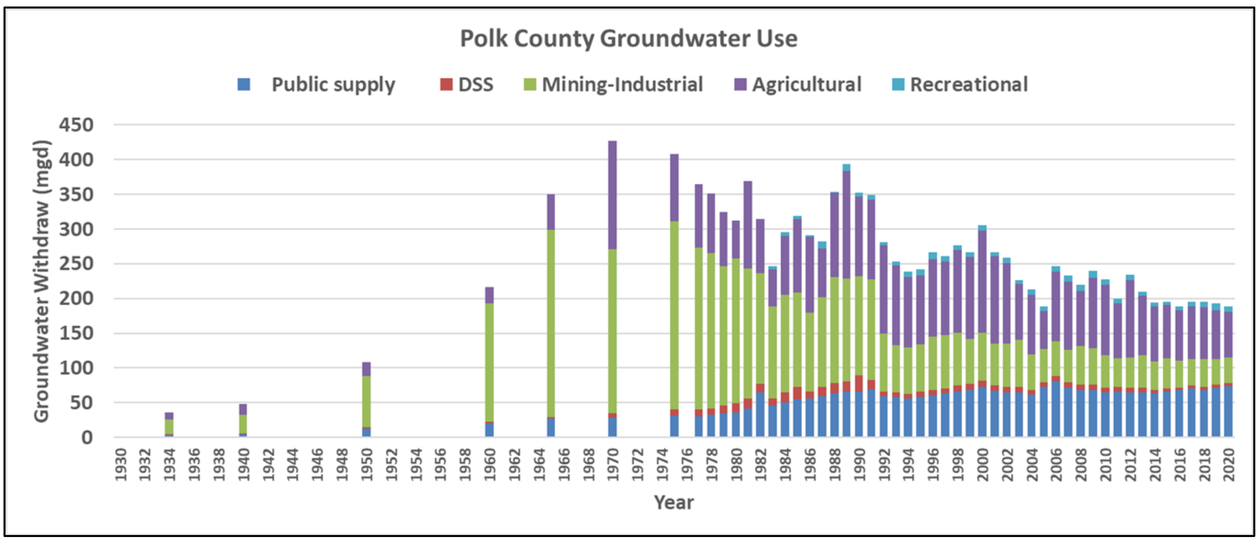


Figure 2-14. Trends in groundwater withdrawals by use type in Polk County from 1934 to 2022, illustrating shifts in public supply, domestic self-supply (DSS), mining-industrial, agricultural and recreational uses. Adapted from Zhang (2024, Appendix C).

A synthesized historical groundwater use record for Polk and Hardee counties (Figure 2-15), with interpolation to fill data gaps, reveals a steady increase in withdrawals from the 1930s through the 1970s, followed by a decline into the 2000s. Over the past 20 years, usage has stabilized. Today, groundwater use in Polk and Hardee counties averages between 200 and 300 mgd (Figure 2-15). This synthesized dataset supported the development of baseline flow estimates, as discussed in Section 5.4.2.

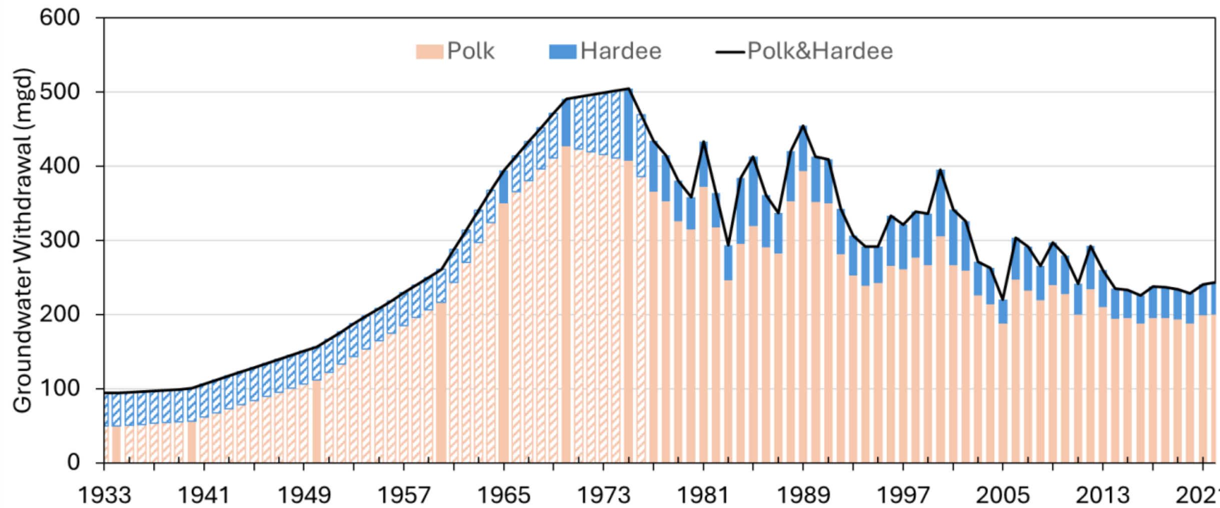


Figure 2-15. Annual groundwater withdrawals in Polk and Hardee Counties (1933-2022). Groundwater withdrawals include public supply, domestic self-supply, mining and industrial, agricultural and recreational uses. Solid bars represent reported values; hashed bars represent estimated values. Data sourced from USGS Historical Water-Use in Florida and the District's Estimated Water Use Reports.

2.2 Hydrogeology

The Peace River is situated within the Southern West-Central Florida Ground-Water Basin (SWCFGWB), a region whose hydrogeologic framework has been extensively documented in prior studies. The subsurface structure consists of three distinct hydrogeologic units, arranged vertically from the surface downward: 1) Surficial Aquifer System, 2) Intermediate Aquifer System, and 3) Floridan Aquifer System. These units exhibit variations in permeability, degree of confinement, and water quality, each contributing significantly to the dynamics of regional groundwater flow. Their spatial and stratigraphic relationships are depicted in Figure 2-16.

2.2.1 Surficial Aquifer System

The surficial aquifer system represents the uppermost water-bearing unit in the study area (Figure 2-16), varying in thickness from a thin veneer of sand to over 50 feet. It consists of undifferentiated sand, clay, and shell (Lewelling et al. 1998). Recharge primarily occurs through rainfall that infiltrates and percolates down to the water table. This aquifer temporarily stores infiltrating water that eventually percolates to deeper aquifers or moves laterally to areas of discharge (Metz and Lewelling 2009).

In the Upper Peace River basin, the surficial aquifer yields relatively modest quantities of water, typically utilized for lawn irrigation or domestic water supply (Basso 2003). In active or reclaimed mining areas, surface sediments have been removed due to phosphate strip mining, resulting in the complete loss of the surficial aquifer. Along the Peace River floodplain, the aquifer is either thin or nonexistent, limiting infiltration and recharge potential.

The water table depth averages 5 to 10 ft below land surface but can be exposed in cut banks or at the surface in the swampy floodplain and adjacent lowlands (Lewelling et al. 1998). During extended dry periods, the aquifer may dry up (Metz and Lewelling 2009). The head gradient of the aquifer is generally toward the river, and the confinement between the surficial and intermediate aquifer is well established (SWFWMD 2001).

SERIES	STRATIGRAPHIC UNIT		GEOLOGY AND LITHOLOGY	HYDROGEOLOGIC UNIT		
Holocene and Pleistocene	Undifferentiated surficial deposits		Sand and fossil fragments	Surficial aquifer system (surficial aquifer)		
Pliocene		Cypresshead Formation	Sand, silt, and clay	Surficial aquifer system (surficial aquifer)		
Pliocene		Cypresshead Formation	Sand, silt, and clay	Intermediate aquifer system[1]		Confining unit
Miocene	Hawthorn Group	Bone Valley Member / Peace River Formation	Sand, clay, marl, phosphate grains and pebbles, limestone and dolostone. Fossils common.	Intermediate aquifer system[1]		Zone 2, upper Arcadia aquifer
Miocene	Hawthorn Group	Arcadia Formation		Intermediate aquifer system[1]		Confining unit
Miocene	Hawthorn Group	Arcadia Formation		Intermediate aquifer system[1]		Zone 3, lower Arcadia aquifer
Miocene	Hawthorn Group	Tampa Member / Nocatee Member		Intermediate aquifer system[1]		Confining unit
Oligocene	Suwannee Limestone		Limestone, sandy limstone and sand. Phosphatic in part. Dolostone beds and fossils common.	Floridan aquifer system	Upper Floridan aquifer	Upper permeable zone
Eocene	Ocala Limestone			Floridan aquifer system	Upper Floridan aquifer	Semiconfining unit
Eocene	Avon Park Formation			Floridan aquifer system	Upper Floridan aquifer	Lower permeable zone
Eocene	Avon Park Formation		Limestone and dolostone with some intervals containing inclusions of gypsum and anhydrite	Floridan aquifer system	Middle confining unit	Middle semiconfining unit
Eocene	Oldsmar Formation			Floridan aquifer system	Lower Floridan aquifer	
Paleocene	Cedar Keys Formation		Limestone and dolostone with beds of gypsum and anhydrite	Sub-Floridan confining unit		

[1]A proposed revision by DeWitt and Mallams (2007) and Mallams and DeWitt (2007) replaces zone 2 and zone 3 from Knochenmus (2006) with the upper and lower Arcadia aquifers, respectively. This revision also proposes to rename the intermediate aquifer system in southwestern Florida to the Hawthorn aquifer system (excluding the upper and lower confining units). There is not a current consensus, however, on the use of "Hawthorn aquifer system," so in this report only the proposed upper and lower Arcadia aquifer names are used.

Figure 2-16. Relation of stratigraphic and hydrogeologic units in the Peace River watershed. Adapted from Metz and Lewelling (2009), modified from Barr (1992), Tihansky et al. (1996), O'Reilly et al. (2002), Sepulveda (2002), Basso and Hood (2005), Knochenmus (2006), Mallams and DeWitt (2007), and Spechler and Kroening (2007).

2.2.2 Intermediate Aquifer System

The intermediate aquifer system encompasses all water bearing units and confining units between the surficial aquifer system and the Floridan aquifer system (Duerr et al. 1988). This system is primarily associated with the Hawthorn Group, which includes the Peace River and Arcadia Formations as its dominant geologic components (Figure 2-16). Within the Upper Peace River basin, the thickness of this system ranges from 100 to 300 ft (Spechler and Kroening 2007).

The Peace River Formation is notable for forming rock ledges or outcrops within the floodplain and streambed (Scott 1988). Its uppermost unit, the Bone Valley Member, consists of clayey and phosphate-rich layer targeted by mining activities (Lewelling et al. 1998). This member is present along the upper reaches of the Peace River from Bartow to Wauchula (Scott 1988). The surficial aquifer and the Peace River Formation of the intermediate aquifer system may be the only units exposed along the Peace River channel (Scott 1988, Lewelling et al. 1998).

The confining units within the intermediate aquifer system have low hydraulic conductivity, thereby restricting water movement between aquifers. These confining units are generally thinner near the Peace River (Metz 1995) and become thicker and more confined toward the southwest.

Groundwater exchange between aquifers is influenced by the relative elevations of the potentiometric surface and the water table. Upward or downward movement may occur depending on hydraulic gradients. In September 1989, Yobbi (1996) mapped the head potential, showing it was downward from upstream of Bartow to the Polk-Hardee County line and upward from the Polk-Hardee County line to south of Arcadia. Aquifer behavior is subject to seasonal and annual variations in water use, rainfall, and recharge conditions.

In the study area, the intermediate aquifer system yields less water for irrigation and public and domestic supply compared to the underlying Upper Floridan aquifer, representing only 1% of groundwater withdrawals in Polk County (Metz and Lewelling 2009).

2.2.3 Floridan Aquifer System

The Floridan aquifer system comprises two major units: the Upper Floridan aquifer (UFA) and Lower Floridan aquifer (LFA), separated by middle confining units (Figure 2-16). Among these, the UFA is the most productive and widely used aquifer in the SWCFGWB, supplying more than ten times the volume of water pumped from the intermediate aquifer system (Metz and Brendle 1996). It supports a wide range of uses, including irrigation, industrial, commercial, public, recreational, and domestic supply. Historically, reports on southwest Florida hydrology have referred to the UFA simply as the "Floridan aquifer".

The UFA is composed of carbonate units: the Suwannee Limestone, Ocala Limestone, and Avon Park Formation (Figure 2-16). It contains two permeable zones separated by a semi-confining unit. The upper permeable zone begins at the top of the Suwannee Limestone, where permeability is primarily intergranular. In the northern part of the Upper Peace River basin, solution cavities and conduits are more prevalent due to the thinning of the intermediate confining unit.

The semi-confining unit, located at the top of the Ocala Limestone, primarily comprises soft, chalky, fine-grained, foraminiferal calcilutite and calcarenitic limestone. Beneath this lies the lower permeable zone, which is the most productive and transmissive part of the UFA. However, its hydraulic conductivity is more variable than overlying zones due to the existence of fractures (Basso 2002).

The Middle Confining Unit (MCU) acts as a hydraulic barrier between the UFA and LFA. Within the Upper Peace River basin, the MCU is subdivided into two components: MCU I and MCU II. The shallower, semi-confining MCU I is absent in the western portion of the study area, while the thicker, more confining MCU II is missing from the eastern portion. The hydraulic head difference between the UFA and LFA is generally much smaller across MCU I than MCU II, reflecting the more permeable and leakier nature of MCU I.

The LFA consists of interbedded dolomite and anhydrite, which is hydraulically isolated from the UFA. It generally exhibits low permeability, poor water quality due to salinity, and limited water yield because of its depth and lithology. Consequently, in the SWCFGWB, it is primarily used for deep well injection of industrial waste. However, in the last decade, the brackish LFA in western Polk County has been investigated as a potential alternative water supply source.

2.2.4 Groundwater Flows and Levels

Groundwater movement in the UFA generally flows in a northeast-to-southwest direction through Polk, Hardee and DeSoto Counties (Figure 2-17). Metz and Lewelling (2009) compared the predevelopment and May 2007 potentiometric surfaces, showing groundwater level ranging from 120 ft in the north to 50 ft to the south, with the greatest decline near Bartow in the west-central part of the Upper Peace River basin. Their analysis also revealed a shift in regional groundwater flow paths from predominantly north-south to more westerly directions (Figure 2-17).

Long-term changes in the UFA potentiometric surface are illustrated in Figure 2-18. Estimated declines between predevelopment and 1975 exceeded 50 feet in the northern Peace River watershed. Since the mid-1970s, the area of greatest decline has shifted southwestward.

Because of significant declines in the potentiometric surface and increasing water demand, the District designated the SWUCA in 1992. This area, as shown in Figure 1-1, spans approximately 5,100 square miles, including Desoto, Hardee, Manatee and Sarasota Counties and parts of Charlotte, Highlands, Hillsborough and Polk Counties. The designation aims to address aquifer level declines primarily caused by groundwater withdrawals.

Groundwater levels in the Upper Peace River basin began to stabilize in the mid-1970s, coinciding with the peak of groundwater use in Polk County (Figure 2-14 and Figure 2-15). Figure 2-19 presents groundwater level trends at six sentinel wells within the SWUCA, with their locations shown in Figure 1-1. The ROMP 50, ROMP 60, and Coley Deep wells represent groundwater level trends in the northern portion of the SWUCA, while the Marshall Deep, Edgeville Deep, and Sarasota 9 wells reflect trends in the southern portion. Notably, ROMP 60 is suited near the Bartow gaging station, making it a valuable reference point for assessing groundwater recovery over time. Since the early 1990s, groundwater levels have been stable or increasing in the northern region while levels in the southern region have been stable or declining. This pattern was anticipated, given the shifts in withdrawal locations and reductions in water use in the northern areas, coupled with increasing water demand in the southern portion of the SWUCA.

The May 2020 potentiometric surface map of the UFA (Figure 2-20) shows a rise of up to 40 feet in groundwater levels compared to those reported in 1975, although levels remain below those observed in the 1930s. Over the past decade, UFA levels have continued to rise, supported by improved rainfall conditions and reduced groundwater withdrawals in Polk County, which have declined to below 200 mgd (Figure 2-14). However, during the spring dry season, water levels remain more than 20 feet below the riverbed between Bartow and Homeland, indicating persistent vulnerability to seasonal flow loss.

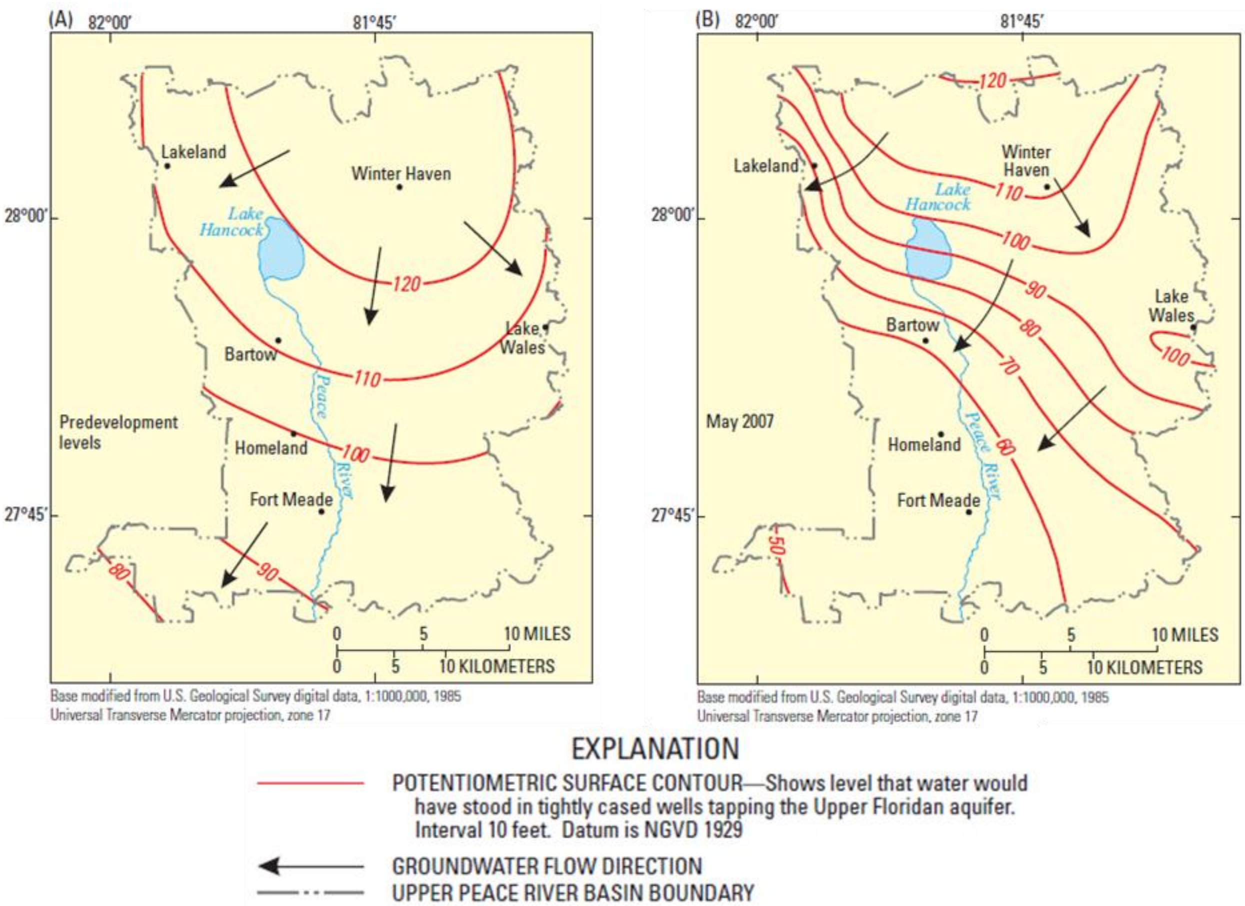


Figure 2-17. (A) Predevelopment potentiometric surface levels (modified from Johnston et al. 1980) and (B) May 2007 levels (modified from Ortiz 2008a), showing regional groundwater flow patterns of the Upper Floridan aquifer within the Upper Peace River basin. Adapted from Metz and Lewelling (2009).

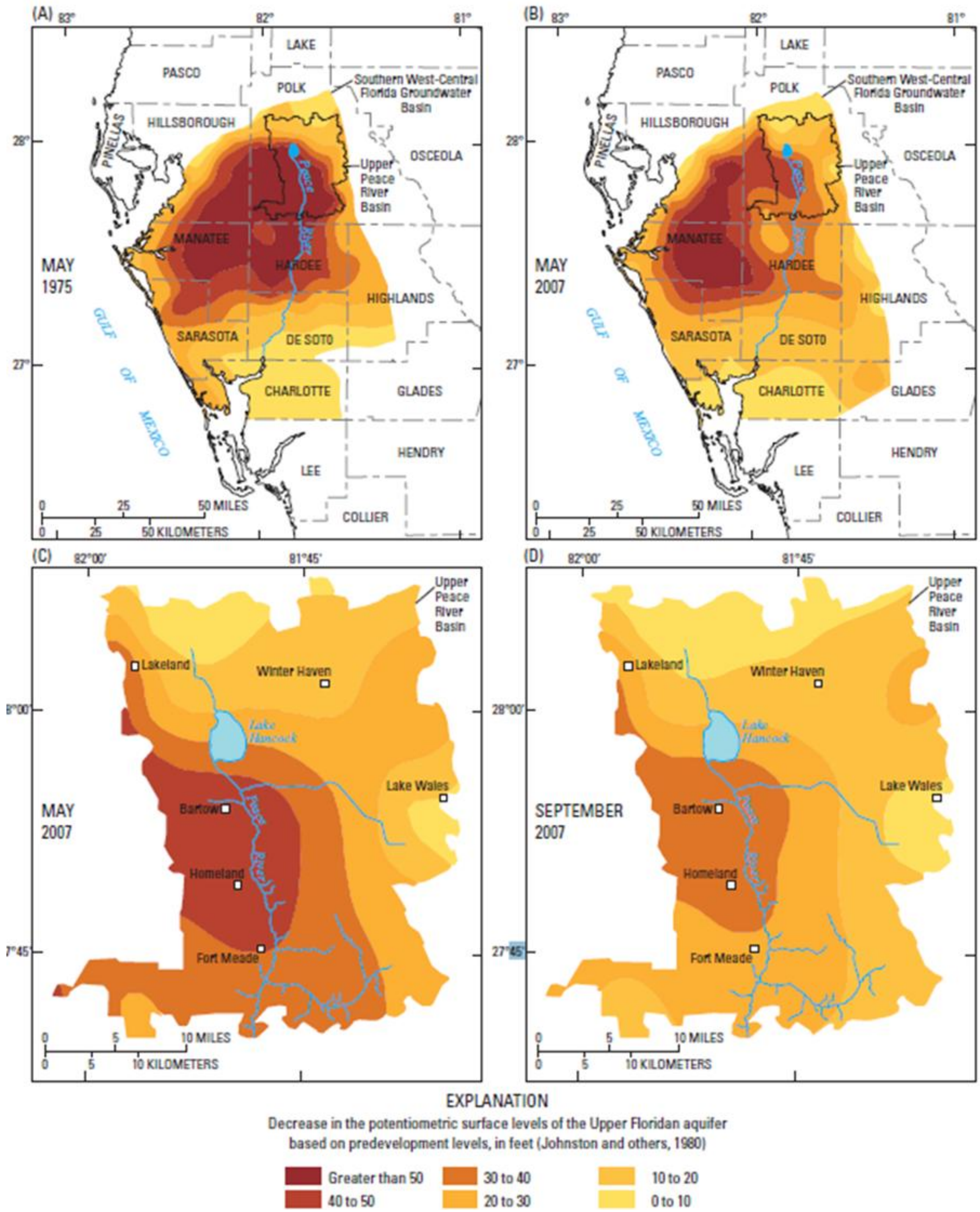


Figure 2-18. Changes in the potentiometric surface of the Upper Floridan aquifer between predevelopment conditions (modified from Johnston et al. 1980) and (A) May 1975 levels (modified from Mills and Laughlin 1976) and (B) May 2007 levels (modified from Ortiz 2008a) for the Southern West-Central Florida Groundwater Basin; and between predevelopment and (C) May 2007 and (D) September 2007 levels (modified from Ortiz 2008b) for the Upper Peace River basin. Adapted from Metz and Lewelling (2009).

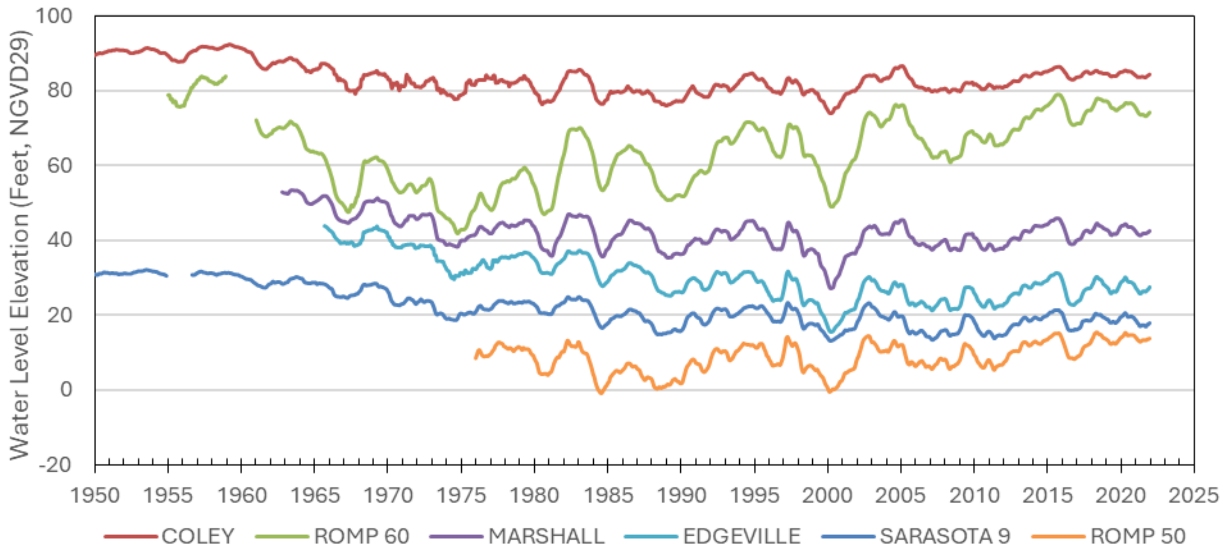


Figure 2-19. Water levels in Southern Water Use Causion Area (SWUCA) monitoring wells (12-month moving average).

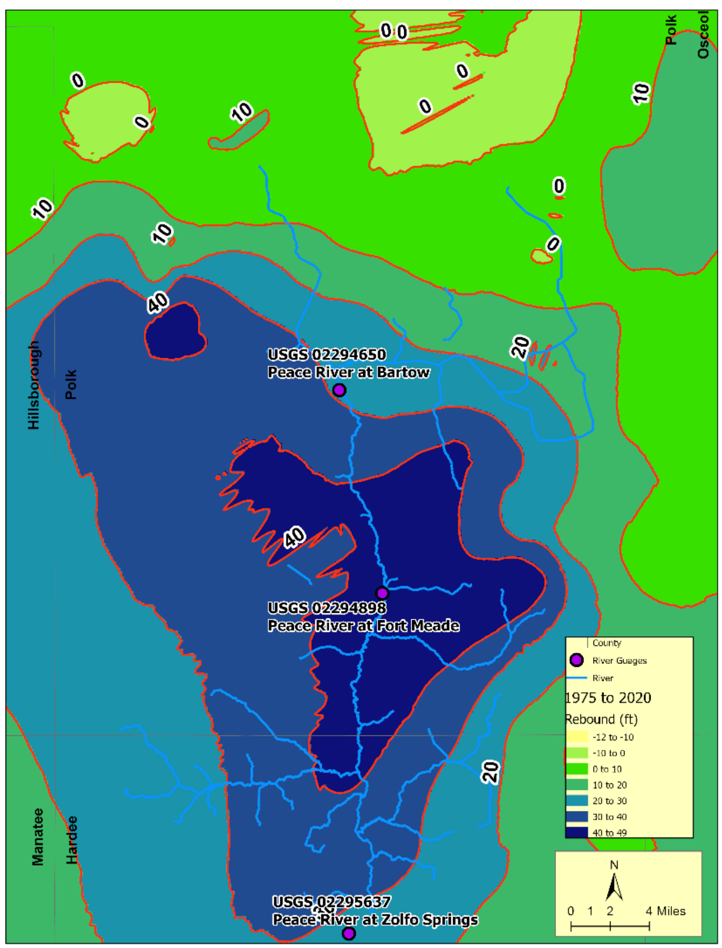


Figure 2-20. Estimated rebound of the potentiometric surface of the Upper Floridan aquifer from May 1975 to May 2020. Modified flowfrom Zhang (2024, Appendix C).

2.2.5 Karst Features

The Upper Peace River exhibits a distinct geological character compared to the rest of Peace River watershed (Metz and Lewelling, 2009). Between Bartow and Fort Meade in Polk County, numerous karstic features (see examples in Figure 2-21) are embedded within the limestone beds that shape the river channel and its floodplain. These limestone formations, rich in calcium carbonate, are highly susceptible to dissolution by weak carbonic acid, commonly found in rainwater and surface streams across Florida. As this acidic water infiltrates the ground and interacts with the limestone, it gradually dissolves the rock, forming karst topography, characterized by caves, underground channels, and irregular ground surface.

Figure 2-21. Prominent karst features in the Upper Peace River basin observed during dry river conditions in mid-May 2002. Features incudes: (A) Fricano fracture, (B) Midway sink, (C) Dover sink, and (D) the crevasses. These features were documented during a USGS study in cooperation with the District. Adapted from Knochenmus (2004).

In mid-May 2002, during a period of no surface flow, the USGS, in collaboration with the District, documented the locations, orientation, and dimensions of several prominent karst features. Examples shown in Figure 2-21 include:

- **Fricano fracture** (Panel A): A coalescing group of vertical pipes
- **Midway sink** (Panel B): A collapsing sinkhole with small fractures near its base
- **Dover sink** (Panel C): Located at the base of outcrop at the end of 1,200-ft-long tributary in the floodplain
- **Crevasses** (Panel D): Multiple fractures, the largest spanning 26 feet across the riverbed

These features occur at the contact zone between the Peace River and Arcadia Formations. The largest mapped karst feature, known as the Catacombs (Figure 2-22), lies within the floodplain and consists of numerous interconnected horizontal and vertical voids. Evidence of water-induced scouring is visible, and some openings are large enough for human entry. Numerous small karst features are also found in the channel and on the floodplain (Knochenmus 2004).

Sinkholes and subsidence features, some likely of recent origin, have emerged in this region and may be linked to large scale groundwater extraction. Karst activity diminishes downstream of Fort Meade, where a thick clay layer (150 to 250 ft) in the intermediate confining unit effectively isolates the river channel from the UFA, thereby limiting direct interaction between surface water and the underlying aquifer.

In the karstic section, a direct hydraulic connection exists between the river channel and the UFA. Streamflow losses occur when the river stage exceeds the aquifer head. The rate of loss depends on several factors: the magnitude of the head difference, the hydraulic conductivity of riverbed deposits, and the saturated area of the channel (Simonds and Sinclair 2002).

Historically, artesian flow was documented in parts of the Upper Peace River prior to regional phosphate mining and agricultural development. However, since 1930s, the potentiometric surface has declined, leading to spring flow cessation. Peek (1951) reported that Kissengen Spring discharged approximately 20 mgd when first measured by the USGS on December 21, 1898. Monthly flow measurements from 1932 to 1937 showed an average discharge of 19 mgd. Flows declined steadily after 1936, with the first cessation in February 1950 and permanent cessation by April 1960 (Peek 1951, Stewart 1966).

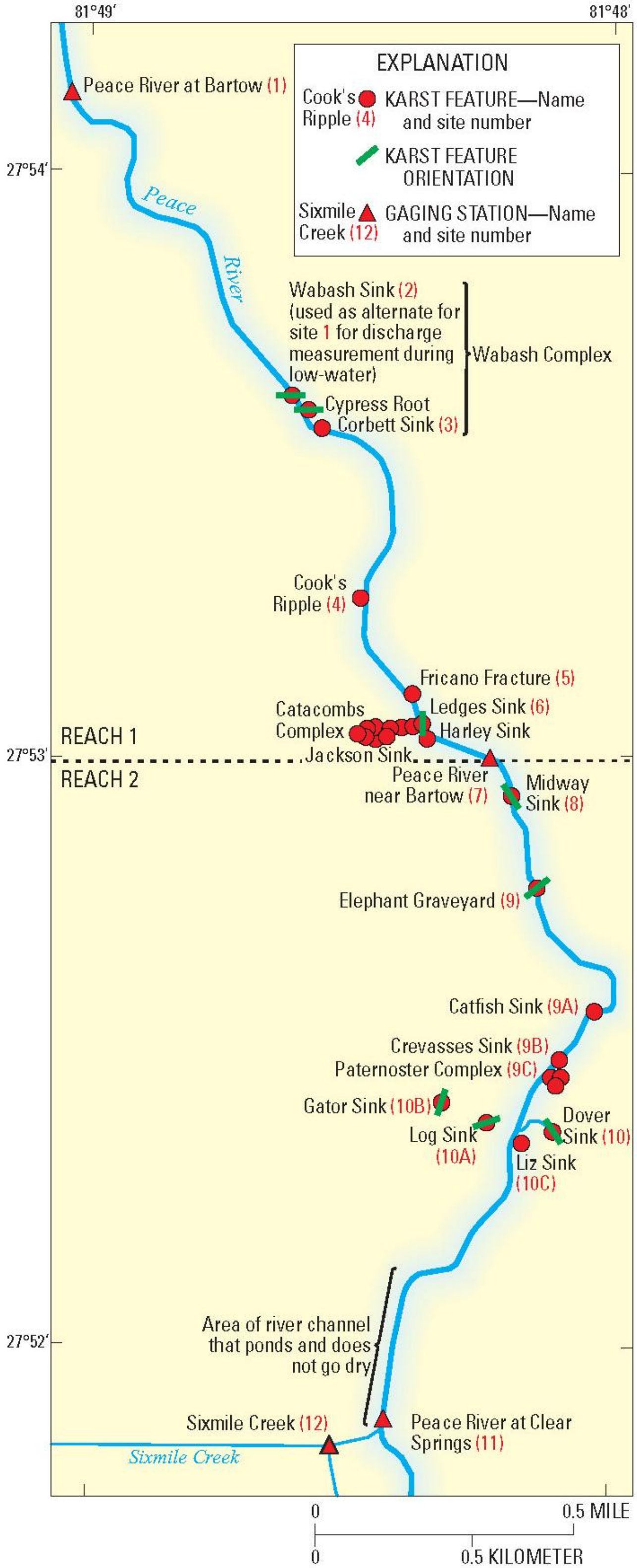


Figure 2-22. Location of karst features between Bartow and Clear Springs in the Upper Peace River basin. Adapted from Metz and Lewelling (2009).

The Peace River historically functioned as a gaining stream, receiving discharge from groundwater throughout its length. Since 1931, the Upper Peace River has experienced a progressive long-term decline in streamflow, primarily due to a lowering of the UFA potentiometric surface by as much as 60 ft resulting from intensive groundwater withdrawals for phosphate mining and agriculture (Lewelling et.al. 1998). This decline has reversed the hydraulic gradient between the Peace River and the underlying aquifers, resulting in occasional loss of perennial flow between Bartow and Homeland during the spring dry season (Basso 2004).

Lewelling et al. (1998) demonstrated that from Bartow to Fort Meade, the river channel and floodplain function primarily as a groundwater recharge area. During the dry season (April–May), groundwater heads in both the intermediate and UFA systems fall below the elevation of the riverbed. Conversely, during wetter periods, groundwater heads in the intermediate aquifer may temporarily exceed river stage, allowing short-term discharge into the river. Because the UFA typically has lower heads than the intermediate aquifer, the intermediate system may simultaneously recharge the Upper Floridan while discharging into the Peace River. This dynamic interaction underscores the complex hydraulic connectivity between aquifer systems and surface water features.

During drought periods, particularly in the typically dry spring season, the riverbed often dries due to losses to the underlying aquifer. The karstic section of the Peace River channel was first observed to dry up during unusually dry springs in the 1980s. Following the severe drought of 1999-2001, the channel dried up every spring except during the above-average rainfall years (2003-2005), prior to the implementation of minimum flow recovery strategies. Lewelling et al. (1998) also documented flow losses into sinkholes and sand filled depressions in the Upper Peace River. A dye-tracing study conducted by McQuivey et al. (1981) confirmed rapid hydraulic connectivity: dye injected into three sinkhole complexes was detected in an UFA well one mile downstream just eight hours after injection, revealing cavernous porosity in the underlying limestone.

Low-flow conditions have improved significantly following the District's SWUCA recovery strategy (2006), adopted in 2006, and the completion of the Lake Hancock Lake Level Modification and Restoration Project (2015). Since the modified P-11 structure began operation in late 2015, minimum flows at the three gaging stations (Bartow, Fort Meade, and Zolfo Springs) have generally been met, except during an extreme drought of spring in 2017, when the river segment between Bartow and Homeland went dry.

2.3 Streamflow and Levels

The reevaluation of minimum flows for the Upper Peace River was based on comprehensive analyses of long-term stream gage records, extending back to the 1930s. Declining trends in Peace River flows, a major regional water management concern, have been extensively documented in early studies (Hammett 1990, Coastal Environmental 1996, Lewelling et al. 1998, Flannery and Barcelo 1998, Hickey 1998, Basso 2002, Garlanger 2002, SWFWMD 2002).

Given that more than two decades have passed since many of these foundational assessments, incorporating up-to-date data is essential to better understand current flow and level trends, as well as their potential causes. To evaluate how different components of the river's flow regime have changed over time, trend analyses were conducted across multiple time scales and for various annual exceedance probabilities.

Accordingly, the analyses presented in Section 2.3.2 focus on three USGS gage sites located along the mainstem of the Upper Peace River, as well as one long-term gage site situated at Arcadia, the most downstream location on the Peace River.

2.3.1 Gaging Stations and Period of Record

As of this reporting period, 11 USGS gaging stations are located along the mainstem of the Upper Peace River (see Figure 2-27 and Figure 2-28; Table 2-6). Four of these stations, Dover Sink, SH 664A near Bowling Green, State HWY 664A near Wauchula, and Wauchula, maintain continuous stage records only. The stations at SH 664A near Bowling Green and Wauchula have been discontinued. The remaining seven gaging stations record both continuous flow and stage data, although the duration of record varies across sites.

Among the mainstem stations, the USGS gaging stations at Bartow, Fort Meade, and Zolfo Springs have the longest periods of record. As described in Chapter 1 and Section 2.1, these three are designated as index gaging stations, or MFLs stations, where the recommended minimum flows are established.

The Peace River at Bartow gage is the most upstream station in the study reach, located just east of the City of Bartow, approximately two miles downstream of the confluence of the Peace Creek Canal and Saddle Creek. This gage is situated 105 miles upstream from the river mouth and measures discharge from a drainage area of approximately 390 square miles. From October 1, 1939, through December 31, 2022 (Figure 2-23 and Table 2-6), the median daily flow at Bartow was 91 cfs.

The Peace River at Fort Meade gage is located 13 miles downstream from the Bartow gage or 91 miles upstream from the river mouth. It captures flow from a drainage area of 480 square miles. While periodic flow measurements were made prior to 1974 (Table 2-6), continuous daily streamflow records began on June 1, 1974 (Figure 2-24; Table 2-6). The median daily flow from 1974 through 2022 is 78.9 cfs. The lower median flow at Fort Meade compared to the Bartow gage is partly attributable to the shorter period of record; for the same time frame, the median flow at Bartow was 56 cfs.

The Peace River at Zolfo Springs gage (No. 02295637) was established on September 1, 1933 (Figure 2-25; Table 2-6), located approximately 0.8 miles north of Zolfo Springs in Hardee County or 69 miles upstream from the river mouth. This station monitors flow from a drainage area of 826 square miles, and the median daily flow from 1933 through 2022 was 305 cfs.

Although not part of the Upper Peace River MFL segment, comparisons are made to the USGS Peace River at Arcadia (No. 02296750) gage, located in DeSoto County approximately 33 miles downstream from the Zolfo Springs gage or 35 miles upstream from the mouth of the river. It is the most downstream gage on the Peace River mainstem and has the longest continuous records among all gaging stations in the Peace River watershed. It encompasses a drainage area of approximately 1,367 square miles, with flow records beginning April 1, 1931 (Figure 2-26; Table 2-6). The median flow at this gage for the period 1931 through 2022 is 448 cfs.

In addition to the mainstem stations, eight active USGS gaging stations are located on tributaries within the Upper Peace River basin between Bartow and Zolfo Springs (Figure 2-27 and Figure 2-28; Table 2-7.), including: Sixmile Creek, Phosphate Mine Outfall, Barber Branch, Bowlegs Creek, Whidden Creek, Payne Creek and Little Charlie Creek, and Thompson Branch. Except for Thompson Branch, all maintain continuous flow and stage records of varying lengths. Bowlegs and Payne Creek have longer periods of record, particularly for flow data (see Table 2-7).

As shown in Figure 2-29, aside from the five long-term gaging stations, most remaining USGS stations were established around 2002, coinciding with the completion of the previous MFLs evaluation. An overlap period for all gaged data across mainstem and tributary sites begins on September 30, 2012 (Table 2-6 and Table 2-7; Figure 2-29). Nearly all USGS gaging stations referenced in this study are operated in cooperation with the District.

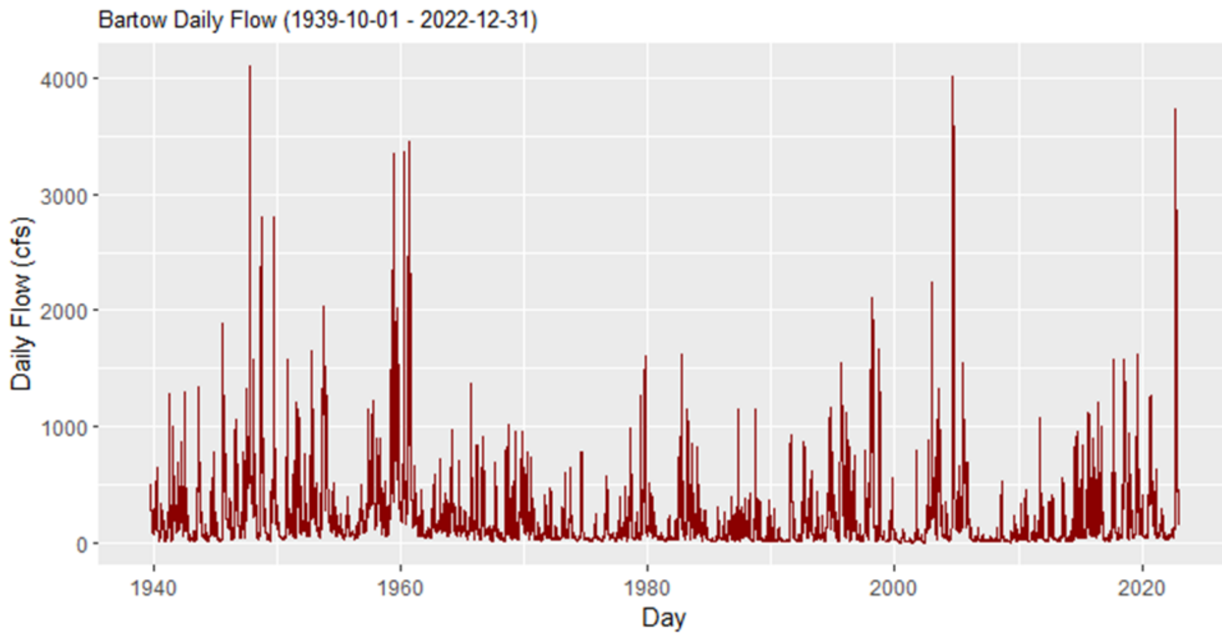


Figure 2-23. Daily average flow for the USGS Peace River at SR60 at Bartow, FL gage (No. 02294650) fromrom October 1, 1939 through December 31, 2022.

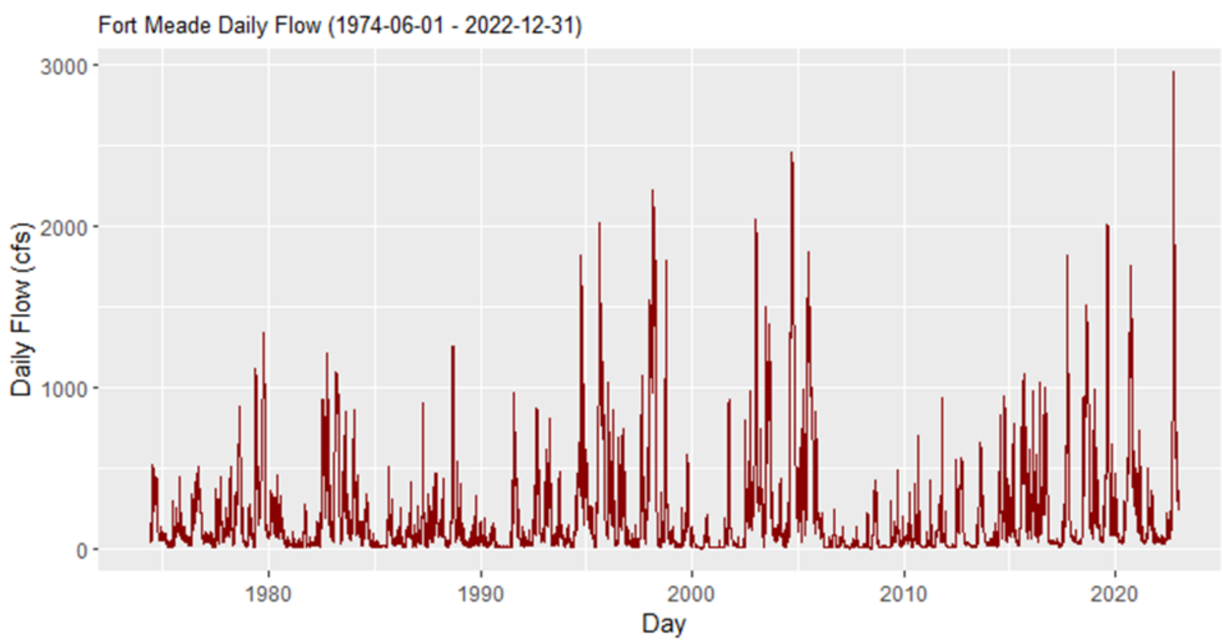


Figure 2-24. Daily average flow for the USGS Peace River at Fort Meade, FL gage (No. 02294898) from June 1, 1974 through December 31, 2022.

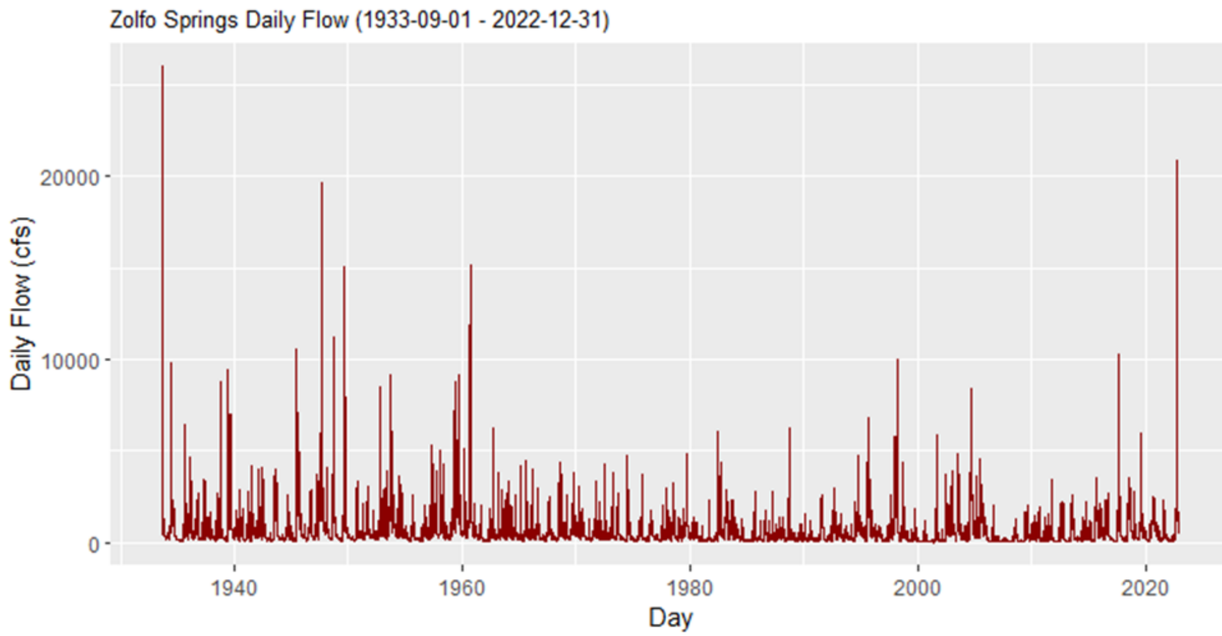


Figure 2-25. Daily average flow for the USGS Peace River US 17 at Zolfo Springs, FL gage (No. 02295637) gage for the period from September 1, 1933 through December 31, 2022.

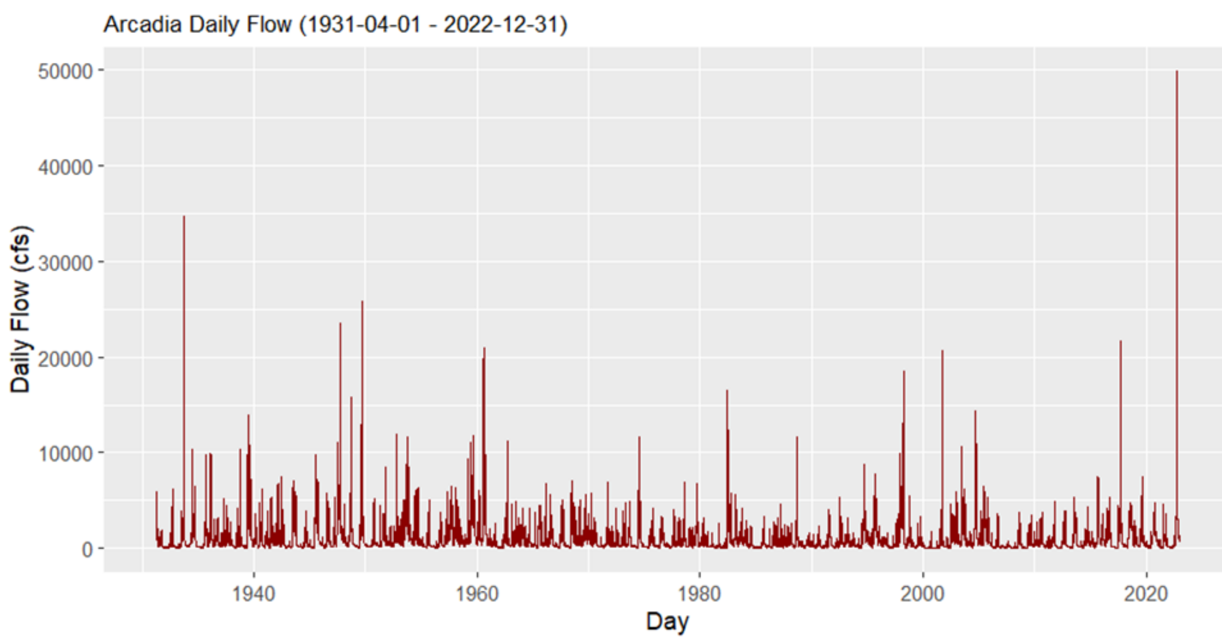


Figure 2-26. Daily average flow for the USGS Peace River at SR70 at at Arcadia, FL (No. 02296750) gage for the period from April 1, 1931 through December 31, 2022.

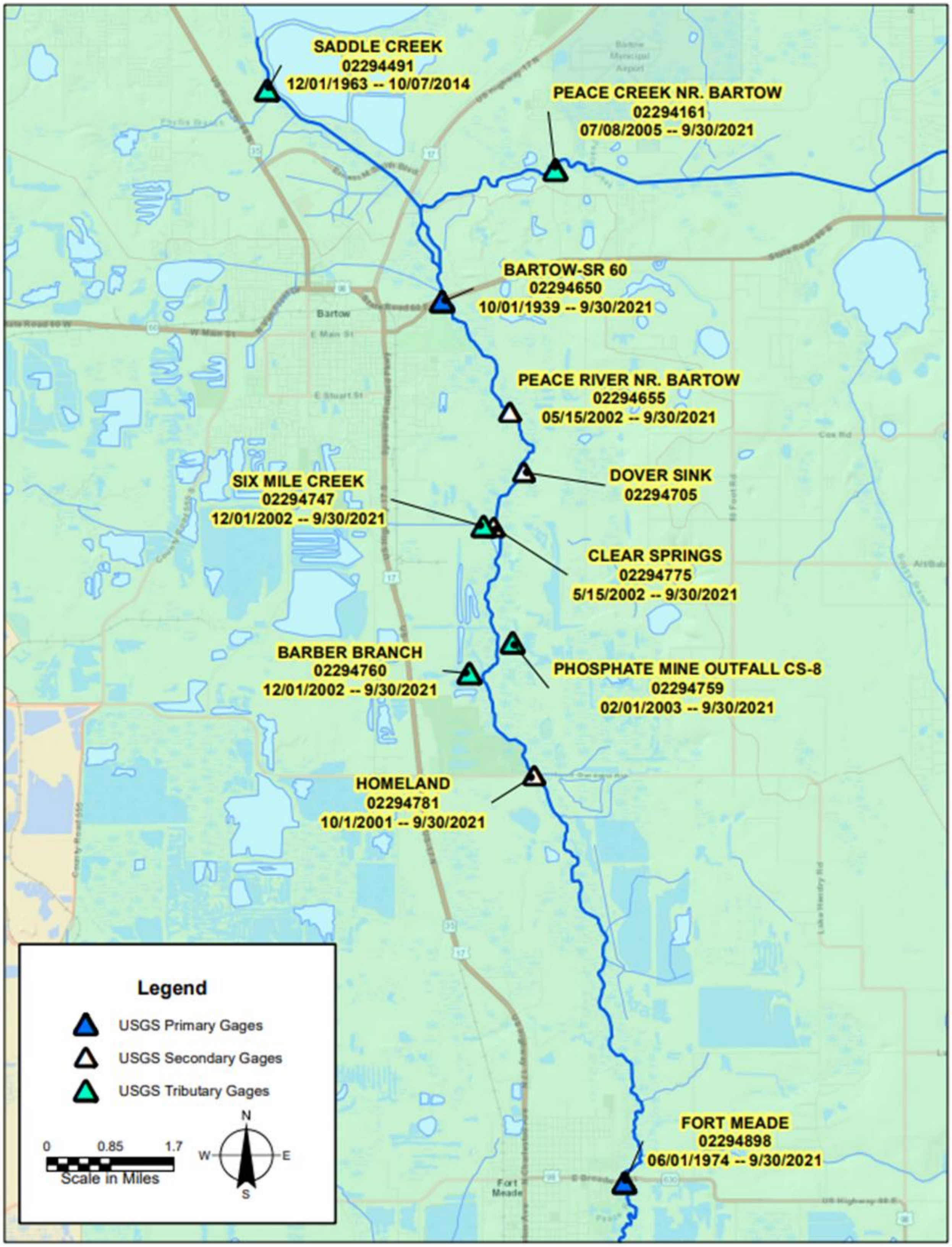


Figure 2-27. Streamflow gages between Bartow and Fort Meade. Adapted from Appendix H, Verdantas (2024).

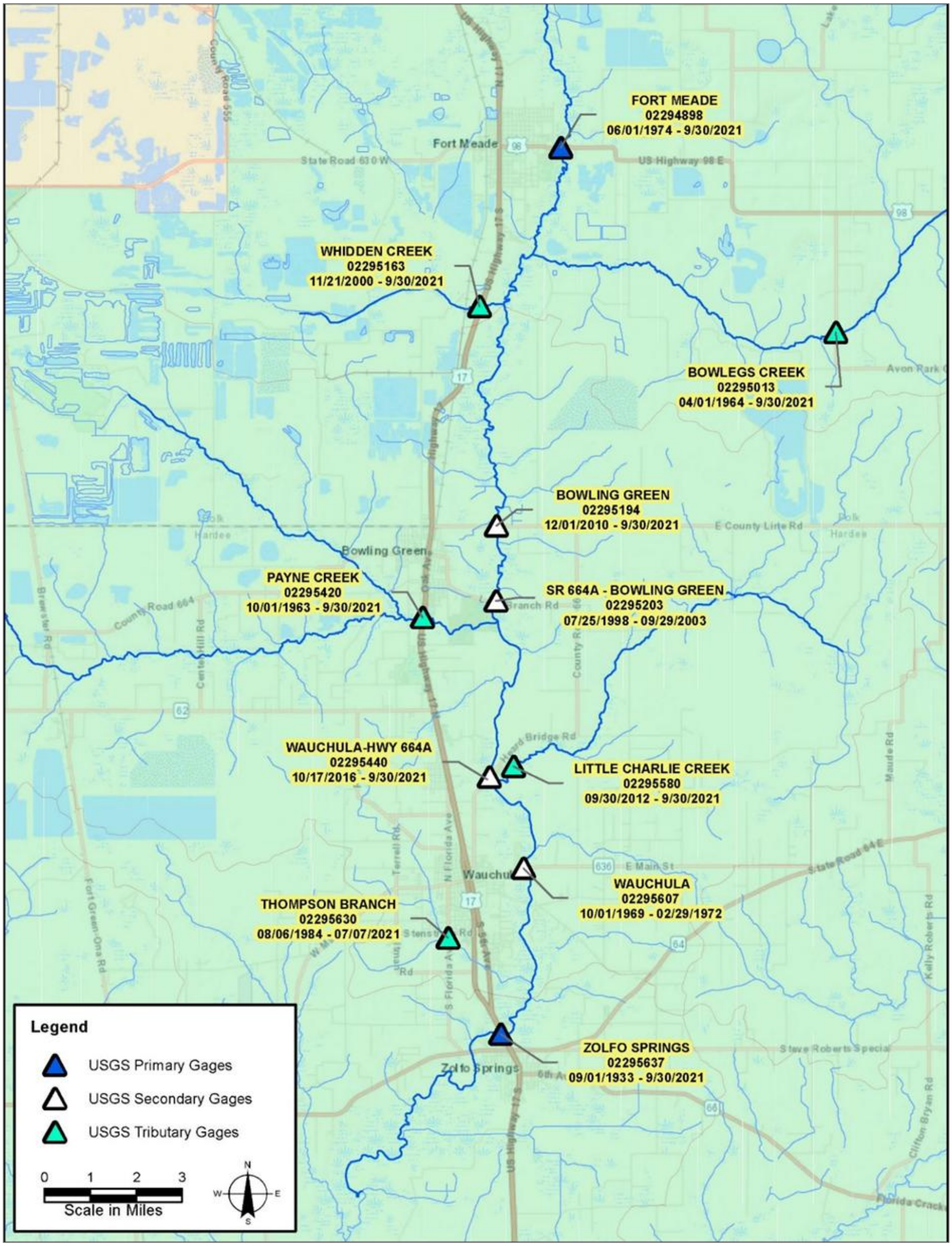


Figure 2-28. Streamflow gages between Fort Meade and Zolfo Springs. Adapted from Appendix H, Verdantas (2024).

Table 2-6. Upper Peace River main channel stream gaging stations and daily data summary. Modified from Appendix H, Verdantas (2024).

Site Name	USGS ID, Drainage Area (A), River Mile (RM) and Datum	District Site ID	Parameter	Begin Date	End Date
Peace River at SR 60 at Bartow, FL	02294650	24833	Gage Height (ft)	11/09/1939	12/31/2022
	A = 390 mile^2		Discharge (cfs)	10/01/1939	12/31/2022
	RM=104.0		Water Level Elevation (ft)	10/10/2011	12/31/2022
	Datum = 86.7 ft ab NAVD		Flow Measurements (cfs)	11/09/1939	12/06/2022
Peace River near Bartow FL	02294655	670663	Gage Height (ft)	05/15/2002	12/31/2022
	A = 395 mile^2		Discharge (cfs)	05/15/2002	12/31/2022
	RM=102.2		Water Level Elevation (ft)	10/01/2007	12/31/2022
	Datum = 79.4 ft ab NAVD		Flow Measurements (cfs)	06/24/2002	12/08/2022
Peace RV Distributary at Dover Sink nr Bartow FL	02294705	700395	Gage Height (ft)	06/13/2006	12/31/2022
			Discharge (cfs)	NA	NA
			Water Level Elevation (ft)	10/01/2007	12/31/2022
	Datum = 0.0 ft ab NGVD		Flow Measurements (cfs)	04/11/2006	03/23/2007
Peace River at Clear Springs nr Bartow FL	02294775	700355	Gage Height (ft)	05/16/2002	12/31/2022
	A = 396 mile^2		Discharge (cfs)	05/15/2002	12/31/2022
	RM=101.3		Water Level Elevation (ft)	10/01/2007	12/31/2022
	Datum = 51.55 ft ab NGVD		Flow Measurements (cfs)	07/15/2002	12/08/2022
Peace River near Homeland FL	02294781	24823	Gage Height (ft)	07/18/1998	12/31/2022
	A = 411 mile^2		Discharge (cfs)	10/01/2001	12/31/2022
	RM=97.0		Water Level Elevation (ft)	10/01/2007	12/31/2022
	Datum = 0.0 ft ab NGVD		Flow Measurements (cfs)	07/11/1974	12/14/2022
Peace River at Fort Meade FL	02294898	24805	Gage Height (ft)	04/22/1964	12/31/2022
	A = 480 mile^2		Discharge (cfs)	06/01/1974	12/31/2022
	RM=91.0		Water Level Elevation (ft)	10/01/2007	12/31/2022
	Datum = 0.0 ft ab NGVD		Flow Measurements (cfs)	05/18/1931	12/14/2022
Peace River at Bowling Green FL	02295194	785819	Gage Height (ft)	12/11/2010	12/31/2022
	A = 613 mile^2		Discharge (cfs)	12/01/2010	12/31/2022
	RM = 80.6		Water Level Elevation (ft)	12/11/2010	12/31/2022

Site Name	USGS ID, Drainage Area (A), River Mile (RM) and Datum	District Site ID	Parameter	Begin Date	End Date
	Datum = 4.72 ft ab NAVD		Flow Measurements (cfs)	02/14/1982	12/06/2022
Peace River at SH 664A near Bowling Green*	02295203	24939	Gage Height (ft)	07/25/1998	09/29/2003
	A = 614 $mile^2$		Discharge (cfs)	NA	NA
			Water Level Elevation (ft)	NA	NA
	Datum = 0.0 ft ab NGVD		Flow Measurements (cfs)	05/13/1939	07/11/1974
Peace River at State HWY 664A near Wauchula FL	02295440	NA	Gage Height (ft)	10/17/2016	12/31/2022
	A = 754 $mile^2$		Discharge (cfs)	NA	NA
	RM = 74.7		Water Level Elevation (ft)	NA	NA
	Datum = 0.0 ft ab NAVD		Flow Measurements (cfs)	12/01/1982	05/24/1983
Peace River at Wauchula FL*	02295607	NA	Gage Height (ft)	10/01/1969	02/29/1972
	A = 808		Discharge (cfs)	NA	NA
			Water Level Elevation (ft)	NA	NA
	Datum = 38.55 ft ab NGVD		Flow Measurements (cfs)	07/11/1974	05/24/1983
Peace River at US 17 at Zolfo Springs FL	02295637	23917	Gage Height (ft)	09/07/1933	12/31/2022
	A = 826 $mile^2$		Discharge (cfs)	09/01/1933	12/31/2022
	RM = 68.6		Water Level Elevation (ft)	10/01/2007	12/31/2022
	Datum = 30.2 ft ab NGVD		Flow Measurements (cfs)	10/05/1919	12/05/2022
Peace River at SR 70 at Arcadia FL	02296750	24149	Gage Height (ft)	04/07/1931	12/31/2022
	A = 1,367 $mile^2$		Discharge (cfs)	04/01/1931	12/31/2022
	RM = 35		Water Level Elevation (ft)	10/01/2007	12/31/2022
	Datum = 6.00 ft ab NGVD		Flow Measurements (cfs)	06/06/1930	12/07/2022

Notes: 1) Source: USGS National Water Information System; 2) Drainage areas (A) and River Miles (RM) listed in table obtained from the USGS. RM based on the distance from the discharge point at Charlotte Harbor; 3) The reference system for the datum of gages varies between NGVD29 and NAVD 88. Water level elevation is relative to NAVD 1988; 4) The cutoff date for data acquisition for this table is 12/31/2022; 5) NA indicates information is unavailable; and 6) * indicates gage no longer active.

Table 2-7. Upper Peace River tributary stream gaging stations and daily data summary. Modified from Appendix H, Verdantas (2024).

Site Name	USGS ID, Drainage Area (A), and Datum	District Site ID	Parameter	Begin Date	End Date
Six Mile Creek at Bartow FL	02294747	700394	Gage Height (ft)	12/04/2002	12/31/2022
	A = NA		Discharge (cfs)	12/01/2002	12/31/2022
			Water Level Elevation (ft)	10/02/2007	12/31/2022
	Datum = 87.56 ft ab NGVD		Flow Measurements (cfs)	06/20/2002	12/08/2022
Phosphate Mine Outfall CS-8 near Bartow FL	02294759	702863	Gage Height (ft)	02/04/2003	12/31/2022
	A = NA		Discharge (cfs)	02/01/2003	12/31/2022
			Water Level Elevation (ft)	10/01/2007	12/31/2022
	Datum = 82.40 ft ab NGVD		Flow Measurements (cfs)	01/21/2003	12/07/2022
Barber Branch near Homeland FL	02294760	700356	Gage Height (ft)	12/04/2002	12/31/2022
	A = NA		Discharge (cfs)	12/01/2002	12/31/2022
			Water Level Elevation (ft)	10/01/2009	12/31/2022
	Datum = 84.31 ft ab NAVD		Flow Measurements (cfs)	08/23/2002	12/07/2022
Whidden Creek near Fort Meade FL	02295163	24879	Gage Height (ft)	11/21/2000	12/31/2022
	A = 43 $mile^2$		Discharge (cfs)	11/21/2000	12/31/2022
			Water Level Elevation (ft)	10/01/2007	12/31/2022
	Datum = 57.32 ft ab NAVD		Flow Measurements (cfs)	05/13/1939	07/08/2022
Bowlegs Creek near Fort Meade FL	02295013	24867	Gage Height (ft)	02/22/1991	12/31/2022
	A = 47.2 $mile^2$		Discharge (cfs)	03/01/1964	12/31/2022
			Water Level Elevation (ft)	10/01/2007	12/31/2022
	Datum = 95.46 ft ab NGVD		Flow Measurements (cfs)	04/01/1964	11/29/2022
Payne Creek near Bowling Green FL	02295420	24943	Gage Height (ft)	10/01/1979	12/31/2022
	A = 121 $mile^2$		Discharge (cfs)	10/01/1963	12/31/2022
			Water Level Elevation (ft)	10/01/2007	12/31/2022
	Datum = 51.06 ft ab NGVD		Flow Measurements (cfs)	05/14/1939	12/06/2022

Site Name	USGS ID, Drainage Area (A), and Datum	District Site ID	Parameter	Begin Date	End Date
Little Charlie Creek nr Mouth nr Wauchula FL	02295580	893414	Gage Height (ft)	09/30/2012	12/31/2022
	A = NA		Discharge (cfs)	09/30/2012	12/31/2022
			Water Level Elevation (ft)	09/30/2012	12/31/2022
	Datum = -0.43 ft ab NAVD		Flow Measurements (cfs)	09/11/2012	12/05/2022
Thompson Branch nr Wauchula FL*	02295630	23939	Gage Height (ft)	NA	NA
	A = 5.22 mile^2		Peak Streamflow (cfs)	08/06/1984	09/29/2022
			Water Level Elevation (ft)	NA	NA
	Datum = 59.59 ft ab NGVD		Flow Measurements (cfs)	01/05/1987	05/30/2018

Notes: 1) Source: USGS National Water Information System; 2) The reference system for the datum of gages varies between NGVD29 and NAVD 88. Water level elevation is relative to NAVD 88; 3) The cutoff date for data acquisition for this table is 12/31/2022; 4) NA indicates information is unavailable; and 5) * indicates gage no longer active.

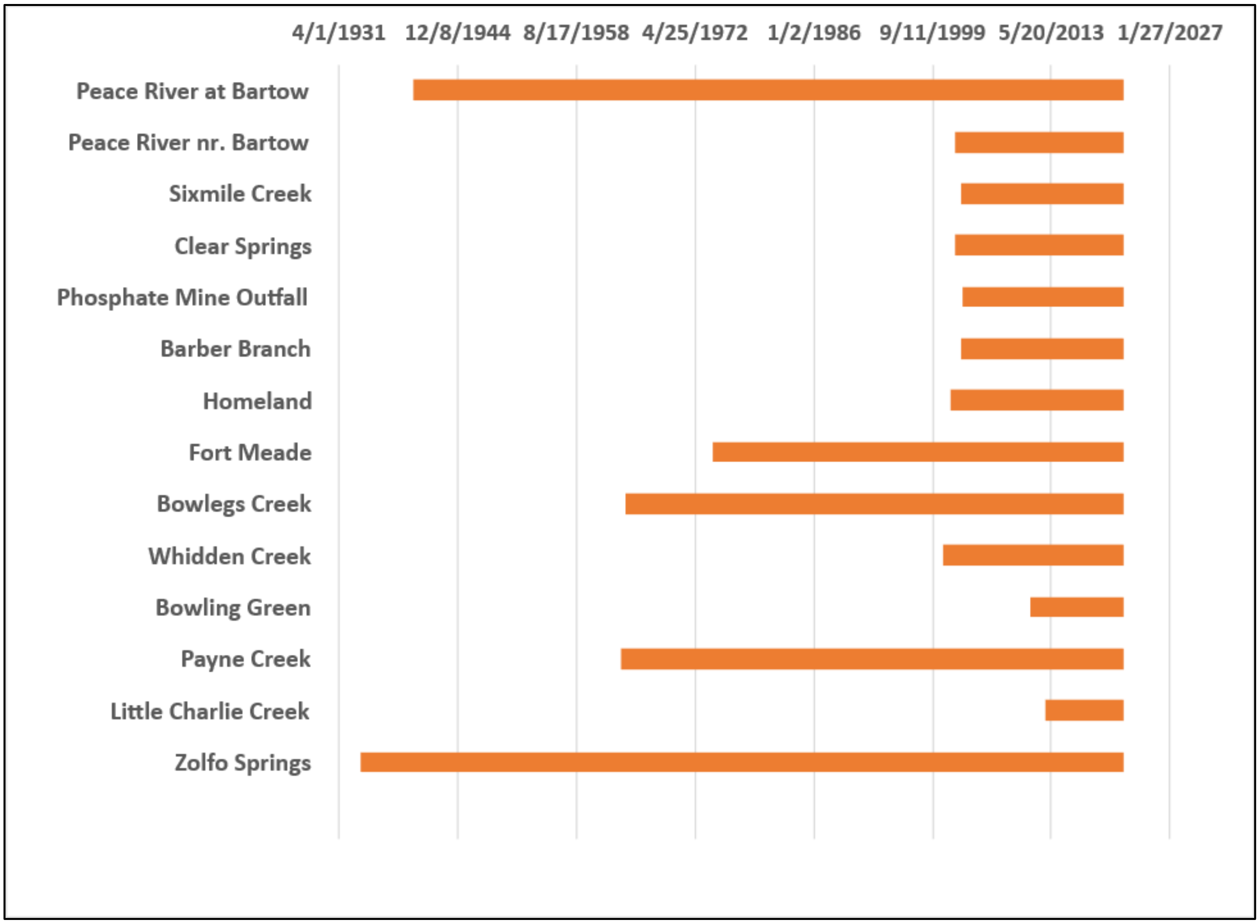


Figure 2-29. Upper Peace River long-term continuous gage flow summary. Gages with short periods of record are not included. Adapted from Appendix H, Verdantas (2024).

2.3.2 Flow Statistics for the Peace River and Its Major Tributaries

Long-term flow data for the Peace River mainstem are available from four gaging stations located at Bartow, Fort Meade, Zolfo Springs, and Arcadia. These stations have varying lengths of record as of 2022, ranging from approximately 49 to 92 years. The earliest records began in 1931 at Arcadia, followed by Zolfo Springs in 1933, Bartow in 1939, and Fort Meade in 1974. As noted in Section 2.3.1, Fort Meade has the shortest record, with complete annual flow data starting in 1975.

To facilitate consistent comparison across all stations, Table 2-8 presents average flow values calculated over the 48-year period from 1975 through 2022. This timeframe aligns with the start of complete records at Fort Meade and enables comparative analysis of flow conditions in the upper (Bartow and Fort Meade), middle (Zolfo Springs), and lower (Arcadia) segments of the Peace River.

The data in Table 2-8 clearly indicates a substantial increase in flow volume downstream. For example, the average gaged flow near the river mouth at the confluence with Shell Creek is 1,573 cfs, which is approximately 7.5 times greater than the mean flow at Fort Meade (209 cfs). Notably, between the Fort Meade and Zolfo Springs gages, the mean flow increases by a factor of 2.5, while the drainage basin expands by a factor of 1.7.

Table 2-8. Drainage areas, gage locations, average flow, and runoff rate for four long-term streamflow gaging stations on the mainstem of the Peace River and at the confluence with Shell Creek for (1975-2022).

USGS Peace River Gage Location	Drainage Area ($mile^2$)	Distance from the River Mouth (miles)	Mean Flow (cfs)	Runoff Rate ($cfs/mile^2$)
at Bartow	390	105	180	0.46
at Fort Meade	480	91	209	0.44
at Zolfo Springs	826	69	519	0.63
at Arcadia	1,367	35	925	0.68
at Shell Creek confluence*	2,090	8	1,573	0.75

* Sum of drainage areas and gaged flows estimated from the following USGS stations: Peace River at SR 70 at Arcadia, FL (No. 02296750; 1,367 $mile^2$), Horse Creek at SR 72 near Arcadia, FL (No. 02297310; 218 $mile^2$), Joshua Creek at Nocatee FL (No. 02297100; 132 $miles^2$), and Shell Creek nr Punta Gorda FL (No. 02298202; 373 $mile^2$).

Runoff rates, expressed in cfs per square mile ($cfs/mile^2$), also show a downstream increase. Rates range from 0.63 to 0.75 $cfs/mile^2$ between Zolfo Springs and the Shell Creek confluence, compared to 0.46 and 0.44 $cfs/mile^2$ at Bartow and Fort Meade, respectively (Table 2-8). The hydrologic complexity of these upstream sub-basins is addressed in Sections 2.2 and 2.4. It is important to note that the runoff rates at downstream gages include contributions from upstream areas, meaning that actual runoff rates between Fort Meade and the Zolfo Springs and Arcadia gages are even higher than the average values listed. These average values for flow and runoff rate show that there is significantly more water available progressively farther downstream.

Percentile flows further illustrate the downstream increase in water availability along the Peace River. Table 2-9 summarizes the minimum, maximum, and percentile flows for the four gages. Between Fort Meade and Zolfo Springs, low-percentile flows show significant increases: P5 flows rise from 3 to 37 cfs, P25 flows from 26 to 111 cfs, and median flows from 78 to 250 cfs. Conversely, P5 and P10 flows decrease between Bartow and Fort Meade, reflecting groundwater losses in the upper reach of the river, as discussed in Section 2.2.5. Additionally, maximum daily flows decline between Bartow and Fort Meade (see Section 2.3.3), while high flows downstream of Fort Meade increase markedly: P90 flows rise from 591 cfs at Fort Meade to 1,280 cfs at Zolfo Springs and 2,390 cfs at Arcadia. These trends underscore the greater water availability for supply or environmental restoration in the lower reaches of the river.

Table 2-9. Non-exceedance percentile values for daily flows at four long-term streamflow gages on the mainstem of the Peace River and at the confluence with Shell Creek (1975-2022).

USGS Peace River Gage Location	Min	P5	P10	P25	P50	P75	P90	P95	Max
at Bartow	0.00	5.9	9.7	22	56	195	510	806	4,010
at Fort Meade	0.01	3.3	7.2	26	78	230	591	923	2,950
at Zolfo Springs	3.6	37	56	111	250	596	1,280	1,943	20,900
at Arcadia	5.6	59	85	159	389	1,030	2,390	3,610	49,900
at Shell Creek confluence*	12	82	122	244	635	1,744	4,190	6,070	64,370

* Flows estimated from the following USGS stations: Peace River at SR 70 at Arcadia, FL (No. 02296750; 1,367 mile^2), Horse Creek at SR 72 near Arcadia, FL (No. 02297310; 218 mile^2), Joshua Creek at Nocatee FL (No. 02297100; 132 miles^2), and Shell Creek nr Punta Gorda FL (No. 02298202; 373 mile^2).

Much of the gain in flow at the downstream locations is due to tributary inflows to the river below Fort Meade. Table 2-10 details the drainage areas, locations, and flow statistics for five major tributaries. For consistency, values are computed for the 1975 to 2022 period, except for Bowleg Creek and Payne Creek, which have complete records starting in 1992 and 1980, respectively.

Flows for Payne Creek are included in the Zolfo Spring gage data (Table 2-8 and Table 2-10), while both Payne Creek and Charlie Creek contribute to the Arcadia gage. Horse, Joshua, and Shell Creeks enter the river below Arcadia, and their mean flows can be added to the Arcadia gage to yield a total average gaged flow 1,573 cfs for 1975-2022. In contrast, the mean flow at Fort Meade (209 cfs) represents only 13% of this total, despite the Fort Meade subbasin comprising 23% of the total gaged watershed area.

Table 2-10.Drainage areas, gage locations, average flow, and area-based runoff, and median flows for six major tributaries to the Peace River (1975-2022, or as noted)[1].

USGS Peace River Gage[2]	Drainage Area (mile^2)	Entry Location to Mainstream	Median Flow (cfs)	Mean Flow (cfs)	Runoff Rate (cfs/mile^2)
Bowlegs Creek nr Fort Meade	47	Between Fort Meade and Zolfo Springs	8.8	35	0.74
Payne Creek nr Bowling Green	121		64	122	1.01
Charlie Creek nr Garner	330	Between Zolfo Springs and Arcadia	54	250	0.76
Joshua Creek at Nocatee	132	Downstream of Arcadia	34	112	0.85
Horse Creek nr Arcadia	218		41	174	0.80
Shell Creek nr Punta Gorda	373		128	361	0.97

[1] The most downstream gage listed if more than one gage exists on a specific tributary. [2] The data record is from 1992 to 2022 for Bowleg Creek and from 1980 to 2022 for Payne Creek.

Flow statistics from the Peace River and its major tributaries demonstrate a pronounced increase in flow volume and runoff rates downstream of Fort Meade. Sub-basins in the middle and lower reaches of the river contribute significantly more water to the system. These findings are consistent with the results of Flannery (2018), who conducted a comparable analysis using data through 2017. As discussed in subsequent sections, human activities have substantially altered flow conditions in the Upper Peace River. Nevertheless, the river's hydrology and ecology show signs of recovery following the implementation of SUWCA recovery strategies.

2.3.3 Trend Analyses

In the early 1980s, Hirsh et al. (1982) developed the Seasonal Kendall Test, a nonparametric extension of the original Kendall Tau method that has since become a cornerstone in environmental statistics. This test evaluates all possible pairs of chronologically ranked data to detect monotonic trends over time.

For each pair of observations, if the later measurement is greater than the earlier, the pair is concordant. Conversely, if the later measurement is smaller, the pair is discordant. If the number of concordant and discordant pairs is not statistically different, no trend is detected. A statistically significant excess of concordant pairs indicates an upward trend, while a predominance of discordant pairs indicates a downward trend.

Hirsh et al. (1982) also introduced the Kendall Slope Estimator, which quantifies the magnitude of the trend. It is calculated as the median of the differences (expressed as slopes) of the ordered pairs of data values. In the context of annual mean streamflow, the slope is typically expressed in cfs per year.

The first study to highlight declining flows in the Peace River was conducted by Hammett (1990), who applied data from 1931 through 1984 and identified statistically significant declines in mean annual flows at the Bartow, Zolfo Springs, and Arcadia gaging stations. Subsequent studies reinforced these findings:

- Coastal Environmental (1996) reported significant declines in both dry and wet season flows at Bartow and Zolfo Springs, as well as in wet season flows at Arcadia using data through 1994.
- Lewelling et al. (1998) found significant declines at Bartow, Fort Meade, Zolfo Springs, and Arcadia when analyzing the full period of record. However, no trends were detected at the 90% confidence level when only the most recent twenty years (1975-1994) were examined.
- Flannery and Barcelo (1998) confirmed declining trends using data through 1996, noting the steepest decline occurred between the late 1950s to the late 1970s or early 1980s.

- Spechler and Kroening (2007) later reported a continuing decline in streamflow from the 1970s to 2003.

During the development of the 2002 MFLs (SWFWMD 2002), the District applied the Kendall Tau test to mean annual and monthly streamflow, percent exceedance streamflow, and water level data from 1940 to 2000. The analysis revealed significant declining trends at all three long-term USGS gaging stations (Bartow, Zolfo Springs, and Arcadia), with the most pronounced declines observed at Bartow. These results aligned with earlier findings.

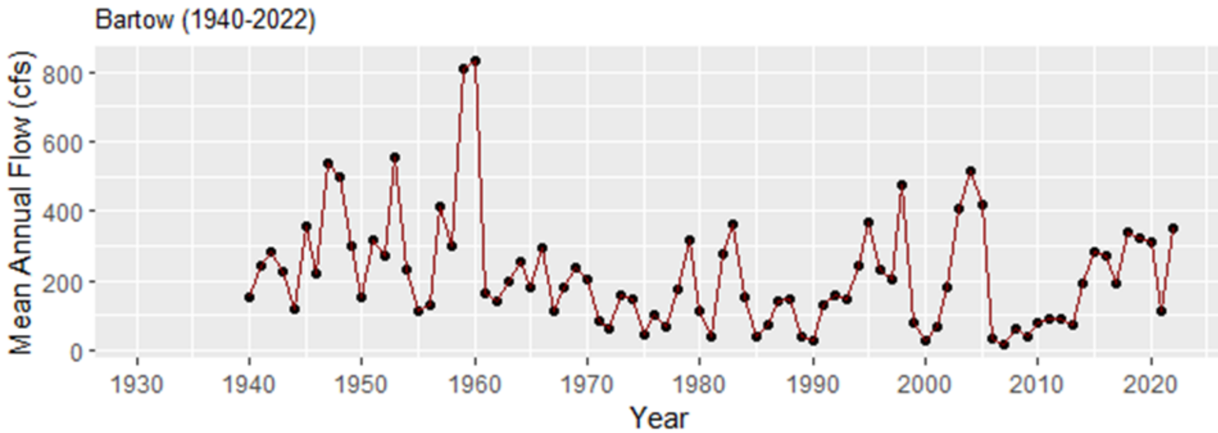
The analysis by Lewelling et al. (1998) was later extended by PBS&J (2007), which found no statistically significant trends in streamflow at Bartow and Zolfo Springs over the 35-year period from 1970 to 2004. This absence of trend may be attributed to groundwater level recovery since 1974 (see Figure 2-19 for ROMP 60 well data and Figure 2-20 for regional groundwater level rebound). The recovery was largely driven by water conservation practices adopted by the phosphorus-mining industry and a reduction in regional groundwater withdrawals.

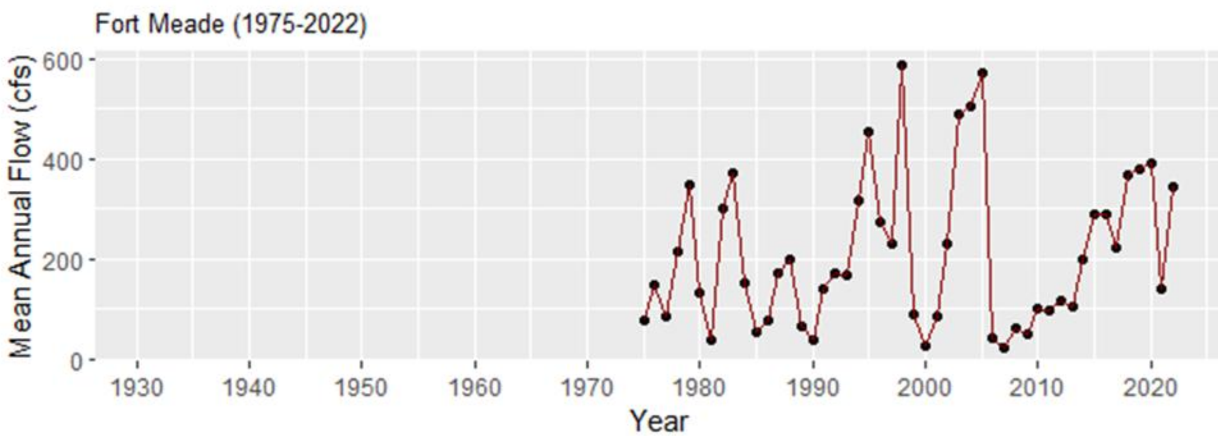
Since the adoption of the Upper Peace River MFLs, recovery strategies under the SWUCA initiative have been implemented across the region. Notably, the Lake Hancock Lake Level Modification Project has substantially improved low-flow conditions in the Upper Peace River, as discussed in previous sections.

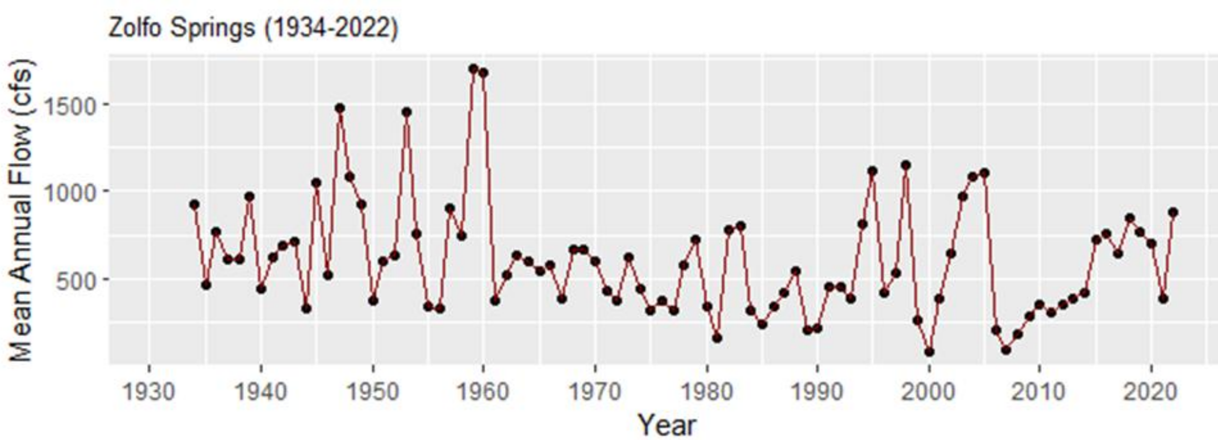
The following analyses evaluate long-term trends using an additional two decades of data and assess the effectiveness of these recovery efforts. All continuous recording stations with 25 or more years of data at the time of this report, i.e., Bartow, Fort Meade, Zolfo Springs, and Arcadia, were analyzed for long-term trends in streamflow and levels.

2.3.3.1 Trends in Streamflow

Hydrographs of mean annual flows at four USGS streamflow gages on the Peace River are presented in Figure 2-30. These values were calculated from the first year of complete daily records through the end of 2022. While the Fort Meade gage has a shorter record than the other three, all hydrographs exhibit similar long-term patterns. Notably, the Peace River experienced higher annual mean flows prior to 1960, with a marked decline between 1960 and the late 1970s, and a modest upward trend beginning around 2006.


Bartow (1940-2022)
Mean Annual Flow (cfs)
0
200
400
600
800
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year


Fort Meade (1975-2022)
Mean Annual Flow (cfs)
0
200
400
600
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year


Zolfo Springs (1934-2022)
Mean Annual Flow (cfs)
500
1000
1500
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

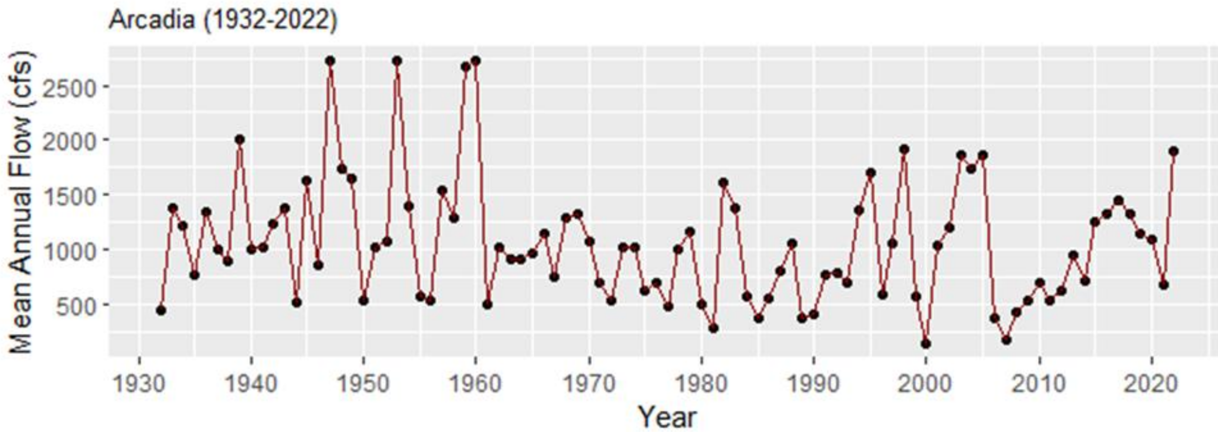


Figure 2-30. Hydrographs of mean annual streamflow at four long-term USGS gaging stations on the Peace River, ordered from upstream to downstream. Mean annual values were calculated from the first year of complete daily records through the end of 2022.

To quantitatively assess these patterns, the nonparametric Kendall Tau test was applied to mean annual streamflow data across multiple time periods, as listed in Table 2-11. These periods were selected to enable comparisons with previous studies, including 1932-1984 (Hammett 1990), 1934-1994 and 1975-1995 (Lewelling et al. 1998), and 1940-2000 (SWFWMD 2002), as well as to evaluate trends over the period including the most recent two decades. Due to its limited record, the Fort Meade gage was included in fewer time periods.

As shown in Table 2-11, results from periods extending from the first year of complete record to 1984, 1994, 2000, and 2022 are consistent with earlier findings by Hammett (1990), Lewelling et al. (1998), and SWFWMD (2002). Statistically significant declining trends (at the 90% confidence level) were observed at the Bartow, Zolfo Springs, and Arcadia gages (except for the period from 1932 to 2022 for Arcadia where no significant trend was detected).

In contrast, analyses of periods starting from 1975 yielded higher p-values (ranging from 0.12 to 0.77), indicating no statistically significant trends for the periods 1975-1994 and 1975-2022 across all four gages. However, for the period 2006-2022, a statistically significant upward trend was observed at all four gages, with p-values ranging from 0.00003 to 0.0005. This trend may reflect a recovery in groundwater levels since 1974, driven by improved water conservation practices in the phosphate-mining industry, which now requires less groundwater withdrawals than before 1974. It may also be associated with the implementation of SWUCA recovery strategies, particularly the operation of the Lake Hancock control structure beginning in 2016 to support compliance with the existing MFLs for the Upper Peace River.

Five-year moving averages of annual mean streamflow at Bartow, Fort Meade, Zolfo Springs, and Arcadia also illustrate similar trends (Figure 2-31). Streamflow declined steadily until the mid-1970s, remained relatively stable through the late 2000s, and then began to rise through the end of the reporting period.

Table 2-11.Summary of Kendall Tau test results for mean annual flows for different time periods at four USGS gaging stations on the Peace River. Slopes are reported in cfs per year and expressed as a percentage of the period mean. All significant values of p (<0.05) are highlighted in bold.

Station Name	Period of Analysis*	Kendall Tau	Significance Level	Trend Slope	
				cfs/year	Percentage
Bartow	1940-1984	-0.25	**0.01**	-3.75	-1.5
	1940-1994	-0.33	**0.0004**	-3.45	-1.54
	1975-1994	0.05	0.77	1.65	1.17
	1940-2000	-0.26	**0.003**	-2.60	-1.16
	1940-2022	-0.15	**0.04**	-1.34	-0.61
	1975-2022	0.16	0.12	2.08	1.16
	2006-2022	0.71	**0.0001**	20.47	12.17
Fort Meade	1975-1994	0.05	0.77	1.34	0.82
	1975-2022	0.16	0.11	2.33	1.12
	2006-2022	0.75	**0.00003**	22.52	11.91
Zolfo Springs	1934-1984	-0.24	**0.01**	-6.18	-0.93
	1934-1994	-0.30	**0.0007**	-6.24	-1.00
	1975-1994	0.09	0.58	4.18	0.95
	1940-2000	-0.25	**0.005**	-5.76	-0.94
	1934-2022	-0.16	**0.03**	-2.79	-0.46
	1975-2022	0.16	0.12	4.70	0.90
	2006-2022	0.74	**0.00005**	44.11	9.03
Arcadia	1932-1984	-0.16	0.10	-7.56	-0.66
	1932-1994	-0.23	**0.008**	-8.88	-0.83
	1975-1994	0.06	0.72	6.19	0.80
	1940-2000	-0.22	**0.01**	-9.77	-0.92
	1932-2022	-0.10	0.18	-3.05	-0.29
	1975-2022	0.19	0.06	8.70	0.94
	2006-2022	0.63	**0.0005**	82.53	9.20

Note: The period of analysis was selected to allow comparison with previous studies, including 1932-1984 (Hammett 1990), 1934-1994 and 1975-1994 (Lewelling et al. 1998), and 1940-2000 (SWFWMD 2002).

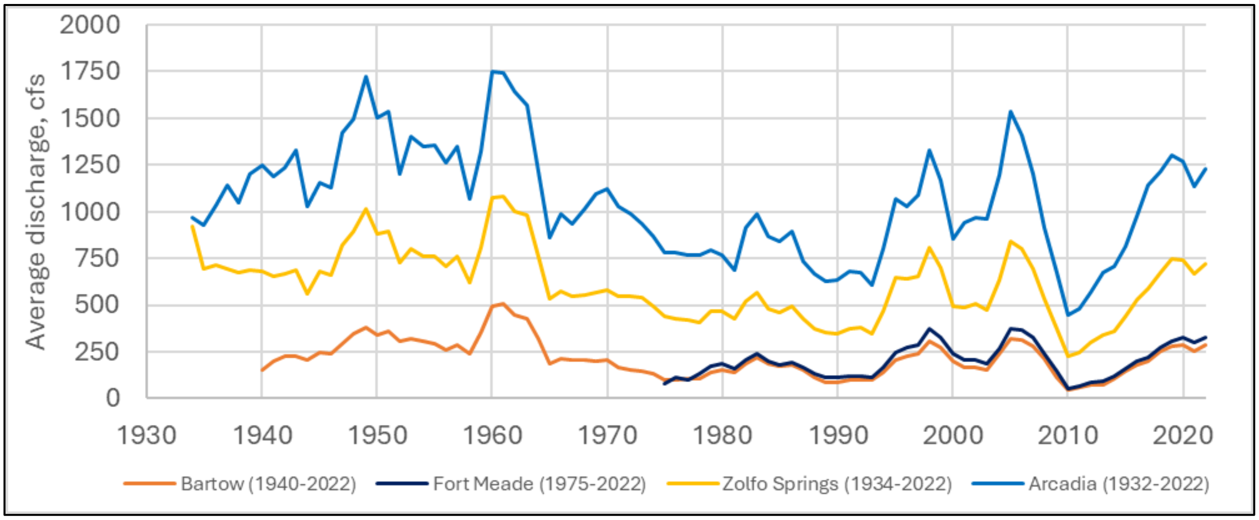


Figure 2-31. Five-year moving averages of annual mean discharge for the Peace River at Bartow, Fort Meade, Zolfo Springs, and Arcadia streamflow gaging stations.

Annual percent exceedance flows represent flow levels that are surpassed by a specific percentage of daily values within each calendar year. These metrics are useful indicators for detecting change in low, medium, or high flow characteristics (Lins and Slack 1999).

Flow trends were evaluated using the Kendall Tau test at three long-term gaging sites, focusing on annual minimum and 90%, 50%, and 10% exceedance flows (Table 2-12). Over the full period ending in 2022, the Bartow and Zolfo Springs gages exhibited declining trends in the annual minimum, as well as the 90% and 50% exceedance flows, which was most pronounced at Bartow. However, no trend was observed for the 10% exceedance flows at both gaging stations.

Trends for the period 1975-2022 were also analyzed. During this period, no declining trends were detected at the three gages for nearly all selected exceedance flows. However, the Zolfo Springs gage displayed a statistically significant upward trend in the 10% exceedance flow (Table 2-12).

Table 2-12.Summary of Kendall Tau test results for annual minimum and 90%, 50% and 10% exceedance flows across selected periods at three long-term USGS gaging stations on the Upper Peace River. Slopes are reported in cfs per year. All significance values of p<0.05 are highlighted in bold.

Period	Station Name	Statistics	Percent Exceedance			
			Min	90%	50%	10%
1940-2022	Bartow	Kendall Tau	-0.32	-0.31	-0.28	-0.09
		p-value	**0.000**	**0.000**	**0.000**	0.226
		Slope	-0.24	-0.39	0.00	0.23
1934-2022	Zolfo Springs	Kendall Tau	-0.42	-0.33	-0.20	-0.10
		p-value	**0.000**	**0.000**	**0.006**	0.17

Period	Station Name	Statistics	Percent Exceedance Min	90%	50%	10%
		Slope	-0.89	-1.16	0.01	-4.16
1975-2022	Bartow	Kendall Tau	-0.07	0.07	0.06	0.18
		p-value	0.49	0.50	0.55	0.07
		Slope	-0.06	0.13	0.32	5.96
1975-2022	Fort Meade	Kendall Tau	0.05	0.03	0.02	0.18
		p-value	0.61	0.78	0.84	0.07
		Slope	0.03	0.07	0.18	6.69
1975-2022	Zolfo Springs	Kendall Tau	-0.17	-0.18	0.01	0.20
		p-value	0.08	0.07	0.90	**0.05**
		Slope	-0.48	-1.00	0.20	14.12

Examining the relationship between annual percent exceedance flows and mean annual flows in the Upper Peace River provides valuable insight. Figure 2-32 presents the five-year moving averages for mean annual flows at the Bartow gage, alongside corresponding averages for the 30% and 50% exceedance flows. The mean annual flow more closely aligns with the 30% exceedance flow than the median (50% exceedance) flow, visually reinforcing that the mean annual flow is influenced by high flow events. Over the period of record, the median flow at Bartow (91 cfs) is slightly less than half of the mean annual flow (218 cfs). This distinction highlights that trends or observations based on mean annual flows tend to be biased toward high flows and may not accurately capture changes in low to medium flow conditions.

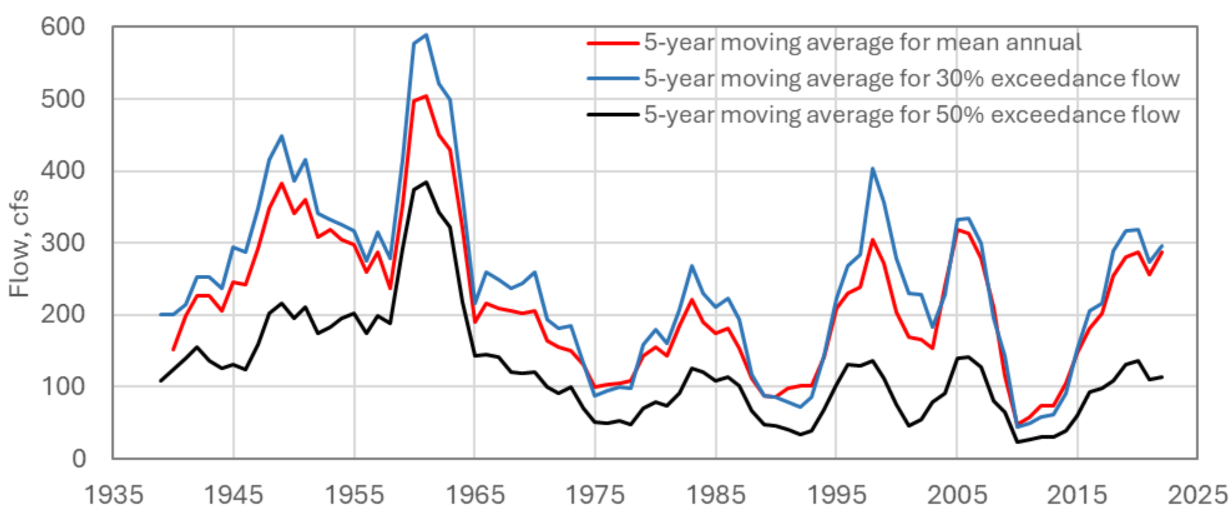


Figure 2-32. Comparison of 5-year moving averages for mean annual flow, 30% exceedance flow, and median flow in the Upper Peace River as measureded at the Bartow gage (1939-2022).

2.3.3.2 Trends in Surface Water Levels

Surface water level is a critical hydrologic variable with significant ecological implications. Analyzing long-term trends in water levels offers valuable insight into the dynamics of river systems. Some of the most extensive water level records in Southwest Florida come from the Peace River's long-term gaging stations.

Time series plots were generated for four annual percent exceedance levels, i.e., annual minimum, 90%, 50%, and 10% exceedance levels, at the Bartow, Fort Meade, and Zolfo Springs gages (Figure 2-33 through Figure 2-35). Statistical trend analyses were performed using the Kendall Tau test for two periods: the full period of record through 2022 for Bartow and Zolfo Springs and the period from 1975 to 2022 for all three gages (Table 2-13).

At the Bartow gage, statistically significant declining trends were observed for all exceedance levels except for the 10% level (Table 2-13). Extended declines in the minimum, 90%, and 50% exceedance levels were evident from 1960 to the late 1990s. This observation is supported by the 10% exceedance flow data, which contrasts with findings from the 2002 MFLs study (SWFWMD 2002), where a declining trend was noted for the 1940-2000 period. The additional two decades of data indicates the recovery in high water levels.

At Zolfo Springs, statistically significant declines were also observed in the minimum, 90%, and 50% exceedance levels. Time series plots show continued declines in these levels through the late 1990s. No declining trend was observed for the 10% exceedance level (Table 2-13)

For the 1975-2022 period, no statically significant trends were found for any exceedance levels at Bartow, nor for the minimum, and 50% and 90% exceedance levels at Fort Meade and Zolfo Springs (Table 2-13). However, water levels at both Fort Meade and Zolfo Springs exhibited increasing trends in the 10% exceedance level, with the increase slightly more pronounced at Zolfo Springs based on slope comparisons.

The trends observed at Bartow and Zolfo Springs from their full period of record are generally consistent with findings from the 2002 MFLs study (SWFWMD 2002), except for the 10% exceedance level. The additional two decades of data suggest some recovery in water levels, particularly at higher elevations.

Table 2-13.Summary of Kendall Tau test results for annual minimum, 90%, 50%, and 10% exceedance stage across selected periods at three long-term USGS gaging stations on the Upper Peace River. Slopes are reported in feet per year. All significance values of p (<0.05) are highlighted in bold.

Period	Station Name	Statistics	Percent Exceedance			
			Min	**90%**	**50%**	**10%**
1940-2022	Bartow	Kendall tau	-0.44	-0.44	-0.40	-0.10

Period	Station Name	Statistics	Percent Exceedance			
			Min	90%	50%	10%
		p-value	**0.00**	**0.00**	**0.00**	0.20
		Slope	-0.02	-0.02	-0.03	-0.01
1934-2022	Zolfo Springs	Kendall tau	-0.54	-0.52	-0.28	0.00
		p-value	**0.00**	**0.00**	**0.00**	0.97
		Slope	-0.02	-0.02	-0.02	0.00
1975-2022	Bartow	Kendall tau	-0.03	0.06	-0.01	0.12
		p-value	0.76	0.55	0.95	0.24
		Slope	0.00	0.00	0.00	0.01
1975-2022	Fort Meade	Kendall tau	-0.04	0.02	0.07	0.25
		p-value	0.72	0.82	0.51	**0.01**
		Slope	0.00	0.00	0.01	0.06
1975-2022	Zolfo Springs	Kendall tau	-0.19	-0.18	0.03	0.28
		p-value	0.054	0.07	0.76	**0.00**
		Slope	-0.01	-0.01	0.00	0.08

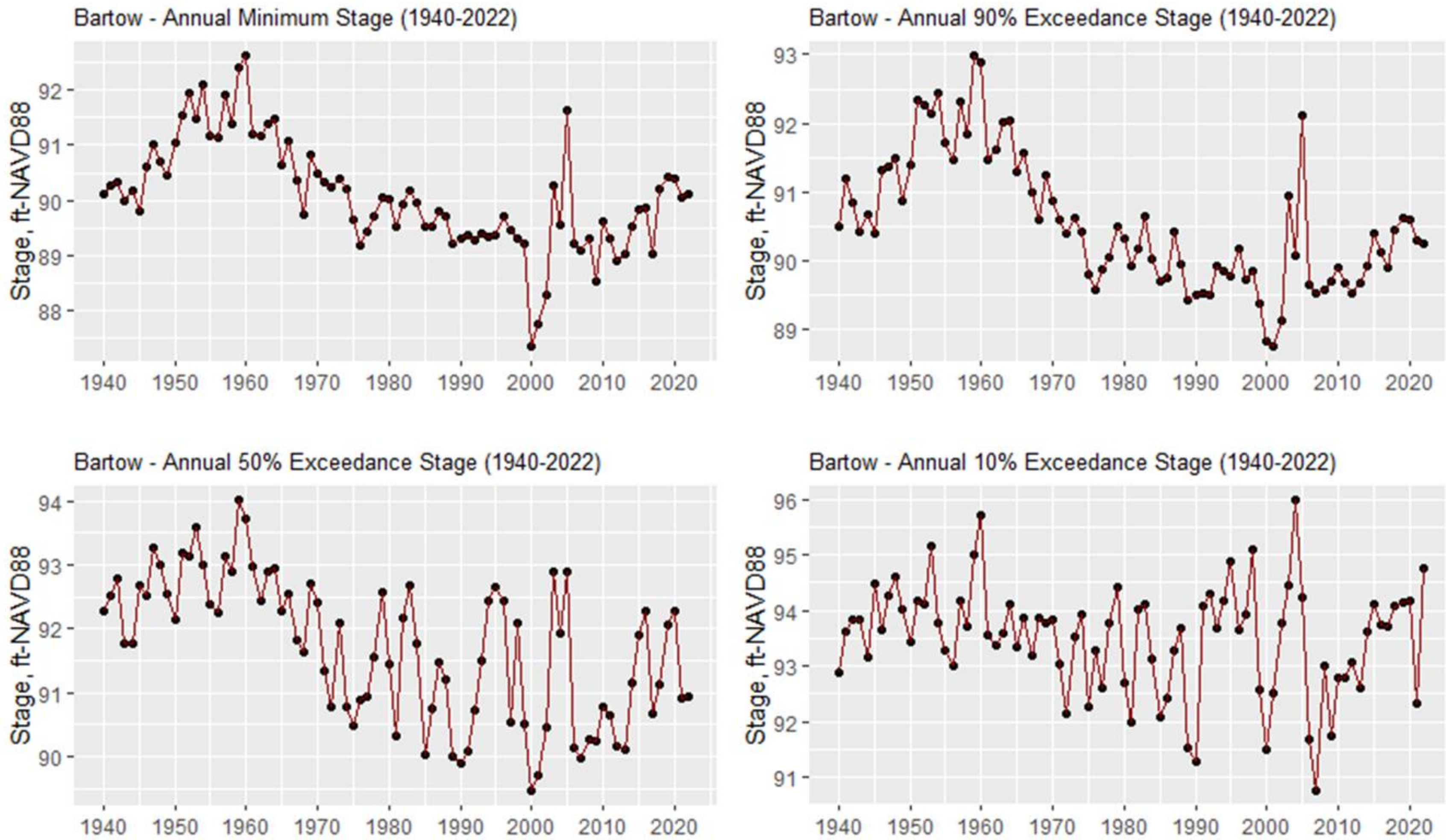


Figure 2-33. Hydrographs of annual minimum, 90%, 50%, and 10% exceedance stages at the USGS Peace River at Bartow gage for the period 1940-2022.

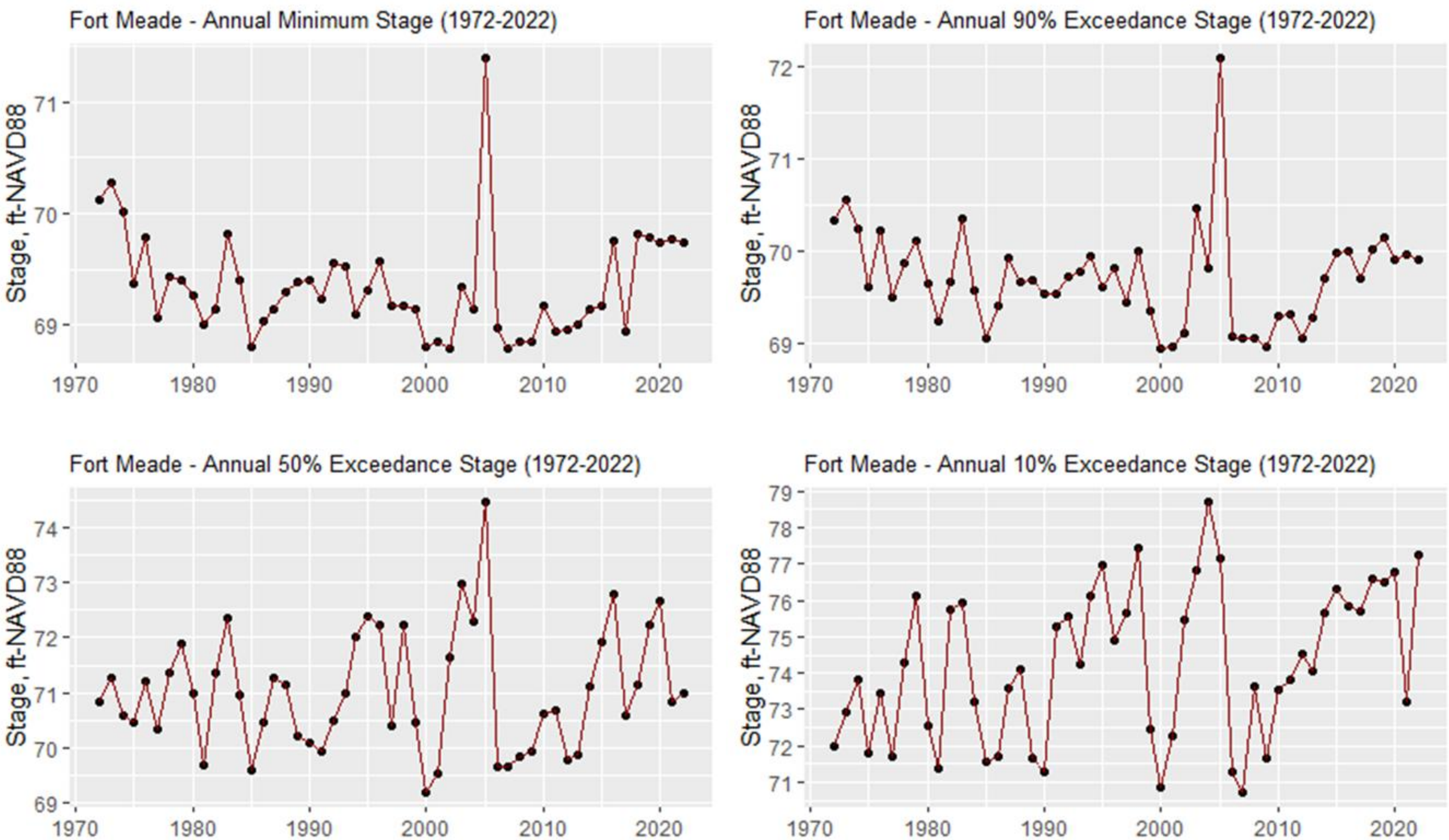


Figure 2-34. Hydrographs of annual minimum, 90%, 50%, and 10% exceedance stages at the USGS Peace River at Fort Meade gage for the period 1972-2022.

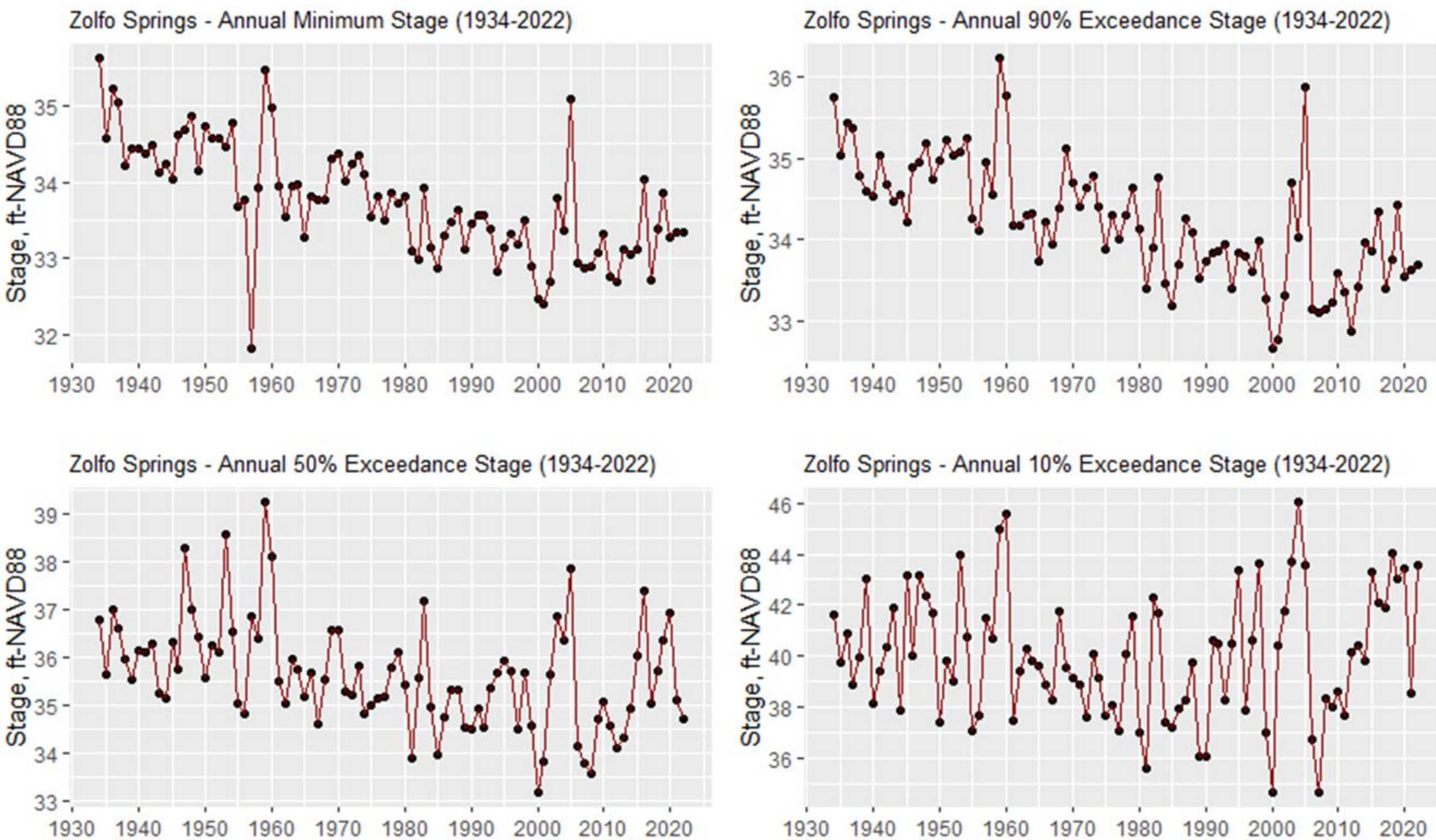


Figure 2-35. Hydrographs of annual minimum, 90%, 50%, and 10% exceedance stages at the USGS Peace River at Zolfo Springs gage for the period 1934-2022.

2.3.4 Streamflow Characteristics between Bartow and Fort Meade

The 13-mile upper segment of the Upper Peace River, stretching from Bartow to Fort Meade, is monitored by five USGS gaging stations: Peace River at Bartow, near Bartow, at Clear Springs, near Homeland, and at Fort Meade (Figure 2-36). Section 2.3.1 provides detailed analyses of long-term flow data from the Bartow gage (1939-2022) and the Fort Meade gage (1974-2022). Data collection began at the remaining three gages on May 15, 2002 (near Bartow and Clear Springs) and on October 1, 2001 (near Homeland). These gages were not available during the previous MFLs study completed in August 2002, which relied on data prior to 2000. As a result, concurrent flow data for the reach between Bartow and Fort Meade was limited at that time.

Despite the shorter periods of record, the mid-reach gages provide valuable insights into streamflow dynamics. As described in Section 2.2.5, the Upper Peace River has become a losing stream, particularly upstream of the Fort Meade gage where flow is lost to the underlying groundwater system. This behavior is confirmed by comparing daily flows at Bartow with those at downstream gages. Numerous instances have been recorded where daily flows at Bartow exceeded those at Fort Meade (Table 2-14). From 1975 through 2022, Bartow flows surpassed Fort Meade flows on an average of 123 days per year or approximately one-third of the year. Annual totals of days when flows were greater at the Bartow gage than the Fort Meade gage range from 26 days in 1989 to 263 days in 2000 (Table 2-14). While some discrepancies may be attributed to storm peak travel time between the gages, it is mainly due to losses to groundwater.

Physical evidence of these losses includes subsidence features within the river channel and floodplain. Patton (1981) and Lewelling et al. (1998) documented numerous sinkholes and subsidence features between Bartow and Fort Meade. During dry periods, the river visibly drains into these sinkholes, some of which are large enough to capture substantial volume of flow. Flow losses between the two gages have been significant in certain years. Mean annual flow loss rates exceeded 30 cfs in the 20 years between 1975 and 2022, with peak losses of 332 cfs in 2004 (Table 2-14). Although rating curve accuracy may influence these estimates, the capacity of sinkholes to capture streamflow remains a critical factor.

Low-flow thresholds for the Upper Peace River were implemented in 2016 following the completion of the Lake Hancock Lake Level Modification Project. Since then, flows at the Bartow and Fort Meade gages have generally remained at or above the low-flow threshold, with exception of the severe drought in 2017. During that year, the Clear Springs gage recorded 36 continuous days of zero flow (Table 2-15). Days with no flow have not been observed at the Near Bartow and Homeland gages since 2016, indicating an overall improvement in streamflow conditions along the Bartow and Fort Meade segments.

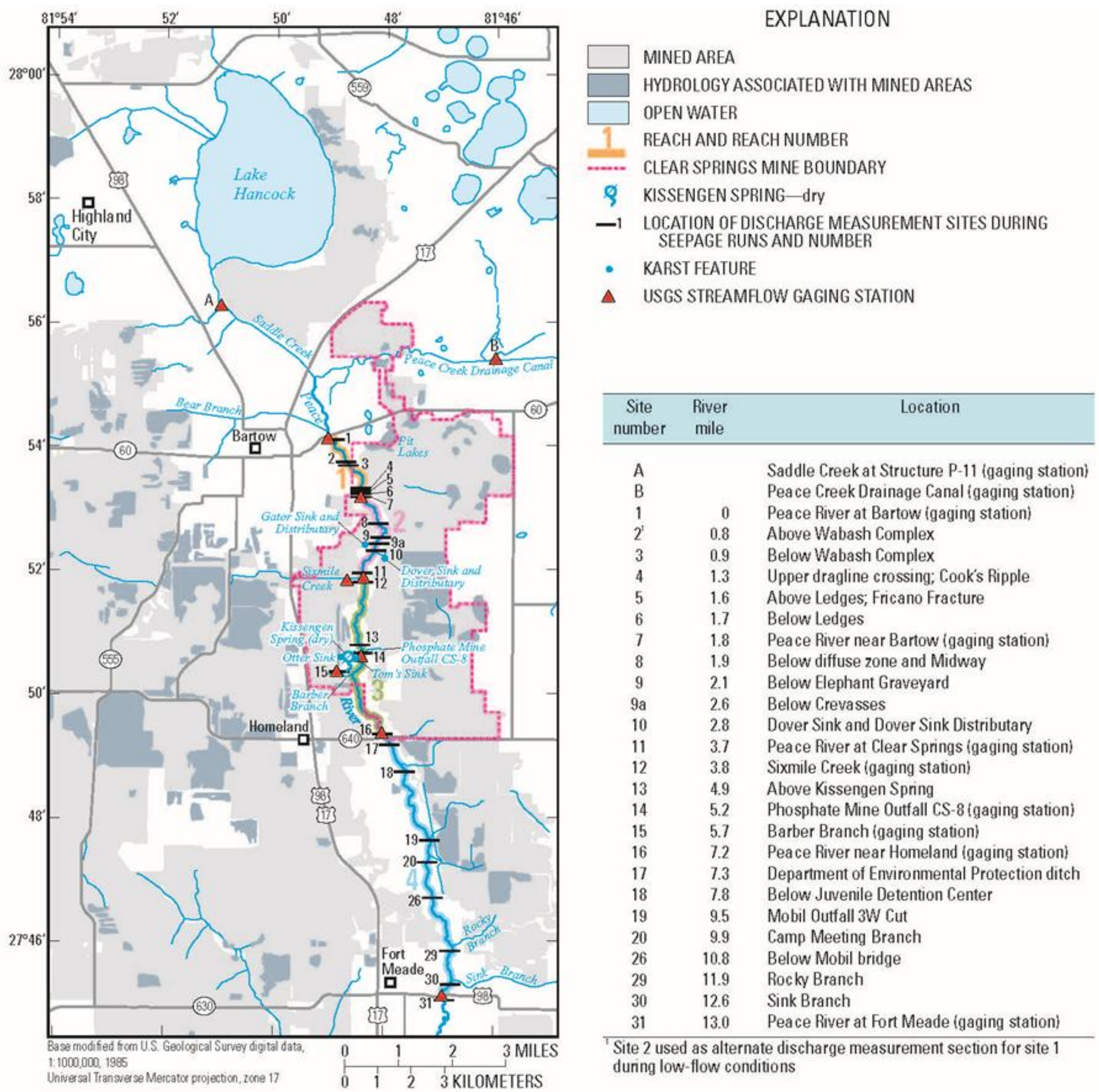


Figure 2-36. Karst features and sinkhole locations in relation to USGS gaging stations between Bartow and Fort Meade. Adapted from Metz and Lewelling (2009).

Table 2-14. Number of days (N) when daily flows at the Bartow gage exceeded those at the Fort Meade gage, along with the mean, minimum (Min), and maximum (Max) differences in flow (cfs) for those days. The annual average represents the estimated rate of flow losses between the two gages, calculated by averaging the total flow difference over the number of days in each year.

Year	N	Mean	Min	Max	Annual Average	Year	N	Mean	Min	Max	Annual Average
1975	65	6.9	0.2	61.0	1.2	**1999**	118	20.8	0.4	134.0	6.7
1976	42	31.5	1.0	185.0	3.6	**2000**	263	10.3	0.2	51.0	7.4

Year	N	Mean	Min	Max	Annual Average	Year	N	Mean	Min	Max	Annual Average
1977	112	10.1	0.7	60.0	3.1	**2001**	134	3.7	0.0	114.0	1.4
1978	59	44.2	2.0	146.0	7.1	**2002**	100	18.8	0.0	370.0	5.1
1979	120	67.2	1.0	320.0	22.1	**2003**	41	53.8	0.3	240.0	6.0
1980	135	30.0	1.0	316.0	11.1	**2004**	99	331.7	0.1	1670	89.7
1981	256	11.7	1.0	79.0	8.2	**2005**	40	21.1	1.0	56.0	2.3
1982	143	55.3	1.0	420.0	21.6	**2006**	173	4.9	0.1	34.2	2.3
1983	126	68.3	1.0	416.0	23.6	**2007**	165	5.1	0.0	15.7	2.3
1984	203	24.2	1.0	279.0	13.4	**2008**	227	18.3	0.2	175.0	11.4
1985	197	6.6	0.2	24.9	3.6	**2009**	178	5.2	0.0	21.3	2.5
1986	162	22.3	0.4	192.0	9.9	**2010**	143	12.0	0.0	160.0	4.7
1987	74	47.4	0.3	445.0	9.6	**2011**	200	20.5	0.1	527.0	11.2
1988	45	24.1	1.0	89.0	3.0	**2012**	170	8.8	0.0	74.6	4.1
1989	26	37.0	0.1	139.0	2.6	**2013**	89	12.2	0.1	225.0	3.0
1990	130	12.4	0.3	129.0	4.4	**2014**	136	53.6	0.1	562.0	20.0
1991	190	16.3	0.2	338.0	8.5	**2015**	141	75.7	0.1	455.0	29.2
1992	81	36.8	0.1	263.0	8.1	**2016**	101	91.1	0.6	581.0	25.1
1993	121	32.8	1.0	180.0	10.9	**2017**	103	29.3	0.3	236.0	8.3
1994	159	26.6	0.7	178.0	11.6	**2018**	135	45.5	0.3	290.0	16.8
1995	75	32.7	1.0	283.0	6.7	**2019**	62	31.8	0.2	214.0	5.4
1996	97	67.3	1.0	610.0	17.8	**2020**	85	13.6	0.2	91.0	3.2
1997	166	22.2	0.1	166.0	10.1	**2021**	70	16.0	0.1	162.0	3.1
1998	43	3.9	0.2	20.0	0.5	**2022**	114	140.3	0.2	1,340	43.8

Table 2-15.Number of zero-flow days at the Bartow (N1), Near Bartow (N2), Clear Springs (N3), Homeland (N4), and Fort Meade (N5) gages, 2003-2022.

Year	N1	N2	N3	N4	N5	Year	N1	N2	N3	N4	N5
2003	0	0	0	0	0	**2013**	0	43	151	0	0
2004	0	14	0	0	0	**2014**	0	0	33	0	0
2005	0	0	0	0	0	**2015**	0	0	2	0	0
2006	0	0	182	0	0	**2016**	0	0	0	0	0
2007	0	112	260	14	0	**2017**	0	0	36	0	0
2008	0	63	177	19	0	**2018**	0	0	1	0	0
2009	7	86	173	11	0	**2019**	0	0	0	0	0
2010	0	9	66	0	0	**2020**	0	0	0	0	0
2011	0	42	108	10	0	**2021**	0	0	0	0	0
2012	0	72	181	12	0	**2022**	0	0	0	0	0

2.4 Factors Affecting Streamflow

As outlined in earlier sections, the Upper Peace River has experienced significant reductions in streamflow over time. Declines in spring flow contributions were first documented in the 1930s. More widespread reductions across the entire flow regime became evident after 1960, with further decline in low flow conditions emerging in the mid-1980s.

Following the adoption of minimum flows in 2006 and the implementation of recovery initiatives within the SWUCA, low-flow conditions have shown significant improvement. Understanding the various contributing factors behind these historical and recent changes is essential for the reevaluation of minimum flows.

2.4.1 Long-Term Changes in Rainfall

Since the 1980s, numerous studies (Hammett 1990, Barcelo et al. 1990, Moore 1996, Coastal Environmental 1996, Hickey 1998, Flannery and Barcelo 1998, Garlanger 2002) have documented a persistent trend of below average rainfall across Central Florida, with particular emphasis on the Peace River basin. While early investigations offered limited consensus on the underlying causes, more recent research (Gray et al. 1997, Landsea et al. 1999, Goldenberg et al. 2001, Enfield et al. 2001, Basso and Schultz 2003) has linked this long-term climatic shift to the Atlantic Multidecadal Oscillation (AMO), a naturally-occurring cycle of sea surface temperature variability in the North Atlantic that recurs every 20 to 50 years. Warmer AMO phases are associated with increased wet-season rainfall and heightened tropical cyclone activity, whereas cooler phases tend to suppress summer rainfall across the Florida peninsula.

Rainfall data from six stations within or near the Peace River basin revealed a significant decline in average annual rainfall when comparing two 30-year periods: 1936-1965 and 1966-1995. The reduction ranged between 4.5 and 5.5 inches per year, with about 80% of the difference attributed to wet-season rainfall. A notable lull in tropical cyclone activity from 1970-1994 further exacerbated the decline, accounting for up to one-third of the wet-season shortfall. Dry-season rainfall also showed a modest decrease, potentially influenced by the shifts in El Niño Southern Oscillation (ENSO) patterns.

Statistical analyses of rainfall records from 21 stations across West-Central Florida confirmed the significance of these changes. Seventeen stations showed a greater than 80% probability that the more recent 30-year period was drier than the previous one. Several stations, particularly those in a band from Avon Park in Highlands County to the Tampa Bay region, exceeded 95 percent confidence levels. Only two stations, Lakeland and Clermont, did not reflect this drying trend.

Recent data from the past two decades continues to reinforce this long-term pattern (Figure 2-37). Between 1996 and 2022, the average rainfall was about 50.9 inches, nearly one inch below the long-term average of 52 inches that was discussed in Section 2.1.1. This sustained deficit reflects the continuation of a broader climatic pattern observed since the mid-20th century, characterized by suppressed wet-season rainfall. Despite the warm AMO phase since 1995, average rainfall in Central

Florida has remained below the long-term average, likely due to the influence of other climate drivers, regional variability, and land use changes.

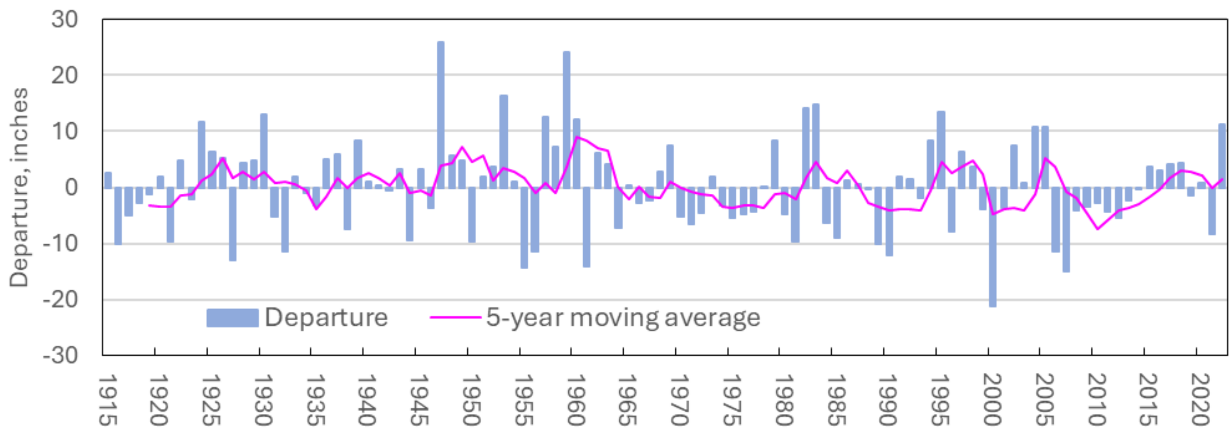


Figure 2-37. Annual rainfall departure from long-term average (52 inches) and 5-year moving average of the annual rainfall departure for the Peace River watershed, 1915-2022. Based on rainfall data summary published by the District.

The impact of declining rainfall on streamflow in the Peace River has been substantial. Regression analyses and surface-water modeling indicate that a five-inch annual drop in rainfall can lead to streamflow reductions ranging from 22 to 35% (Basso and Schultz 2003). At the Zolfo Springs and Arcadia stations, approximately 90% of the observed streamflow decline was attributed to post-1970 rainfall declines. Similarly, at Bartow, about 75% of the decline was linked to long-term rainfall changes. Garlanger (2002) estimated that 89% of the flow reduction at Arcadia was due to rainfall, with only 11% resulting from human activities such as agriculture, mining, and urban development.

Further upstream, anthropogenic impacts become more pronounced. Nevertheless, long-term streamflow declines remain consistent across multiple watersheds, including the Alafia, Hillsborough, and Withlacoochee River basins, suggesting a dominant climatic influence across the region. Coastal Environmental (1996) reinforced this conclusion by demonstrating that 90% of the streamflow change at Arcadia could be explained by rainfall variations, although upstream stations showed decreasing correlation due to increasing human influence.

In conclusion, natural climate cycles, particularly the AMO and ENSO, have played a critical role in shaping long-term rainfall and streamflow trends in the Peace River basin. These changes, compounded by human activities, underscore the need for adaptive water management strategies that account for both climatic variability and anthropogenic pressures to ensure the sustainability of regional water resources.

2.4.2 Regional Groundwater Withdrawals

Groundwater withdrawals have significantly impacted the potentiometric surface of the UFA, with declines exceeding 40 feet since the 1930s in South-Central Polk County (Peek 1951, Kaufman 1967, Robertson 1973, Mills and Laughlin 1976, Wilson 1977, Geraghty and Miller 1980, Yobbi, 1983, Hammett 1990, Barcelo et al. 1990, Basso 2002). This drawdown has increased the potential for downward leakage from the intermediate and the surficial aquifers, thereby reducing the amount of water available to contribute to streamflow (Hammett 1990).

As a result of the gradual lowering of the UFA's potentiometric surface, Kissengen Spring, which once discharged between 20 cfs and 30 cfs during the 1930s, ceased continuous flow in 1950 (Peek1951, Hammett 1990). In addition, the presence of extensive karst features along the river corridor, particularly between Bartow and Fort Meade, complicates efforts to quantify streamflow losses (Patton 1981, Sinclair 1982, Tihansky 1999).

Flow loss measurements by Lewelling et al. (1998) revealed a 17.6 cfs loss along a 3.2-mile section of the Upper Peace River during high baseflow conditions in May 1996. During high streamflow conditions in August 1995, when discharge at Bartow exceeded 970 cfs, a loss of 118 cfs or roughly 10% of total river flow was recorded along a 7.2-mile reach from the Clear Springs mine bridge to the Mobile mine bridge near Fort Meade. Although some losses fell within the margin of measurement error (5-8%), these findings highlight the substantial impact of groundwater withdrawals on river hydrology.

Since the early 1990s, groundwater levels have been generally stable or increasing in the northern part of the watershed. This trend, illustrated in Figure 2-19 using data from six long-term sentinel wells across the SWUCA, reflects anticipated shifts in withdrawal locations, namely, reduced water use in northern areas and increased demand in the southern portion of the watershed. Romp 60 and Coley Deep are the two key wells used to monitor conditions in the northern SWUCA. From the mid-1970s through the most recent data, water levels at these wells have risen by 24.1 and 6.4 feet, respectively (SWFWMD 2023).

2.4.3 Phosphate Mining

Phosphate mining activity in Peace River watershed began in the 1880s. The mineable phosphate deposits are mainly in the western half of the watershed. The main ore zone lies within the Peace River Formation and Bone Valley Member of the Hawthorne Group, which corresponds to the intermediate aquifer described in Section 2.2.2. The Bone Valley formation has historically provided high grade, easily processed phosphate, making it a key resource since phosphate mining started in Florida.

The first phosphate discovery was in 1881 near Fort Meade, leading to the mining of the world's largest known phosphate rock deposit, the "Bone Valley Deposit" (Florida Institute of Phosphate Research 2006). These early deposits, known as river pebbles, were extracted from coarse gravel bars in and along the Upper Peace River during the late 1800s. By 1908, production from the river itself had ceased due to depletion and rising extraction costs. Prospecting for land pebble deposits began in 1890 near the river's headwaters in Bartow (Landquist 1955), shifting mining operations to the floodplain and surrounding regions. From the 1920s through the 1940s, mining was concentrated near Bartow and Fort Meade. Operations expanded to Homeland in the 1950s and to the Clear Springs and Kissengen Spring area by the 1960s (Metz and Lewelling 2009).

In the upper portions of the Peace River watershed, phosphate mining and reclamation activities are largely complete. By the 1970s, mining operations began shifting southward into Desoto, Hardee, and Manatee Counties. Overall, more than 63% of the Peace River watershed has been converted from its natural land cover, with agriculture and phosphate mining directly responsible for over 50% of this transformation (SWFWMD 2000).

Mining has significantly altered the hydrology of the Upper Peace River, particularly upstream of Bowling Green. Approximately 318 square miles, or 38% of the Upper Peace River drainage area, has been impacted by mining (SWFWMD 2000). Much of the land, termed nonmandatory lands, was mined before mandatory land reclamation required by the State of Florida on July 1, 1975. As a result, approximately 120 square miles of phosphate-mined lands and associated beneficiation and fertilizer manufacturing areas received no reclamation.

The dominant reclaimed landforms in the Upper Peace River basin are clay-settling areas, which can span hundreds of acres and reach depths exceeding 40 feet. These areas often line both sides of the floodplain between Bartow and Bowling Green. Typically, a reclaimed clay-settling area is built by constructing a high perimeter dam around a mined area, forming a containment to hold the clay-waste slurry (Lewelling and Wylie 1993). The dam is built using disturbed overburden from the mining process, maximizing storage volume. The slurry, separated during the phosphate beneficiation, is pumped into the clay-settling area to dewater, settle, and consolidate.

These clay-settling areas provide entirely different physical properties, in terms of water storage and transmission, than the landscape prior to mining (Brickmann and Koening 2007). They impede natural groundwater recharge and surface water drainage into the Upper Peace River (Lewelling et al. 1998). Consequently, surface water drainage from Bartow to Bowling Green is largely limited to phosphate mine outfalls and reclaimed stream channels. Naturally incised, dendritic stream networks are often replaced by swales and other poorly drained features during reclamation. Soils of unmined areas are typically well sorted and permeable, allowing infiltration of rainfall and runoff. In contrast, reclaimed soils tend to be less pervious because of an increased clay content in surface horizons (Lewelling et al. 1998).

2.4.4 Wastewater Discharges

Declines in low flows within the Upper Peace River basin are attributed not only to climatic variability, such as fluctuations in rainfall, but also to significant anthropogenic influences, among these is the removal or reduction of wastewater discharges since approximately 1985 has played a critical role in diminishing baseflow levels.

Analysis of 90% annual exceedance flows indicates that the most substantial reductions occurred between the mid-1980s through the 1990s (Figure 2-38). This trend contrasts with concurrent increases in mean annual flows and rainfall, suggesting a paradox explained by the curtailment of wastewater discharges. These reductions included effluents from phosphate processing facilities, chemical plants, and municipal wastewater treatment facilities.

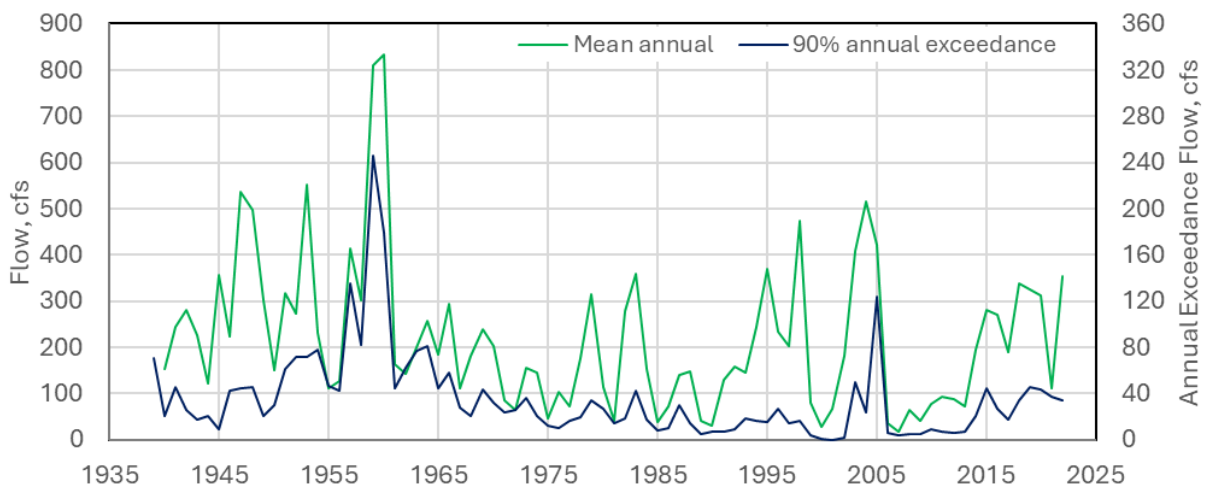


Figure 2-38. Comparsion of 90% exceedance flow and mean annual flow (1940-2022) at the USGS Peace River gage at Bartow.

A notable decline in fluoride and phosphorus concentrations in the Peace River, particularly at the Arcadia Gage, further supports the conclusion that the removal of mining-related discharges occurred around 1985, as documented in SWFWMD (2002). This shift marks a pivotal moment in the basin's water quality history, reflecting both evolving industrial practices and regulatory changes.

One key example is the 1987 cessation of the City of Lakeland's wastewater discharge (9-10 mgd) into Stahl Canal, which previously flowed through Banana Lake and Lake Hancock before entering the Upper Peace River. Although the river began losing flow in the 1950s to 1960s, earlier anthropocentric discharges had masked the full impact on low flows. Their subsequent removal revealed more pronounced declines.

Lake Hancock, historically affected by domestic and industrial discharges (Harper et al. 1999), also experienced significant changes. Effluent from the Lakeland Wastewater Treatment Plant, along with discharges from two citrus processing plants and a distillery in Auburndale via Lake Lena Run (Harper et al. 1999), previously contributed substantial inflows to Lake Hancock. From 1926 through April 1987, the City of Lakeland Wastewater Treatment Plant alone discharged nearly 10 cfs through Stahl Canal, accounting for about 20% of Lake Hancock's average outflow (Yang et al. 2020).

2.4.5 Structural Alterations

In addition to the hydrologic factors discussed in Sections 2.4.1 and 2.4.2, extensive land-use changes over the past 150 years have significantly influenced flow dynamics within the Peace River watershed. Activities, such as mining, drainage modifications, paving, and land re-contouring for residential and commercial development, transportation, agriculture, recreation, timber harvesting, power generation, and mineral extraction, have altered the watershed's natural characteristics and hydrologic behavior, as outlined in Section 2.1.3.

These structural changes have affected key hydrologic parameters, including water storage capacity, timing of flows, drainage patterns and roughness coefficients, ET rates, and groundwater recharge. Consequently, the volume and timing of runoff generated by equivalent rainfall events have changed.

Mining, urbanization, dredge-and-fill activities for agriculture and other land-use practices have permanently altered substantial portions of the Upper Peace River and its associated tributaries and floodplains. Quantifying the cumulative impacts on streamflow requires the use of fully integrated and well-calibrated surface and groundwater models, supported by comprehensive datasets. For the Peace River watershed, these dynamics were characterized using PRIM, a model described in detail in Section 5.3.1.

2.4.6 Lake Hancock Lake Levels Modification Project

The Lake Hancock Lake Level Modification Project, as described earlier, introduced operational changes to the P-11 control structure at the lake's outfall. Since 2015, the District has managed drainage from the Lake Hancock watershed by storing water during wet, or high-flow, seasons and releasing it strategically during dry, or low-flow, periods. These controlled releases are designed to support maintaining the minimum low-flow thresholds established for the Upper Peace River.

While these operations have significantly improved low-flow conditions downstream, they have also modified the natural flow regime below the P-11 structure. Specifically:

- **High-flow attenuation**: Water that would have naturally entered the river during high-flow periods is retained in Lake Hancock.
- **Low-flow augmentation**: Controlled releases introduce water during dry periods when natural inflows would otherwise be minimal or absent.
- **Losses to subsurface features**: A portion of released water may be lost to sinkholes, fractures, and cracks in the riverbed; however, the overall effect is a net increase in downstream flow availability.

The hydrologic impact of the P-11 structure was assessed by Yang et al. (2020) using an empirical water budget model. Based on data from 1975 through 2012, their analysis estimated average flow adjustment resulting from the removal of effluent from the City of Lakeland Wastewater Treatment Facility and the operation of the P-11 structure as follows: 5.17 cfs at the Zolfo Springs gage, 5.12 cfs at the Fort Meade gage, and 2.94 cfs at the Bartow gage. These values represent modeled estimates of how historical flows might have differed had the P-11 structure been operational throughout the evaluation period.

2.5 Ecological Resources

2.5.1 Benthic Macroinvertebrates

Benthic macroinvertebrates are relatively sedentary taxa that are effective indicators of a variety of environmental factors, including habitat quality and pollution levels. They also form an essential link in food webs by processing organic material and transferring energy to secondary consumers (FDEP 2011, Tampo 2021).

The FDEP has conducted Stream Condition Index (SCI) and Habitat Assessments (HA) to monitor the benthic macroinvertebrate community along the Upper Peace River, particularly between Fort Meade and Zolfo Springs. The SCI quantifies macroinvertebrate health and diversity, while the HA method quantifies overall habitat quality using criteria known to impact stream biota.

Since 2008, the FDEP has collected 179 taxa at eight sampling locations along the Upper Peace River (Table 2-16). Of the specimens collected, the five most dominant taxa were Non-biting midges (Chironomidae), including *Asheum beckae* (18% of total catch), *Dicrotendipes simpsoni* (6% of total catch), *Glyptotendipes* (6% of total catch), *Chironmidae sp.* (5% of total catch), and *Goeldichironomus carus* (2% of total catch). Importantly, forty-five taxa of Mayflies (Ephemeroptera) and Caddisflies (Trichoptera) were observed, species indicative of high habitat quality (Jacobus 2019, Morse 2019). Figure 2-39 demonstrates the percent contribution of these taxa to the overall catch during each sampling event.

Table 2-16. Florida Department of Environmental Protection benthic macroinvertebrate sampling results.

Station	Sampling Date	Abundance	Taxa Richness	Percent (%) Mayflies or Caddisflies
PEACE@FTMD	6/21/2010	296	40	20
TPPEACE02F	12/9/2013	304	44	15
	4/10/2013	300	42	17
FTMEADETST	9/20/2010	3086	53	3
TP178	3/27/2013	640	53	7
	12/18/2013	320	29	15
G3SW0090	3/11/2020	287	48	29
PEACE@664A	1/30/2008	318	42	17
Z4LR3022	4/21/2009	311	36	17
	10/15/2009	296	43	19
G3SW0047	3/16/2020	300	40	26

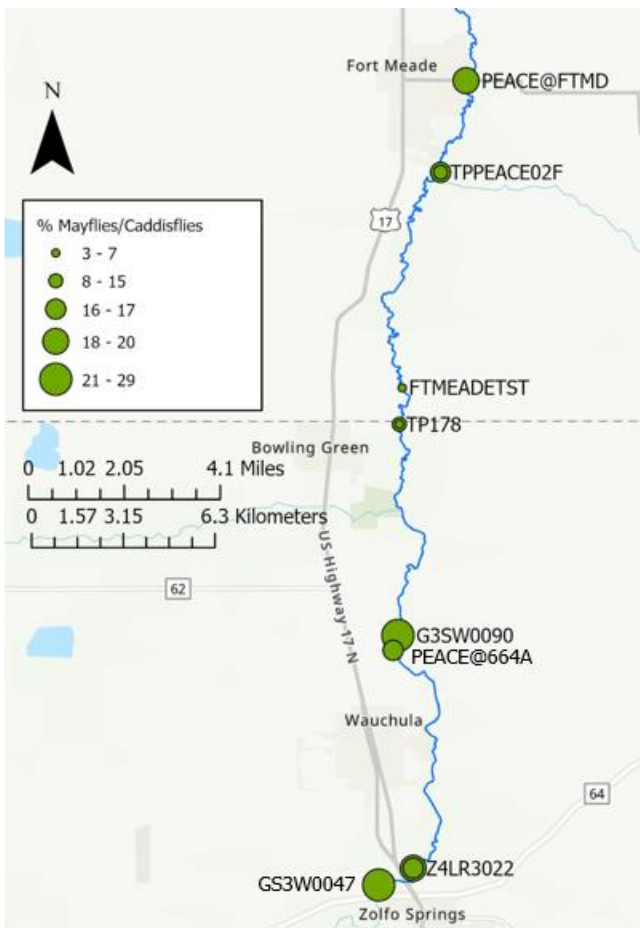


Figure 2-39. Locations of benthic macroinvertebrate data collection by the Florida Department of Environmental Protection from 2008 through 2020. The size of circles

corresponds to the percent contribution of Mayflies and Caddisflies to the total catch during each sampling event.

Habitat Assessment scores within the system range from 87 to 140, within the Suboptimal to Optimal categories, indicating habitat suitable to support an ecosystem. The SCI scores for the area averaged 60.6 (range of 48-75), which is indicative of a healthy benthic macroinvertebrate community (FDEP 2011).

2.5.2 Fish

The Florida Fish and Wildlife Conservation Commission (FWC) has performed several studies of the fish community within the Peace River. In the late fall and winter of 2005 and 2006, the FWC collected samples via electrofishing and compared the community to that observed in collections from 1983-1992. Three transects were sampled at each of four stations, two of which overlapped with the Upper Peace River (the Homeland and Wauchula stations). Despite large-scale disruptions prior to sampling, due to significant hurricanes and associated hypoxia in 2004, species composition within the sampling zones appeared to stabilize by 2006, indicating ecological resilience within the community. Species richness and diversity were stable between the historic and more recent sampling periods (Champeau et al. 2009).

From 2007 through 2010, six additional sampling events occurred throughout the river on a biannual basis, culminating in 188 electrofishing transects within the Upper Peace River (Figure 2-40, Call et al. 2013). In total, 1,940 specimens were collected from 36 taxa. Shannon Weaver diversity, a mathematical measure of species diversity in a community combining both richness and evenness by sampling event, ranged from 1.78 (Spring 2010) to 2.51 (Spring 2008) with a mean of 2.33, and taxa richness ranged from 14 (Spring 2010) to 25 (Fall 2007 and Spring 2009), with a mean of 22 taxa per event. The most abundant species included Spotted Sunfish (*Lepomis punctatus*), Shiners (*Notropis sp.*), and Seminole Killifish (*Fundulus seminolis*) (Table 2-17). Four species accounted for 62% of the total biomass collected: (Florida Gar (*Lepisosteus platyrhincus*, 24% of total biomass), Common Snook (*Centropomus undecimalis,* 19% of total biomass), Florida Bass (*Micropterus salmoides,* 11% of total biomass), and Sailfin Catfish (*Pterygoplichthys sp.*, 8% of total biomass).

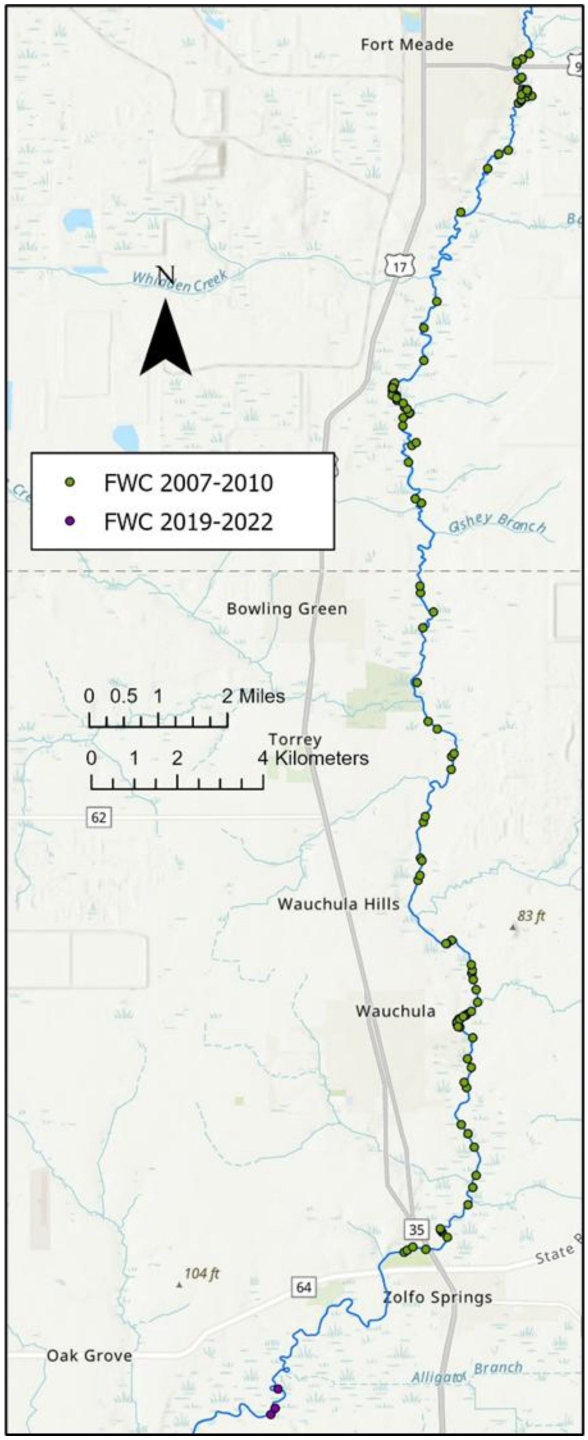


Figure 2-40. Location of Florida Fish and Wildlife Conservation Commission electrofishing transects in or near the Upper Peace River, based onthe 2007-2010 dataset summarized by Call et al. (2013) and the 2019-2022 restoration site dataset.

The FWC determined that while fish communities varied by river section the assemblages did not vary by season or year. They also noted that Spotted Sunfish, Shiners, and Florida Bass were more prevalent in the Upper Peace River than in the

Lower Peace River. In general, macrophyte cover and water velocity best correlated with the fish community structure within the Upper Peace River (Call et al. 2013). Note, the "Upper River" designation in this study had a southern terminus at Wauchula, while the statistics presented in the preceding table and paragraphs are reflective of data available between Fort Meade and Zolfo Springs.

During 10 sampling events between 2019 and 2022, the FWC collected over 4,500 fish representing 36 taxa from stations just south of Zolfo Springs, for a project related to stream restoration. The 15 most abundant species are listed in Table 2-18, along with their percent frequency and ecotype. In total, 81% of the specimen caught were freshwater species, 6% were associated with saltwater, and 13% were exotic (primarily Sailfin Catfish species). The species observed in the above studies are expected for freshwater sections of rivers in Southwest Florida with estuarine connectivity.

Table 2-17. Fifteen most abundant species collected by the Florida Fish and Wildlife Conservation Commission in the Upper Peace River, 2007-2010.

Common Name	Scientific Name	Abundance	Percent Frequency (%)	Ecotype
Spotted Sunfish	*Lepomis punctatus*	479	25	Fresh
Eastern Mosquitofish	*Gambusia holbrooki*	202	10	Fresh
Shiners	*Notropis sp.*	178	9	Fresh
Seminole Killifish	*Fundulus seminolis*	113	6	Fresh
Florida Bass	*Micropterus salmoides*	82	4	Fresh
Florida Gar	*Lepisosteus platyrhincus*	59	3	Fresh
Bluegill	*Lepomis macrochirus*	54	3	Fresh
Redear Sunfish	*Lepomis macrolophus*	54	4	Fresh
Sailfin Catfish species	*Pterygoplichthys sp.*	53	3	Exotic
Brook Silverside	*Labidesthes sicculus*	49	3	Fresh
Pugnose Minnow	*Opsopoeodus emiliae*	31	2	Fresh
Sailfin Molly	*Poecilia latipinna*	30	2	Fresh
Hogchoker	*Trinectes maculatus*	23	2	Saltwater
Blue Tilapia	*Oreochromus aurea*	18	1	Exotic
African Jewelfish	*Hemichromis bimaculatus*	13	1	Exotic

Table 2-18. Fifteen most abundant species observed by the Florida Fish and Wildlife Conservation Commission near Zolfo Springs, 2019-2022.

Common Name	Scientific Name	Abundance	Percent Frequency (%)	Ecotype
Coastal Shiner	*Netropis petersoni*	959	21	Fresh
Spotted Sunfish	*Lepomis punctatus*	685	15	Fresh
Eastern Mosquitofish	*Gambusia holbrooki*	578	13	Fresh

Common Name	Scientific Name	Abundance	Percent Frequency (%)	Ecotype
Sailfin Catfish species	*Pterygoplichthys sp.*	464	10	Exotic
Brook Silverside	*Labidesthes sicculus*	263	6	Fresh
Florida Gar	*Lepisosteus platyrhincus*	204	4	Fresh
Seminole Killifish	*Fundulus seminolis*	204	4	Fresh
Redear Sunfish	*Lepomis microlophus*	160	4	Fresh
Bluegill	*Lepomis macrochirus*	138	3	Fresh
Snook sp.	*Centropomus sp.*	138	3	Saltwater
Hogchoker	*Trinectes maculatus*	120	3	Saltwater
Channel Catfish	*Ictalarus punctatus*	118	3	Fresh
Pugnose Minnow	*Opsopoeodus emiliae*	109	2	Fresh
Florida Bass	*Micropterus salmoides*	93	2	Fresh
White Catfish	*Ameiurus catus*	64	1	Fresh

2.5.3 Other Wildlife

According to the Florida National Areas Inventory (FNAI) Biodiversity Matrix, the most likely federally threatened species to be found along the Upper Peace River include the Eastern Indigo Snake (*Drymarchon couperi*) and the Wood Stork (*Mycteria americana;* FNAI 2025).

The Peninsular Florida Landscape Conservation Cooperative identified 19.5% of the Upper Peace River basin (167 square miles) as suitable habitat for the Florida Sandhill Crane (*Antigone canadensis pratensis*; PFLCC 2021, Figure 2-41). Florida Sandhill Cranes are a non-migratory species designated as threatened by the state, with a current population estimate of between 4,000 and 5,000 birds (FWC 2020). Their preferred locales include freshwater marshes and wetlands for nesting, with nearby pastures, prairies, or other grasslands for foraging (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 lands for foraging and roosting (FWC 2020; Donnelly et al., 2021).

According to the 2025 U.S. Fish and Wildlife Service National Wetland Inventory (NWI) data, the Upper Peace River basin contains 45 square miles of emergent wetlands and 71 square miles of forested or shrub wetlands, encompassing 5.5% and 8.6% of the watershed (USFWS 2025).

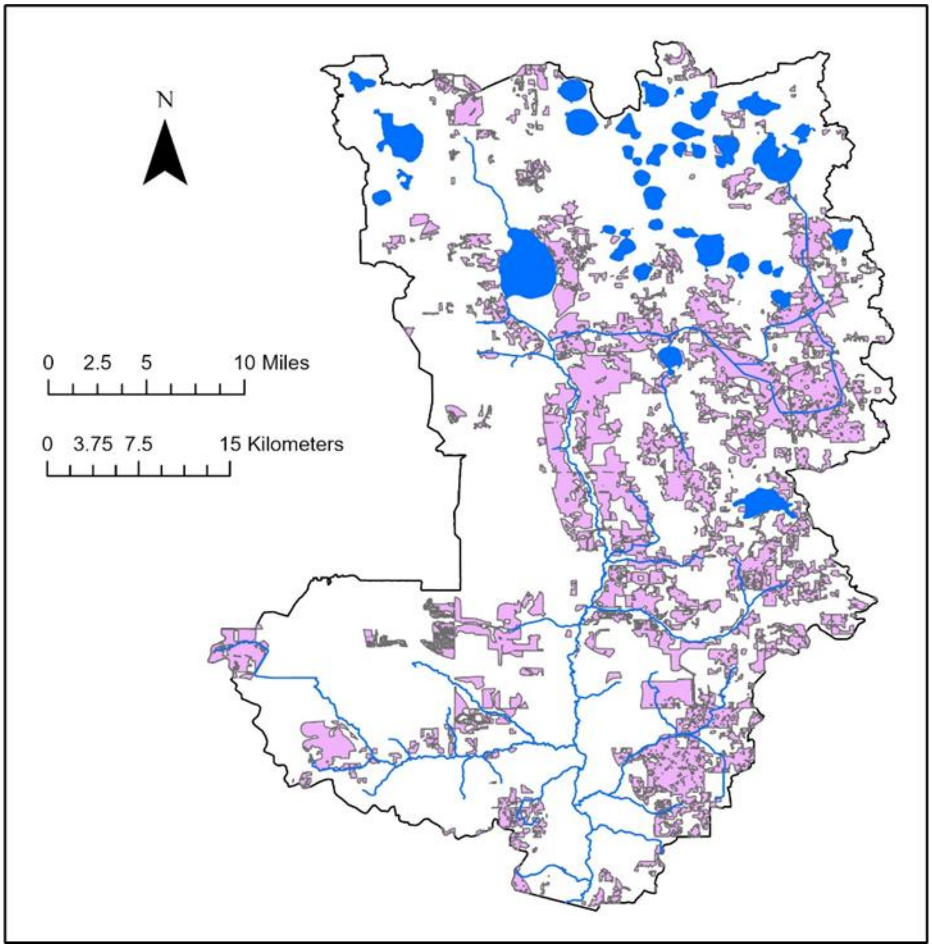


Figure 2-41. Potential Florida Sandhill Crane habitat (purple polygons) within the Upper Peace River basin (source: Peninsular Florida Landscape Conservation Cooperative (2021) Sandhill Crane Habitat GIS layer).

2.5.4 Vegetation

To broadly categorize the vegetation surrounding the Upper Peace River, the NWI palustrine vegetation classifications within a 450-meter (1,476 feet) buffer of the river mainstem were evaluated. The most dominant class of vegetation within this buffer zone was forested vegetation (95% of vegetated area), followed by emergent vegetation (4%) and shrub-scrub (1%) (Figure 2-42). Of these classes of vegetation, 59% may be considered hydrologically sensitive, designated as either seasonally flooded (36%) or semi-permanently flooded (23%) (USFWS 2025).

The District 2023 Level Four classifications from the Land Use and Land Cover GIS data indicates that of the total area within the 450-meter buffer of the river mainstem, the land is primarily stream and lake swamp bottomland, with hardwood forests, shrub and brushland, and freshwater marshes dominating other natural land use classes (Figure 2-43).

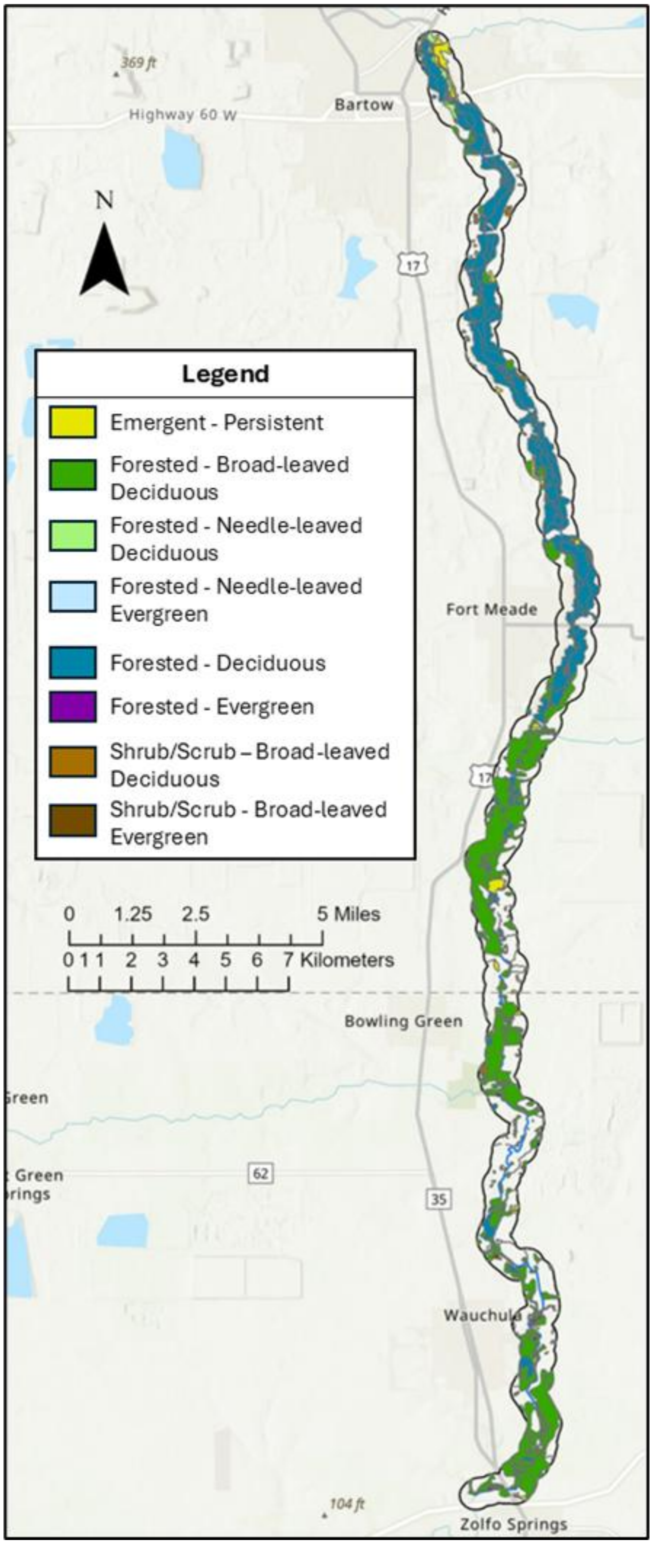


Figure 2-42. Dominant palustrine classes within a 450-meter buffer (black outline) of the river mainstem (source: U.S. Fish and Wildlife Service National Wetland Inventory (2025) GIS layer).

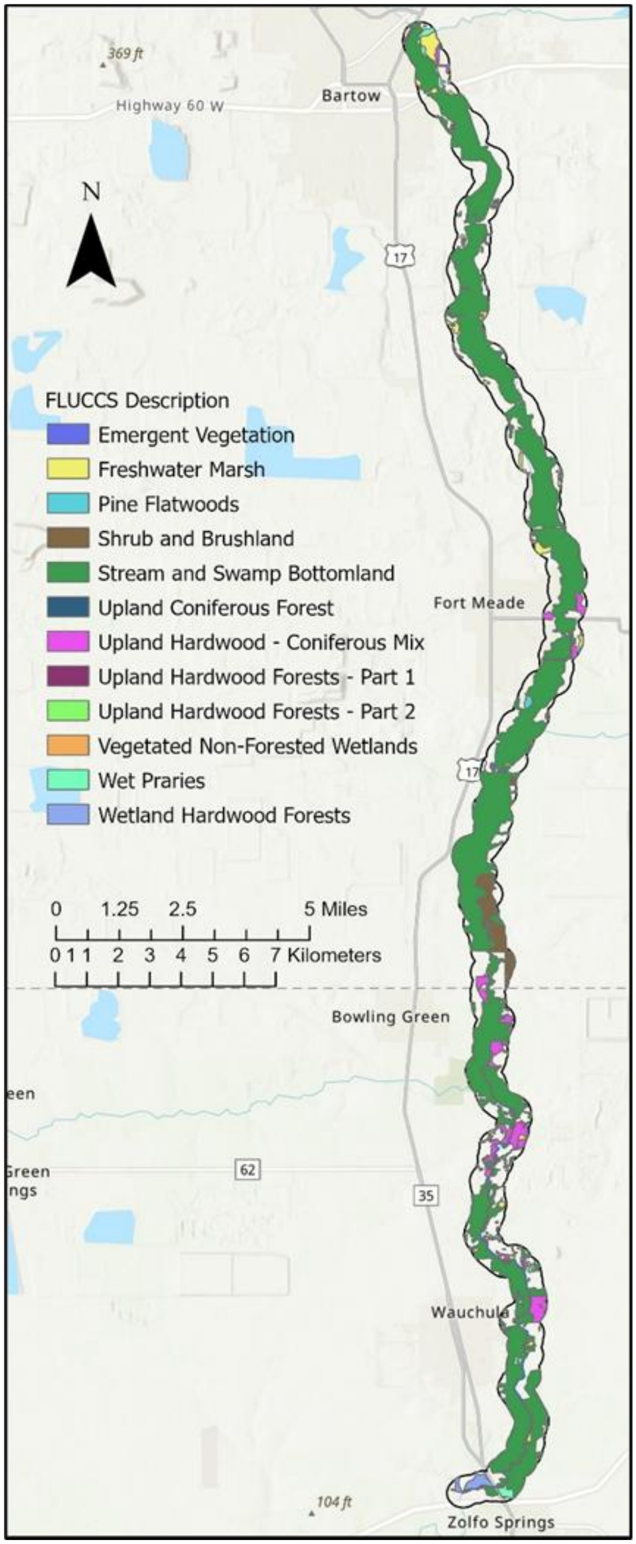


Figure 2-43. Dominant vegetation land cover based on 2023 Land Use Land Cover Level Four designations within a 450-meter buffer (black outline) of the river mainstem (source: Southwest Florida Water Management District 2023 Land Use Land Cover GIS layer).

2.5.5 Conservation Areas

The Florida Ecological Greenways Network (FEGN) is a database maintained by the University of Florida Center for Landscape Conservation Planning (2021) that identifies and ranks connected public and private lands in terms of ecological benefit. 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. As of the 2021 update, approximately 255 square miles of the Upper Peace River basin are included in the FEGN (University of Florida Center for Landscape Planning 2021). Of the lands included, the majority (79%) are considered Priority 2 or 3, meaning they are considered critical to support biodiversity and ecosystem services by providing a functional, connected network. These lands typically overlap with the Florida Wildlife Corridor, a group of contiguous lands intended to protect imperiled species within the state (Figure 2-44).

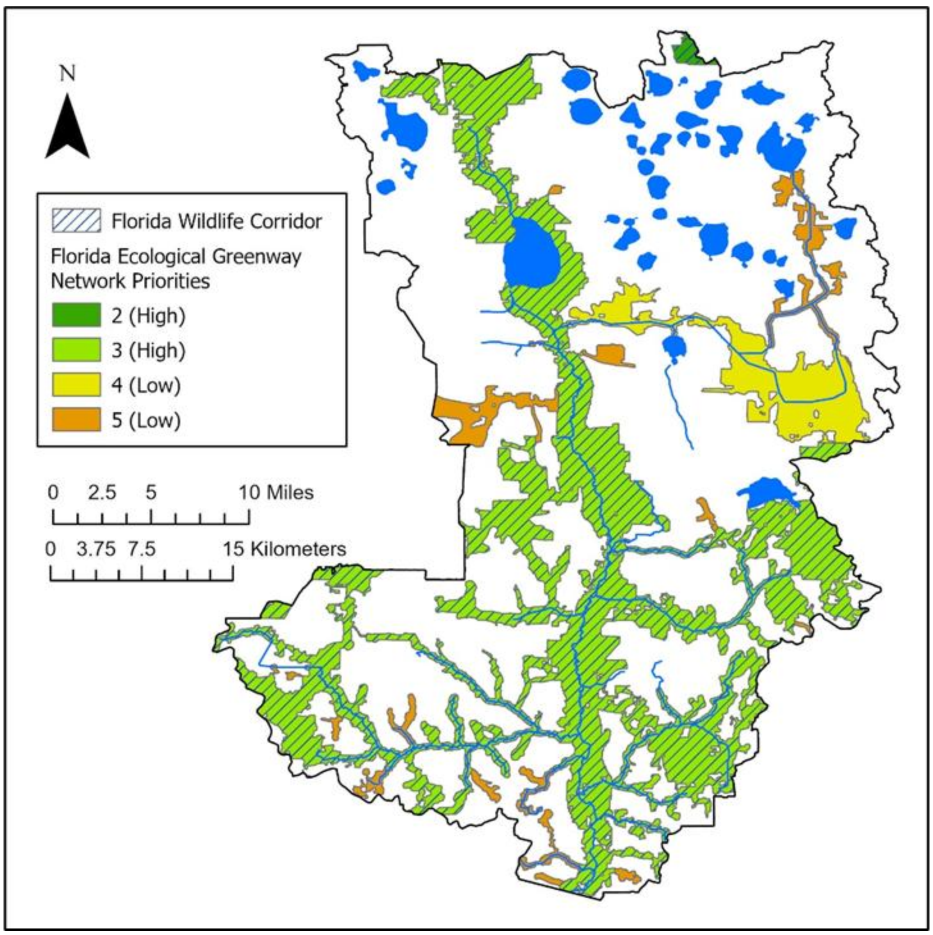


Figure 2-44. Florida Wildlife Corridor lands (cross-hatched) within the Upper Peace River basinoverlapping lands designated by the Florida Ecological Greenway Network (FEGN), color-coded by priority (source: Florida Natural Areas Inventory Geospatial Open Data, Florida Wildlife Corridor (2021) GIS layer file and University of Florida FEGN (2021) GIS layer file).

CHAPTER 3 WATER QUALITY ASSESSMENT: PARAMETERS, PATTERNS, AND MANAGEMENT IMPLICATIONS

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 in water quality parameters measured in the Upper Peace River, including exploratory evaluations of the relationships between water quality and flow. 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 Introduction

3.1.1 Water Quality Criteria

Water quality is an environmental value affected by flows; however, water quality criteria in Florida are regulated independently from MFLs. Together, MFLs and water quality regulations including Total Maximum Daily Loads (TMDLs) and Numeric Nutrient Criteria (NNC) address both the quality and quantity of water to ensure sustainable ecosystems and human use.

TMDLs and NNC differ from MFLs in their management goals. TMDLs and NNC are designed to address water quality issues by setting limits on pollutants, such as nutrients, sediments, and other contaminants. These measures aim to reduce pollutant loads to meet water quality standards and prevent issues like algal blooms and habitat degradation. In contrast, MFLs are established to protect water bodies from significant harm due to water withdrawals. They ensure that there is enough water to support ecological functions, maintain habitats, and sustain wildlife populations.

In addition to having different management goals, TMDLs and NNC differ from MFLs in their regulatory framework: TMDLs and NNC are implemented under Section 303(d) of the Clean Water Act and Chapters 62-302 and 62-304, F.A.C., while MFLs are established under Section 373.042, F.A.C. and focus on maintaining minimum water levels and flows to prevent ecological damage specifically due to water withdrawals.

The final difference between TMDLs and NNC vs. MFLs is in the management actions associated with each. TMDLs and NNC lead to actions like upgrading wastewater treatment plants, implementing best management practices in agriculture, and reducing stormwater runoff. MFLs lead to regulating water withdrawals, managing water use permits, and implementing water conservation measures.

To summarize, TMDLs and NNC differ from MFLs in their management goals, regulatory frameworks, and management actions associated with each. Though distinct in purpose, legislative mandates, and implementation, all are crucial for comprehensive water resource management, addressing different aspects of water sustainability.

3.1.2 Water Quality Study Area

The Upper Peace River originates from two primary headwater tributaries: Saddle Creek, which begins its lower portion at the P-11 structure, and Peace Creek (Figure 3-1).

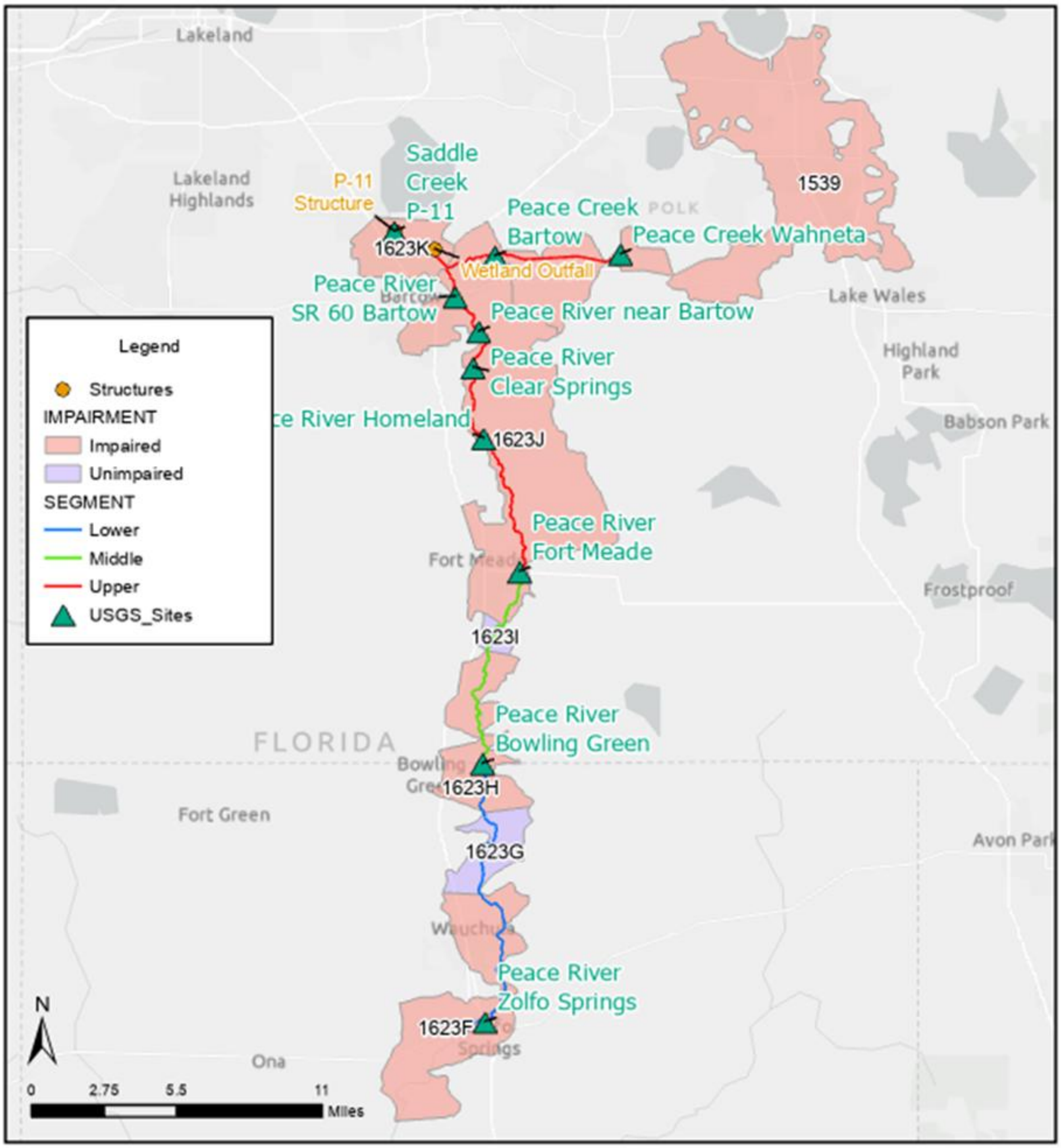


Figure 3-1. Overview of the Upper Peace River study area with USGS streamflow gages, water control structures, and Water Body IDs (WBIDs).

On Saddle Creek, the P-11 Structure, owned and operated by the District, regulates flows out of Lake Hancock at the lake's outlet, which also serves as the location of the P-11 streamflow gage. In addition, the Wetland Outfall, another District operated structure, contributes additional flows to Saddle Creek from the Lake Hancock Wetland (Figure 3-1).

On Peace Creek, the Peace Creek Wahneta streamflow gage acts as the upper boundary for this analysis and provides flow data used for analysis with water quality parameters.

These two tributaries converge downstream to form the Upper Peace River, which flows southward though Polk and Hardee Counties. The Peace River Zolfo Springs streamflow gage is the downstream boundary of the study area. Together, these three gages delineate the upstream and downstream boundaries of the study area for our water quality analysis. In total, ten USGS streamflow gages provide data on the Upper Peace River and its two tributaries for this study (Figure 3-1).

3.1.3 Water Body Identification Numbers (WBIDs) and Impairment

The FDEP has designated seven WBIDs overlapping the streams within the study area: 1539, 1623K,1623J, 1623I, 1623H, 1623G, and 1623F (Figure 3-1; Table 3-1). These WBIDs are useful for accessing water quality data from repositories because those data are typically organized and retrieved by WBID. Impairments are listed here as background information (FDEP 2024).

The NNC for all WBIDs of the Upper Peace River are an annual geometric mean of 1.65 mg/L for total nitrogen and 0.49 mg/L for total phosphorus (63-302.531 F.A.C.).

Water quality impairments may be listed under one or more categories, including the 303(d) List, the Verified List, and the Study List. The 303(d) List refers to impaired or threatened waters that do not meet state water quality standards. Section 303(d) of the Clean Water Act requires states to submit their list for the U.S. Environmental Protection Agency (EPA) approval every two years, on even numbered years.

A water body is placed on the Verified List when one or more water quality parameters do not meet applicable water quality criteria, which indicates that the water body does not fully support its designated use. A previously Verified Listed water body segment may be proposed for removal from the Verified List, which is termed "delisted", if it has been shown to meet applicable standard(s) or if a restoration plan has been adopted. In some cases, a parameter may be delisted from the Verified List because it has a restoration plan, including a TMDL, yet still remain on the 303(d) List if it does not meet state water quality standards.

The Study List includes waterbodies where one or more water quality parameters do not meet applicable water quality criteria, which indicates that the water body does not fully support its designated use; however, additional data or information is needed to determine attainment of the designated use. These lists are referred to each WBID in the status notes shown in Table 3-1.

Table 3-1. Water Body IDs (WBIDs) with impaired water quality parameters. Status based on Cycle 6, the 2022–2024 Biennial Assessment (BA).

WBID	Impairment Parameter	Status Notes
1539	Biology	Failed bioassessments. Study List and the 303(d) List because a causative pollutant has not been identified.
	E. coli	On Verified List and the 303(d) List.
	Fecal Coliform	State Adopted and EPA Approved TMDLs (FDEP 2007b)
1623K	Chlorophyll-a Total Nitrogen	On 303(d) List and Study List because ongoing restoration activities to address the nutrient impairment documented in the Saddle Creek Pollutant Reduction Plan.
	Dissolved Oxygen (Percent Saturation)	Included in the Saddle Creek Pollutant Reduction Plan.
	Fecal Coliform	On 303(d) and Verified List. Impaired based on the previous assessment but is no longer the applicable bacteria parameter for this water body classification. Escherichia coli will be included in the FDEP Strategic Monitoring Plan for this water body in order to collect the new applicable bacteria parameter.
1623J	Fecal Coliform	State Adopted and EPA Approved TMDLs (FDEP 2007c)
	Total Phosphorus	On Verified List and the 303(d) List.
	Total Nitrogen	On Verified List and the 303(d) List.
	Macrophytes	On Verified List and the 303(d) List.
	Chlorophyll a	This water body is impaired for this parameter because the annual geometric means exceed the threshold of 3.2 μg/L but were below 20 μg/L more than once in a three-year period and nutrients exceed the threshold. This parameter is being removed from the Verified List, but will be added to the Study List and will remain on the 303(d) List.
1623H	Total Phosphorus	On 303(d) List and added to Study List based on insufficient supporting biological data.
	Total Nitrogen	On 303(d) List and added to Study List based on insufficient supporting biological data.
	Chlorophyll a	This water body is impaired for this parameter because the annual geometric means exceed the threshold of 3.2 μg/L but were below 20 μg/L more than once in a three-year period and nutrients exceed the threshold. This parameter will remain on the Study List and the 303(d) List.
1623F	Total Phosphorus	Study List and the 303(d) List based on insufficient supporting biological data.

WBID	Impairment Parameter	Status Notes
	Chlorophyll a	This water body is impaired for this parameter because the annual geometric means exceed the threshold of 3.2 µg/L but were below 20 µg/L more than once in a three-year period and nutrients exceed the threshold. This parameter is being added to the Study List and the department is requesting EPA add it to the 303(d) List.

3.1.4 Data Input and Compilation

The analysis presented in this chapter makes use of existing water quality data collected through various monitoring programs, as described below. Flow data are collected by the USGS and co-funded in some cases by the District. These data serve various purposes and are critical inputs for the development of minimum flows.

The District Water Quality Monitoring Program (WQMP) performs water quality sampling, data management and analysis, and report writing for several long-term ground and surface water monitoring efforts designed to assess water resource quality. This report makes use of surface water data that was collected as quarterly grab samples as part of this long-term data collection program.

Water quality data were also collected as monthly grab samples by the Peace River Monitoring Program (PRMP), which was established in 2012 as part of a settlement agreement between Mosaic Fertilizer, LLC (Mosaic), the Sierra Club, Manasota-88, and the People for Protecting the Peace River. The PRMP was designed to ensure that mining activities at Mosaic's South Fort Meade-Hardee County (SFM-HC) mine do not cause significant adverse effects on water quality or biological communities in the Peace River between Fort Meade and Wauchula (Cardno 2021).

All data used in this analysis are imported and stored in publicly accessible repositories. Importing and selecting target data from these repositories are described below.

Data collection procedures were chosen by the individual monitoring programs. The PRMP data sampling and preservation followed DEP's Standard Operating Procedures (SOPs) for all samples and events, specifically FS-2000 and FT-1000. The WQMP data collection adhered to District SOPs (SWFWMD 2020). Procedures for USGS streamflow gages are described for individual gages by USGS and are available through their National Water Information System: Web Interface (USGS 2024).

The three water quality data repositories surveyed for data are:

1. The District's Environmental Data Portal (EDP)
   [https://www.swfwmd.state.fl.us/resources/data-maps/environmental-data-portal]

2. The Watershed Information Network Advanced View & Extraction System (WIN WAVES)
   [https://prodenv.dep.state.fl.us/DearWin/public/wavesSearchFilter?calledBy=menu]
3. STOrage and RETrieval (STORET) Public Access (SPA)
   [https://prodenv.dep.state.fl.us/DearSpa/public/searchStoretPI.action]

Water quality parameters are often given different names by various agencies and across different time periods. To ensure consistency, parameter names were standardized in this analysis according to Table 3-2.

Table 3-2. Parameter names and units used in this analysis.

Parameter	Units	Parameter	Units
Chlorophyll-a	µg/L	Specific Conductance	µS/cm
Color	PCU	Total Kjeldahl Nitrogen	mg/L
Dissolved Oxygen	mg/L	Total Nitrogen	mg/L
Fluoride	mg/L	Total Phosphorus	mg/L
Nitrate + Nitrite	mg/L	Total Suspended Solids	mg/L
Orthophosphate	mg/L	Turbidity	NTU
pH	SU	Water Temperature	^{o}C
Potassium	mg/L		

3.2 Methods

3.2.1 Water Quality Data Management

Water quality data from the EDP, WIN, and STORET were combined and filtered for analysis. A minimum of 20 data collection events was used as a pre-screening value to narrow down stations with enough data for long-term analysis. There are 17 total station locations where data were collected on at least 20 events (Figure 3-2, Table 3-3). To ensure consistency across datasets, December 31, 2022 was selected as the cutoff date to standardize inclusion of data at all stations in this analysis.

Two stations, Peace Rvr10 and Peace Rvr78, were collected by Polk County and have older data stored in STORET and newer data stored in WIN. These datasets were combined prior to analysis. In addition, there are instances where WQMP data is stored in both District EDP, WIN, and STORET. In these cases, WIN and STORET data were prioritized for use.

Of the 17 qualifying stations, 9 primary stations had the most robust data records and could be apportioned evenly into the three main segments of the Upper Peace River (Table 3-4). For these 9 water quality stations, names are shortened to the name given in parenthesis in the following paragraphs, with short names used in tables and figures. The most data (over 200 sampling dates spanning over 20 years) were collected at five WQMP stations: Peace River at Zolfo Springs (Zolfo Springs), Peace River at Fort Meade WQMP (Fort Meade), Peace River at Bartow (Bartow), Peace Creek Canal nr Wahneta (Peace Creek), and Saddle Creek at P-11 (Saddle Creek).

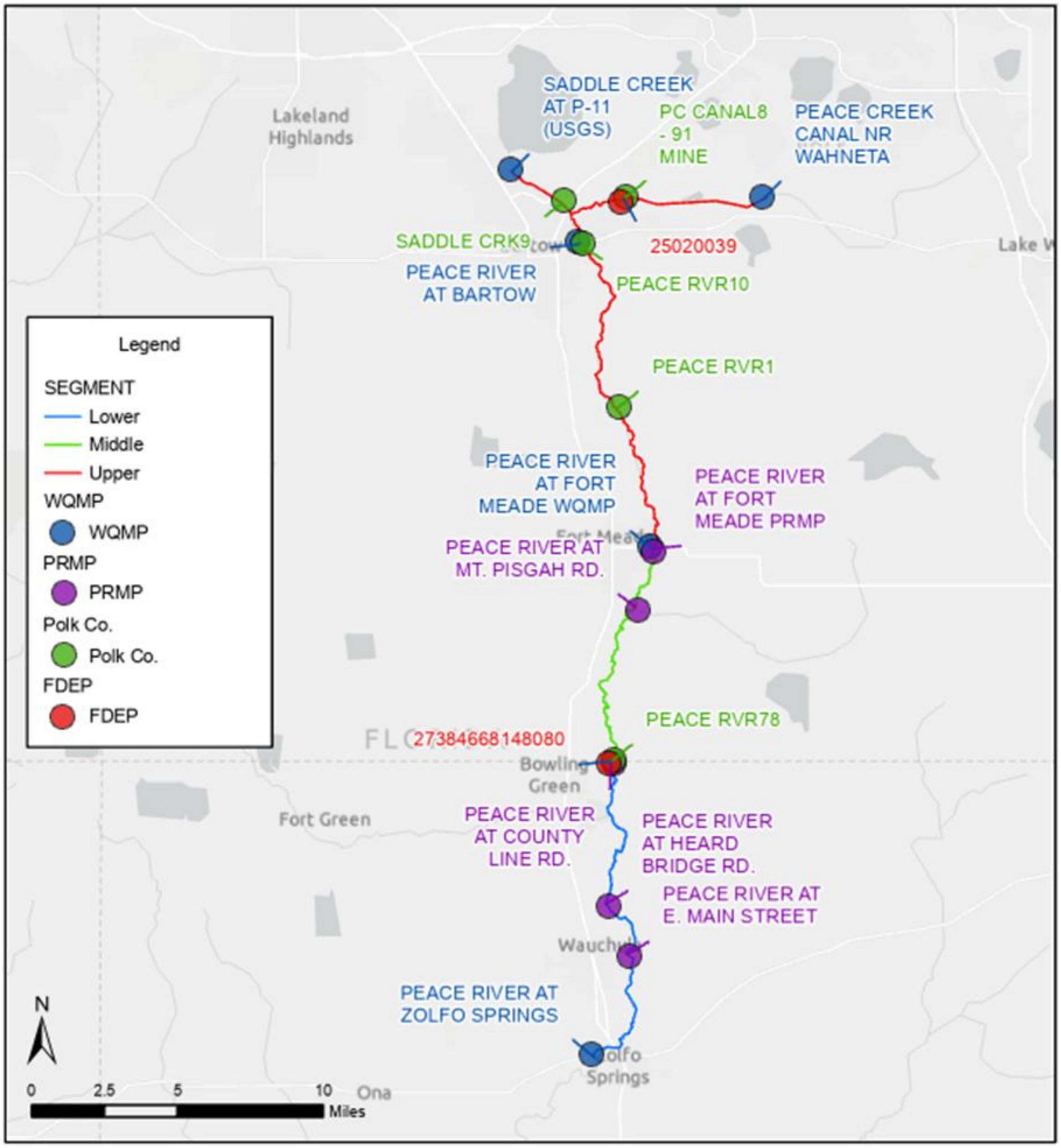


Figure 3-2. Water quality station locations with at least 20 sampling events.

In addition, four of five PRMP stations, Peace River at County Line Rd. (Co. Line Rd.), Peace River at Mt. Pisgah Rd. (Mt. Pisgah), Peace River at Heard Bridge Rd. (Heard Bridge), and Peace River at E. Main Street (E. Main St.) had data from at least 129 dates spanning over 10 years (Cardno 2021). These stations were also evenly divided into three major segments of the river (Figure 3-2). The analysis presented in this chapter focuses on these nine primary water quality stations.

Table 3-3. Water quality stations in compiled dataset. Station = unique station identification name or number, Creator = data collecting agency that originally reported the data, Events = number of sampling events, Parameters = number of parameters across all events, Start = First date of data collection, End = last date of data collection. December 31, 2022 was the last date for inclusion of data in this analysis.

Station	Creator	Events	Parameters	Start	End
Peace River at Zolfo Springs	WQMP	310	21	1997-08-04	2022-12-05
Peace River at Fort Meade WQMP	WQMP	290	21	1997-08-04	2022-12-05
Peace River at Bartow	WQMP	290	21	1997-08-04	2022-12-05
Peace Creek Canal nr Wahneta	WQMP	286	21	1997-08-04	2022-12-05
Saddle Creek at P-11	WQMP	211	12	2002-10-01	2022-12-05
Peace River at County Line Rd.	PRMP	154	16	2012-04-16	2022-12-12
Peace River at Heard Bridge Rd.	PRMP	129	16	2012-04-16	2022-12-12
Peace River at E. Main Street	PRMP	129	16	2012-04-16	2022-12-12
Peace River at Mt. Pisgah Rd.	PRMP	129	16	2012-04-16	2022-12-12
Peace River at Fort Meade PRMP	PRMP	123	16	2012-04-16	2022-09-19
Peace Rvr10	Polk Co.	107	16	1993-02-11	2022-11-08
Saddle Crk9	Polk Co.	60	14	1993-02-11	2022-11-03
Peace Rvr78	Polk Co.	52	16	2010-03-24	2022-11-09
Peace Rvr1	Polk Co.	43	14	1994-12-01	2009-08-19
27384668148080	FDEP	36	5	2003-02-12	2013-12-18
25020039	FDEP	28	17	1998-03-10	2008-12-01
Pc Canal8 - 91 Mine	Polk Co.	22	15	2017-07-25	2022-11-08

Table 3-4. Nine selected water quality stations across the three main segments of the Upper Peace River.

Station	Events	Parameters	Start	End	Latitude	Longitude	Segment
Saddle Creek	257	20	1997-08-04	2022-12-05	27.9385	-81.8510	Upper
Peace Creek	286	19	1997-08-04	2022-12-05	27.9250	-81.7263	Upper
Bartow	290	19	1997-08-04	2022-12-05	27.9024	-81.8176	Upper
Fort Meade	290	19	1997-08-04	2022-12-05	27.7517	-81.7819	Middle
Mt. Pisgah	129	16	2012-04-16	2022-12-12	27.7228	-81.7901	Middle
Co. Line Rd.	154	16	2012-04-16	2022-12-12	27.6463	-81.8022	Middle
Heard Bridge	129	16	2012-04-16	2022-12-12	27.5759	-81.8045	Lower
E. Main St.	129	16	2012-04-16	2022-12-12	27.5508	-81.7941	Lower
Zolfo Springs	310	19	1997-08-04	2022-12-05	27.4997	-81.8104	Lower

3.2.2 Flow Data Management

Flow data were compiled from two repositories:

1. USGS National Water Information System (NWIS) [https://waterdata.usgs.gov/nwis]
2. District estimates of discharge at the P-11 structure

There are 10 USGS gaging stations providing flow data with starting dates between September 1, 1933 and December 1, 2010 (Figure 3-1). Of these, seven stations are located along the mainstem of the Peace River, while two are suited on tributaries: Saddle Creek and Peace Creek. All flow data were truncated on December 31, 2022 to align with the water quality dataset. Water quality data were paired with flow data from six streamflow gages that were either collocated with or upstream of the water quality monitoring sites (Table 3-5).

The Zolfo Springs gage was chosen as the reference gage for defining wet and dry seasons to ensure seasonal consistency across all gages and WQ sites. The start of the wet season approximately begins when the mean annual flow rises above the 60th percentile (P60) and the wet season ends when the flow drops below the P60 (Figure 3-3). These seasons are used to evaluate the effect of season on water quality parameters as a comparison of groups.

Table 3-5. Streamflow gage and water quality (WQ) station pairings by river segment in the Upper Peace River.

WQ Station Short Name	Streamflow Gage Long Name	Streamflow Gage Short Name	River Segment
Saddle Creek	Saddle Creek at P-11 (USGS)	P11 Gage	Upper
Peace Creek	Peace Creek Canal nr Wahneta	Peace Creek Gage	Upper
Bartow	Peace River SR 60 Bartow	Bartow Gage	Upper
Fort Meade	Peace River Fort Meade	Fort Meade Gage	Middle
Mt. Pisgah	Peace River Fort Meade	Fort Meade Gage	Middle
Co. Line Rd.	Peace River Bowling Green	Bowling Green Gage	Middle
Heard Bridge	Peace River Bowling Green	Bowling Green Gage	Lower
E. Main St.	Peace River Bowling Green	Bowling Green Gage	Lower
Zolfo Springs	Peace River at Zolfo Springs	Zolfo Springs Gage	Lower

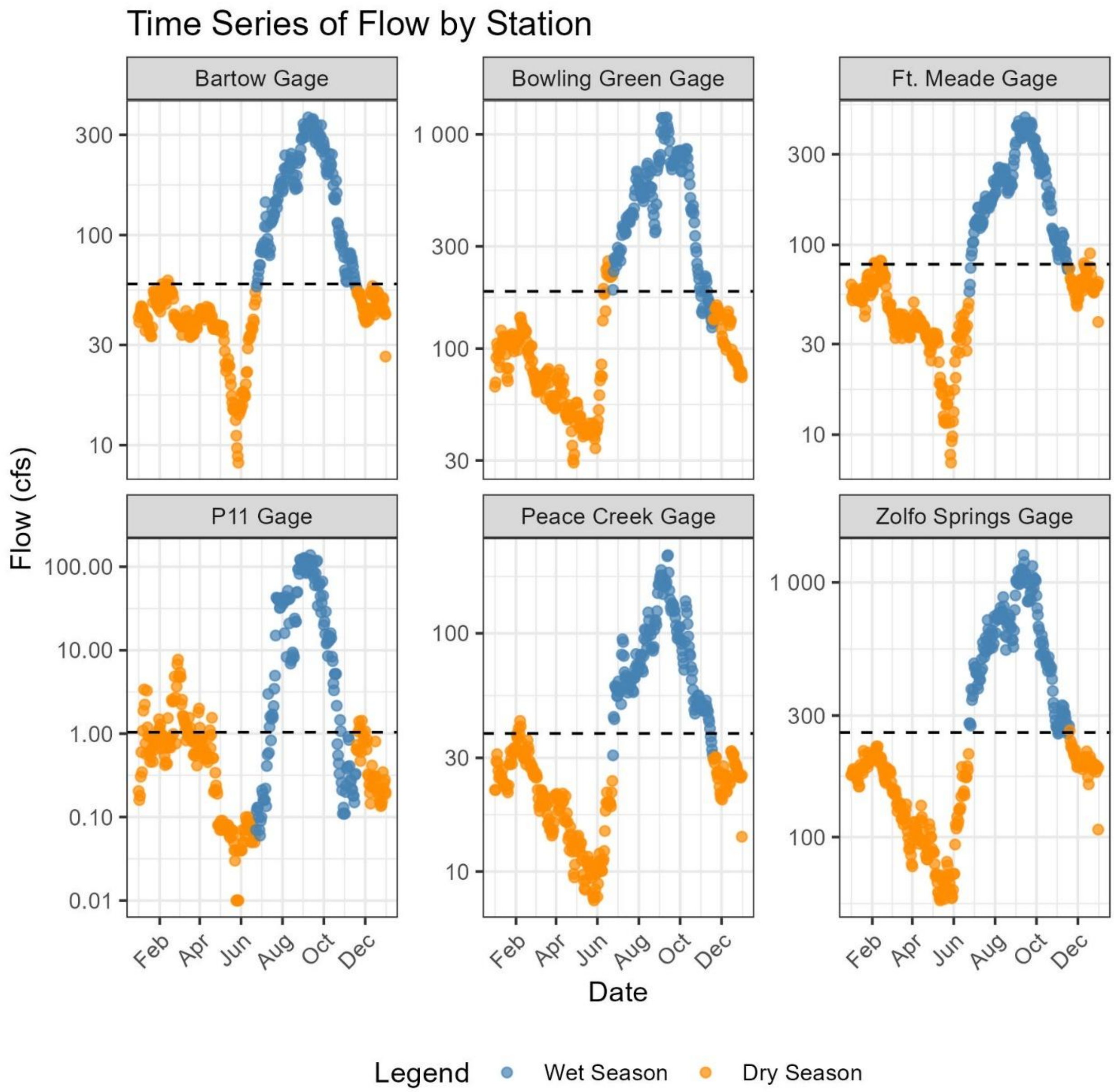


Figure 3-3. Flow-based seasons at six streamflow gaging sites. Wet and dry season determination based on P60 at Zolfo Springs gage, which ensures seasons are the same at all sites. Dashed lines indicate P60 at each gage, which varies by gage. The discrepancy between the definition of wet and dry seasons based only on the Zolfo Springs gage and the P60, which varies among gages results in some apparent mismatch between season and P60 line at some gages.

3.2.3 Statistical Methods

3.2.3.1 Testing for Differences Between Stations and Seasons

To assess differences in water quality parameters across both seasonal (wet vs. dry) and spatial (nine monitoring stations) groupings, Kruskal-Wallis rank sum tests were performed. This non-parametric method evaluates whether the distributions of a continuous variable differ significantly among two or more independent groups. Significant results ($\alpha = 0.05$) indicate that at least one group differs from the others, warranting further pairwise comparisons. The Kruskal-Wallis test statistic, denoted as H, follows a chi-squared distribution under the null hypothesis.

Following the Kruskal-Wallis tests, pairwise Wilcoxson rank-sum tests (also known as Mann-Whitney U tests) were conducted to identify specific group differences for each parameter. These non-parametric tests compare the distributions of values between all possible pairs of groups (e.g., stations or seasons) without assuming normality. To account for multiple comparisons, Bonferroni-adjusted p-values were used. Based on the results, grouping letters were assigned using the multcompLetters function from the multcompView package, where groups that do not share a letter are significantly different at the $\alpha = 0.05$ level. These letters are displayed on plots to visually indicate statistically distinct groups.

3.2.3.2 Trend Analysis

Flow-based and temporal trends in water quality parameters were analyzed using a two-stage approach, following the methodology outlined by Helsel et al. (2020).

In the first stage, Locally Estimated Scatterplot Smoothing (LOESS) was applied to concentration-date relationships to isolate temporal patterns. The residuals from this analysis were interpreted as date-adjusted concentrations and tested for trends with streamflow.

In a parallel analysis, LOESS was applied to concentration-flow relationships to isolate flow patterns. The residuals from this analysis were interpreted as flow-adjusted concentrations and tested for trends with date.

For both analytical pathways, Kendall's tau was applied to test for monotonic trends, with Bonferroni-adjusted p-values to account for multiple comparisons across stations. Theil-Sen slopes were used to estimate the magnitude of trends.

This dual approach enables a robust assessment of both flow-concentration dynamics and temporal trends, while accounting for their potential confounding effects.

3.3 Nutrients: Nitrogen and Phosphorus

Nitrogen and phosphorus are the two primary nutrients required by plants for growth, used in fertilizers, and responsible for eutrophication of natural waters. Both nitrogen and phosphorus are elements and can be found as constituents of various molecules and as part of both organic and inorganic material in the air, waters, geologic substrate, sediments, and as part of living organisms.

Nitrogen:

- **Nitrate (NO_3^-):** A highly soluble form of nitrogen that is readily available for uptake by plants, algae, and phytoplankton. It is a common component of fertilizers and can easily leach into water bodies, contributing to nutrient pollution.
- **Nitrite (NO_2^-):** An intermediate form of nitrogen in the nitrification process, where ammonium is converted to nitrate. Nitrite is less stable and typically found in lower concentrations than nitrate but is still important in the nitrogen cycle.
- **Ammonium (NH_4^+)**: Another form of nitrogen that is available for plant uptake. It is often found in water bodies as a result of agricultural runoff, wastewater discharge, and the decomposition of organic matter.
- **Organic Nitrogen**: Linked to complex carbon-based organic groups, organic nitrogen can be converted into ammonium and then into nitrates by microorganisms through the processes of mineralization and nitrification.
- **Total Nitrogen (TN)**: The sum of all forms of nitrogen in the water, including Total Kjeldahl Nitrogen (TKN), which consists of organic and reduced nitrogen, plus nitrate, nitrite, and ammonium. This parameter provides a comprehensive measure of the nitrogen available in the ecosystem.

Phosphorus:

- **Orthophosphate (PO_4^{3-})**: The most bioavailable form of phosphorus, orthophosphate is directly taken up by plants and algae. It is often found in fertilizers and can enter water bodies through agricultural runoff and wastewater discharge.
- **Condensed Phosphates**: These include forms like pyrophosphate and polyphosphate, which can be found in detergents and industrial effluents. They can be converted into orthophosphate by natural processes.
- **Organic Phosphorus**: Part of organic matter, organic phosphorus can be mineralized by microorganisms to release orthophosphate.

- **Total Phosphorus (TP)**: The sum of all forms of phosphorus in the water, including orthophosphate, condensed phosphates, and organic phosphorus. This parameter is a key indicator of the potential for eutrophication in water bodies.

The parameters selected for this analysis: Nitrate-Nitrite, TN, Orthophosphate, and TP, are commonly included in water quality monitoring programs due to their ecological significance and regulatory relevance.

3.3.1 Descriptive Statistics of Nutrients

Means and medians across all sites for key nutrient parameters including nitrate-nitrite, TN, orthophosphate, and TP are shown in Table 3-6. Comparing nutrient sampling distributions, we see that total nitrogen is the most skewed with the highest skewness coefficient (G) and quartile skew coefficient (QS) (Table 3-6). Nitrate-nitrite is also positively skewed. Total phosphorus and orthophosphate are positively skewed when considering all data indicated by the positive skewness coefficient (G) but negatively skewed within the middle 50% indicated by the negative QS.

Table 3-6. Univariate summary statistics for nutrients at all sites. The interquartile range (IQR) = P75 – P25. The skewness coefficient (G) is the adjusted third moment divided by the cube of the standard deviation, and is a measure of skewness that is sensitive to outliers (Helsel et al. 2020). A distribution is symmetric if |G| < 0.5, moderately skewed when 0.5 ≤ |G| < 1, and highly skewed when |G| ≥ 1. The quartile skew coefficient (QS) quantifies skewness as the difference in distances of the upper and lower quartiles from the median, divided by the IQR for a resistant measure of skewness. A distribution is symmetric when |QS| < 0.1, moderalely skewed when 0.1 ≤ |QS| < 0.2, and highly skewed when |QS| ≥ 0.2.

Statistics	Parameter Nitrate-Nitrite (mg/L)	Total Nitrogen (mg/L)	Orthophosphate (mg/L)	Total Phosphorus (mg/L)
Min	0.001	0.156	0.005	0.085
P25	0.122	1.301	0.308	0.386
P50	0.33	1.628	0.627	0.746
Mean	0.406	2.026	0.647	0.766
P75	0.604	2.093	0.848	0.986
Max	2.787	21.2	3.92	3.99
Obs	1,821	1,086	1,597	1,823
G	1.388	4.99	1.754	1.675
IQR	0.482	0.792	0.54	0.6
QS	0.137	0.174	-0.181	-0.2

Notes: Obs refer to the number of observations and is dimensionless. G (skewness coefficient) and QS (quartile skew) are also dimensionless.

Boxplots (Figure 3-4) provide visual summaries of: 1) the center of the data (the median is the center line of the box), 2) the variation or spread (interquartile range is the box height), 3) the skewness (quartile skew is the relative size of box halves), and

4) presence or absence of unusual values (lines represent up to 1.5 times the interquartile range [IQR], and circles are outliers beyond 1.5 IQR). The data are displayed on a log scale due to the wide range and skewness of concentrations. This log scale obscures skewness within each distribution but improves visualization of relative data centrality and spread across parameters.

Total nitrogen is the sum of all nitrogen forms including ammonia, nitrate-nitrite, and organic nitrogen (not included as a standard analyte but calculated as Total Kjeldahl Nitrogen minus ammonia). Therefore, total nitrogen has larger concentrations than nitrate-nitrite alone. Orthophosphate makes up the majority of phosphorus present, so although total phosphorus values are greater than orthophosphate values, the difference is not as large as the difference between nitrate-nitrite and total nitrogen.

All nutrient parameters were found to be non-normally distributed according to the Anderson-Darling and Probability Plot Correlation Coefficient tests for normality, even after Log_{10} transformation of the data (Appendix G).

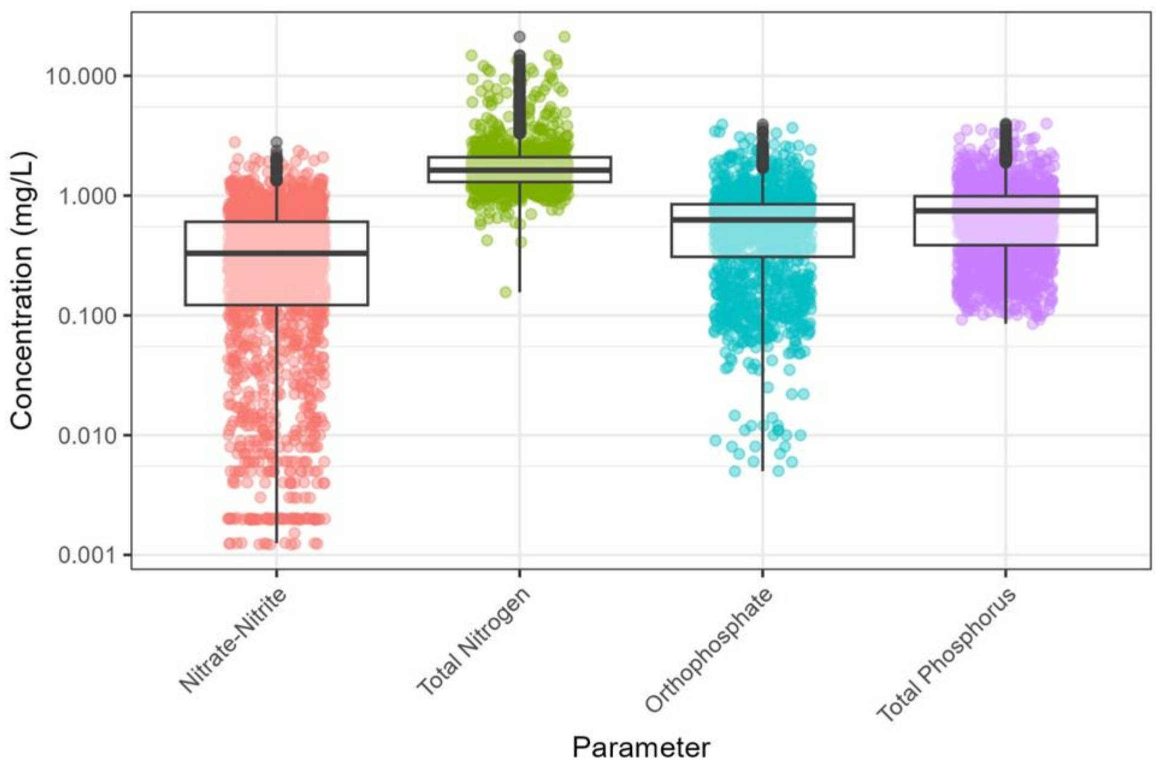


Figure 3-4. Concentrations of nutrients (nitrate-nitrite, total nitrogen, orthophosphate, and total phosphorus) using jittered points to display individual data values and boxplots to summarize the distributions. The y-axis is scaled logarithmically to better visualize the range of concentrations, and boxplot statistics are calculated on non-transformed data.

3.3.2 Seasonal and Spatial Comparisons of Nutrient Parameters

There are significant differences between wet and dry seasons for nitrate-nitrite, with higher values in the wet season compared to the dry season (Figure 3-5). No significant seasonal variation was detected for total nitrogen, orthophosphate, or total phosphorus.

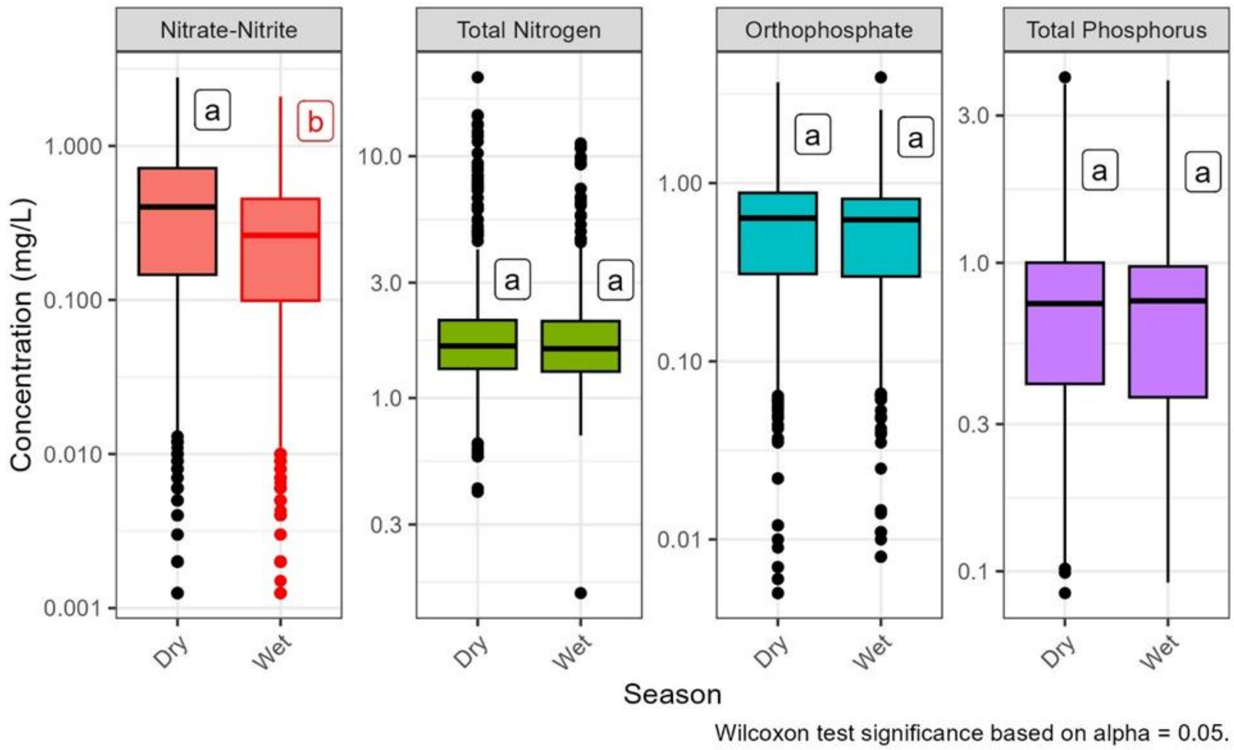


Figure 3-5. Seasonal differences in nutrient concentrations. Boxes with different outline colors and letters are significantly different according to a Wilcoxson rank-sum test.

Pairwise Wilcoxson rank-sum tests revealed differences between nine stations (Figure 3-6):

Nitrate-nitrite was lowest in Saddle Creek and highest in waters from Mt. Pisgah downstream to Zolfo Springs.

Total nitrogen was highest in Saddle Creek, lowest in Peace Creek through Fort Meade, intermediate from Mt. Pisgah through E. Main Street, and low again at Zolfo Springs.

Orthophosphate was low in Peace Creek and Bartow, with a sharp rise beginning at Fort Meade and continuing through Zolfo Springs. Orthophosphate data were not available for Saddle Creek.

Total phosphate was relatively low in Saddle Creek through Bartow, then rises at Fort Meade and stays high through Zolfo Springs.

These patterns highlight both seasonal and spatial variability in nutrient dynamics across the Upper Peace River system.

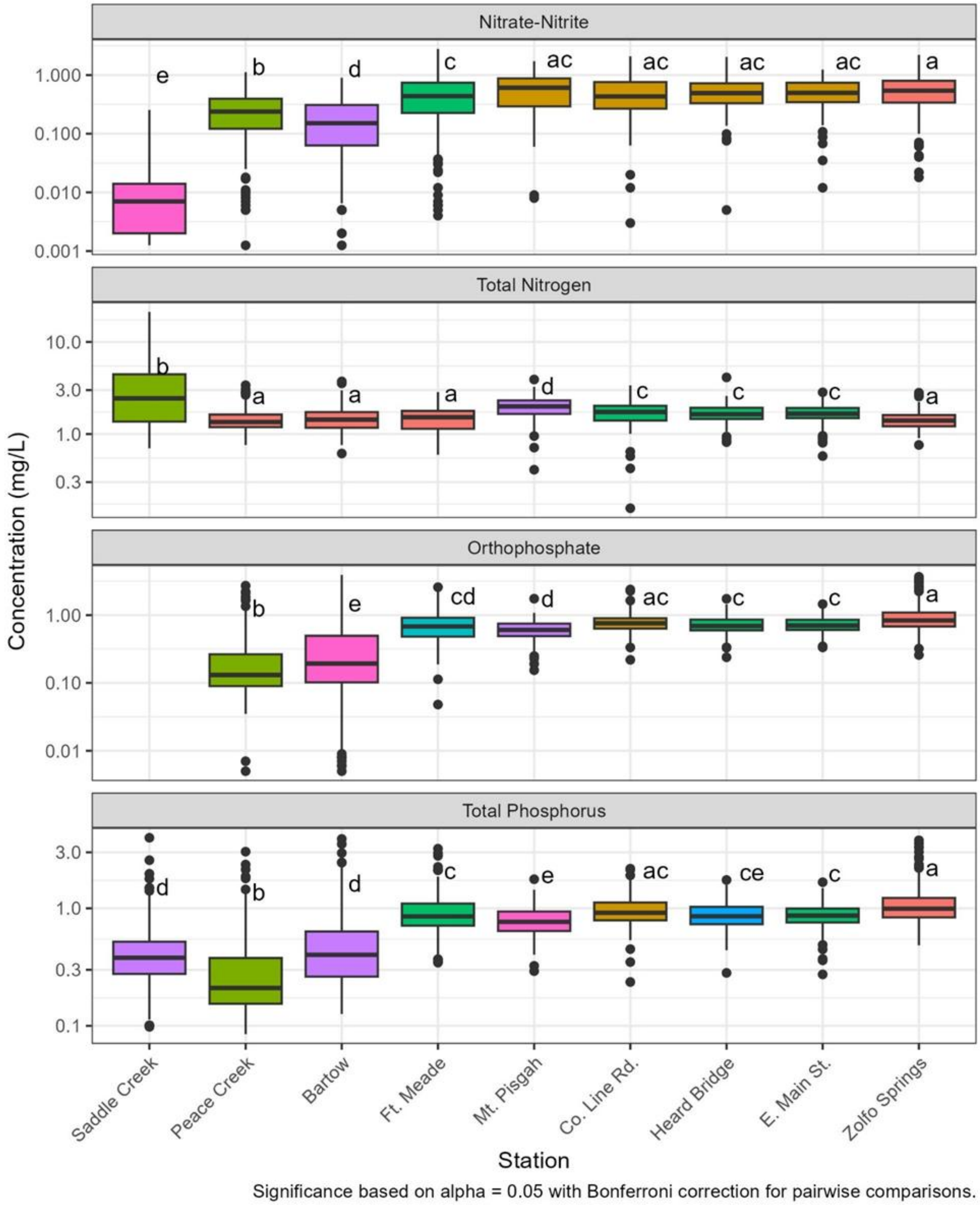


Figure 3-6. Comparison of nutrient parameters by station. Significance values are based on within-parameter comparisons. Stations are ordered from upstream (left) to downstream (right).

3.3.3 Trends in Nutrients with Time and Flow

Trends over time for flow-adjusted nutrient parameters show a mixture of significant and not-significant tests for nutrient parameters (Table 3-7). Of the 35 relationships evaluated, nearly half of relationships (17 of 35) have no significant trend, while most significant trends (17 of 35) show decreases in concentration with time (Table 3-8). Results of trends with flow are also mixed (Table 3-9). Most flow trends (26 of 35) are decreasing (Table 3-10). Plots of all trends are shown in Appendix G.

Table 3-7. Results of trends over time for flow-adjusted nutrients. Slope scaled per decade. Trends are classified as Increasing, Decreasing, or Not Significant, based on Kendall's Tau significance (α = 0.05). Adjusted p values (p_adj.) are adjusted using Bonferroni correction for the number of stations tested.

Parameter	Station	Slope	Tau	p_adj.	Trend
Nitrate-Nitrite	Saddle Creek	-0.187	-0.183	0.001	Decreasing
Nitrate-Nitrite	Peace Creek	-0.051	-0.100	0.121	Not Significant
Nitrate-Nitrite	Bartow	-0.114	-0.169	0.000	Decreasing
Nitrate-Nitrite	Fort Meade	0.074	0.119	0.030	Increasing
Nitrate-Nitrite	Mt. Pisgah	0.012	0.014	7.394	Not Significant
Nitrate-Nitrite	Co. Line Rd.	0.028	0.035	4.802	Not Significant
Nitrate-Nitrite	Heard Bridge	-0.001	-0.002	8.755	Not Significant
Nitrate-Nitrite	E. Main St.	-0.019	-0.029	5.712	Not Significant
Nitrate-Nitrite	Zolfo Springs	-0.069	-0.185	0.000	Decreasing
Total Nitrogen	Saddle Creek	-0.201	-0.327	0.000	Decreasing
Total Nitrogen	Peace Creek	-0.067	-0.351	0.000	Decreasing
Total Nitrogen	Bartow	-0.063	-0.308	0.000	Decreasing
Total Nitrogen	Fort Meade	-0.004	-0.015	7.397	Not Significant
Total Nitrogen	Mt. Pisgah	-0.071	-0.134	0.328	Not Significant
Total Nitrogen	Co. Line Rd.	-0.047	-0.087	1.235	Not Significant
Total Nitrogen	Heard Bridge	-0.041	-0.095	1.138	Not Significant
Total Nitrogen	E. Main St.	-0.045	-0.109	0.826	Not Significant
Total Nitrogen	Zolfo Springs	-0.047	-0.286	0.000	Decreasing
Orthophosphate	Peace Creek	-0.201	-0.306	0.000	Decreasing
Orthophosphate	Bartow	-0.258	-0.268	0.000	Decreasing
Orthophosphate	Fort Meade	-0.065	-0.183	0.000	Decreasing
Orthophosphate	Mt. Pisgah	-0.116	-0.174	0.030	Decreasing
Orthophosphate	Co. Line Rd.	-0.048	-0.092	1.005	Not Significant
Orthophosphate	Heard Bridge	-0.042	-0.092	0.979	Not Significant
Orthophosphate	E. Main St.	-0.052	-0.111	0.532	Not Significant
Orthophosphate	Zolfo Springs	-0.064	-0.255	0.000	Decreasing
Total Phosphorus	Saddle Creek	-0.060	-0.100	0.269	Not Significant
Total Phosphorus	Peace Creek	-0.153	-0.287	0.000	Decreasing

Parameter	Station	Slope	Tau	p_adj.	Trend
Total Phosphorus	Bartow	-0.133	-0.250	0.000	Decreasing
Total Phosphorus	Fort Meade	-0.052	-0.185	0.000	Decreasing
Total Phosphorus	Mt. Pisgah	-0.112	-0.206	0.006	Decreasing
Total Phosphorus	Co. Line Rd.	-0.060	-0.122	0.251	Not Significant
Total Phosphorus	Heard Bridge	-0.057	-0.119	0.438	Not Significant
Total Phosphorus	E. Main St.	-0.049	-0.109	0.645	Not Significant
Total Phosphorus	Zolfo Springs	-0.046	-0.202	0.000	Decreasing

Table 3-8. Counts of trends over time for flow-adjusted nutrients.

Parameter	Increasing	Decreasing	Not Significant
Nitrate-Nitrite	1	3	5
Total Nitrogen	0	4	5
Orthophosphate	0	5	3
Total Phosphorus	0	5	4
Total	1	17	17

Table 3-9. Results of trends with flow for date-adjusted nutrients. Trends are classified as Increasing, Decreasing, or Not Significant, based on Kendall's Tau significance (α = 0.05). Adjusted p values (p_adj.) are adjusted using Bonferroni correction for the number of stations tested.

Parameter	Station	Slope	Tau	p_adj.	Trend
Nitrate-Nitrite	Saddle Creek	-0.027	-0.095	0.408	Not Significant
Nitrate-Nitrite	Peace Creek	-0.352	-0.337	0.000	Decreasing
Nitrate-Nitrite	Bartow	-0.245	-0.230	0.000	Decreasing
Nitrate-Nitrite	Fort Meade	-0.221	-0.278	0.000	Decreasing
Nitrate-Nitrite	Mt. Pisgah	-0.391	-0.439	0.000	Decreasing
Nitrate-Nitrite	Co. Line Rd.	-0.421	-0.472	0.000	Decreasing
Nitrate-Nitrite	Heard Bridge	-0.323	-0.435	0.000	Decreasing
Nitrate-Nitrite	E. Main St.	-0.373	-0.454	0.000	Decreasing
Nitrate-Nitrite	Zolfo Springs	-0.254	-0.352	0.000	Decreasing
Total Nitrogen	Saddle Creek	-0.030	-0.180	0.001	Decreasing
Total Nitrogen	Peace Creek	0.054	0.228	0.008	Increasing
Total Nitrogen	Bartow	0.014	0.075	2.400	Not Significant
Total Nitrogen	Fort Meade	-0.063	-0.212	0.014	Decreasing
Total Nitrogen	Mt. Pisgah	-0.065	-0.192	0.024	Decreasing
Total Nitrogen	Co. Line Rd.	-0.060	-0.178	0.021	Decreasing
Total Nitrogen	Heard Bridge	-0.009	-0.028	5.897	Not Significant
Total Nitrogen	E. Main St.	-0.032	-0.087	1.628	Not Significant
Total Nitrogen	Zolfo Springs	-0.037	-0.176	0.079	Not Significant

Parameter	Station	Slope	Tau	p_adj.	Trend
Orthophosphate	Peace Creek	-0.177	-0.221	0.000	Decreasing
Orthophosphate	Bartow	-0.149	-0.175	0.000	Decreasing
Orthophosphate	Fort Meade	-0.006	-0.019	5.045	Not Significant
Orthophosphate	Mt. Pisgah	-0.070	-0.214	0.003	Decreasing
Orthophosphate	Co. Line Rd.	-0.133	-0.455	0.000	Decreasing
Orthophosphate	Heard Bridge	-0.114	-0.361	0.000	Decreasing
Orthophosphate	E. Main St.	-0.099	-0.366	0.000	Decreasing
Orthophosphate	Zolfo Springs	-0.118	-0.356	0.000	Decreasing
Total Phosphorus	Saddle Creek	-0.022	-0.131	0.053	Not Significant
Total Phosphorus	Peace Creek	-0.127	-0.187	0.000	Decreasing
Total Phosphorus	Bartow	-0.078	-0.149	0.002	Decreasing
Total Phosphorus	Fort Meade	-0.008	-0.028	4.349	Not Significant
Total Phosphorus	Mt. Pisgah	-0.053	-0.186	0.019	Decreasing
Total Phosphorus	Co. Line Rd.	-0.096	-0.347	0.000	Decreasing
Total Phosphorus	Heard Bridge	-0.082	-0.269	0.000	Decreasing
Total Phosphorus	E. Main St.	-0.084	-0.300	0.000	Decreasing
Total Phosphorus	Zolfo Springs	-0.087	-0.297	0.000	Decreasing

Table 3-10.Summary of trends with flow for date-adjusted nutrients.

Parameter	Increasing	Decreasing	Not Significant
Nitrate-Nitrite	0	8	1
Total Nitrogen	1	4	4
Orthophosphate	0	7	1
Total Phosphorus	0	7	2
Total	1	26	8

3.4 Water Clarity: Chlorophyll a, Turbidity, Total Suspended Solids, and Color

The clarity of water can be affected by numerous factors, the most important of which are chlorophyll a, turbidity, total suspended solids, and color. These parameters reflect both biological activity and the presence of particulate and dissolved materials in the water column.

Chlorophyll a is a pigment found in phytoplankton, the microscopic algae that forms the base of the aquatic food web. It plays a crucial role in photosynthesis, the process by which these organisms convert sunlight into energy. Because photosynthesis is necessary for algal growth, the concentration of chlorophyll a is a reliable indicator of the amount of phytoplankton present.

Nutrient eutrophication is a chain reaction that occurs when elevated nutrient levels lead to rapid phytoplankton growth and overabundance. The excess algae eventually decompose, consuming oxygen in the water and resulting in hypoxic conditions. Lowered oxygen levels can cause fish die-offs. Thus, eutrophication not only creates unsightly, thick, green waters but also disrupts ecosystems and diminishes the environmental values associated with aesthetic qualities and fish and wildlife habitats.

Turbidity is an optical property of water rather than a chemical or biological measurement. It is measured by assessing the scattering and absorption of light as it passes through the water. The more particles suspended in the water, such as silt, clay, algae, and other microscopic organisms, the higher the turbidity. This light scattering is expressed in Nephelometric Turbidity Units (NTU), providing a standardized way to compare turbidity levels across different water samples.

Total Suspended Solids (TSS) is a measure of the concentration of suspended particles in water. These particles can include a variety of materials such as soil particles (clay and silt), organic matter (like decaying plant material), algae, and microscopic organisms. Total Suspended Solids is an important parameter in water quality because high levels of suspended solids can reduce light penetration, affecting aquatic life and the overall health of the ecosystem.

To measure TSS, a water sample is typically filtered through a pre-weighed filter. The filter traps the suspended particles, and after drying, the filter is weighed again. The increase in weight represents the mass of the suspended solids in the sample. This mass is then divided by the volume of the water sample to calculate the concentration of TSS, usually expressed in milligrams per liter (mg/L). Monitoring TSS helps in assessing the impact of runoff, erosion, and other environmental factors on water bodies.

Similarly, color, both apparent and true, is an optical property of water, measured in Platinum Cobalt Units (PCU) based on comparison with a standard platinum-cobalt solution. Apparent color is based on unfiltered samples and includes effects of suspended solids, while true color is based on filtered samples and reflects influence of tannins and other dissolved molecules.

3.4.1 Descriptive Statistics of Water Clarity Parameters

Means and medians for water clarity parameters across all sites are shown in Table 3-11. Comparing nutrient sampling distributions, we see that chlorophyll a is the most skewed with the highest skewness coefficient (G) and quartile skew coefficient (QS). Other clarity parameters are also positively skewed, though to a lesser extent.

Boxplots (Figure 3-7) provide visual summaries of: 1) the center of the data (the median is the center line of the box), 2) the variation or spread (interquartile range is the box height), 3) the skewness (quartile skew is the relative size of box halves), and 4) presence or absence of unusual values (lines represent up to 1.5 times the interquartile range [IQR], and circles are outliers beyond 1.5 IQR). The data are displayed on a log scale due to the wide range and skewness of concentrations. This log scale obscures visualization of skewness within each parameter but improves visualization of relative data centrality and spread between parameters.

All parameters are non-normal according to the Anderson-Darling and Probability Plot Correlation Coefficient tests for normality after Log10 transformation of data (Appendix G).

Table 3-11. Univariate summary statistics for water clarity at all sites. The interquartile range (IQR) = P75 – P25. The skewness coefficient (G) is the adjusted third moment divided by the cube of the standard deviation, and is a measure of skewness that is sensitive to outliers (Helsel et al. 2020). A distribution is symmetric if |G| < 0.5, moderately skewed when 0.5 ≤ |G| < 1, and highly skewed when |G| ≥ 1. The quartile skew coefficient (QS) quantifies skewness as the difference in distances of the upper and lower quartiles from the median, divided by the IQR for a resistant measure of skewness. A distribution is symmetric when |QS| < 0.1, moderalely skewed when 0.1 ≤ |QS| < 0.2, and highly skewed when |QS| ≥ 0.2.

Statistics	**Parameter**			
	Chlorophyll a (µg/L)	**Color (PCU)**	**TSS (mg/L)**	**Turbidity (NTU)**
Min	0.5	5	0.25	0.07
P25	2.1	73.5	3.56	4.38
P50	5.17	130	6.54	7.3
Mean	42.3	144.7	10	10.6
P75	20.6	200	11.8	12.3
Max	1,628	600	151	103
Obs*	1,610	1,811	1,516	1,851
G	5.682	1	4.623	2.933
IQR	18.485	126.5	8.265	7.925
QS	0.668	0.107	0.28	0.262

Notes: Obs refer to the number of observations and is dimensionless. G (skewness coefficient) and QS (quartile skew) are also dimensionless.

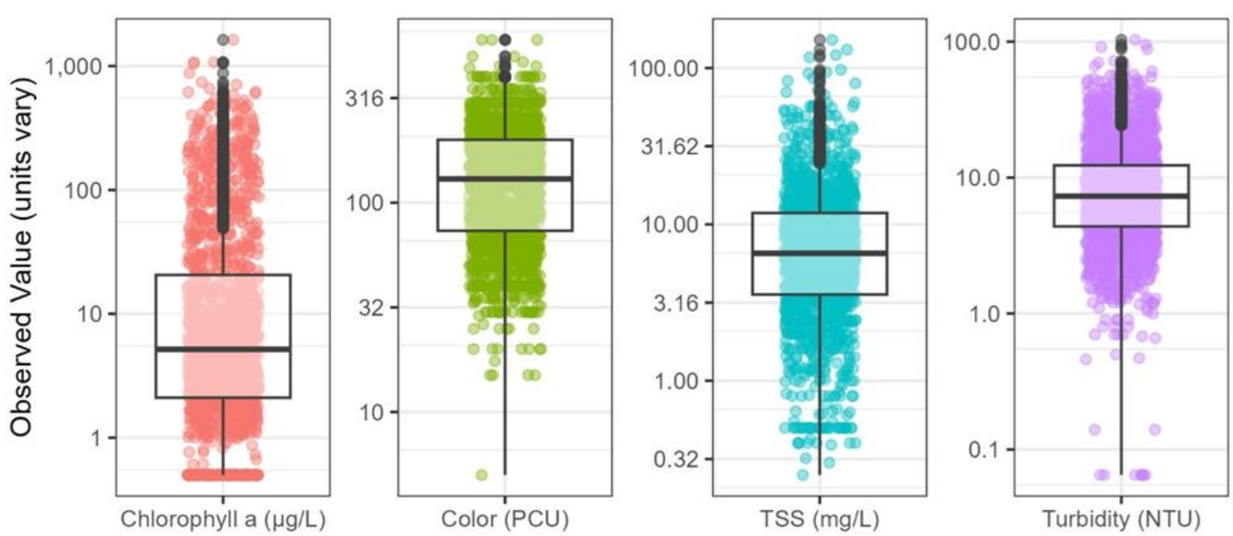


Figure 3-7. Concentrations of chlorophyll a, color, TSS, and turbidity using jittered points to display individual data values and boxplots to summarize the distribution. The y-axis is scaled logarithmically to better visualize the range of concentrations, and boxplot statistics are calculated on non-transformed data.

3.4.2 Seasonal and Spatial Comparisons of Water Clarity

Significant seasonal differences were observed for turbidity, TSS, and color, with higher values typically occurring in the wet season. Chlorophyll a did not exhibit significant seasonal variation (Figure 3-8). Pairwise Wilcoxon rank-sum tests revealed differences between nine stations (Figure 3-9). Chlorophyll a was highest in Saddle Creek and lowest in Peace Creek, Fort Meade, and Zolfo Springs. Color was lowest in Saddle Creek. Total Suspended Solids (TSS) was highest at Bartow and lowest at Zolfo Springs. Turbidity was highest in Saddle Creek and lowest at Fort Meade and Zolfo Springs. These patterns reflect both seasonal hydrologic variability and localized influence on water clarity across the Upper Peace River system.

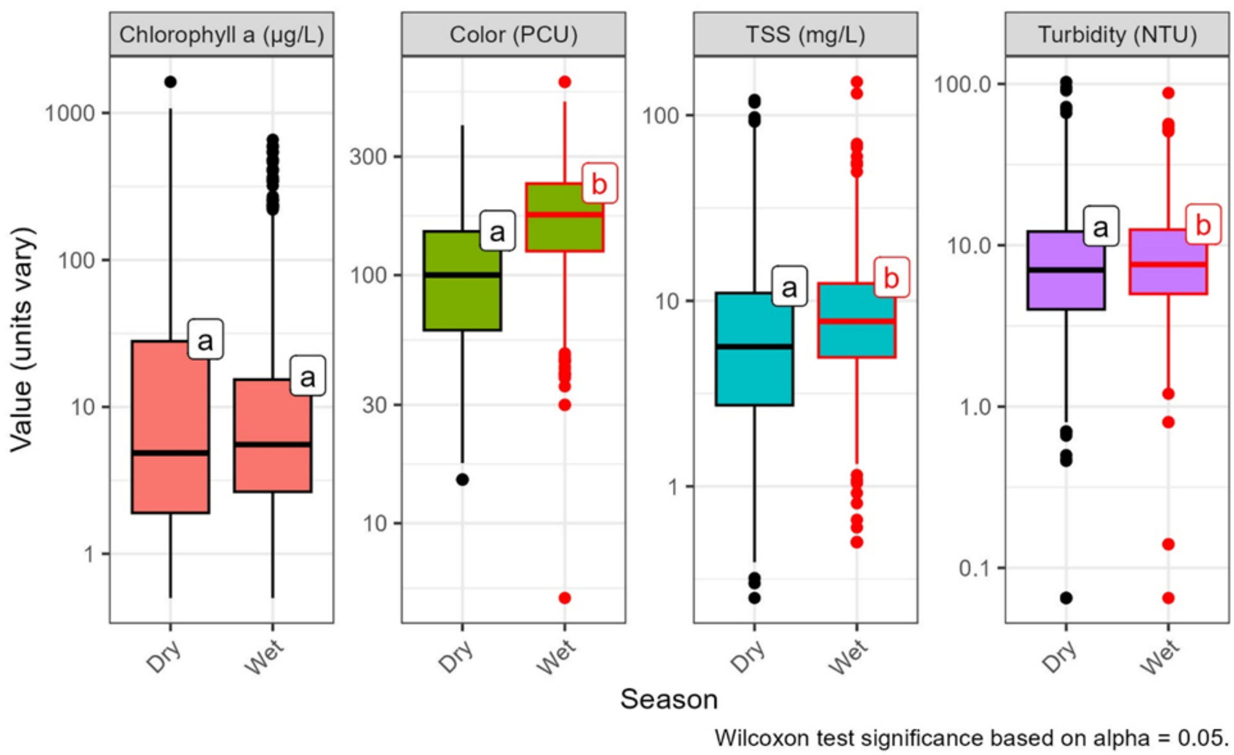


Figure 3-8. Seasonal differences in water clarity parameters. Boxes with different outline colors and letters are significantly different according to a Wilcoxon rank-sum test.

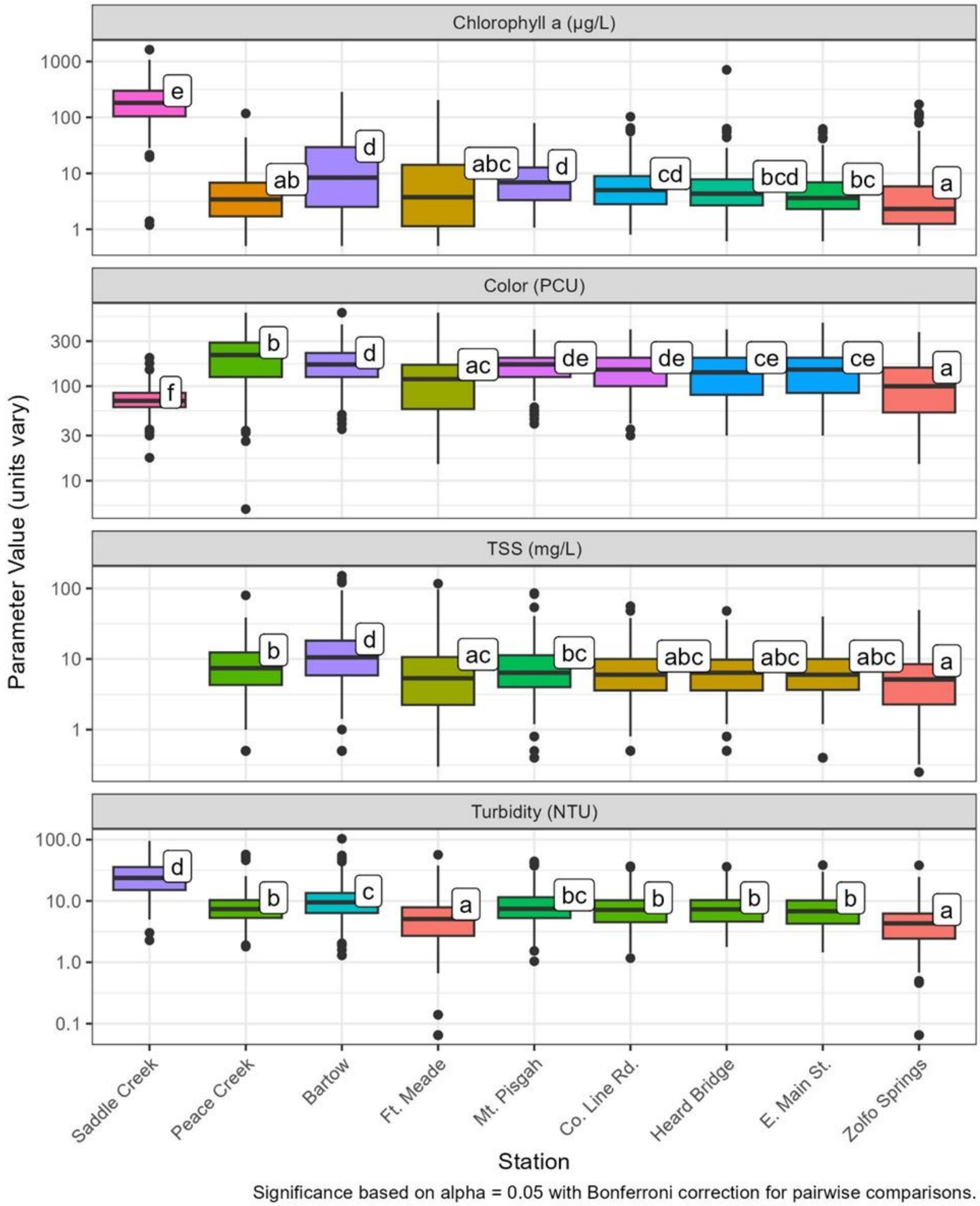


Figure 3-9. Comparison of water clarity parameters by station. Significance values are based on within-parameter comparisons. Stations are ordered from upstream (left) to downstream (right).

3.4.3 Trends in Water Clarity with Time and Flow

For trends over time, there was a mixture of significant and not-significant tests for clarity parameters (Table 3-12). Most relationships (28 of 35) had no significant trend, while significant trends were nearly evenly split between increasing (3 of 35) and decreasing (4 of 35) with time (Table 3-13). Results of trends with flow were also mixed (Table 3-14). Most flow trends (24 of 35) are positive (Table 3-15). Plots of all trends are shown in Appendix G.

Table 3-12.Results of trends over time for flow-adjusted water clarity parameters. Slope scaled per decade. Trends are classified as Positive, Negative, or Not Significant based on Kendall's Tau significance (α = 0.05). Adjusted p values (p_adj.) are adjusted using Bonferroni correction for the number of stations tested.

Parameter	Station	Slope	Tau	p_adj.	Trend
Chlorophyll a (µg/L)	Saddle Creek	0.007	0.009	7.550	Not Significant
Chlorophyll a (µg/L)	Peace Creek	0.193	0.196	0.000	Increasing
Chlorophyll a (µg/L)	Bartow	0.190	0.152	0.005	Increasing
Chlorophyll a (µg/L)	Fort Meade	0.189	0.138	0.013	Increasing
Chlorophyll a (µg/L)	Mt. Pisgah	0.118	0.047	4.164	Not Significant
Chlorophyll a (µg/L)	Co. Line Rd.	0.148	0.070	2.416	Not Significant
Chlorophyll a (µg/L)	Heard Bridge	0.091	0.036	5.129	Not Significant
Chlorophyll a (µg/L)	E. Main St.	0.092	0.044	4.441	Not Significant
Chlorophyll a (µg/L)	Zolfo Springs	0.108	0.099	0.209	Not Significant
Color (PCU)	Saddle Creek	-0.078	-0.229	0.000	Decreasing
Color (PCU)	Peace Creek	-0.086	-0.308	0.000	Decreasing
Color (PCU)	Bartow	-0.079	-0.246	0.000	Decreasing
Color (PCU)	Fort Meade	-0.033	-0.105	0.083	Not Significant
Color (PCU)	Mt. Pisgah	0.019	0.034	5.143	Not Significant
Color (PCU)	Co. Line Rd.	0.122	0.154	0.089	Not Significant
Color (PCU)	Heard Bridge	0.061	0.075	1.900	Not Significant
Color (PCU)	E. Main St.	0.062	0.088	1.305	Not Significant
Color (PCU)	Zolfo Springs	-0.024	-0.088	0.260	Not Significant
TSS (mg/L)	Peace Creek	0.025	0.044	2.394	Not Significant
TSS (mg/L)	Bartow	0.045	0.065	1.011	Not Significant
TSS (mg/L)	Fort Meade	-0.012	-0.016	5.672	Not Significant
TSS (mg/L)	Mt. Pisgah	0.224	0.153	0.084	Not Significant
TSS (mg/L)	Co. Line Rd.	0.194	0.145	0.121	Not Significant
TSS (mg/L)	Heard Bridge	0.140	0.123	0.321	Not Significant
TSS (mg/L)	E. Main St.	0.140	0.111	0.520	Not Significant
TSS (mg/L)	Zolfo Springs	0.018	0.026	4.343	Not Significant
Turbidity (NTU)	Saddle Creek	-0.088	-0.144	0.017	Decreasing
Turbidity (NTU)	Peace Creek	0.038	0.091	0.231	Not Significant

Parameter	Station	Slope	Tau	p_adj.	Trend
Turbidity (NTU)	Bartow	0.029	0.053	1.751	Not Significant
Turbidity (NTU)	Fort Meade	0.015	0.023	5.035	Not Significant
Turbidity (NTU)	Mt. Pisgah	0.070	0.062	2.709	Not Significant
Turbidity (NTU)	Co. Line Rd.	0.048	0.046	3.566	Not Significant
Turbidity (NTU)	Heard Bridge	0.067	0.061	2.778	Not Significant
Turbidity (NTU)	E. Main St.	0.040	0.039	4.656	Not Significant
Turbidity (NTU)	Zolfo Springs	0.023	0.054	1.660	Not Significant

Table 3-13. Counts of trends over time for in flow-adjusted water clarity parameters.

Parameter	Increasing	Decreasing	Not Significant
Chlorophyll a (µg/L)	3	0	6
Color (PCU)	0	3	6
TSS (mg/L)	0	0	8
Turbidity (NTU)	0	1	8
Total	3	4	28

Table 3-14.Results of trends with flow for date-adjusted water clarity parameters. Trends are classified as Increasing, Decreasing, or Not Significant, based on Kendall's Tau significance (α = 0.05). Adjusted p values (p_adj.) are adjusted using Bonferroni correction for the number of stations tested.

Parameter	Station	Slope	Tau	p_adj.	Trend
Chlorophyll a (µg/L)	Saddle Creek	-0.010	-0.042	3.390	Not Significant
Chlorophyll a (µg/L)	Peace Creek	0.241	0.225	0.000	Increasing
Chlorophyll a (µg/L)	Bartow	0.483	0.349	0.000	Increasing
Chlorophyll a (µg/L)	Fort Meade	0.349	0.304	0.000	Increasing
Chlorophyll a (µg/L)	Mt. Pisgah	0.078	0.067	2.655	Not Significant
Chlorophyll a (µg/L)	Co. Line Rd.	0.109	0.101	1.031	Not Significant
Chlorophyll a (µg/L)	Heard Bridge	0.094	0.095	1.235	Not Significant
Chlorophyll a (µg/L)	E. Main St.	0.110	0.098	1.132	Not Significant
Chlorophyll a (µg/L)	Zolfo Springs	0.265	0.209	0.000	Increasing
Color (PCU)	Saddle Creek	0.017	0.162	0.006	Increasing
Color (PCU)	Peace Creek	0.298	0.582	0.000	Increasing
Color (PCU)	Bartow	0.178	0.443	0.000	Increasing
Color (PCU)	Fort Meade	0.281	0.579	0.000	Increasing
Color (PCU)	Mt. Pisgah	0.186	0.406	0.000	Increasing
Color (PCU)	Co. Line Rd.	0.271	0.432	0.000	Increasing
Color (PCU)	Heard Bridge	0.318	0.481	0.000	Increasing
Color (PCU)	E. Main St.	0.327	0.517	0.000	Increasing
Color (PCU)	Zolfo Springs	0.413	0.662	0.000	Increasing

Parameter	Station	Slope	Tau	p_adj.	Trend
TSS (mg/L)	Peace Creek	0.239	0.304	0.000	Increasing
TSS (mg/L)	Bartow	0.205	0.266	0.000	Increasing
TSS (mg/L)	Fort Meade	0.172	0.210	0.000	Increasing
TSS (mg/L)	Mt. Pisgah	0.085	0.092	1.005	Not Significant
TSS (mg/L)	Co. Line Rd.	0.217	0.202	0.005	Increasing
TSS (mg/L)	Heard Bridge	0.138	0.152	0.089	Not Significant
TSS (mg/L)	E. Main St.	0.203	0.195	0.010	Increasing
TSS (mg/L)	Zolfo Springs	0.334	0.298	0.000	Increasing
Turbidity (NTU)	Saddle Creek	-0.012	-0.064	1.602	Not Significant
Turbidity (NTU)	Peace Creek	0.055	0.106	0.081	Not Significant
Turbidity (NTU)	Bartow	0.086	0.156	0.001	Increasing
Turbidity (NTU)	Fort Meade	0.118	0.194	0.000	Increasing
Turbidity (NTU)	Mt. Pisgah	0.055	0.072	2.018	Not Significant
Turbidity (NTU)	Co. Line Rd.	0.093	0.121	0.231	Not Significant
Turbidity (NTU)	Heard Bridge	0.141	0.181	0.022	Increasing
Turbidity (NTU)	E. Main St.	0.162	0.200	0.007	Increasing
Turbidity (NTU)	Zolfo Springs	0.288	0.356	0.000	Increasing

Table 3-15.Counts of trends with flow for date-adjusted water clarity parameters

Parameter	Increasing	Decreasing	Not Significant
Chlorophyll a (μg/L)	4	0	5
Color (PCU)	9	0	0
TSS (mg/L)	6	0	2
Turbidity (NTU)	5	0	4
Total	24	0	11

3.5 Inorganic Ions: Fluoride, pH, Potassium, and Specific Conductance

Inorganic ions grouped in this analysis included fluoride, pH, potassium, and specific conductance. Fluorapatite is a naturally occurring mineral that contains fluoride as a key component of its chemical structure. Phosphate rock mined in the Bone Valley is rich in fluorapatite, making it a significant source of fluoride (Cathcart 1952). Fluoride is reported as both "Fluoride" and "Fluoride-dissolved" at Saddle Creek, these are combined to a single parameter here.

The pH is a logarithmic measure of the concentration of hydrogen ions (H^+), with higher concentrations indicating a lower pH and a more acidic solution, while lower concentrations result in a higher pH and a more alkaline solution. Freshwater systems exhibit natural pH variations influenced by factors like geology and the activity of aquatic organisms. pH significantly impacts the availability of essential nutrients and the toxicity of metals, affecting the health and survival of aquatic organisms.

Potassium is an essential macronutrient for plant growth and plays a crucial role in various biological processes. In aquatic ecosystems, potassium concentrations can vary significantly due to factors such as geology, weathering, and human activities like agriculture and wastewater discharge. Elevated potassium levels can impact aquatic life by altering osmotic balance, influencing plant growth rates, and potentially contributing to eutrophication.

Specific conductance is a measure of the presence of dissolved ions in a solution. Four major cations, sodium, potassium, calcium, and magnesium and four major anions bicarbonate, carbonate, sulfate, and chloride are the dominant ions in fresh water (Allan et al. 2021).

3.5.1 Descriptive Statistics of Inorganic Ions

Means and medians across all sites for inorganic ions are shown in Table 3-16. Comparing nutrient sampling distributions, we see that potassium is the most skewed with the highest skewness coefficient (G) and quartile skew coefficient (QS). Fluoride and specific conductance are also positively skewed, while pH is negatively skewed.

Boxplots (Figure 3-10) provide visual summaries of: 1) the center of the data (the median is the center line of the box), 2) the variation or spread (interquartile range is the box height), 3) the skewness (quartile skew is the relative size of box halves), and 4) presence or absence of unusual values (lines represent up to 1.5 times the interquartile range [IQR], and circles are outliers beyond 1.5 IQR). The data are displayed on a log scale due to the wide range and skewness of concentrations. This log scale obscures visualization of skewness within each parameter but improves visualization of relative data centrality and spread between parameters.

All parameters are non-normal according to the Anderson-Darling and Probability Plot Correlation Coefficient tests for normality after Log10 transformation of data (Appendix G).

Table 3-16. Univariate summary statistics for inorganic ions at all sites. The interquartile range (IQR) = P75 – P25. The skewness coefficient (G) is the adjusted third moment divided by the cube of the standard deviation, and is a measure of skewness that is sensitive to outliers (Helsel et al. 2020). A distribution is symmetric if $|G| < 0.5$, moderately skewed when $0.5 \le |G| < 1$, and highly skewed when $|G| \ge 1$. The quartile skew coefficient (QS) quantifies skewness as the difference in distances of the upper and lower quartiles from the median, divided by the IQR for a resistant measure of skewness. A distribution is symmetric when $|QS| < 0.1$, moderalely skewed when $0.1 \le |QS| < 0.2$, and highly skewed when $|QS| \ge 0.2$.

Statistics	Parameter			
	Fluoride (mg/L)	**Potassium (mg/L)**	**Specific Conductance (µS/cm)**	**pH (SU)**
Min	0.01	0.96	72	4.34

Statistics	Parameter			
	Fluoride (mg/L)	Potassium (mg/L)	Specific Conductance (µS/cm)	pH (SU)
P25	0.37	3.91	237	6.95
P50	0.61	5.33	323	7.28
Mean	0.7	7.43	357	7.27
P75	0.9	8.36	439	7.6
Max	5.5	133	2,115	9.17
Obs	1,741	1,224	1,585	1,584
G	2.226	6.897	2.528	-0.177
IQR	0.529	4.452	202	0.65
QS	0.096	0.361	0.149	-0.023

Notes: Obs refer to the number of observations and is dimensionless. G (skewness coefficient) and QS (quartile skew) are also dimensionless.

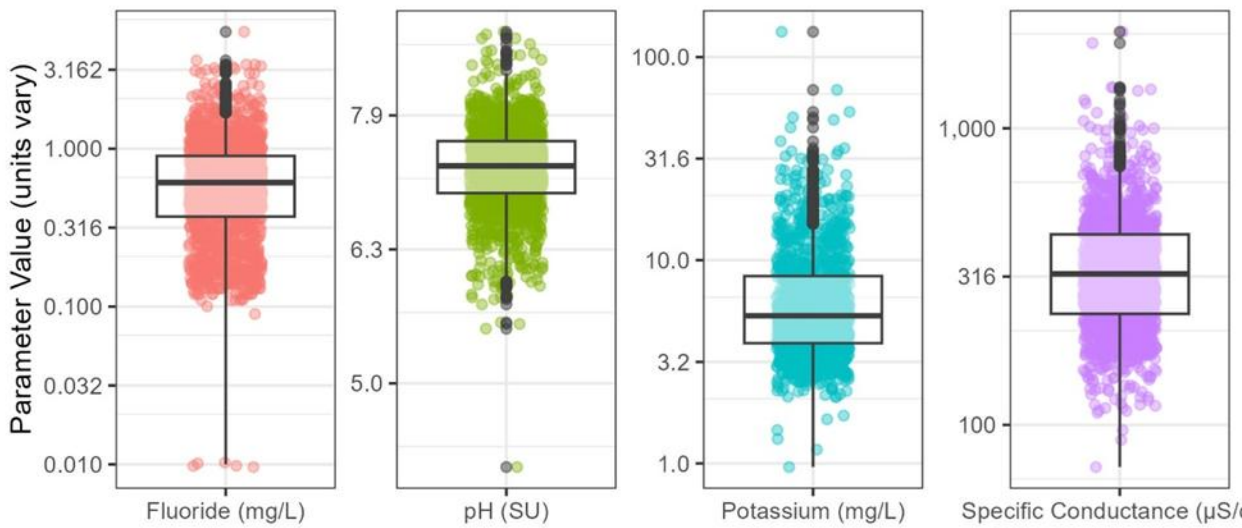


Figure 3-10. Concentrations of inorganic ions using jittered points to display individual data values and boxplots to summarize the distribution. The y-axis is scaled logarithmically to better visualize the range of concentrations, and boxplot statistics are calculated on non-transformed data.

3.5.2 Seasonal and Spatial Comparisons of Inorganic Ions

There were significant differences between wet and dry seasons in all inorganic ions (Figure 3-11). Pairwise Wilcoxson tests revealed differences between nine stations (Figure 3-12). Fluoride was highest at Zolfo Springs and lowest in Peace Creek. pH was highest at Mt. Pisgah through Zolfo Springs, and lowest at Peace Creek. Potassium was highest at Peace Creek and lowest at Saddle Creek. Specific conductance was highest at Zolfo Springs and lowest at Bartow.

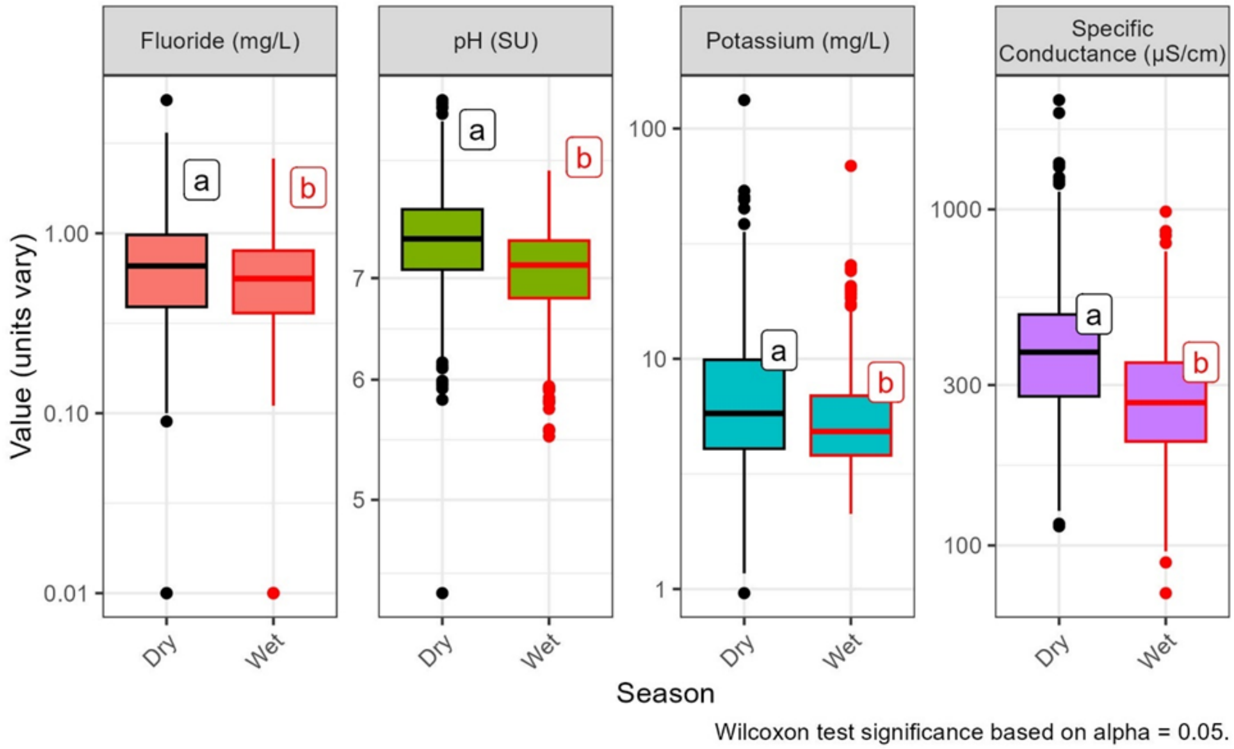


Figure 3-11. Seasonal differences in inorganic ions. Boxes with different outline colors and letters are significantly different according to a Wilcoxson rank-sum test.

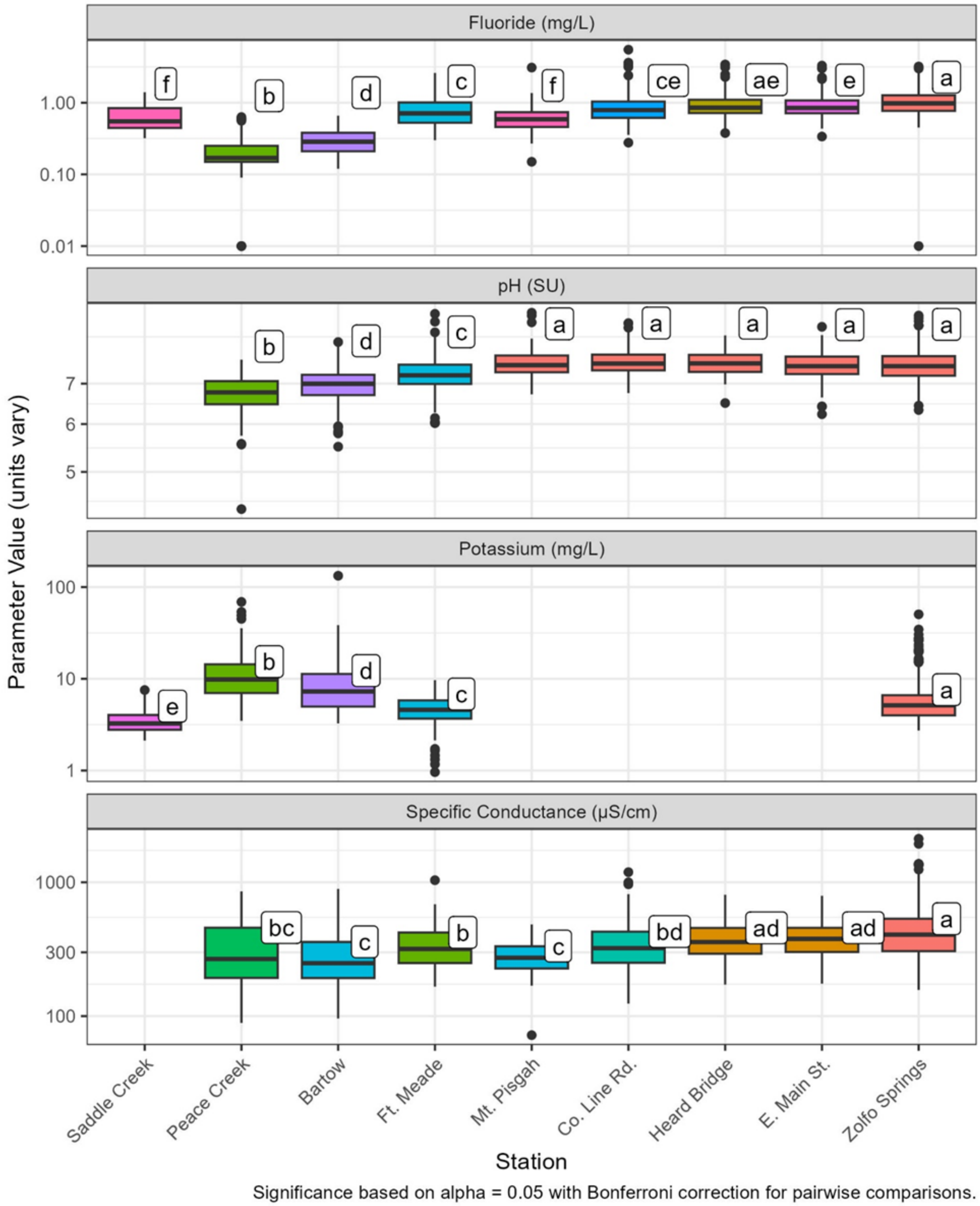


Figure 3-12. Comparison of inorganic ions by station. Significance values are based on within parameter compsrisons. Stations are ordered from upstream (left) to downstream (right).

3.5.3 Trends in Inorganic Ions

For trends over time, there was a mixture of significant and not-significant tests for inorganic ions (Table 3-17). Many relationships (11 of 30) had no significant trend, while significant trends were more often decreasing (14 of 30) than increasing (5 of 30) with time (Table 3-18). Results of trends with flow were either decreasing or not significant (Table 3-19). Most flow trends (28 of 30) were decreasing (Table 3-20). Plots of all trends are shown in Appendix G.

Table 3-17.Results of trends over time for flow-adjusted inorganic ions. Slope scaled per decade. Trends are classified as Positive, Negative, or Not Significant based on Kendall's Tau significance (α = 0.05). Adjusted p values (p_adj.) are adjusted using Bonferroni correction for the number of stations tested.

Parameter	Station	Slope	Tau	p_adj.	Trend
Fluoride (mg/L)	Saddle Creek	-0.019	-0.093	0.409	Not Significant
Fluoride (mg/L)	Peace Creek	-0.021	-0.076	0.643	Not Significant
Fluoride (mg/L)	Bartow	-0.011	-0.032	4.105	Not Significant
Fluoride (mg/L)	Fort Meade	-0.101	-0.316	0.000	Decreasing
Fluoride (mg/L)	Mt. Pisgah	-0.119	-0.235	0.001	Decreasing
Fluoride (mg/L)	Co. Line Rd.	-0.205	-0.363	0.000	Decreasing
Fluoride (mg/L)	Heard Bridge	-0.152	-0.319	0.000	Decreasing
Fluoride (mg/L)	E. Main St.	-0.134	-0.281	0.000	Decreasing
Fluoride (mg/L)	Zolfo Springs	-0.046	-0.189	0.000	Decreasing
Potassium (mg/L)	Saddle Creek	0.011	0.062	0.916	Not Significant
Potassium (mg/L)	Peace Creek	-0.094	-0.386	0.000	Decreasing
Potassium (mg/L)	Bartow	-0.094	-0.378	0.000	Decreasing
Potassium (mg/L)	Fort Meade	-0.016	-0.070	0.468	Not Significant
Potassium (mg/L)	Zolfo Springs	0.006	0.017	3.398	Not Significant
Specific Conductance (µS/cm)	Peace Creek	0.042	0.192	0.000	Increasing
Specific Conductance (µS/cm)	Bartow	0.007	0.042	2.484	Not Significant
Specific Conductance (µS/cm)	Fort Meade	-0.045	-0.260	0.000	Decreasing
Specific Conductance (µS/cm)	Mt. Pisgah	-0.069	-0.240	0.000	Decreasing
Specific Conductance (µS/cm)	Co. Line Rd.	-0.095	-0.336	0.000	Decreasing
Specific Conductance (µS/cm)	Heard Bridge	-0.087	-0.373	0.000	Decreasing
Specific Conductance (µS/cm)	E. Main St.	-0.076	-0.313	0.000	Decreasing
Specific Conductance (µS/cm)	Zolfo Springs	0.011	0.062	0.994	Not Significant
pH (SU)	Peace Creek	0.020	0.036	3.177	Not Significant
pH (SU)	Bartow	0.018	0.025	4.458	Not Significant
pH (SU)	Fort Meade	-0.031	-0.053	1.664	Not Significant
pH (SU)	Mt. Pisgah	0.242	0.272	0.000	Increasing
pH (SU)	Co. Line Rd.	0.202	0.200	0.002	Increasing
pH (SU)	Heard Bridge	0.200	0.197	0.007	Increasing

Parameter	Station	Slope	Tau	p_adj.	Trend
pH (SU)	E. Main St.	0.344	0.199	0.007	Increasing
pH (SU)	Zolfo Springs	-0.083	-0.139	0.005	Decreasing

Table 3-18. Counts of trends over time for in flow-adjusted inorganic ions.

Parameter	Increasing	Decreasing	Not Significant
Fluoride (mg/L)	0	6	3
Potassium (mg/L)	0	2	3
Specific Conductance (µS/cm)	1	5	2
pH (SU)	4	1	3
Total	5	14	11

Table 3-19. Results of trends with flow for date-adjusted inorganic ions. Trends are classified as Increasing, Decreasing, or Not Significant, based on Kendall's Tau significance ($\alpha = 0.05$). Adjusted p values (p_adj.) are adjusted using Bonferroni correction for the number of stations tested.

Parameter	Station	Slope	Tau	p_adj.	Trend
Fluoride (mg/L)	Saddle Creek	-0.020	-0.282	0.000	Decreasing
Fluoride (mg/L)	Peace Creek	-0.196	-0.454	0.000	Decreasing
Fluoride (mg/L)	Bartow	-0.034	-0.098	0.192	Not Significant
Fluoride (mg/L)	Fort Meade	-0.125	-0.369	0.000	Decreasing
Fluoride (mg/L)	Mt. Pisgah	-0.145	-0.445	0.000	Decreasing
Fluoride (mg/L)	Co. Line Rd.	-0.202	-0.526	0.000	Decreasing
Fluoride (mg/L)	Heard Bridge	-0.186	-0.547	0.000	Decreasing
Fluoride (mg/L)	E. Main St.	-0.180	-0.534	0.000	Decreasing
Fluoride (mg/L)	Zolfo Springs	-0.174	-0.540	0.000	Decreasing
Potassium (mg/L)	Saddle Creek	-0.011	-0.190	0.000	Decreasing
Potassium (mg/L)	Peace Creek	-0.261	-0.671	0.000	Decreasing
Potassium (mg/L)	Bartow	-0.207	-0.583	0.000	Decreasing
Potassium (mg/L)	Fort Meade	0.024	0.078	0.320	Not Significant
Potassium (mg/L)	Zolfo Springs	-0.187	-0.479	0.000	Decreasing
Specific Conductance (µS/cm)	Peace Creek	-0.306	-0.712	0.000	Decreasing
Specific Conductance (µS/cm)	Bartow	-0.187	-0.652	0.000	Decreasing
Specific Conductance (µS/cm)	Fort Meade	-0.124	-0.464	0.000	Decreasing
Specific Conductance (µS/cm)	Mt. Pisgah	-0.171	-0.615	0.000	Decreasing
Specific Conductance (µS/cm)	Co. Line Rd.	-0.235	-0.700	0.000	Decreasing
Specific Conductance (µS/cm)	Heard Bridge	-0.210	-0.735	0.000	Decreasing
Specific Conductance (µS/cm)	E. Main St.	-0.207	-0.712	0.000	Decreasing
Specific Conductance (µS/cm)	Zolfo Springs	-0.226	-0.689	0.000	Decreasing
pH (SU)	Peace Creek	-0.500	-0.543	0.000	Decreasing

Parameter	Station	Slope	Tau	p_adj.	Trend
pH (SU)	Bartow	-0.279	-0.388	0.000	Decreasing
pH (SU)	Fort Meade	-0.352	-0.516	0.000	Decreasing
pH (SU)	Mt. Pisgah	-0.447	-0.572	0.000	Decreasing
pH (SU)	Co. Line Rd.	-0.473	-0.558	0.000	Decreasing
pH (SU)	Heard Bridge	-0.394	-0.459	0.000	Decreasing
pH (SU)	E. Main St.	-0.406	-0.361	0.000	Decreasing
pH (SU)	Zolfo Springs	-0.513	-0.578	0.000	Decreasing

Table 3-20.Summary of trends with flow for date-adjusted inorganic ions.

Parameter	Increasing	Decreasing	Not Significant
Fluoride (mg/L)	0	8	1
Potassium (mg/L)	0	4	1
Specific Conductance (µS/cm)	0	8	0
pH (SU)	0	8	0
Total	0	28	2

3.6 Dissolved Oxygen and Water Temperature

Oxygen gas from the atmosphere dissolves into water based on partial pressure and temperature. It is crucial for fish habitats, as low oxygen levels can lead to fish die-offs. Dissolved oxygen also influences redox potential, which affects the bioavailability of minerals and ions (Allan et al. 2021). Temperature is another important aspect of water quality. Gases like oxygen are more soluble in water at lower temperatures, leading to higher potential concentrations. Additionally, temperature impacts the growth rates of phytoplankton and other organisms. For example, metabolic rates increase with temperature. However, if temperature gets too high, it can stress organisms and reduce growth. Different species have varying temperature preferences and tolerances. Changes in temperature can shift the composition of communities in the ecosystem.

Dissolved oxygen (DO) is measured in milligrams per liter (mg/L). Since temperature affects the solubility of oxygen, the percentage of oxygen relative to the maximum possible concentration varies with temperature. This percentage is known as saturation (DO sat) and is expressed as a percentage (%). At higher temperatures, the same concentration of oxygen will have a higher percent saturation.

3.6.1 Descriptive Statistics of Dissolved Oxygen and Water Temperature

Means and medians across all sites for dissolved oxygen and temperature are shown in Table 3-21. Both dissolved oxygen and water temperature were negatively skewed.

Boxplots (Figure 3-13) provide visual summaries of: 1) the center of the data (the median is the center line of the box), 2) the variation or spread (interquartile range is the box height), 3) the skewness (quartile skew is the relative size of box halves), and 4) presence or absence of unusual values (lines represent up to 1.5 times the interquartile range [IQR], and circles are outliers beyond 1.5 IQR). The data are displayed on a log scale due to the wide range and skewness of concentrations. This log scale obscures visualization of skewness within each parameter but improves visualization of relative data centrality and spread between parameters.

All parameters are non-normal according to the Anderson-Darling and Probability Plot Correlation Coefficient tests for normality after Log10 transformation of data (Appendix G).

Table 3-21.Univariate summary statistics for dissolved oxygen and water temperature at all sites. The interquartile range (IQR) = P75 – P25. The skewness coefficient (G) is the adjusted third moment divided by the cube of the standard deviation, and is a measure of skewness that is sensitive to outliers (Helsel et al. 2020). A distribution is symmetric if |G| < 0.5, moderately skewed when 0.5 ≤ |G| < 1, and highly skewed when |G| ≥ 1. The quartile skew coefficient (QS) quantifies skewness as the difference in distances of the upper and lower quartiles from the median, divided by the IQR for a resistant measure of skewness. A distribution is symmetric when |QS| < 0.1, moderaleły skewed when 0.1 ≤ |QS| < 0.2, and highly skewed when |QS| ≥ 0.2.

Statistics	**Parameter**		
	DO (mg/L)	**DO_sat (%)**	**Water Temperature (°C)**
Min	0.06	24.1	8.94
P25	4.71	72.9	20.15
P50	6.14	80.7	24.4
Mean	6.113	79.858	23.487
P75	7.72	88.1	27.3
Max	13.94	133	34.64
Obs	1309	461	1585
G	-0.052	-0.332	-0.621
IQR	3.01	15.2	7.15
QS	0.05	-0.026	-0.189

Notes: Obs refer to the number of observations and is dimensionless. G (skewness coefficient) and QS (quartile skew) are also dimensionless.

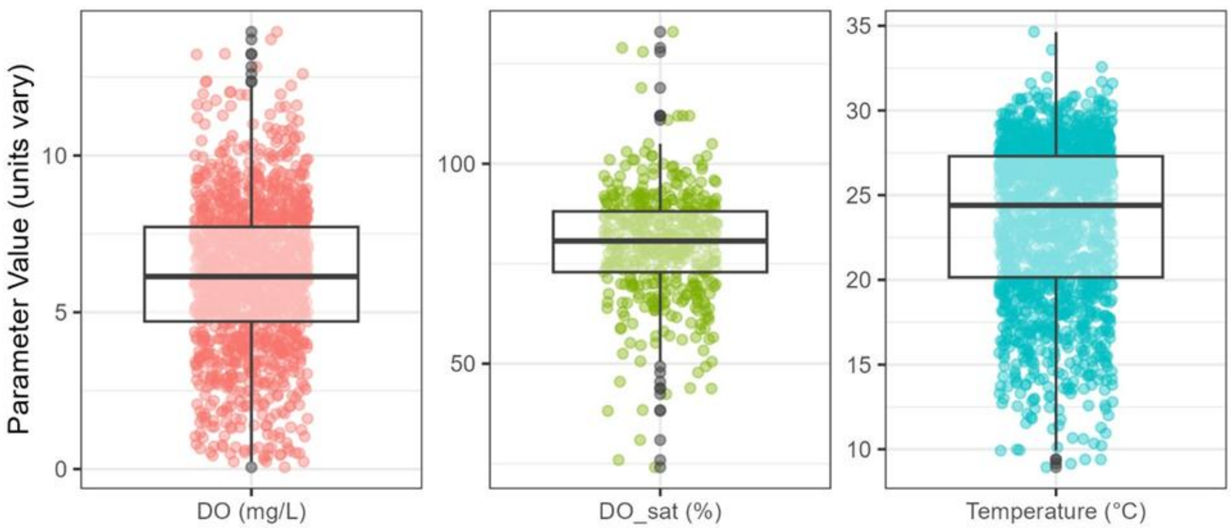


Figure 3-13. Concentrations of dissolved oxygen and water temperature using jittered points to display individual data values and boxplots to summarize the distribution. The y-axis is scaled logarithmically to better visualize the range of concentrations, and boxplot statistics are calculated on non-transformed data.

3.6.2 Seasonal and Spatial Comparisons of Dissolved Oxygen and Water Temperature

There were significant differences between wet and dry seasons for dissolved oxygen and temperature (Figure 3-14). Pairwise Wilcoxson rank-sum tests revealed differences between nine stations (Figure 3-15). Dissolved oxygen concentration was highest at Zolfo Springs and lowest at Bartow. DO saturation was only available at Mt. Pisgah, Co. Line Rd., Heard Bridge, and E. Main St. Median water temperature was highest at Co. Line Rd. and lowest at Fort Meade.

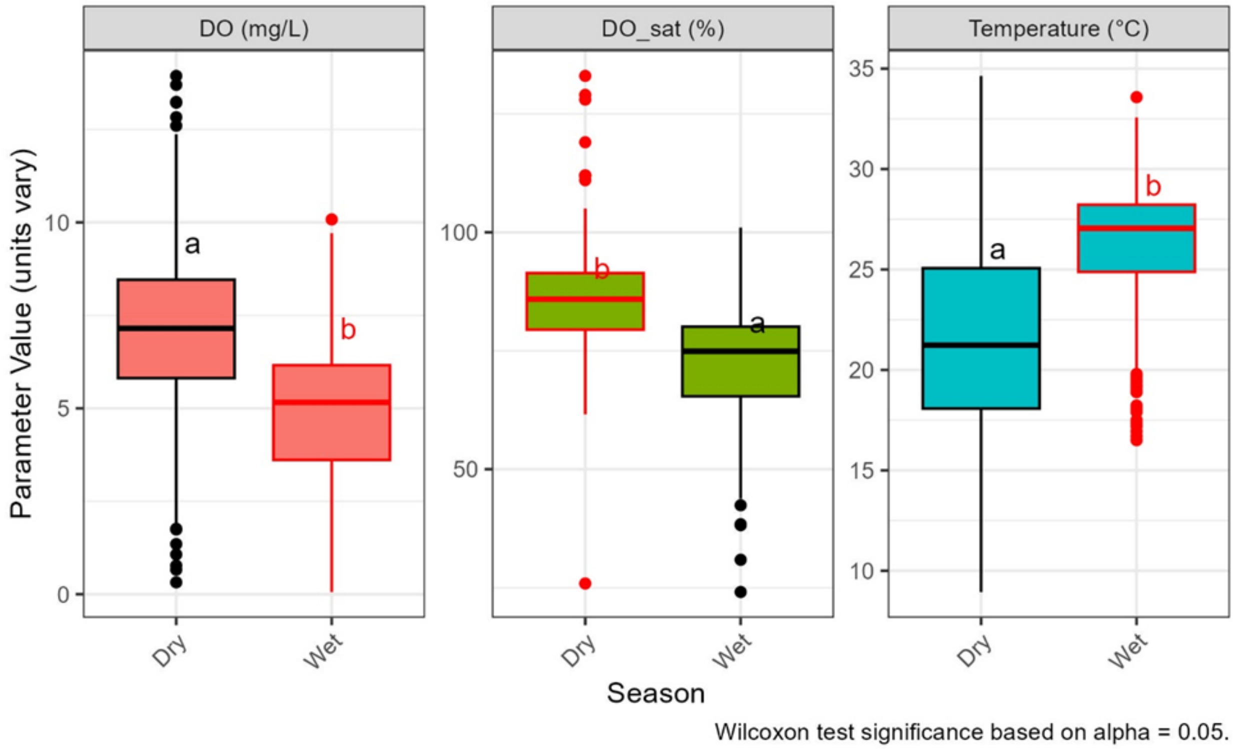


Figure 3-14. Seasonal differences in dissolved oxygen and water temperature. Boxes with different outline colors and letters are significantly different according to a Wilcoxson rank-sum test.

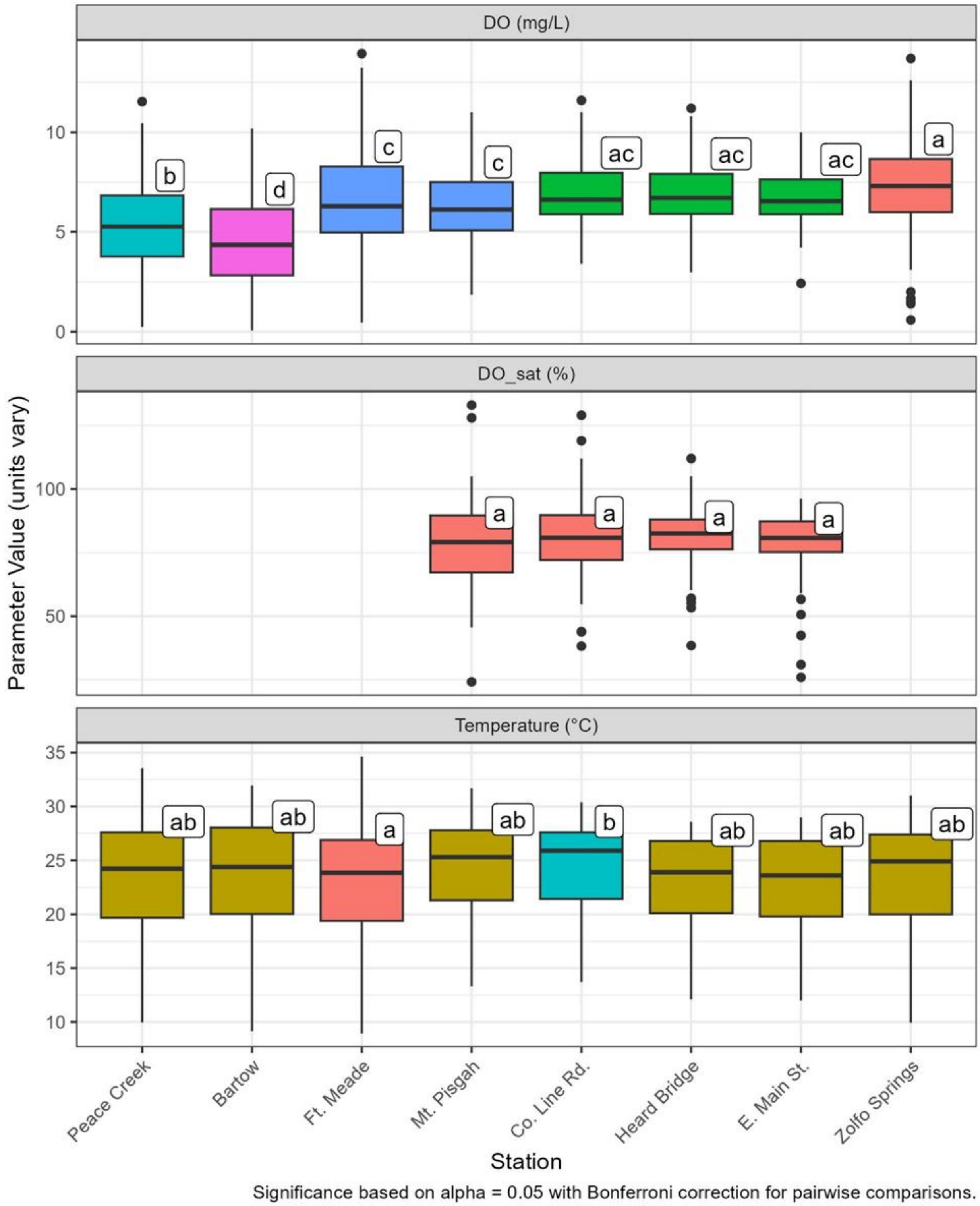


Figure 3-15. Comparison of dissolved oxygen and water temperature by station. Significance values are based on within parameter compsrisons. Stations are ordered from upstream (left) to downstream (right).

3.6.3 Trends in Dissolved Oxygen and Water Temperature

For trends over time, saturated dissolved oxygen and water temperature were not significant at all stations. However, dissolved oxygen trend increased over time at Peace Creek and Mt. Pisgah (Table 3-22). Most relationships (18 of 20) had no significant trend, while all significant trends were increasing (2 of 20) and none were decreasing (0 of 20) with time (Table 3-23). Results of trends with flow are mixed (Table 3-24). Most flow trends (12 of 20) were decreasing (Table 3-25). Plots of all trends are shown in Appendix G.

Table 3-22. Results of trends over time for flow-adjusted dissolved oxygen and water temperature. Slope scaled per decade. Trends are classified as Positive, Negative, or Not Significant based on Kendall's Tau significance (α = 0.05). Adjusted p values (p_adj.) are adjusted using Bonferroni correction for the number of stations tested.

Parameter	Station	Slope	Tau	p_adj.	Trend
DO (mg/L)	Peace Creek	0.633	0.143	0.006	Increasing
DO (mg/L)	Bartow	0.340	0.075	0.591	Not Significant
DO (mg/L)	Fort Meade	0.023	0.005	7.256	Not Significant
DO (mg/L)	Mt. Pisgah	3.828	0.284	0.005	Increasing
DO (mg/L)	Co. Line Rd.	2.000	0.187	0.193	Not Significant
DO (mg/L)	Heard Bridge	1.607	0.144	0.660	Not Significant
DO (mg/L)	E. Main St.	1.670	0.130	0.937	Not Significant
DO (mg/L)	Zolfo Springs	-0.286	-0.089	0.229	Not Significant
DO_sat (%)	Mt. Pisgah	7.937	0.154	0.071	Not Significant
DO_sat (%)	Co. Line Rd.	4.015	0.099	0.361	Not Significant
DO_sat (%)	Heard Bridge	1.128	0.034	2.417	Not Significant
DO_sat (%)	E. Main St.	1.083	0.026	2.747	Not Significant
Temperature (°C)	Peace Creek	0.455	0.043	2.466	Not Significant
Temperature (°C)	Bartow	0.375	0.038	2.926	Not Significant
Temperature (°C)	Fort Meade	0.178	0.019	5.256	Not Significant
Temperature (°C)	Mt. Pisgah	0.473	0.025	5.423	Not Significant
Temperature (°C)	Co. Line Rd.	0.245	0.014	6.334	Not Significant
Temperature (°C)	Heard Bridge	-0.299	-0.016	6.255	Not Significant
Temperature (°C)	E. Main St.	-0.330	-0.019	5.957	Not Significant
Temperature (°C)	Zolfo Springs	0.096	0.010	6.369	Not Significant

Table 3-23. Count of trends over time for in flow-adjusted dissolved oxygen and temperature.

Parameter	Increasing	Decreasing	Not Significant
DO (mg/L)	2	0	6
DO_sat (%)	0	0	4
Temperature (°C)	0	0	8

Parameter	Increasing	Decreasing	Not Significant
Total	2	0	18

Table 3-24. Results of trends with flow for date-adjusted dissolved oxygen and water temperature. Trends are classified as Increasing, Decreasing, or Not Significant, based on Kendall's Tau significance (α = 0.05). Adjusted p values (p_adj.) are adjusted using Bonferroni correction for the number of stations tested.

Parameter	Station	Slope	Tau	p_adj.	Trend
DO (mg/L)	Peace Creek	-1.193	-0.206	0.000	Decreasing
DO (mg/L)	Bartow	-0.613	-0.131	0.014	Decreasing
DO (mg/L)	Fort Meade	-1.662	-0.399	0.000	Decreasing
DO (mg/L)	Mt. Pisgah	-1.824	-0.457	0.000	Decreasing
DO (mg/L)	Co. Line Rd.	-1.627	-0.428	0.000	Decreasing
DO (mg/L)	Heard Bridge	-1.237	-0.299	0.002	Decreasing
DO (mg/L)	E. Main St.	-0.965	-0.258	0.015	Decreasing
DO (mg/L)	Zolfo Springs	-1.851	-0.402	0.000	Decreasing
DO_sat (%)	Mt. Pisgah	-22.033	-0.577	0.000	Decreasing
DO_sat (%)	Co. Line Rd.	-21.592	-0.657	0.000	Decreasing
DO_sat (%)	Heard Bridge	-12.910	-0.452	0.000	Decreasing
DO_sat (%)	E. Main St.	-9.020	-0.315	0.000	Decreasing
Temperature (°C)	Peace Creek	1.331	0.113	0.058	Not Significant
Temperature (°C)	Bartow	1.068	0.115	0.047	Increasing
Temperature (°C)	Fort Meade	0.772	0.099	0.149	Not Significant
Temperature (°C)	Mt. Pisgah	1.793	0.190	0.011	Increasing
Temperature (°C)	Co. Line Rd.	2.089	0.218	0.000	Increasing
Temperature (°C)	Heard Bridge	2.447	0.244	0.000	Increasing
Temperature (°C)	E. Main St.	2.384	0.236	0.001	Increasing
Temperature (°C)	Zolfo Springs	0.326	0.036	2.996	Not Significant

Table 3-25. Counts of trends with flow for date-adjusted dissolved oxygen and water temperature.

Parameter	Increasing	Decreasing	Not Significant
DO (mg/L)	0	8	0
DO_sat (%)	0	4	0
Water Temperature (°C)	5	0	3
Total	5	12	3

3.7 Water Quality Summary

As part of the reevaluation of minimum flows for the Upper Peace River, in-depth analyses of water quality have been conducted with the intent to illustrate status and trends of key water quality parameters through the periods of record, as well as their relationships with flow. Each water quality parameter exhibits unique characteristics, and understanding the causes behind fluctuations in concentration levels requires a tailored, parameter-specific approach.

As an example of such a causal analysis, the FDEP has developed TMDLs and Basin Management Action Plans (BMAPs) elsewhere in the state. These BMAPS address nutrient pollution by determining sources of nutrients within a system and developing targets for nutrient reductions within designated focus areas of a basin by targeting sources of nutrient pollutants.

Water quantity trends varied with location and time. For example, nitrate-nitrite had consistent, negative relationships with flow at all monitoring sites but Saddle Creek at P11, which receives untreated water from Lake Hancock. In contrast, Total Nitrogen increased with flow in Peace Creek, decreased with flow at mid-reach sites (Fort Meade, Mt. Pisgah, and Co. Line Rd.), and showed no significant trend at downstream sites (Heard Bridge, E. Main St., and Zolfo Springs). As shown in Figure 3-1 and Table 3-1, WBID 1623H, which includes Co. Line Rd. is impaired for Total Nitrogen, total phosphorus, and chlorophyll a. However, Total Nitrogen did not increase at Co. Line Rd. over its period of record, and Total Nitrogen is not impaired at the two downstream-most WBIDs 1623G and 1623F which are in the lower segment of the river.

Given these inconsistencies, a blanket recommendation to maintain higher flows throughout the Peace River based on correlations between flow and Total Nitrogen was not supported by the regression results. Instead, management of nitrogen should follow FDEP's established framework for TMDLs and BMAPs focusing on identifying sources of nitrogen within the watershed and collaborating with local counties, municipalities, and other entities to reduce nutrient loads through improved wastewater treatment and other mitigation means.

Although a majority of the nutrient trends with flow were negative, showing reduced concentrations with increased flow, temporal trends were also frequently negative, demonstrating decreasing concentrations over the past 10-20 years. However, chlorophyll a and turbidity tended to increase with flow, while DO decreased. These findings highlight the complexity of water quality dynamics and caution against simplistic flow-based solutions. Increasing flow to reduce nutrient concentrations may overlook the underlying causes and interactions among various water quality parameters.

CHAPTER 4 RESOURCES OF CONCERN: MANAGEMENT GOALS AND KEY HABITAT INDICATORS

4.1 Resources and Area of Concern

This minimum flows reevaluation focuses on the surface waters and biological communities of the Upper Peace River system, including its main river channel and adjoining floodplain areas. The Upper Peace River is recognized as one of the most important hydrologic and ecological features in West-Central Florida. Characterized by a meandering channel and expansive floodplain wetlands, the system's physiographic complexity supports a diverse array of flora and fauna species. As noted by Bunn and Arthington (2002), "aquatic species have evolved life history strategies primarily in direct response to the natural flow regimes."

The Peace River system has also been identified as a critical component of the region's wildlife corridor network (Cox et al. 1994, SWFWMD 2001). Consequently, a primary objective of this MFLs analysis is to define the hydrologic conditions required to sustain the biological communities dependent on the Upper Peace River. In addition to ecological functions, the reevaluation acknowledges the importance of human uses, including fishing, swimming, boating, scenic and wildlife viewing, and other forms of general recreation.

4.2 Resource Management Goals

As outlined in Section 1.5, the District approach for developing minimum flows is habitat-based. The river system contains a diverse array of aquatic and wetland habitats that support a wide range of biological communities. To facilitate the minimum flows analysis, key habitats were identified for evaluation, and, where feasible, the hydrologic requirements of specific biotic assemblages associated with these habitats were determined.

The resource management goals for the Upper Peace River are summarized in Table 4-1. These goals are designed not only to protect measurable ecological attributes but also to help preserve other vital ecological functions that are not practically quantified, such as the transport of organic matter and the maintenance of river channel geomorphology.

Table 4-1. Summary of resource management goals, relevant environmental values and specific criteria used to address the goals and develop recommended minimum flows for the Upper Peace River.

Goals	Relevant Environmental Values	Criteria
Maintenance of minimum water depths in the river	• Recreation in and on Water • Fish and Wildlife Habitats and the Passage of Fish	A minimum of 0.6 ft water depth considered for low-flow threshold.

Goals	Relevant Environmental Values	Criteria
channel for fish passage and recreational use.	• Water Quality • Navigation	
Maintenance of water depths above inflection points in the productive wetted perimeter of the river channel to maximize aquatic habitat.	• 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	Wetted perimeter inflection points considered for multiple flow thresholds.
Maintenance of instream habitat suitability for selected fish species and macroinvertebrate assemblages.	• Fish and Wildlife Habitats and the Passage of Fish • Transfer of Detrital Material Sediment Loads	Limiting instream habitat losses to 15 percent based on System for Environmental Flow Analysis (SEFA).
Maintenance of Inundation of woody habitats (e.g., snags and exposed roots) in stream.	• Fish and Wildlife Habitats and the Passage of Fish • Transfer of Detrital Material Sediment Loads	Limiting temporal changes in the inundation of woody habitats to 15 percent based on long-term inundation analyses.
Maintenance of seasonal hydrologic connections between the river channel and floodplain to protect floodplain structure and function.	• 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	Limiting spatial and temporal changes in floodplain inundation to 15 percent based on long-term inundation analyses.

These management goals align with those recognized by other researchers, as discussed in Chapter 1. The rationale for selecting these goals, along with the associated habitats or ecological indicators, is discussed in the subsections that follow. Chapter 5 describes the field work and analytical methods used to assess the hydrologic requirements of these habitats and indicators, while Chapter 6 presents the results of the minimum flows analysis.

4.2.1 Fish Passage and Recreational Use

The U.S. Fish and Wildlife Service (USFWS) defines *fish passage* as the ability of fish or other aquatic species to move freely through aquatic systems and access all habitats necessary to complete their life cycles. River fragmentation, caused by dams, culverts, or significant flow reductions, can prevent fish from reaching breeding grounds, food sources, or safe refuges. Ensuring adequate flows to support fish passage is therefore essential for the protection of aquatic life and the preservation of ecosystem integrity.

Tharme and King (1998, as cited in Postel and Richter 2003) identified the retention of a river's natural perenniality or non-perenniality as one of eight foundational principles for river flow management. Maintaining adequate longitudinal connectivity, i.e., continuous flow along the river corridor, is critical for natural fish movement and is a key consideration in minimum flow development.

Beyond ecological importance, maintaining flow facilitates recreational navigation (e.g., canoeing), enhances aesthetic value, and mitigates the risks of pool isolation. Isolated pools are more susceptible to elevated water temperatures, reduced dissolved oxygen levels, localized phytoplankton blooms, and heightened predation due to reduced cover or habitat availability.

Historically, many rivers in the District, including the Upper Peace River, relied on baseflow during the dry season to maintain flow depths sufficient for fish passage. The Upper Peace River once supported perennial flow even during low-flow seasons, allowing fish to migrate along most of the river corridor (SWFWMD 2002). However, beginning in the 1950s, the river became a losing stream, with flow conditions frequently inadequate for aquatic connectivity. Prolonged dry spells fragmented the upper river into isolated pools, some of which contracted severely or dried entirely, resulting in significant impacts to fish populations and other aquatic communities.

The shift in flow regime has been attributed to several factors, including regional groundwater withdrawals and extended periods of reduced rainfall, as discussed in Section 2.4. These impacts were especially pronounced during drought years, most notably within the river segment between Bartow and Fort Meade, where inadequate flows severely limited fish passage.

In response, the District adopted MFLs for the Upper Peace River in 2006 and subsequently developed the SWUCA Recovery Strategy (SWFWMD 2006a). One of its primary goals is to restore MFLs in the Upper Peace River by 2025 through the implementation of recovery projects. Among these initiatives is the Lake Hancock Lake Level Modification Project, which focused on modifying the P-11 control structure and was completed in 2014 (see Section 1.1 for details). Since 2016, the District has operated the modified P-11 control structure with the central goal of achieving the existing minimum (low) flow targets for the Upper Peace River. Flow conditions have shown significant improvement since then, except in 2017, which experienced an exceptionally dry spring. Notably, the Upper Peace River consistently met its MFLs from 2020 through 2024.

To support the reevaluation of minimum flows and evaluate conditions favorable to fish passage, both historical and recent flow data are being analyzed, particularly in relation to perennially and the likelihood of natural fish passages in the absence of consumptive water use.

To preserve ecological connectivity and support sustained low-flow conditions, the District applies a 0.6-ft fish-passage depth criterion. This fish-passage criterion has been consistently used in District minimum flows determinations and was endorsed by the peer review panel for the Upper Peace River (Gore et al. 2002), along with subsequent review panels. Shaw et al. (2005) affirmed this standard, stating that "the 0.6-ft standard represents best available information and is reasonable". In an evaluation of the FWC's Florida Trophy Catch dataset (Dutterer 2015), Nagid (2022) found that this criterion is protective of the vast majority of Florida Bass inhabiting streams throughout Florida.

4.2.2 Wetted Perimeter Inflection Point

The wetted perimeter refers to the length of the channel's boundary that is in contact with water, including the bottom and sidewalls. This parameter is fundamental in hydrology, geomorphology, and environmental engineering and plays a key role in assessing aquatic habitats, particularly for fish, benthic macroinvertebrates, and floodplain ecosystems. It is often used in conjunction with hydraulic radius or hydraulic diameter to analyze channel dynamics and morphology.

In open-channel flow, plotting wetted perimeter against incremental changes in discharge produces a curve that often features a point of inflection, referred to as Wetted Perimeter Inflection Point (see Figure 4-1). The point represents the discharge level at which small reductions in flow result in disproportionally large losses in wetted perimeter, signaling a threshold critical for aquatic habitat availability, particularly for organisms like benthic macroinvertebrates that rely on streambed conditions.

Studies by Benke et al. (1985) on southeastern streams demonstrated that the greatest amount of macroinvertebrate biomass per unit stream reach occurs on the stream bottom. While productivity per unit area may be greater on snag and root habitats, the broader area of stream bottom makes it the most productive habitat under low flow conditions. As such, the wetted perimeter method (WPM) is considered an important technique for evaluating minimum flows and levels in the low end of the flow regime.

Annear and Conder (1984) noted that WPMs assume a direct relationship between wetted perimeter and fish habitat. Stalnaker et at. (1995) described 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." This approach is especially valuable in riffle or shoal areas (shallow, fast-flowing areas), where minimum flows are assumed to support food production, fish passage, and spawning.

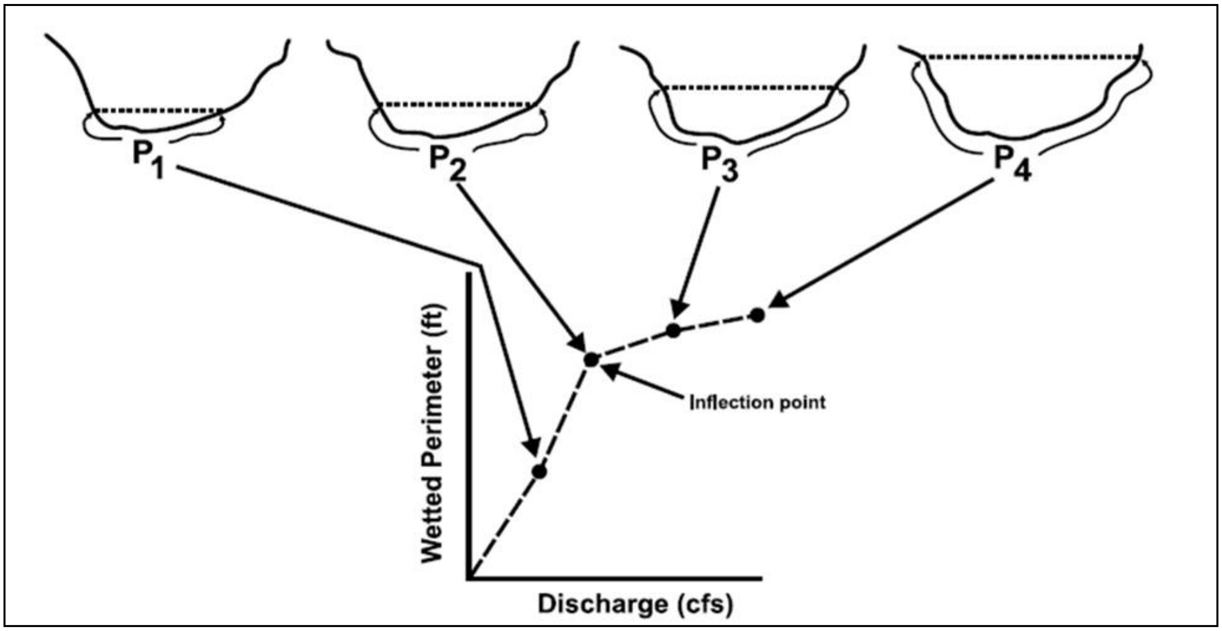


Figure 4-1. Relationship between wetted perimeter and discharge with identified inflection point. Labels P1 through P4 represent progressively higher discharge and water levels. P1 indicate the lowest water level, where the wetted perimeter is relatively small. As discharge increases through P2, P3, and P4, the wetted perimeter expands as more of the channel's cross-sectional boundary becomes submerged. Adopted from Nelson (1980).

The method involves measuring the wetted perimeter at different flow rates and plotting these values against discharge (flow rate) to identify breakpoints. The inflection point, or point of maximum curvature on the graph, indicates a critical flow threshold: below this discharge, a small decrease in flow leads to a rapid decline in the wetted perimeter, indicating a significant decrease in the available aquatic habitat.

Historically, minimum flows development has focused on identifying a single inflection point, termed the Lowest Wetted Perimeter Inflection Point (LWPIP) in the low-flow regime. However, multiple inflection points may be present, particularly in streams with complex channel geometries or highly variable flow regimes. These points could be identified either virtually by inspecting the changes in curve slope or analytically using methods that assess where the slope change or curvature is maximized.

In addition to the LWPIP that is commonly used in minimum flows studies, this reevaluation for the Upper Peace River MFLs also considers additional inflection points for bankfull and low floodplain inflection stage.

- **Bankfull Stage** represents the discharge at which a stream channel is full and further increases in flow results in overbank flooding. Inflection points associated with bankfull conditions often correspond to a noticeable change in curve slope, marking the transition from in-channel to overbank flow, which is important criteria in evaluating the hydrologic connection between the river and floodplain as further discussed in Section 4.2.5.
- **Low Floodplain Inflection Stage** refers to conditions where the river approaches the tops of its banks but not yet overflowing onto the wider floodplain. The inflection point here identifies the discharge at which a relatively small increase in water level inundates a large portion of the floodplain, causing a pronounced increase in the wetted perimeter.

The WPM is instrumental in identifying minimum flow thresholds needed to sustain ecological functions in streams and rivers. By identifying critical discharges, whether for in-channel habitat maintenance or floodplain connectivity, it helps ensure that the river maintains a sufficient level of water to support aquatic ecosystems. While WPM provides valuable insights into flow-habitat relationships, it is typically integrated into broader instream flow assessments, which combine multiple techniques and ecological indicators to develop robust minimum flow recommendations.

4.2.3 Instream Habitat for Fish and Benthic Macroinvertebrates

Instream habitat is included in the ten environmental values in the Water Resource Implementation Rule (62-40.473, F.A.C.) as "fish and wildlife habitats and the passage of fish." Fish, including both game and non-game taxa, and the invertebrates that support the ecosystem have specific requirements for water depth, velocity, and qualitative aspects of the environment, including substrate type (e.g., sand, mud) and presence of cover, such as large woody debris. Instream habitat modeling combines field measurements with hydraulic equations to predict changes to habitat under modified flow regimes.

Habitat is the resources and conditions present in an area that produce occupancy, including survival and reproduction, by a given organism (Hall et al. 1997). The resources and conditions present include various physical, chemical, and biological aspects which can vary across a wide range of values. Water depth and velocity are continuous, quantifiable metrics that can be measured in the field and modeled as part of alternative flow regimes. In addition, qualitative habitat variables, including fallen logs, vertical and overhanging banks, and vegetated shorelines, are differentially inundated as flows advance and recede along the streambed and floodplain.

The SEFA software package offers a flexible modeling framework for quantifying changes to the habitat of fish and other stream life in response to changing flow regimes (Jowett et al. 2020). The SEFA software is capable of analysis identical to

PHABSIM or Physical Habitat Simulation (Milhous and Waddle 2012), which was commonly used in past minimum flows analysis by the District, and offers options for analysis in addition to PHABSIM methods. The SEFA approach models the effects of flow on depth, velocity, and inundation of qualitative habitat features to predict overall habitat suitability under varying flow regimes.

Because habitat includes all the conditions present, it can be characterized in a stream by measuring water depths and velocities and reporting presence of qualitative habitat aspects in cross-sections perpendicular to flow (Figure 4-2). Habitat suitability is quantified individually for species, life history stages, or habitat-use guilds as indices where suitability is scaled from zero (unsuitable) to one (most suitable) (Nestler et al. 2019). The Florida Handbook of Habitat Suitability Indices provides a list of habitat suitability indices appropriate for use in Florida and describes the history of their development (Nagid 2022, 2025). These indices relate water depth, velocity, and qualitative aspects (e.g., presence of wood, sediment characteristics, and other discrete characteristics) to relative suitability for occupancy (Figure 4-3).

SEFA uses these habitat suitability indices, along with depth, velocity and inundation of qualitative aspects to calculate habitat suitability at discrete intervals in a cross section as a combined suitability index (i.e., the combination of depth, velocity, and qualitative aspects). Furthermore, those combined suitability indices at each interval are weighted by the area of the cross section they represent and averaged to create an area-weighted suitability index (AWS). The AWS can be summed across numerous cross sections to provide a metric of total habitat suitability for a species within a reach of a stream.

The ultimate output of SEFA is an AWS-flow relationship for each species, life history stage, or habitat guild. This relationship links flow values to corresponding AWS values, allowing time series of flows to be converted into time series of habitat suitabilities. These can then be compared across alternative flow regimes to evaluate ecological impacts.

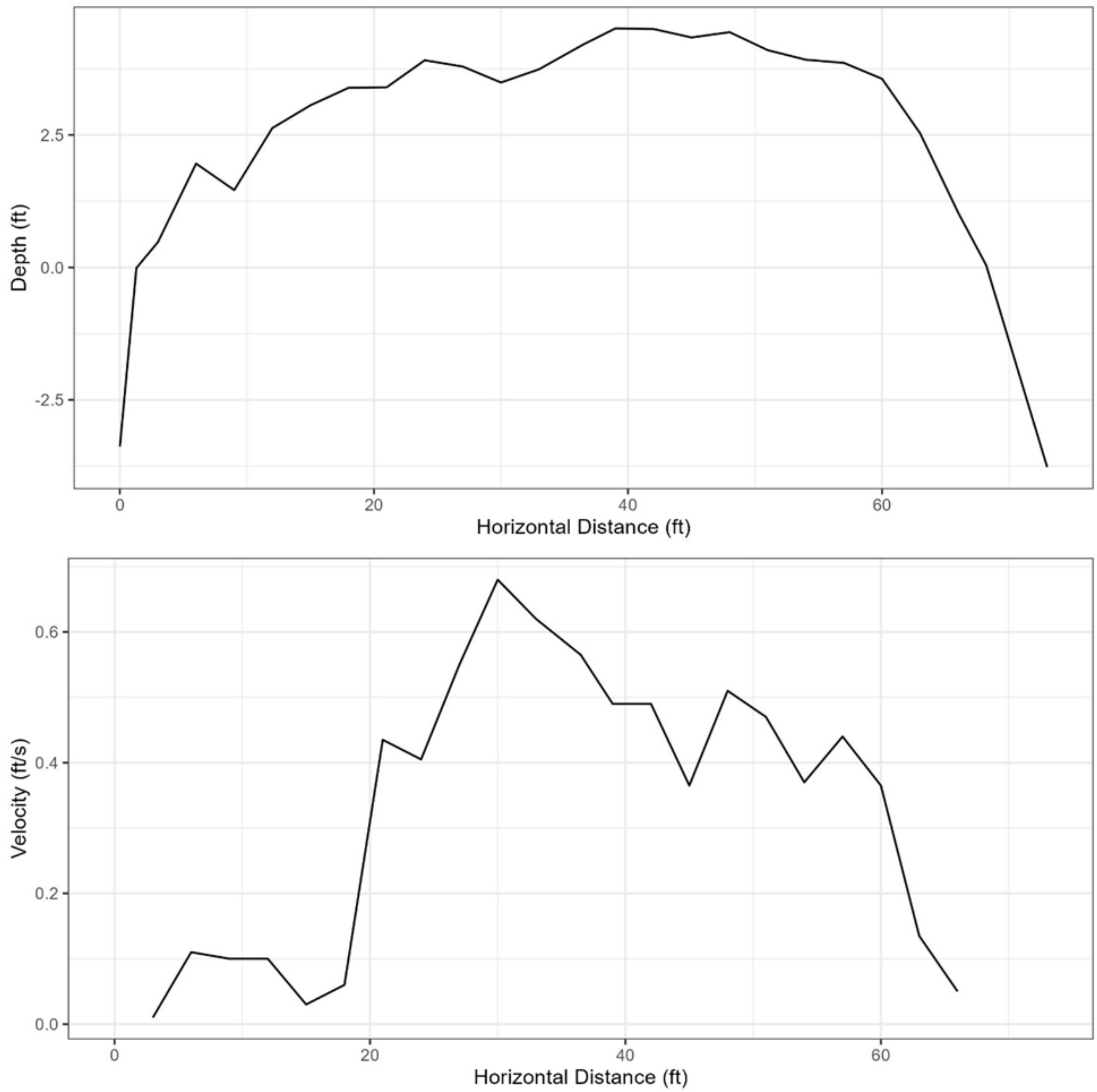


Figure 4-2. Example cross-section profile of depth and velocity from field observations.

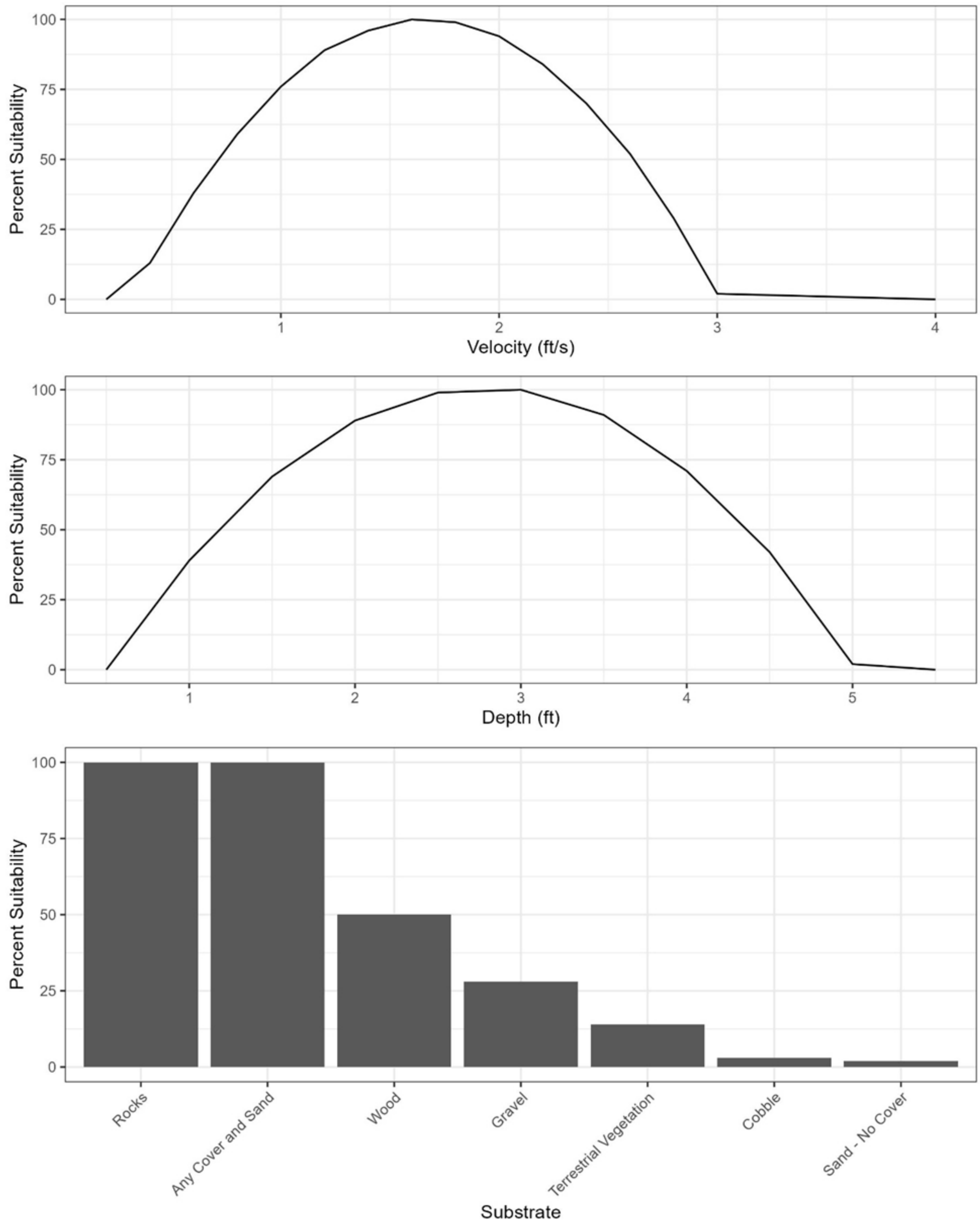


Figure 4-3. Example of habitat suitability curves for net-spinning caddisflies (Hydropsychidae). Substrate category descriptions simplified for plotting.

4.2.4 Instream Woody Habitats

Woody habitats are important instream features that serve as a relatively stable, structurally multifaceted medium that provides cover for organisms, particularly invertebrates and fish (Benke and Wallace 1990). As structurally stable physical impediments to flow, woody structures enhance the formation of leaf packs and debris dams that further improve instream habitat complexity and diversity. With sustained inundation, microbial conditioning and periphyton growth can occur on woody materials, leading to macroinvertebrate colonization and subsequent support for aquatic food webs (Edwards and Meyer 1987, Benke and Wallace 2003). Studies in the Southeast U.S. have demonstrated that woody habitats can harbor the most biologically diverse instream fauna of those examined and are the most productive habitat on a per area basis (Benke et al. 1985). Maintaining flows required to ensure different periods of woody habitat inundation can be protective of instream habitats.

4.2.5 Hydrologic Connections between the River and Floodplain

Floodplains have long been recognized as seasonally vital components of riverine ecosystems. A key objective of the District's MFLs approach is to ensure that the hydrologic requirements of biological communities associated with floodplains are met during seasonally predictable wet periods. Periodic inundation of riparian floodplains by high flows is closely linked with the overall biological productivity of river ecosystems (Crance 1988, Junk et al. 1989).

Many fish and wildlife species that inhabit rivers rely on both instream and floodplain habitats, and inundation of the river floodplains greatly expands the habitat and food resources available to these organisms (Wharton et al. 1982, Ainsle et al. 1999, Hill and Cichra 2002). Inundation during high flows also provides a subsidy of water and nutrients that supports high rates of primary production in river floodplains (Conner and Day 1979, Brinson et al. 1981). This primary production generates large amounts of organic detritus, which is critical to food webs on the floodplain and within the river channel (Vannote et al. 1980, Gregory et al. 1991).

In addition to supporting food webs, floodplain inundation influences other physical and chemical processes that can affect biological production, uptake, and transformation of macro-nutrients (Kuensler 1989, Walbridge and Lockaby 1994). Alluvial processes associated with variable flow regimes shape topographically diverse floodplains, characterized by features such as levees, sloughs, secondary stream channels, and broad, gently sloping plains (Leopold et al. 1964, Stanturf and Schoenholtz 1998). These landforms create a mosaic of habitats supporting a wide range of plant and animal species (Wharton et al 1982, Wigley and Lancia 1998).

Hydrologic conditions within floodplains vary considerably, with the duration of soil saturation and inundation varying with factors, such as surface elevation, channel connectivity, and groundwater levels (Light et al. 1998, Williams 1998). These hydrologic gradients foster biological diversity (Mitsch and Gosselink 1993, Uranowski et al. 2002). While some dominant species may share similar hydrologic requirements, others depend on more narrowly defined flow regimes. These differences are often reflected in the development of distinct soil types, which in turn influence the composition and structure of floodplain communities.

Thus, assessing the hydrologic requirements of dominant taxa or communities alongside the distribution of floodplain soils may be important for determining minimum flows in the higher range of the flow regime for the Upper Peace River.

CHAPTER 5 ESTABLISHING MINIMUM FLOWS: METHODS, DATA, AND ANALYTICAL FRAMEWORKS FOR THE UPPER PEACE RIVER

5.1 Overview

This chapter presents the data collection efforts, baseline flow characterization, modeling tools, and analytical approaches used to determine minimum flows for the Upper Peace River. The study reach extends from the USGS Peace River at SR 60 at Bartow, FL gage (02294650) to the USGS Peace River at US 17 at Zolfo Springs, FL gage (02295637).

The chapter begins with a summary of topographic, bathymetric, and instream habitat data collection. It then describes the two primary modeling tools: PRIM and HEC-RAS, which provided the foundational data for establishing minimum flow thresholds and assessing ecological responses. This is followed by a description of the development of baseline flows and the construction of flow blocks.

The methodology incorporates analyses of fish passage, wetted perimeter, floodplain inundation, and instream habitats. Each analytical method is introduced individually, highlighting its role in identifying minimum flow thresholds based on its relevance to low-, medium-, and high-flow conditions. These assessments were applied across three river segments of the Upper Peace River, as illustrated in Figure 2-2.

5.2 Data Collection for Minimum Flows Assessment

In support of reevaluating the minimum flows for the Upper Peace River, topographic, hydrographic, and habitat data were essential for model development and technical analyses. These data were collected through contracted projects with consultants, which aimed to characterize floodplain topography, river bathymetry, and instream habitat features. The hydrologic data collected by USGS at the gaging stations on the main channel and tributaries serve as the primary data sources for this reevaluation. Detailed descriptions of this hydrologic data are provided in Section 2.3.

5.2.1 Topographic LiDAR Mapping

In 2014, the District contracted with Aerial Cartographics of America, Inc. (ACA) and two additional consultants, and the USGS to collectively perform a topographic survey using LiDAR technology. The project area covered approximately 150 square miles, including the entire Peace River corridor, Lower Saddle Creek, and Lake Hancock Treatment Wetland area across four counties: Polk, Hardee, DeSoto, and Charlotte (Figure 5-1). The purpose of this study was to produce accurate, high-resolution ground LAS, a standardized format for interchanging and archiving LiDAR point cloud data.

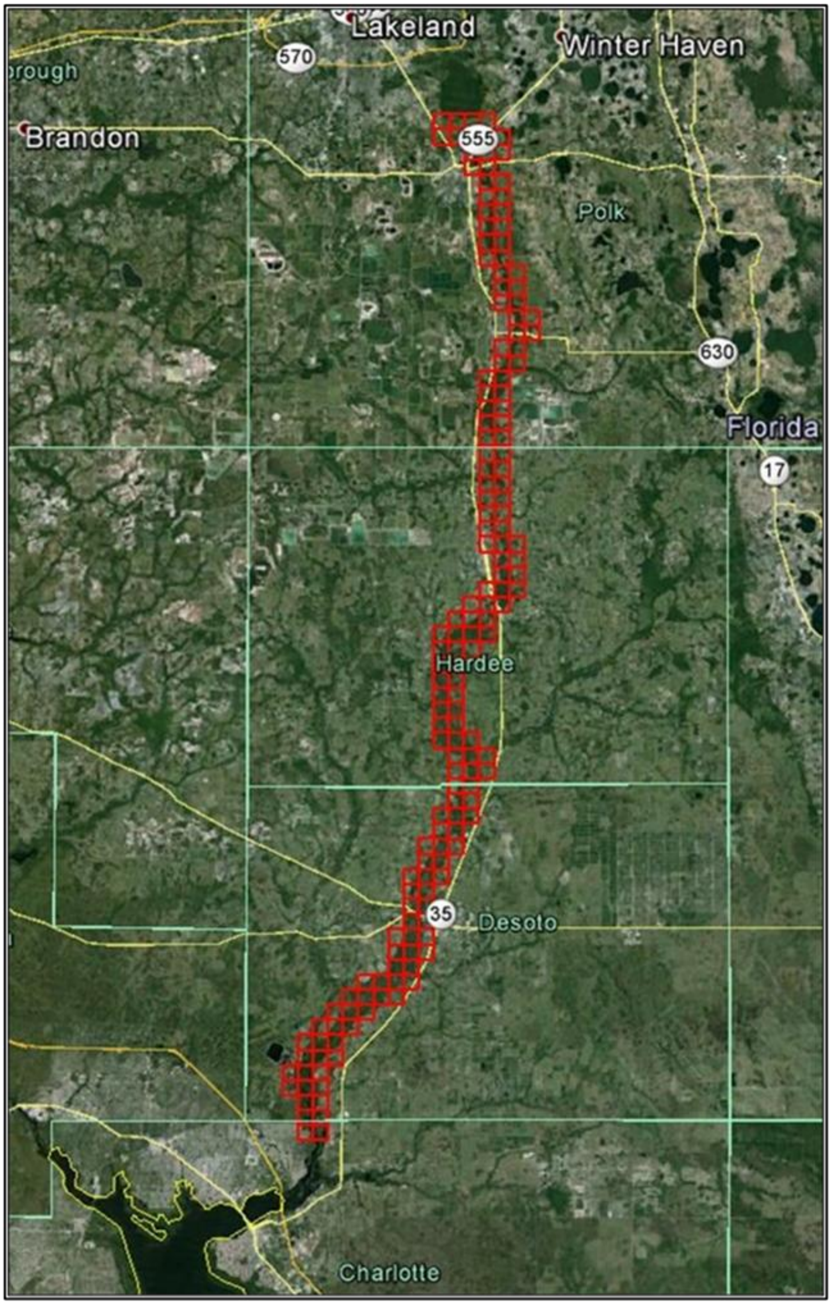


Figure 5-1. llustration of the 2014 LiDAR acquisitionalong the Peace River. Adapated from Figure 1 in ACA (2014).

ACA utilized the RIEGL Q680i Laser technology to collect the LiDAR data. The resulting dataset was used to generate detailed topographic products, including breaklines, one-foot contours, and a digital elevation model (DEM) for 167 standard titles measuring 5,000-feet by 5,000-feet, as illustrated in Figure 5-1.

To support the HEC-RAS model development and other floodplain elevation analyses for the MFLs reevaluation, the District merged the LiDAR data with the most current county DEMs at that time, specifically the 2015 Polk and Hardee County LIDAR/DEM datasets, to generate countywide DEMs. These merged countywide DEMs were spatially sufficient to represent inundation extents during historical high-flow events along the Peace River corridor.

Although during HEC-RAS model development, the newer statewide DEMs from the USGS Florida's 2019 Peninsula LiDAR Project, covering Polk and Hardee Counties, had been accepted by the USGS, they were still under review by the District's enhancement process and were therefore not considered in this effort.

It is important to note that LiDAR technology has limitations in capturing channel bathymetry. These limitations were likely due to poor light penetration in the highly tannic and turbid water, as well as interference from aquatic vegetation extending above the water surface in some portions of the river during the 2014 LiDAR survey. As a result, a dedicated bathymetry survey of the main channel was essential to supplement the LiDAR data.

5.2.2 Bathymetric Data Survey

A channel bathymetric survey, which maps the depth and shape of a channel's underwater terrain, is crucial for navigation, dredging, and understanding water flow. This survey was necessary to acquire river bottom elevation data to construct the required geometry data for the HEC-RAS modeling briefly discussed in Section 5.3.2. The channel bathymetric data supplements the floodplain DEMs to overcome the limitations of LiDAR, as mentioned in Section 5.2.1.

The HEC-RAS model used for the previous minimum flows assessment for the Upper Peace River (SWFWMD 2002) was originally obtained from the USGS by the District in 2000. The geometry data were primarily based on information acquired in the 1970s, although the model was updated by adding 18 cross-sections by the District (SWFWMD 2002). Since 2002, various surveys for cross-sections and bridges were conducted by PBS&J (2003), Lombardo, Foley & Kolarik, Inc. (2008), BCI (2010), Pickett Surveying & Photogrammetry (2011 and 2020), and HSW-Verdantas (2021) through various District projects, summarized below. The survey performed by Pickett in 2020 was particularly significant for supporting the current minimum flows reevaluation, as they collected cross-sectional data to fill in areas where existing geometric data were limited or outdated.

Below, we summarize surveys performed by various entities between 2000 and 2024 through contracts with the District:

- 2002: 18 vegetation transects surveyed by the District, in collaboration with PBS&J, as documented in SWFWMD (2002).

- 2008: Lombardo, Foley, & Kolarik, Inc. surveyed cross sections and hydraulic features in the Upper Peace River's tributaries Bear Branch and Sixmile Creek in June and five bridges and their associated cross-sections in the Upper Peace River in July through Ardaman & Associates, Inc. (2008). Four of the 5 bridges were resurveyed by BCI in 2010.
- 2011: Pickett collected transect data at nine bridges and 13 shoal locations. A single transect line was collected for each shoal location, and a total of four transect lines were collected for each bridge.
- 2013: Field data at four locations (i.e., Bartow, Fort Meade, Bowling Green, and O'Neal) along the Peace River were surveyed by Gore for use in PHABSIM. The Bartow, Fort Meade, and Bowling Green sites were part of Pickett's 2011 survey, and the O'Neal site was part of the 18 vegetation transects surveyed in 2002.
- 2020: Pickett collected elevation data at 93 transects. At 89 locations, a single transect line was collected, and at the one bridge survey (US 17), a total of four transect lines were collected. The lengths of the transect lines were extended 100 feet beyond the water boundaries of the LiDAR data provided by the District.
- 2022: Verdantas collected data at nine SEFA sites (three transects per site) for a total of 27 cross-sections between the SR 60 at Bartow and Zolfo Springs gages. This effort mainly supported instream habitat data collection as discussed in Section 5.2.3 and partially supplemented the bathymetric data for the HEC-RAS modeling.

In 2020, Pickett surveyed 44 cross sections between the SR 60 at Bartow and Fort Meade gages. Of these, 38 cross sections overlap with the existing HEC-RAS model cross sections (Figure 5-2 and Figure 5-3), and six new cross sections were added. Between Fort Meade and Zolfo Springs, Pickett surveyed 49 cross sections, with 40 overlapping the existing HEC-RAS model cross sections (Figure 5-2 and Figure 5-3) and nine new cross sections added. Among the 78 overlapping cross sections, 45 replaced outdated USGS surveyed cross sections, 17 replaced previous vegetation transects, 11 replaced previous BCI cross sections, four were for the bridge on US 17, and one was for shoal 16 that were used in the 2011 HEC-RAS model (Chen 2011), as introduced in Section 5.3.2.1. Fifteen newly added cross sections were used to fill large gaps that existed between some cross sections in the 2011 HEC-RAS model.

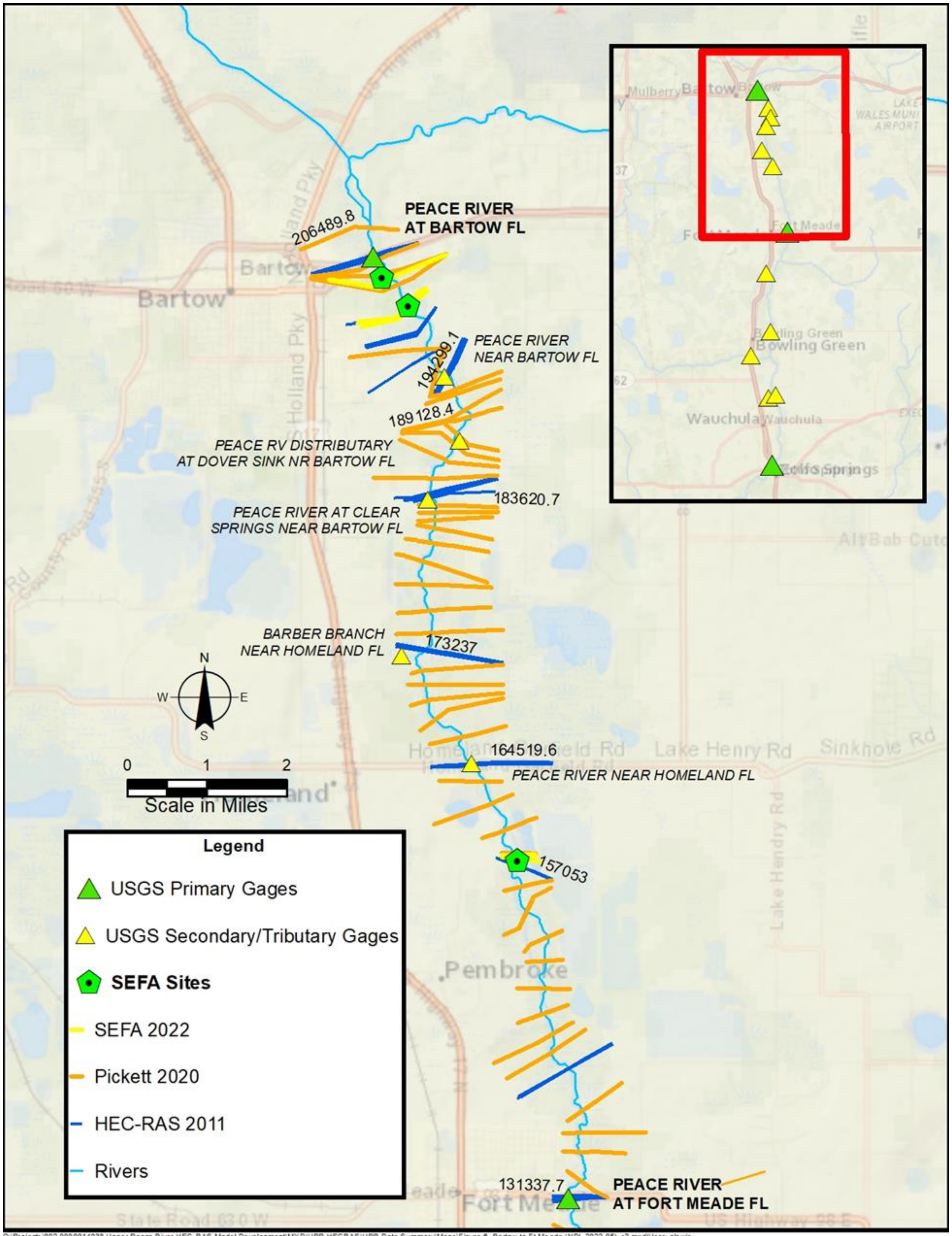


Figure 5-2. Preliminary cross-section cutlines between Bartow and Fort Meade. Adpated from Appendix H, Verdantas (2024).

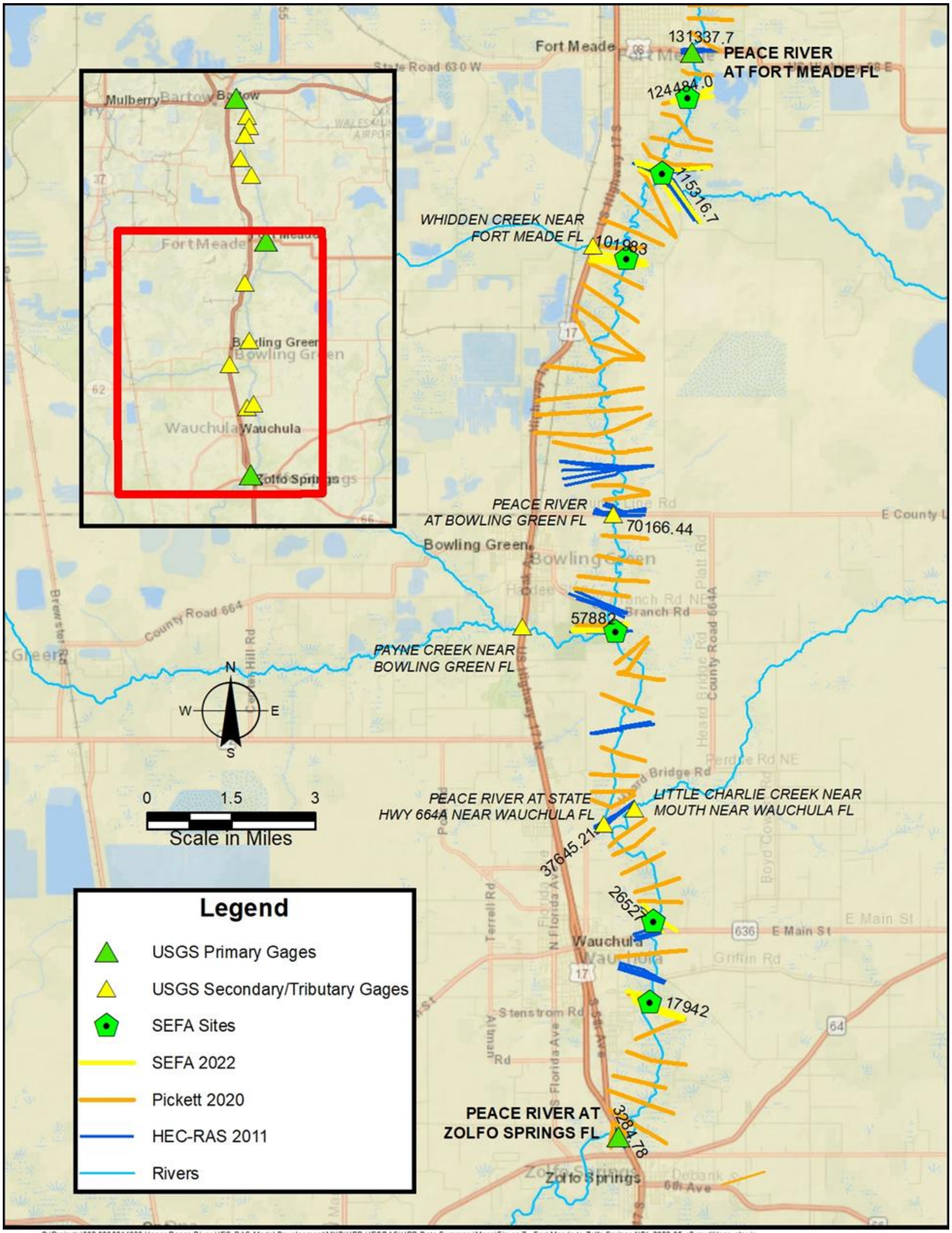


Figure 5-3. Preliminary cross-section cutlines between Fort Meade and Zolfo Springs. Adpated from Appendix H, Verdantas (2024)

There are 15 bridge and culvert crossings in the Upper Peace River between the Bartow and Zolfo Springs gages, as summarized in Table 5-1. Their topographic and bathymetric surveys were completed by: Lombardo, Foley & Kolarik in 2008, BCI Engineers & Scientists, Inc. in 2010, and Pickett in 2011 and 2020. Pertinent data and information for each structure, necessary to determine the structure location, geometry and associated parameters in the HEC-RAS model, were obtained from the Florida Department of Transportation (FDOT), CSX Railroad, and Polk County.

Table 5-1. Summary of bridges and culvert crossings in the Upper Peace River.

Crossing Name[1]	Owner	FDOT ID	Year Constructed	Last Inspection
SR 60 Bridge at Bartow[2,3]	FDOT	160042	1964	10/19/2020
Abandoned Phosphate Mine Bridge near Bartow[2,3]	TIITF / DEP	N/A[5]	N/A	N/A
Clear Springs Mine Bridge near Bartow[2,3]	TIITF / DEP	N/A	N/A	N/A
Three Pipes (66, 48 & 48 cm)[2,3]	TIITF / DEP	N/A	N/A	N/A
CR 640 Bridge at Homeland[2]	Polk County	160108	1969	9/21/2021
US 98 Bridge[4]	FDOT	160064	1931	8/30/2021
Old Railroad Bridge[4]	TIITF / DEP	N/A	N/A	N/A
Mt. Pisgah Road Bridge[4]	Polk County	160107	1961	7/29/2021
Pipeline Bridge[4]	Mosaic Fertilizer	N/A	N/A	N/A
County Line Bridge[4]	Polk County	160101	1958	N/A
Lake Branch Road Bridge[4]	Hardee County	060031	1962	2/25/2021
Heard Road Bridge[4]	Hardee County	060017, 064080	1954, 1965	2/25/2021
SR 64A Main Street Bridge[4]	FDOT	060054	1999	1/9/2020
CR 652 Griffin Road Bridge[4]	FDOT	060030	1970	2/23/2021
US 17 Bridge at Zolfo Springs[4]	FDOT	060052, 060053	2001, 2001	1/20/2020

Notes: [1] Top 9 crossings are in Polk County and the bottom 6 in Hardee County, sorted from upstream to downstream. [2] Surveyed by Lombardo, Foley & Kolarik in 2008. [3] Surveyed by BCI Engineers & Scientists, Inc. in 2010. [4] Surveyed by Pickett Surveying & Photogrammetry in 2011 or 2020. [5] Not available.

For the Upper Peace River, BFA (Appendix A) concluded that the new topographic and bathymetric database was sufficient to support the development of both unsteady-flow and steady-flow HEC-RAS models, which will be further discussed in Section 5.3.2.

5.2.3 Instream Habitat Data Acquisition

5.2.3.1 Instream Habitat Data for System for Environmental Flows Analysis

Data collection was performed by HSW-Verdantas (2021) at a subset of sites selected by the District based on known locations of shallow shoals. Data collection occurred at nine sites, dispersed between the USGS gage at Bartow at the upstream end and the USGS gage at Zolfo Springs at the downstream end of the Upper Peace River (Figure 5-4). Each site consisted of three transects: a shallow shoal, a deep pool, and a run with intermediate depth.

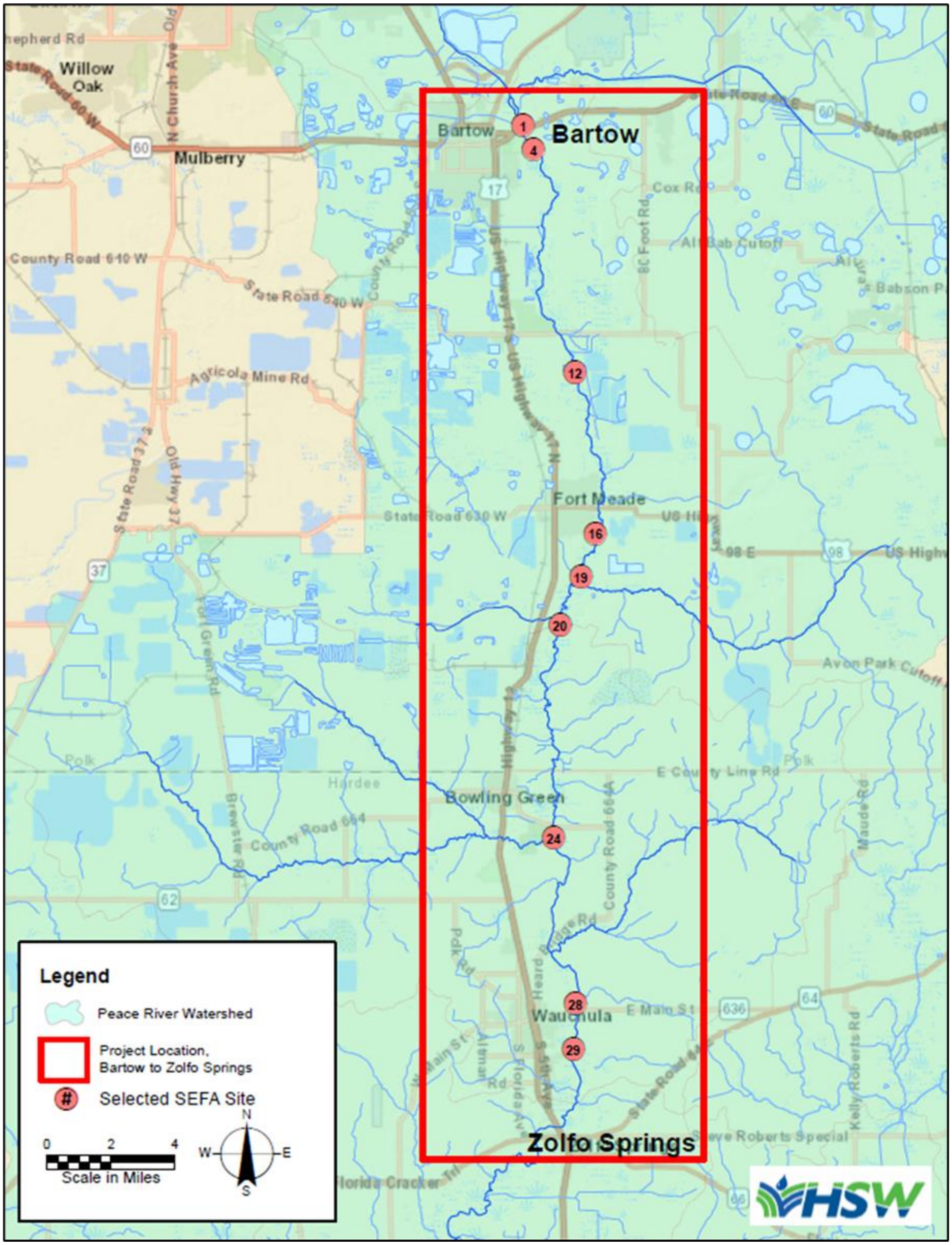


Figure 5-4. Locations of nine SEFA data collection sites in the Upper Peace River.

Sites were selected to evenly represent three main river segments: upper (Bartow to Fort Meade), middle (Fort Meade to Bowling Green), and lower (Bowling Green to Zolfo Springs) (Figure 2-2 and Table 5-2). Data were collected on 25 dates from 9/1/2021 through 2/1/2023 (Table 5-3). These data collection events were chosen to represent low, medium, and high flows, which were used to create stage-flow rating curves for each cross section.

Collected data included substrate and cover descriptions, relative elevations of sediment surface, water surface elevations at left bank and right bank looking downstream, and depth-averaged velocity at a minimum of 20 wetted intervals and on dry land from top of left bank to top of right bank. In smaller channels and at edges of larger channels, velocity was measured with a handheld acoustic doppler velocimeter at six-tenths depth when depths were less than 1.5 ft or at two-tenths and eight-tenths depth when depths were greater than or equal to 1.5 feet (Turnipseed & Sauer, 2010). Where feasible, velocity was measured with ADCP, and depth-average velocity was calculated with RiverSurveyor Live software.

This analysis used Habitat Suitability Criteria developed for all 32 species, life history stages, and guilds recommended for use in the Peace River basin by the Florida Handbook of Habitat Suitability Indices (Table 5-4) (Nagid 2022, Nagid 2025).

Table 5-2. Locations of SEFA data collection sites.

Site No.	Selected Site	Latitude/Longitude
	Upper Segment (Bartow to Fort Meade)	
1	Site 1	27.899072/-81.815720
2	Site 4 (Bartow PHAB)	27.894444/-81.811028
3	Site 12	27.805658/-81.791195
	Middle Segment (Fort Meade to Bowling Green)	
4	Site 16	27.741000/-81.783083
5	Site 19 (Fort Meade PHAB)	27.723779/-81.789653
6	Site 20	27.704472/-81.798972
	Lower Segment (Bowling Green to Zolfo Springs)	
7	Site 24 (Bowling Green PHAB)	27.619555/-81.801789
8	Site 28	27.553510/-81.792060
9	Site 29 (O'Neill PHAB)	27.535078/-81.792942

Table 5-3. Data collection dates for high-, medium-, and low-flow events.

Site	High	Medium	Low
P1, R1, S1	8/24/2022	10/8/2021	1/12/2022
P4, R4, S4	8/25/2022	10/7/2021	1/12/2022
P12, S12, R12	12/14/2022	10/6/2021	1/13/2022
P16, R16, S16	12/15/2022	10/13/2021	2/10/2022
P19, R19	12/16/2022	10/15/2021	2/11/2022

Site	High	Medium	Low
S19	12/15/2022	10/15/2021	2/11/2022
P20, R20, S20	2/1/2023	10/14/2021	2/11/2022
P24, R24, S24	9/3/2021	12/9/2021	1/7/2022
P28, R28, S28	9/1/2021	12/7/2021	1/21/2022
P29, R29, S29	9/2/2021	12/8/2021	1/6/2022

Table 5-4. Taxa for which habitat suitability criteria curves were used for the SEFA for the Upper Peace River

Name from Nagid 2022	Name in This Report	Descriptor 1	Descriptor 2	H Code[1]
AMEE	AMEE	American Eel	Yellow	W
BLUE	BLUA	Bluegill	Adult	G
BLUE	BLUF	Bluegill Fry	Fry	G
BLUE	BLUJ	Bluegill Juvenile	Juvenile	G
BLUE	BLUS	Bluegill Spawning	Spawning	G
CHCA	CATA	Channel Catfish	Adult	G
CHCA	CATF	Channel Catfish	Fry	G
CHCA	CATJ	Channel Catfish	Juvenile	G
CHCA	CATS	Channel Catfish	Spawning	G
COSN	COSA	Common Snook	Adult	E
COSN	COSJ	Common Snook	Juvenile	E
EPHE	EPHE	Ephemeroptera	Richness	G
Habitat Guilds	HGDF	Deep	Fast	G
Habitat Guilds	HGDS	Deep	Slow	G
Habitat Guilds	HGSF	Shallow	Fast	G
Habitat Guilds	HGSS	Shallow	Slow	G
HYDR	HYDR	Hydropsychidae	Naiad	G
IRSH	IRSH	Ironcolor Shiner	Adult	D
LMB	LMBA	Florida Bass	Adult	G
LMB	LMBF	Florida Bass	Fry	G
LMB	LMBJ	Florida Bass	Juvenile	G
LMB	LMBS	Florida Bass	Spawning	G
MCD	MACD	Macroinvertebrate	Community Diversity	G
MESH	MESH	Metallic Shiner	Adult	A
PIPE	PIPE	Pirate Perch	Adult	D
PSEP	PSEP	*Pseudocloeon Ephippiatum*	Naiad	G
SPSU	SPSA	Spotted Sunfish	Adult	G
SPSU	SPSF	Spotted Sunfish	Fry	G
SPSU	SPSJ	Spotted Sunfish	Juvenile	G
SPSU	SPSS	Spotted Sunfish	Spawning	G
TORG	TINV	Invertebrates	Total	G
TRIC	TRIC	Trichoptera	Naiad	G

[1]Habitat codes defined in Nagid (2025): W = Warren and Nagid 2008, G = Jim Gore (unpublished), A = Nagid et al. 2014, and D = Nagid 2022.

5.2.3.2 Instream Habitat Data for Woody Habitat Analysis

During a low-flow period in April and May 2022, Environmental Science Associates (ESA) collected woody habitat data at 20 sites dispersed between the Bartow and Zolfo Springs gages (Figure 5-5). Sites were selected based on the existence of previously-established benchmarks, suitable access, the presence of representative woody habitat, and relatively even geographic distribution throughout the study reach.

At each site, along both banks, the elevation, percent cover, and volume of woody habitats were determined, as briefly described below. Additional details regarding site selection and data collection may be found in ESA (2023).

To collect elevation data, a representative 15.24-meter (m) section of bank was selected. Within this sampling boundary, the top and bottom elevations of 15 dead and live woody habitat were measured. Dead wood included snag habitats.

To estimate the percent coverage of woody habitat, five 10-m long transects were established parallel to the water surface between the water's edge and the top of the bank, within the 15.24 m section of bank previously delineated for elevation data collection. The transects were at least 0.5 m apart from one another. Along each transect, five 0.5-m x 0.5-m quadrats were used to quantify percent coverage of representative woody habitat in increments of 10%.

To calculate volume of woody habitat, a minimum of 20 pieces of woody habitat with diameters greater than 3 centimeters (cm) were measured along each of the transects established for estimation of percent coverage. Volume was then calculated according to Van Wagner's formula (Van Wagner 1968):

$$V = (\pi^2 \sum d^2)/8L$$

where V = surface area of wood, per unit area, d = diameter of wood, and L = the length of the transect.

Figure 5-5. Locations of woody habitat data collection (dots with white text) by Environmental Science & Associates (2023), color-coded by segment of the Upper Peace River and primary flow gages (yellow dots and text).

5.3 Modeling Tools Supporting Minimum Flow Development

5.3.1 Peace River Integrated Modeling (PRIM)

The PRIM project, initiated by the District in 2008, was developed to enhance understanding of the hydrologic processes and interactions affecting the Peace River Basin. The original model, PRIM1 (HGL 2012), was built using the MODFLOW-based

Hydrologic Modeling System (MODHMS) to simulate integrated groundwater and surface water systems. It covered the basin upstream of the Peace River Manasota Regional Water Supply Authority (PRMRWSA) intake, as shown in Figure 5-6, and was calibrated using data from 1998 through 2002, with validation from 1994 through 1997.

The primary objective of PRIM1 was to establish a numerical framework for evaluating water resource management strategies. By simulating interactions between surface water and groundwater, the model supported assessments of past watershed development impacts and strategies for achieving the District's recovery goals for the basin.

The model includes three key components: a land surface layer representing hydrologic processes such as rainfall and runoff, a surface water system comprising ponds, streams, canals, and hydraulic structures, and a subsurface system including the unsaturated zone and underlying aquifers. Land surface processes are represented by two-dimensional grid cells, while streams and lakes are modeled as a network of one-dimensional channel and storage nodes. Subsurface layers are simulated using three-dimensional grid blocks. These components interact between layers through infiltration, ET, and exchanges between overland flow, streams, and groundwater.

According to HGL (2023), PRIM 1 was developed by extending the Saddle Creek Basin Integrated Model (SCBIM; HGL 2008), retaining its spatial and temporal discretization. Initial parameter values for ET, soil, and land use were derived from the SCBIM calibration. Additional models contributed to the development of PRIM, including: 1) The Southern District (SD) groundwater model (Beach 2006) and District-Wide Regulation Model 2 (DWRM2) (ESI 2007), which provided initial values for hydraulic conductivity and leakance. 2) Surface water models, such as Lake Hancock Single Event Watershed model (BCI 2006), Peace Creek Storm Water Management Model (PBS&J 2004), and Mike-SHE integrated model for the Horse Creek subbasin (SDI 2003). And 3) HEC-RAS models of the Peace River, developed for the District Minimum Flow and Levels Program (SWFWMD 2002), used for Peace River channel cross sections.

Regional groundwater impacts are incorporated by linking PRIM to the SD groundwater model (Beach 2006) through prescribed, time-variable heads in the Intermediate Aquifer System and UFA layers at PRIM's lateral boundaries. The model uses daily rainfall inputs, monthly ET, and stress periods for groundwater withdrawals and permitted discharges (i.e., groundwater pumping and National Pollutant Discharge Elimination System discharges).

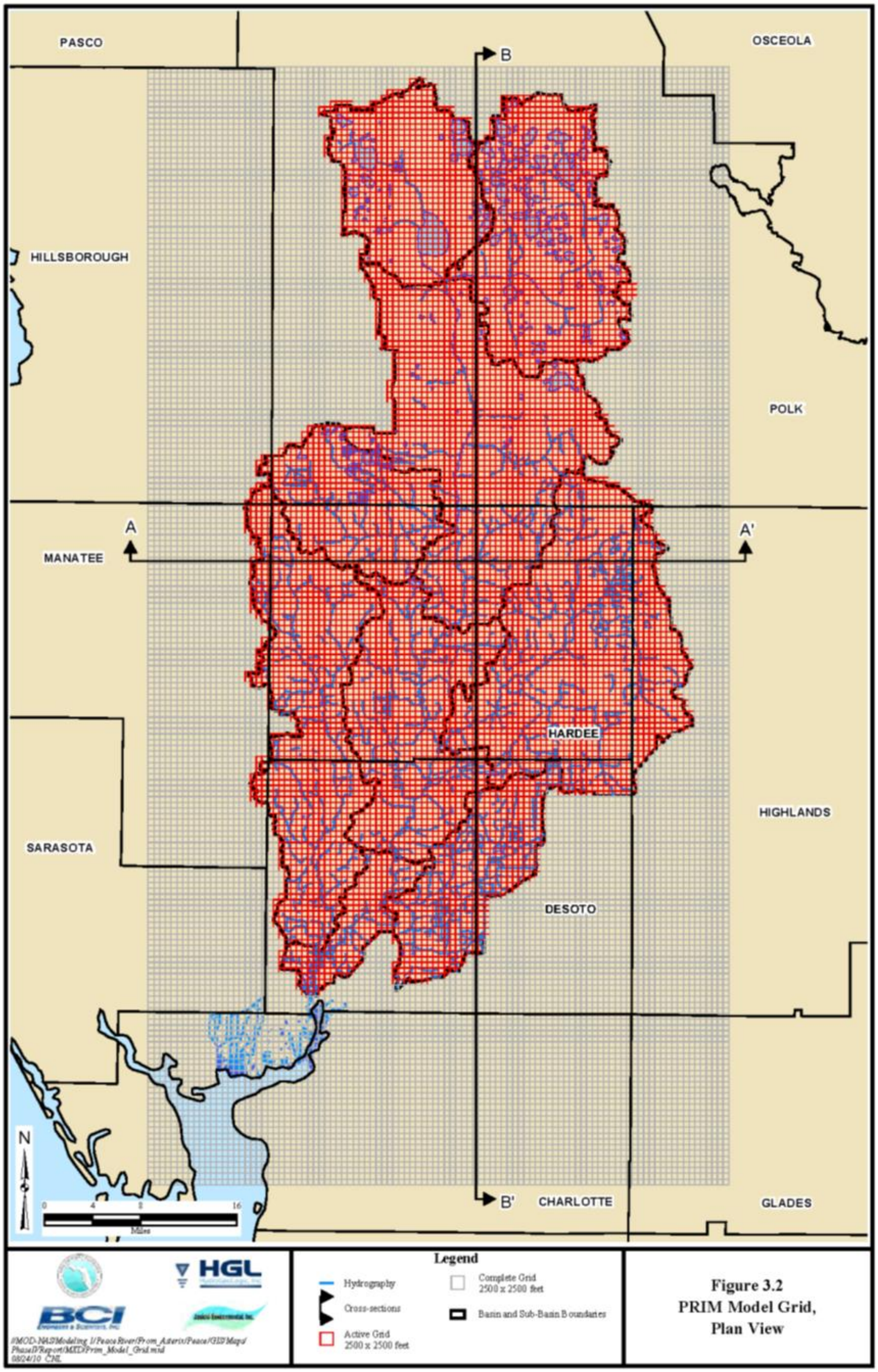


Figure 5-6. The PRIM model domain and grid discretization for the Peace River watershed (adapted from Appendix B, Figure 3.2).

To improve long-term performance and recalibration, the model was updated in 2022 to PRIM2 (Appendix B), extending the calibration period to 2003-2018. The PRIM2 demonstrated enhanced accuracy in simulating streamflow, lake levels, and groundwater potentiometric elevations under both high- and low-flow conditions. It underwent peer review in 2023 by Tetra Tech and Anclote Consulting (Tetra Tech 2023, Anclote Consulting 2023) and was used to assess groundwater withdrawal impacts for Horse Creek, Charlie Creek, and the Upper Peace River minimum flows development.

The PRIM2 was calibrated using measured streamflow data from 18 gaging stations, including four located along the Peace River and six positioned on major tributaries near their confluences with the river. Model performance was evaluated using streamflow percentiles and other statistical metrics. Model calibration criteria were met, demonstrating reasonable replication of magnitude, temporal fluctuation, and percentile distributions. Additionally, the calibration achieved reasonable agreement between simulated streamflow losses through karst features between Bartow and Homeland and observed discharges through karst conduits during the 2002 -2006 period. Further documentation of the PRIM2 model is provided in Appendix A.

5.3.2 HEC-RAS Modeling

HEC-RAS is a public domain software developed by the United States Army Corps of Engineers (USACE). It is an integrated modeling system comprising of a graphic user interface, analytical components, data storage and management tools, as well as graphics, mapping, and reporting functions (USACE 2023). The system incorporates four river analysis components: 1) one-dimensional steady flow for water surface profile computations; 2) one- and two-dimensional unsteady flow simulation; 3) quasi-unsteady or fully unsteady sediment transport computations for moveable boundaries; and 4) one dimensional water quality analysis.

One of HEC-RAS's primary strengths is its unified geometric data representation, ensuring consistency across all four components. The steady and unsteady flow models can simulate subcritical, supercritical and mixed flow regimes. Water surface profile computations begin at a cross-section with known or assumed starting condition, progressing upstream for subcritical flow or downstream for supercritical flow. Additionally, hydraulic calculations for cross-sections, bridges, culverts, and other structures, originally developed for steady flow simulation, have been incorporated into the unsteady flow module.

In addition, RAS Mapper, an advanced spatial data integration and mapping system in HEC-RAS, allows users to develop and refine model geometry, as well as analyze computed results. By visualizing geometric data (terrain, river networks, cross section locations and parameters, and 2D meshes, etc.) and simulation results (water surface depths, velocities, etc.), RAS Mapper helps users identify model deficiencies and refine hydraulic simulations more efficiently.

5.3.2.1 Limitations of the Previous Upper Peace River HEC-RAS Model

Since its inception, the District's MFLs program has utilized HEC-RAS as a primary hydraulic modeling tool for assessing freshwater flowing systems. Historically, most models used in these assessments have focused on steady flow simulation (SWFWMD 2002, Kelly et al. 2005a, 2005b, and 2005c, SWFWMD 2006, Munson et al. 2007, Flannery et al. 2008, Heyl et al. 2010, Basso et al. 2011, Holzwart et al. 2016, Leeper et al. 2018), with the notable exception of the Rainbow River model (Holzwart et al. 2017), which incorporated both unsteady and steady flow simulation.

The steady flow HEC-RAS model used in the previous Upper Peace River MFLs evaluation (SWFWMD 2002) originated from a step-water flood profile model (Murphy et al. 1978) developed by the USGS. Initially designed for three Peace River study reaches: Bartow to Fort Meade, Fort Meade to Zolfo Springs, and Zolfo Springs to Arcadia, excluding the downstream reach from Arcadia to Charlotte Harbor due to tidal backwater influences. This model used percentile flow profile data for the period 1940-1998, based on records from three Peace River gages: Arcadia (02296750), Zolfo Springs (02295637), and Bartow (02294650). Flow values at selected cross-sections were apportioned based on drainage area ratios.

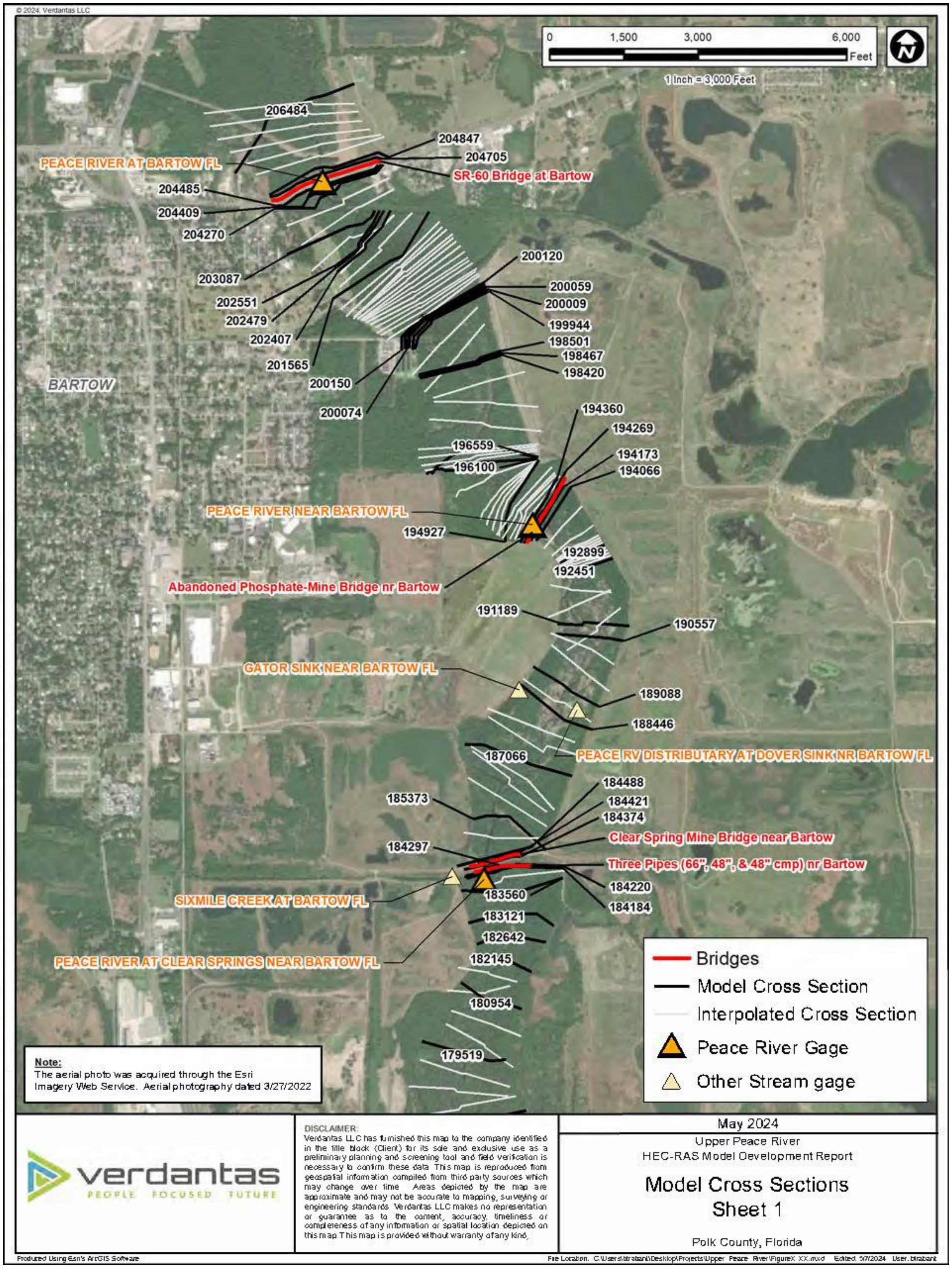
Lewelling (2003) later updated the step-water model using HEC-RAS to evaluate the extent of inundation in riverine wetlands along the Peace River in West-Central Florida. The District acquired this model from the USGS in December 2002, subsequently enhancing it with 18 additional cross-sections surveyed in 2001 and expanding the dataset from 16 to 28 flow profiles (adding 12 low steady flow profiles) to support the 2002 Upper Peace River MFLs development (SWFWMD 2002).

Despite reasonable calibration, the USGS HEC-RAS model had several limitations. One major issue was that the model did not account for streamflow losses to groundwater caused by karst features along the riverbed between Bartow and Fort Meade. This omission led to inaccurate simulation of low flows. Statistical analysis of gaged flow data confirms this discrepancy, showing that flows exceeding 80% at the USGS Fort Meade gage are lower than that at the USGS Bartow gage (Table 2-9), even though the Fort Meade gage is located 13 miles downstream of the Bartow gage (Table 2-8).

Another limitation was that the cross-sectional data used in the USGS model was sparse and outdated. These data were derived from old aerial 1-foot topographic contour maps, field surveys, or other analyses conducted over 40 years ago. Given that the river's morphology changes over time, these cross sections may no longer accurately represent the current bathymetric condition of the river even if they were accurate decades ago.

Chen (2011) upgraded the 2002 steady flow HEC-RAS model using data from the three-index gaging stations dating back to 1974. This update replaced 119 cross-sections with newer surveys conducted since 2001, while retaining 46 cross-sections from the 2002 model. Each cross section in the 2011 model was limited to a 1000-foot buffer on both banks, regardless of the actual floodplain extent. By incorporating data from the Fort Meade gage, the model partially accounted for stream flow losses due to sinkhole activity between Bartow and Fort Meade. However, the methodology used to apportion flow between paired gages for each simulated flow profile was not documented.

To address these limitations, the District initiated several technical projects including new cross-section surveys (see Section 5.2.2), and the development of a new HEC-RAS model using version 6.4.1. This new model incorporates both unsteady and steady flow simulations and covers the reach between Zolfo Springs and Bartow. It includes 206 surveyed cross-sections and 15 bridges (Figure 5-7). Compared to previous models, this version introduces several key advancements, detailed in sections 5.3.2.2 through 5.3.2.4 and outlined in Appendix H.



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Abandoned Phosphate-Mine Bridge nr Bartow
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PEACE RV DISTRIBUTARY AT DOVER SINK NR BARTOW FL
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Clear Spring Mine Bridge near Bartow
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Three Pipes (66", 48", & 48" cmp) nr Bartow
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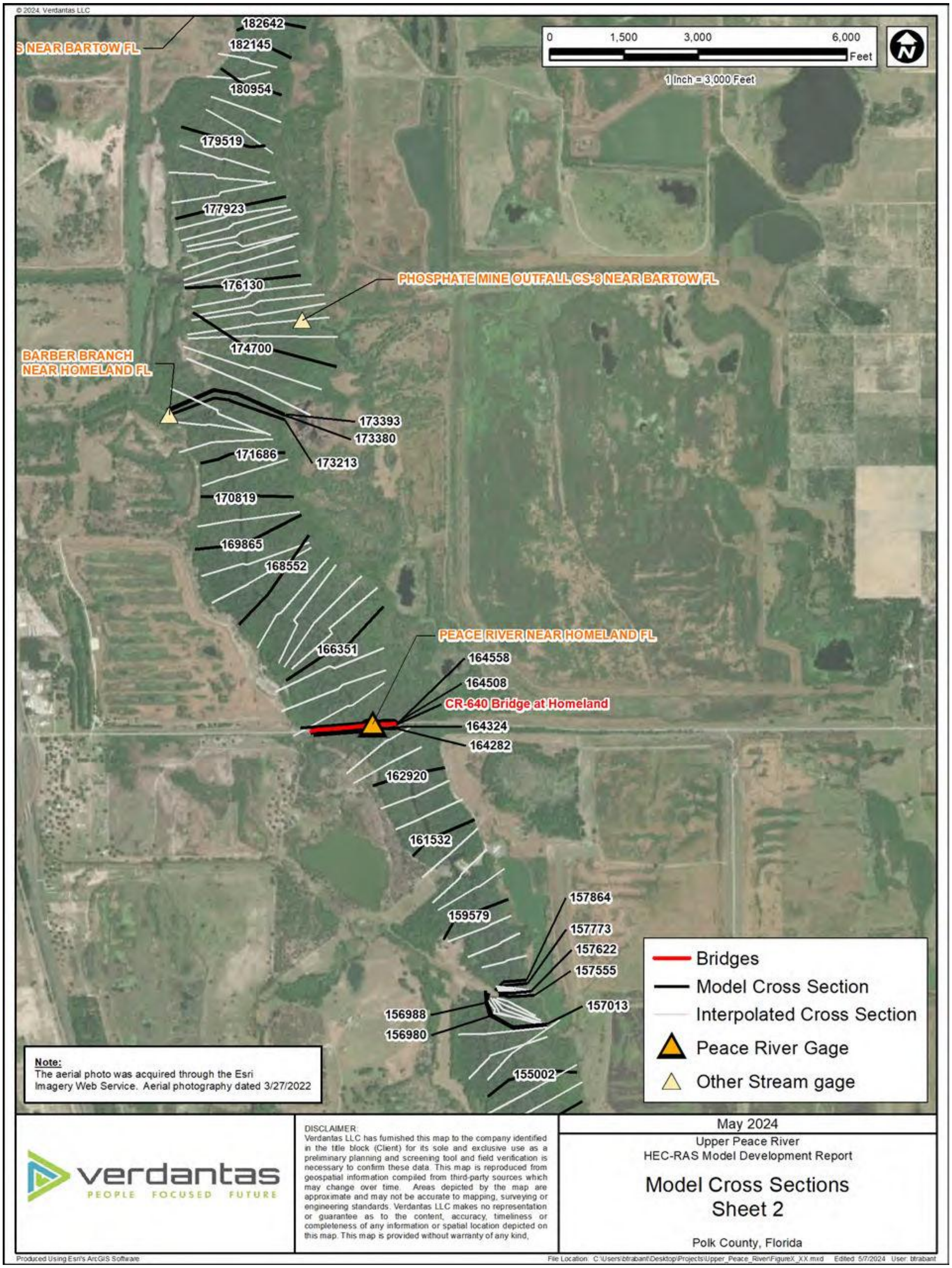
HEC-RAS Model Development Report
Model Cross Sections
Sheet 1
Polk County, Florida
Produced Using Esri's ArcGIS Software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Model Cross Sections
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Polk County, Florida
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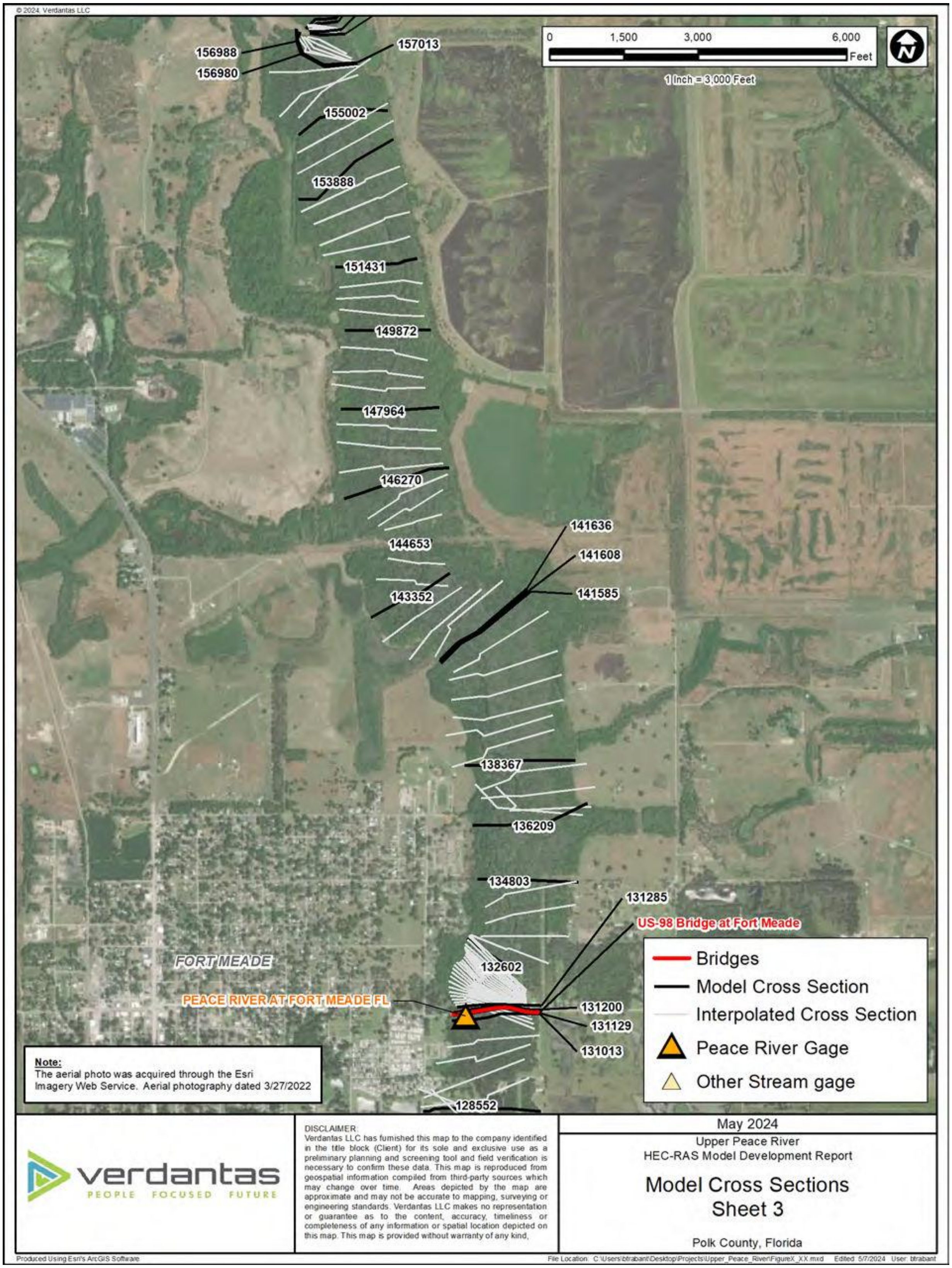
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134803
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US-98 Bridge at Fort Meade
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FORT MEADE
PEACE RIVER AT FORT MEADE FL
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Bridges
Model Cross Section
Interpolated Cross Section
Peace River Gage
Other Stream gage
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Mt Pisgah Road Bridge
Old Rail Road Bridge near Fort Meade
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WHIDDEN CREEK NEAR FORT MEADE FL
Note:
The aerial photo was acquired through the Esri Imagery Web Service. Aerial photography dated 3/27/2022
Bridges
Model Cross Section
Interpolated Cross Section
Peace River Gage
Other Stream gage
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Railroad Bridge near Bowling Green
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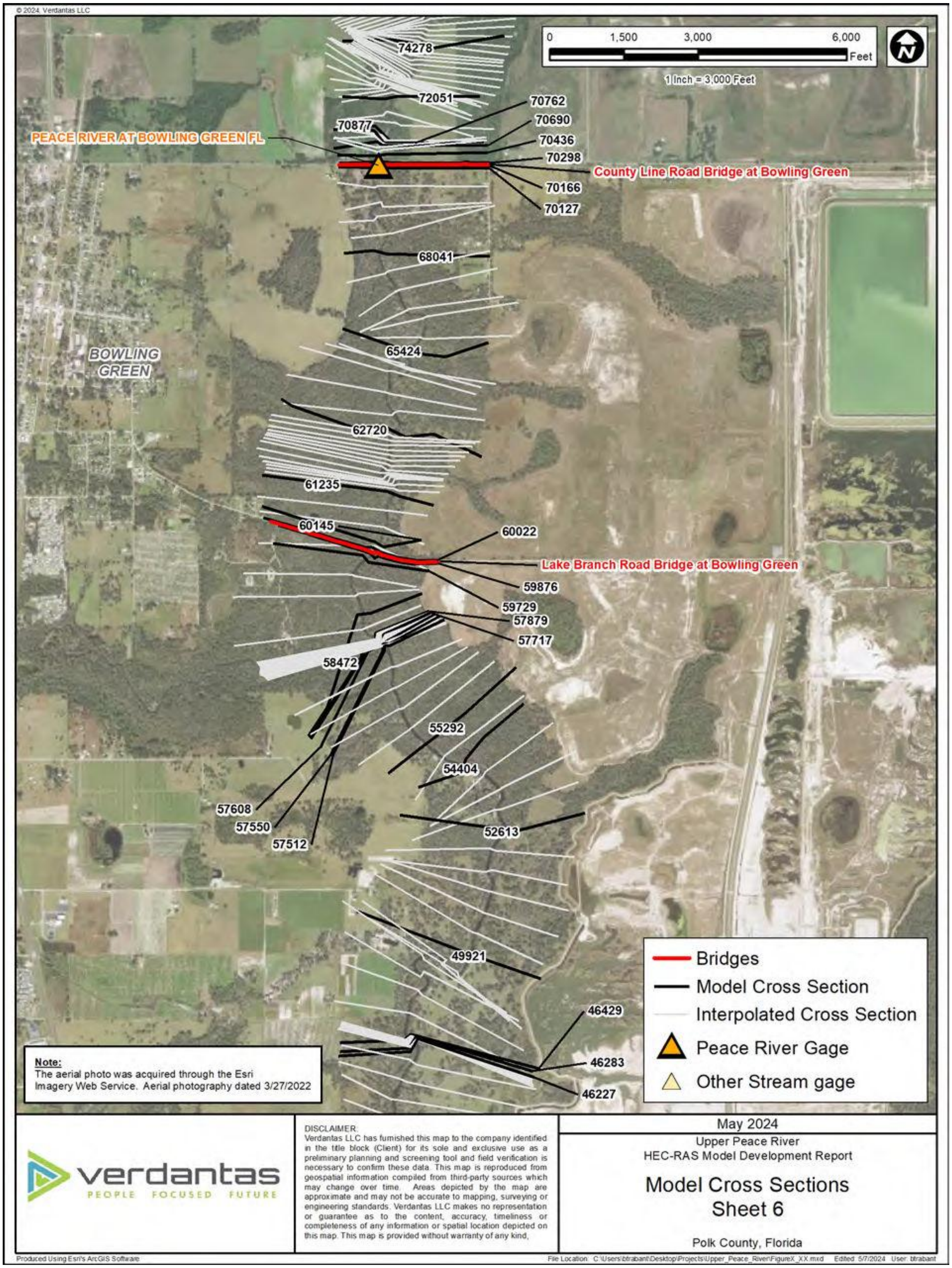
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Peace River Gage
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Polk County, Florida
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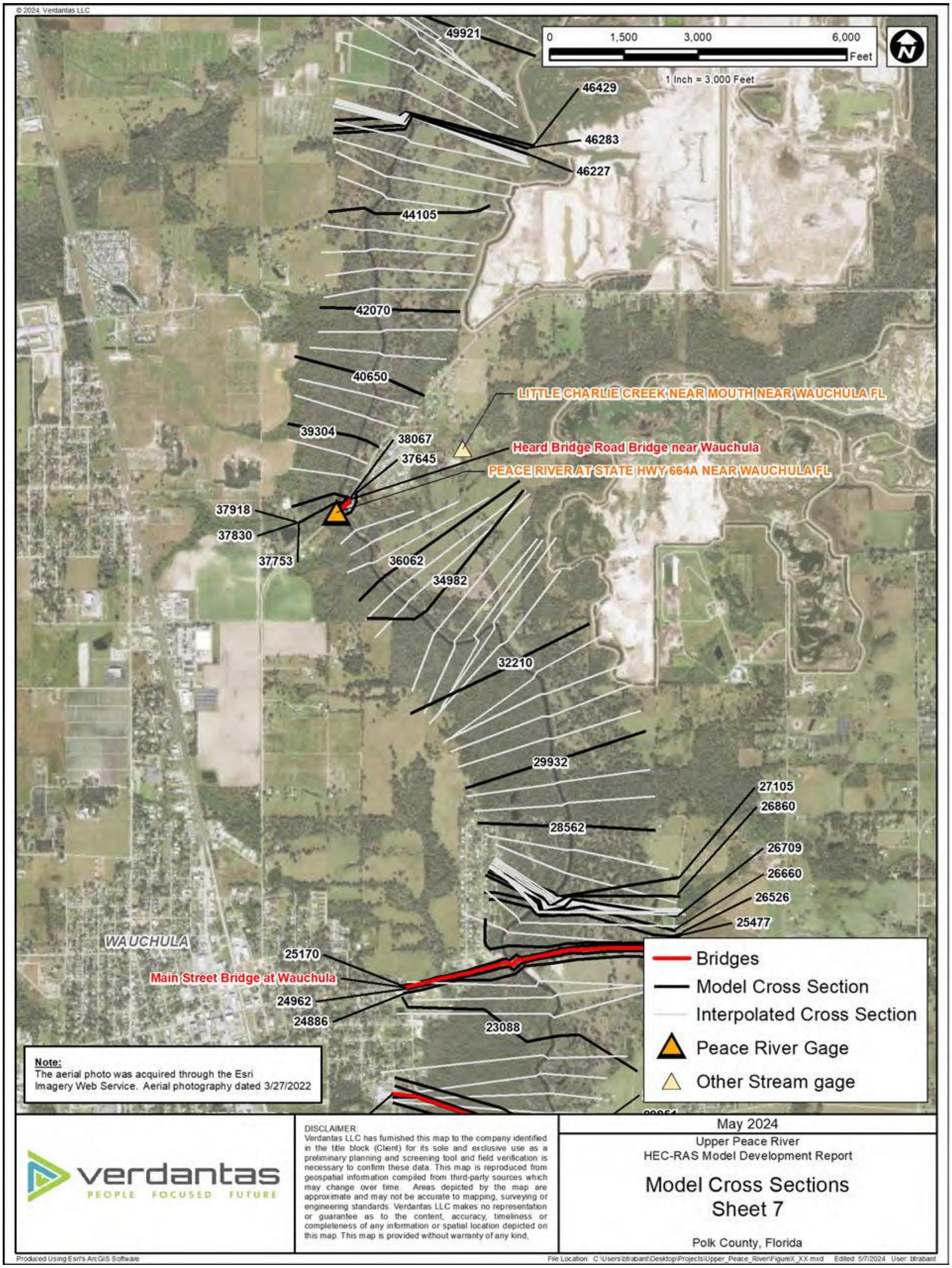
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LITTLE CHARLIE CREEK NEAR MOUTH NEAR WAUCHULA FL
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38067
37645
Heard Bridge Road Bridge near Wauchula
PEACE RIVER AT STATE HWY 664A NEAR WAUCHULA FL
37918
37830
37753
36062
34982
32210
29932
27105
26860
28562
26709
26660
26526
25477
WAUCHULA
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Main Street Bridge at Wauchula
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24886
23088
Bridges
Model Cross Section
Interpolated Cross Section
Peace River Gage
Other Stream gage
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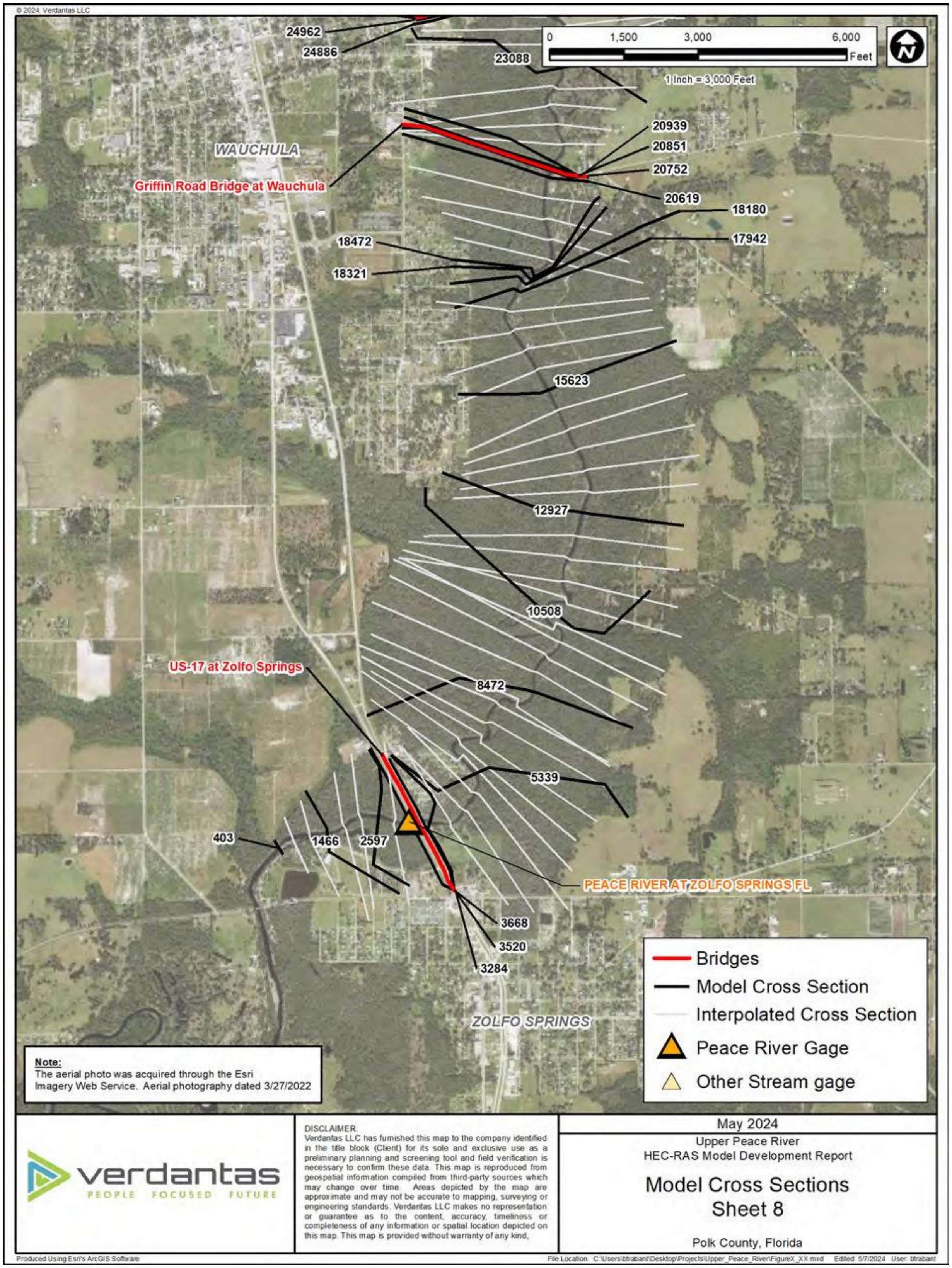


Figure 5-7. Upper Peace River HEC-RAS model cross sections shown in Sheets 1-8, with river station lables indicating distances in feet from the downstream end, as well as bridge

locations and USGS gages on both the mainstem and tributaries. (Adpated from Appendix A of Appendix H, Verdantas 2024).

5.3.2.2 Development of Unsteady and Steady HEC-RAS Simulations

Before constructing the HEC-RAS model, evaluations of utility of unsteady flow analysis were performed by BFA (2020; see Appendix A) and Verdantas (2024; see Appendix H) for the Upper Peace River. Both studies recommended using a combination of unsteady and steady flow simulation based on the following considerations:

- Karst-Induced Flow Losses – between Bartow and Fort Meade, karst features and sinkholes cause streamflow losses to groundwater, particularly during low-flow conditions of the spring dry season. South of Fort Meade the river is well-confined by underlying aquifers, preventing significant river flow losses to groundwater.
- Tributary Inflows & Hydrologic Influence – Tributaries significantly impact Upper Peace River flow, especially during low-flow conditions. Channelization and control structures, such as the Peace Creek Drainage Canal and Saddle Creek, regulate inflows, while tributary storage reduces discharge into the Upper Peace River. Additional influences include urban runoff, phosphate mine channels, and distributary channels (e.g., Dover Sink Distributary and Gator Sink Distributary) also affect flow dynamics.
- Unsteady Flow Behavior – Flow in the Upper Peace River behaves as unsteady flow, attenuating as it moves downstream. Discharge-stage ratings vary at different cross-sections, with flow rates of the same exceedance percentage occurring at different times along the river.
- Advantages of Integrating Unsteady Flow Model – The existing steady-flow HEC-RAS model did not adequately capture unsteady flow behavior, limiting its accuracy for minimum flow assessment. Incorporating a calibrated unsteady flow model would not only improve simulation precision but also provide valuable hydraulic parameters (e.g., Manning's roughness coefficient, roughness factor) and boundary condition inputs such as hydrographs and rating curves to enhance steady-flow simulations.

Following these recommendations, Verdantas calibrated the HEC-RAS model for unsteady flow conditions over selected periods representative of minimum flows conditions. The purpose of this calibration was to simulate system hysteresis, refine model parameters, and analyze flow changes. However, the unsteady model could not establish a one-to-one relationship between flow and surface water elevation at local sites and index gaging stations, an essential component of the District's methodology for determining MFLs in flowing water systems. Therefore, the calibrated HEC-RAS model was converted to a steady HEC-RAS model and applied to a series of steady flow profiles necessary to support minimum flows evaluations, as detailed in Appendix H of Verdantas (2024).

5.3.2.3 Flow Apportionment Method

To support the steady-flow HEC-RAS model, flow profiles were developed using the full period of record at Zolfo Springs. Established apportionment ratios determine the flow relationships between river cross-sections, enabling flow series implementation with Zolfo Springs as an index gage.

Daily flow data for a common period (12/01/2010 – 10/01/2023) from thirteen USGS streamflow gages, seven mainstem gages and six tributary gages (Table 5-5), were used for developing flow duration curves, which established flow exceedance values for each gage, forming the basis of flow apportionment. Mainstem gage flows were used as known flows at their respective river stations, while tributary gage flows accounted for inflows between mainstem gages. Unaccounted flows between mainstem gages were attributed to karst losses, major ungaged tributaries, and uniform flow changes.

Table 5-5. Periods of record for daily flow at thirteen Upper Peace River streamflow gages, ordered upstream to downstream.

Gage Name/Location	USGS Gage ID	Starting Date*	Gage Type
Peace River at SR 60 at Bartow, FL	02294650	10/01/39	Mainstem
Peace River near Bartow, FL	02294655	05/15/02	Mainstem
Peace River at Clear Springs Near Bartow, FL	02294775	05/15/02	Mainstem
Sixmile Creek at Bartow, FL	02294747	12/01/02	Tributary
Phosphate Mine Outfall CS-8 Near Bartow, FL	02294759	02/01/03	Tributary
Barber Branch Near Homeland, FL	02294760	12/01/02	Tributary
Peace River Near Homeland, FL	02294781	10/01/01	Mainstem
Peace River at Fort Meade, FL	02294898	06/01/74	Mainstem
Bowlegs Creek Near Fort Meade, FL	02295013	03/01/64	Tributary
Peace River at Bowling Green, FL	02295194	12/01/10	Mainstem
Payne Creek Near Bowling Green, FL	02295420	10/01/63	Tributary
Little Charlie Creek Near Mouth Near Wauchula, FL	02295580	09/30/12	Tributary
Peace River at US 17 at Zolfo Springs, FL	02295637	09/01/33	Mainstem

* All data and modeling inputs used in this analysis reflect conditions up to October 1, 2023.

Major ungaged tributaries, including Rocky Branch, Sink Branch, Whidden Creek, Hog Branch, Max Branch, Thompson Branch, and Hickory Branch, were proportioned based on their drainage area relative to the sub-reach. GIS watershed boundary layers and topographic mapping were used for these estimates, as summarized in Appendix H of Verdantas (2024).

For residual unaccounted flows, a uniform distribution method was applied. Flow change locations were spaced at 0.5-mile increments in upstream sub-reaches (SR 60 to Clear Springs) and 1-mile increments downstream sub-reaches (Clear Springs to Zolfo Springs). Positive unaccounted flows were distributed across uniform flow change locations, capturing overland runoff, groundwater discharge, and smaller ungaged tributaries. Outflows between mainstem gages were attributed to karst features in the upper reaches, as further discussed in Section 5.3.2.4, and evenly distributed in downstream sub-reaches where karst features are minimal. These uniformly distributed outflows represent losses to groundwater, floodplain storage, and potential unidentified karst features.

All flow components, including mainstem and tributary gages, karst sink losses, ungaged tributary inflows, and uniform flow change points, were systematically accounted for in the flow profile developments. Duration curves developed for the 13 gages serve as the best approximation of varying flow conditions and their exceedance frequencies.

5.3.2.4 Consideration of Streamflow Losses Due to Karst Features Between Bartow and Clear Springs

The upper portion of the study reach contains numerous karst features known to contribute to streamflow losses. As identified by Metz & Lewelling (2009), along with studies cited therein, key karst features responsible for these losses include the Wabash Complex, Cooks Ripple, Fricano Fracture, Ledges Sink, Midway Sink, Elephant Graveyard, Crevasses, Gator Sink, and Dover Sink (Figure 5-8).

At higher percent exceedance flows (lower discharge value), flow losses are observed between SR 60 at Bartow and Clear Springs, primarily due to these karst features. Metz & Lewelling (2009) provided measured losses for individual features. These values were reviewed, and engineering judgement was applied to determine the approximate maximum measured loss for each feature.

To estimate the flow loss distribution, the maximum losses for each feature were compared within sub-reaches between mainstem gages (SR 60 at Bartow, near Bartow, and Clear Springs). For example, the Wabash Complex, Cooks Ripple, Fricano Fracture, and Ledges Sink are all located within the reach between SR 60 at Bartow and near Bartow (Figure 5-8). The total estimated maximum loss for the reach is 14.75 cfs, with the Wabash Complex accounting for 5 cfs. Based on this proportion, approximately 33% of the total flow loss in this reach is attributed to the Wabash Complex.

This method was repeated for each subsequent reach and major karst feature. Given the close proximity of these features and the relatively coarse cross-section spacing in the model, certain features were grouped into “Karst Areas” (Figure 5-8). Each karst area was assigned to the nearest river station in the HEC-RAS model within the flow apportionment method. This ensures that observed flow losses within these reaches are proportionally distributed among the respective karst areas.

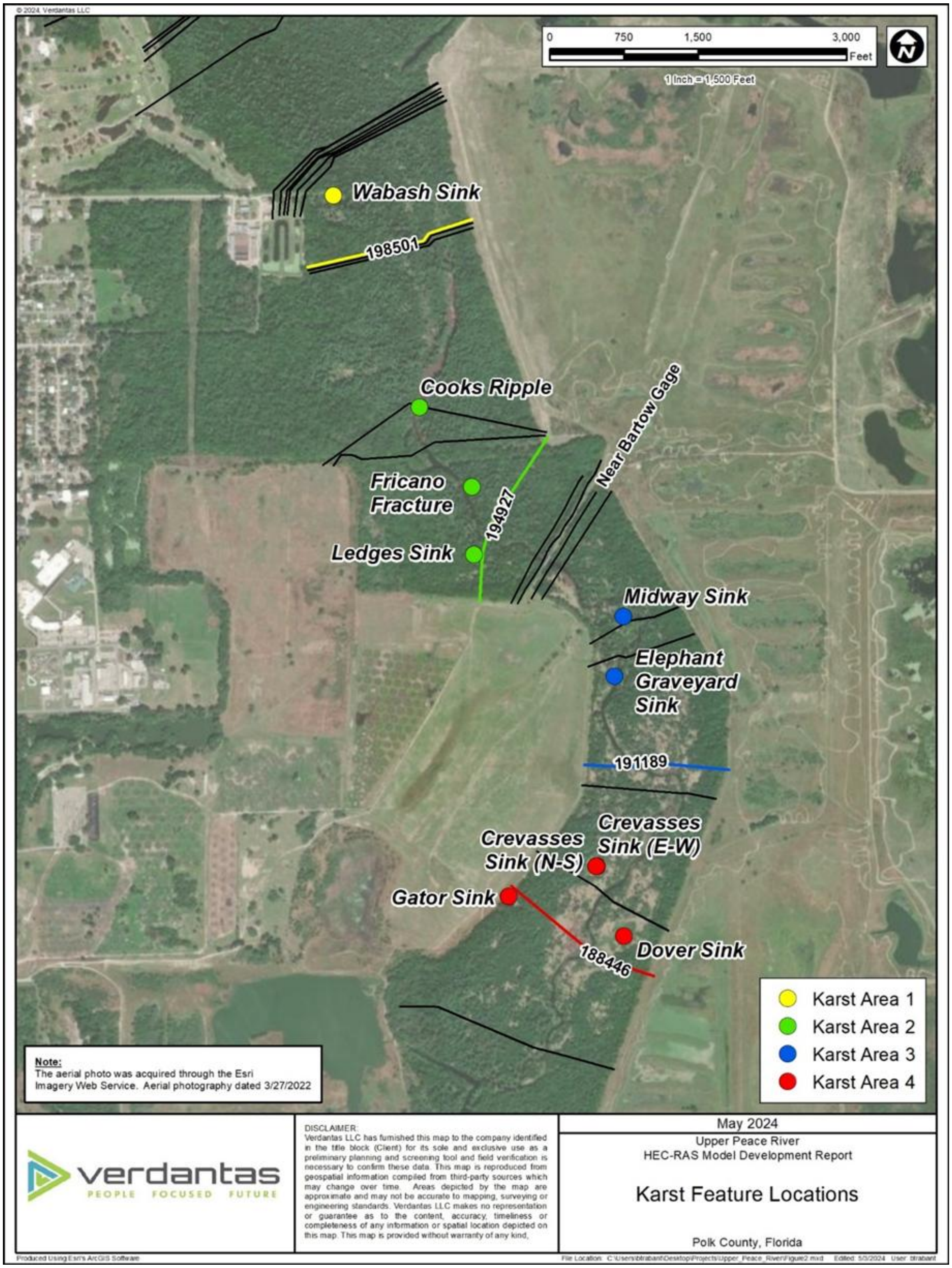


Figure 5-8. Locations of karst features in the Upper Peace River between SR 60 at Bartow and Clear Springs. Labelled lines indicate the stationing of measured cross-sections, defining the boundaries of the color-coded karst areas. Unlabeled lines represent additional measured cross-sections within this portion of the HEC-RAS model. Adapted from Appendix H, Verdantas 2024.

Given the length of the report, detailed information regarding the HEC-RAS model development, calibration, verification, and flow profile simulations is not included herein but can be found in Appendix H.

5.4 Baseline Flow Development and Flow Blocks

5.4.1 Baseline Period

Defining the baseline period and adjusting historical gaged data to account for the effects of groundwater withdrawals are critical steps in determining minimum flows. For the Upper Peace River, the period from January 1,1975, through December 31, 2022, was selected to serve as the baseline period for the recommended MFLs evaluation. This 48-year span represents the most consistent and widely approved streamflow records available across the three long-term index gaging stations at Bartow, Fort Meade, and Zolfo Springs.

This baseline period extends 24 years beyond the timeframe used in the previous MFLs study (SWFWMD 2002) and includes an 8-year period from 2016 and 2022 during which the Upper Peace River was under active management to meet the low minimum flow thresholds adopted in 2006, primarily through operation of the P-11 structure.

Throughout this report, the baseline period serves as the reference framework for flow record adjustments, flow profile development, flow analyses, flow reduction scenario assessments, and the establishment of recommended MFLs.

5.4.2 Baseline Flow Calculation

As discussed in Section 5.3.1, the PRIM2 model is capable of simulating the impacts of regional groundwater withdrawal, making it a critical tool in establishing baseline flow conditions for the reevaluation of minimum flows in the Upper Peace River. Following calibration and validation, PRIM2 was used to assess the effects of groundwater withdrawal changes by simulating scenarios at the index gaging stations on the Upper Peace River: Bartow, Fort Meade and Zolfo Springs, under both current (100% pumping) and reduced (50% pumping) conditions.

Given the uncertainties associated with model inputs and simplified assumptions and approximations of complex hydrologic interactions, daily flows generated by PRIM2 were averaged to monthly values. This averaging approach facilities a more stable and interpretable cause-and-effect relationship between baseline and impacted flows. Monthly differences in flows between the 100% pumping and 50%

reduced pumping scenarios were calculated and then doubled to derive the monthly adjustment rates for a zero-pumping condition (Table 5-6). These adjustment values were applied to the daily gaged flows at Bartow, Fort Meade and Zolfo Springs to correct for the effects of historic groundwater withdrawals.

The impact of reduced groundwater withdrawals was most pronounced at Bartow and Fort Meade, where average flow increases of 13.4 cfs and 17.1 cfs, respectively, were observed (Table 5-6). In contrast, modeled simulations indicated a 6.5 cfs decrease in flow at Zolfo Springs under the same conditions. This decrease is attributed to the tighter confinement of the UFA in that region and the influence of excess runoff associated with agricultural irrigation return flows.

Table 5-6. Estimated monthly adjustment flows based on PRIM2 simulations for both the baseline (100% pumping) and reduced (50% pumping) scenarios from 2003 to 2018 at the USGS Peace River gaging stations: Bartow, Fort Meade, and Zolfo Springs.

Month	**Monthly Adjustment Rate (cfs) ***		
	Bartow	**Fort Meade**	**Zolfo Springs**
January	2.50	6.60	-12.48
February	10.30	14.22	-12.84
March	8.81	13.66	-4.45
April	5.11	10.71	-5.29
May	-0.62	4.31	-12.39
June	4.45	5.99	-25.18
July	12.92	14.69	-17.66
August	22.74	25.50	-11.10
September	32.73	34.78	3.21
October	24.03	26.23	12.22
November	23.32	29.84	7.58
December	14.73	19.32	-0.49
Average	**13.41**	**17.14**	**-6.54**

* Negative values indicate a deduction from the historical flow, while positive values represent an addition.

Because water withdrawals during the baseline period were highly variable (see Figure 2-15 in Section 2.1.5), an additional adjustment was necessary. The PRIM2 model only simulated conditions from 2003 to 2018, a period characterized by average water withdrawals that were lower than those in earlier years and higher than those in subsequent years within the broader baseline timeframe as shown in Figure 2-15. To account for this variability, a methodology outlined in Appendix C was employed to further refine the monthly adjustment rates using a yearly ratio approach.

This ratio was calculated by dividing the total groundwater withdrawals for each baseline year by the average water use during the 2003-2018 model period. Table 5-7 presents these yearly ratios, which range from 0.848 (in 2005) to 1.945 (in 1975).

Daily baseline flows at the Peace River gaging stations (Bartow, Fort Made and Zolfo Springs) were then computed by applying the monthly adjustment rates (Table 5-6), each scaled by its corresponding yearly ratios (Table 5-7). The resulting baseline flow represents an estimate of the streamflow time series that would have occurred in the absence of regional water withdrawals (see Figure 5-9). In this report, "baseline flow" refers to the constructed time series, which incorporate adjustments to historical flows as predicted by the PRIM2 model (Appendix B).

Table 5-7. Estimated yearly adjustment ratios for annual water use consideration (1975-2022)*.

Year	Ratio	Year	Ratio	Year	Ratio	Year	Ratio
1975	1.945	**1987**	1.296	**1999**	1.294	**2011**	0.930
1976	1.809	**1988**	1.619	**2000**	1.522	**2012**	1.126
1977	1.674	**1989**	1.750	**2001**	1.316	**2013**	1.003
1978	1.599	**1990**	1.590	**2002**	1.256	**2014**	0.905
1979	1.465	**1991**	1.575	**2003**	1.045	**2015**	0.900
1980	1.378	**1992**	1.320	**2004**	1.012	**2016**	0.870
1981	1.670	**1993**	1.180	**2005**	0.848	**2017**	0.917
1982	1.403	**1994**	1.123	**2006**	1.169	**2018**	0.913
1983	1.129	**1995**	1.124	**2007**	1.121	**2019**	0.903
1984	1.481	**1996**	1.285	**2008**	1.023	**2020**	0.880
1985	1.591	**1997**	1.236	**2009**	1.144	**2021**	0.927
1986	1.392	**1998**	1.306	**2010**	1.075	**2022**	0.937

* Ratio values are rounded to the third decimal place for demonstration purposes.

Figure 5-9 shows that, for Bartow and Fort Meade, the baseline flow typically exceeds the gaged flow for most of the year, indicating a common flow loss in the river segment between these locations. In the case of the Zolfo Springs gage, the baseline flow generally aligns with the gaged flow but is marginally lower during certain periods, reflecting the impact of watershed excess runoff returned from agriculture irrigation.

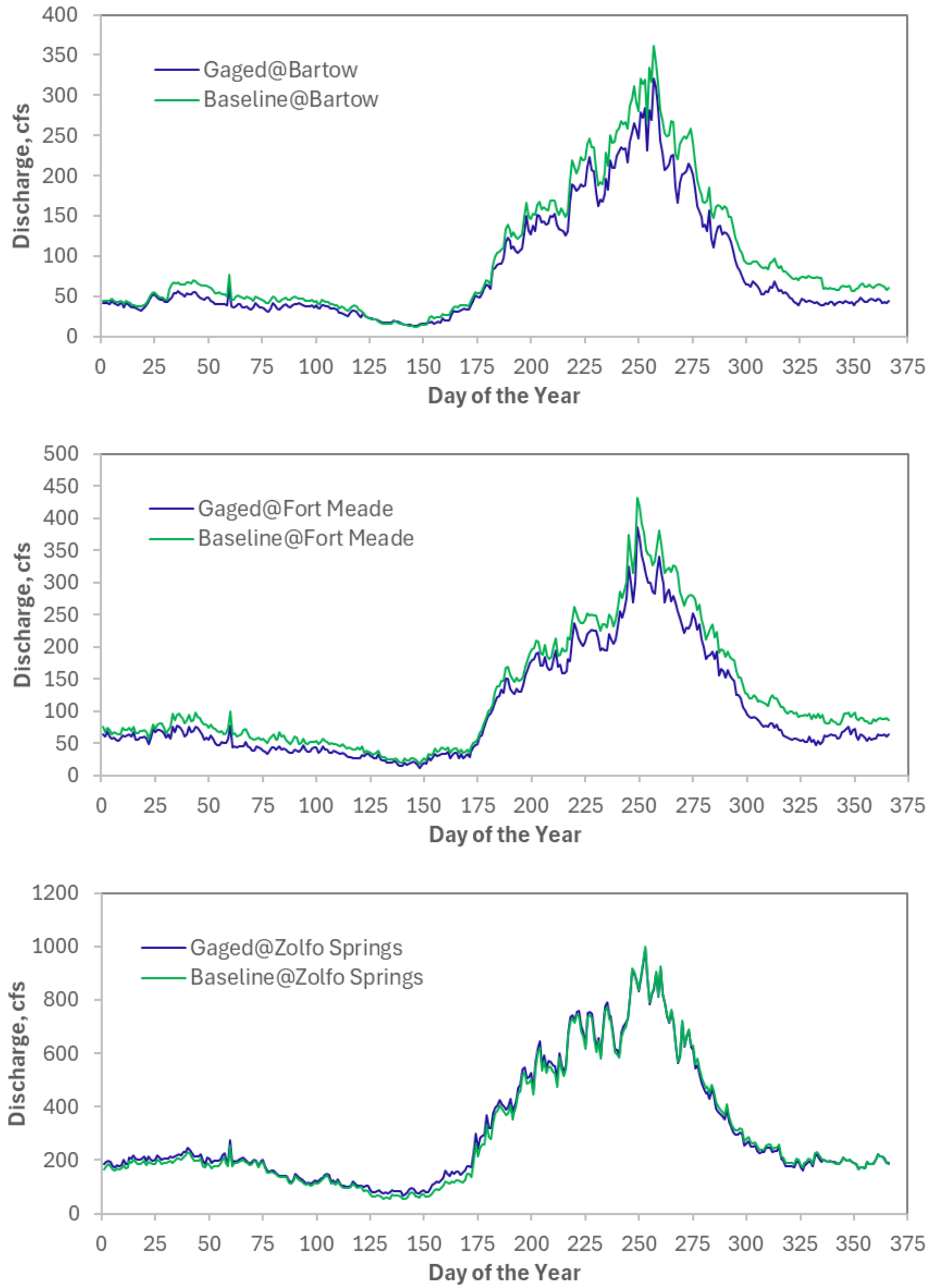


Figure 5-9. Median daily historical and baseline flow at the USGS Peace River gages: Bartow (upper), Fort Meade (middle), and Zolfo Springs (lower).

5.4.3 Flow-Based Block Development

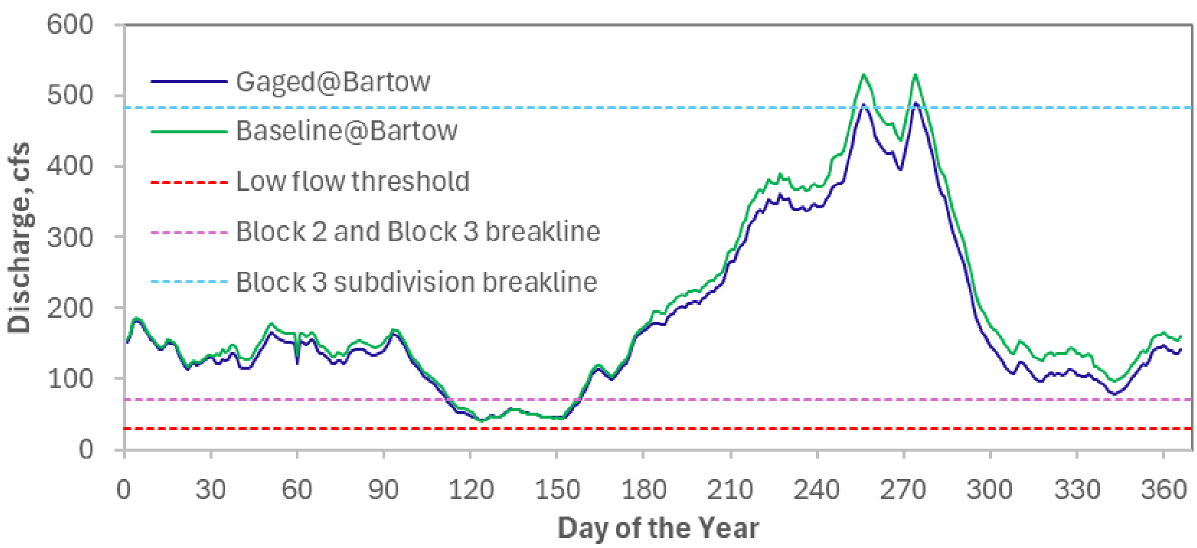
Using the methodology discussed in Section 1.5.3, flow-based Blocks 1, 2, 3A, and 3B were defined for the Upper Peace River through analyses of fish passage, wetted perimeter, and floodplain inundation criteria, as further detailed in Section 5.5.

The delineation of these flow blocks is based on the following flow thresholds:

- **Low-flow threshold**: Marks the transition between Block 1 (low-flow) and Block 2 (medium-flow); determined using fish passage and wetted perimeter analyses.
- **High-flow thresholds**: Defines the boundary between Block 2 (medium-flow) and Block 3 (high-flow), as well as the subdivisions within Block 3 (3A and 3B); based on the floodplain inundation and wetted perimeter analyses.

Once the low- and high-flow were established, flow ranges for Blocks 1, 2 and 3, including subdivisions within Block 3, were delineated accordingly.

These blocks were established using the baseline flow record detailed in Section 5.4.2, which covers the baseline period from January 1, 1975, through December 31, 2022 (as discussed in Section 5.4.1), and incorporate data from the three USGS Peace River gaging stations at Bartow, Fort Meade, and Zolfo Springs, as illustrated in Figure 5-10.



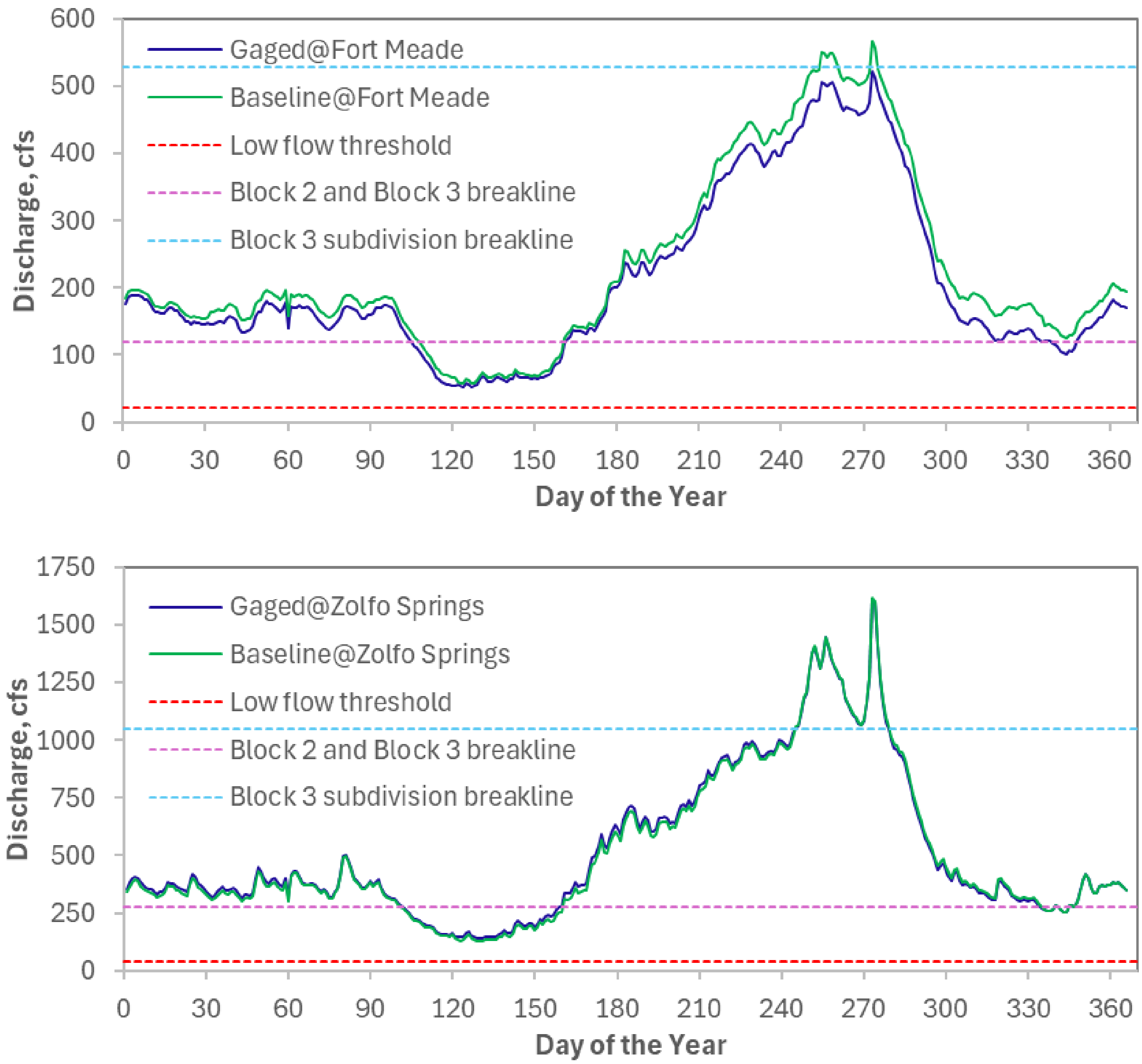


Figure 5-10. Flow blocks are superimposed on hydrographs displaying the mean observed daily flows (solid blue line) and mean baseline daily flows (soild green line) at three USGS Peace River gaging stations: SR60 at Bartow, FL (upper panel, No. 02294650); Fort Meade, FL (middle panel, No. 02294898); and US 17 at Zolfo Springs, FL (lower panel, No. 02295637). High flow Block 3 is subdivided into two sub-blocks, as indicated by a blue dashed horizontal line. The boundary between high-flow (Block 3) and medium-flow (Block 2) is shown by a purple dashed line, while the boundary between medium-flow (Block 2) and low-flow (Block 1) is marked with a red dashed line. Although the mean hydrographs are included for reference, the flow blocks were determined using criteria based on fish passage, wetted perimeter, and floodplain inundation rather than mean flows.

5.5 Technical Approaches for Minimum Flows Determination

Following the establishment of baseline flows, definition of flow-based blocks, and completion of the HEC-RAS model, a suite of technical analyses was conducted to determine minimum flows for each block at the three USGS index gaging stations:

Bartow, Fort Meade, and Zolfo Springs. Table 5-8 summarizes the methodologies applied across each flow block.

Table 5-8. Technical approaches for minimum flows determination by Block for the Upper Peace River.

Technical Approaches	Low Flow Block 1	Medium Flow Block 2	High Flow Block 3
Fish passage	√		
Wetted perimeter (low flow)	√		
SEFA analysis		√	
Woody habitat analysis		√	
Floodplain inundation area			√
Wetted perimeter (medium/high flow)			√

- **Low Flow (Block 1)** - Minimum flows for Block 1 were determined using two ecological criteria: fish passage depth and wetted perimeter standards. The higher of the two values was selected as the low-flow threshold, representing the flow rate below which surface water withdrawals are prohibited to protect ecological resources during very low flow periods.
- **Medium Flow (Block 2)** - Minimum flows for Block 2 were based on two metrics aimed at maintaining instream habitats. The first involved the use of SEFA to evaluate flow requirements for maintaining fish and macroinvertebrates habitats. The second metric ensured adequate flows for maintaining woody habitat structures. The higher of these two values was adopted as the minimum flow for Block 2.
- **High Flow (Block 3)** – Analyses for this block focused on the sensitivity of floodplain inundation to flow reductions, supplemented by wetted perimeter inflection points under medium and high flow conditions. The wetted perimeter analysis primarily served to support and refine the high flow thresholds.

Block 1 is fully protected, meaning 100% of its flow is preserved with no allowable reductions. For Blocks 2 and 3, a percent-of-flow approach (outlined in Section 1.5.6) was applied. This method involved incrementally reducing baseline flows until a 15% loss in habitat was observed. The resulting percentage of flow reduction defined the maximum allowable withdrawal, while the remaining flow constituted the minimum flow for the respective block. This approach ensures that ecological functions and communities of the Upper Peace River are protected from significant harm.

Final minimum flow recommendations were developed by integrating results across all three blocks, forming a comprehensive flow regime tailored to each index gaging station. This approach accounts for site-specific environmental and hydrologic conditions.

5.5.1 Fish Passage Assessment

Customized output from the HEC-RAS model was used to evaluate flow necessary to maintain depths for fish passage along the Upper Peace River, including site-specific flow, minimum channel elevation, and water surface elevation. Table 5-9 provides an example of these outputs for selected parameters at the Bartow gage and survey site 179715, based on selected low flow profiles.

Given the variability in channel morphology, cross-sectional data from 206 surveyed sites between Bartow and Zolfo Springs was analyzed by segments, i.e., Bartow to Fort Meade, Fort Meade to Bowling Green, and Bowling Green to Zolfo Springs, to determine site specific conditions.

Table 5-9. Example of HEC-RAS model output for two transects (Bartow gage and Transect 179519) used to develop stage-discharge relationship at the site and relate site flow to its associated USGS index gaging station at Bartow.

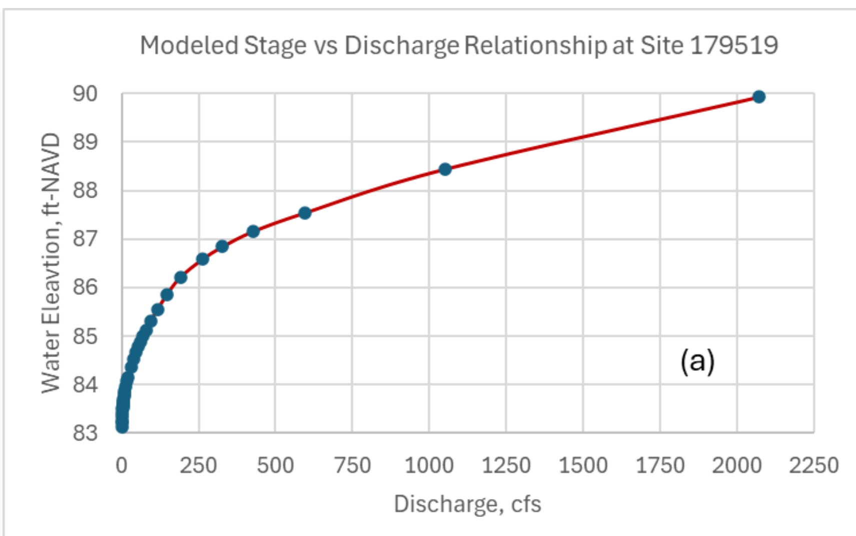
Profile	Bartow Gage			Site 179519		
	Gage Flow (cfs)	**Minimum Channel Elevation (ft NAVD)**	**Water Surface Elevation (ft NAVD)**	**Site Flow (cfs)**	**Minimum Channel Elevation (ft NAVD)**	**Water Surface Elevation (ft NAVD)**
80	42.2	88.85	90.45	30.5	83	84.36
85	34.6	88.85	90.31	20.1	83	84.14
86	33.4	88.85	90.28	17.3	83	84.08
87	32.0	88.85	90.26	12.6	83	83.95
88	30.1	88.85	90.22	9.81	83	83.87
89	28.9	88.85	90.20	8.19	83	83.81
90	26.9	88.85	90.16	6.99	83	83.77
91	23.8	88.85	90.09	5.99	83	83.70
92	21.3	88.85	90.04	5.28	83	83.66
93	18.7	88.85	89.98	4.54	83	83.62
94	15.9	88.85	89.91	4.08	83	83.59
95	12.9	88.85	89.82	3.67	83	83.57
96	11.2	88.85	89.77	3.32	83	83.54
97	8.27	88.85	89.65	2.65	83	83.50
98	5.44	88.85	89.52	1.70	83	83.42
99	4.00	88.85	89.45	1.03	83	83.34
99.5	1.65	88.85	89.28	0.43	83	83.24
99.75	1.11	88.85	89.24	0.34	83	83.22
100	0.11	88.85	89.06	0.09	83	83.13

Each surveyed cross section was inspected to determine the minimum channel elevation, representing the deepest part of the river, where fish passage is most likely to occur during periods of extreme low water.

Using model generated stage-discharge relationships for each cross section in Figure 5-11(a), 0.6 feet was added to the minimum channel elevation to establish the fish passage elevation (= minimum channel elevation + 0.6 feet). Then, the flow necessary to achieve this fish passage elevation was calculated for each of 206 surveyed cross sections.

Once site-specific flows were determined, they were linked to their respective index gages, i.e., the Peace River at Zolfo Springs, Fort Meade, and Bartow gages using the stage-discharge relationship, for example as shown in Figure 5-11(b) to calculate their corresponding site-specific gaged flows.

Finally, site-specific gaged flows were plotted against distance, measured in feet from the downstream end at Zolfo Springs, and visually evaluated to determine the highest flow rate for each river segment. This flow rate was identified as the minimum flow necessary to maintain fish passage across different segments of the Upper Peace River.



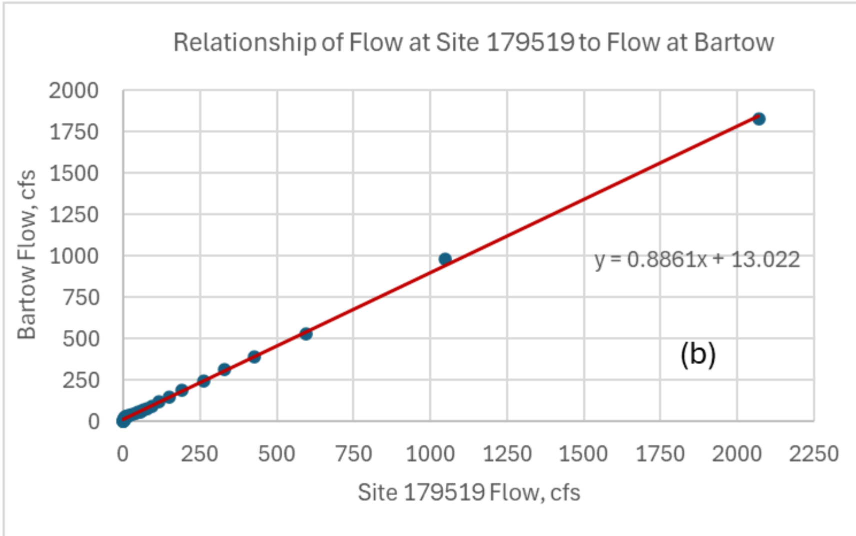


Figure 5-11. Example of graphic outputs generated from modeled flow data used to (a) develop stage-discharge curves at each site to determine the discharge needed to achieve a target water level, and (b) to convert from site flow to gage site flow.

5.5.2 Wetted Perimeter Analysis

Following execution of the steady-state HEC-RAS model, rating curves for total wetted perimeter versus flow were generated for all surveyed cross-sections (see Figure 5-12 for an example at Site 179519). These curves are available in HEC-RAS for viewing, copying, and customization. As illustrated in Figure 5-12, multiple local curvature maxima, i.e., inflection points, representing changes in slope, typically emerge within the low, medium, and high flow ranges of each rating curve, although some are more distinct than others. Curvature, in this context, quantifies how quickly the curve bends or changes direction and is calculated as the rate of change of wetted perimeter per unit change in flow.

The LWPIP was used as a metric for low flow assessment, while mid- and high-range inflection points supported high flow analysis. Customized HEC-RAS profile output was exported into Excel, where Visual Basic scripts were used to calculate curvature between adjacent flow profiles (Table 5-10).

The LWPIP was identified at each survey site for flows less than or equal to the 85th percentile. Site-specific flow rates were then converted to corresponding values at their respective index gage using HEC-RAS profile output.

Additional inflection points often aligned with topographic transitions, such as the top of bank or the shift from swamp to lower floodplain. Inflection points in the medium-flow range typically occurred between the 45th and 55th percentiles, while high flow infection points were generally identified between the 9th to 16th percentiles. These ranges were adjusted slightly by river segment to account for topographic variation, as the Upper Peace River transitions from extensive low-lying floodplains in its upper segment to more defined, incised morphology in its lower segment. Medium- and high-range inflection points were likewise converted to index gage flows, and maximum flow values derived from this analysis were integrated with the floodplain inundation sensitivity framework discussed in Section 5.5.3 to define high flow thresholds.

At Site 179519, for instance, a distinct inflection point was observed near 7 cfs, with a wetted perimeter of about 48 feet (see Figure 5-13). At modeled flow of 7 cfs, the wetted perimeter is 48.32 feet (Table 5-10). When flow was increased nearly sixfold (to 48 cfs), the wetted perimeter increased to only 57.8 feet – an increase of roughly 20%. Conversely, a 1 cfs reduction in flow resulted in a wetted perimeter of 38.43 feet, reflecting a similar 20% decrease. This suggests that a flow of 6.99 cfs provides a relatively large habitat area, favorable for aquatic macroinvertebrates colonization. Any reduction below this rate would significantly diminish available habitat. Some transects exhibited no apparent inflection points between the lowest modeled flow and the 85th percentile flow. These were typically located in pool areas, where standing water above the lowest wetted perimeter was present even at very low streamflow.

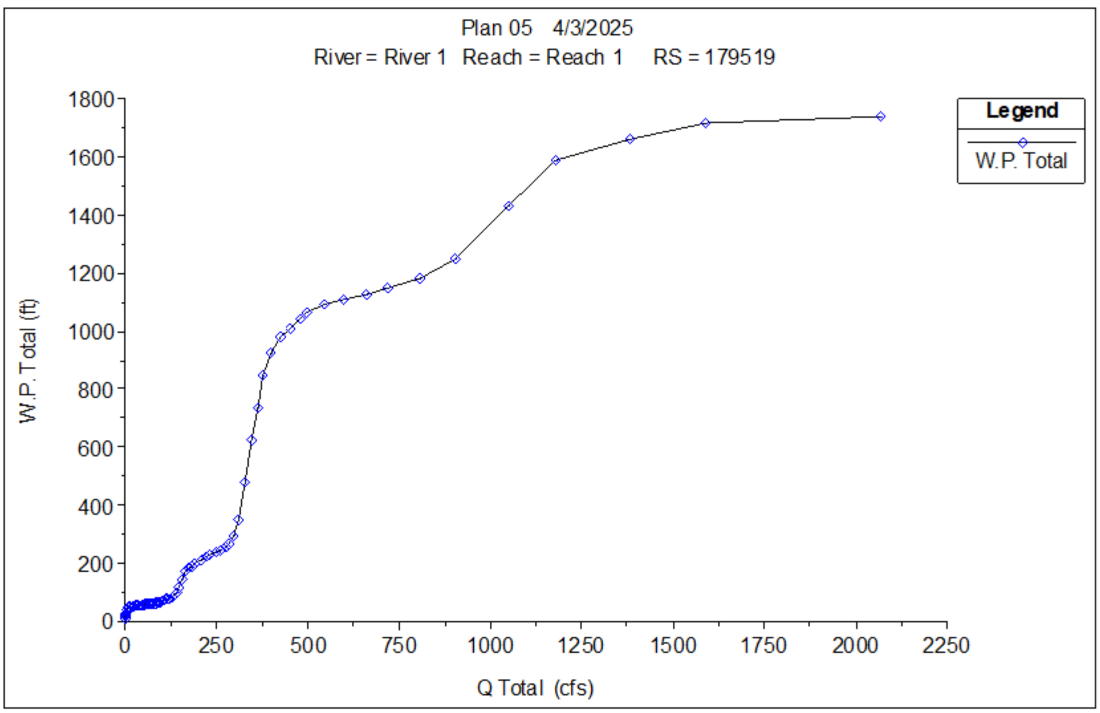


Figure 5-12. Total wetted perimeter versus discharge at Site 179519.

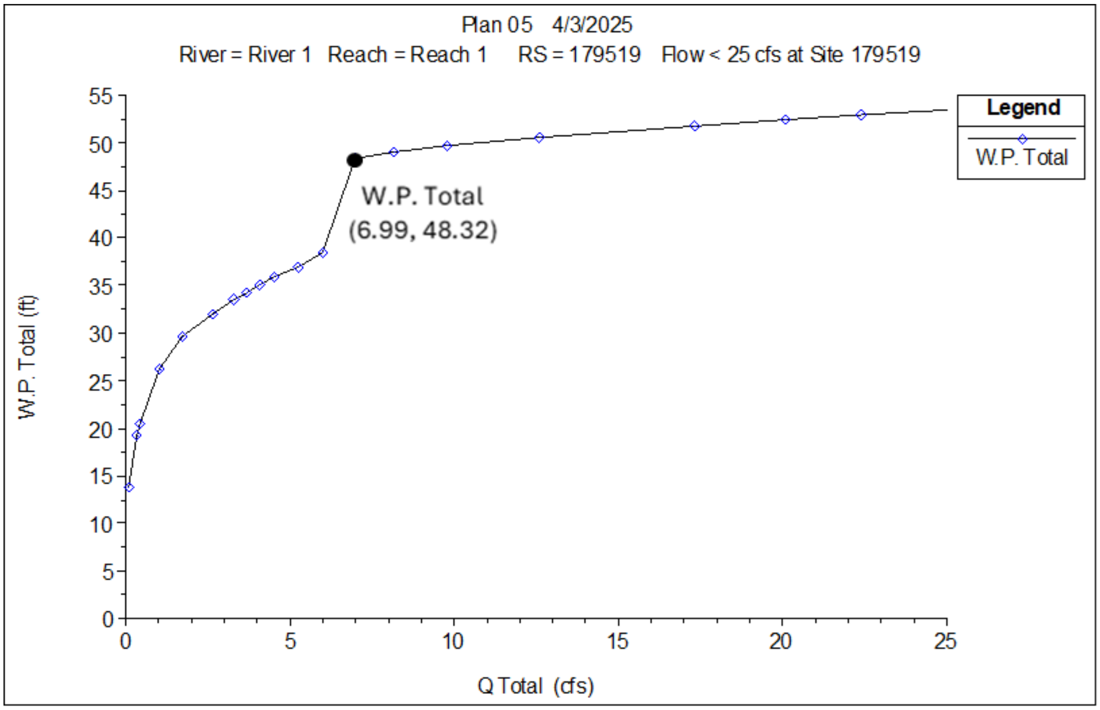


Figure 5-13. Total wetted perimeter versus discharge at Site 179519 for flows below 25 cfs.

Table 5-10. Example of HEC-RAS model output used to calculate curvature for the total wetted perimeter (WP) versus the discharge curve. Data shown for Site 179519, located in the upper segment of the Upper Peace River and associated with the Bartow index gage.

Profile	Gage Flow (cfs)	Site Flow (cfs)	Site Total WP (ft)	Curvature	Profile	Gage Flow (cfs)	Site Flow (cfs)	Site Total WP (ft)	Curvature
1	1,830	2,070	1,741		51	78.3	76.8	62.05	(0.00)
2	1,500	1,590	1,716	(0.21)	52	76.7	74.8	61.79	(0.00)
3	1,310	1,380	1,660	(0.09)	53	74.6	72.9	61.54	0.00
4	1,120	1,180	1,588	(0.83)	54	73.2	70.9	61.28	(0.01)
5	980	1,050	1,434	(0.08)	55	71.7	68.9	61.01	0.00
6	870	903	1,247	0.60	56	70.2	67.4	60.81	(0.00)
7	746	806	1,182	0.31	57	68.7	65.2	60.51	(0.00)
8	662	719	1,150	(0.01)	58	67.3	63.4	60.26	(0.01)
9	590	659	1,127	0.06	59	65.9	62.6	60.14	(0.00)
10	526	596	1,108	(0.01)	60	65.5	61.5	59.97	0.01
11	484	544	1,091	(0.24)	61	63.7	60.2	59.78	(0.00)
12	454	498	1,065	(0.64)	62	62.3	58.6	59.54	(0.00)
13	434	477	1,040	0.04	63	61.2	56.9	59.28	(0.01)
14	409	450	1,009	(0.12)	64	60.8	56.4	59.20	(0.00)
15	393	426	979	(0.70)	65	59.3	54.9	58.96	(0.01)
16	374	398	924	(1.77)	66	58.0	53.9	58.79	0.00
17	359	378	849	(3.02)	67	56.9	52.4	58.54	(0.00)

Profile	Gage Flow (cfs)	Site Flow (cfs)	Site Total WP (ft)	Curvature	Profile	Gage Flow (cfs)	Site Flow (cfs)	Site Total WP (ft)	Curvature
18	344	361	734	0.01	68	55.8	51.0	58.30	0.01
19	327	345	626	(2.00)	69	54.4	49.6	58.07	(0.00)
20	313	328	477	1.00	70	53.5	48	57.8	0.00
21	299	312	354	3.48	71	52.5	46.3	57.52	(0.01)
22	287	298	294	2.46	72	51.8	44.9	57.28	(0.00)
23	273	284	268	0.40	73	50.7	43.3	57.00	(0.00)
24	260	274	254	0.52	74	49.8	41.2	56.63	(0.01)
25	247	263	245	0.47	75	48.5	39.9	56.39	0.01
26	231	249	239	(0.03)	76	47.4	38.5	56.14	(0.00)
27	219	232	231	(0.50)	77	46.4	36.8	55.83	(0.00)
28	211	221	221	0.20	78	45.4	34.8	55.46	(0.01)
29	200	207	210	(0.00)	79	43.9	32.2	54.95	(0.00)
30	190	191	199	(0.13)	80	42.2	30.5	54.61	0.01
31	180	180	189	0.34	81	40.4	29.2	54.36	0.00
32	172	173	185	(1.08)	82	38.7	27.6	54.06	(0.01)
33	167	164	171	(2.31)	83	37.9	25.3	53.60	(0.02)
34	158	157	143	1.05	84	36.1	22.4	52.97	(0.03)
35	150	148	117	0.35	85	34.6	20.1	52.40	0.03
36	145	142	102	0.85	86	33.4	17.3	51.78	(0.04)
37	139	136	92.15	0.59	87	32.0	12.6	50.53	(0.05)
38	131	128	83.49	0.66	88	30.1	9.81	49.66	(0.02)
39	122	120	80.13	(0.04)	89	28.9	8.19	49.12	(0.33)
40	117	116	78.27	0.04	90	26.9	6.99	48.32	(9.22)
41	111	110	75.69	(0.06)	91	23.8	5.99	38.43	7.86
42	107	106	73.74	0.03	92	21.3	5.28	36.99	0.51
43	102	101	71.47	(0.00)	93	18.7	4.54	35.87	(0.27)
44	96.6	96.9	69.60	0.00	94	15.9	4.08	35.05	(0.12)
45	93.6	93.6	68.11	(0.01)	95	12.9	3.67	34.27	(0.27)
46	91.3	91.0	66.92	(0.02)	96	11.2	3.32	33.51	(0.04)
47	88.4	88.0	65.48	0.02	97	8.27	2.65	32.03	(0.28)
48	85.8	85.8	64.46	0.01	98	5.44	1.70	29.67	(2.56)
49	83.2	82.6	63.00	0.27	99	4	1.03	26.29	(8.27)
50	80.2	79.0	62.33	0.06	100	0.11	0.09	13.77	

Note: Values shown in parentheses represent negative curvature.

5.5.3 Floodplain Habitat Inundation Evaluation

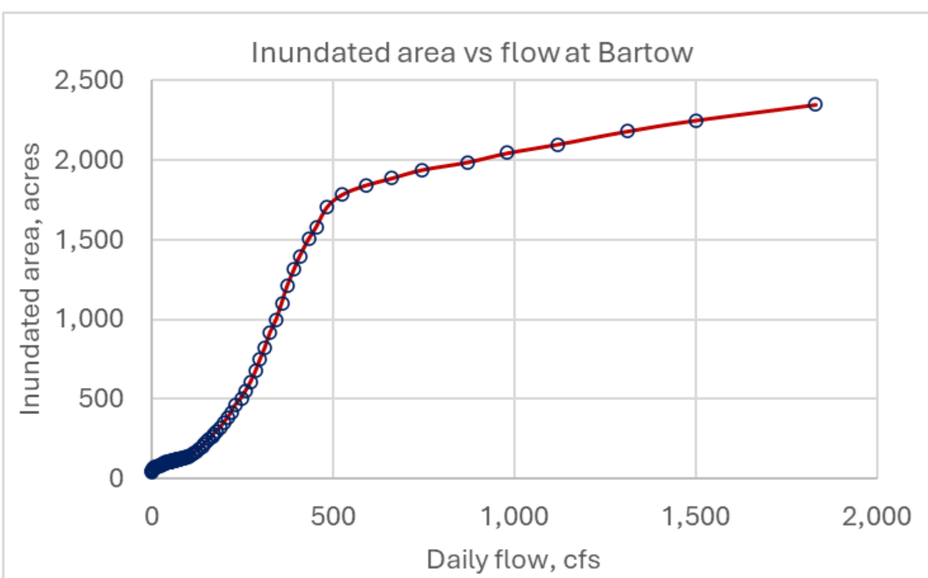
The District's approach to protecting high flows that support floodplain habitats, ecological communities, and associated functions incorporates both spatial and temporal considerations of floodplain inundation. Spatially the analysis encompasses the entire Upper Peace River basin, including all associated wetlands. Temporally, it evaluates the degree of protection provided to floodplain habitats by ensuring flow reductions do not cause 15% or greater decrease in floodplain inundation over the baseline period of 1975-2022.

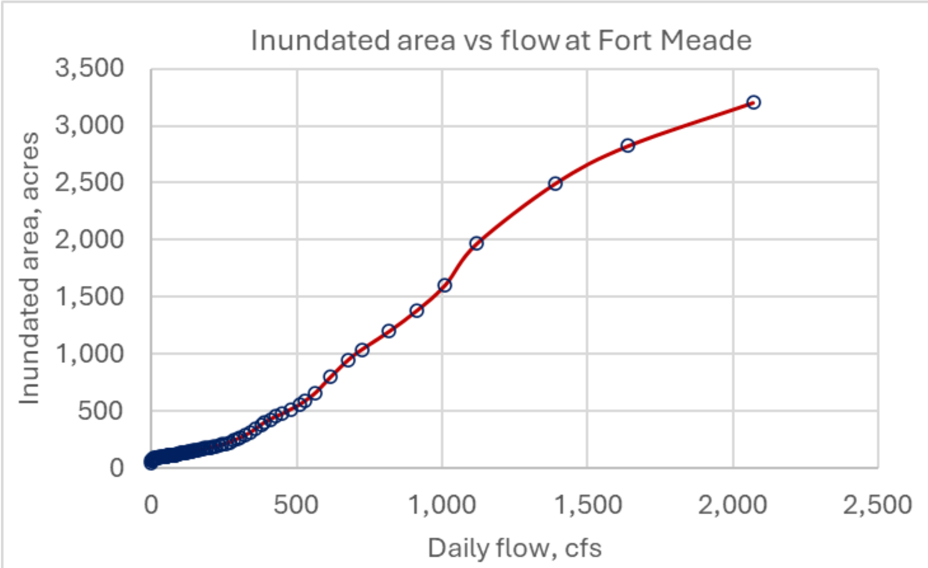
The floodplain inundation analysis for the Upper Peace River has three primary objectives:

- To define the high-flow threshold, which serves to delineate the boundary between Block 2 (medium flow) and Block 3 (high flow).
- To assess whether further subdivision of Block 3 is warranted to better protect floodplain habitats associated with very high flow regimes.
- To calculate recommended minimum flows for Block 3 that would protect at least 85% of floodplain inundations for each river segment within the Upper Peace River.

As an initial step, the HEC-RAS model output was used to calculate the extent of floodplain inundation, referred to here as the Total Inundation Area (TIA), for each of the three river segments as a function of percentile flows corresponding to their respective USGS index gaging stations: Bartow, Fort Meade and Zolfo Springs.

Due to limitations in LiDAR data coverage for the main channel, the DEM could not be used directly in GIS to generate inundation polygons for all flow profiles. Instead, an alternate method was applied: top width values (representing the top width of the water surface across each cross section, as derived from HEC-RAS simulation results) were multiplied by channel length between surveyed cross-sections to approximate the inundation area. Detailed procedures for calculating TIA are provided in Appendix H. For each percentile flow, a single inundation area was computed. By pairing a range of percentile flow profiles (from low to high) with their corresponding inundation areas, a rating curve of inundation area versus flow was developed for each gaging station (see Figure 5-14).





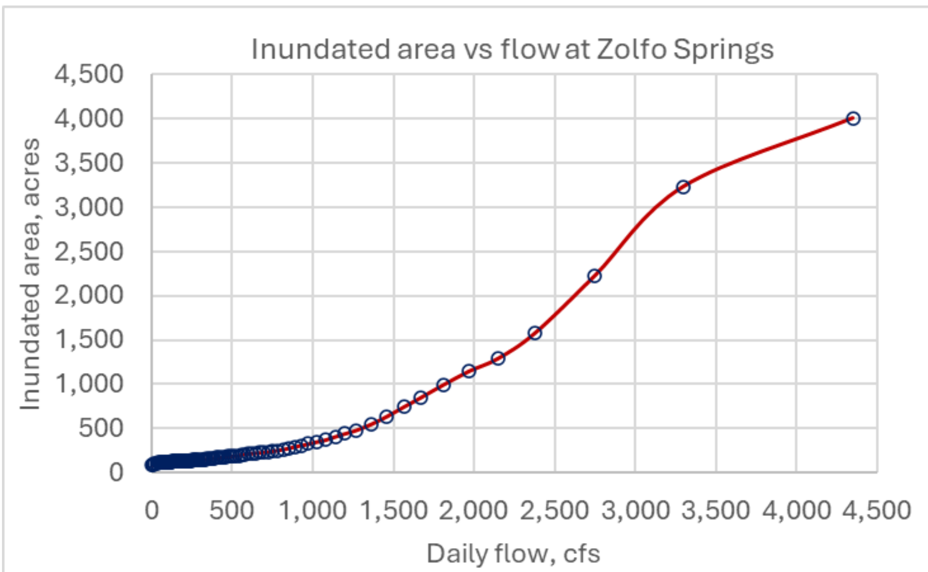


Figure 5-14. Rating curves of inundated area versus percentile flow at the three USGS gaging stations: Bartow (top), Fort Meade (middle), and Zolfo Springs (bottom).

The rating curves of inundation area versus flow were subsequently used to evaluate floodplain inundation losses associated with flow reductions across a range of flow percentiles at each of the three index gaging stations. Floodplain habitat availability was thus assessed under both the long-term baseline flow condition and corresponding reduced flow scenarios to determine the percent-of-flow reduction that would result in a 15% loss in floodplain inundation area. These percent-of-flow reductions were considered the limiting thresholds for respective percentiles. The resulting flow reduction values versus flow percentiles were then plotted to generate the flow sensitivity curves for the three index gaging stations (see Figure 6-8, Figure 6-9, and Figure 6-10 in Section 6.2.2.2)

Analysis of each curve revealed that the slope changes gradually up to approximately the 90th flow percentile. Beyond this point, the slope becomes markedly steeper, indicating that floodplain habitat in this very high flow regime is significantly more sensitive to flow reductions. As such, further subdivision of high flow Block 3 is warranted to better reflect this heightened sensitivity.

From the low-flow percentile through approximately the 90th percentile, the range of flow transitions gradually, from in-channel conditions to bankfull and eventually to overbank inundation across the floodplain. To more effectively align minimum flow requirements with habitat -specific needs, a clearly defined flow threshold is needed to distinguish instream flows from overbank flows. This delineation would help ensure that both in channel aquatic habitats and floodplain dependent communities receive appropriate protection under varying hydrologic conditions.

Subsequently, a combined coefficient of determination (R^2) was calculated across three defined percentile flow ranges. Each range was individually fitted using linear regression to obtain its corresponding R^2 value. The average of these R^2 values was then computed for each configuration, and the setup yielding the highest combined R^2 was identified. This optimization process facilitates the identification of percentile-based breakpoints that delineate the transition between Block 2 (medium flow) and Block 3 (high flow), as well as subdivisions within Block 3. The flow rate corresponding to the breakpoint percentile was established as the flow threshold for these transitions.

To assess the physical validity of the identified flow threshold for each river segment, a cross-validation was performed using inflection points derived from the wetted perimeter analysis for medium and high flows, as described in Section 5.5.2. When the threshold derived from the floodplain sensitivity analysis aligned with the corresponding wetted perimeter inflection points, the floodplain-based value was adopted. In instances of greater discrepancy, engineering judgment was applied to determine the appropriate threshold.

5.5.4 Instream Habitat Assessment for Fish and Macroinvertebrates

5.5.4.1 Upper Segment Habitat

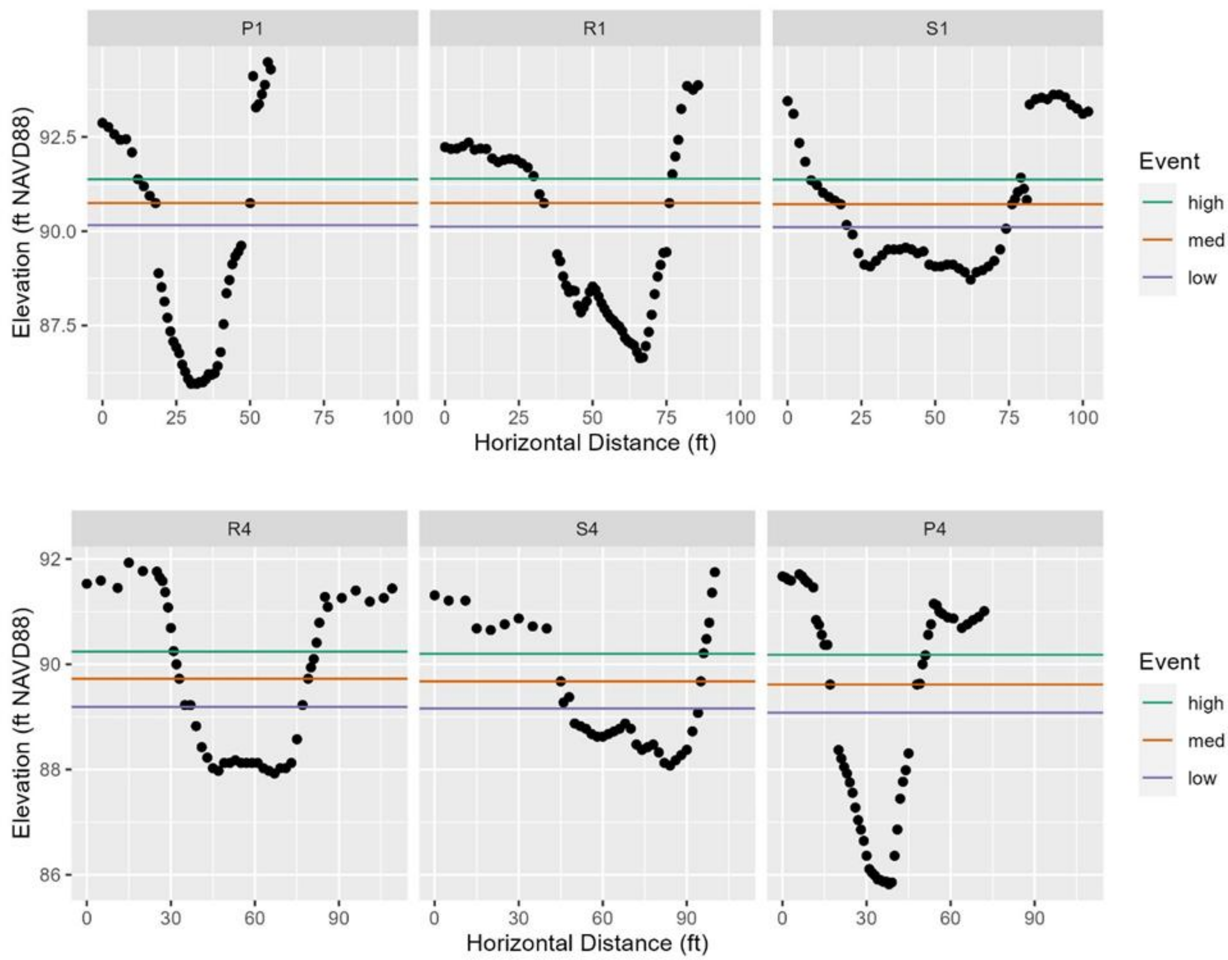
The cross-sectional geometry and water levels varied among individual transects within the upper segment of the Upper Peace River (Figure 5-15). Water surface elevation data were collected at three events representing low, medium, and high flow conditions.

Site 1 is approximately 25 feet wide from bank to bank with pool, run, and shoal habitats closely spaced (Figure 5-15). During the medium flow data collection event, the pool and run were approximately 4 feet deep, and the shoal is approximately 2 feet deep. The site has sand substrate with cover near the banks (HSW 2021).

Site 4 is approximately 30 to 45 feet wide from bank to bank (Figure 5-15). The run and shoal have maximum depths under 2 feet, while the pool reaches a maximum depth between 3 and 4 feet at medium flow. The shoal is sandy, located between the upstream run and downstream pool.

Site 12 is approximately 50 to 60 feet wide from bank to bank (Figure 5-15). The shoal has a maximum depth between 2 and 3 feet at medium flow, while the run and pool are approximately 5 feet deep. Site 12 is downstream of the Heritage Peace River boat ramp (Figure 5-15) and is dominated by bare sand, sand with cover, and terrestrial vegetation at the banks.

Habitat-flow curves show how the average habitat across all nine cross sections varies with changes in flow (Figure 5-16). For many species, habitat availability increases with flow, often in a nonlinear manner.



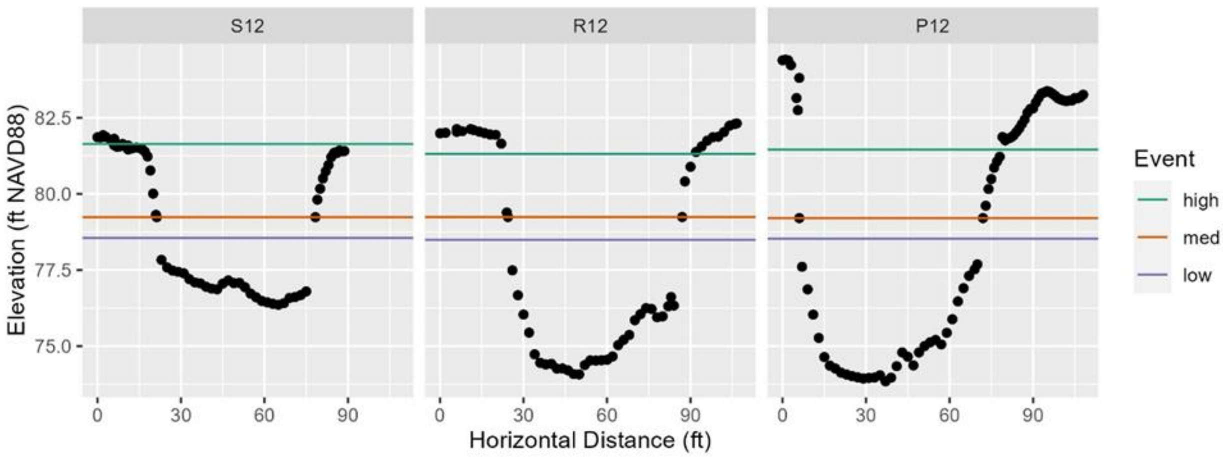


Figure 5-15. Cross-section elevations in the upper segment of the Upper Peace River. Horizontal lines are water surface elevations at high, medium, and low flow events. P, R and S indicate the pool, run and shoal transects, respectively at each site. Within each numbered site, cross sections are arranged from left to right, upstream to downstream.

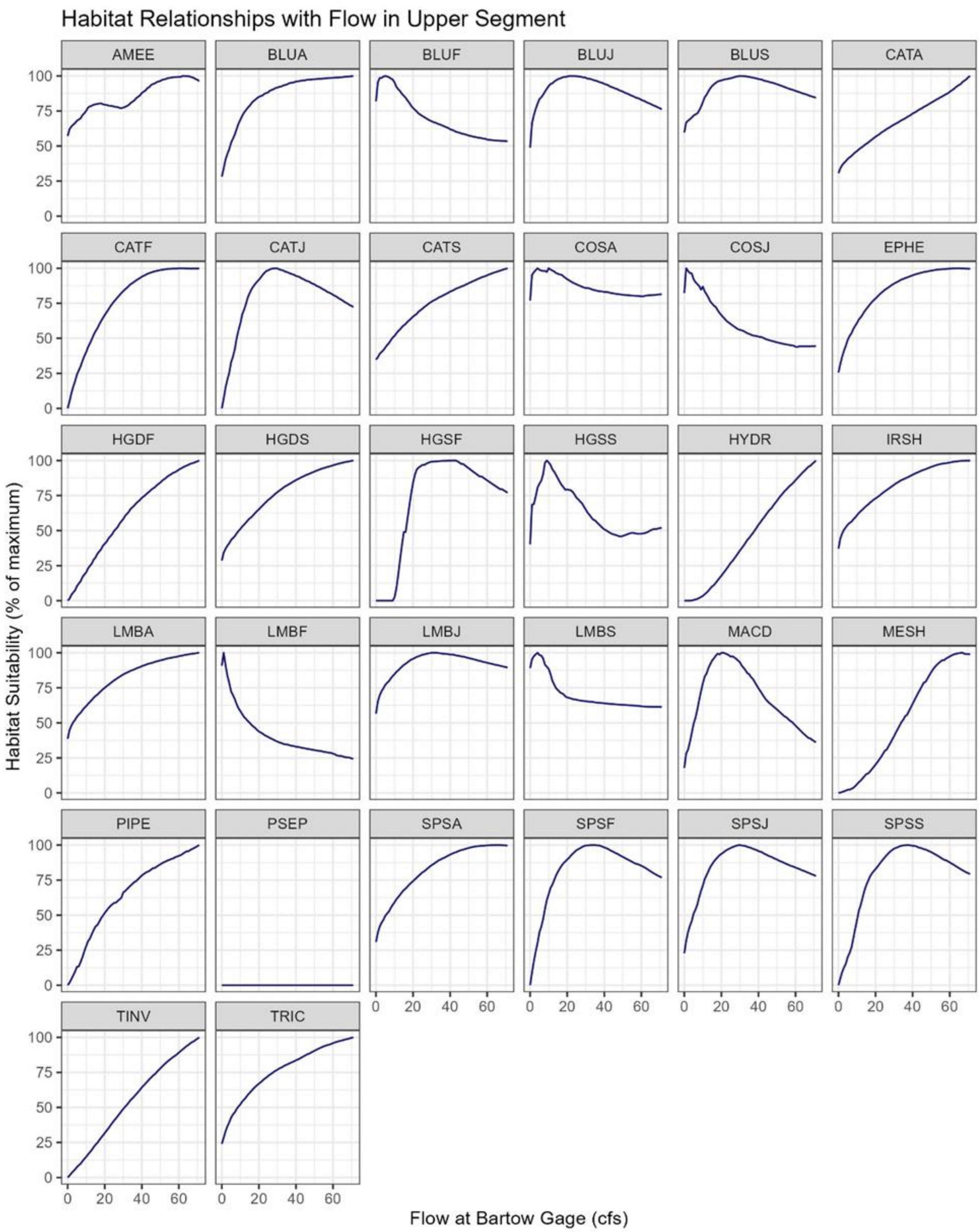


Figure 5-16. Average habitat – flow relationships in the upper segment of the Upper Peace River. Habitat suitability is expressed relative to the maximum for each species; all species with any habitat reach a maximum of 100% at some flow. The curves illustrate how habitat suitability responds to changes in flow. PSEP does not exhibit suitable habitat under any flow condition.

The baseline flow record at Bartow was bounded at 0 and 71 cfs to represent the instream portion of the flow regime. The upper limit of 71 cfs corresponds to the threshold for medium flow in the upper segment, as further discussed Chapter 6. The baseline flow record was then reduced up to 25% in 1% intervals and matched to the habitat-flow curves. These alternative time series of habitat were then averaged across all dates to create a single habitat value for each flow scenario between 100% (baseline) and 75%.

5.5.4.2 Middle Segment Habitat

The cross-sectional geometry and water levels varied among individual transects in the middle segment of the Upper Peace River (Figure 5-17). Water surface elevation data were collected at three events representing low, medium, and high flows.

Site 16 has wetted widths of approximately 50 feet with flat, sandy floodplains on both sides. During medium flow ranges, the run and shoal are approximately 2 feet deep, and the pool reaches approximately 5 feet deep. The site has sand substrate, with cover near the banks (HSW 2021).

Site 19 is approximately 100 feet wide. This location is hydrologically complex, with a meandering pattern between the pool and the shoal, artificial berms, a bridge for Mt. Pisgah Road, and Bowlegs Creek entering near the three cross sections. This was the site of a previous PHABSIM data collection effort, chosen for ease of access rather than ideal hydrologic or habitat conditions.

Cross sections at Site 20 vary from the pool, which is approximately 75 feet wide, to the shoal, which is approximately 125 feet wide. These cross sections are in a straight section of the river.

Habitat-flow curves show how the average habitat across all nine cross sections varies with changes in flow (Figure 5-18). Many species show habitat increases as flow increases, often in a nonlinear manner.

The baseline flow record at Fort Meade was bounded at 120 cfs to represent the instream portion of the flow regime. The upper limit of 120 cfs corresponds to the threshold for medium flow in the middle segment, as further discussed Chapter 6. The baseline flow record was then reduced up to 25% in 1% intervals and matched to the habitat-flow curves. These alternative time series of habitat were then averaged across all dates to create a single habitat value for each flow scenario between 100% (baseline) and 75%.

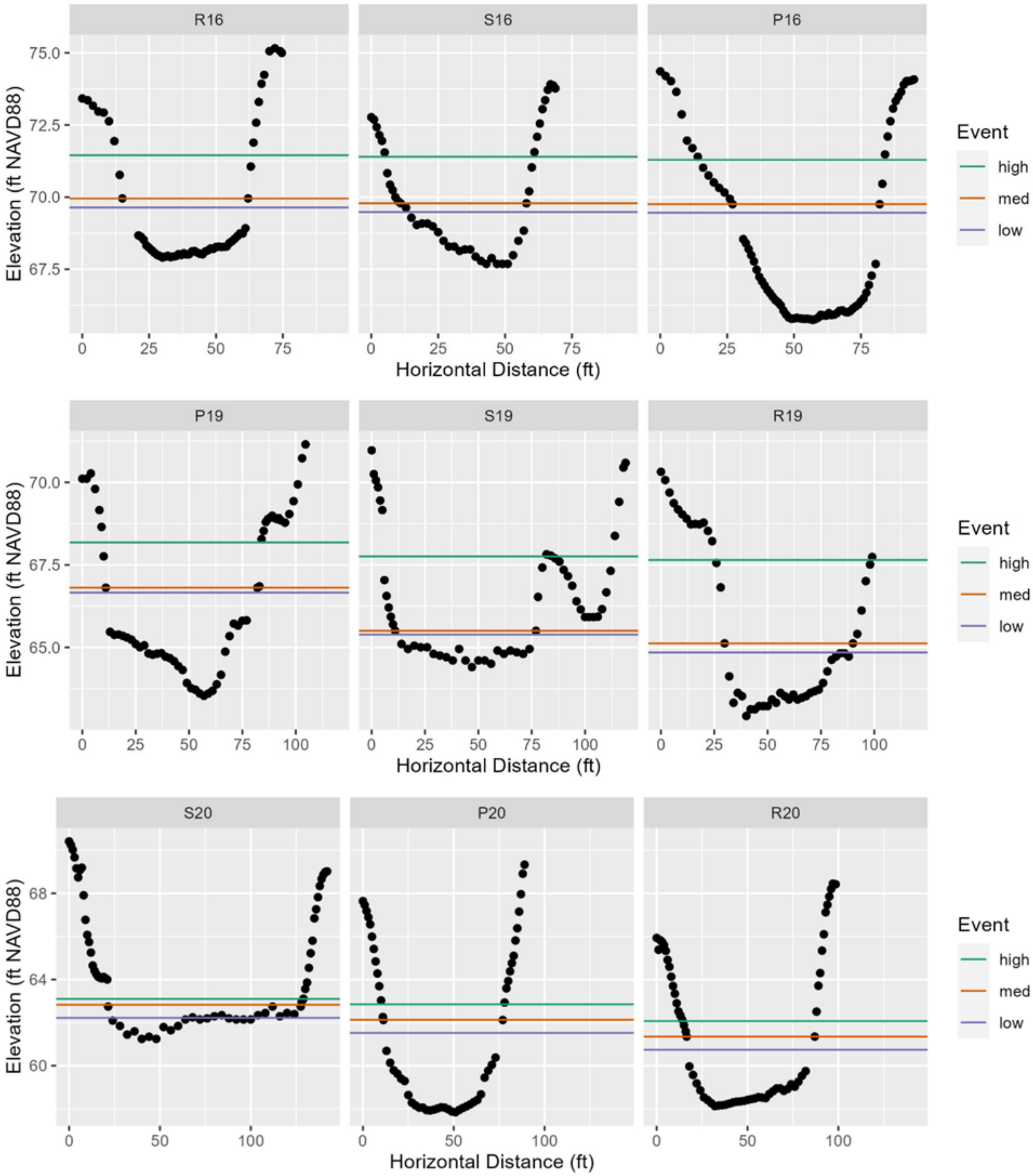


Figure 5-17. Cross-section elevations in the middle segment of the Upper Peace River. Horizontal lines are water surface elevation at high-, medium-, and low-flow events. P, R, and S indicate the pool, run and shoal transects, respectively at each site. Within each numbered site, cross sections are arranged from left to right, upstream to downstream.

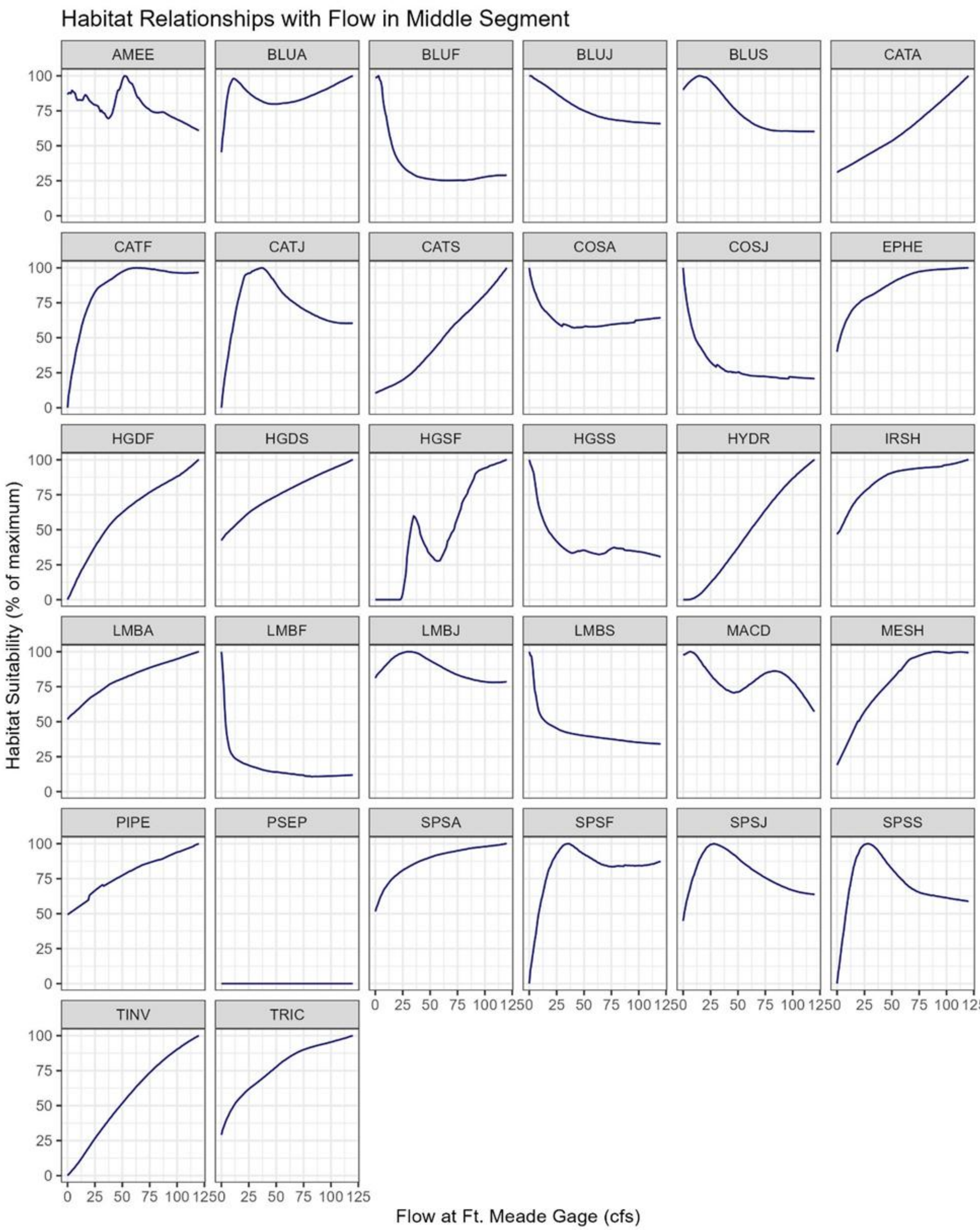


Figure 5-18. Average habitat – flow relationships in the upper segment of the Upper Peace River. Habitat suitability is expressed relative to the maximum for each species; all species with any habitat reach a maximum of 100% at some flow. The curves illustrate how habitat suitability responds to changes in flow. PSEP does not exhibit suitable habitat under any flow condition.

5.5.4.3 Lower Segment Habitat

The cross-sectional geometry and water levels varied among individual transects in the lower segment of the Upper Peace River (Figure 5-19). Water surface elevation data were collected at three events representing low, medium, and high flows.

The run at site 24 is approximately 45 feet wide, while the pool and shoal are 60 to 70 feet wide during medium flows. During medium flow, the shoal is approximately 2 feet deep, the run approximately 4 feet deep, and the pool reaches depths approximately 6 feet. These three cross sections are located near a bend in the river. This was the site of a previous PHABSIM data collection effort.

The three cross sections of site 28 are in a relatively straight section of the river. All three cross sections are approximately 75 feet wide. The run is 3-4 feet deep, the shoal under 2 feet deep, and the pool approximately 6 feet deep at medium flows.

The shoal at site 29 is around 60 feet wide and 2 feet deep, the run is 75 feet wide and 2.5 feet deep and the pool is 85 feet wide and nearly 5 feet deep. These cross sections are in a broad curve near the Zolfo Springs boat ramp.

Habitat-flow curves show how the average habitat across all nine cross sections varies with changes in flow (Figure 5-20). Many species show habitat increases as flow increases, often in a nonlinear manner.

The baseline flow record at Zolfo Springs was bounded at 0 and 274 cfs to represent the instream portion of the flow regime. The upper limit of 274 cfs corresponds to the threshold for medium flow in the lower segment, as further discussed Chapter 6. The baseline flow record was then reduced up to 25% in 1% intervals and matched to the habitat-flow curves. These alternative time series of habitat were then averaged across all dates to create a single habitat value for each flow scenario between 100% (baseline) and 75%.

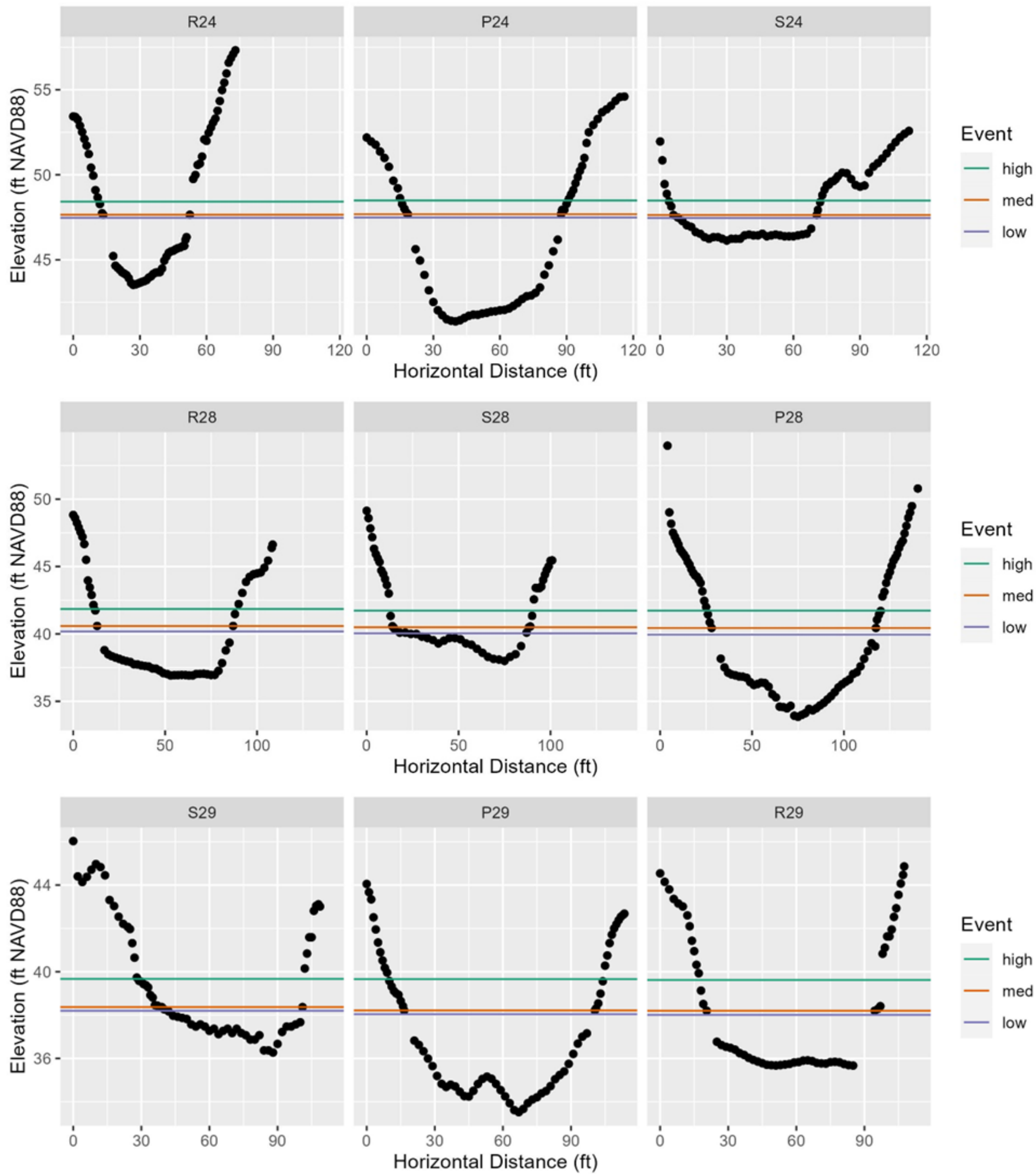


Figure 5-19. Cross-section elevations in the lower segment of the Upper Peace River. Horizontal lines are water surface elevation at high-, medium-, and low-flow events. P, R, and S indicate the pool, run, and shoal transects, respectively at each site. Within each numbered site, cross sections are arranged from left to right, upstream to downstream.

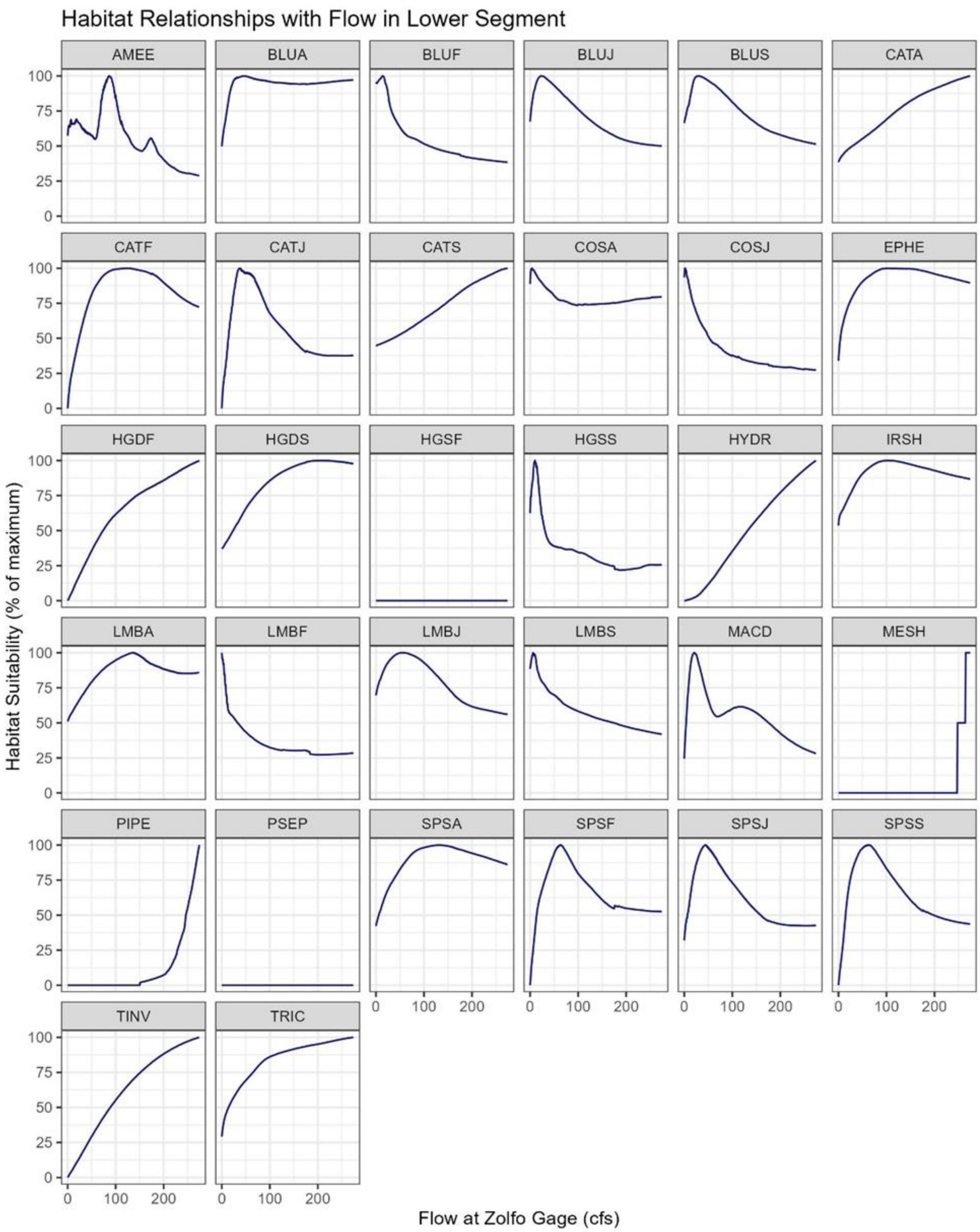


Figure 5-20. Average habitat – flow relationships in the upper segment of the Upper Peace River. Habitat suitability is expressed relative to the maximum for each species; all species with any habitat reach a maximum of 100% at some flow. The curves illustrate how habitat suitability responds to changes in flow. PSEP does not exhibit suitable habitat under any flow condition.

5.5.5 Evaluation of Instream Woody Habitat

For analysis purposes, the sites were divided into three river reaches (Figure 5-5):

- Upper reach spans from Bartow to Fort Meade and includes stations SEFA01, SEFA04, E01, E02, E03, and SEFA12.
- Middle reach spans from Fort Meade to Bowling Green and includes stations E04, SEFA16, SEFA19, SEFA20, E05, E06, and E07.
- Lower reach spans from Bowling Green to Zolfo Springs and includes stations E08, SEFA24, E09, E10, SEFA28, SEFA29, and E11.

All stations are listed from upstream to downstream within their respective segment.

Stations within each river reach were associated with a corresponding USGS index gage:

- Upper reach: USGS Peace River at SR 60 at Bartow gage (No. 02294650)
- Middle reach: USGS Peace River at Fort Meade gage (No. 02294898)
- Lower reach: USGS Peace River at Zolfo Springs gage (No. 02295637)

All analyses used the same period of record January 1, 1975, through December 31, 2022.

To examine how woody habitat may be impacted by flow reductions during Blocks 1 and 2 (low to medium flow conditions), individual elevations of live and dead wood were identified that were associated with water elevations corresponding below the Block 2/Block 3 threshold, as identified during the floodplain inundation analysis in Section 5.5.3. The Block 2/Block 3 threshold corresponded to flows of less than or equal to 71 cfs at the USGS Peace River at SR60 at Bartow gage (No. 02294650), to flows of less than or equal to 120 cfs at the USGS Peace River at Fort Meade gage (No. 02294898), and to flows of less than or equal to 274 cfs at the USGS Peace River at Zolfo Springs gage (No. 02295637).

The flows required at the site-associated USGS index gage to inundate select elevations of woody habitat were determined along the river bank with the most abundant woody habitat at each site. Then, the maximum percent-of-flow reduction at the USGS index gage that would lead to a 15% change in the number of 1-day, 7-day, and 30-day periods of inundation for specific woody habitat elevations were calculated using the period of baseline record from January 1, 1975, to December 31, 2022. The results were then averaged by river segment. Additional details on woody habitat data analysis may be found in Appendix D.

CHAPTER 6 MINIMUM FLOWS: RESULTS, RECOMMENDATIONS, AND PROTECTION OF ENVIRONMENTAL RESOURCE VALUES

6.1 Overview

The development of minimum flows for the Upper Peace River from Bartow to Zolfo Springs was grounded in field investigations, modeling efforts, and the technical framework presented in Chapter 5. Results from minimum flow assessments for each flow block were presented and then integrated to establish recommended minimum flows, as detailed in Section 6.2. Comprehensive minimum flow recommendations were developed for low (Block 1), medium (Block 2), and high (Blocks 3A and 3B) flow conditions at the USGS Peace River gaging stations at Bartow, Fort Meade, and Zolfo Springs, as outlined in Section 6.3. The recommended minimum flows were subsequently assessed to ensure the ten environmental values identified in the Water Resource Implementation in Rule are protected, as discussed in Section 6.4.

6.2 Results of Minimum Flow Analyses

6.2.1 Low-Flow Threshold

The low-flow threshold defines flows that are to be protected in their entirety, meaning no surface water withdrawal is permitted when flows fall below this limit. To establish low-flow thresholds for the Upper Peace River at the three index gaging stations, analyses of fish passage and wetted perimeter were conducted. The recommended thresholds derived from these evaluations are presented below.

6.2.1.1 Fish Passage Results

The fish passage metric focuses on maintaining fish passage and recreational use along the river corridor, ensuring continued accessibility and ecological connectivity. Flow required to achieve a water depth of 0.6 foot at each site was determined using the HEC-RAS model outputs. Once site-specific flow values were established, they were translated into corresponding index gage flows, plotted against river station data (Figure 6-1), and visually analyzed to identify the highest flow necessary for maintaining adequate fish passage depth along each segment.

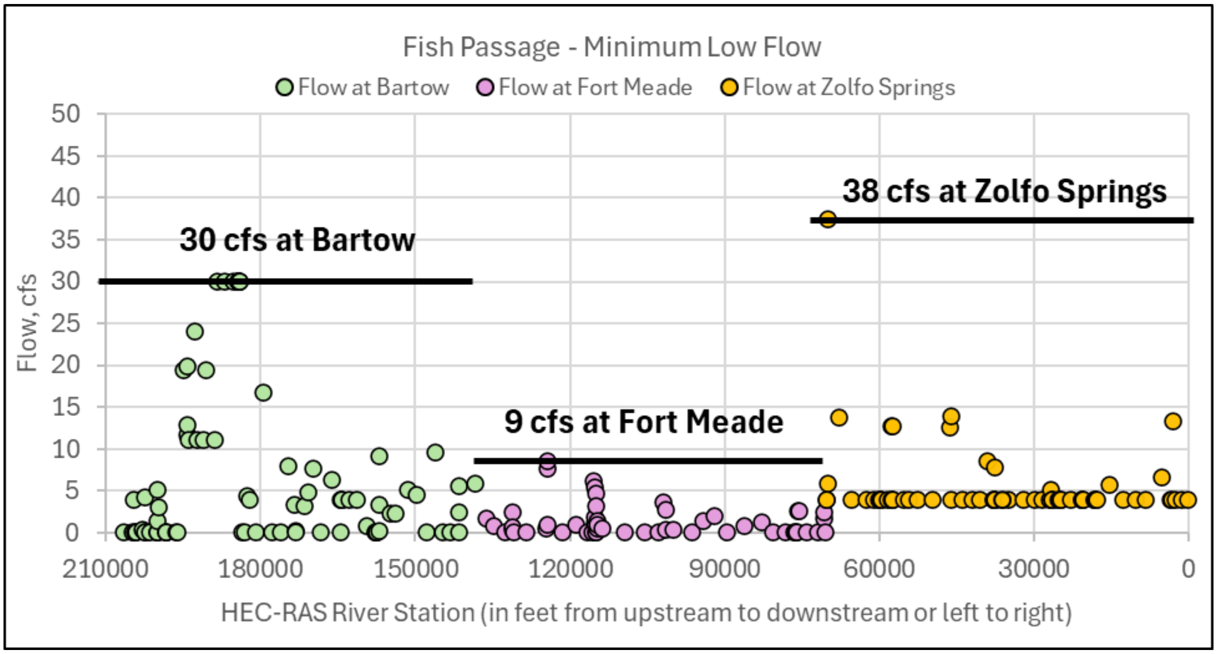


Figure 6-1. Flow requirements at surveyed transect sites on the Upper Peace River to achieve a fish passage depth of 0.6 ft. Superimposed on this plot are the recommended minimum fish passage flows across three distinct river sections, ensuring connectivity and habitat accessibility for aquatic species.

Inspection of Figure 6-1 indicates that a flow of 30 cfs is sufficient to maintain a fish passage depth of 0.6 ft at the most restrictive cross-sections in the upper river segment, allowing movement from the uppermost portion of the river near Bartow to just above Fort Meade. Similarly, in the middle segment extending from the vicinity of the Fort Meade gage to just above the Bowling Green gage, a flow of 9 cfs meets the fish passage depth criterion. Lastly, for the lower segment from the vicinity of the Blowing Green gage all the way to the Zolfo Springs gage, the required fish passage depth of 0.6 ft can be maintained with a flow of 38 cfs.

6.2.1.2 Low-Flow Wetted Perimeter Results

The relationship between wetted perimeter and flow rates was analyzed for the 206 surveyed transect sites using the HEC-RAS model outputs to identify the LWPIP as potential low flow threshold protective of benthic macroinvertebrates and other benthic organisms and processes. Each transect rating was thoroughly examined, both numerically and visually, for the LWPIP. Given the stream's structure, which consists of a series of riffles (shoals), pools, and runs, some wetted perimeter ratings for the 206 transects sites lack discernible inflection points at flows below the 85th percentile. This occurs because, in pools and runs, the LWPIP is already achieved at the lowest modeled flow.

The site-specific flows required to inundate the LWPIP at all transect sites were determined, then translated to their corresponding index gage flow and plotted against river station (Figure 6-2). Inspection of the figure suggests a flow 30 cfs or greater at the Bartow gage is sufficient to meet the LWPIP at all cross-sections in the upper river segment. In the middle river segment, a flow of 21 cfs at the Fort Meade gage maintains the LWPIP, while in the lower river segment, a flow of 40 cfs at the Zolfo gage is sufficient to maintain the LWPIP.

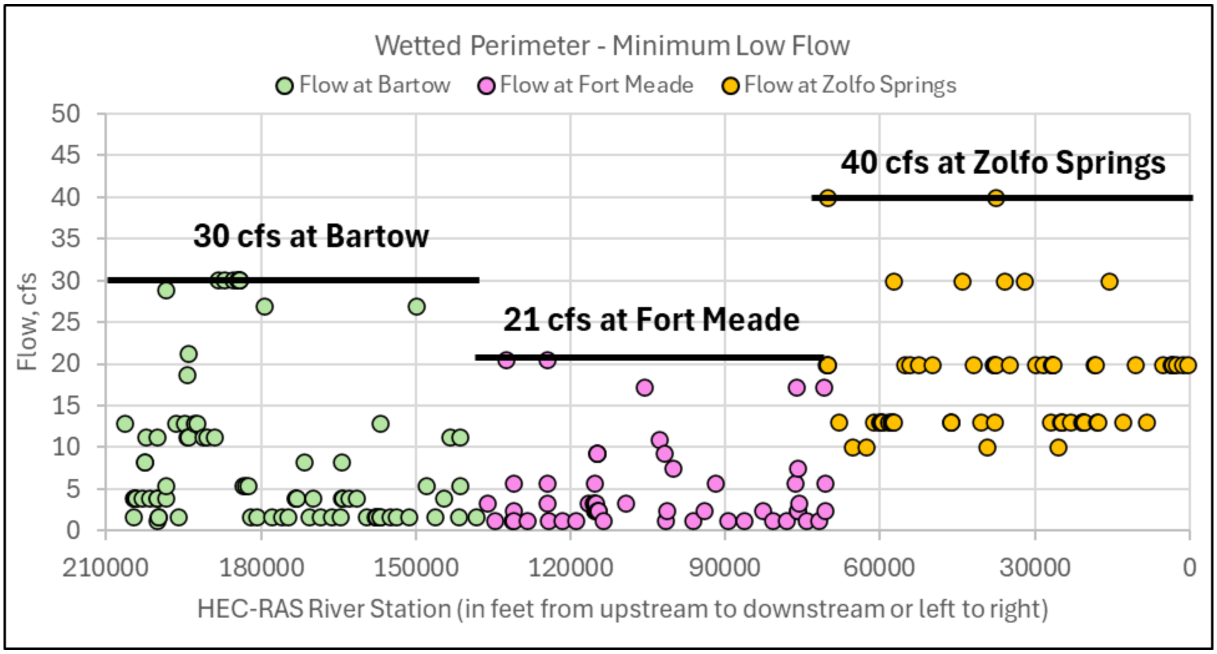


Figure 6-2. Flow requirements at surveyed transect sites on the Upper Peace River to wet the LWPIP. Superimposed on this plot are the recommended minimum LWPIP flows across three dinstinct river sections.

6.2.1.3 Recommended Low-Flow Threshold

The low flow threshold establishes the upper limit of Block 1 (low flow) and defines flows below which must be fully protected, meaning they are unavailable for consumption at any time throughout the year. Fish passage needs are not assumed to be met by wetted perimeter requirements, nor vice versa. Instead, both approaches were applied in tandem to determine the low minimum flow requirement, with the higher flow of the two selected as a conservative means for establishing the recommended low flow threshold.

As such, the low flow threshold is determined by the higher of two flow standards: maintaining fish passage and maximizing wetted perimeter for the least amount of flow in the river channel. For the Upper Peace River, low flow thresholds were respectively developed for the USGS Peace River gages at Bartow, Fort Meade, and Zolfo Springs.

As illustrated in Figure 6-3, which combines minimum LWPIP flows and minimum fish passage depth flows for the Upper Peace River, different segments of the Upper Peace River adhere to distinct minimum flow criteria. In the upper segment, both fish passage depth and LWPIP set the same minimum flow standard, while in the middle and lower segments, LWPIP dictates the minimum flow standard. The proposed flows also account for recreational canoeing and aesthetic value during low flow periods, ensuring a minimum depth of at least 0.6 ft at the highest points in the channel and continuous flow over most of the riverbed.

Therefore, the following low flow thresholds are proposed for the Upper Peace River:

- 30 *cfs* at the *USGS* Peace River gage at *Bartow*
- 21 *cfs* at the *USGS* Peace River gage at *Fort Meade*
- *40 cfs* at the *USGS* Peace River gage at *Zolfo Springs*

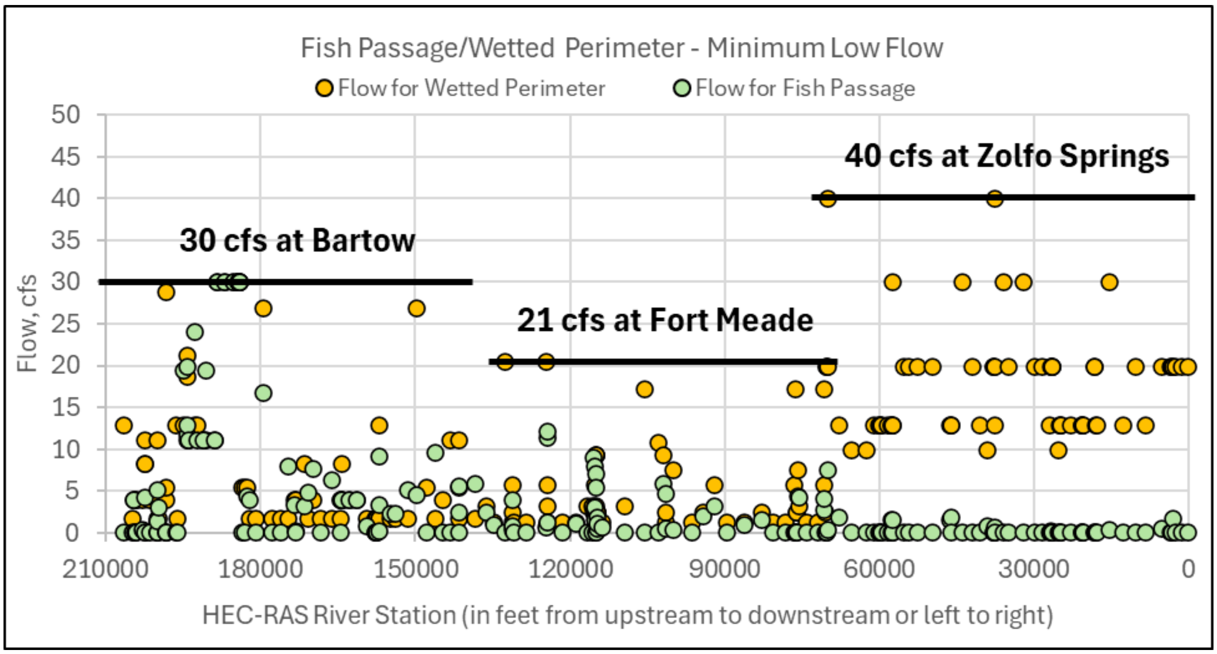


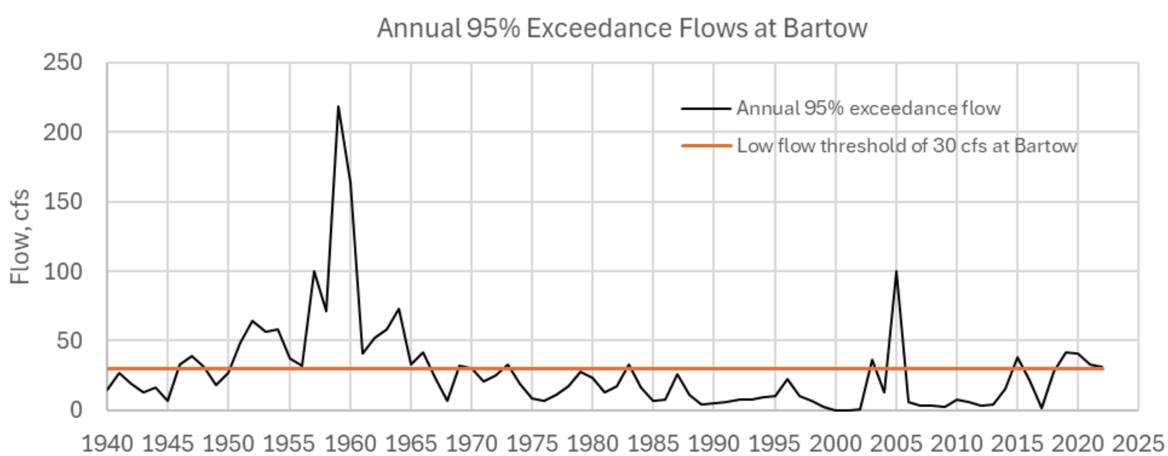
Figure 6-3. Integration of fish passage and LWPIP flow requirements across all surveyed cross sections, with proposed minimum low flows for the Upper Peace River.

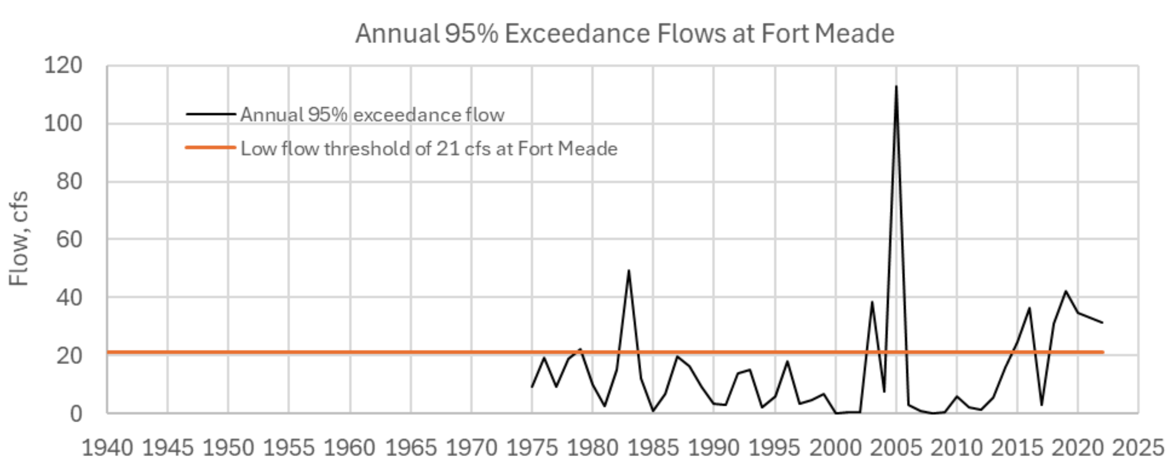
The low-flow threshold was established as a regulatory limit on withdrawals; however, it is not expected to be met at all times. As with other river systems, natural hydrologic fluctuations can cause flows to fall below this threshold. What makes the Upper Peace River unique is the presence of numerous karst features, primarily between Bartow and Clear Springs, which partially or completely intercept flow from upstream, as discussed in Sections 2.2.5 and 5.3.2.4.

When flows remain below the low-flow threshold for extended periods, portions of the river channel may dry out, especially during severe drought years. While it would be ideal for flows to consistently meet or exceed the threshold to prevent such occurrences, this expectation is impractical due to inherent hydrologic uncertainties involved. Therefore, establishing an annual exceedance criterion in relation to the low-flow threshold is necessary from both operational and compliance perspectives.

Analysis of the 95% exceedance flow plots for each of the three gage sites (Figure 6-4) reveals notable difference in how often the proposed low-flow thresholds were met. at the Bartow gage, the low-flow threshold of 30 cfs was met only 8 years since 1975. At Fort Meade, the 21 cfs threshold was met in 11 years over the same period. In contrast, the proposed low-flow threshold of 40 cfs at the Zolfo Springs gage was met all but 13 years between 1975 and 2022.

Additionally, between 2016 and 2022, when the Lake Hancock Reservation was in effect and the lake was operated to meet the existing MFLs, the annual 95% exceedance was met in all years except 2017 at both Fort Meade and Zolfo Springs, coinciding with a severe spring drought. At Bartow, 4 of 8 years in which the 95% annual exceedance surpassed the low flow thresholds over the 48-year record (1975-2022) occurred during this same operational period. These observations suggest that the Lake Hancock Reservation and its releases contributed favorably to maintaining low flow conditions in the Upper Peace River.





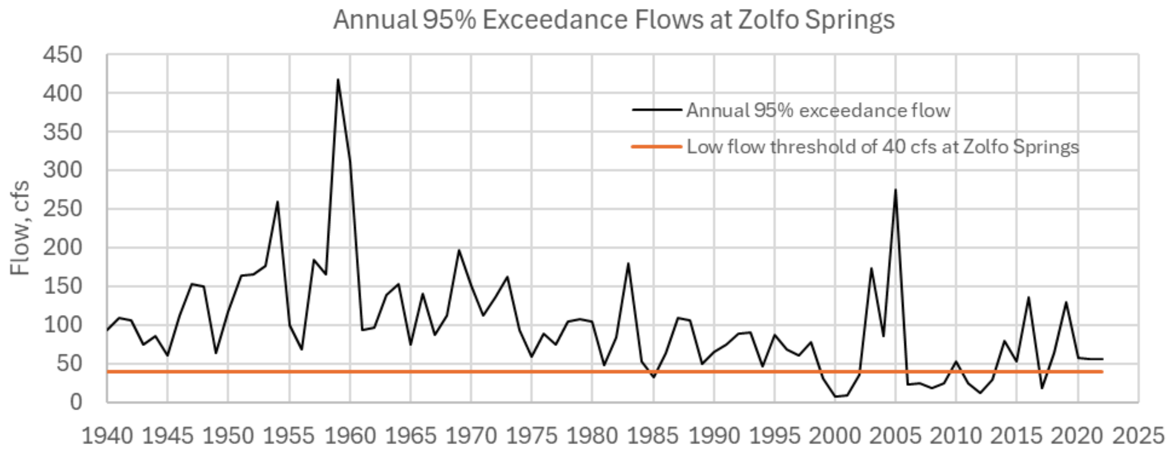


Figure 6-4. Annual 95% exccedance flow for the period 1940 through 2022 for the three USGS Peace River gages.

Furthermore, the annual exceedance curves for two different periods, an 83-year period from 1940 to 2022 and a 48-year period from 1975 to 2022, were compared for both gaged flow and baseline flow conditions for the three index gaging stations in Figure 6-5 to Figure 6-7. In these figures, the y axis is presented on a logarithmic scale, making it easier to observe how annual exceedance relates to the low-flow threshold, represented by the yellow horizon line, and the 95% annual exceedance, indicated by the green vertical line.

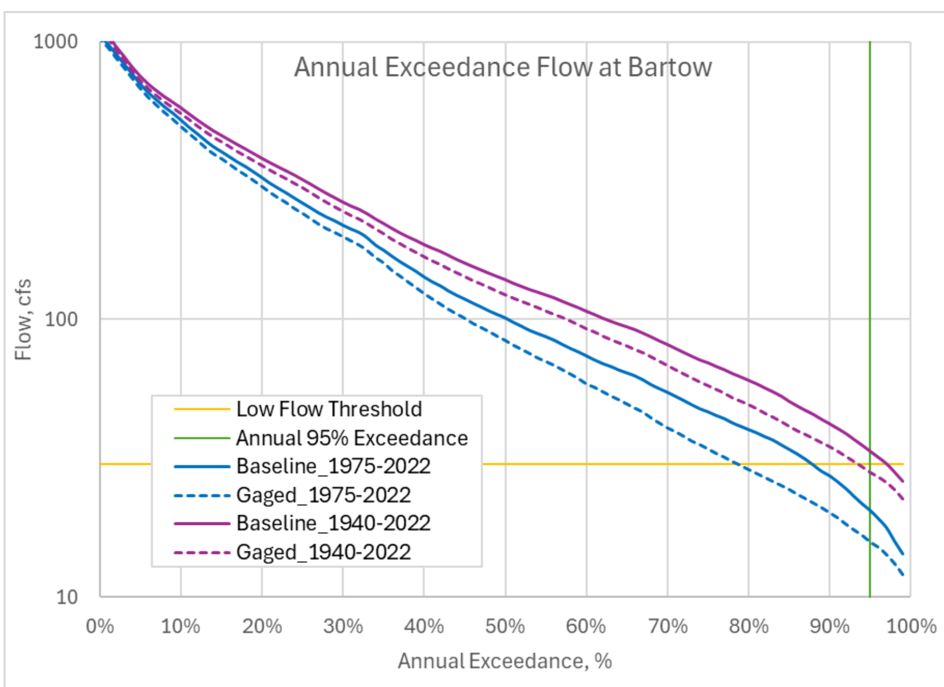


Figure 6-5. Annual exceedance flow for the USGS Peace River gage at Batow for the periods 1975-2022 and 1940-2022, comparing baseline and gaged flows in relation to the low flow threshold.

As shown in Figure 6-5 for the Bartow gage, the annual exceedance associated with the low-flow threshold for baseline flow is approximately 97% for the period from 1940 to 2022, indicating that the low-flow threshold is achievable without water withdrawals. However, the more recent period from 1975 through 2022 includes relatively more years with very low flows, resulting in a reduced annual exceedance of about 88%. Considering the water withdrawal will not be allowed during the low flow block and accounting for the influence of Lake Hancock Reservation, it is anticipated that an annual exceedance of 95% may be achievable.

The Fort Meade gage has a shorter period of record compared to the Bartow and Zolfo Springs gages, so the curves in Figure 6-6 represent only the period from 1975 to 2022. Under baseline flow conditions, a low-flow threshold of 21 cfs corresponds to an annual exceedance of 98%, suggesting that setting a 95% annual exceedance may be achievable.

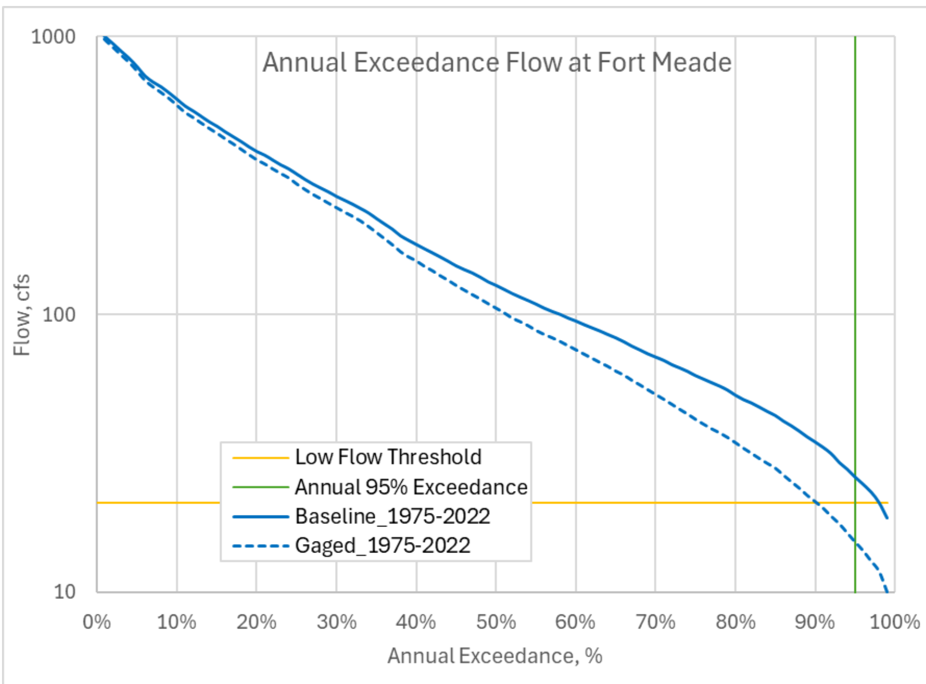


Figure 6-6. Annual exceedance flow for the USGS Peace River gage at Fort Meade for the periods 1975-2022, comparing baseline and gaged flows in relation to the low flow threshold.

For Zolfo Springs, both gaged and baseline curves indicate that a low-flow threshold of 40 cfs corresponds to an annual exceedance greater than 99%, demonstrating that a 95% annual exceedance has been successfully achieved (Figure 6-7).

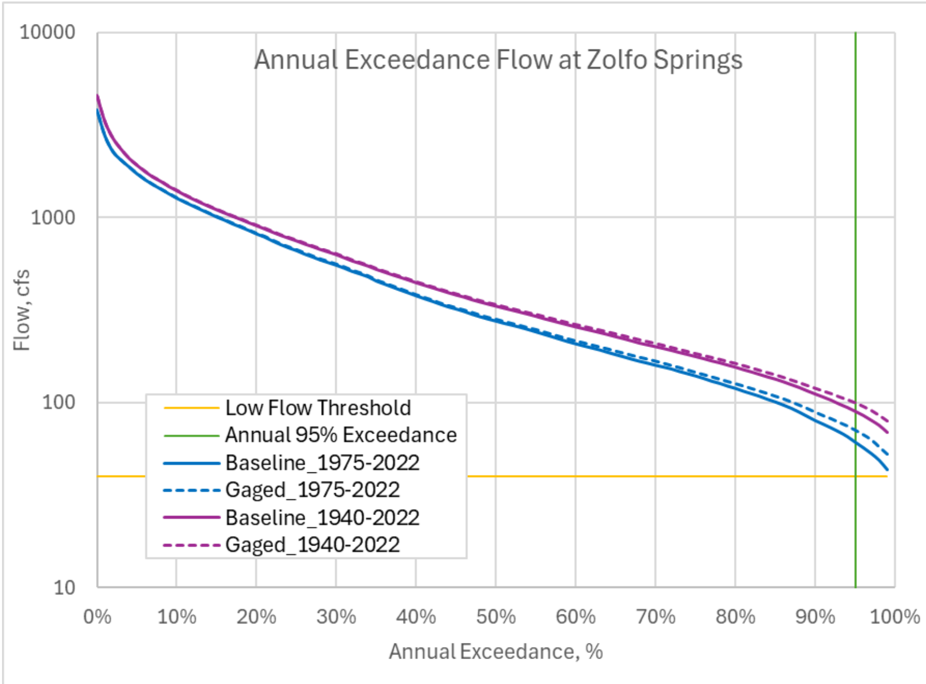


Figure 6-7. Anuual exceedance flow for the USGS Peace River gage at Zolfo Springs for the periods 1975-2022 and 1940-2022, comparing baseline and gaged flows in relation to the low flow threshold.

Given the discussions above, a 95% annual exceedance is recommended in relation to the low-flow threshold at the three index gaging stations at Bartow, Fort Meade and Zolfo Springs. This means that flows will remain at or above the proposed threshold at least 95% of the time annually. The 95% exceedance value accounts for periodic drought conditions without violating the minimum flow criteria.

This recommendation is reasonable given various uncertainties, including annual rainfall variations, provisional USGS data, sinkhole losses, Lake Hancock water storage capacity, and structure maintenance. It would allow flow to drop below the low-flow threshold for no more than 18 days during severe drought conditions.

The proposed low minimum flow thresholds are based on a balance of fish passage needs, wetted perimeter analysis, and historical flow patterns. By implementing the 95% exceedance standard, these flows account for natural variability, ensuring ecological sustainability while allowing for occasional low-flow events due to drought conditions.

6.2.2 Floodplain Inundation Analyses

High flow thresholds used to define the flow boundary between medium flow Block 2 and high Flow Block 3, as well as between the two subblocks within Block 3 were initially derived from the floodplain inundation analysis. These thresholds were subsequently refined, as needed, through wetted perimeter analyses conducted under mid- and high-flow conditions prior to calculating the associated minimum flows and allowable flow reductions.

6.2.2.1 Floodplain Inundation Sensitivity Analysis Results

Floodplain inundation criteria were established to protect intermittent high flows that sustain wetland vegetation, biogeochemical processes, and habitat values within the Upper Peace River floodplain. A prescriptive standard was adopted, allowing up to a 15% change in floodplain inundation from baseline conditions, defining the threshold beyond which further withdrawals would result in significant harm.

Using the methods outlined in Section 5.5.3, flow reduction percentages and corresponding flow percentiles associated with a 15% reduction in inundated area were identified for each river segment associated with the index gaging stations at Bartow, Fort Meade, and Zolfo Springs (Figure 6-8 through Figure 6-10 and Table 6-1).

Historic flow records indicate that floodplain inundation in the Upper Peace River typically occurs during Block 3, when flow exceeds the capacity of the river channel and water spills over the river banks into adjacent low-lying floodplains. When plotted against flow percentiles, percent-of-flow reductions exhibited three general sensitivity patterns (Figure 6-8 through Figure 6-10). At low-flow percentiles, changes in flow reductions were relatively flat, indicating minimal sensitivity. In contrast, mid- to high-flow percentiles exhibited increasing sensitivity, with greater reductions in inundated areas as flows increased. Based on these patterns, Block 3 was subdivided into two subblocks (B3A and B3B), to reflect the varying sensitivity of floodplain inundation to flow reductions across the high flow range.

For the upper river segment at Bartow, a 15% flow reduction for baseline flows between 71 cfs and 483 cfs, and a 7% flow reduction for flows exceeding 483 cfs, would result in no more than 15% decrease in total inundated floodplain area.

For the middle river segment at Fort Meade, a 10% flow reduction for baseline flows between 120 cfs to 529 cfs, and a 7% flow reduction for flows greater than 529 cfs, would result in no more than 15% reduction in total inundated floodplain area. Notably, the 529 cfs threshold was informed by the wetted perimeter analysis, discussed in Section 6.2.2.2.

For the lower river segment at Zolfo Springs, a 9% flow reduction for baseline flows ranging from 274 cfs up to 1,047 cfs, and a 7% flow for flows more than 1,047 cfs, would result in 15% or less reduction in total inundated floodplain area.

Table 6-1 presents the maximum allowable flow reductions and corresponding minimum flows for each subblock and river segment, based on the 1975-2022 baseline flow record.

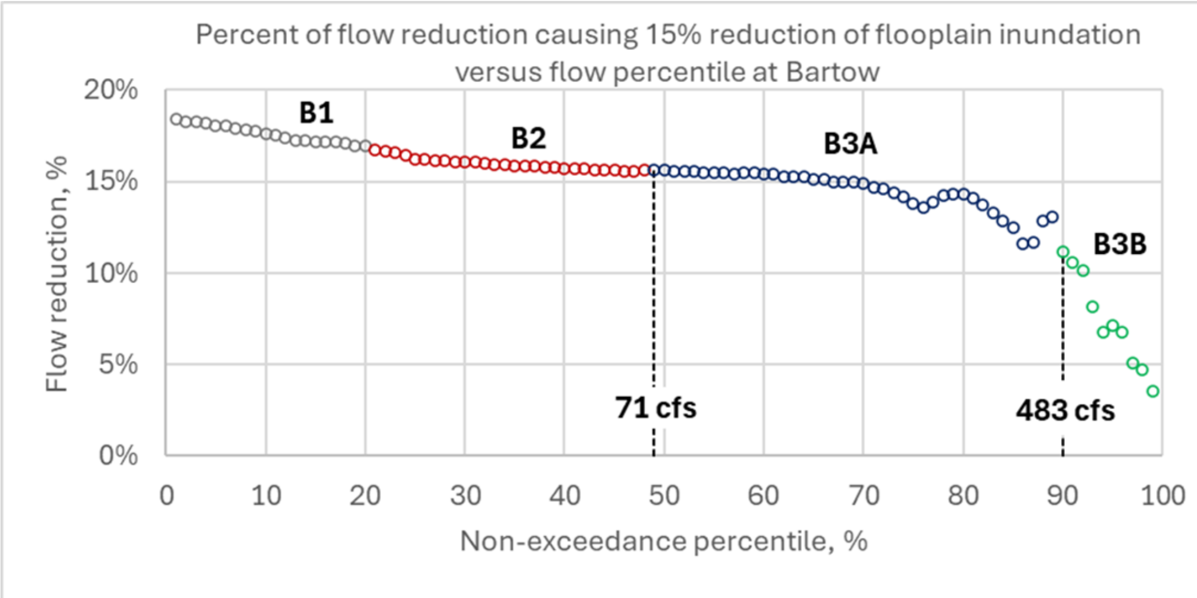


Figure 6-8. Percent flow reductions that result in a 15% decrease in the inundated flooplain areas versus flow percentiles for the USGS Bartow gaging station.

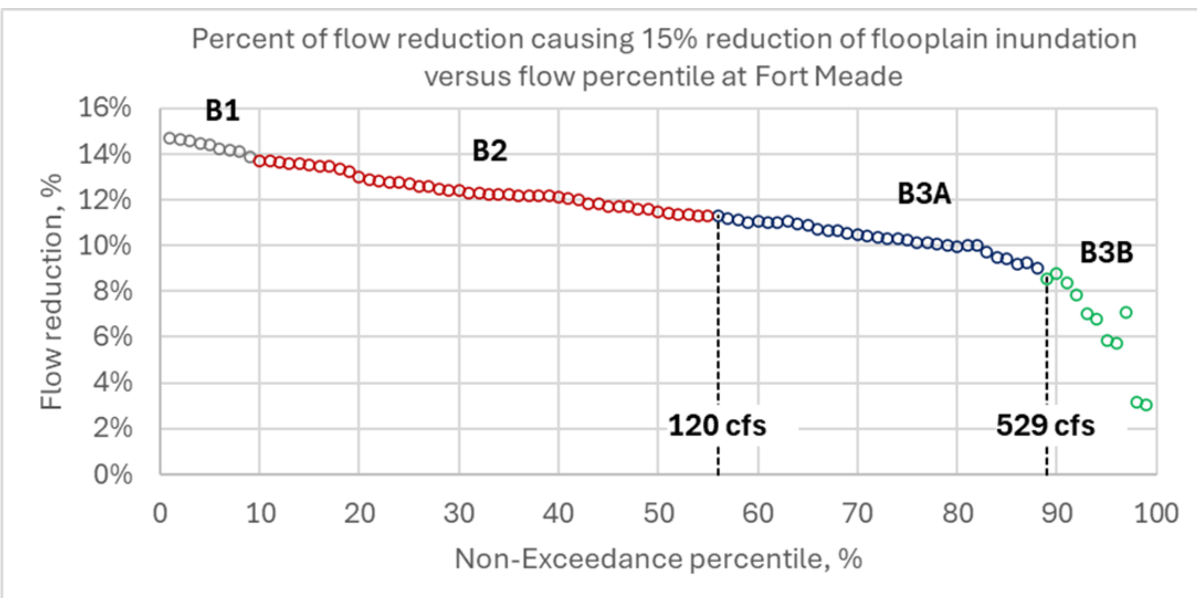


Figure 6-9. Percent flow reductions that result in a 15% decrease in the inundated flooplain areas versus flow percentiles for the USGS Fort Meade gaging station.

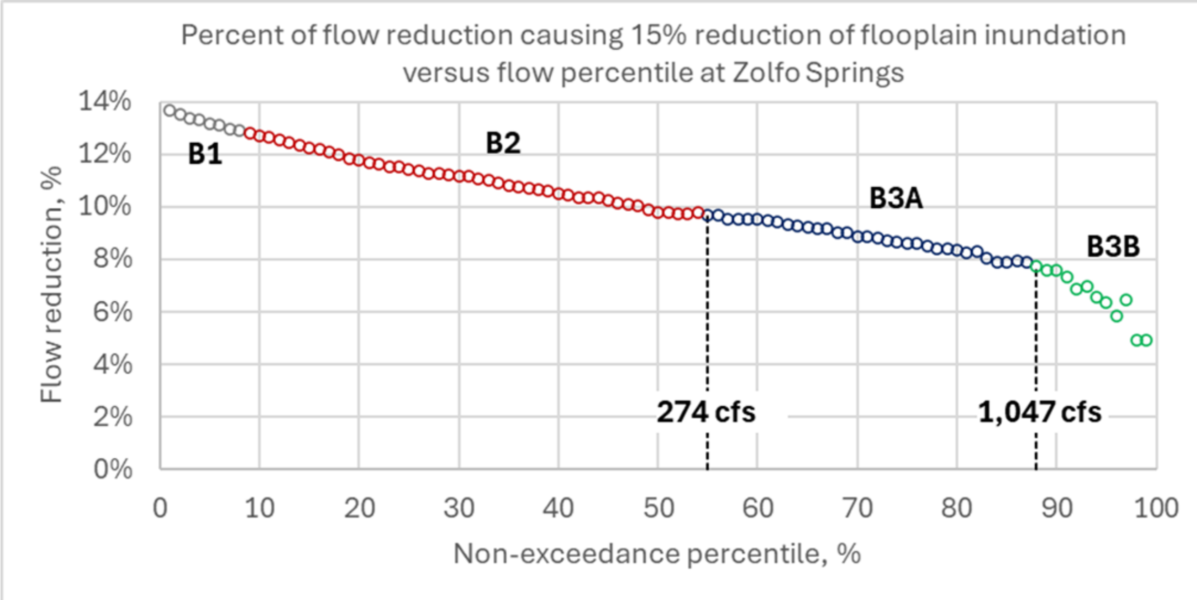


Figure 6-10. Percent flow reductions that result in a 15% decrease in the inundated flooplain areas versus flow percentiles for the USGS Zolfo Springs gaging station.

Table 6-1. Summary of maximum allowable flow reductions and minimum flows for high-flow Block 3 at the three index gaging stations at Bartow, Fort Meade, and Zolfo Springs without causing 15% decrease in the floodplain inundation areas associated with the baseline flow for the period from 1975 through 2022.

River Segment	Index Gaging Station	High-Flow Subblock	Flow Range	Maximum Allowable Flow Reduction (%)	Minimum Flow (%)
Upper	Bartow	B3A	>71 cfs and ≤483 cfs	15	85
		B3B	>483 cfs	7	93
Middle	Fort Meade	B3A	>120 cfs and ≤529 cfs	10	90
		B3B	>529 cfs	7	93
Lower	Zolfo Springs	B3A	>274 cfs and ≤1,047 cfs	9	91
		B3B	>1,047 cfs	7	93

6.2.2.2 Medium and High-Flow Wetted Perimeter Analysis Results

The relationship between wetted perimeters and flow rates was analyzed for 206 surveyed transect sites using output from the HEC-RAS model. Each rating was thoroughly examined, both numerically and virtually, for the medium wetted perimeter inflection point (MWPIP), ranging from the 45th to the 55th percentile. Site-specific flows required to inundate the MWPIP at all transect sites were identified, converted into their corresponding index gage flow, and plotted against river station in Figure 6-11.

Inspection of Figure 6-11 suggests that flow of 73 cfs at Bartow, 118 cfs at Fort Meade, and 272 cfs at Zolfo Springs correspond to the minimum bankfull elevations for their respective river segments. These flow values align well with the high flow thresholds that define the transition between Block 2 and Block 3A, as presented in Table 6-1.

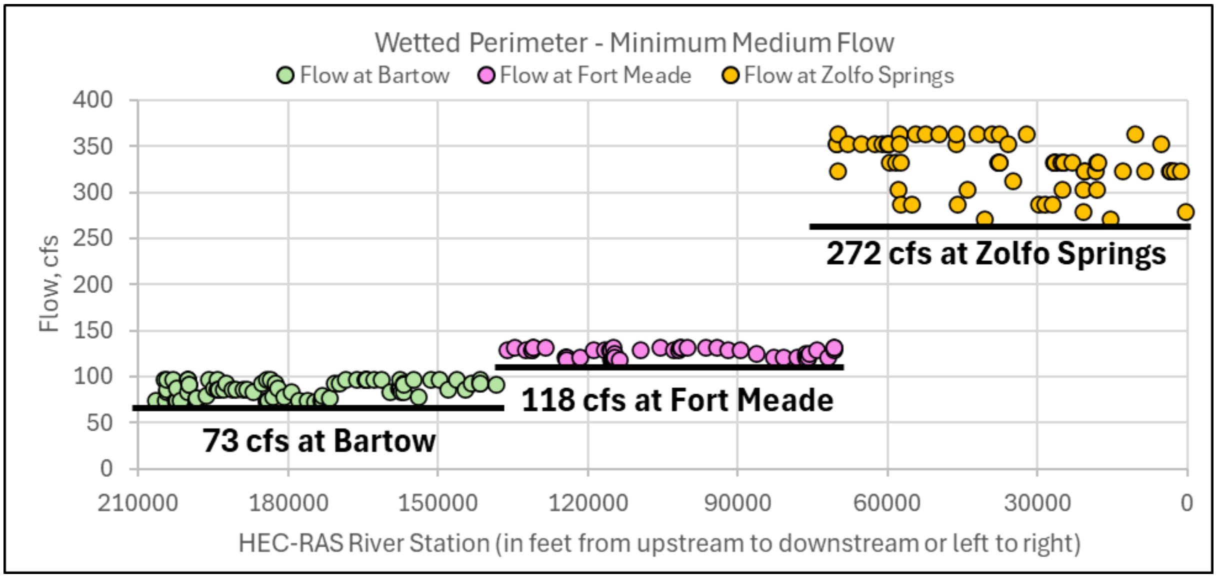


Figure 6-11. Flow requirements at surveyed transect sites on the Upper Peace River to wet the medium wetted perimeter inflection point (MWPIP). Superimposed on this plot are the identified mimimum MWPIP flows across three dinstinct river sections.

Using the same analytical approach, flow requirements to inundate the high wetted perimeter inflection points (HWPIP) were also developed for each of the 206 transects, based on HEC-RAS model output. These ratings focused on high flows within the 9th to 16th percentile range, as shown in Figure 6-12.

Analysis of Figure 6-12 indicate that flows of 484 cfs at Bartow, 526 cfs at Fort Meade, and 1,080 cfs at Zolfo Springs correspond to transitional elevations between low-lying and upper floodplain areas for each river segment. These flow values generally align with the high flow thresholds at Bartow and Zolfo Springs that delineate the transition between Block 3A and Block 3B, as shown in Table 6-1. For Fort Meade, however, the wetted perimeter analysis suggests a more reasonable flow threshold than that derived from the floodplain sensitivity analysis. Consequently, a value of 529 cfs was adopted to define the boundary between the two subdivisions within Block 3 (see Table 6-1).

As discussed in Section 5.5.3, wetted perimeter analysis under medium and high-flow conditions serves as a supplemental method to cross-validate the high flow thresholds derived from floodplain inundation regression analyses. This dual approach adds an additional layer of protection to ensure ecological integrity.

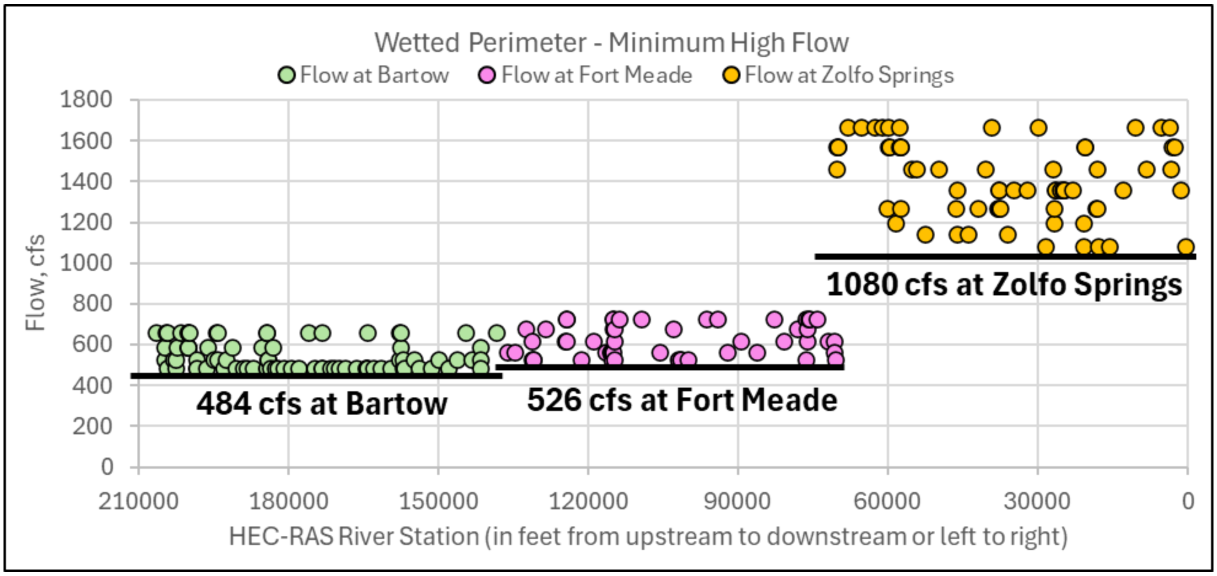


Figure 6-12. Flow requirements at surveyed transect sites on the Upper Peace River to wet the high wetted perimeter inflection point (HWPIP). Superimposed on this plot are the identified minimum HWPIP flows across three dinstinct river sections.

6.2.3 Instream Habitat Suitability Analyses

The analysis of instream habitat includes the result of SEFA modeling to evaluate the impacts of flow reductions on changes in the availability of suitable habitat for fish and invertebrates and the impacts of flow reductions on instream woody habitat inundation using HEC-RAS modeling.

6.2.3.1 System for Environmental Flow Analysis Results

Many species lose habitat as flows are reduced from 100% to 75% of the baseline. The most sensitive species that are predicted to lose 15% or more of their habitat suitability with flow reduction less than or equal to 25% are identified.

The most sensitive species identified in the upper river segment include the net-spinning caddisflies of the family Hydropsychidae (HYDR) (Figure 6-13), a composite habitat for total invertebrates (TINV), the deep-fast habitat guild (HGDF) and the Pirate Perch (PIPE) (Figure 6-14). In the middle river segment of the river, the most sensitive species include the net-spinning caddisflies of the family Hydropsychidae (HYDR), a composite habitat for total invertebrates (TINV), the deep-fast habitat guild (HGDF), and Channel Catfish spawning habitat (CATS) (Figure 6-15). In the lower river segment, the most sensitive species include Hydropsychidae (HYDR), a composite habitat for total invertebrates (TINV), and the deep-fast habitat guild (HGDF) (Figure 6-16).

Summary results for all three segments show that Hydropsychidae (HYDR) is the most sensitive species, with a flow reduction of 12% at Bartow and Fort Meade and a flow reduction of 13% at Zolfo Springs corresponding to a 15% loss in habitat suitability (Table 6-2).

(a) (b)

Figure 6-13. (a): Filter net and gravel retreat of *Hydropsyche* sp. (Hydropsychidae) between large stones. (b): Larva of *Hydropsyche bulgaromanorum* Malicky, 1977 (Hydropsychidae). Both images © W. Graf. (from Morse et al. 2019).

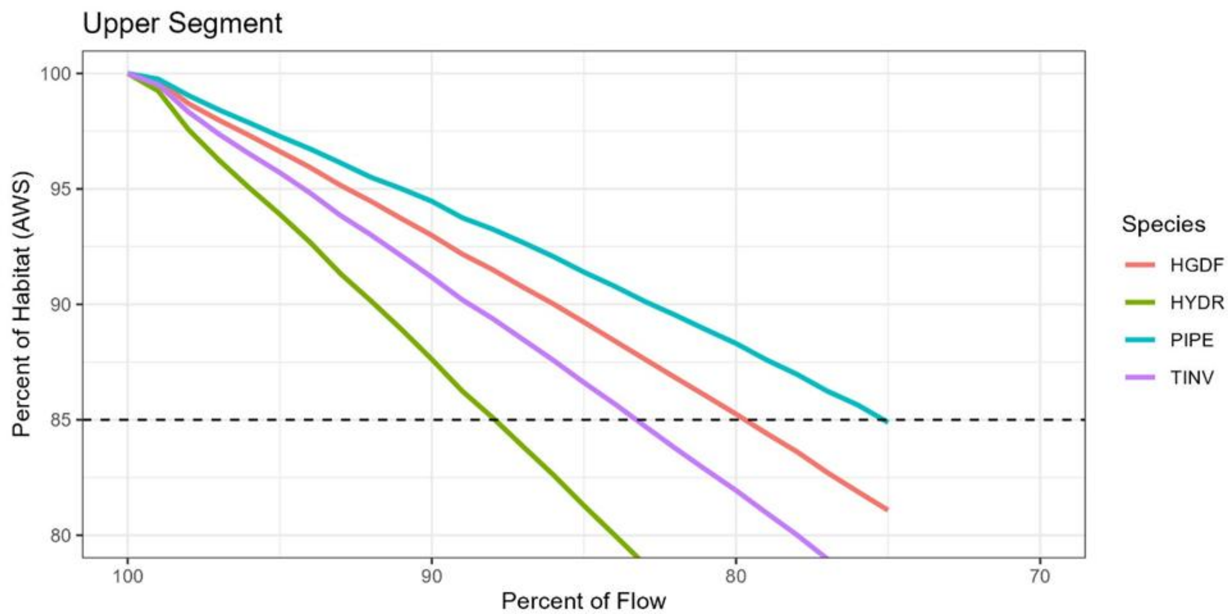


Figure 6-14. Habitat loss for the most sensitive species in the upper segment between Bartow and Fort Meade USGS gages.

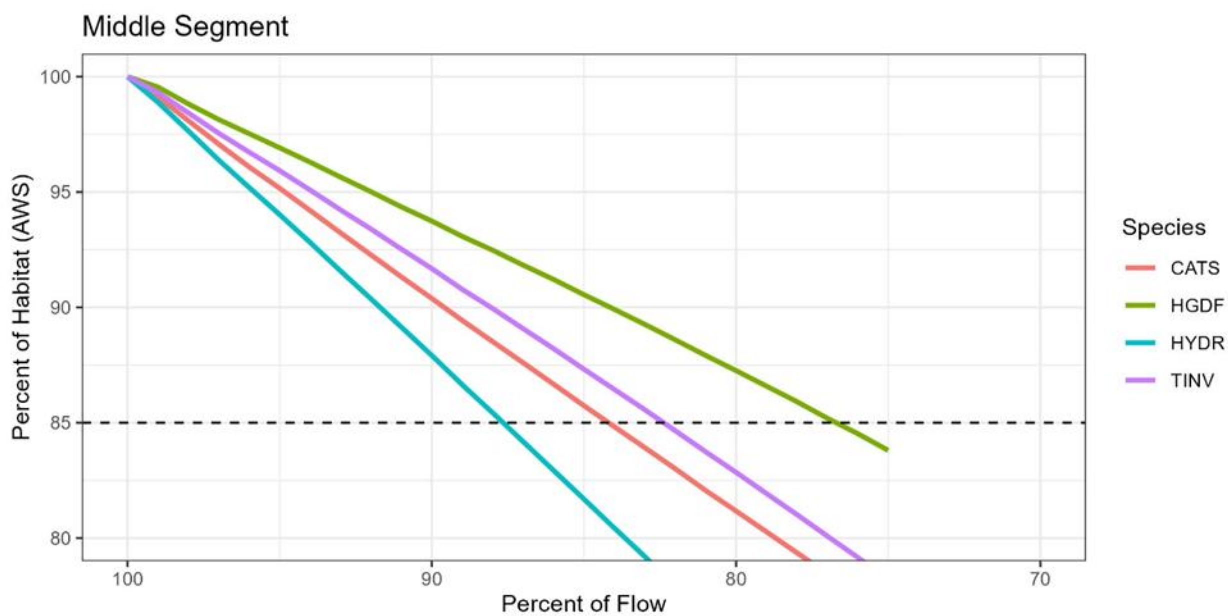


Figure 6-15. Habitat loss for the most sensitive species in the middle segment between Fort Meade and Bowling Green USGS gages.

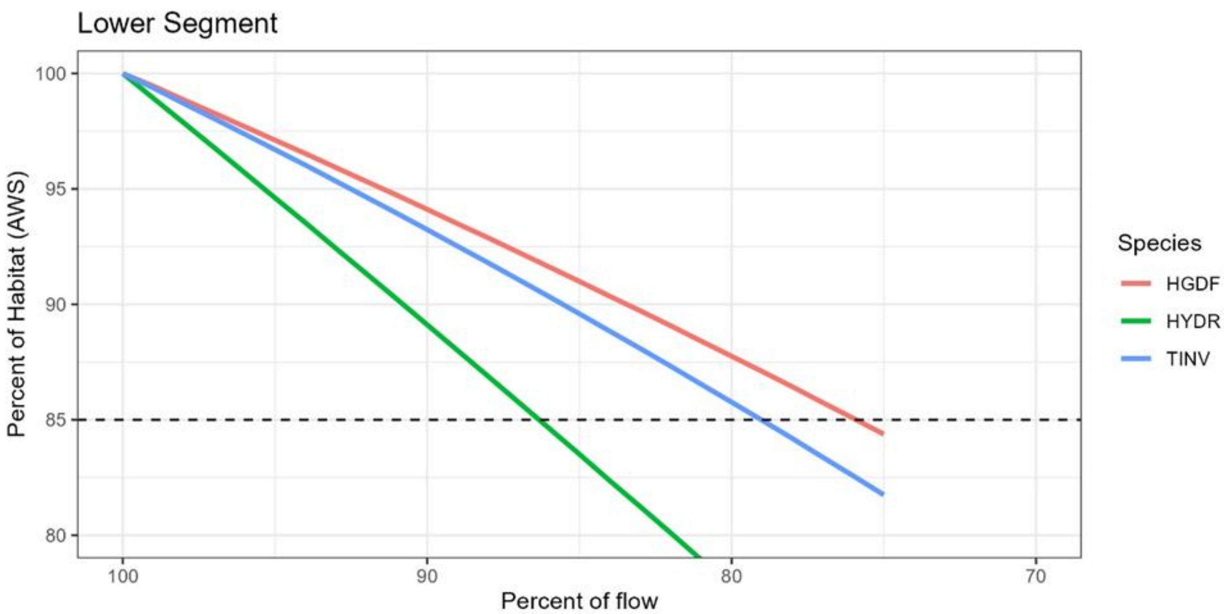


Figure 6-16. Habitat loss for the most sensitive species in the lower segment between Bowling Green and Zoflo Springs USGS gages.

Table 6-2. Minimum flow percentages required to maintain 85% of area-weighted habitat suitability (AWS) in the three segments, based on baseline flow records at their respectve gages for the associated flow range.

River Segment	Index Gage	Flow Range	Minimum Flow (%) by Species			
			HYDR	CATS	TINV	HGDF
Upper	Bartow	≤71 cfs	88	-	84	80
Middle	Fort Meade	≤120 cfs	88	85	83	77
Lower	Zolfo Springs	≤274 cfs	87	-	80	76

6.2.3.2 Woody Habitat Inundation Results

The inundation patterns of woody habitats with elevations anticipated to be submerged at flows below the Block 2/Block 3 threshold (as defined in Section 6.2.2) were examined at 20 locations in the Upper Peace River. The number of days that the flow targets associated with qualifying woody habitat elevations were equaled or exceeded for 1-day, 7-day, and 30-day durations was assessed using the baseline flow record for each index gage over the period of record from January 1, 1975, to December 31, 2022. The percent-of-flow reductions that would result in greater than a 15% reduction in the number of days of the specified duration-events relative to those associated with baseline flows were calculated.

For the upstream river segment between Bartow and Fort Meade, all six sampled sites contained measured woody habitat at elevations anticipated to be inundated during targeted flows. This included 31 samples of dead wood and 14 samples of live wood throughout the reach. The mean allowable flow reduction associated with 1-day duration events was 24%, with a range from 22% to 34%. The mean allowable flow reduction for inundations of 7-day duration was 21%, with a range of 20% to 29%. Inundations of 30-day durations were most sensitive to flow reductions as expected, with a mean allowable flow reduction of 16% and a range of 14% to 24%. Based on these results, a 16% flow reduction in Block 2 is considered protective of woody habitat in this river segment (Table 6-3).

For the middle river segment between Fort Meade and Bowling Green, all seven sampled stations contained at least one sample of woody habitat that was expected to be inundated during target flows. In total, the elevations of 21 samples of dead wood and two samples of live wood were considered. The mean allowable flow reduction associated with 1-day duration events was 25% with a range of 21% to 29%. The mean allowable flow reduction for inundations of 7-day duration was 22%, with a range of 18% to 27%. Inundations of 30 days were most sensitive to flow reductions, with a mean allowable flow reduction of 16% and a range of 10% to 25%. Based on these results, a 16% flow reduction in Block 2 is considered protective of woody habitat in this river segment (Table 6-3).

For the downstream river segment between Bowling Green and Zolfo Springs, six of the seven sampled stations contained at least one sample of woody habitat that was expected to be inundated during target flows, including 38 samples of dead wood and five samples of live wood within this river reach. The mean allowable flow reduction associated with 1-day duration events was 31% with a range of 19% to 63%. The mean allowable flow reduction for inundations of 7-day duration was 26%, with a range of 15% to 57%. Inundations of 30 days were most sensitive to flow reductions, with a mean allowable flow reduction of 20% and a range of 10% to 46%. Based on these results, a 20% flow reduction in Block 2 is considered protective of woody habitat in this river segment (Table 6-3).

Table 6-3. Summary of maximum allowable flow reductions (%) and minimum flow (%) in each segment of the Upper Peace River associated with a 15% reduction from baseline flow conditions over the period of record (1975-2022) at the respective index gage in the number of days of flow sufficient to inundate woody habitat for 1-day, 7-day, and 30-day durations.

River Segment	**Index Gage**	**Flow Range (cfs)**	**Average Target Flow at Index Gage (cfs)**	**Allowable Flow Reduction (%)**			**Minimum Flow (%)**		
				1-Day	7-Days	30-Days	1-Day	7-Days	30-Days
Upper	Bartow	≤71	55	24	21	16	76	79	84

Middle	Fort Meade	≤120	78	25	22	16	75	78	84
Lower	Zolfo Springs	≤274	158	31	26	20	69	74	80

6.2.3.3 Recommended Minimum Flows for Block 2

Minimum flows for Block 2 are identified based on the more protective of two criteria: habitat suitability for aquatic biota and woody habitat inundation. Minimum flows for Instream habitat suitability were assessed using SEFA. The HEC-RAS model was used to identify flow-stage relationships at woody habitat sites and based on these relationships minimum flows required to inundate the mean elevation of woody habitats were determined (Table 6-4).

Table 6-4. Recommeded minimum flows for Block 2 based on the most sensitive criteria.

River Segment	Index Gage	Flow Range at Index Gage (cfs)	Instream Habitat Minimum Flow (%)	Woody Habitat Minimum Flow (%)	Most Sensitive Minimum Flow (%)
Upper	Bartow	≤71	88	84	88
Middle	Fort Meade	≤120	88	84	88
Lower	Zolfo Springs	≤274	87	80	87

Across all three river segments, the SEFA results for instream habitat change for sensitive species proved to be more restrictive than those derived from woody habitat inundation analysis. Therefore, the recommended minimum flows for Block 2 are based on SEFA-derived habitat suitability results to ensure adequate protection of instream habitats.

6.3 Summary of Recommended Minimum Flows for the Upper Peace River

To support development of minimum flows for the Upper Peace River, flow requirements were evaluated for fish and recreational boat passage, and wetted perimeter within the river channel. Additionally, the effects of flow reductions on habitat availability for fish and invertebrates, instream woody habitats, and floodplain habitats were assessed.

A percent-of-flow approach was applied using block-specific criteria to maintain at least 85% of the most sensitive criterion, thereby safeguarding all resource management goals. A low-flow threshold was identified to ensure flow continuity for both environmental and human use values.

Based on the analyses presented in Sections 6.2.1 through 6.2.3, proposed minimum flows were established for the three river segments in the Upper Peace River. These recommendations are summarized in Table 6-5 and illustrated in Figure 6-17. Each flow-based block represents a distinct flow range, collectively forming a comprehensive minimum flow regime. The development of these blocks was guided by low-flow and high-flow thresholds. Low-flow thresholds were identified to maintain fish passage and lowest wetted perimeter inflection point, while high-flow thresholds were derived from evaluating the sensitivity of floodplain inundation to flow reduction along with wetted perimeter analyses under medium and high flow conditions at the three index gages.

Minimum flows for Block 1 were determined based on fish passage depth and wetted perimeter inflection points. Minimum flows for Block 2 were based on maintaining available instream habitat for aquatic biota and woody habitats. Minimum flows for Block 3A and 3B were based on maintaining floodplain inundation. The recommended minimum flows (Table 6-5) are based on the previous day's flow at the three index gaging stations, adjusted for withdrawal effects. Recommended minimum flows are also depicted in Figure 6-17 alongside baseline flow duration curve for the three index gages.

For the **upper river segment**, the recommended minimum flows include a low-flow threshold of 30 cfs, which serve as a limit to surface water withdrawals throughout the year. For medium flows (Block 2), when the baseline flows range from 30 cfs to 71 cfs, the recommended minimum flow is 88%. For high flows (Block 3A), ranging from 71 cfs to 483 cfs, the recommended minimum flow is 85%. For very high flows (Block 3B), above 483 cfs, the recommended minimum flow is 93%.

For the **middle river segment**, the recommended minimum flows include a low-flow threshold of 21 cfs, which serve as a year-round limit for surface water withdrawals. For medium flows (Block 2), ranging from 21 cfs to 120 cfs, the recommended minimum flow is 88%. For high flows (Block 3A), ranging from 120 cfs to 529 cfs, the recommended minimum flow is 90%. For very high flows (Block 3B), above 529 cfs, the recommended minimum flow is 93%.

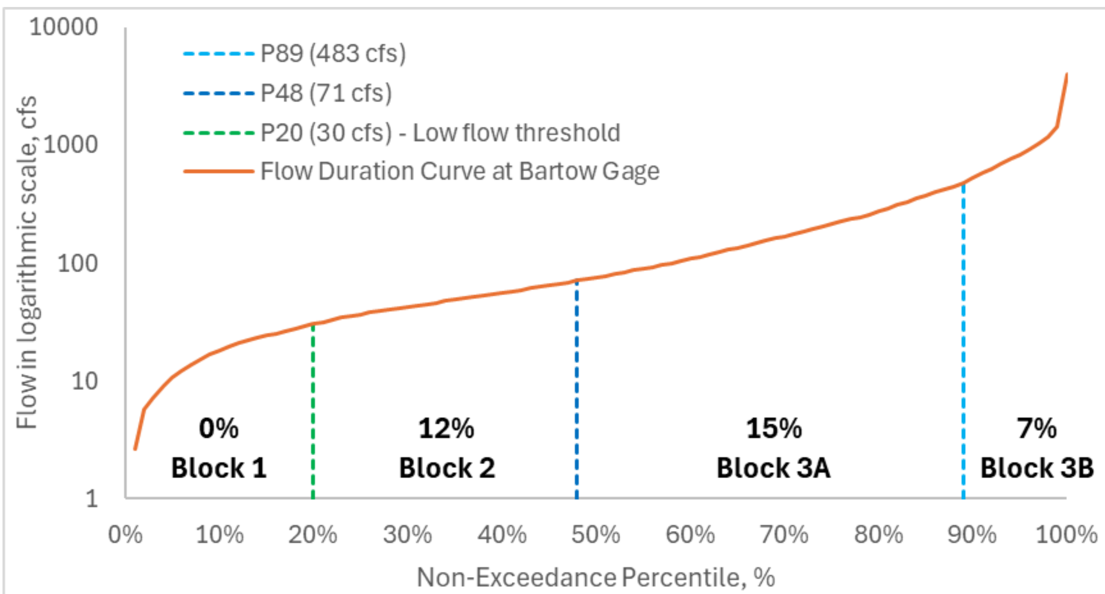
For the **lower river segment**, the recommended minimum flows include a low-flow threshold of 40 cfs, which serves as a limit to surface water withdrawals throughout of the year. For medium flows (Block 2), ranging from 40 cfs to 274 cfs, the recommended minimum flow is 87%. For high flows (Block 3A), from 274 cfs to 1047cfs, the recommended minimum flow is 91%. For very high flows (Block 3B), above 1047 cfs, the recommended minimum flow is 93%.

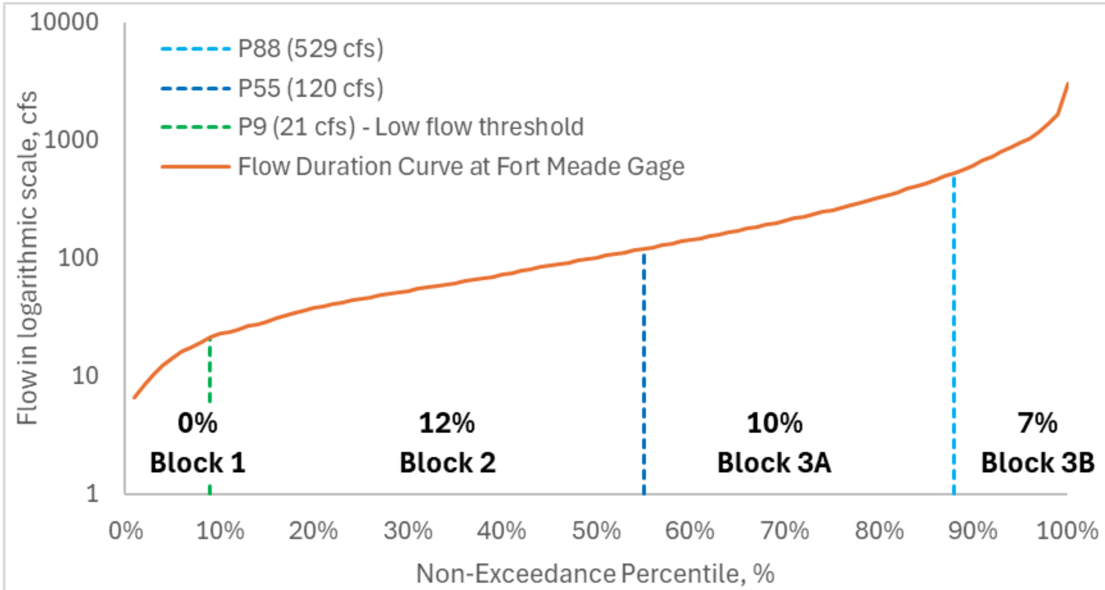
Table 6-5. Summary of proposed minimum flows and allowable flow reductions for three river segments of the Upper Peace River, referencing index gages at Bartow, Fort Meade, and Zolfo Springs.

River Segment	Index Gage Name (Site ID)	Flow Block	Flow Range	Maximum Allowable Reduction[a]	Minimum Flow[a]
Upper	Bartow	B1	≤ 30 cfs	0%	100%[b]
	(02294650)	B2	>30 cfs and ≤71 cfs	12%	30 cfs or 88%[c]

		B3A	>71 cfs and ≤483 cfs	15%	85%
		B3B	>483 cfs	7%	93%
Middle	Fort Meade (02294898)	B1	≤21 cfs	0%	100%[b]
		B2	>21 cfs and ≤120 cfs	12%	21 cfs or 88%[c]
		B3A	>120 cfs and ≤529 cfs	10%	90%
		B3B	>529 cfs	7%	93%
Lower	Zolfo Springs (02295637)	B1	≤40 cfs	0%	100%[b]
		B2	>40 cfs and ≤274 cfs	13%	40 cfs or 87%[c]
		B3A	>274 cfs and ≤1,047 cfs	9%	91%
		B3B	>1,047 cfs	7%	93%

Notes: [a] Based on previous day baseline flow. [b] A 95% annual exceedance is proposed to account for uncertainties related to annual rainfall variations, provisional USGS data, sinkhole losses, Lake Hancock water storage capacity, and structure maintenance, etc. [c] Whichever is greater.





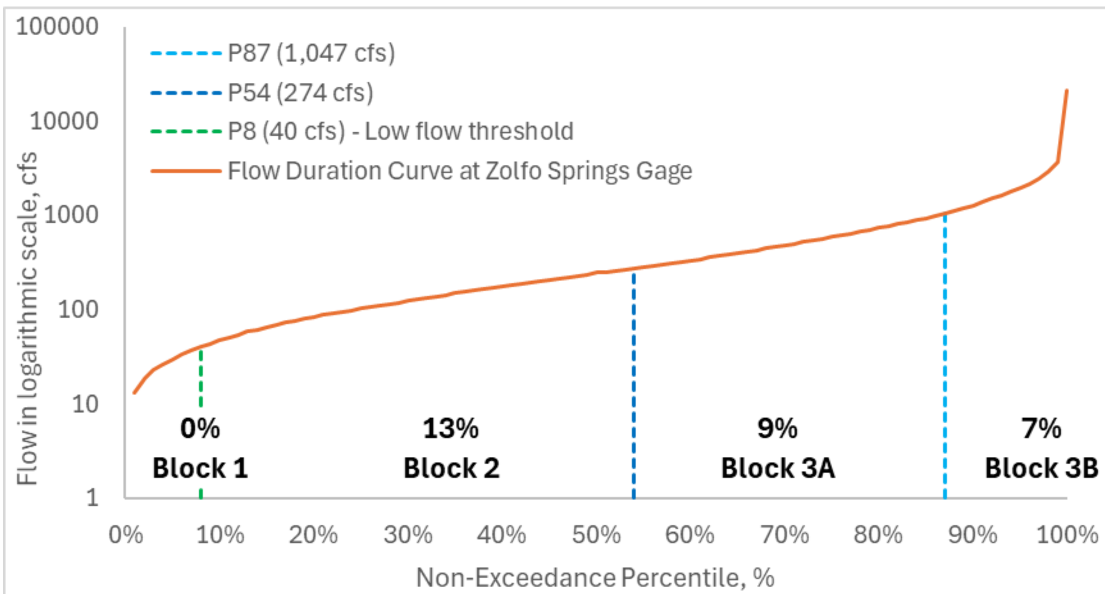


Figure 6-17. Recommended minimum flows for the Upper Peace River, including block-specific allowable percent-of-flow reductions and low-flow thresholds. These values are shown alongside a baseline flow duration curve for the USGS 02294650 Peace River at SR60 at Bartow, FL gage (upper), USGS 02294898 Peace River at Fort Meade FL gage (middle), and USGS 02295637 Peace River at US 17 at Zolfo Springs, FL gage (lower).

6.4 Consideration of Protection of Environmental Resource Values

Ten environmental resources values were identified in Florida's Water Resource Implementation Rule (Chapter 62-40.473, F.A.C.) and the Water Resources Act of 1972, which guides the establishment of minimum flows. These values represent a comprehensive range of water-related functions essential to both ecosystems and human communities. The rule stipulates:

"In establishing minimum flows and levels pursuant to Sections 373.042 and 373.0421, F.S., 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."

To ensure adequate protection of these ten environmental values, a habitat-based approach was employed in developing the proposed minimum flow for the Upper Peace River. The approach incorporated both instream and floodplain habitat considerations, including maintaining minimum water depths to facilitate fish passage, preserving water levels above the lowest inflection points in the wetted perimeter to maximize aquatic habitats for fish, benthic macroinvertebrates, and other organisms dependent on these environments, maintaining inundation of instream woody habitat, including snags and exposed roots in the river channel, and protecting floodplain wetland inundation to maintain essential ecological functions.

While most of these environmental values were assessed alongside technical analyses used to develop the recommended minimum flows, additional analyses were conducted for Transfer of Detrital Material, Sediment Loads, and Water Quality. The following sections summarize the findings for all environmental values, confirming that the recommended minimum flows effectively protect all relevant environmental values.

6.4.1 Recreation in and on the Water

The Recreation in and on the Water environmental value for the Upper Peace River was evaluated by assessing water depths and analyzing potential changes in floodplain inundation, as well as examining fish and invertebrate habitats. Using the HEC-RAS model output, water levels were reviewed to ensure protection of the floodplain (Sections 5.5.3 and 6.2.2) and instream habitats (Sections 5.5.4, 5.5.5, and 6.2.3), including fish passage (Sections 5.5.1, 6.2.1, and 6.2.3). These evaluations confirm that the recommended minimum flows also protect recreational use of the Upper Peace River.

6.4.2 Fish and Wildlife Habitat and the Passage of Fish

To support the environmental value of Fish and Wildlife Habitat and the Passage of Fish, Section 2.5 provides a summary of nekton, benthic macroinvertebrate, other wildlife, and vegetative communities in the Upper Peace River.

Using the HEC-RAS model developed for the Upper Peace River (Section 5.3.2), low-flow thresholds of 30 cfs, 21 cfs, and 40 cfs were established for the upper, middle and lower segments, respectively to ensure the protection of the passage of fish (Sections 5.3.2, 5.5.1, and 6.2.1).

In addition, SEFA analysis was used to identify the minimum flows necessary to sustain instream habitats for fish and wildlife (Sections 5.2.3.1, 5.5.4, and 6.2.3.1). Woody habitat inundation analysis was performed to ensure adequate inundation of habitats for microbial colonization and subsequent probable use by other organisms (Sections 5.2.3.2, 5.5.5, and 6.2.3.2). Flows and water levels were also evaluated to ensure the protection of critical floodplain habitats for fish and wildlife, ensuring ecological integrity throughout the river system (Sections 5.5.3 and 6.2.2).

6.4.3 Estuarine Resources

The Upper Peace River flows through the middle and lower segments of the Peace River before ultimately emptying into Charlette Habor estuary. The Upper Peace River is not directly connected to estuarine resources. Therefore, this environmental value was not considered directly relevant for the development of minimum flows for the Upper Peace River.

6.4.4 Transfer of Detrital Material

Detrital material in rivers includes dead, particulate organic material originating from upland areas, floodplain, and in-channel sources. Detrital transfer occurs laterally and longitudinally in flowing water bodies as a function of water levels, flow rates, velocities, and residence times. These transport processes may be especially active during high-flow conditions, when strong hydrologic interactions between the floodplain and the river channel mobilize large volumes of suspended organic material.

The environmental value of Transfer of Detrital Material was considered for development of recommended minimum flows for the Upper Peace River using the percent-of-flow approach. This method aims to maintain characteristics of the baseline flow regime and floodplain inundation patterns of the Upper Peace River (Sections 5.5.3 and 6.2.2). Maintenance of the floodplain habitats in the Upper Peace River is essential to supporting their structural and functional roles in detrital transfer processes, including serving as sources or sinks, and conduits for organic matter production, export, and utilization.

For this evaluation, transfer of detrital material is defined as the movement of loose organic material, debris, and decomposing biota from floodplain overbanks into the main channel. Based on the floodplain inundation analysis (Section 6.2.2), flow thresholds were identified at which overbank flooding begins: 71 cfs, 120 cfs, and 274 cfs at the Bartow, Fort Meade, and Zolfo Springs gages, respectively. Flow events exceeding these thresholds for durations of 1- and 7-day were used as primary indicators of detrital transfer in the Upper Peace River (Table 6-6). These events were assumed to transfer detritus to the main channel, where it would be subsequently transported downstream.

To assess the potential impact of proposed minimum flows on these detrital transfer events, allowable percent-of-flow reductions were applied. While these reductions are expected to decrease the number of detrital transfer events, all projected changes remain below the 15% threshold for significant harm. At the Bartow gage, it would result in a 10% and 11% decrease in the number of 1-day and 7-day duration events, respectively, with flow continuously exceeding 71 cfs. At Fort Meade Gage, it would result in a 10% and 13% decrease in the number of 1-day and 7-day duration events, respectively, with flow continuously exceeding 120 cfs. At Zolfo Spring Gage, it would result in a 13% and 14% decrease in the number of 1-day and 7-day duration events respectively with flow continuously exceeding 274 cfs (Table 6-6). Based on these results, the recommended minimum flows for the Upper Peace River are expected to adequately protect the transfer of detrital material.

Table 6-6. Number (n) of 1- and 7-day flow events continuously exceeding floodplain inundation flow thresholds at Bartow, Fort Meade and Zolfo Springs in the Upper Peace River under the baseline and minimum flows (MF) scenarios.

Index Gage	Floodplain Inundation Threshold (cfs)	Number of 1-day Events above Flow Threshold (average/year)			Number of 7-day Events above Flow Threshold (average/year)		
		Baseline (n)	MF (n)	Change (%)	Baseline (n)	MF (n)	Change (%)
Bartow	71	189	171	10%	167	149	11%
Fort Meade	120	137	123	10%	115	100	13%
Zolfo Springs	274	72	63	13%	54	37	14%

6.4.5 Maintenance of Freshwater Storage and Supply

The maintenance of freshwater storage and supply is protected through the implementation of the District's Water Use Permitting and Environmental Resource

Permitting Programs. This protection is ensured, in part, by permit conditions that stipulate water withdrawals must not violate any adopted minimum flows.

Additionally, cumulative impact analysis for new water use permits or increased allocations for existing permits must demonstrate that existing legal users and established minimum flows or levels remain protected, further reinforcing the connection between minimum flows regulations and the protection of freshwater storage and supply.

This environmental value is supported by the development of minimum flows for the Upper Peace River, which establish block-specific, allowable percent-of-flow reductions. These reductions can be directly applied to permit conditions for existing and future surface water withdrawals, ensuring continued protection of freshwater storage and supply. The low flow threshold proposed for the Upper Peace River further strengthens this protection.

The District's Environmental Resource Permitting Program also integrates freshwater storage and supply considerations into minimum flow and level regulations. Design requirements for permitted stormwater treatment and management systems specify that, where practical, these systems must:

- Maintain water tables, base flows, and low flows at the highest practicable level.
- Preserve site environmental values and prevent freshwater loss through over drainage
- Ensure water table levels do not adversely affect existing legal users
- Retain site groundwater recharge characteristics
- Keep water on-site for use and reuse for irrigation and other beneficial applications.

Additionally, permitted stormwater systems must not reduce or suppress flows or water levels in a manner that prevents the achievement of an established minimum flow or level.

6.4.6 Aesthetic and Scenic Attributes

The aesthetic and scenic attributes of the Upper Peace River are closely intertwined with other environmental values, including 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 sections of this chapter, all environmental values have been thoroughly considered. In some cases, specific criteria used in habitat-based methods have been applied to develop minimum flow recommendations for the Upper Peace River. As a result, the recommended minimum flows ensure that the aesthetic and scenic attributes of the system remain protected.

6.4.7 Filtration and Absorption of Nutrients and Other Pollutants

The Filtration and Absorption of Nutrients and Other Pollutants environmental value was assessed by evaluating system bathymetry, floodplain inundation, and instream habitats. This environmental value is closely linked to other considerations discussed throughout this chapter, including Recreation in and on the Water, Fish and Wildlife and the Passage of Fish, Transfer of Detrital Material, Sediment Loads, and Water Quality.

6.4.8 Sediment Loads

Sediment loads refer to the total quantity of sediment transported by a river, including both suspended particles and bedload (material rolling or sliding along the riverbed). These loads typically increase during flood events, when inundated floodplains and elevated flows transport large volume of sediment. The transport of sediment in rivers is influenced by water velocity, channel morphology, and sediment size.

Modeling sediment transport requires detailed understanding of processes involved in erosion, movement, and deposition within the water column. Accurate model calibration and validation of sediment transport also depend on measured bed and suspended sediment loads. Sediment loads were considered for development of recommended minimum flows for the Upper Peace River at Bartow, Fort Meade and Zolfo Springs using the Engelund-Hansen method (Engelund and Hansen 1972). This approach evaluates changes in sediment transport capacity under the recommended minimum flows conditions, assuming unlimited sediment availability. It is important to note that simulated sediment discharges represent the system's capacity to transport sediment, not actual sediment loads, and are used to assess whether the long-term sediment transport capacity of the Upper Peace River will be protected under the recommended minimum flows.

There are several empirical methods that can be applied to calculate sediment discharge capacity. The Engelund-Hansen method was selected for this study because of its simplicity and suitability for sandy-bed rivers, which are common in Florida. Sediment discharges are predicted based on mean flow velocity, bed shear stress, particle size, specific gravity, and channel width. The specific steps undertaken to evaluate sediment loads for the Upper Peace River at Bartow, Fort Meade and Zolfo Springs were as follows:

1. Critical shear stress values by particle size classification for sediment mobility was obtained from the USGS Scientific Investigations Report (USGS 2013; Table 6-7). Sediment mobility for a given particle size is

assumed to occur when the bed shear stress exceeds these critical values. The particle size distribution in the Upper Peace River generally falls within the medium to coarse sand range. 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 the Upper Peace River.

2. The Upper Peace River steady flow HEC-RAS model was run for 102 flow profiles, generating paired flow-bed shear-velocity relationships at each of the HEC-RAS cross-sections in the model. These flow profiles range from the 1% to 100% exceedance. Detailed information regarding these flow profiles is provided in Appendix H.
3. Flow-sediment discharge rating curves were developed at selected cross-sections using the Engelund-Hansen method and the 102 flow profile scenarios.
4. Daily sediment discharge values were generated for the baseline condition for each selected cross-section for the period from 1975 through 2022 using the rating curves and an interpolation function in Excel.
5. Mean daily sediment transport capacity (tons/day) were calculated at each selected cross-section.
6. Steps 4 and 5 were repeated using flow records reduced 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 assess potential long-term impacts.

Table 6-7. Critical shear stress by particle-size classification for determining approximate condition for sediment mobility at 20 degrees Celsius (Source: USGS 2013).

Particle Classification Name	Range of Particle Diameter (mm)	Critical Bed 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	0.00290 - 0.00388

Particle Classification Name	Range of Particle Diameter (mm)	Critical Bed Shear Stress (lb/ft^2)
Very fine sand	0.0625 – 0.125	0.00220 - 0.00290
Coarse silt	0.0310 – 0.0625	0.001652 - 0.00220
Medium silt	0.0156 – 0.0310	0.001260 - 0.001652
Fine silt	0.0078 – 0.0156	0.000756 - 0.001260

Assuming unlimited sediment availability in the river, the estimated sediment transport capacity under the baseline condition ranged from 3 to 103 tons/day in the river segment between Bartow and Fort Meade, 13 to 852 tons/day between Fort Meade and Bowling Green, and 38 to 359 tons/day downstream of Fort Meade. Under the minimum flows condition, these ranges were reduced to 3 to 88 tons/day, 12 to 738 tons/day, and 33 to 316 tons/day for the respective river segments (Table 6-8). These estimates may be over-predicted in some sites 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 provides a useful measure of 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 at Bartow, Fort Meade and Zolfo Springs are predicted to result, respectively, in an average of 12%, 12% and 11% decrease of the mean baseline sediment transport capacity (Table 6-8). Based on these findings, the recommended minimum flows for the Upper Peace River at Bartow, Fort Meade and Zolfo Springs are, therefore, not expected to negatively affect sediment loads.

Table 6-8. Sediment transport capacity (tons/day) in the Upper Peace River at Bartow, Fort Meade and Zolfo Springs under the baseline and minimum flows (MF) scenarios were evaluated using the Engelund-Hansen method.

Index Gage	Sediment Transport Capacity		
	Baseline (ton/day)	MF (ton/day)	Change (%)
Bartow	3-103	3-88	12%
Fort Meade	13-852	12-738	12%
Zolfo Springs	38-359	33-316	11%

6.4.9 Water Quality

As part of the minimum flow evaluation, 14 water quality parameters at nine monitoring stations are evaluated for status and trends as described in Chapter 3 and Appendix G. The results indicate that the recommended minimum flows for the Upper Peace River are not expected to negatively affect water quality or impair the water designated use of the water body.

6.4.10 Navigation

Given the availability of existing boat launch facilities and docks along the river, the waterway is not expected to support commercial and large-scale recreational boating, aside from canoeing or kayaking. The navigation criterion is defined as the flow corresponding to a water depth of 0.5 ft (0.15 m), consistent with minimum flow evaluations conducted for the Lower Santa Fe River (HSW 2021), Charlie Creek (Deak et al. 2023), Horse Creek (Ghile et al. 2023), and Little Manatee River (Holzwart et al. 2023).

Since the critical depth required for canoe and kayak navigation is shallower than the depth necessary for fish passage, the recommended minimum flows are not expected to adversely affect canoeing and kayaking in the Upper Peace River.

CHAPTER 7 MINIMUM FLOWS STATUS ASSESSMENT, IMPLEMENTATION, AND CONCLUSIONS

7.1 Minimum Flows Status Assessment

The District assessed the status of the flow regime of the Upper Peace River, supported by numerical modeling and other data, to determine whether current and projected flows over the next 20 years will remain above the recommended minimum flows developed through this study.

These assessments were conducted in accordance with the Florida Water Resources Act of 1972, which stipulates that if the existing flow or level in a water body is below, or projected to fall within 20 years below, its established minimum flow or level, the FDEP or the governing board 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.

To assess the status of the recommended minimum flows in the Upper Peace River, the District analyzed historic and current flow conditions and examined the influence of withdrawals and other anthropogenic factors. As detailed in Section 5.3.1, the District developed PRIM2 to evaluate the impacts of climate variability, groundwater pumping, land use changes, and other influences on river flows in the Peace River and its tributaries.

PRIM2 simulation results revealed that observed discharges in the Upper Peace River have generally declined at the Bartow and Fort Meade gages due to groundwater withdrawals, while flows at the Zolfo Springs gage have increased, attributing to excess runoff from agriculture irrigation return flows.

Table 5-6 presents estimated monthly adjustment flows due to withdrawal-related effects over a 16-year assessment period. Collectively, these findings indicate the recommended minimum flows for the Upper Peace River are currently being met. Furthermore, predictions based on projected 2045 water demands suggest that the recommended minimum flows will continue to be met over the 20-year planning horizon.

In 2020, the District adopted the Lake Hancock Reservation, which enables the release of water from Lake Hancock to Lower Saddle Creek in support of the recovery of low flows in the Upper Peace River. The District anticipates continued use of this reservation when flow thresholds of 30 cfs, 21 cfs and 40 cfs at Bartow (USGS Gage No. 02294650), Fort Meade (USGS Gage No. 02294898), and Zolfo Springs (USGS Gage No. 02295637), respectively, are not met. As a result, a specific recovery or prevention strategy is not required at this time.

7.2 Minimum Flows Implementation

The implementation of minimum flows for the Upper Peace River will rely heavily on ongoing, periodic status assessments, as outlined in the preceding section of this chapter. These evaluations are vital for monitoring compliance and understanding the long-term impacts of water use.

Routine assessments of predicted river flows, derived from updated groundwater modeling, will be essential for assessing the potential effects of permitted withdrawals. Additionally, observed flow data from the USGS gaging stations at Bartow, Fort Meade, and Zolfo Springs will be critical. Withdrawals-corrected flow measurements from these stations will inform allowable withdrawal thresholds and may be used to potentially limit permitted surface water withdrawals from the Upper Peace River.

Compliance with District's water use permits will ensure that withdrawals do not exceed adopted minimum flows, thereby supporting the preservation of the ecological integrity of the Upper Peace River system.

7.3 Concluding Remarks

To ensure the long-term protection of the Upper Peac River, the District will apply an adaptive management approach to continue monitoring and evaluating the status of established minimum flows. Recognizing the potential impacts of climate change, structural alterations, water withdrawals, and other changes within the watershed and contributing groundwater basin, the District remains committed to periodic reevaluation and, when necessary, revision of minimum flows for this priority water body. Any revisions will be incorporated into Chapter 40D-8, F.A.C.

In support of this commitment, the District, working in partnership with the USGS, will maintain ongoing monitoring flow conditions used in minimum flow development and assessment. These status assessments will be conducted annually, every five years as part of the regional water supply planning process, and on an as-needed basis in association with permitting and project activities.

This proactive and science-based approach ensures that minimum flows continue to reflect current conditions and emerging data, safeguarding the ecological integrity of the Upper Peace River for future generations.

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