Technical Publication SJ2017-2

MINIMUM FLOWS DETERMINATION FOR SILVER SPRINGS MARION COUNTY, FLORIDA

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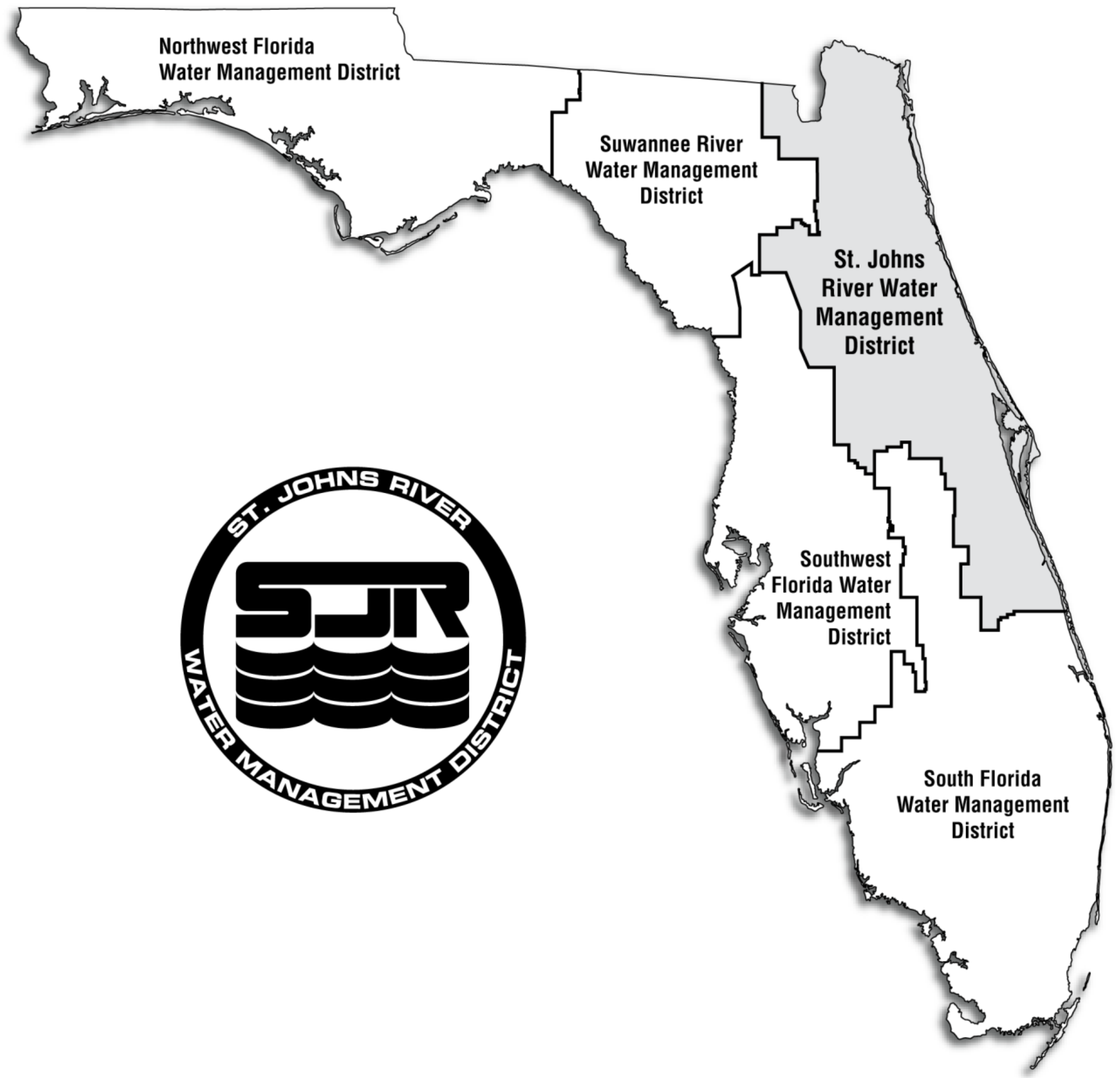
Palatka, Florida

2017



The St. Johns River Water Management District was created in 1972 by passage of the Florida Water Resources Act, which created five regional water management districts. The St. Johns District includes all or part of 18 counties in northeast and east-central Florida. Its mission is to preserve and manage the region's water resources, focusing on core missions of water supply, flood protection, water quality and natural systems protection and improvement. In its daily operations, the district conducts research, collects data, manages land, restores and protects water above and below the ground, and preserves natural areas.

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EXECUTIVE SUMMARY

As a part of fulfilling its mission and statutory responsibilities, the St. Johns River Water Management District (SJRWMD) establishes minimum flows and levels (MFLs) for priority water bodies within its boundaries. MFLs define the limits at which further consumptive use withdrawals would be significantly harmful to the water resources or ecology of the area. MFLs are one of many effective tools used by the SJRWMD to assist in making sound water management decisions and preventing significant adverse impacts due to water withdrawals. Section 373.042, *Florida Statutes* (F.S.), requires the adoption of minimum flows and levels for Outstanding Florida Springs (OFS), including Silver Springs, by July 1, 2017.

Silver Springs is a first magnitude spring located in Marion County. The springs and the associated Silver River, are popular recreation destinations enjoyed by thousands of visitors each year. In addition to being designated an OFS in 2016, Silver Springs and Silver River were designated Outstanding Florida Waters (OFWs) in 1987 for their many exceptional natural attributes. The SJRWMD is charged with protecting these unique natural resources by developing MFLs pursuant to SJRWMD's adopted MFL priority list and Section 373.042 F.S.

Recommended minimum flows were developed for Silver Springs using a hydrologic event-based approach. By maintaining essential characteristics of the system's natural seasonal flooding and drying events, the basic structure and functions of the environmental system will also be maintained. The three minimum flows for Silver Springs (Table ES1) are based on criteria developed from vegetation, soils and topography data in and adjacent to the Silver River floodplain because the floodplain is more sensitive to withdrawals and exhibits more hydrological variability than the in-channel habitats. By protecting the more sensitive higher-elevation habitats (e.g., floodplain metrics) the other critical habitats at lower elevations (e.g., springs, in-channel habitat) will also be protected, thereby providing protection for the entire system.

Table ES1. Recommended minimum flows for Silver Springs, Marion County, Florida

Minimum Flows	Flow (cfs)	Duration (days)	Return Interval (years)
Frequent High (FH)	828	30	5
Minimum Average (MA)	638	180	1.7
Frequent Low (FL)	572	120	3

The recommended FH is a flooding event that is based on providing a sufficient number of flood events to protect the entire extent of floodplain wetlands and their wildlife habitat values. These flood events also promote filtration and absorption of nutrients and other pollutants on the floodplain. The recommended MA prevents an excessive number of drying events to protect organic soils from oxidation and subsidence and avoid adverse impacts to habitat and water quality. The recommended FL prevents an excessive number of drying events to protect marsh ecotones along the Silver River and their associated wildlife values. The FL also maintains an appropriate water-table level in soils of the floodplain during periodic droughts

Because the MFLs for Silver Springs are based on flows, once they are adopted, they can more readily be used to support the SJRWMD's water supply planning and water use regulation programs. The minimum flows can be used to determine future/projected and ongoing compliance status for consumptive use permitting through a compliance assessment analysis. Groundwater models are used to estimate the future impact of individual and cumulative consumptive use permits on MFLs. By setting the Silver Springs MFLs as a series of minimum flows, it enables SJRWMD to use groundwater modeling to estimate spring flow reduction, and thus readily perform a compliance assessment to ensure the MFLs are being met.

The minimum flows for Silver Springs set the limit at which further water withdrawals would be significantly harmful to the system. In order to assess the status of the minimum flows it is important to understand and quantify the effects of groundwater withdrawals on spring flows. The flow at Silver Springs has declined over 30% since the 1930s. To understand the possible causes of the flow reduction, the SJRWMD performed a series of hydrological statistical and modeling analyses. The results of these analyses indicate long-term rainfall deficit (112"), submersed aquatic vegetation (SAV)-related flow suppression and regional pumping from the upper Floridan aquifer system are the main reasons for flow reduction. In addition, the analysis further revealed the effects of rainfall deficit and SAV-related flow suppression on spring flows are much more pronounced than the effect of regional pumping from the upper Floridan aquifer.

The amount of flow reduction due to groundwater withdrawals was estimated to be 26 cubic feet per second (cfs), based on the Northern District Model (NDMv5). This flow reduction represents the change from a no-pumping scenario to the baseline scenario. The baseline represents a best estimate of current impacts due to pumping. For Silver Springs the 2010-pumping condition was the latest pumping and hydrologic condition to which the NDMv5 was calibrated. Therefore, it represents the best available information regarding the impact of current groundwater withdrawals on spring flow at Silver Springs. Pumping during more recent years has actually been less than the amount pumped in 2010.

A status assessment of the minimum flows for Silver Springs was conducted to determine if the flows are met under baseline and projected pumping for the 20-year planning horizon. The analysis indicates all three recommended minimum flows for Silver Springs are currently being achieved under baseline conditions. Water availability, or freeboard was calculated and resulted in the FL being the most constraining with a freeboard of 17 cfs. The recommended minimum flows protect 94% of the long-term average flows. Of the allowed

6% reduction, approximately 3.5% has already occurred, leaving about 2.5% of additional allowable reduction. Analyses also indicate, based upon current water use projections, groundwater pumping will cause the FL to no longer be met in approximately 2025. Therefore, a prevention strategy is recommended for adoption concurrent with the minimum flows that includes the necessary projects and regulatory measures to prevent the existing flow from falling below the recommended minimum flow.

The St. Johns River Water Management District concludes the recommended minimum flows, which have been developed primarily for the protection of significant harm to "fish and wildlife habitats and the passage of fish" and "filtration and absorption of nutrients & other pollutants," will protect all other relevant Rule 62-40.473, *F.A.C.*, environmental values. The SJRWMD is committed to implementing this MFL, once adopted by SJRWMD's Governing Board as rule in Rule 40C-8.031, *F.A.C.,* to ensure proper protection of this valuable water body.

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ACRONYMS AND ABBREVIATIONS

ATM	Applied Technology and Management Inc.
BMAP	Basin Management Action Plan
BOCC	Board of County Commissioners
CUP	Consumptive Use Permit
F.A.C.	Florida Administrative Code
FDEP	Florida Department of Environmental Protection
F.S.	*Florida Statutes*
GIS	Geographic Information System
HEC-RAS	Hydrologic Engineering Center–River Analysis System
FH	minimum frequent high
FL	minimum frequent low
MA	minimum average
MFLs	minimum flows and levels
MIH	minimum infrequent high
MIL	minimum infrequent low
MWRA	Moving Window Regression Analysis
NCF	North-central Florida Regional Groundwater Flow Model
NGVD	1929 National Geodetic Vertical Datum
NRCS	Natural Resources Conservation Service
OFW	Outstanding Florida Water
PAR	photosynthetically active radiation
POR	period of record
SAV	submersed aquatic vegetation
SJRWMD	St. Johns River Water Management District
SRWMD	Suwannee River Water Management District
SWFWMD	Southwest Florida Water Management District
SMI	Soil Moisture Index
SMW	Split Moving Window
SPI	Springs Protection Initiative
SSURGO	Soil Survey Geographic database
SWIDS	Surface Water Inundation/Dewatering Signatures
TMDL	total maximum daily load
UFA	Upper Floridan aquifer
USGS	U.S. Geological Survey
WBID	Water Body Identification

ACKNOWLEDGEMENTS

The authors are grateful to the many people who have contributed to the understanding of Silver River and Silver Springs, and especially to the following for their assistance with this report:

Travis Richardson, Jane Mace, Chrissy Carr, Tara Rodgers, Will Mahler, Tommy Walters, Mike Deloach, Mark Willick, J.P. Flint, Jason McKinley, Ching-Tzu Huang, Patrick Burger, Doug Munch, Stan Williams, Tom Mirti, David Hornsby, Awes Karama, Price Robison, Cliff Neubauer, Fay Baird, Nathan Johnson, John Fitzgerald, Mike Lattin, Mitch Wainwright, Howard Mullis, Rob Mattson, Ed Lowe, Stephen Speaks, Kermit Hilliard, Doug Hearn and Joanne Chamberlain, St. Johns River Water Management District

Bob Lamont, Sally Lieb, Jeff Sowards, and Alice Bard, Florida Department of Environmental Protection

Jason Hood, Marty Kelly, Jon Morales, Gary Williams, Tammy Hinkle, Ron Basso, Southwest Florida Water Management District

Darrell Lambeth and Sonny Anderson, U.S. Geological Survey

Gail Mowry, Marion County Office of the County Engineer

INTRODUCTION

The St. Johns River Water Management District (SJRWMD) completed a minimum flows determination for Silver Springs in Marion County. Silver Springs, and the associated Silver River, are popular recreation destinations enjoyed by thousands of visitors each year. Silver Springs and Silver River are designated Outstanding Florida Waters (OFWs) for their many exceptional natural attributes. SJRWMD is charged with protecting these unique natural resources by developing minimum flows and levels (MFLs) pursuant to *Florida Statutes*. Silver Springs has been designated an Outstanding Florida Spring (OFS), and as such, Section 373.042(2), *Florida Statutes* (F.S.), requires the adoption of MFLs for this priority water body by July 1, 2017.

SJRWMD is recommending minimum flows for Silver Springs, because this is a spring MFL. The Silver Springs MFLs were assessed using flow data from the U. S. Geological Survey (USGS) 02239501 gaging station located downstream of the 30+ vents that make up the Silver Springs Group (Figure 1). Descriptions of water levels and flows from this gage refer to the total contribution of the Silver Springs Group, which is for this report synonymous with "Silver Springs." Although SJRWMD is recommending minimum flows for Silver Springs, these flows are based on critical stages in and adjacent to the Silver River floodplain. The Silver River floodplain is more sensitive to withdrawal and exhibits more hydrological variability than in-channel habitats. Maintaining a minimum frequency of flooding events and a maximum frequency of drying events in and adjacent to the Silver River floodplain will prevent impacts to critical habitats at lower elevations (e.g., within the springs and river channel). The purpose of the recommended Silver Springs minimum flow is to protect the entire Silver Springs ecosystem, including the springs, river and floodplain. See the *Technical Approach* and *Results and Discussion* sections for more details.

Because the MFLs for Silver Springs are based on flows, once they are adopted, they can more readily be used to support SJRWMD's water supply planning and water use regulation programs. The MFLs can be used to determine future/projected and ongoing compliance status for consumptive use permitting through a compliance assessment analysis. Groundwater model projections are used to estimate the future impact of individual and cumulative consumptive use permits on MFLs. By setting the Silver Springs MFLs as a series of minimum flows, it enables SJRWMD to use groundwater modeling to estimate spring flow reduction, and thus readily perform a compliance assessment to ensure the MFLs will be met. The recommended minimum flows were developed based on the flows necessary to protect critical water stages. As such the, the critical stages within the Silver Springs ecosystem are protected by the recommended minimum flows.

LEGISLATIVE OVERVIEW

SJRWMD establishes minimum flows and levels for priority water bodies within its boundaries (section 373.042, F.S.). Minimum flows and levels for a given water body are the

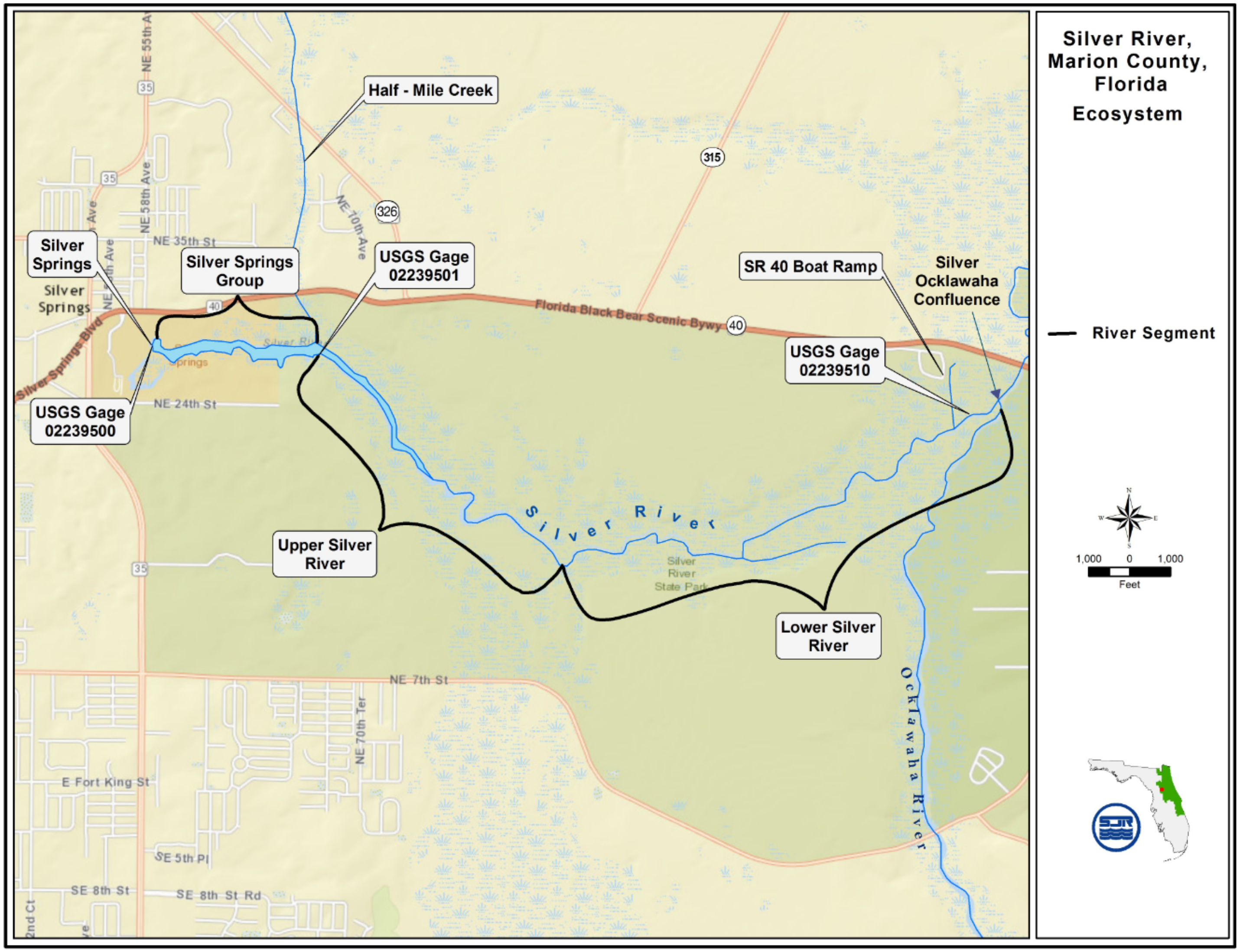


Figure 1. Silver Springs ecosystem, including Silver Springs, the Silver Springs Group (30 springs), and the upper and lower Silver River

limits "at which further withdrawals would be significantly harmful to the water resources or ecology of the area" (section 373.042, F.S.). Minimum flows and levels are established using the best information available (section 373.042(1), F.S.), with consideration also given to "changes and structural alterations to watersheds, surface waters, and aquifers and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of the affected watershed, surface water, or aquifer...," provided that none of those changes or alterations shall allow significant harm caused by withdrawals (section 373.0421(1)(a), F.S.).

The minimum flows and levels section of the State Water Resources Implementation Rule (rule 62-40.473, Florida Administrative Code [F.A.C.]) also requires 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." These environmental values are described later in this report.

Rule 62-40.473, F.A.C., states that minimum flows and levels "should be expressed as multiple flows or levels defining a minimum hydrologic regime, to the extent practical and necessary, to establish the limit beyond which further withdrawals would be significantly harmful." Water bodies experience variations in flows and levels that often contribute to significant functions of the system. Multiple MFLs are recommended for Silver Springs because variations in river flow and stage create and maintain associated habitats. Floods interact with channel and floodplain geomorphology to create a heterogeneous landscape that supports high biodiversity and ecosystem services. Similarly, periodic droughts, as long as they don't occur too often, can have regenerative affects on habitats of aquatic and riparian biota. Riverine organisms are closely adapted to the local magnitude, return interval, duration, and seasonality of hydrologic events. Setting multiple MFLs helps to characterize and protect these variations in flow.

MFLs are used in SJRWMD's regional water supply planning process (Section 373.0361, F.S.), the consumptive use permitting program (Chapter 40C-2, *Florida Administrative Code* [*F.A.C.*]), and the environmental resource permitting program (Chapter 62-330, *F.A.C.*).

SJRWMD MFLs Program Overview

SJRWMD is engaged in a districtwide effort to develop MFLs for protecting priority surface water bodies, watercourses, associated wetlands, and springs from significant harm caused by water withdrawals. MFLs provide an effective tool for decision-making regarding planning and permitting of surface water or groundwater withdrawals. If MFLs are not being met or are expected to not be met during the 20-year planning horizon, due to withdrawals, a recovery or prevention plan must be developed and implemented.

A fundamental element of the SJRWMD's MFLs approach is that alternative hydrologic regimes exist that are lower than historical but will protect the ecological structure and function of priority water bodies, watercourses, associated wetlands, and springs from significant harm caused by water withdrawals.

Significant harm is a function of changes in frequencies of water level and/or flow. For the Silver Springs MFL, this change in hydrologic regime is described as a change in the return interval of flooding and drying events of defined magnitude and duration that would be caused by water withdrawals. These changes due to water withdrawals would be sufficient to cause impairment or loss of ecological structure (e.g., permanent downhill shift in plant communities) or function (e.g., insufficient fish reproduction or nursery habitat).

MFLs typically define the return interval of high, intermediate, and low water events necessary to protect relevant water resource values. Three MFLs are usually defined for each system (Neubauer et al. 2008; see *Technical Approach* for more detail). No matter how many MFLs are adopted, the most constraining (i.e., most sensitive to water withdrawal) MFL is used for water supply planning and permitting. By ensuring that the most sensitive MFL is met, assurance is also provided that the other MFLs will be met.

SILVER SPRINGS HYDROLOGY OVERVIEW

A thorough understanding of Silver Springs hydrology, particularly the main factors affecting spring flows, is crucial to understanding the context and rationale for setting the Silver Springs MFLs. As detailed in this report, an extensive investigation and analysis of hydrologic data was conducted using the best available data, scientific literature, inferences from hydraulic and hydrologic models, and professional judgment. Some aspects of the following discussion are presented in greater detail in different sections of this report. However, it was deemed important to highlight these important issues early in the report to increase understanding of the rationale behind the recommended MFLs.

Flow Data

Data from the two stations (USGS 02239500 and USGS 02239501) were combined to obtain the full period of record (POR) of field flow measurements for Silver River. SJRWMD contracted with Edward German (formerly USGS hydrologist) to review the combined USGS dataset and clarify the dynamics between upstream and downstream flow, and to create a single dataset that could be used as the basis for MFLs analyses. German (2010) determined that measured flow at the USGS 02239501 gaging station was an average of 10% lower than measured flow downstream near the Silver River and Ocklawaha River confluence (USGS 02239510 gage), based on 23 pairs of concurrent USGS flow measurements in 2004 and 2005. Therefore, German (2010) recommended development of a spatially homogeneous flow dataset for MFLs determination, adjusted to reflect conditions at the USGS 02239501 gaging station, to serve as a more representative long-term flow POR at that location. As a result, the adjusted dataset of field flow measurements at the USGS

02239501 gaging station was used in the MFL development. This is referred to as the USGS-adjusted data set.

Spring Flow Declines

Silver Springs and Silver River have experienced a large decline in flow (more than 30%) since the 1930s. To understand the possible causes of the flow reduction, a series of hydrological statistical and modeling analysis were performed. The results of the analysis indicated that flow suppression related to increased submersed aquatic vegetation (SAV), long-term rainfall deficit, and the regional pumping were the main reasons for reduction in spring flows. In addition, the analysis further revealed that the effects of rainfall deficit and SAV-related flow suppression on spring flows were much more pronounced than the effect of regional pumping.

Analyses and results are discussed in detail in the *Hydrology* section.

Period of Record

Determining the most appropriate POR is especially critical for the Silver Spring MFLs because of the distinct shift that occurred in the Silver River stage-flow relationship in or around the year 2000. After 2000, a given flow has resulted in a markedly higher stage, relative to pre-2000.

Evidence suggests that this condition is largely due to SAV-related flow suppression. The prolonged deficit rainfall (112” deficit from 1970s to 2000, and average rainfall since then), lack of scour and dark water suggest this drought may be the cause of the increase in SAV. While there is still uncertainty about the permanence of SAV and the current stage-flow relationship, it is possible that pre-2000 conditions may return when sufficient above average rainfall combined with large flooding events (with associated high scour from the Silver River, dark water from the Ocklawaha River, reduced SAV, and lower stages) return for an adequate period.

There is uncertainty regarding the permanence of this change and the potential that this condition may be primarily climate driven and temporary, or cyclic in nature. There is also uncertainty regarding the role of nutrient enrichment and food web changes due to Kirkpatrick Dam at Rodman Reservoir (i.e., reduced grazing pressure) on the stage-discharge shift. Because of this uncertainty, SJRWMD has chosen to use the entire flow and stage time series (1946 to 2014) in the development of the Silver Springs MFL. Analyses and results are discussed in detail in the *Hydrology* section.

SILVER SPRINGS SETTING AND DESCRIPTION

LOCATION AND PHYSIOGRAPHIC SETTING

Silver Springs, located in Marion County in north-central Florida, is Florida's largest freshwater spring (Rosenau et al. 1977; Scott et al. 2002; Scott et al. 2004) and is also likely the largest limestone spring in the United States (Meinzer 1927; Rosenau et al. 1977). Silver Springs is located approximately 6 miles (mi) northeast of Ocala, at the western edge of the Ocklawaha River valley, and forms the headwaters of the Silver River (Figure 2). From the spring vents, water flows eastward down the Silver River approximately 5 mi to its confluence with the Ocklawaha River. The Ocklawaha River flows northward and is a major tributary to the Lower St. Johns River Basin, which ultimately flows to the Atlantic Ocean (Figure 3). Major water control structures are located on the Ocklawaha River, upstream and downstream of the confluence with Silver River. The Rodman Reservoir and lock and dam complex are located approximately 22 river miles downstream from the Silver River-Ocklawaha River confluence and the Moss Bluff lock and dam is located approximately 12 river miles upstream (Figure 3).

SITE DESCRIPTION

Silver River was designated as an Outstanding Florida Water (OFW) in 1987 as a water resource designated as Special Waters (Rule 62-302.700(9)(i)32., *F.A.C.*, Silver River (Marion County] [4-9-87]). Additionally, Silver Springs and Silver River were designated as OFWs in 1988 as water resources within Florida State Parks, State Wildlife Parks, and State Recreation Areas (Rule 62-302.700(9)(c)70., *F.A.C.*, Silver River State Park [4-19-88; as modified 10-4-90, 8-8-94]). Pursuant to Section 373.042(2), F.S., Silver Springs was designated as an Outstanding Florida Spring (OFS) in 2016, and it must have MFLs adopted by July 1, 2017.

The Silver River and its headwater springs are in the Silver River State Park (Figure 4). The state park was created in 1987 and encompasses approximately 4,230 acres, designated for public recreation and conservation. Additionally, the Silver River is located entirely within the Ocklawaha River Aquatic Preserve, where the majority of the land is in public ownership (Wetherell 1992).

The upper 3,900 feet (ft) of Silver River around the headsprings was leased to Palace Entertainment and devoted to the Silver Springs—Nature's Theme Park (park). The park is possibly most famous for its glass bottom boat rides (Figure 5) from which the numerous springs and the associated aquatic life may be viewed and has been a popular tourist destination for more than 100 years (Crum 1954; Martin 1966). While tourist attendance has

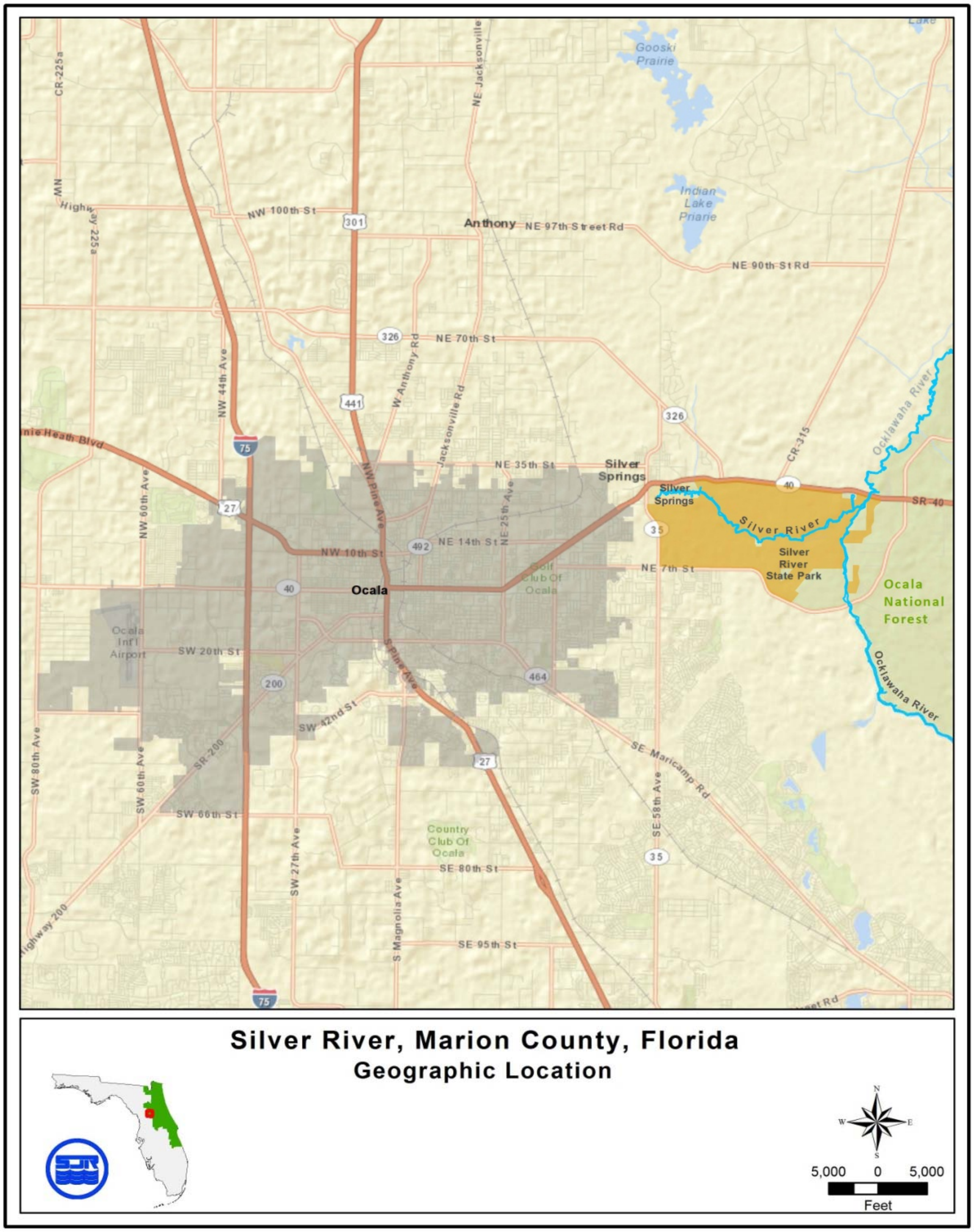


Figure 2. Location map for the Silver Springs and Silver River

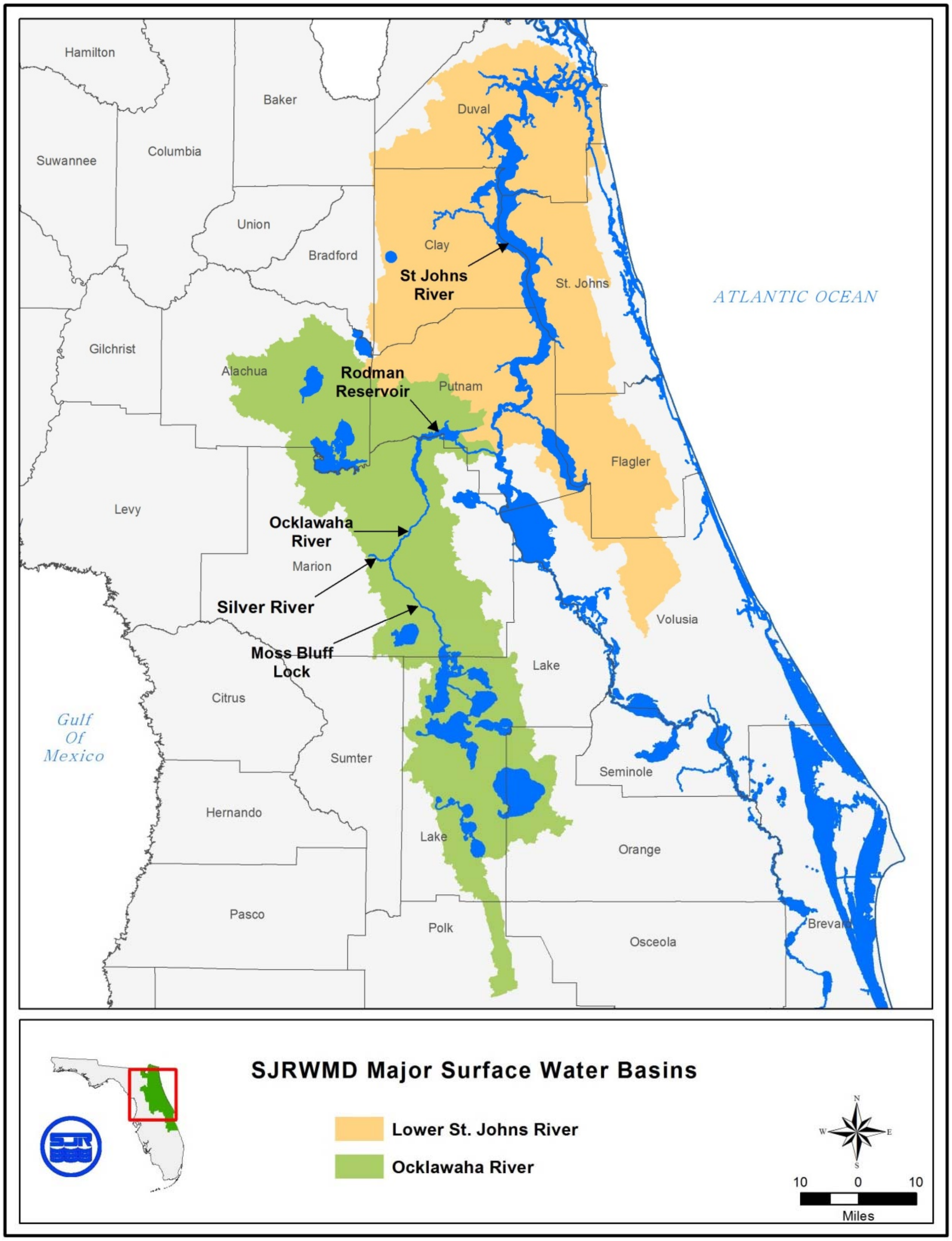


Figure 3. St. Johns and Ocklawaha River basins in relation to Silver River

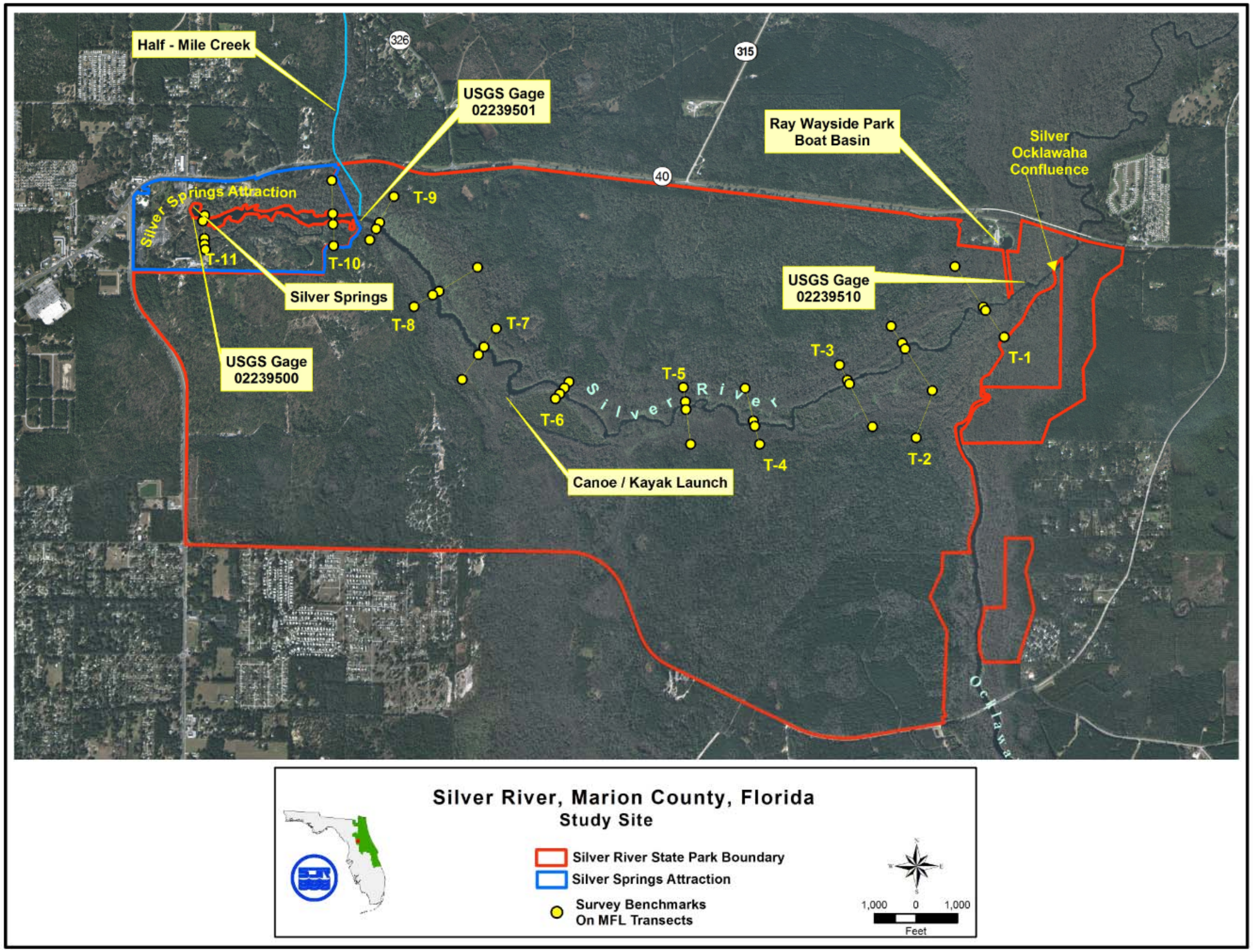


Figure 4. Silver Springs and Silver River study site

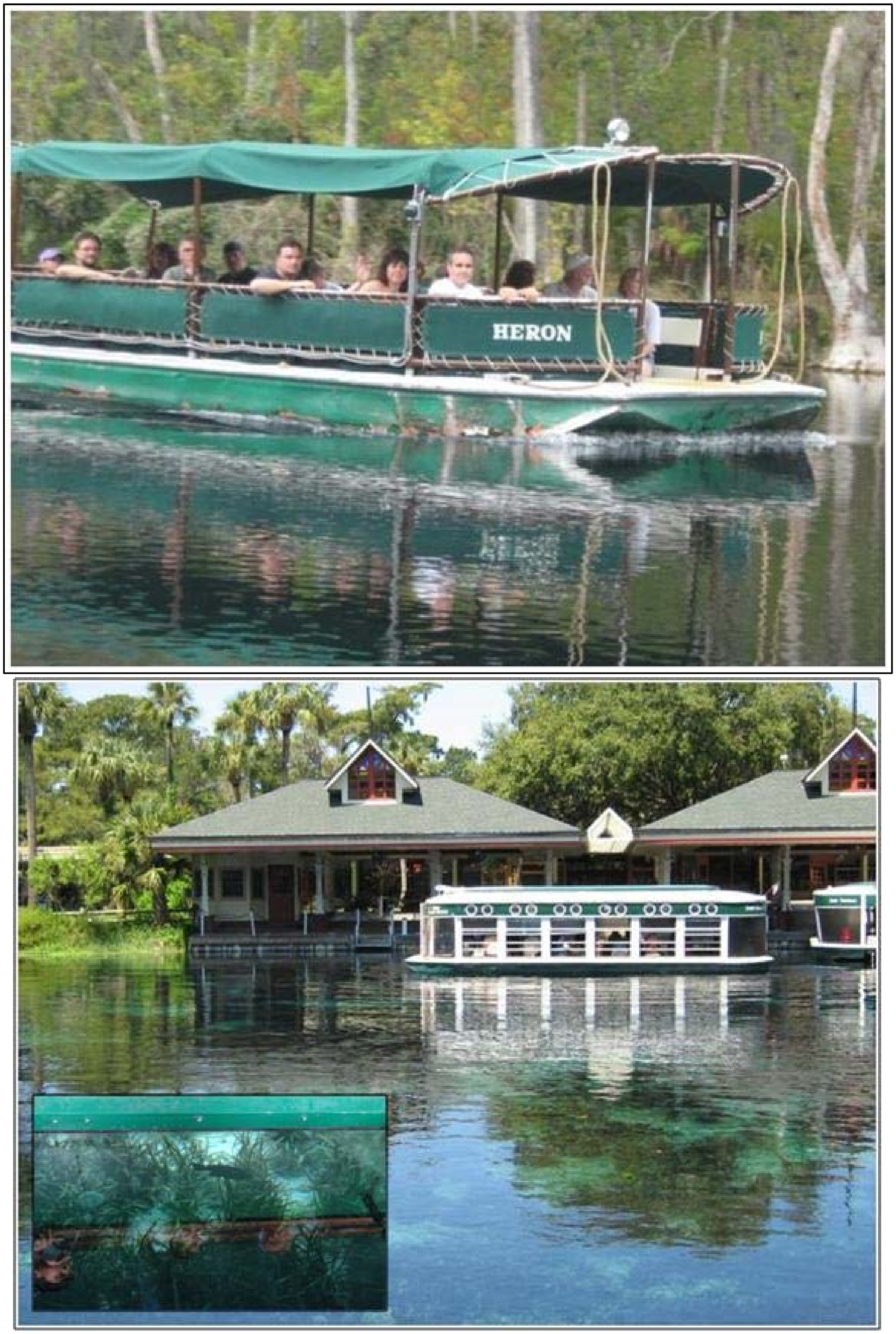


Figure 5. Glass bottom boats used by the Silver Springs State Park, (inset photo is a typical view through a glass bottom boat)

declined during recent years, the park typically received a million or more visitors annually, generating an estimated annual economic impact of approximately $65 million (Bonn 2004). The park lease expired in October 2013, at which time the property was integrated into the Florida State Park system.

Access to the headspring is also possible by kayak and canoe from the River Trail launch point, approximately 2 mi downstream of the headsprings, or by kayak, canoe, or powerboat directly via the Ocklawaha River or from Ray Wayside Park (Ocala Boat Basin), a Marion County park and boat ramp located on the Silver River approximately 0.5 mi upstream of its confluence with the Ocklawaha River (Figure 4).

HYDROGEOLOGICAL SETTING

Physiography

Silver Springs and Silver River occur within the Anthony Hills subdivision of the Marion Hills subdistrict, both of which lie within the Ocala Uplift District (Brooks 1982). The Anthony Hills are characterized as an area of low hills where Miocene clays are thin or nonexistent, and sands and clayey sands of Upper Miocene rest directly on limestone. The residual sandy soils support a xeric vegetation of longleaf pine and turkey oak. Only a few hills exceed an elevation of 100 ft (Brooks 1982).

The Ocala Uplift District is a region of relict hills and karst features. Because of the xeric hills and the internal drainage, this is a principle recharge area of the Floridan aquifer (Brooks 1982). The springs primary recharge basin is located almost wholly within the Ocala Uplift District physiographic province, except for small portions along the eastern boundary that lie in the Central Lakes District (Brooks 1982).

Geologic Formations

The geologic formations of interest in the Silver Springs springshed in ascending order from deepest and oldest to shallowest and youngest are the Avon Park Formation, the Ocala Limestone, the Hawthorn Group, and surficial, unconsolidated post-Miocene (< 5 million years ago) deposits (Munch et al. 2006). The Avon Park Formation consists of alternating layers of hard dolomite and softer limestone that are fractured and cavernous. The Ocala Limestone overlays the Avon Park formation and an erosional unconformity separates the two formations. The Ocala Limestone consists of soft cream to white fossiliferous limestone. The Ocala Limestone is exposed at the surface over much of central Marion County and is at or near the land surface north, south, and west of Silver Springs. In the southwestern portion of Marion County, the Avon Park Formation occurs closer to the surface, due to erosion of the overlying Ocala Limestone (Munch et al. 2006).

The Hawthorn Group overlies the Ocala Limestone and consists of sand, silt, clay, and hard limestone and dolostone interbeds (Munch et al. 2006). The Hawthorn Group ranges in thickness from a few feet to about 100 ft in eastern Marion County. In central and western Marion County, most of the Hawthorn Group has been removed by erosion. Here it occurs on the tops of hills. East of the Ocklawaha River, the Hawthorn Group is present as a continuous layer; this results in a change in the landscape from rolling karst hills in the western part of the county to a flatter, more poorly drained landscape in the eastern part of the county. Surficial post-Miocene deposits overlie the Hawthorn Group. These deposits vary in thickness from zero to about 100 ft. In most of the Silver Springs springshed, the thickness of deposits above the Ocala Limestone is generally less than 50 ft (Munch et al. 2006).

Hydrogeology

The principal hydrogeologic unit in the springshed is the Upper Floridan aquifer (UFA). The UFA is approximately 300 ft thick in this region and occupies the Avon Park Formation and the Ocala Limestone where present (Munch et al. 2006). Both of these limestone units have a high matrix porosity and the presence of conduits. These structural features result in extraordinarily high transmissivity (i.e., a measure of the ease with which water can move through pore spaces or fractures) when compared to noncarbonate aquifers. UFA transmissivity ranges from 10,700 to 25,500,000 feet squared per day (ft^2/day), with an average value of 2,000,000 ft^2/day (Faulkner 1973). The high transmissivity values result in the rapid flow of water in the springshed.

Springshed Characteristics

Springshed Contributing Area

The contributing area (springshed) is defined as the land surface area that is a source of groundwater that contributes to the flow of the spring. It is generally defined on the basis of the direction of groundwater flow. The movement of groundwater within an aquifer can be affected by many variables, including groundwater levels driven by climate and the locations and quantities of water withdrawals and variation in spring pool elevations. Hence, springshed boundaries can vary over time. Munch et al. (2006) summarized previous studies conducted to delineate contributing areas to the Silver Springs springshed.

The Silver Springs primary contributing area includes approximately 500 square miles (mi^2), almost all of it lying within Marion County, with small portions extending into Alachua and Sumter counties (Figure 6). The delineated boundary is a representation of the area in which groundwater flows perpendicular to potentiometric elevations of equal but decreasing elevations toward Silver Springs. Because Silver Springs springshed delineation was based on simulations using a regional groundwater model with some limitations, they should be viewed as estimates.

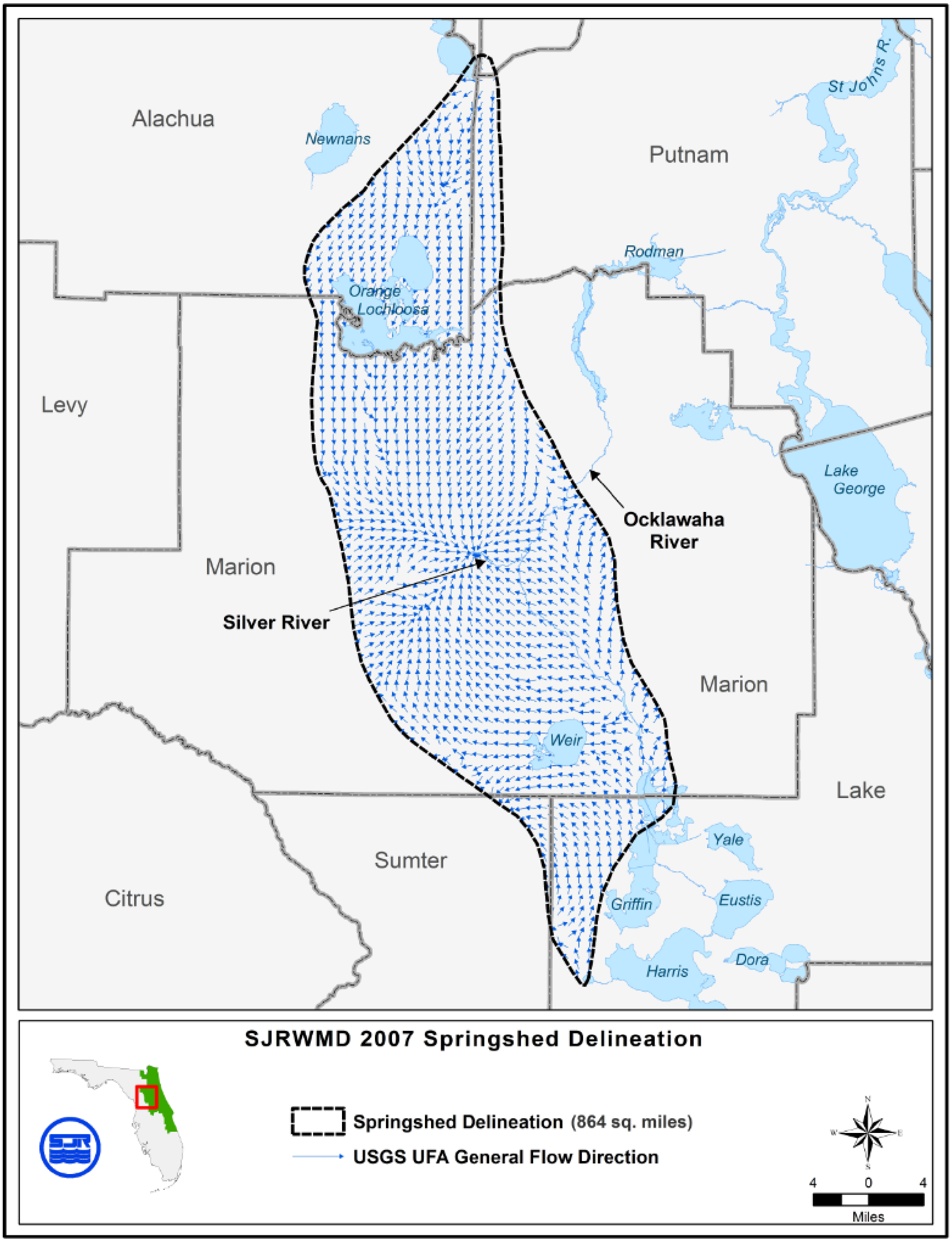


Figure 6. Primary contributing area of the Silver Springs Group

The flow of Silver Springs is supplied through a network of fractures and solution channels in the limestones and dolomites of the Floridan aquifer. Silver Springs flow is derived from the Floridan aquifer system. Groundwater flow to Silver Springs emanates from two areas of high potentiometric levels, one located in the north in the lakes region of Alachua, Bradford, Clay, and Putnam counties. The other area to the south is the potentiometric high centered around Polk County. Groundwater flows from these areas toward Silver Springs.

Annual groundwater recharge varies markedly within the springshed boundaries (Figure 7). Generally, lower recharge (0 to 12 in. per year) occurs in the northern and southeastern portions of the springshed. These areas typically have a confining unit overlaying the UFA, and the landscape is generally flat, open, and poorly drained. The western portion of the springshed is generally unconfined, and recharge ranges between 12 to 20 or more inches per year. The landscape is characterized by rolling karst hills that are well-drained (Boniol et al. 1993).

Silver Springs Group

Silver Springs consists of at least 30 different springs, with 69 vents (Butt and Aly 2008) in the bed or in coves at the edges of the upper 3,900 ft of the Silver River, collectively called the Silver Springs Group (Figures 4 and 8). The largest of the spring vents is Mammoth Springs (also called the Silver Main Spring), which has multiple vents in the main pool that discharge nearly half of the total flow of Silver River (Ferguson et al. 1947; Hutcheson et al. 1993). Mammoth Springs forms a pool about 250 ft in diameter at the head of Silver River. The pool is deepest in its eastern part near the main spring vent. From the vent opening, the floor of the pool slopes gradually upward to the south and southwest to a depth of about 5 ft, where the spring flows out over the lip of the pool, forming the Silver River. The largest of the vents, Mammoth East, is located approximately 100 ft east of the glass bottom boat loading platform. The vent is a horizontal, oval-shaped opening about 5 ft high and 135 ft wide beneath a limestone ledge. The depth of water measured over the vent opening is about 30 ft. The second, smaller vent, Mammoth West, is located in the northwestern part of the main pool near the boat loading platform. Approximately 45% of the Silver Springs flow is from Mammoth Springs, with added flow from smaller springs and boils downstream of the main pool (Munch et al. 2006).

Differences in water chemistry from 30 vents in the Silver Springs Group were previously documented (Phelps 2004; Munch et al. 2006; Knowles et al. 2010). However, similarities in vent water quality have also been noted. To better understand the chemistry and source of water discharging from these springs, Butt and Aly (2008) statistically analyzed and clustered water chemistry from the 30 vents into five subgroups. Knowles et al. (2010) analyzed one representative spring from each subgroup and concluded that water chemistry in downstream vents indicated more shallow flow paths than water at the headsprings, and that all of the springs contained a complex mixture of water from different groundwater flow paths.

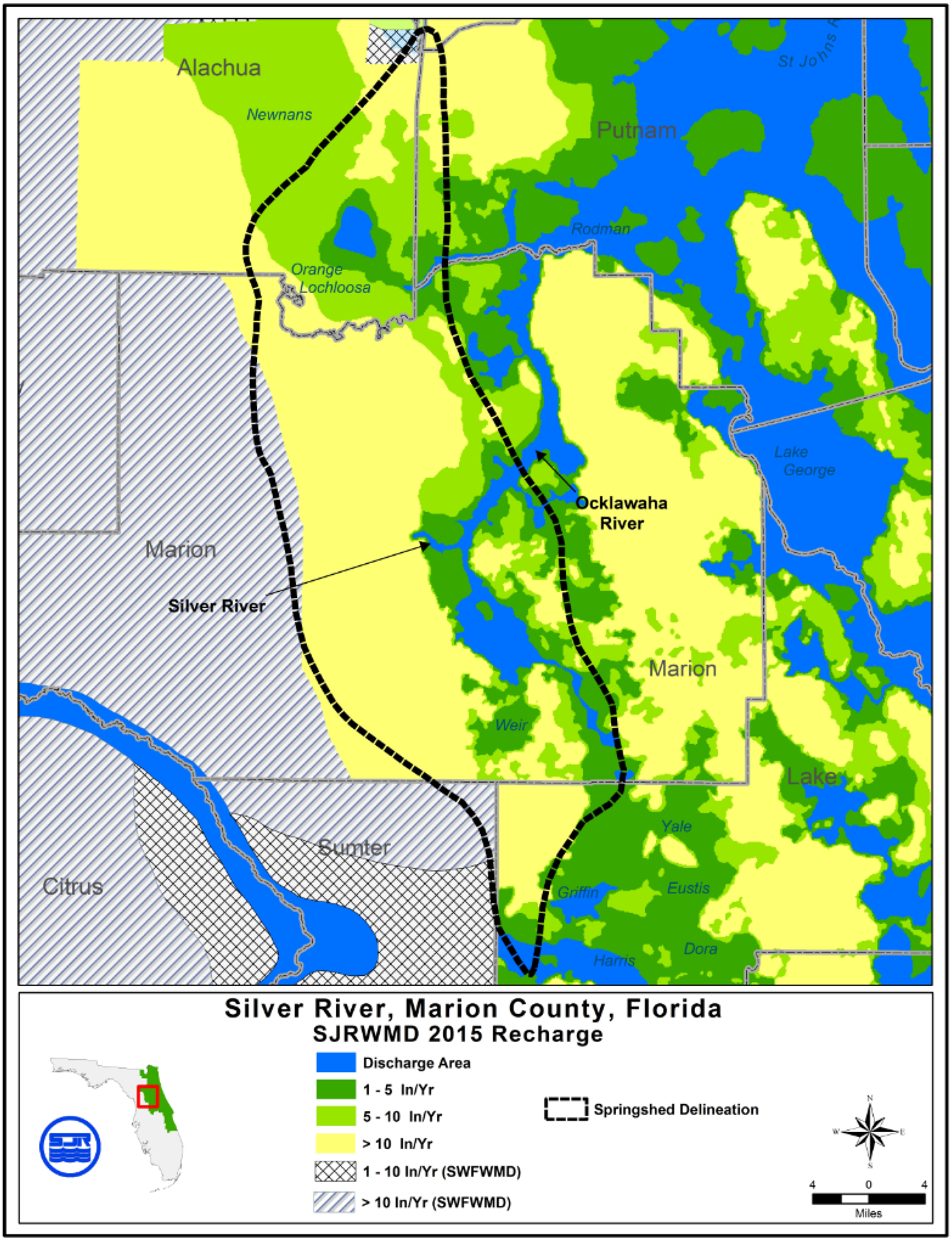


Figure 7. Annual recharge map of the Silver Springs springshed.

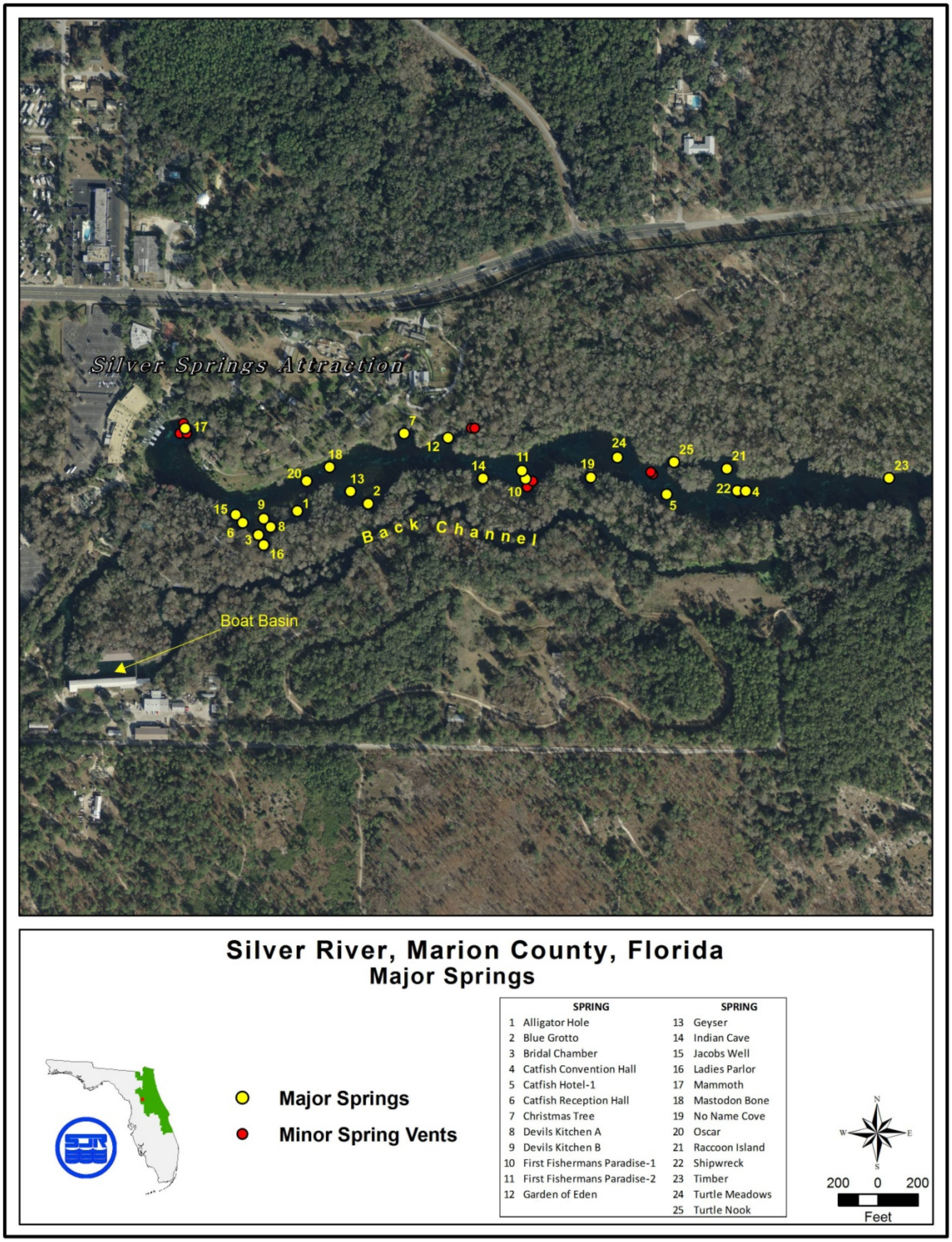


Figure 8. Springs of the Silver Springs Group

Age of Source Water

In May 2001, the age of water discharging from Silver Springs (Mammoth Springs) and selected springs within the Silver Springs Group was determined by measuring the concentration of tritium, delta carbon-13, and carbon-14 from the spring flow (Toth 2003). Mammoth Springs had a tritium concentration of 3.51 tritium units, which suggests that the water is less than 48 years old. USGS measured tritium and helium-3 in Mammoth Springs, Catfish Reception Hall, and Blue Grotto in January 2002 and found the tritium/helium-3 ages to be 27, 10, and 19 years, respectively (Phelps 2004). Mammoth Springs had a delta carbon-13 value of 10.0 parts per thousand and a carbon-14 concentration of 47% modern carbon, which results from the reaction of rainfall with calcite, dolomite, and sediment organic matter. The adjusted carbon-14 age is recent. Because of the karstic nature of the Floridan aquifer in the Marion County area and the relatively young age of the waters, the groundwater within the uppermost parts of the aquifer likely provides a large portion of the Silver Springs flow (Munch et al. 2006).

HYDROLOGY

Hydrologic Gaging Stations

The USGS monitors the Silver River and publishes gage height and flow data at the headspring (USGS Station 02239500, “Silver Springs near Ocala”), at a location 3900 feet downstream from the headspring (USGS Station 02239501, “Silver River near Ocala”), and at the confluence of Silver and Ocklawaha Rivers (USGS Station 02239510, “Silver River near Conner”). This latter station was operated from November 2003 to September 2010 but since discontinued. Further hydrologic data is provided by gages at four MFLs transects (T3, T5, T7, and T9) and one additional cross-section (T1). These gages have been monitored by SJRWMD from 2007 to the present and locations are shown in Figure 4.

The main location for MFLs development is at the USGS 02239501 gaging station. Prior to October 2002, the historical daily flows were computed with rating curves relating potentiometric head measurements at the Sharps Ferry Well (USGS 291115081592501) near the springs and sporadic flow measurement at various locations along the Silver River downstream of the USGS 02239501 station. Because of the collapse of the Sharps Ferry Well in October 2002, the rating curves now relate differences between potentiometric head measurements at the CE-76 Well (USGS 291100082010003, also known as M-0028) near the springs and the spring pool elevation, and flow is measured at a more consistent location near the USGS 02239501 gaging station.

Flow and Water Level Data

The USGS archives the full data record of field measurements at two Silver Springs/Silver River stations: USGS 02239500, Silver Springs near Ocala gaging station, located near the spring pool, and USGS 02239501, Silver River near Ocala gaging station, located 3900 feet downstream of the spring pool (Figure 4).

Water levels have been collected by the USGS at the 02239500 gaging station, near the Silver Springs pool, from February 20, 1947, to the present and at the 02239501 gaging station from February 7, 1967, to June 30, 1972, and November 21, 2003, to the present (Figure 11 and 12). A USGS station near the confluence with the Ocklawaha River (02239510) was established on November 25, 2003, and ran concurrently with the USGS 02239501 station until it was discontinued on September 11, 2010.

Flow field measurements archived under the USGS 02239501 station were all made since 2003, while those at the USGS 02239500 station are from various spring run locations (from 300 ft to greater than 19,000 ft [3.6 mi] downstream of the spring pool) during the POR (1932 to 2010). Data from the two stations must be combined to obtain the full POR of field flow measurements for Silver River.

SJRWMD contracted with Edward German (formerly USGS hydrologist) to clarify the dynamics between upstream and downstream flow, and to create a dataset that could be used as the basis for MFLs analyses.

Daily mean flow estimates are available prior to 1947, but the methods used to generate these earlier flow estimates were not the same as after 1947. Data availability affected the methods that could be used to compute daily flow estimates before 1947 (German 2010), as follows:

Prior to February 1947, flow estimates are based only on water level at the reference well because no data are available for spring pool water level.

Prior to July 1947, water level observations at the reference well were made on a weekly rather than a daily basis. Daily well levels used to determine flow estimates were, therefore, based on interpolation between these weekly observations.

German (2010) determined that measured flow at the USGS 02239501 gaging station was an average of 10% lower than measured flow downstream near the Silver River and Ocklawaha River confluence (USGS 02239510 gage), based on 23 pairs of concurrent USGS flow measurements in 2004 and 2005. Therefore, German (2010) recommended development of a spatially homogeneous flow dataset for MFLs determination, adjusted to reflect conditions at the USGS 02239501 gaging station, to serve as a more representative long-term flow POR at that location. The adjusted dataset of field flow measurements at the USGS 02239501 gaging station generally has lower values than the published USGS record (Table 1), as is expected considering the location farther upstream.

The USGS-adjusted flow POR hydrograph and flow duration curve (1946 to 2014) at the USGS 02239501 gaging station are displayed in Figures 9 and 10, respectively, and the descriptive statistics are summarized in Table 2. The flow records show a decreasing trend in

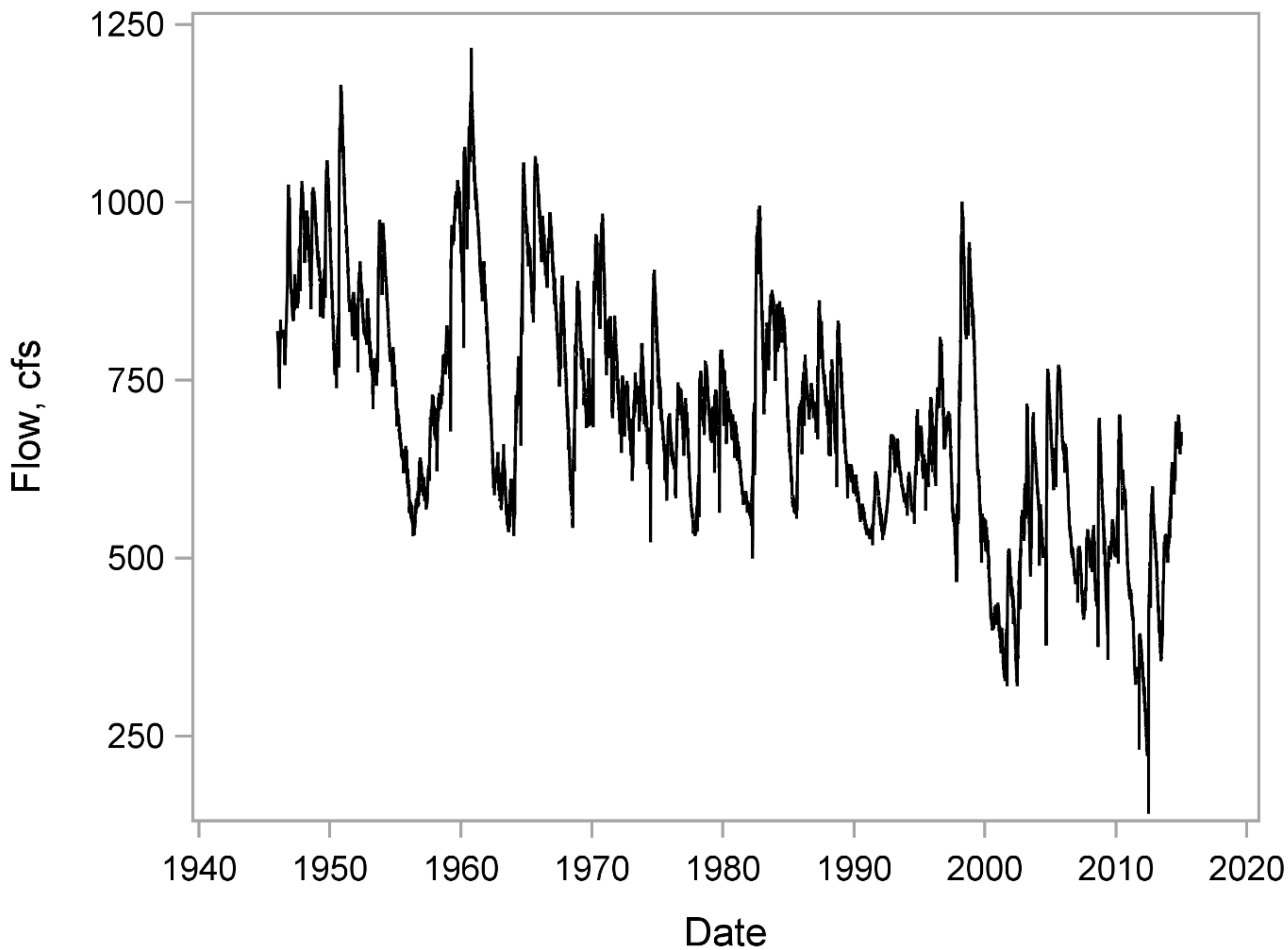


Figure 9. Flow hydrograph for the spatially adjusted period of record for the Silver River, USGS 02239501. Source: USGS

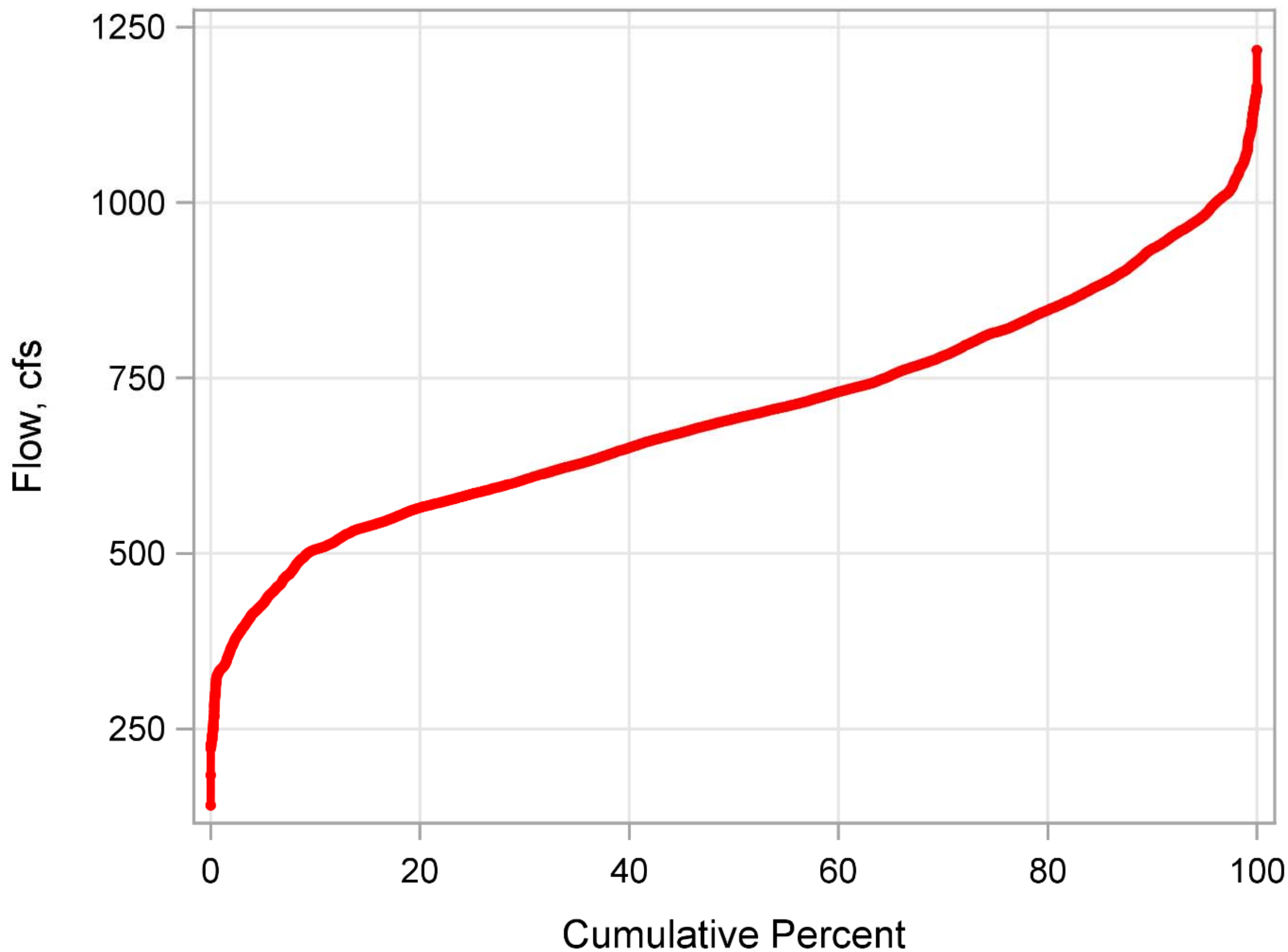


Figure 10. Flow duration curve for the spatially adjusted period of record (1947 to 2014) for the Silver River, USGS 02239501. Source: USGS

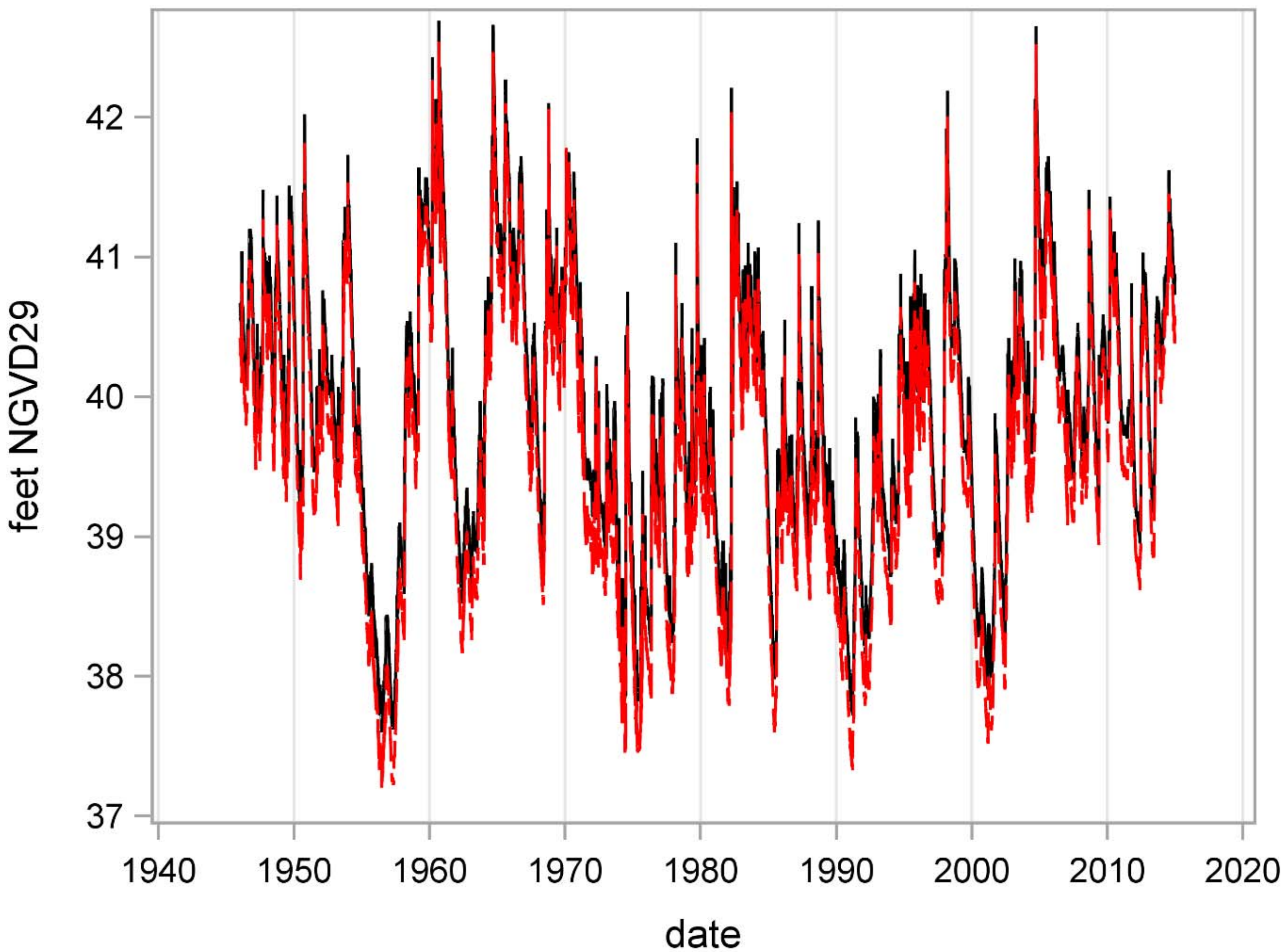


Figure 11. Stage hydrograph (1946 to 2014) for the USGS 02239500 located at the spring pool (black line), and USGS 02239501, located 3,900 ft downstream of the Silver Springs pool (red line). Source: USGS

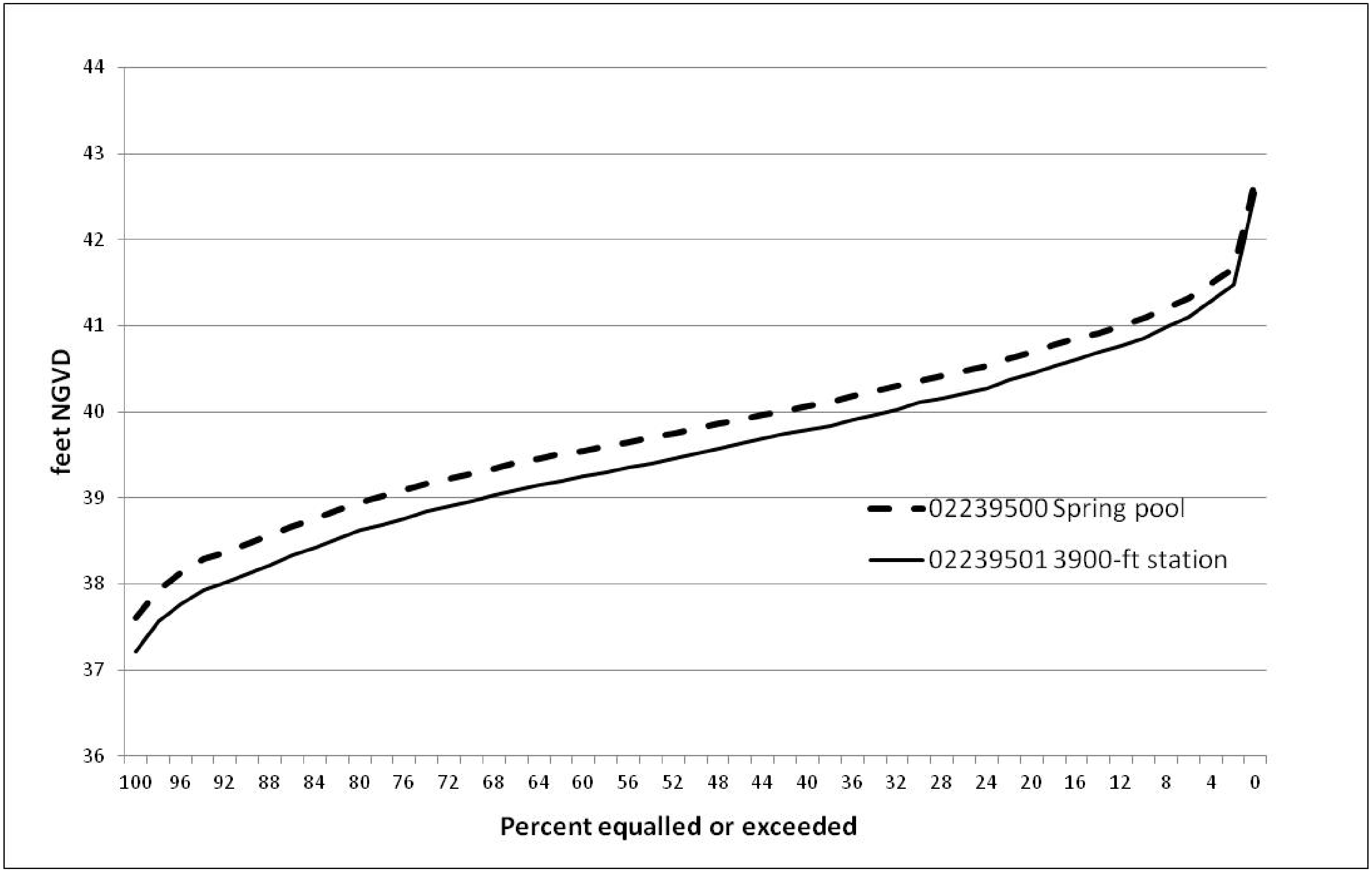


Figure 12. Comparison of stage duration curves (1946 to 2014) for the USGS 02239500, gaging station, located at the spring pool, and USGS 02239501 gaging station, located 3,900 ft downstream of the Silver Springs pool

Table 1. Comparison of flow measurements for USGS 02239501 gaging station with adjusted values. Source: USGS

Silver River Field Measurements (cfs)	Period	Min	Mean	Median	Max	Count
Published USGS 02239501 record	1947–2003	250	772	768	1,290	271
Adjusted to 02239501 gaging station (USGS-adjusted 2010 data)	1947–2003	226	722	708	1,196	271

Table 2. Summary statistics for daily mean flow for the USGS published record and for the spatially adjusted dataset at the USGS 02239501. Source: USGS

Period and Dataset	Flow (cfs)				Count
	Minimum	Mean	Median	Maximum	
1947–2010					
MFLs dataset adjusted to 02239501 gaging station*	141	700	693	1,217	25202
Published USGS 02239501	141	735	742	1,290	25202
Difference	0	-35	-49	-73	0

Note: *Prior to 2003, field measurements in this dataset were spatially adjusted to the USGS 02239501 gaging location. After 2003, USGS 02239501 was the actual location of field measurements.

spring flow, especially since the 1960s. Table 3 shows includes water level summary statistics for the USGS 02239500 and 02239501 gages.

Overall, the adjusted dataset of daily mean flows for the 02239501 gage location indicates lower flows than the published USGS record, with a difference of 44 cfs between the 1947 to 2003 mean flows for the two datasets. This difference is consistent with the 02239501 gage location farther upstream than measurement locations used by USGS prior to 2003.

Table 3. Summary statistics for water level at the USGS 02239500 gaging station, located at the spring pool, and USGS 02239501 gaging station, located 3,900 ft downstream of the Silver Springs pool

Station	Period of Record
	Elevation (ft NGVD)
Silver Springs Pool (USGS 02239500)	**1946 to 2014**
Minimum	37.61
Mean	39.81
Median	39.80
Maximum	42.69

Station	Period of Record
	Elevation (ft NGVD)
Silver River 3,900-ft Station (USGS 02239501)	**1946 to 2014**
Minimum	37.21
Mean	39.52
Median	39.52
Maximum	42.54

Analysis of Spring Flow Declines

Silver Springs and Silver River have experienced a large decline in flow (more than 30%) since the 1930s. A 10-year moving average flow was used to estimate the decline in spring flow since 1930s because of the need to smooth the effect of the short-term climatic cycles such as El-Nino Southern Oscillations (Figure 13).

Silver Springs has experienced a flow decline of approximately 32% since the 1930s. This is based on a comparison of the mean flow (775 cfs) for the period from 1930-1939 to the mean flow (525 cfs) for the period 2005 – 2015. Based on analyses presented below the decline in flow at Silver Springs and Silver River is not primarily due to groundwater withdrawal. Evidence suggests that the decline is most likely caused by:

- Flow suppression due to increased vegetation in the lower Silver River, causing an approximate 15.5% decline in flows;
- A 112-inch rainfall deficit from the 1970s to 2000, and average rainfall since then, causing an approximate 13.3% decline in flows; and
- Groundwater withdrawals, causing an approximate 3.5% decline in flows.

Flow suppression

Analysis of hydrologic data indicates that there has been a change in the stage-flow relationship at Silver River, which started in approximately 2000 (Figure 14). Prior to 2000, a given flow typically resulted in markedly lower stages, relative to the post-2000 period (Figure 15). To better understand the causes of change in stage-flow relationship, statistical and modeling analysis were performed.

The relationship between water elevation at M-0028 (also known as CE-76), a long-term groundwater elevation monitoring station, and Silver Springs flow were compared between pre- and post-2000 periods (Figure 16). As shown in Figure 16, the spring flows deviated from the groundwater level after 2000. Flow declined in post-2000 for the same water level in the groundwater well (M-0028) when compared to pre-2000. It should be noted that regional groundwater levels reflect primarily the effect of climate and groundwater

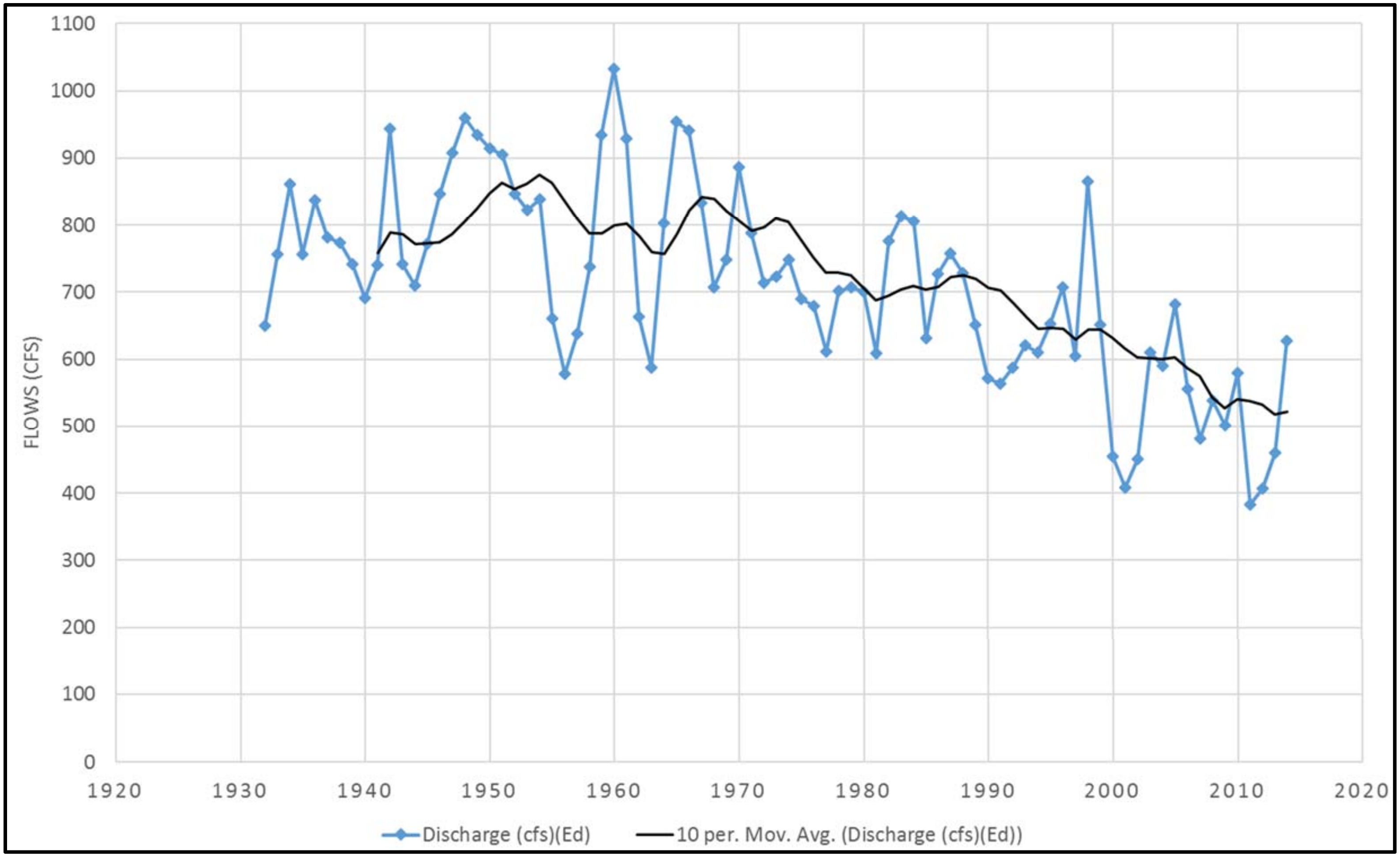


Figure 13. Silver River flow hydrograph for the spatially adjusted period of record for USGS 02239501

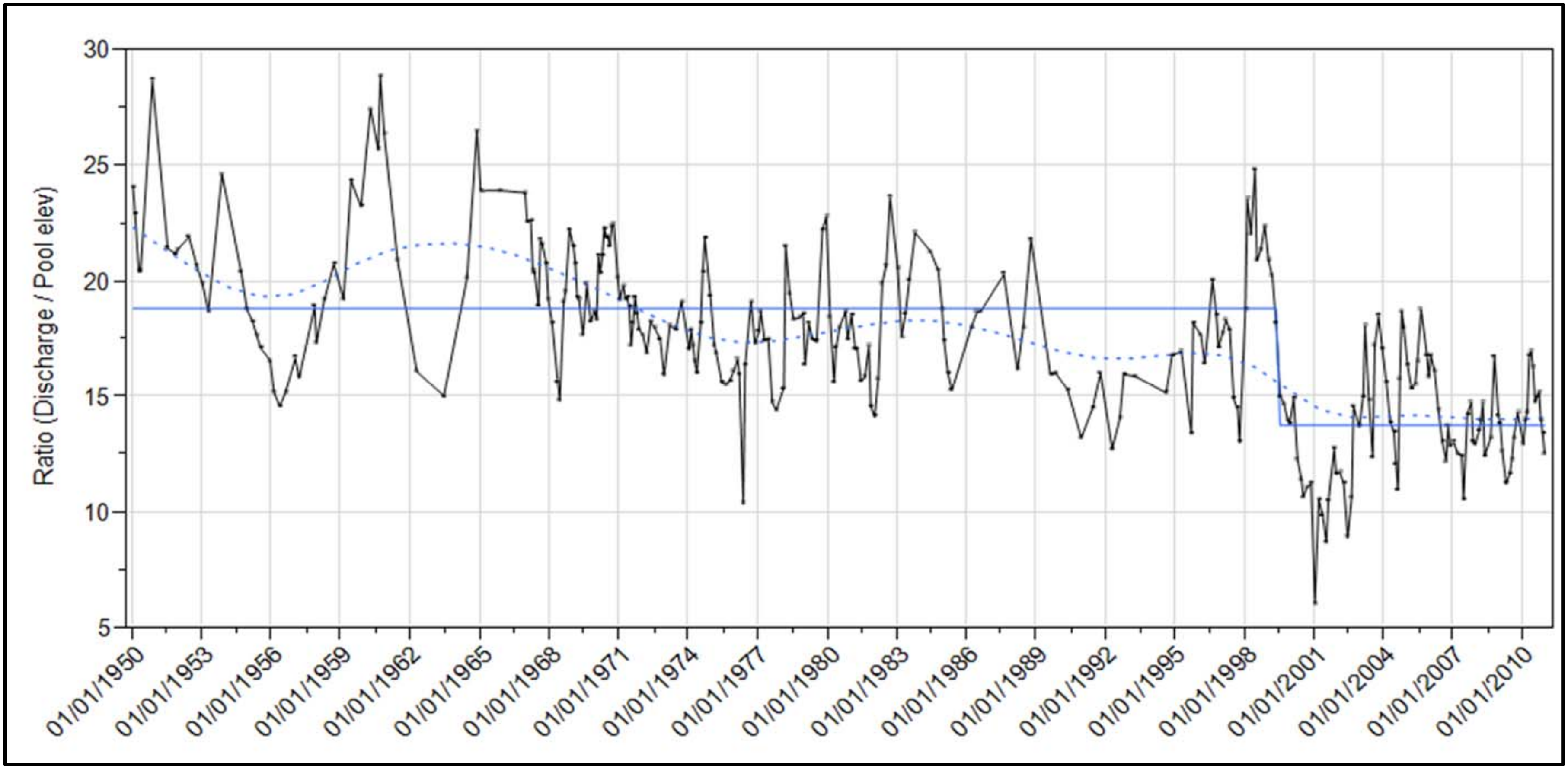


Figure 14. Ratio (Flow / Pool Elevation) Graph for Silver Springs (USGS gage 02239500)

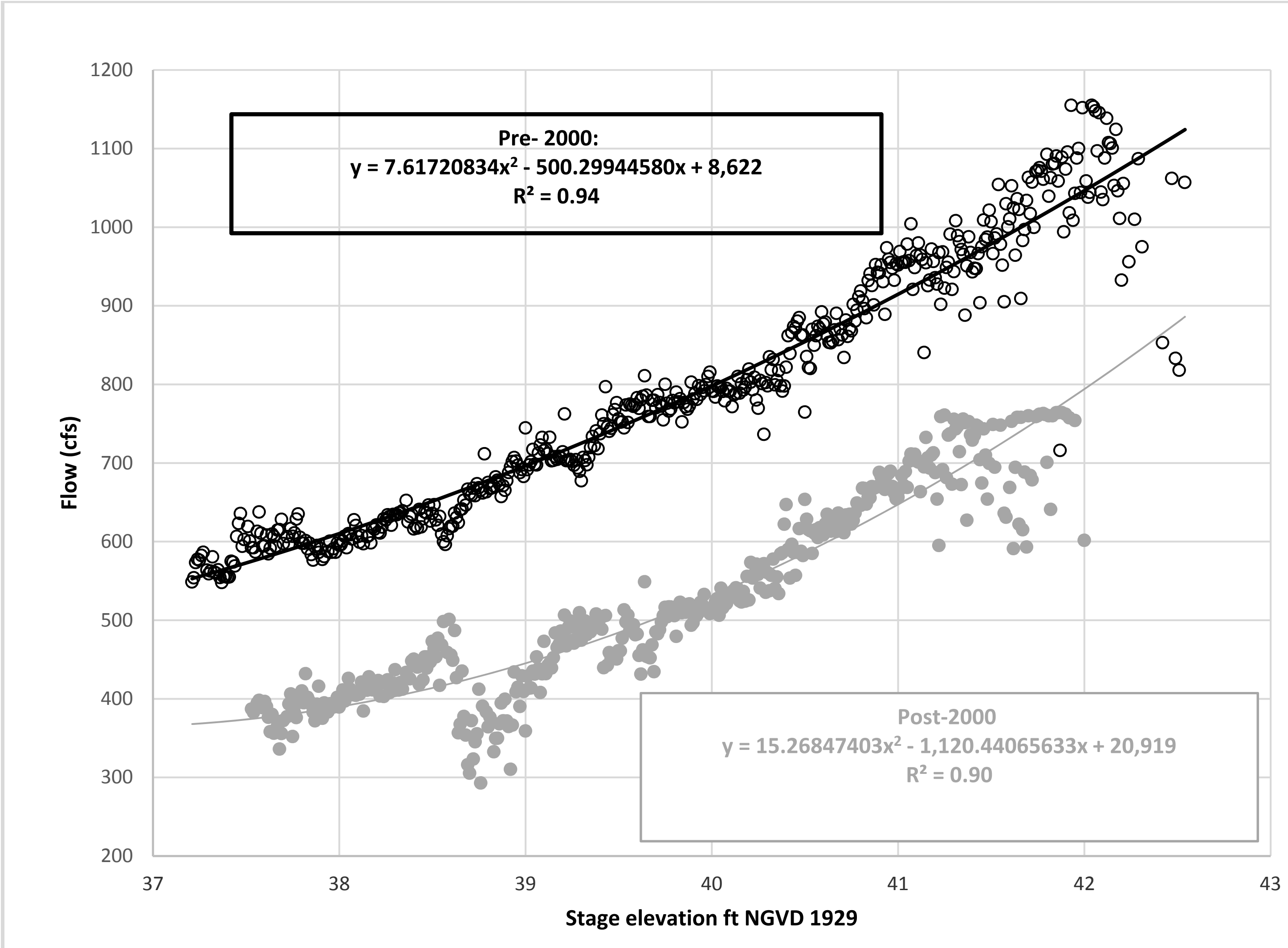


Figure 15. Pre-2000 (black) and post-2000 (grey) stage-flow relationship for Silver River at USGS gage 02239501

Figure 16. Silver Springs flow and water elevation in M-0028 well, illustrating the downward shift of flow in the post-2000 period, while water elevations in UFA well M-0028 increased post-2000.

withdrawals. Any deviation of spring flows from groundwater levels should indicate that there are factors other than climate and groundwater withdrawals affecting the spring flows. Based on the statistical analysis described in this report, the primary cause of this deviation (downward shift) is the increase in spring pool elevation in the post-2000 period.

The statistical test analysis of covariance (ANCOVA) was used to examine the shift in stage-flow relationship while controlling for the effect of the covariate, groundwater elevation at the M-0028 well. To evaluate the difference between pre- and post-2000 changes, the covariate effect on flow was controlled using ANCOVA. The statistical formulation of the analysis is as follows:

> H_o (null hypothesis): at a given elevation in the groundwater well spring flow in the pre-2000 period is same as the post-2000 period ($\mu_1 = \mu_2$) at 95% confidence level.
>
> H_a (alternative hypothesis): at a given elevation in the groundwater well spring flow in the pre-2000 period is significantly different than that in the post-2000 period ($\mu_1 \neq \mu_2$) at 95% confidence level.

Rejecting the H_o means at a given elevation in the groundwater well, spring flow in the pre-2000 period is significantly different than that in the post-2000 period and the difference between μ_1 and μ_2 would be representing the approximate amount of flow reduction due to increase in spring pool elevation. The data for the pre-2000 is from 1985 through 1999 and for the post-2000 is from 2000 through 2015. Because only 15 years of data was available for the post-2000 period, only 15 years of data was used for the pre-2000 period as well to avoid introducing any potential bias due to using different length of periods.

Table 4 and Figure 17 show that the flow is significantly different between the two periods, and at the mean flow is about 531 cfs and 652 cfs respectively for the post- and pre-2000 periods. As a result, an average flow decline of about 121 cfs decline was estimated, which is likely due to the increase in pool elevation. Evidence presented in this report suggests that the reason for this increase in pool elevation is likely due to a vegetative damming effect in the lower Silver River.

Table 4. ANCOVA result of flow = water level + pre-2000 and post-2000 treatment model.

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	3	3670567.854	1223522.618	650.22	<.0001
Error	258	485477.805	1881.697		
Corrected Total	261	4156045.659			
Source	DF	Type III SS	Mean Square	F Value	Pr > F
period	1	13335.105	13335.105	7.09	0.0083
mon_avg_ce76	1	2001640.203	2001640.203	1063.74	<.0001

Least Squares Means Adjustment for Multiple Comparisons: Tukey-Kramer		
	avg_cfs	H0:LSMean1= LSMean2
period	LSMEAN	Pr > |t|
Post-2000	530.609218	<.0001
Pre-2000	652.156614	

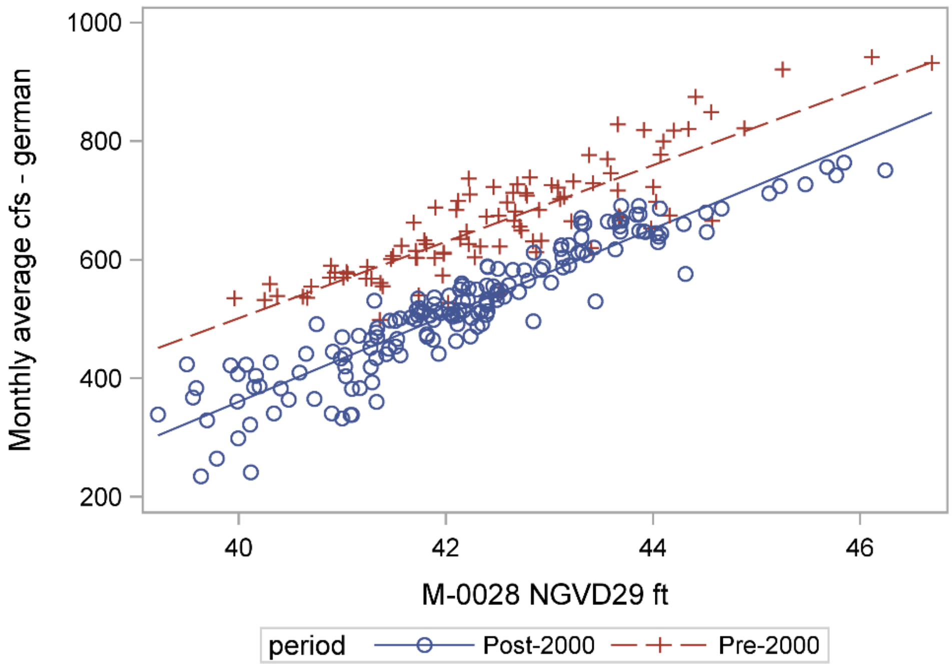


Figure 17. Silver Springs flow and M-0028 elevation relationship for pre- and post-2000 periods.

<u>Potential cause of flow suppression at Silver Springs</u>

A working hypothesis for the cause of the change in the Silver River stage-flow relationship is a change in channel morphology and roughness due to an increase in SAV in the lower half of the river. As described in this report, evidence suggests that an increase in native SAV (*Sagittaria* and *Vallisneria*) and invasive exotic SAV (*Hydrilla*) is likely creating a damming effect in the lower portion of Silver River, and the Ocklawaha River near Conner, and causing a corresponding suppression of flow at Silver Springs.

While studies clearly demonstrate that SAV within Silver Springs and the upper 0.75 miles of Silver River has declined significantly since the 1950s (Odum 1957, Knight 1980, Munch et al. 2006), evidence suggest that the reverse has occurred within the lower portions of the 4.5-mile-long river. The first line of evidence is based on a comparison of past and present observations of the lower river. Odum (1957) and Whitford (1956) both described a distinct absence of SAV within the lower portion of the Silver River.

Odum (1957) described the lower section of the Silver River, below the upper 0.75-mile study reach, as follows: *"Except for its thick bed of rich muck Silver River would be a rushing canal through a pipe of limestone rock. Further downstream below the study area* [below the upper 0.75 miles] *it is of this nature."*

Similarly, Whitford (1956) noted the following: *"After the first mile Silver Springs run becomes narrow and the banks heavily wooded. It also receives some brown water down run. Consequently about 2 ½ miles from the boil flowering plants largely disappear probably due to reduced light…The deeper channel has relatively little plant life."*

In stark contrast to these early descriptions, preliminary observations and data collected by SJRWMD and the University of Florida (UF), as part of the Collaborative Research Initiative on Sustainability and Protection of Springs (CRISPS), suggests that approximately 80% of the lower river is now covered with mats of SAV, with dense mats close to the confluence of the Ocklawaha River. Coverage of the lower river by SAV is so dense that current sonar mapping efforts by SJRWMD and UF are often impeded by benthic vegetation. Preliminary CRISPS vegetation monitoring also indicates that *Hydrilla* is encroaching throughout the Silver River and much of the Ocklawaha River near the confluence, up to Moss Bluff. Based on these preliminary findings, and many years of observation by SJRWMD field staff, it is clear that the lower portion of the Silver River is now much more highly vegetated than when Odum and Whitford described it.

Hydraulic and hydrodynamic modeling efforts indicate that increased channel roughness (most likely resulted from increased SAV biomass/biovolume) is the probable cause of the observed change in stage-flow relationship, and that the mechanism for flow reduction is spring flow suppression. An Environmental Fluid Dynamics Code (EFDC) model, that accounts for vegetative drag and turbulence, was successfully implemented and tested for Silver River (Kaplan and Sucsy 2016). Preliminary results of this three-dimensional hydrodynamic model suggest that the post-2000 shift in stage-flow is likely a result of an alteration to vegetation within the riverbed.

In addition to expansion of native SAV within the lower portion of Silver River, model results also suggest that expansion of *Hydrilla* in the lower Silver River and Ocklawaha River near Conner, is a possible secondary mechanism for increased channel roughness. A Hydrologic Engineering Centers River Analysis System (HEC-RAS) model was also developed to compare the effects of changing channel roughness on in-channel flow and velocity. Resulting channel roughness coefficients, necessary to simulate observed changes in pre- and post-2000 flows and velocities, suggest that increased roughness is a probable cause of increased stages and the resultant decreased flows and velocities for the post-2000 period. As previously stated, the most likely cause of this increased roughness is the observed abundant SAV in the lower river and Ocklawaha River near Conner.

Observations of *Hydrilla* dynamics also provide support for the link between increasing SAV and flow suppression. In 2011 and 2012 SJRWMD staff observed large mats of *Hydrilla* on the Ocklawaha River (near the Silver River confluence) following prolonged periods of drought. After very high rainfall events, increased flow in the Ocklawaha River scoured out the *Hydrilla* and caused a shift in the stage-flow relationship (i.e., stage dropped and flow increased).

Figure 18 shows stage for the Ocklawaha River at Conner (red line; just downstream of confluence with the Silver River) increasing over time due in part to *Hydrilla* growth, and then peaking after a large storm event. This storm event removed the *Hydrilla* (observed by field staff), lowered the stage in the Ocklawaha, reducing the backwater effect on the Silver River, and was associated with increasing flow in the Silver River (blue line). This is the type of shift in stage-flow anticipated from Silver Springs when SAV in the lower river is reduced due to scour or shading. Also evident from this graph is the likely flow suppression effect of increased Ocklawaha stage on Silver River flow. Increased SAV damming is thought to cause the same effect.

As discussed, one probable explanation for the change in the Silver River stage-flow relationship is a change in channel morphology and roughness due to an increase in SAV which may be creating a damming effect in the river and causing suppression of flow at Silver Springs. The following analysis of wells near Silver Springs supports the hypothesis that recent flow reductions at Silver Springs and Silver River may be due in part to increased roughness causing groundwater “mounding” or flow suppression.

An analysis of groundwater wells in the vicinity of the Silver Springs pool also indicates that a phenomenon known as groundwater “mounding” is occurring at Silver Springs and may be evidence of flow suppression due to increased roughness. Figure 19 shows the location of the groundwater wells used in the analysis. The average water level was decreased in all wells between pre- and post-2000 except at the spring pool and a nearby well (Figures 20 and 21).

As water levels drop within the springshed, represented by well elevation declines, it is expected that the water level at the spring pool would also drop. However, the water level has increased at the spring pool and a nearby well, which is an indication of mounding (Figure 22). A two-dimensional map of spring pool and well levels in the vicinity of Silver Springs also shows that the water level at the spring pool has increased by 0.24 ft in post 2000 compared to pre-2000 level (Figure 23). This is further evidence of a mounding effect that is dissipating with distance from the spring pool. These analyses strongly suggest groundwater mounding and flow suppression. Taken together with evidence for an increase in SAV, a likely cause of this suppression and mounding is due to SAV growth in the lower Silver River and Ocklawaha River.

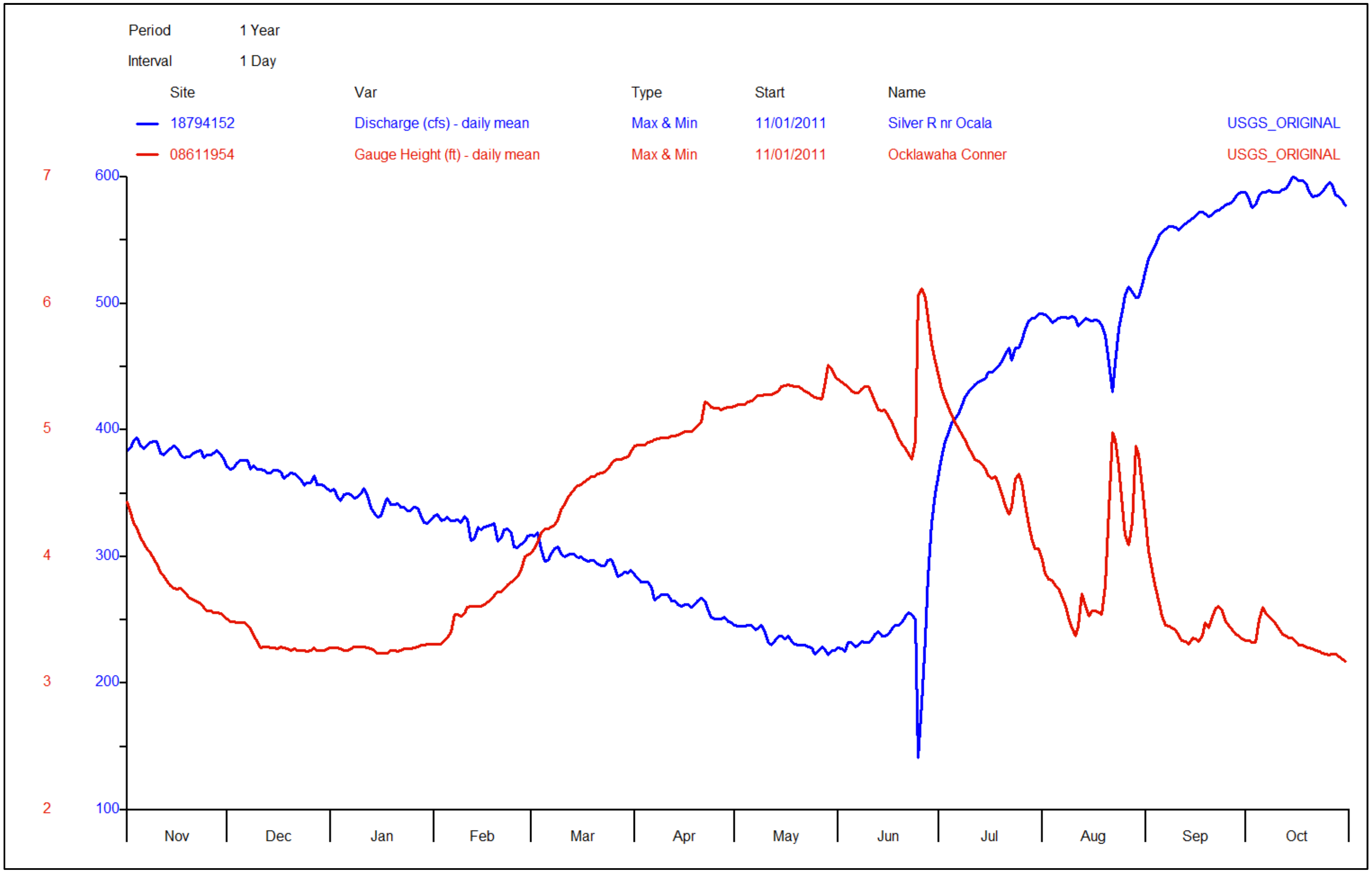


Figure 18. Ocklawaha River stage (red line) and Silver River flow (blue line) before and after tropical storm (note peak stage) that occurred in June 2012.

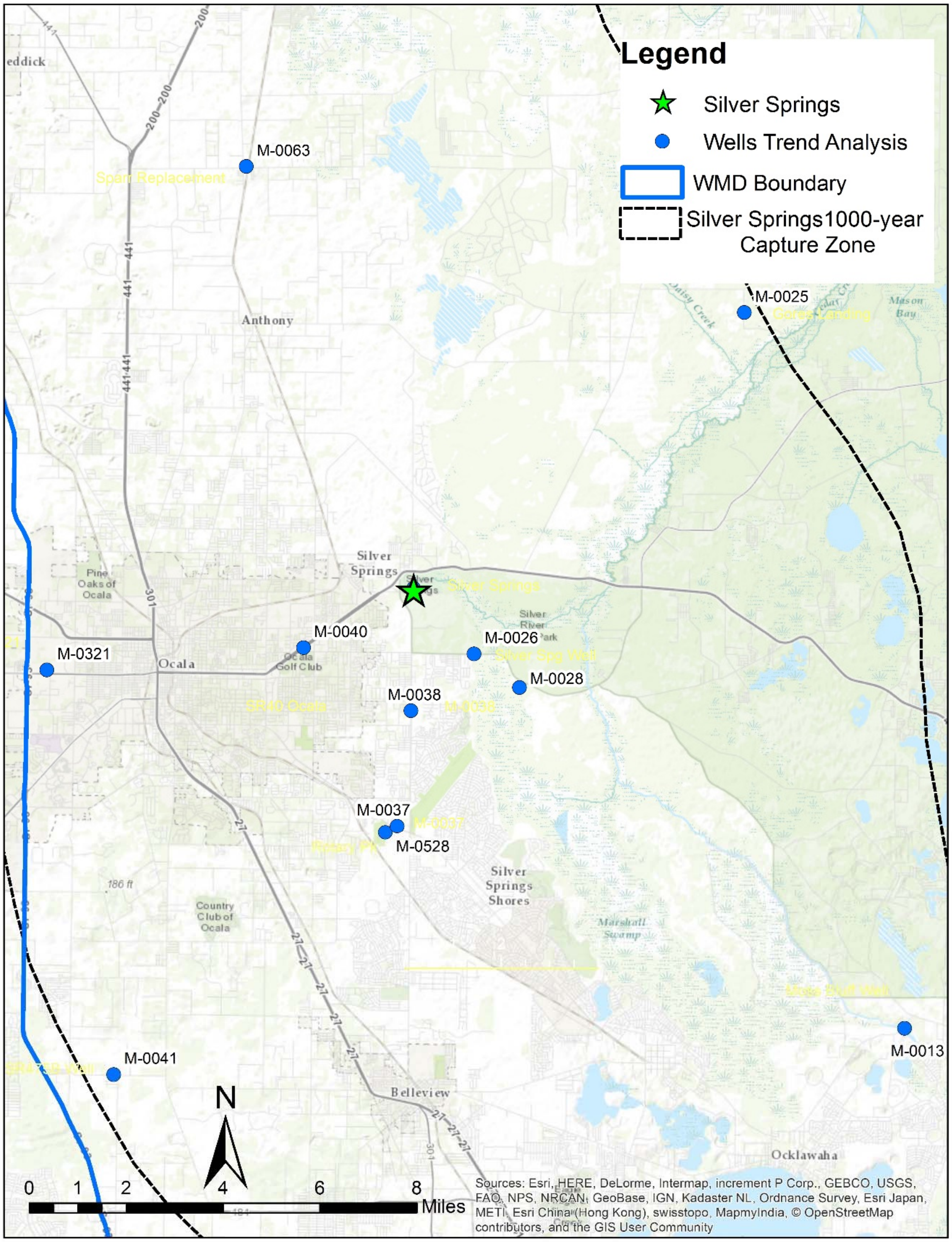


Figure 19. Water level wells within the Silver Spring springshed

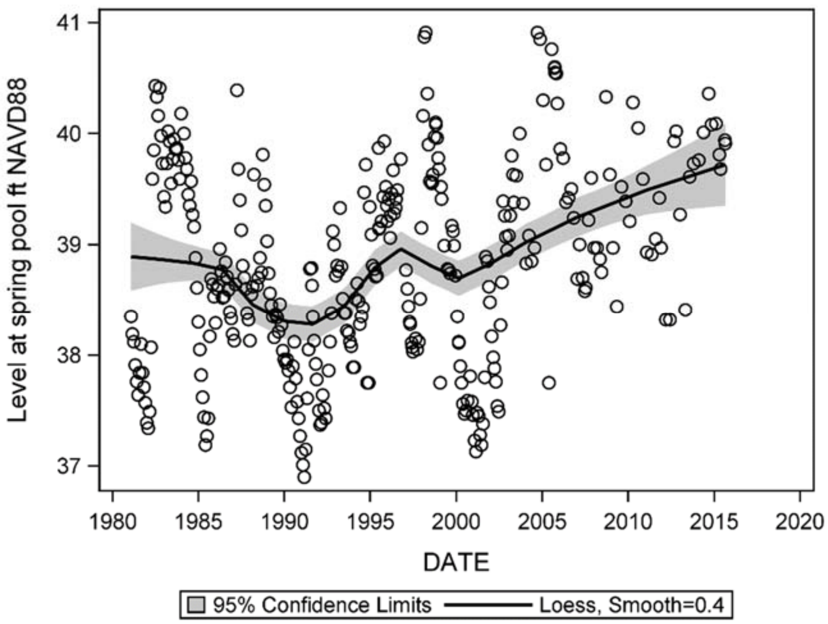
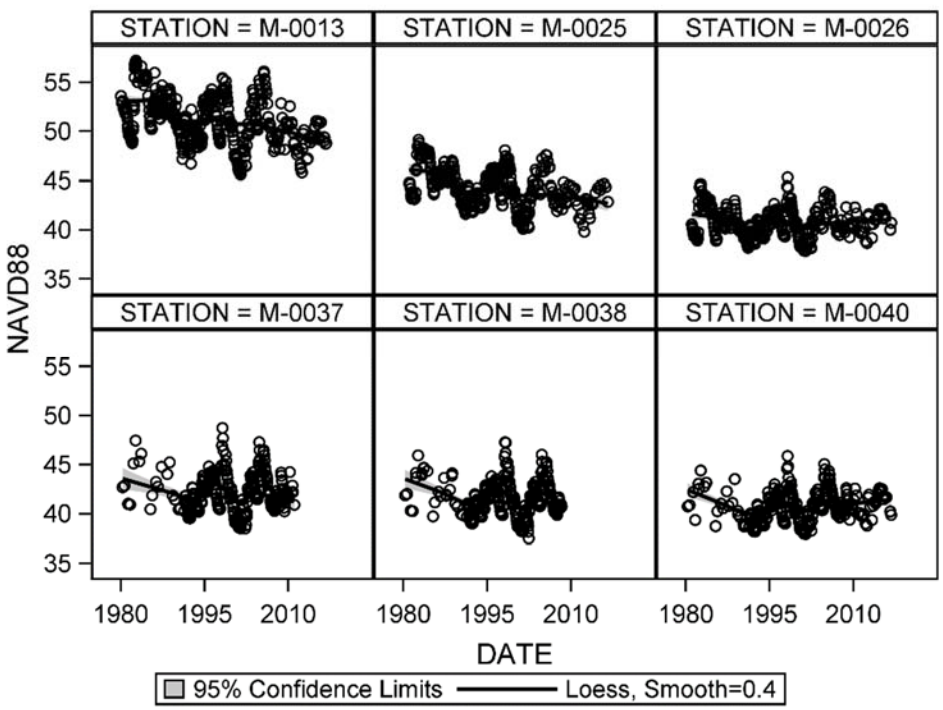


Figure 20. Water elevation at Silver Spring pool 1980–2015



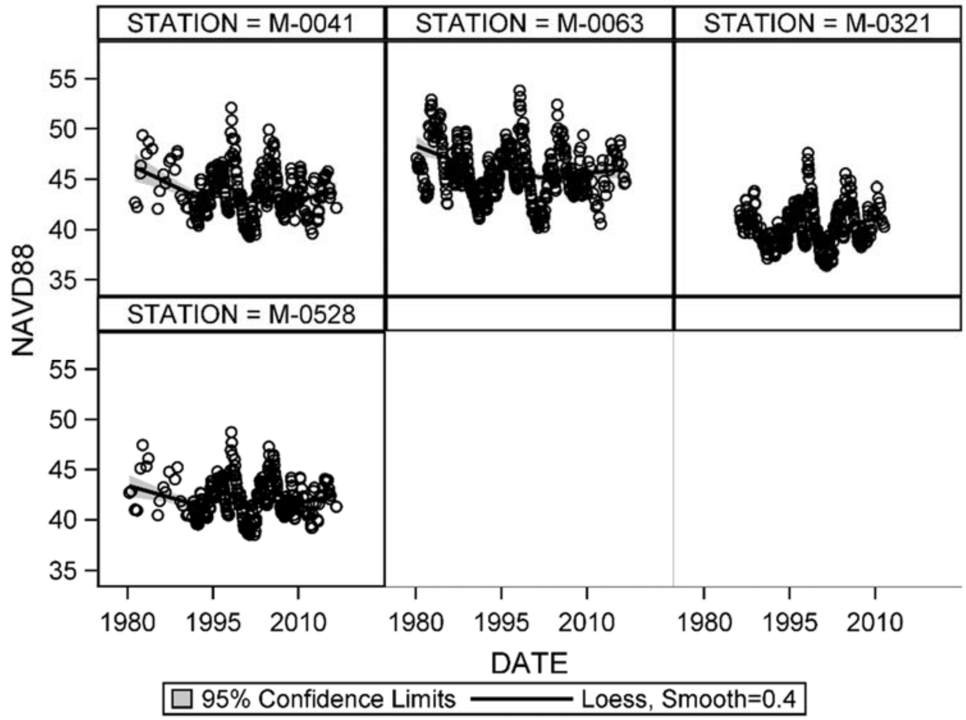


Figure 21. Water elevation at 10 wells within the Silver Spring springshed 1980–2015

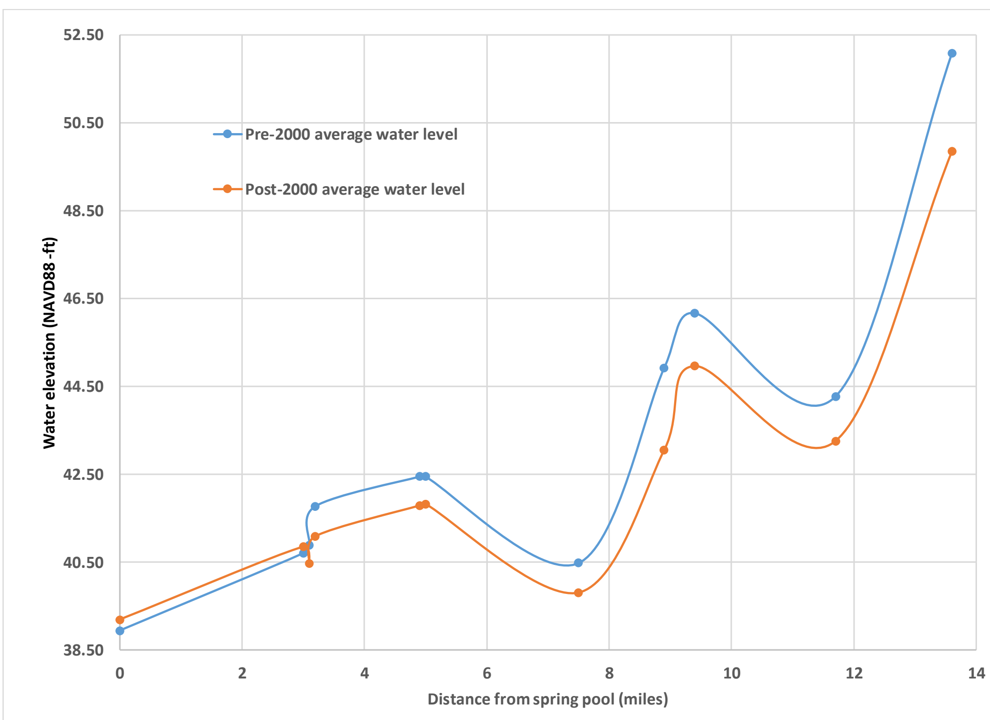


Figure 22. Average water elevations at Silver Spring pool and in 10 wells with various distances from the spring pool during pre- and post-2000 periods

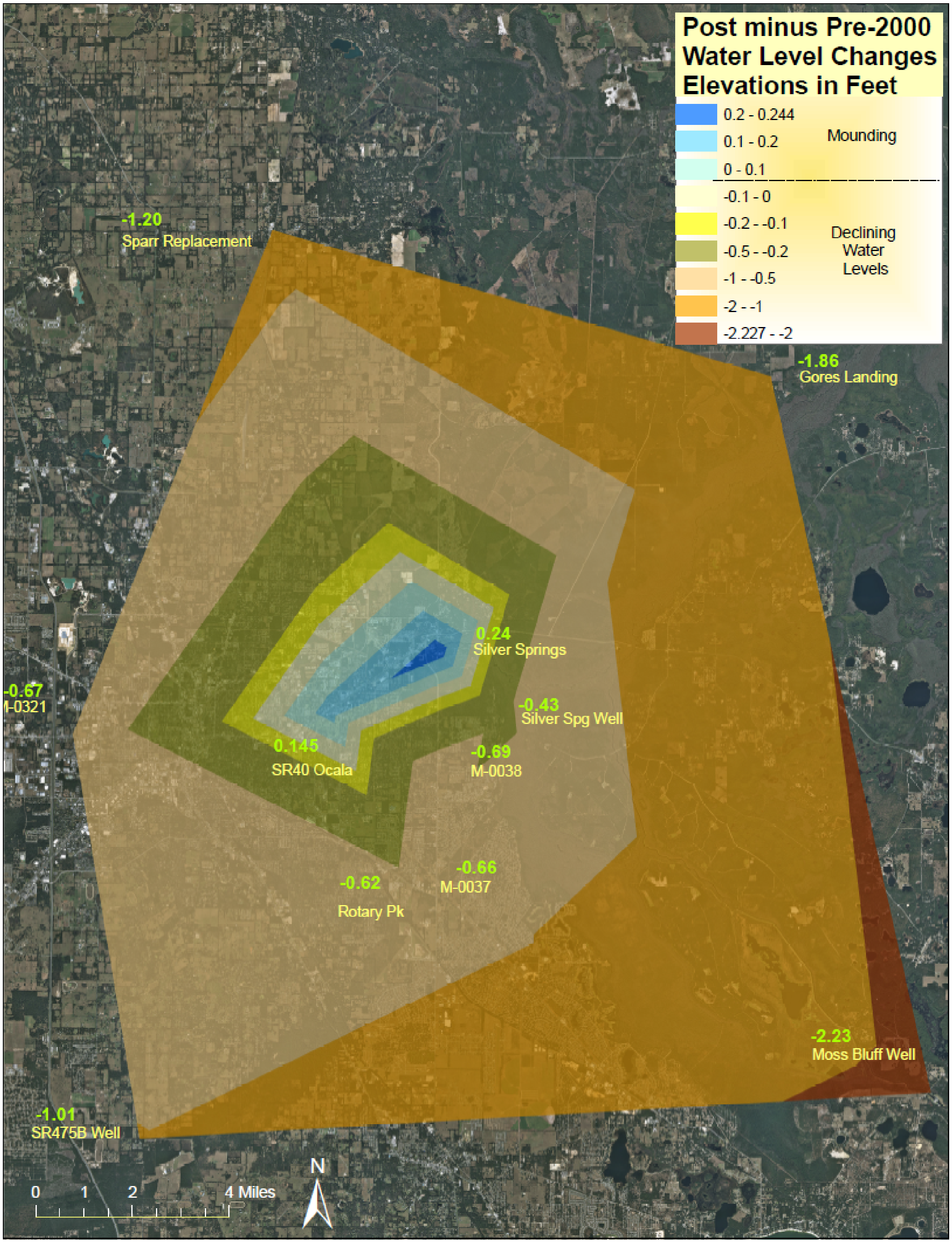


Figure 23. Water elevation changes between pre- and post-2000 periods in wells and at the spring pool

Rainfall Deficit

The Standardized Precipitation Index (SPI) is a widely used index to characterize meteorological drought on a range of timescales. On short timescales, the SPI is closely related to soil moisture, while at longer timescales, the SPI can be related to groundwater and reservoir storage (the National Center for Atmospheric Research). Figure 24 shows the SPI graph developed using Ocala rainfall. As shown in the figure, several severe dry periods were observed in the post-1970 period, when the spring flow declined significantly.

Silver Springs is located within an area of thick sand deposits, high transmissivity and high recharge rates. A significant reduction in recharge due to cumulative (i.e., back to back) years of below mean rainfall is one of the primary drivers of lower spring flows. The correspondence of deficit (below average) rainfall and declining flow at Silver Springs were examined by calculating the cumulative departure from average rainfall (i.e., deficits and surpluses) over time. Figure 25 shows the cumulative departure from average rainfall from 1914 to 2014 based on rainfall data from the NOAA Ocala gage. From the mid-1940s to 1970, there was a cumulative rainfall surplus of approximately 98 inches. From 1970 to 2000, there has been a rainfall deficit of approximately 112 inches. This period of deficit rainfall corresponds to a period of steep flow decline at Silver Springs. This suggests that deficit rainfall may, in part, explain the large decline in Silver Springs flow since 1970. This analysis also suggests that it may take many years of above average rainfall to offset the prolonged period of drought and return Silver Spring flow to levels seen prior to 1970.

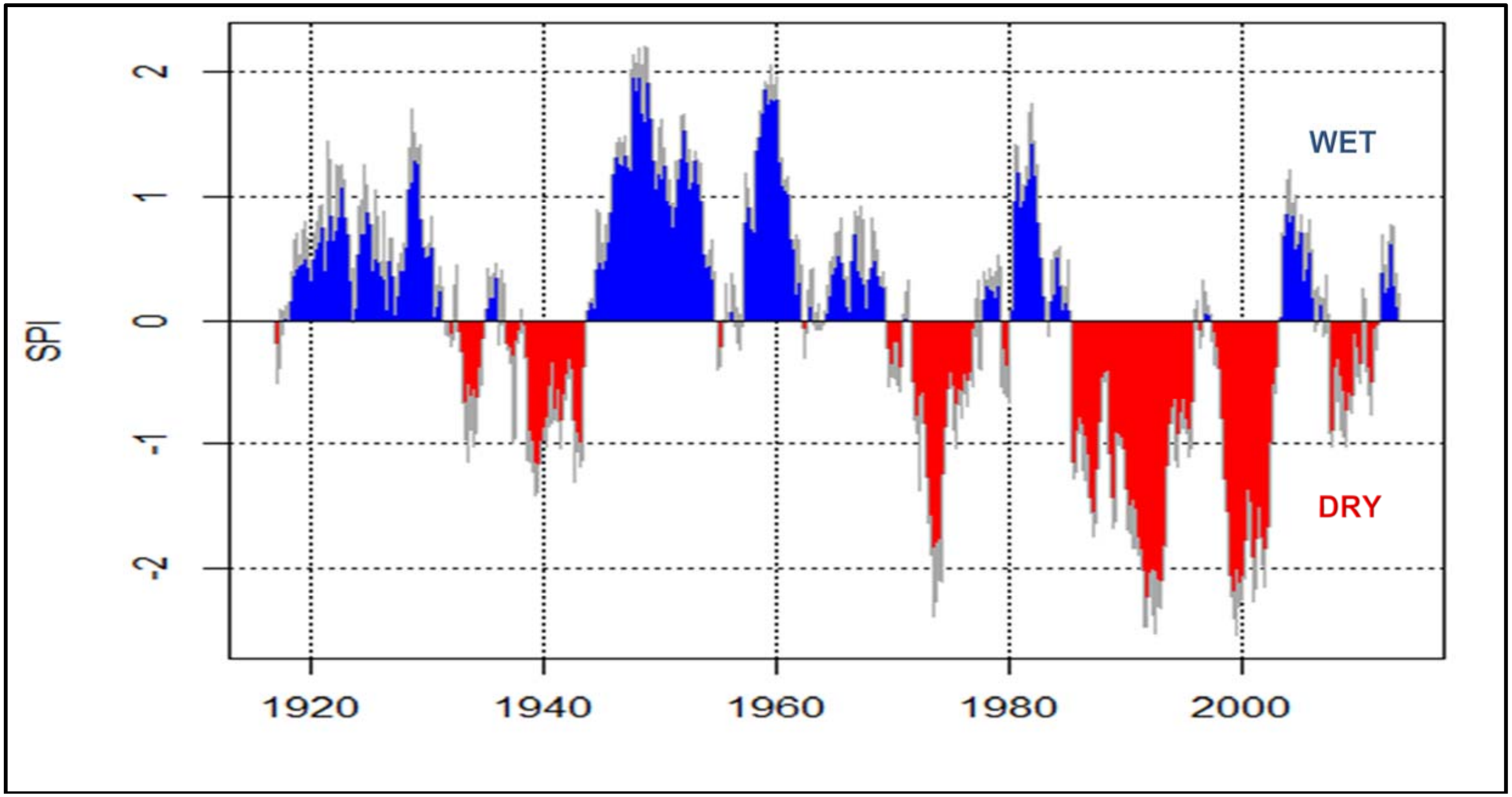


Figure 24. Standard Precipitation Index (Drought Index)

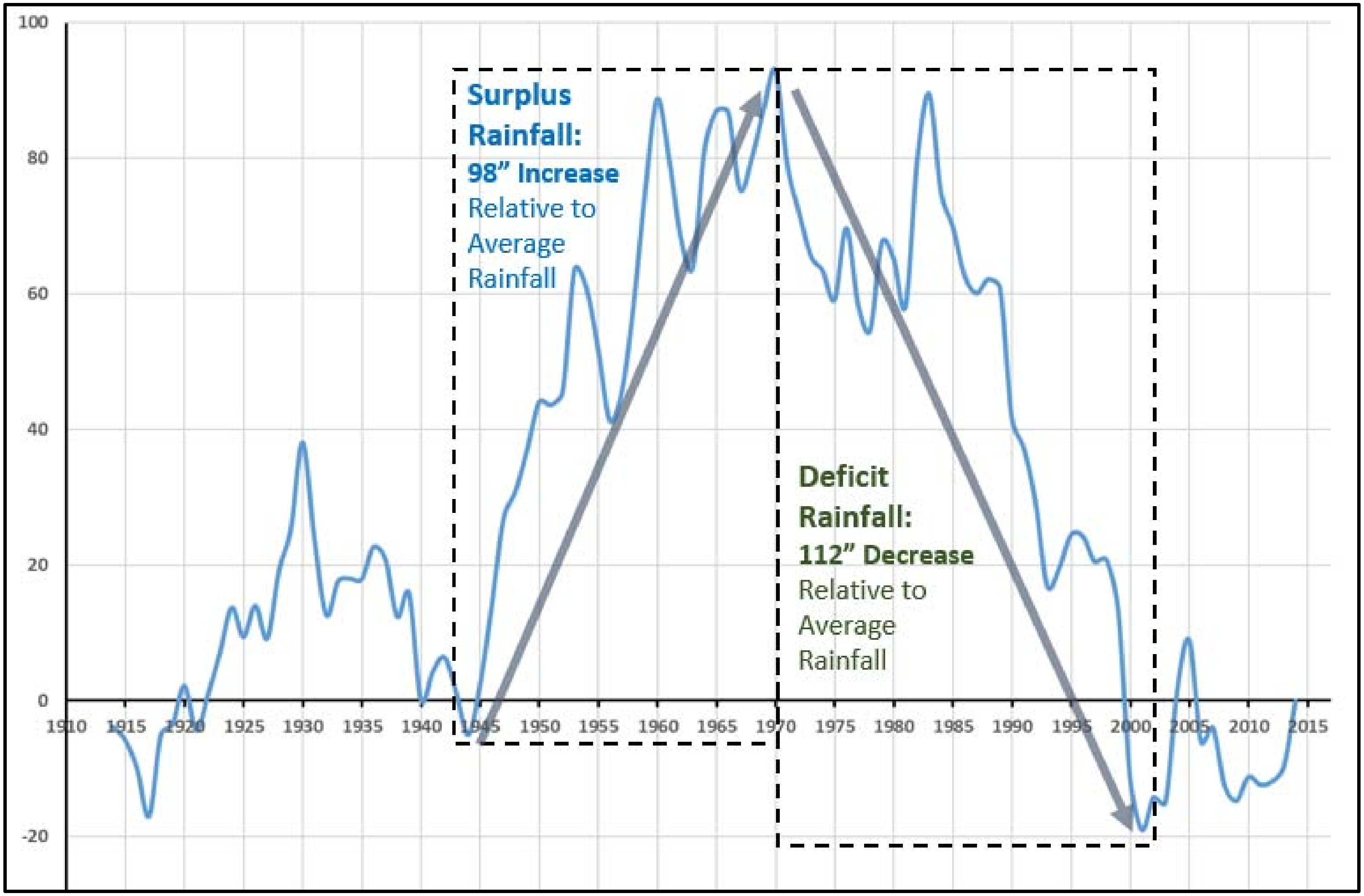


Figure 25. Cumulative departure from average rainfall for the NOAA Ocala gage near Silver Springs

Groundwater Withdrawals

Historical population and water use data were available only at the county level before 1995. Therefore, the groundwater use in Marion County was estimated to understand historical pumping in the vicinity of Silver Springs. Because most of the groundwater contributing area of the spring is within Marion County, this is considered a reasonable assumption. The actual groundwater use for Marion County was available for every year from 1978 to present. The population data for the county was available for every 10 years from 1930 to 1970 and for every year thereafter. An average annual gross groundwater use per capita was calculated at 339 gpcd by dividing the average annual groundwater use by average population using the data from the earliest three years (1978, 1979 and 1980) for which groundwater use data were available. To estimate groundwater use from 1930 to 1977, the population data were multiplied by the estimated average annual groundwater use per capita (Figure 26). A general upward trend in pumping was observed until 2006 and then declined thereafter. The magnitude of recent pumping is similar to the pumping in late 1990s.

While groundwater suppression and deficit rainfall are responsible for the majority of decline as previously described, groundwater withdrawal is also responsible for some of the observed decline in Silver Springs flow. Flow reduction due to groundwater withdrawal was estimated using the best available tool, version 5 of the Northern District Model (NDMv5) regional groundwater model. A flow reduction of 26 cfs was estimated, based on the NDMv5. This represents the change from a no-pumping condition to the best estimate of the current impacted condition (baseline condition). Based on the best available data, an estimated ~3.5% change has occurred from the no-pumping to baseline condition. Groundwater model results, along with evidence of deficit rainfall and flow suppression, taken together suggest that consumptive use is not the primary driver of the observed decline in Silver Springs flow.

Period of Record (POR) — 1946 to 2014

Determining the most appropriate POR is especially critical for the Silver Spring MFLs because of the distinct shift that occurred in the Silver River stage-flow relationship in or around the year 2000 as previously described. After 2000, a given flow has resulted in a markedly higher stage, relative to pre-2000.

As previously described, evidence suggests that the change in stage-discharge relationship is largely due to damming caused by drought-related increased SAV abundance and biomass. While the shift from SAV to algae in the upper 0.75 miles of the river is well documented (Odum 1957, Knight 1980, Munch et al. 2006), SAV in the lower portion of Silver River has changed from being largely absent in the 1950s to currently abundant (see above for more detail). The decision for using the entire POR for the Silver Springs MFLs is based on the uncertainty as to whether the post-2000 change in stage-flow relationship is permanent.

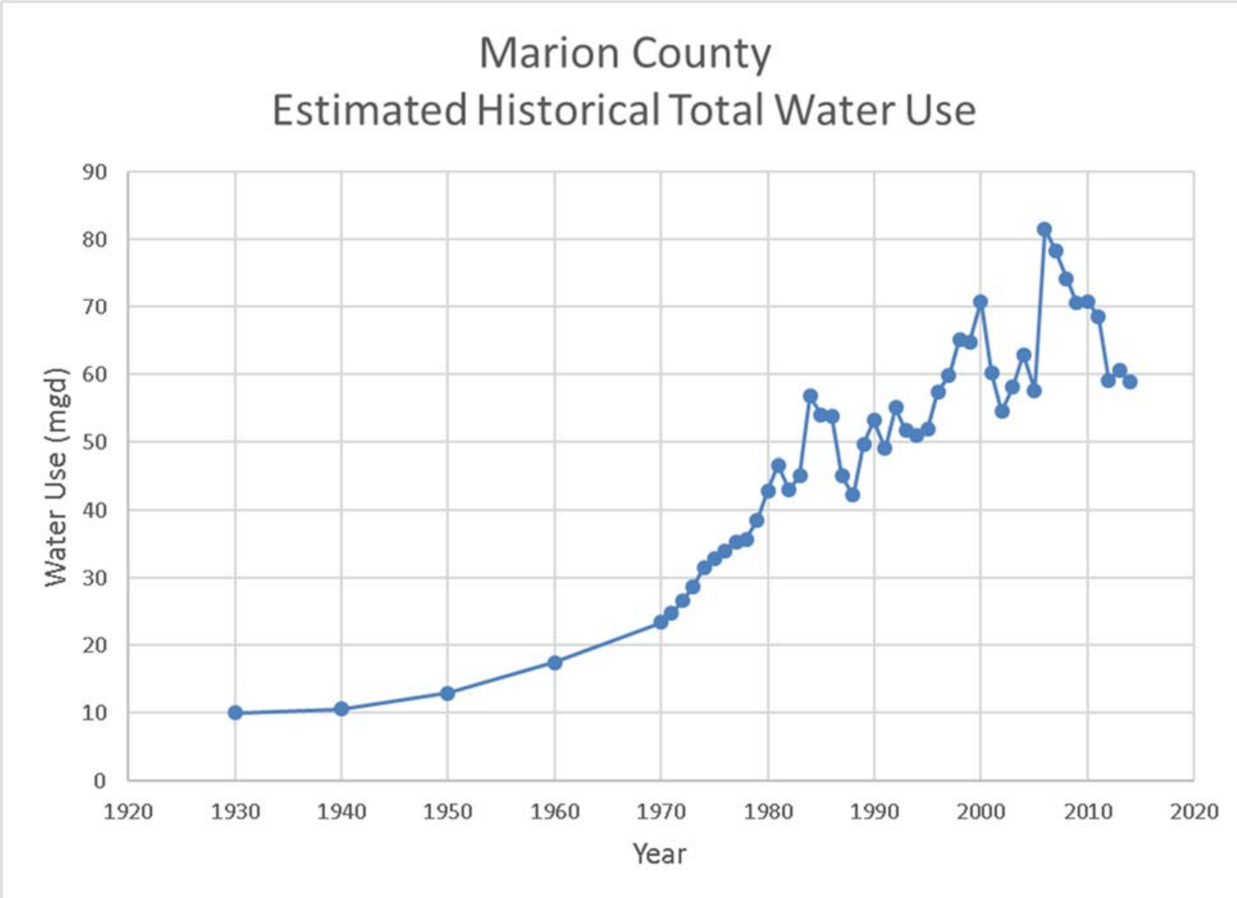


Figure 26. Historical total groundwater use for Marion County

Several factors led SJRWMD to believe that the change in SAV in the lower river may be largely driven by climate (i.e., multi-decadal drought). While two non-climatic factors, including 1) excessive nutrient enrichment (primarily nitrate-nitrite) and 2) food web changes (greatly reduced grazing pressure), are contributing to increased SAV abundance/biomass in the lower river, other climate-driven processes may be having a larger effect. These factors are related to drought (i.e., a 112-inch deficit rainfall) and include:

- A scarcity of large flood events on the Ocklawaha River since 2000, resulting in fewer back-water events flooding the Silver River with dark, tannin-stained water and thereby shading SAV;
- Fewer large flood events on the Silver River since 2000, producing fewer high energy, high velocity scour events to physically remove SAV;

  - As described above, the removal of SAV by high-velocity flood events, and a shift in stage-flow relationship, has been documented in the Ocklawaha River; and
- An increase in stands of the exotic invasive *Hydrilla verticellata* have become more prevalent in the lower Silver River and Ocklawaha River in recent years.

A review of the historical stage-flow relationship indicated there was a significant change in the relationship after 2000. As discussed above, evidence suggests that this condition is largely due to SAV-related flow suppression. The prolonged deficit rainfall (112-inch deficit from 1970s to 2000 and average rainfall since then), lack of scour and dark water suggest this drought may be the cause of the increase in SAV. However, uncertainty remains about the additional role of nutrient enrichment and food web changes on this increase in SAV in the lower river.

While there is still uncertainty about the permanence of SAV and the current stage-flow relationship, it is possible that pre-2000 conditions may return when sufficient above average rainfall combined with large flooding events (with associated high scour from the Silver River, dark water from the Ocklawaha River, reduced SAV, and lower stages) return for an adequate period. As a result of the considerations previously described, SJRWMD decided that using the full POR for MFLs determination was appropriate.

Surface Water Basin Characteristics

The following sections summarize the land use, mapped soils, and mapped wetland characteristics of the Silver River surface water basin (Figure 27), which covers approximately 4,162 acres (6.5 mi^2).

Land Use

The most current land use mapping (2014, Figure 28 and Table 5) indicates the western portion of the basin is urbanized as part of the City of Silver Springs and the development of the Silver Springs theme park (1,530 ac [12%] developed lands). The majority of the basin remains undeveloped with the majority of wetland plant communities protected by inclusion in the Silver River State Park.

A single surface water tributary, Half Mile Creek, enters the basin approximately 4,000 ft below Mammoth Springs (Figure 27). This tributary has been a source of sediment, nutrient, and pollutant loading to the spring run from portions of the City of Ocala and the City of Silver Springs and drainage along State Road (SR) 40 on the northern boundary of the basin (Figure 27).

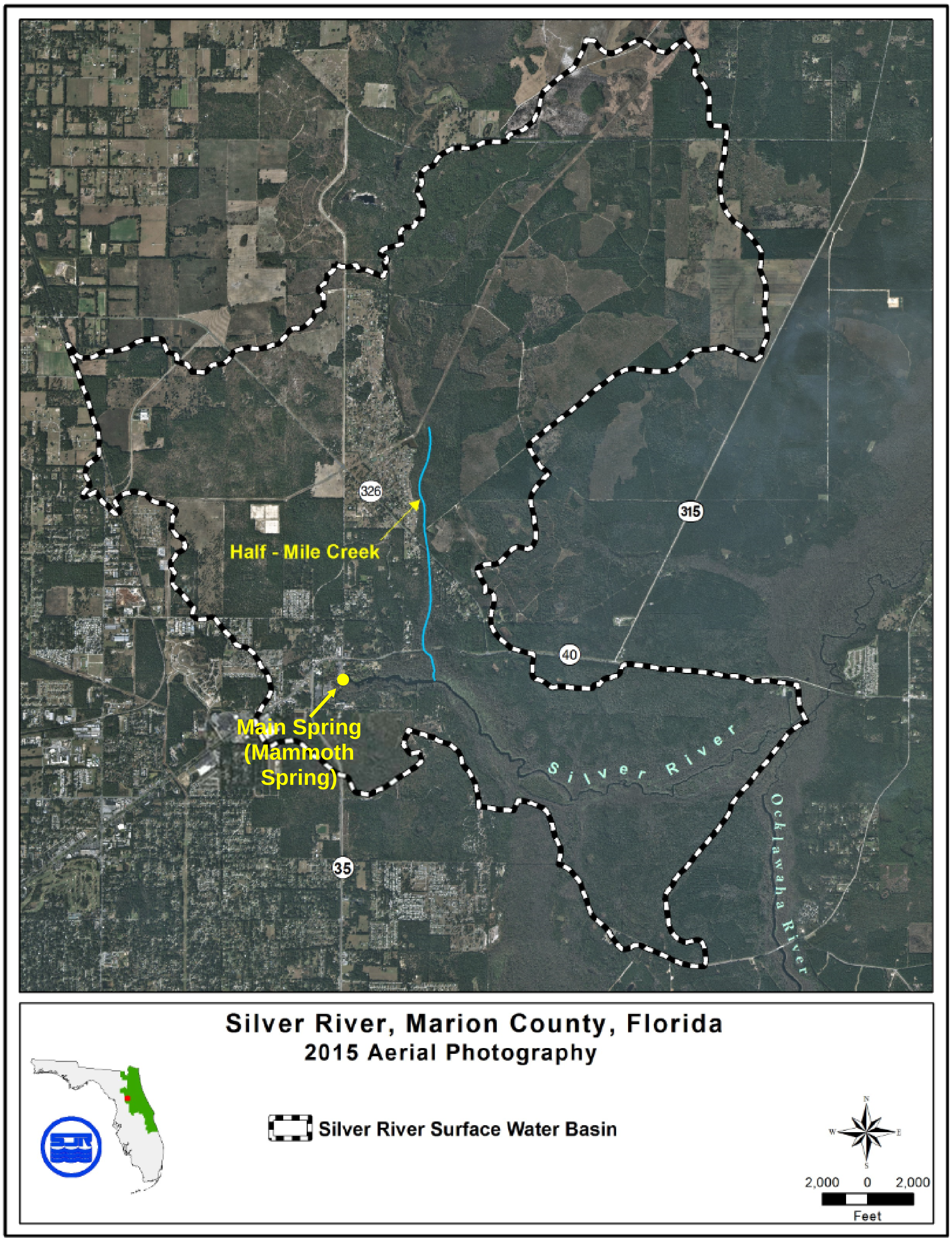


Figure 27. Silver River surface water basin. Source: SJRWMD

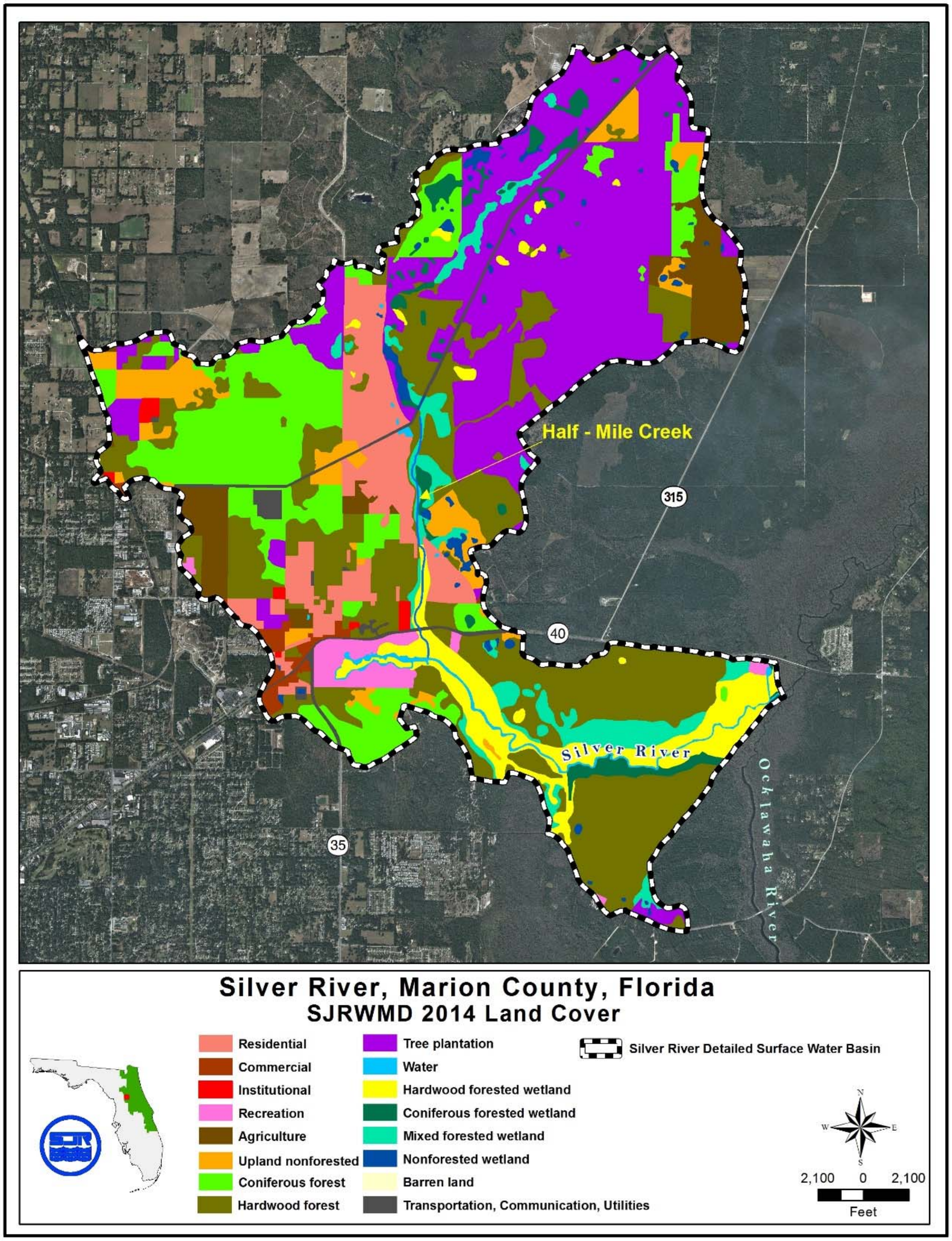


Figure 28. Land use/land cover map of the Silver River surface water basin; Source: SJRWMD

Table 5. Summary of 2014 land use/land cover within the Silver River surface water basin. Source: SJRWMD

Description	Acres	Percent
Agriculture	607.6	4.6
Commercial/institutional	169.8	1.3
Recreation	214.0	1.6
Residential	919.9	7.0
Upland—forested	8,559.2	65.1
Upland—nonforested	584.7	4.4
Water	88.7	0.7
Wetland—forested	1,648.5	12.5
Wetland—nonforest	138.6	1.1
Transportation, communication, utilities	226.7	1.7
Total Basin Area	13,157.6	100.0

Mapped Soils

The Soil Survey Geographic database (SSURGO) soil map (Figure 29) illustrates the geographic extent of soils, grouped according to hydric (wetland) and nonhydric (upland) characteristics. Approximately 35% of the surface water basin was mapped as nonhydric soils, located primarily in the western basin area. The eastern portion of the basin was mapped primarily as hydric soils (10%) and as partially hydric soils (54%, areas of nonhydric soils with hydric soil inclusions) (Table 6).

Table 6. Summary of hydric soil groups within the Silver River surface water basin. Source: SJRWMD

Soil Type	Acres	Percent
Hydric	1,373.9	10.4
Partially hydric	7,162.6	54.4
Nonhydric	4,566.4	34.7
Water	61.9	0.5
Total Basin Area	13,164.8	100

Mapped Vegetation

Extensive wetland communities occur within the Silver River surface water basin (Table 7, Figure 30). Based on SJRWMD geographic information system (GIS) wetland coverage (Kinser 2012), 14 different plant communities were delineated in the Silver River Basin (Table 7). The most common plant communities include uplands (predominantly xeric and mesic hammocks)

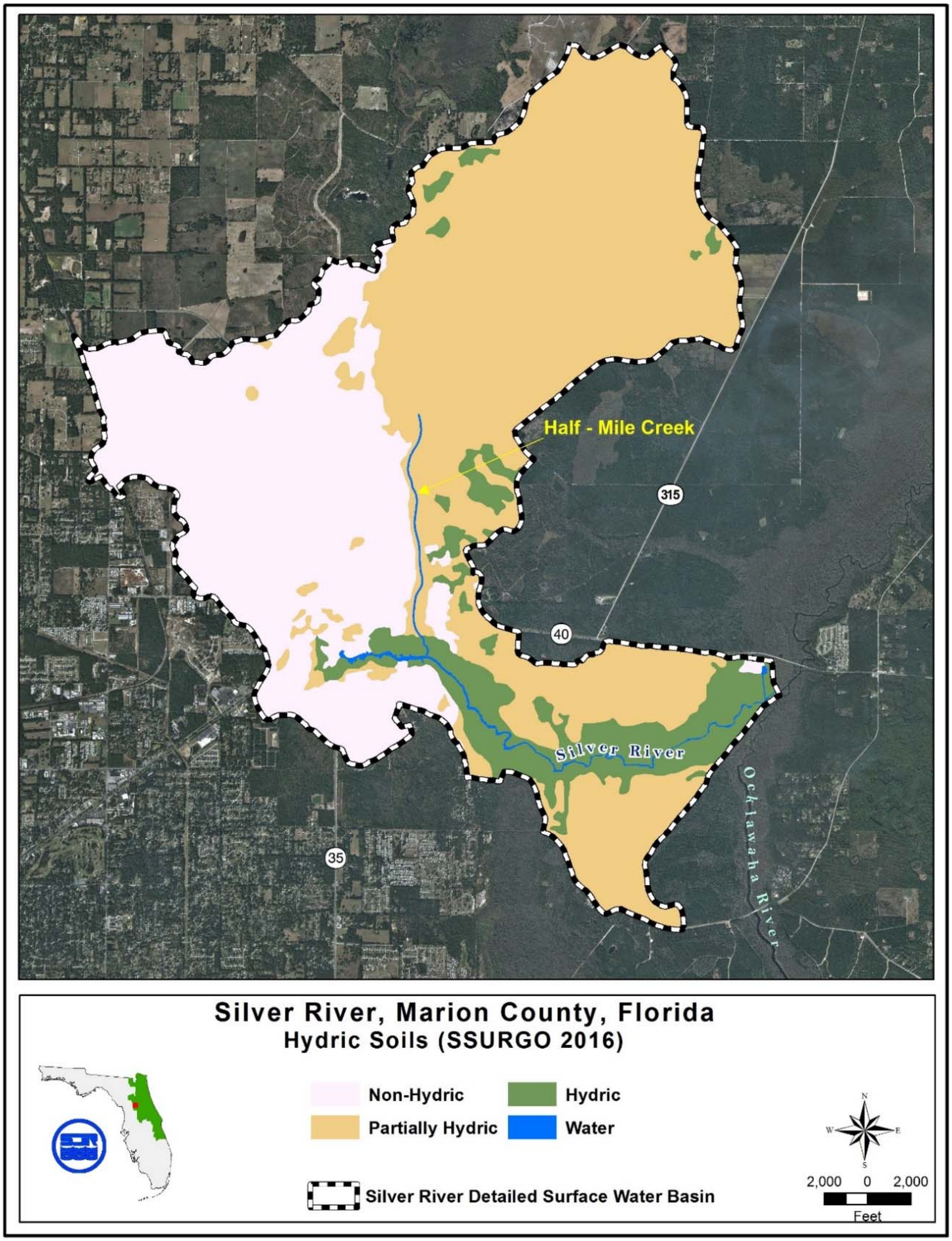


Figure 29. Hydric and non-hydric soils map of the Silver River surface water basin. Source: SJRWMD

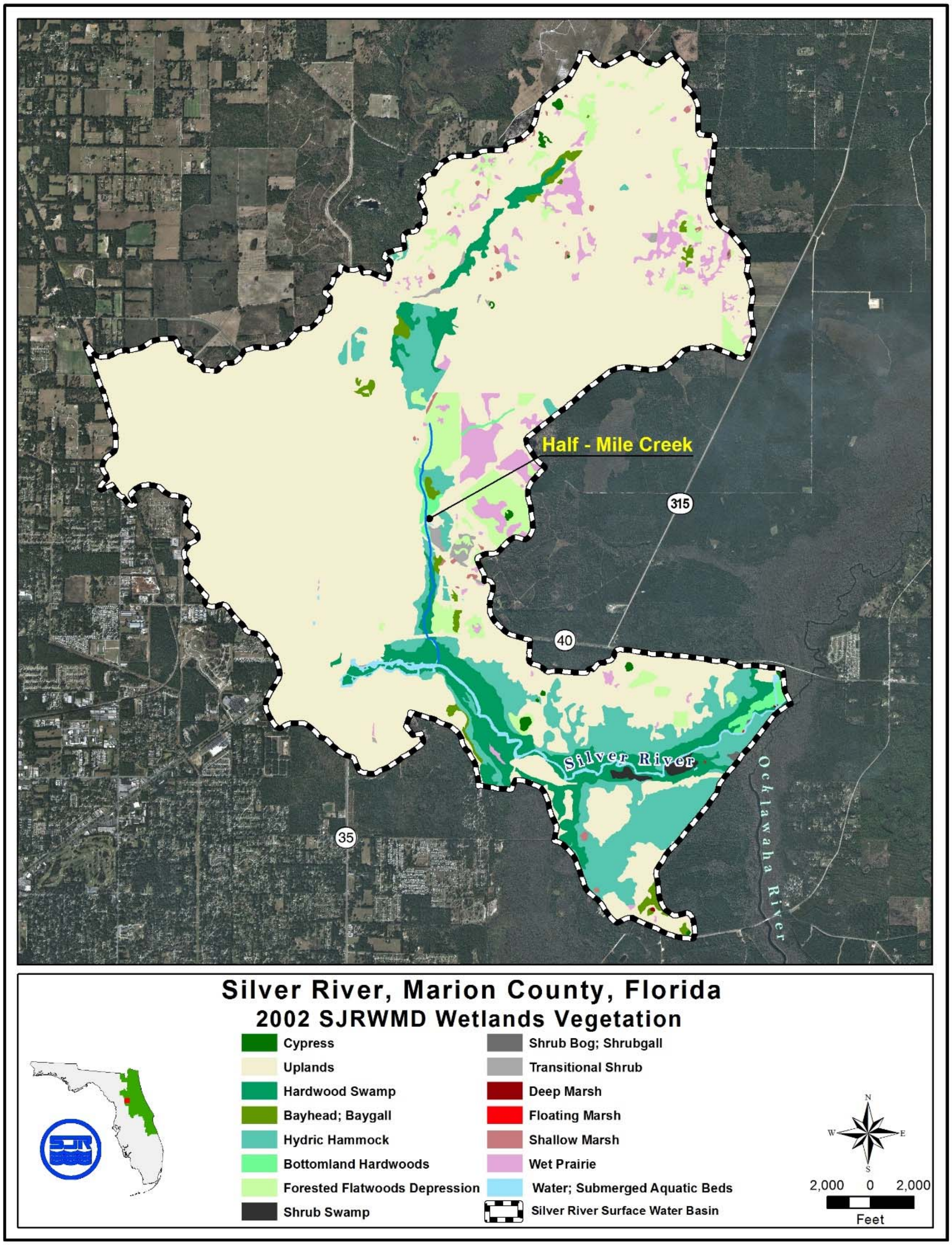


Figure 30. Plant communities in the Silver River surface water basin. Source: SJRWMD

and three wetland communities: hydric hammock, hardwood swamp, and open water, which in Silver River is typically analogous to SAV beds. Each of these four plant community types was surveyed at each of the four vegetation and soils transects traversed at Silver River as part of this MFLs determination.

Table 7. Summary of mapped upland and wetland plant communities within the Silver River surface water basin, Marion County, Florida. Source: SJRWMD

Vegetation Name	Code	Acres	Percent
Uplands	U	9,882.8	75.1
Hydric hammock	HH	1,144.8	8.7
Hardwood swamp	HS	762.8	5.8
Water (SAV beds)	W	103.5	0.8
Forested flatwood depressions	FD	543.1	4.1
Bayhead/baygall	BH/BG	112.1	0.9
Bottom land hardwood	BL	75.0	0.6
Shrub swamp	SS	32.1	0.2
Wet prairie	WP	392.8	3.0
Cypress	CY	27.8	0.2
Shrub bog	SB	35.8	0.3
Deep marsh	DM	1.0	0
Floating marshes	FF	0.5	0
Transitional shrub	TS	43.3	0.3
Total basin area		13,157.5	100

WATER QUALITY

The character of Silver River water quality is based on a composite of the 30+ springs (with 69 or more contributing vents), except when influenced by direct rainfall and surface runoff (Knowles et al. 2010). Previous studies have documented distinct differences in water chemistry among many of the spring vents (Munch et al. 2006; Butt and Aly 2008; Knowles et al. 2010), and the differences are indicative of the complexity of the supporting groundwater flow system.

USGS has sampled Mammoth Springs since 1956, with additional field measurements sampled periodically through time. USGS currently samples the Mammoth Springs six times per year. Summary statistics of selected water quality parameters sampled at Mammoth Springs presented in Table 8. This spring was listed as an impaired water body due to elevated concentrations of nitrate + nitrite (NOx). The numeric standard for NOx is 0.35 mg/L for Florida springs (Florida Impaired Waters Rule — Rule 62-303, *F. A. C.*). Only two observed data points had a concentration less than 0.35 mg/L from 1964 to 2016 and the average NOx concentration is 0.95 mg/L for the period of record (Table 8 and Figure 31). NOx increased dramatically over the past 50-plus years from 0.4 mg/L in 1964 to 1.28 mg/L in 2016 (Figure 31). The increase in dissolved nitrogen is clearly linked to anthropogenic nitrogen sources from agricultural and developed landscapes, based on nitrogen and oxygen isotope ratios of NOx (Munch et al. 2006; Knowles et al. 2010). Phosphorus does not show an increasing temporal trend in the Silver Springs system, and concentrations remain close to those levels observed during the 1950s (Figure 32; Hicks and Holland 2012).

Table 8. Summary statistics of water quality data for selected variables sampled at Mammoth Springs. Source: USGS

PARAMETER	Min	Mean	Median	Max	Count	Beginning Date	Recent Date
Alkalinity, total, mg/L as $CaCO^3$	140	181	175	214	63	5/2/1956	10/20/2016
Calcium, total, mg/L as Ca	71	82	81	112	29	5/8/2001	8/11/2016
Chloride, total, mg/L as Cl	5	10	10	17	167	5/2/1956	8/11/2016
Dissolved Oxygen	1.00	1.99	2.00	5.70	41	5/8/2001	8/11/2016
Fluoride, total, mg/L as F	0.12	0.19	0.19	0.26	23	5/8/2001	10/20/2016
Magnesium, total, mg/L as Mg	8.5	9.8	9.6	11.1	28	5/8/2001	8/11/2016
Nitrate + nitrite, total, mg/L as N	0.07	0.95	1.00	1.37	116	2/3/1964	10/20/2016
Orthophosphate, total, mg/L as P	0.02	0.04	0.04	0.07	112	5/11/1967	10/20/2016
pH, field	5.70	7.34	7.31	8.10	118	5/2/1956	8/11/2016
Phosphorus, total, mg/L as P	0.01	0.04	0.04	0.07	110	4/28/1969	10/20/2016
Potassium, total, mg/L as K	0.24	0.64	0.67	0.91	26	3/24/2005	8/11/2016
Sodium, total, mg/L as Na	5.81	6.95	6.90	8.15	28	5/8/2001	8/11/2016
Specific conductance, field, µmhos/cm at 25°C	438	471	466	523	48	9/26/2000	8/11/2016
Specific conductance, lab, µmhos/cm at 25°C	350	434	428	499	190	5/2/1956	10/20/2016
Sulfate, total, mg/L as SO_4	18	38	38	58	108	5/2/1956	8/11/2016
Total dissolved solids, mg/L	229	271	271	318	94	11/1/1960	9/18/2014
Water temperature, °C	21.0	23.1	23.1	27.5	181	11/10/1960	8/11/2016

The Florida's Impaired Waters Rule (Rule 62-303, F.A.C.) identified Silver Springs (Water Body Identification [WBID] 2772A), the Silver Springs Group (WBID 2772C), and the Upper Silver River (WBID 2772E) as impaired by nutrients (Figure 33). These spring-related waters were listed as impaired by nutrients because of their consistently elevated concentrations of NOx (above 0.6 mg/L) and corresponding evidence of imbalance of flora and fauna caused by the expansion of algal mats covering bottom sediments and over-growing SAV beds (Hicks and Holland 2012).

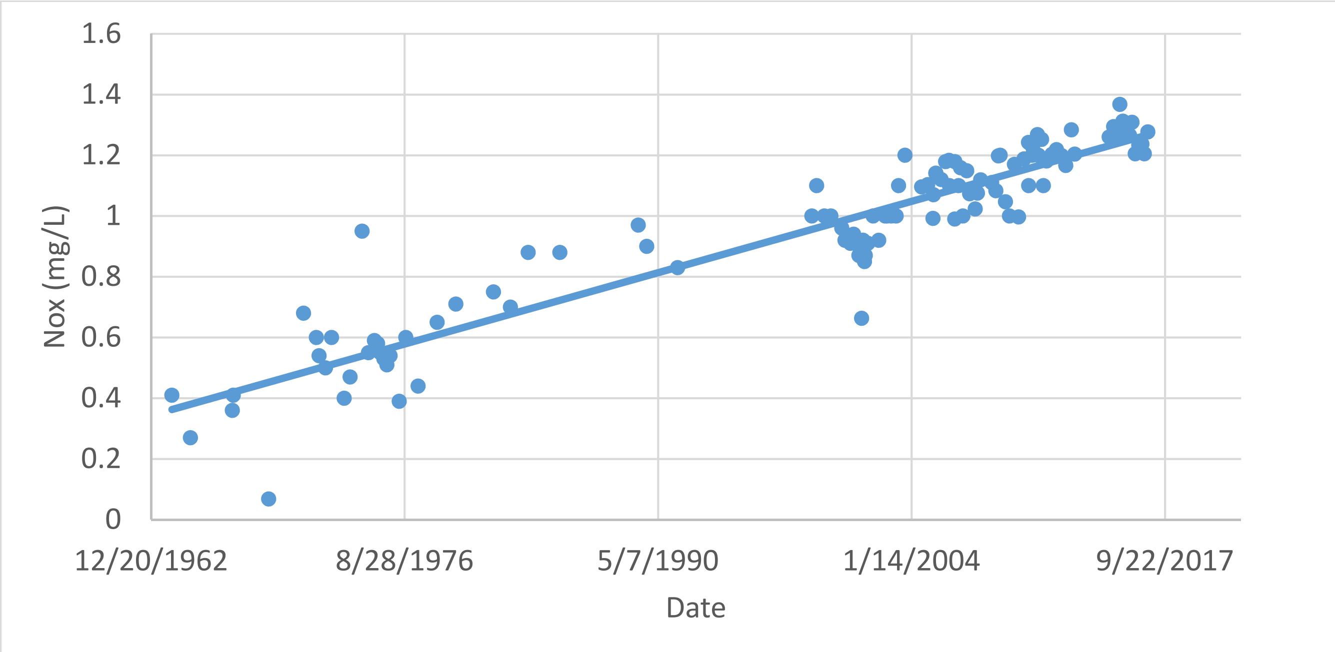


Figure 31. NOx concentration at Mammoth Springs 1964–2016. Source: USGS

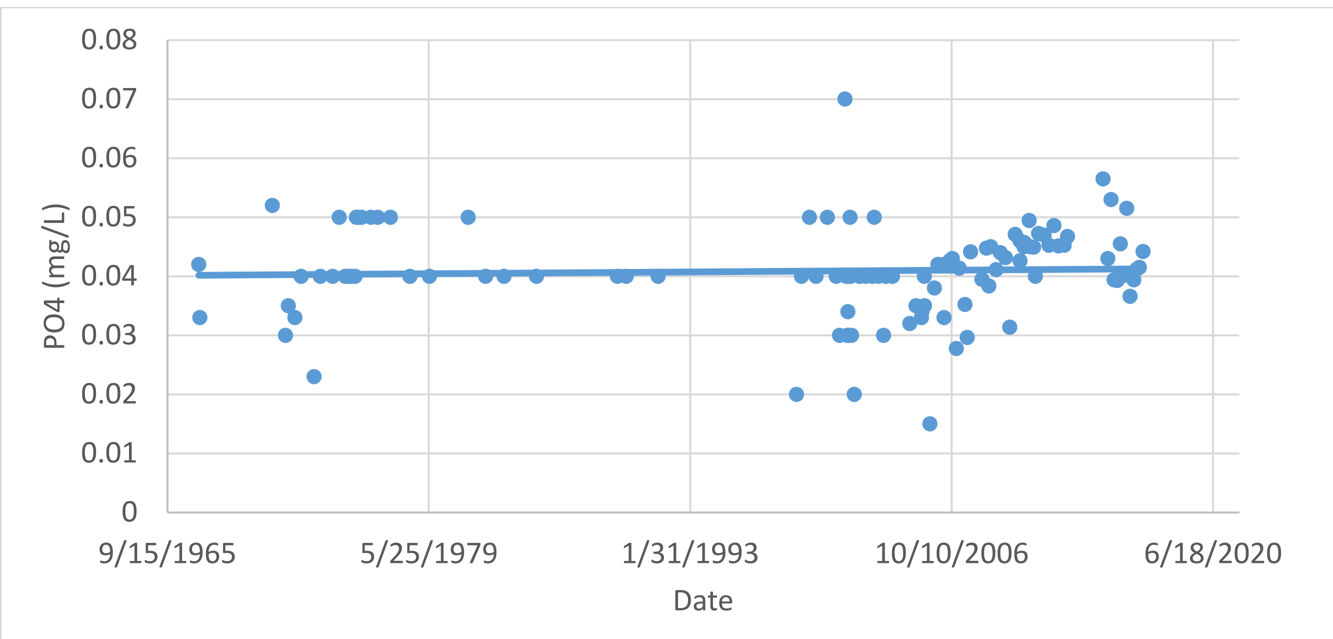


Figure 32. Orthophosphate concentration at Mammoth Springs 1969–2016. Source: USGS

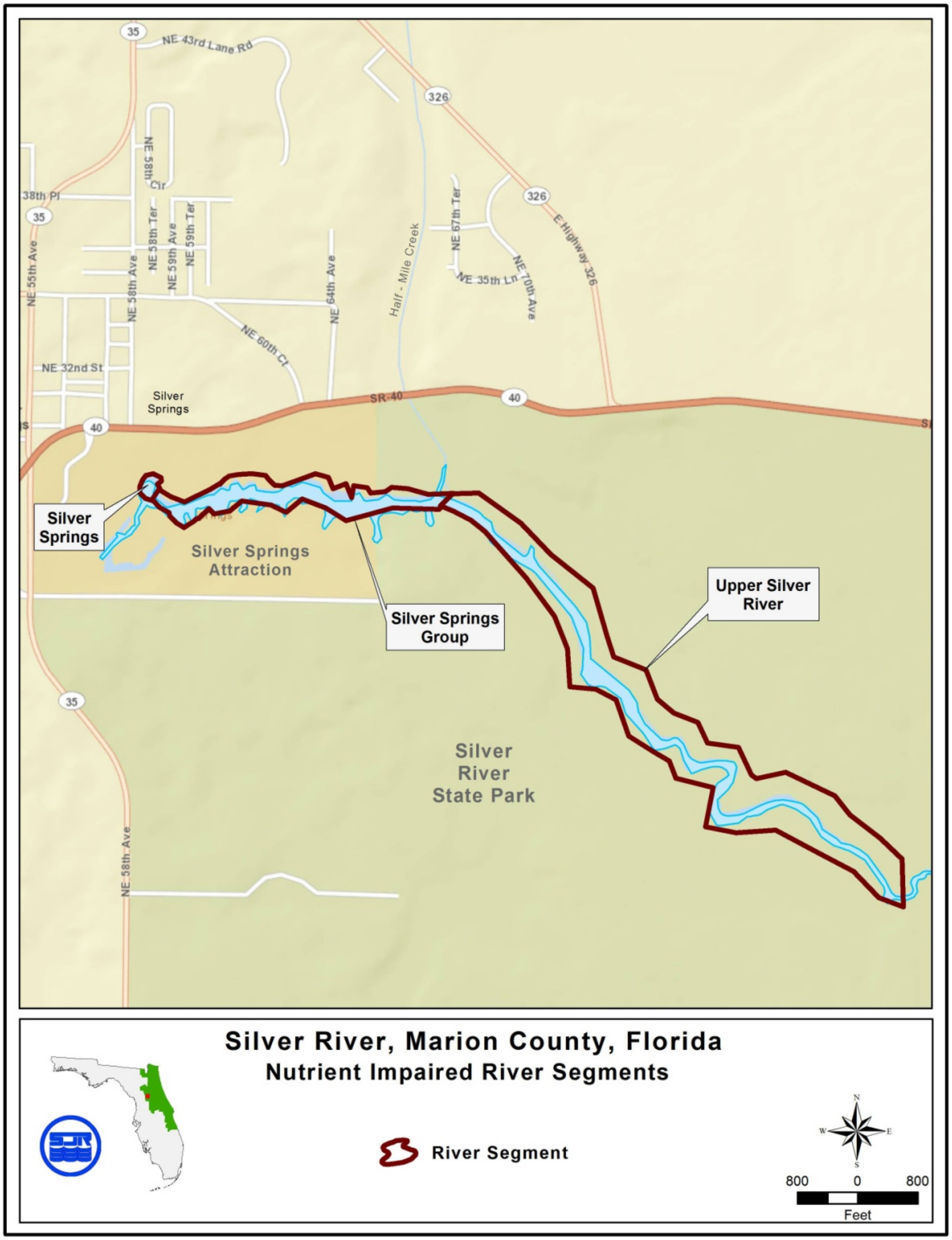


Figure 33. Location map showing the three nutrient impaired reaches of the Silver River

These reaches of Silver River were included on the verified list of impaired waters for the Ocklawaha River Basin adopted by secretarial order in May 2009 (Hicks and Holland 2012).

RESEARCH AND MONITORING AT SILVER SPRINGS

Previous Ecological Studies

Odum (1957) conducted the first extensive ecological study of Silver Springs in the mid-1950s. Odum's research provided a detailed assessment of the Silver Springs' water quality, productivity, biological structure, and ecosystem metabolism. Approximately 25 years later, Knight (1980, 1983) conducted a second ecological study of Silver Springs that built on Odum's original 1950s work.

Most recently, and as a follow-up to the earlier work of Odum (1957) and Knight (1980, 1983), SJRWMD conducted a 50-year retrospective study of Silver Springs ecological structure and function (Munch et al. 2006). The retrospective study assessed land use and water quality changes in Silver Springs over the decades since Odum's original work, with a goal to develop cause-and-effect relationships, if any, between these changes and the ecological integrity of the springs.

The study's scope was to review available data for the upper 3,900 ft of the Silver River, collect additional data as needed for comparison to historical data, and develop linkages between springshed land use changes and the Silver Springs' ecology. By focusing on the upper 3,900 ft of the Silver River, the study included all of the major spring boils studied by Odum (1957) and Knight (1980, 1983), as well as the USGS spring pool and spring flow gaging stations (USGS 02239500 and 02239501).

The retrospective study clearly documented the impaired nature of Silver Springs by demonstrating significant changes in many ecological health indicators since the mid-1950s (Munch et al. 2006). The following is a summary of some of the significant changes in ecological parameters in Silver Springs (upper 3,900 ft of Silver River) since the mid-1950s as reported by Munch et al. (2006):

- Vertical light attenuation coefficients increased approximately 267%, from 0.06 per meter (m-1) to 0.16 m-1, indicating a general decline in the overall water clarity.
- Average NOx concentration increased approximately 276%, from about 0.38 to 1.05 milligrams per liter (mg/L).
- Nitrogen loading rate increased 1,121%, from 94,400 pounds per year (lbs/yr) to 1,058,000 lbs/yr. Note: this is the total annual loading to the land surface within the two-year capture zone (Table 7-1 in Munch et. al 2006). This is not the loading at the spring boil. The relationship between watershed loading and concentration in the spring is not 1:1 and likely is not linear.

- Average annual SAV biomass decreased approximately 21%.
- Average annual attached algal biomass increased by about 171%.
- Benthic algal biomass was considered too low to estimate by Odum (1957), but was comparable to macrophyte and epiphytic biomass estimated in 2004 through 2005.
- Average daily emergence of aquatic insects declined by approximately 72%.
- Overall estimated annual average fish liveweight biomass declined by 92% from 526.7 kilograms per hectare (kg/ha) to 41.90 kg/ha. These reductions were due to large declines in a few species (e.g., catfish, striped mullet [Mugil cephalus]) and most other fish species were of similar total biomass between the time periods.
- Annual average gross primary productivity declined 27% from about 15.6 grams oxygen per square meter per day (g O2/m2/d) to 11.4 g O2/m2/d.
- Community respiration also declined 26% from 14.8 g O2/m2/d to 10.9 g O2/m2/d.
- Resulting net community primary productivity declined approximately 59%, from 1.0 g O2/m2/d to about 0.42 g O2/m2/d.
- Ecological efficiency declined 13% from 1.09 grams oxygen per mole of photosynthetically active radiation (g O2/mol of PAR) to about 0.94 g O2/mol of PAR.

Recent Research

More recently, UF and SJRWMD have conducted a three-year (2013–2016), comprehensive study of springs with groups dedicated to examining biology/ecology, hydrogeology/chemistry, hydrology, and hydrodynamics. More information on CRISPS can be foundonline: *www.sjrwmd.com/springs/investigation.html*

Monitoring and Restoration Efforts

Public interest in the restoration and protection of the springs and river prompted the formation of the Silver Springs Working Group in 1999. The group, which was funded by the Florida Department of Environmental Protection (FDEP) until 2011, raised public awareness of anthropogenic impacts to the springs such as nutrient enrichment and declining flows. In 2011, the working group, coordinated at that time by Normandeau Associates, Inc. (Normandeau), produced a draft restoration plan for Silver Springs and the Silver River (Normandeau 2011, draft) that outlined goals and actions for water quality, fish and wildlife, flows, and ecosystem-level restoration to be achieved through stakeholder participation. The Silver Springs and Silver River MFLs determination considered the recommendations from the Normandeau report when selecting criteria for MFLs development.

In a major undertaking to improve springs’ water quality and to protect spring flows, SJRWMD implemented a Springs Protection Initiative (SPI) in coordination with FDEP, Florida Department of Agriculture and Consumer Services, Florida Fish and Wildlife Conservation Commission, National Resources Conservation Service (U.S. Department of

Agriculture), Marion County, City of Ocala, Southwest Florida Water Management District, and other nongovernmental stakeholder groups. The initial focus of the SPI was Silver Springs and the Wekiva River basin springs. The SPI has included cost-sharing with FDEP to complete reclaimed water and stormwater projects beneficial to springs protection. The SPI also included a multi-year scientific investigation to provide a scientific foundation to develop cost-effective approaches for management of forcing functions influencing the hydrology, hydrodynamics, physicochemistry, and biology of spring ecosystems.

TECHNICAL APPROACH

The SJRWMD MFLs approach involves two separate, but interrelated, analyses for each priority water body:

- MFLs determination; and
- MFLs status assessment.

The purpose of these analyses is to answer an overarching question: What hydrologic regime is needed to protect from significant harm the critical environmental functions and values of a priority water body? This section describes the methods used in the MFLs determination and status assessment for Silver Springs, including field procedures such as site selection and field data collection, data analyses, hydrologic data analyses and consideration of relevant environmental criteria. Neubauer et al. (2008) provides further description of the SJRWMD MFLs methods.

MFLS DETERMINATION

MFLs to protect the Silver Springs Ecosystem

As described above, the Silver Springs ecosystem is comprised of the main spring vent (Mammoth Spring), more than 30 springs (with 69 vents) that make up the Silver Springs Group, and the 4.5-mile Silver River which includes in-channel and floodplain habitat (Figure 1). The flow time series used to develop the Silver Springs MFLs is from USGS gage 02239501, located immediately downstream of the Silver Springs Group. Descriptions of water levels and flows from this gage refer to the total contribution of the Silver Springs Group, which is for this report synonymous with “Silver Springs.” The goal of the recommended Silver Springs minimum flow is to protect the entire Silver Springs ecosystem, including the springs, river and floodplain.

While determining the most appropriate criteria to protect the entire Silver Springs ecosystem, preliminary analysis of system hydrology and field survey data suggested that in-channel habitats are dewatered less often, over the long-term, than habitats at higher elevations. These preliminary analyses also suggested that metrics higher in the landscape (i.e, on the floodplain) are more sensitive to withdrawal. Therefore, protection of higher-elevation habitats will maintain other critical habitat at lower elevations (e.g., springs, in-channel fish and invertebrate habitat), and thereby provide protection for the entire system.

An analysis of the no-pumping condition (i.e., flow and stage time series with groundwater withdrawal effects removed), based on groundwater model results and field data, indicated that in-channel habitat is inundated over 80% of the time (i.e., is fairly stable).

As detailed later in this report, ecological criteria developed in the river floodplain and channel margins (e.g., location of aquatic beds) are more sensitive to changes in stage and flow, and thus more constraining than using in-channel criteria (e.g., fish habitat). The most constraining recommended minimum flow results in very little change (1.2%) to in-channel inundation or critical velocities (i.e., those related to maintaining system metabolism, algae scour or sediment transport). These analyses are described in a resource evaluation analysis conducted by Applied Technology and Management, Inc. (ATM 2017).

Ecological criteria located higher in the landscape (i.e., the floodplain of the Silver River) are more sensitive than in-channel metrics and thus the most appropriate metrics with which to protect the entire Silver Springs ecosystem, including spring flow and in-channel habitat. Because the MFLs are centered on the floodplain, the analyses and ecological descriptions are focused on floodplain wetland communities, floodplain organic soils, and channel-margin wetlands.

The conclusion that in-channel criteria are less sensitive to withdrawal than floodplain criteria may seem at odds with the current impairment documented for instream ecological communities. However, many of the changes to the Silver Springs ecosystem (e.g., increased nutrients, increased filamentous algae, reduced SAV, change in fish community), documented in the upper 0.75-mile of the headsprings and river, are due to factors other than withdrawal.

MFLs are established to set limits to groundwater and surface water withdrawals. Impacts due to increased nutrients, reduced grazer migration/pressure related to Rodman Reservoir, and flow reductions due to drought-driven, SAV-related groundwater mounding and suppression, are not intended to be addressed through the development of MFLs. Much of the ecological impairment documented in the headsprings and upper 0.75-mile (including declining velocities due to flow suppression, food web changes and reduced diversity) will not begin to improve until there is a change in conditions resulting from drought-driven SAV growth and flow suppression, Rodman Reservoir and nutrient enrichment.

This MFLs will be adopted as the “Silver Springs” MFL. Because this is a spring MFLs, SJRWMD recommends minimum flow events. These MFLs flows are based on critical stages in and adjacent to the Silver River floodplain. Maintaining minimum flooding and maximum dewatering of these floodplain elevations will prevent impacts to critical habitats at lower elevations (e.g., within the springs and river channel), thereby protecting the entire Silver Springs ecosystem.

Environmental Analyses

The first step in the MFLs determination is to conduct environmental analyses to characterize ecological attributes and other sensitive beneficial uses of a water body. This typically includes consideration of site-specific field-based ecological and topographical information, empirical data collected at other MFLs sites and supportive information from the scientific literature. Using this information, a determination is made of the most critical environmental features to protect, and of the minimum hydrologic regime (MFLs condition) required for their protection.

Field Transect Site Selection

Ecological, soils and topography data for the Silver Springs MFLs were collected along transects that extended from uplands to open water (Figure 4). A literature and data search was conducted prior to establishing field transects. This included a review of SJRWMD library documents, project record files, the hydrologic database, and SJRWMD surveying files. The Florida Natural Areas Inventory (FNAI) biodiversity matrix tool (*http://www.fnai.org/*) was queried for the presence of threatened or endangered species. The goal of the search was to familiarize investigators with site characteristics, locate important floodplain features, and assess prospective sampling locations. Proposed transects were inspected prior to intensive data collection to confirm the presence of desired features, including: representative examples of common wetland communities; unique or high quality wetlands; edge of uplands or open water; hydric soils and organic soils.

Field Data Collection

Sampling of soil and vegetation followed standard field procedures in soil science and vegetation ecology. Detailed information on these methods and transect selection procedures are provided in Appendix A.

Surface Water Inundation/ Dewatering Signatures (SWIDS)

Annual maximum and minimum series stage frequency analyses of long-term modeled stage data provide probabilities of flooding/dewatering events for wetland plant communities and organic soil indicators used as MFLs criteria. Because ground elevations are transformed to durations and probabilities, comparisons of like plant communities or soils indicators from different systems at different landscape elevations results in quantitative hydrologic signatures. The mean, minimum, and maximum elevations of vegetation (species and communities), and soil indicators are often used for SWIDS analysis (Neubauer et al. 2004; Neubauer et al. 2007, draft).

SWIDS of vegetation communities provide a hydrologic range for each community, with a transition to a drier community on one side of the range and a transition to a wetter community on the other side. These hydrologic signatures provide a target for MFLs determinations that are focused on vegetation community protection criteria, and provide an estimate of how much the return interval or probability of a flooding or dewatering can be shifted at a specified duration and still maintain a vegetation community within its observed hydrologic range.

In the SWIDS analysis, a boxplot is utilized to show the range of the probabilities of flooding (exceedence) or dewatering (nonexceedence) events of selected durations for different plant community elevations (i.e., maximum, mean, and minimum elevations) occurring at different water bodies. The boxplot displays a five-number summary, consisting of the (1) minimum data value; (2) the first quartile (25th percentile), which sets the limit of the lowest 25% of the data; (3) the median (50th percentile); (4) fourth quartile (75th percentile), which sets the limit of the highest 25% of the data; and (5) the maximum data value. The boxplot is a simple graphical tool to show the shape of the data distribution, its location of central tendency, and variability.

An Event-Based Approach

Wetland and aquatic species, and hydric soils require a minimum frequency of critical hydrologic (drying and/or flooding) events for long-term persistence. Wetland communities require a range of flooding and drying events to fulfill many different aspects of their life-history requirements (Euliss et al. 2004, Murray-Hudson et al. 2014). Because of the role of hydroperiod in structuring and maintaining wetland and aquatic communities, the SJRWMD MFLs approach is centered around the concept of protecting a minimum number of flooding events or preventing more than a maximum number of drying events for a given ecological system.

Hydroperiod is a primary driver of wetland plant distribution and diversity, hydric soils type and location, and to a lesser degree freshwater fauna (Foti et al. 2012, Murray-Hudson et al. 2014). Hydroperiod is often described as the inter-annual and seasonal pattern of water level resulting from the combination of water budget and storage capacity (Welsch et al. 1995). Wetland hydroperiods vary spatially and temporally and consist of multiple components, including: return interval, duration and magnitude. Native wetland and aquatic communities have adapted to and are structured by this natural variability (Poff et al. 1997, Richter et al. 1997, Murray-Hudson et al. 2014).

Five critical components of hydrological events are typically recognized: return interval, duration, magnitude, rate of change and timing (Poff et al., 1997). However, because the latter two are thought to be a function of climate, only the first three are a focus of the SJRWMD approach. Magnitude and duration components define the critical ecological events that effect species at an individual level (i.e., individual organisms). The return interval of an event is what changes due to climate and/or water withdrawal. Therefore, by assessing the effects of water withdrawal on the return interval of MFLs events a determination is made regarding whether additional water is available. By comparing the frequency of ecologically critical events under, to the allowable frequency of these same events, the SJRWMD MFLs method is able to determine the amount of water that is available (or needed for recovery) within a given ecosystem under different withdrawal conditions. The sections on hydrologic modeling and compliance assessment give more details about this process.

Variable flooding and/or drying events are necessary to maintain the extent, composition, and function of wetland and aquatic communities. For example, the long-term maintenance of the maximum extent of a wetland may require an infrequent flooding event, of sufficient duration and return interval, to ensure that upland species do not permanently shift downslope into that wetland. In addition to flooding events, some aspects of wetland ecology (e.g., plant recruitment, soil compaction, nutrient mineralization) are also dependent upon drying events, as long as they do not occur too often. Because hydroperiods vary spatially and temporally (Mitsch and Gosselink 2015), multiple MFLs are typically used to address and protect different portions of a system's natural hydrologic regime (Neubauer et al. 2008). For many systems SJRWMD sets three MFLs: a minimum frequent high (FH), minimum average (MA), and minimum frequent low (FL) flow and/or water level. In some cases (e.g., for sandhill-type lakes) a minimum infrequent high (IH) and/or minimum infrequent low (IL) may also be set. After a comprehensive review and characterization of the soils, wetlands and aquatic fauna, SJRWMD recommends setting a FH, MA and FL for Silver Springs.

Hydrologic Data Analyses for MFLs Determination

After determining minimum stages necessary to protect critical environmental criteria, hydrological analyses were conducted to determine the recommended minimum flows necessary to maintain these critical stages. The following sections describe the hydrologic data analyses conducted to determine these protective flows.

Homogeneous Hydrologic Record

The USGS 02239500 gaging station has stage data for a POR from February 2, 1947, through the present. USGS Station 02239501 has a POR stage data from February 7, 1967, to June 30, 1972, and November 21, 2003, through the present. Using the stage data for the concurrent POR between these two gaging stations, a simple linear regression equation was developed. The linear regression equation was used to estimate missing stages at the USGS 02239501 Station. As previously discussed, a spatially homogenized flow time series is used in the MFLs analysis and is referred to as the "USGS-adjusted" data set. See the Hydrology section and Appendix B for more details.

Flow Time Series Period of Record

A significant hydrologic change in the Silver Springs flow regime appears around the year 2000. The post-2000 period has not yet been shown to be a permanent hydrologic and/or ecological shift. Therefore, this MFLs determination is based on both pre- and post-2000 hydrologic data and encompasses a POR from 1946 to 2014. See Appendix B for more details on the flow time series used for the MFLs determination and assessment.

Transfer of Stages to 02239501 Gage

The critical elevations of MFLs thresholds were calculated from field data at the different MFLs transects along the Silver River. However, the recommended MFLs regime is set at the USGS 02239501 gaging station. The further the distance of the MFLs transect from the USGS 02239501 gaging station, the weaker the relationship between the stages. Backwater effects from the Ocklawaha River complicate these relationships, particularly for downstream MFLs transects. Therefore, regression equations were developed in a sequential manner. All MFLs elevation data were transferred to the USGS 02239501 gaging station using this method. See Appendix B for more details.

Stage — Flow Relationships

Due in part to the backwater effect from the Ocklawaha River, and potentially due to changes in channel roughness over time, there is no single Silver River flow that can be related to a single stage. Minimum stages determined based on the environmental analyses described above (and in the Results and Discussion section) were translated to minimum flows using a rating curve of the "USGS-adjusted" flow time series for 1946 to 2014. This process is described in Appendix B.

MFLs Status Assessment

Hydrologic Data Analyses for MFLs Assessment

MFLs status is assessed by comparing the MFLs condition with the current impacted condition, called the "baseline" condition. Using frequency analysis, or other methods, the MFLs and baseline conditions are compared to determine if there is currently water available for withdrawal (freeboard). MFLs are achieved if the freeboard is greater than or equal to zero. If freeboard is less than zero, a water body is in recovery. If freeboard is projected to be less than zero within the 20-year planning horizon the water body is in prevention.

Hydrological analyses are conducted to characterize the hydrological (flow and/or stage) regime that exists under the baseline condition for assessment of MFLs current status. Two key types of information are required to generate this baseline condition. The first is an estimate of the long-term variability in the system, which is represented by long-term flow or stage time series. This provides the long-term frequency distribution of high, low and average conditions for a given water body. This is determined using various types of data analyses, groundwater models and, in many cases, surface water models to general long-term time series (stages, flows, groundwater levels, climate). However, the flow and stage time series at Silver Springs are sufficiently long for MFLs assessment, and the use of a surface water model was not necessary.

The second requirement for establishing the baseline condition is a best estimate of current impact due to water withdrawal. This is typically determined using best available groundwater models and water use data.

No-pumping condition

The no-pumping condition represents the Silver River flow time series as if there had been minimal consumptive use of water during the POR. The no-pumping condition was created by adding an estimate of impact due to historical pumping (i.e., spring flow reduction due to pumping) to each year in the USGS-adjusted observed record. The estimated groundwater pumping in the region and the NDMv5 groundwater model were used to estimate the impact due to historical pumping. See Appendix B for more details on the calculation of impact due to pumping and creation of the no-pumping condition flow time series.

Baseline condition

The baseline condition represents a best estimate of current impacted condition, and for the Silver Springs MFLs is defined as the 2010-pumping condition. The baseline condition incorporates the natural variability of the flow time series, as if impacted by pumping equal to that caused by 2010 water use. The baseline year was chosen because it was necessary to use the most current regional groundwater model output available. See Appendix B, section 6 for more details on the baseline condition.

Current Status

MFLs status was assessed using frequency analysis to compare the frequency of critical ecological events under baseline conditions to the frequency of those same events based on the recommended MFLs. Frequency analysis was used to determine the amount of water available for withdrawal (freeboard), defined as the flow reduction (cfs) that is allowable before the most constraining MFL is no longer achieved.

Frequency analysis is used to estimate how often, on average over the long term, a given environmentally important event will occur, and to compare that frequency with the recommended MFLs frequency. Using annual series data generated from a flow time series (e.g., baseline condition), frequency analysis is used to estimate the probability of a given hydrologic (exceedance or non-exceedance) event happening in any given year. Annual series data are ranked using the Weibull plotting position formula:

$$P(S \geq \hat{S}_m) = \frac{m}{n+1}$$

Ranked data are then graphed on a frequency plot, thus summarizing the flow characteristics of the water body. The annual flow frequency under baseline conditions plotted and compared graphically to the recommended flow for each MFL. The difference between baseline condition flow and minimum flow constitutes the allowable flow reduction (freeboard) or necessary recovery before the MFLs is achieved (deficit).

Future / Projected Status

If the MFLs are currently being achieved but are projected to not be achieved within the 20-year planning horizon, then a water body is in “prevention,” and a prevention strategy must be developed. Whether an MFLs is being achieved within the planning horizon is determined by comparing the freeboard under baseline conditions to the amount of projected flow reduction at the planning horizon. For Silver Springs, the projected drawdown at 2035 was estimated using version 5 of the NDMv5 (SJRWMD 2017).

Ongoing Status / Adaptive Management

A screening level analysis, which incorporates change in rainfall trend and uncertainty in MFLs, will be performed approximately every five years to monitor the status of an adopted MFL, as well as when permit applications are considered that may impact an MFL. If the screening level analysis shows that MFLs are being met based on the rainfall-adjusted flows or levels, then no further actions are required beyond continued monitoring. If the analysis shows that MFLs are not being met, or are trending toward not being met based on the rainfall-adjusted flows and levels, SJRWMD will conduct a cause-and-effect analysis to independently evaluate the potential impacts of various stressors on the MFLs water body being assessed. Factors other than consumptive uses of water (e.g., long-term drought) can cause the flow or level of a surface watercourse, aquifer, surface water, or spring to drop below an adopted minimum flow or level. Factors to be considered in the determination of causation include, but are not limited to:

- rainfall or other climatic variables;
- consumptive use;
- land use changes or development;
- surface water drainage;
- geology/hydromorphology (e.g., sinkhole formation);
- water levels/flows in other appropriate water resources (e.g., nearby wells, lakes, streams, wetlands); and
- ecological assessment information.

The types of tools used in the causation analysis include, but are not limited to:

- double-mass analyses;
- rainfall/flow statistical analysis or flow regression;
- stage/duration/return interval analysis;
- modeling (regional, groundwater, ecological or water budget models); and
- ecological tools.

SJRWMD will assess existing MFLs criteria and any associated recovery and prevention strategies to determine the effectiveness of the strategies in recovering from or preventing significant harm to the water body.

CONSIDERATION OF WATER RESOURCE VALUES UNDER 62-40.473, *F.A.C.*

Pursuant to Sections 373.042 and 373.0421, F.S., SJRWMD considered the following 10 environmental values identified in rule 62-40.473, F.A.C.. A screening analysis of these environmental values was conducted and is described in the Results and Discussion section; the screening analysis table is presented in Appendix F. The effect of the recommended MFL was evaluated for all relevant environmental values by ATM and is presented in Appendix E.

1. Recreation in and on the water—The active use of water resources and associated natural systems for personal activity and enjoyment. These legal water sports and activities may include, but are not limited to swimming, scuba diving, water skiing, boating, fishing, and hunting.

2. Fish and wildlife habitat and the passage of fish—Aquatic and wetland environments required by fish and wildlife, including endangered, endemic, listed, regionally rare, recreationally or commercially important, or keystone species; to live, grow, and migrate. These environments include hydrologic magnitudes, frequencies, and durations sufficient to support the life cycles of aquatic, wetland and wetland-dependent species.

3. Estuarine resources—Coastal systems and their associated natural resources that depend on the habitat where oceanic salt water meets freshwater. These highly productive aquatic systems have properties that usually fluctuate between those of marine and freshwater habitats.

4. Transfer of detrital material—The movement by surface water of loose organic material and associated biota.

5. Maintenance of freshwater storage and supply—The protection of an adequate amount of freshwater for non-consumptive uses and environmental values associated with coastal, estuarine, riverine, spring, aquatic, and wetlands ecology.

6. Aesthetic and scenic attributes—Those features of a natural or modified waterscape usually associated with passive uses, such as bird-watching, sightseeing, hiking, photography, contemplation, painting and other forms of relaxation.

7. Filtration and absorption of nutrients and other pollutants—The reduction in concentration of nutrients and other pollutants through the process of filtration and absorption (i.e., removal of suspended and dissolved materials) as these substances move through the water column, soil or substrate, and associated organisms.

8. Sediment loads—The transport of inorganic material, suspended in water, which may settle or rise. These processes are often dependent upon the volume and velocity of surface water moving through the system.

9. Water quality—The chemical and physical properties of the aqueous phase (i.e., water) of a water body (lentic) or a watercourse (lotic) not included in definition number 7 (i.e., nutrients and other pollutants).

10. Navigation—The safe passage of watercraft (e.g., boats and ships), which is dependent upon adequate water depth and channel width.

RESULTS AND DISCUSSION

This section briefly describes elevation, soil, and vegetation data collected at MFLs transects. A detailed description of vegetation and soils data is located in Appendix A. The rationale for criteria and recommended minimum flows are also presented, along with a discussion of the effect of these flows on maintaining ecological structure and function of wetland and aquatic communities.

MFLs Transect Sites

The four field transects used for the Silver Springs MFLs determination are a subset of the 12 hydrologic transects established in 2003 by DeGrove Surveyors, Inc. under SJRWMD direction (Figure 4). Transects 3, 5, 7, and 9 were deemed representative sites based on review of aerial photography, inspection of vegetation and soils maps, and field reconnaissance visits. FDEP issued permits (Numbers 07110301 and 09140733) for the proposed data collection activities. Necessary permits were also obtained from Silver River State Park and the Silver Springs Theme Park prior to field work.
Soils and vegetation sampling took place between July 2003 and 2012 and involved staff from SJRWMD, BCI Engineers and Scientists, AEV Consulting, and Jones, Edmunds and Associates. SJRWMD staff surveyed transect elevations using benchmarks installed by DeGrove Surveyors Inc. SJRWMD Bureau of Water Resource Information staff installed and monitored water level gages at Transects 1, 3, 5, 7, and 9. All elevations are relative to 1929 National Geodetic Vertical Datum (NGVD). Photographs of MFLs transects are presented in Appendix A.

Recommended MFLs are derived in part from elevations of delineated plant communities and associated soil characteristics. In general, hydric soil data supported the delineation of plant communities. Plant community data were also supplemented with semi-quantitative line intercept measurements, which was used in a split moving windows analysis (for more details on the split moving windows analysis, see Appendix A). However, in general, vegetation discontinuities identified by this approach did not significantly change the delineated community boundaries since many breaks were the result of changes in vegetation composition, such as decreased groundcover or overstory that did not signal a habitat/community change.

Transect 3 Field Data Collection

Transect 3 is located approximately 1.2 river miles upstream of the confluence with the Ocklawaha River (Figure 4). It begins in the uplands north of the floodplain and extends 2,000 ft across the floodplain and channel to end near the uplands south of the river (Figure 4 and Appendix A). Figure 34 provides a topographic cross-section with vegetation and soils features as well as elevation summary statistics.

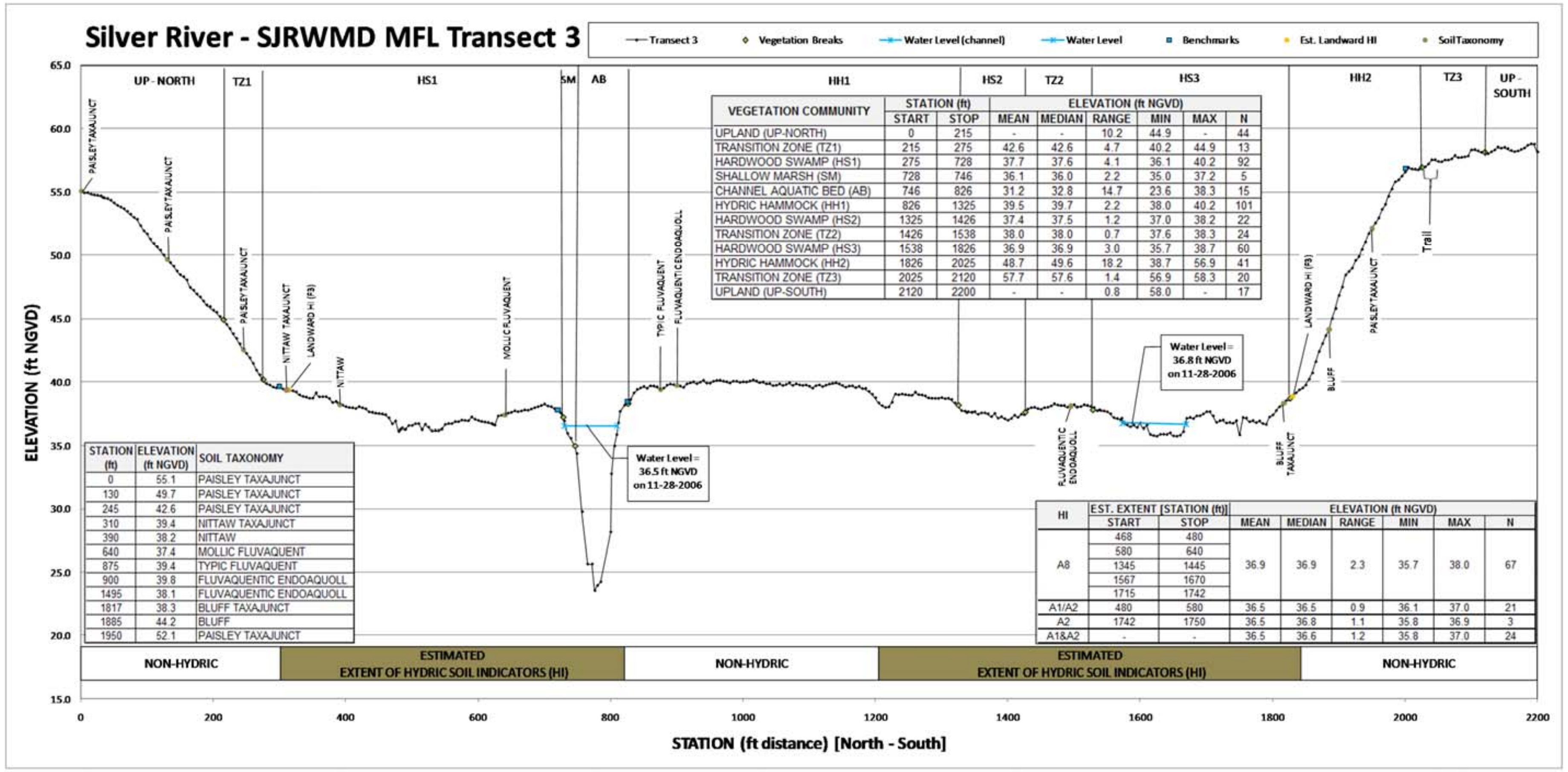


Figure 34. Elevation cross-section of MFLs Transect 3 plant communities and hydric soil indicators

Transect 5 Field Data Collection

Silver River Transect 5 is located approximately 2.2 river miles upstream of the confluence with the Ocklawaha River and extends 1,600 ft from the northern uplands, across the floodplain and river channel, to the uplands south of the floodplain (Figure 4 and Appendix A). Figure 35 provides a topographic cross-section with vegetation and soils features, as well as elevation summary statistics.

Transect 7 Field Data Collection

Transect 7 is located approximately 3.7 river miles upstream of the confluence with the Ocklawaha River and extends 2,175 ft from the northern uplands, across the floodplain and river channel, to the uplands south of the floodplain (Figure 4 and Appendix A). Figure 36 provides a topographic cross-section with vegetation and soils features, as well as elevation summary statistics.

Transect 9 Field Data Collection

Transect 9 is located approximately 4.5 river miles upstream of the confluence with the Ocklawaha River and is the transect closest to the USGS 02239501 gaging station and Half Mile Creek (Figure 4 and Appendix A). Transect 9 extends 1,400 ft from the northern uplands, across the floodplain and river channel, to the uplands south of the floodplain. Figure 37 provides a topographic cross-section with vegetation and soils features, as well as elevation summary statistics.

Additional Data Collection Transects

Additional cross-sections were surveyed to assess spatial and depth restrictions for boats at low water levels. These included 12 transects at shallow points along the routes of glass bottom boat tours (Figure 38) and seven transects at various other points (Figure 39). Appendix C shows cross-section profiles and Appendix D provides information on glass bottom boat dimensions. These data are important for evaluating effects of recommended MFLs on the environmental values of recreation, aesthetics, and navigation/ boat passage (Appendix E). Several short transects were also collected along the edge of the Silver River channel to assess the distribution of emergent marsh species.

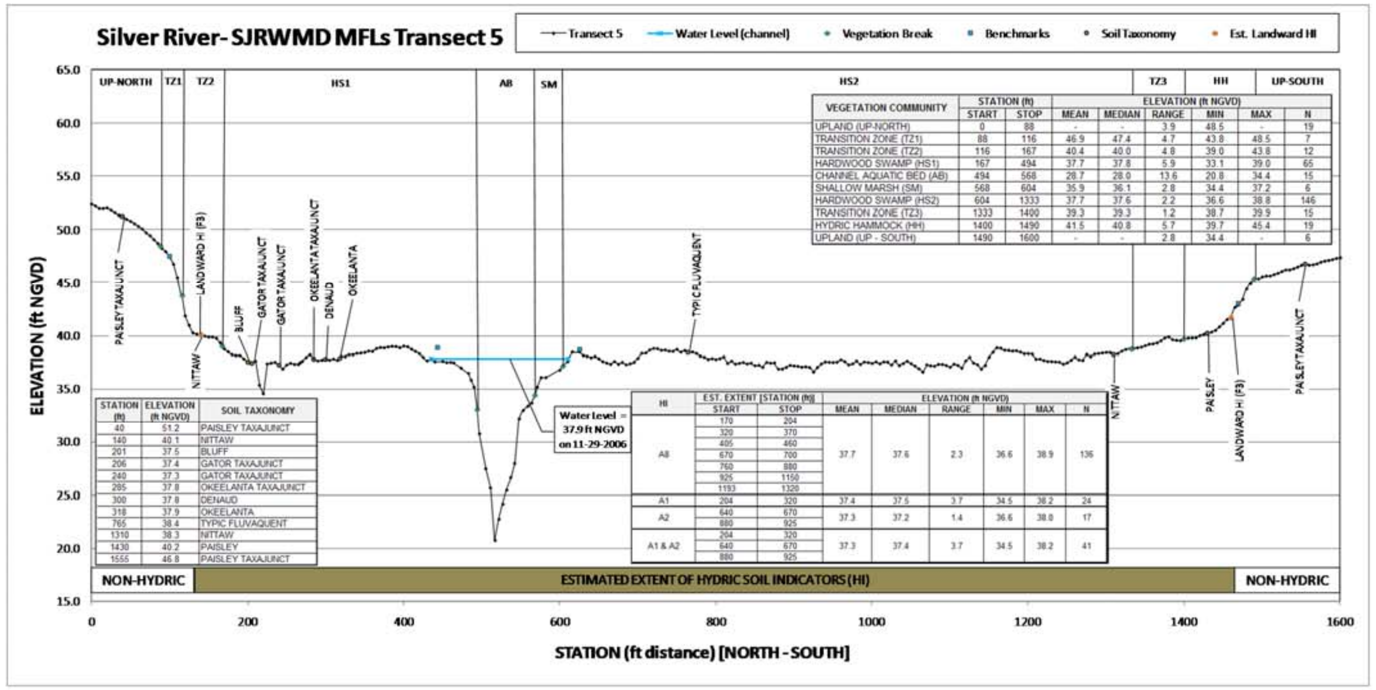
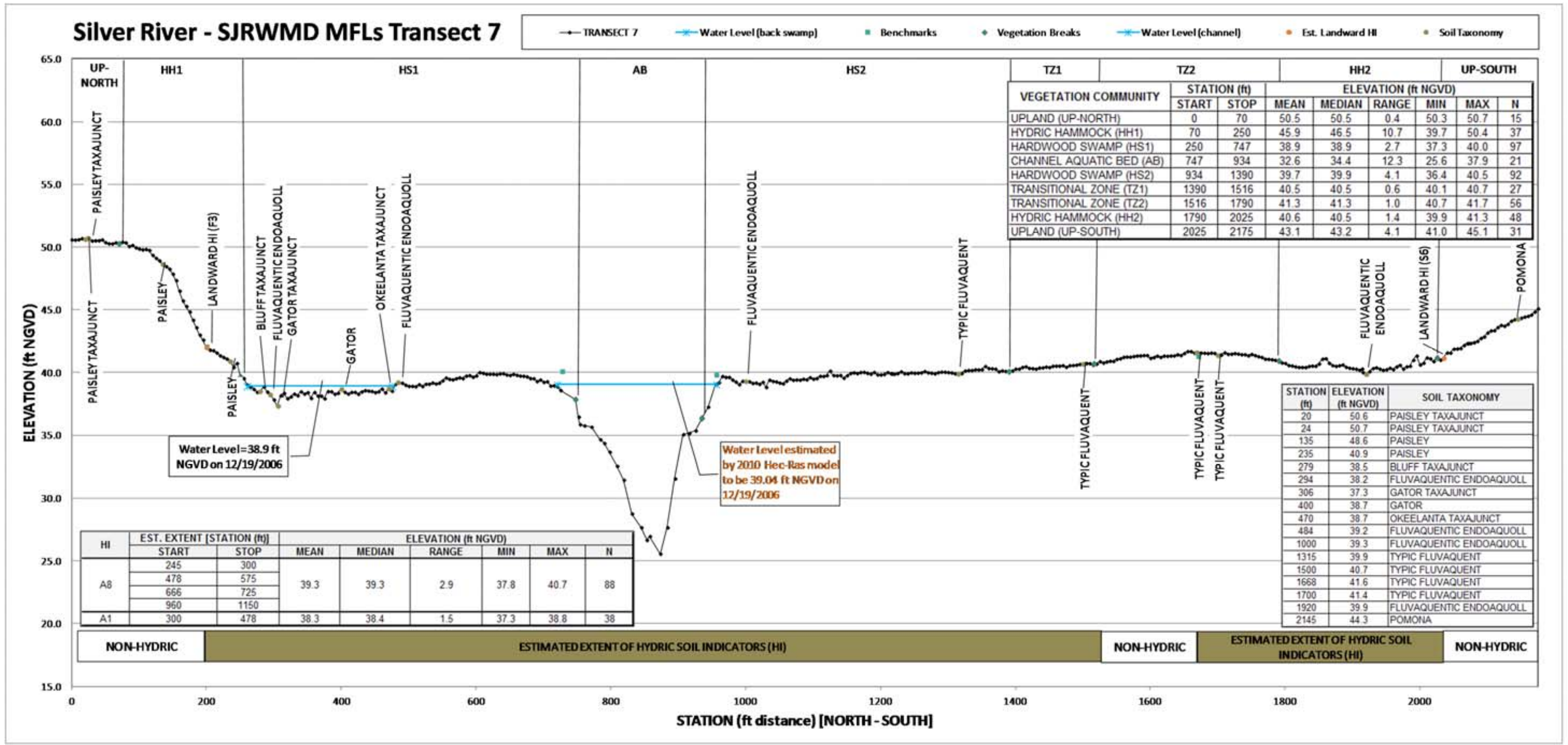


Figure 35. Elevation cross-section of MFLs Transect 5 plant communities and hydric soil indicators



VEGETATION COMMUNITY	STATION (ft)		ELEVATION (ft NGVD)					
	START	STOP	MEAN	MEDIAN	RANGE	MIN	MAX	N
UPLAND (UP-NORTH)	0	70	50.5	50.5	0.4	50.3	50.7	15
HYDRIC HAMMOCK (HH1)	70	250	45.9	46.5	10.7	39.7	50.4	37
HARDWOOD SWAMP (HS1)	250	747	38.9	38.9	2.7	37.3	40.0	97
CHANNEL AQUATIC BED (AB)	747	934	32.6	34.4	12.3	25.6	37.9	21
HARDWOOD SWAMP (HS2)	934	1390	39.7	39.9	4.1	36.4	40.5	92
TRANSITIONAL ZONE (TZ1)	1390	1516	40.5	40.5	0.6	40.1	40.7	27
TRANSITIONAL ZONE (TZ2)	1516	1790	41.3	41.3	1.0	40.7	41.7	56
HYDRIC HAMMOCK (HH2)	1790	2025	40.6	40.5	1.4	39.9	41.3	48
UPLAND (UP-SOUTH)	2025	2175	43.1	43.2	4.1	41.0	45.1	31

HI	EST. EXTENT [STATION (ft)]		ELEVATION (ft NGVD)					
	START	STOP	MEAN	MEDIAN	RANGE	MIN	MAX	N
A8	245	300	39.3	39.3	2.9	37.8	40.7	88
	478	575						
	666	725						
	960	1150						
A1	300	478	38.3	38.4	1.5	37.3	38.8	38

STATION (ft)	ELEVATION (ft NGVD)	SOIL TAXONOMY
20	50.6	PAISLEY TAXAJUNCT
24	50.7	PAISLEY TAXAJUNCT
135	48.6	PAISLEY
235	40.9	PAISLEY
279	38.5	BLUFF TAXAJUNCT
294	38.2	FLUVAQUENTIC ENDOAQUOLL
306	37.3	GATOR TAXAJUNCT
400	38.7	GATOR
470	38.7	OKEELANTA TAXAJUNCT
484	39.2	FLUVAQUENTIC ENDOAQUOLL
1000	39.3	FLUVAQUENTIC ENDOAQUOLL
1315	39.9	TYPIC FLUVAQUENT
1500	40.7	TYPIC FLUVAQUENT
1668	41.6	TYPIC FLUVAQUENT
1700	41.4	TYPIC FLUVAQUENT
1920	39.9	FLUVAQUENTIC ENDOAQUOLL
2145	44.3	POMONA

Figure 36. Elevation cross-section of MFLs Transect 7 plant communities and hydric soil indicators

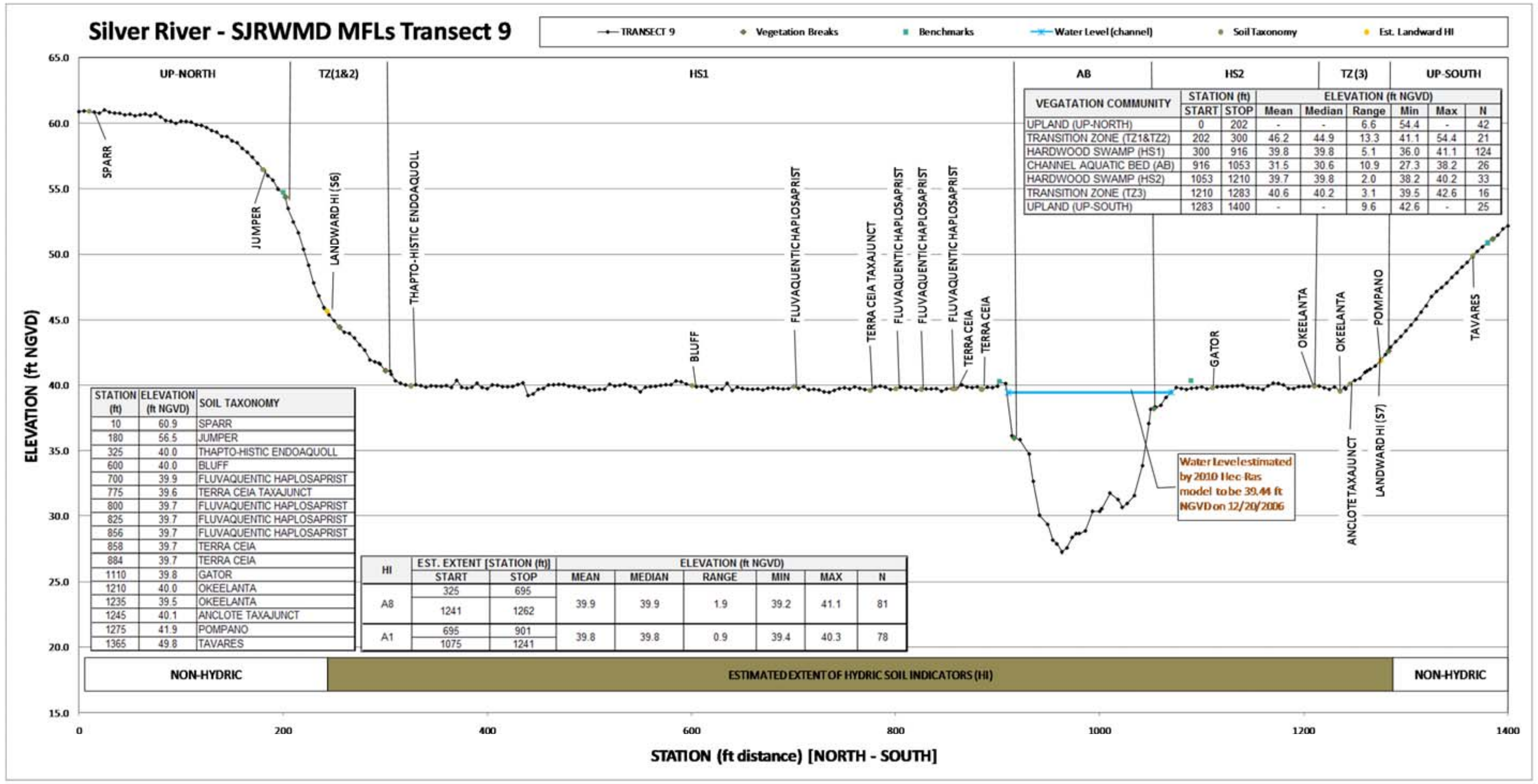


Figure 37. Elevation cross-section of MFLs Transect 9 plant communities and hydric soil indicators

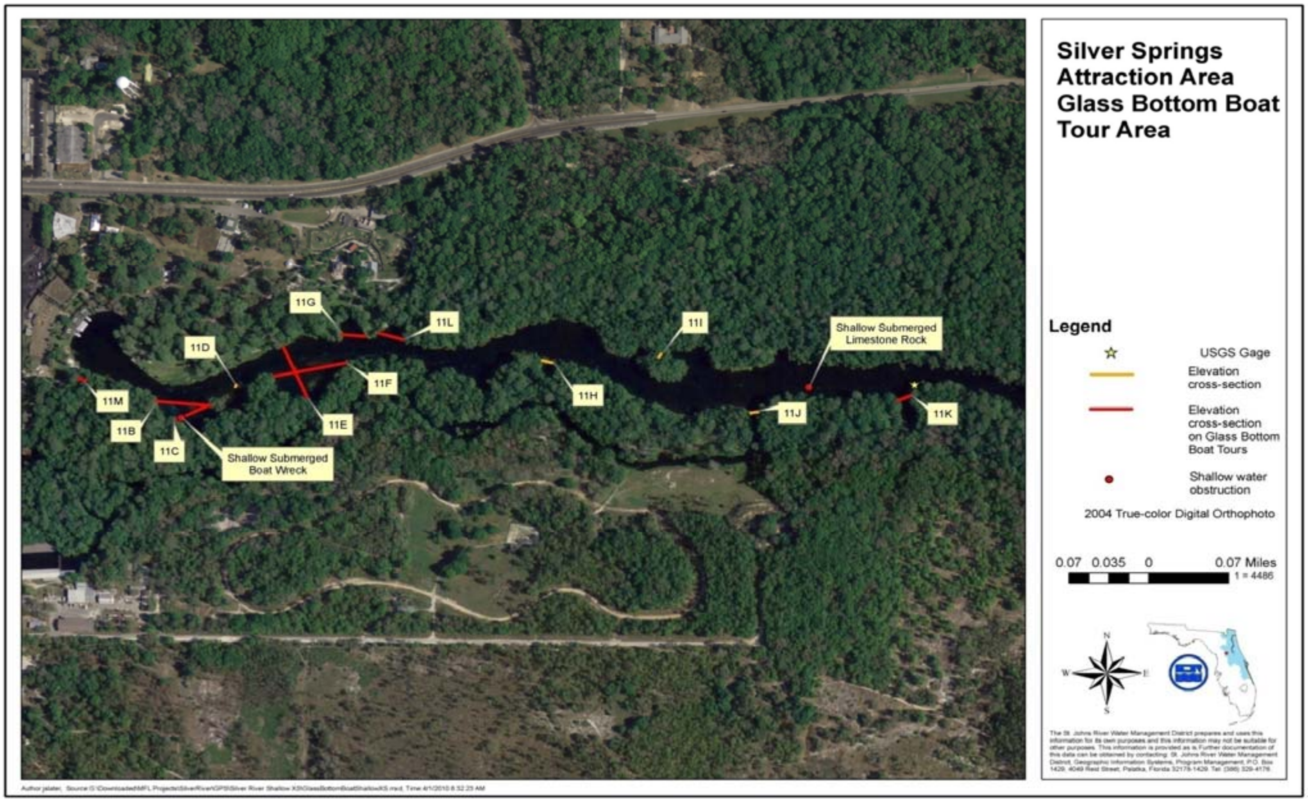


Figure 38. Location map of Silver River shallow river cross sections in Silver Springs theme park

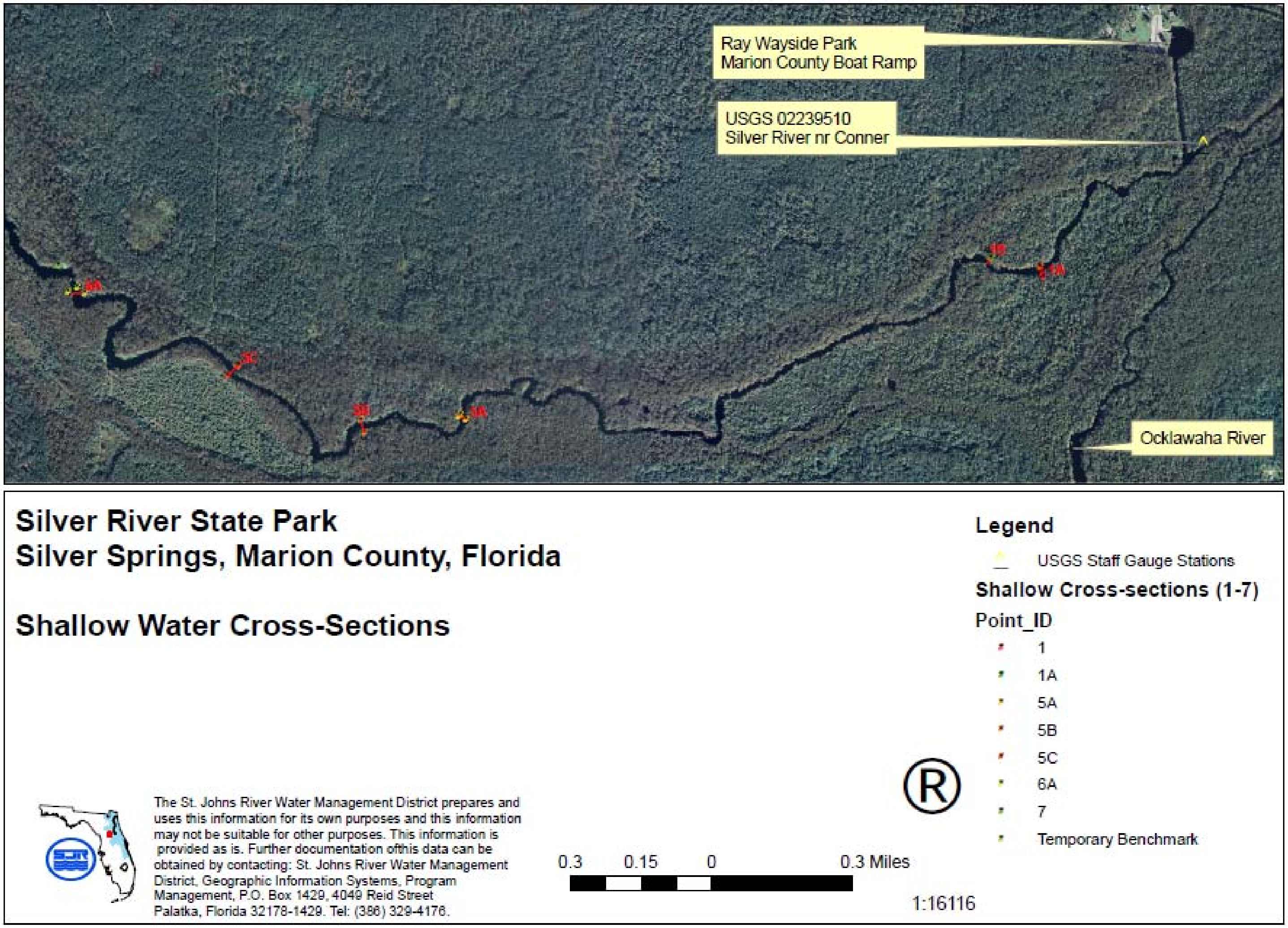


Figure 39. Shallow river cross-sections in the Silver River State Park

MINIMUM FLOWS DETERMINATION FOR SILVER SPRINGS

An environmental values screening analysis (Appendix F) identified two relevant values that are considered to be sensitive to the consumptive use of water. These include “fish and wildlife habitats and the passage of fish” and “filtration and absorption of nutrients and other pollutants.” Therefore, these environmental values informed the development of MFLs protection criteria. Because the recommended MFLs should protect the most sensitive environmental values, they should also protect the remaining functions, values and beneficial uses of Silver Springs.

Three minimum flows are recommended for Silver Springs based on minimum levels that protect ecological functions of the Silver River. The recommended MFLs are minimum frequent high (FH), minimum average (MA), and minimum frequent low (FL), each with associated durations and return intervals. These MFLs protect the natural flow regime of Silver Springs and Silver River and ensure that the range of water levels and flows will persist over the long term. The recommended MFLs define the minimum number of flooding events per century (FH) or the maximum number of dewatering events per century (MA and FL), on average, needed to protect ecologically important and hydrologically sensitive functions from significant ecological harm caused by groundwater withdrawals.

The recommended FH provides sufficient numbers of flood events to protect the entire extent of floodplain wetlands and their wildlife habitat values. These flood events also promote filtration and absorption of nutrients and other pollutants on the floodplain. The recommended MA prevents an excessive number of dewatering events to protect organic soils from oxidation and subsidence and avoid adverse impacts to habitat and water quality. The recommended FL prevents an excessive number of dewatering events to protect marsh ecotones along the Silver River and their associated wildlife values. The FL also maintains an appropriate water table level in soils of the floodplain during periodic droughts.

Minimum Frequent High (FH) Flow: 828 cfs, 30-day continuous flood duration, 5-year return interval at the USGS 02239501 gaging station.

The goal of the recommended FH is to ensure sufficient flooding to maintain wetland vegetation, hydric soils, and their associated wildlife habitats and biogeochemical processes.

The general indicator of protection is frequently inundated conditions in the hardwood swamps sufficient to maintain species composition, vegetative structure, and associated ecological functions. Withdrawals should not reduce the number of flooding events in hardwood swamps beyond the return interval threshold of the FH. These high-water level events occur during wet seasons in periods of normal or above normal precipitation.

The specific indicator of protection is a water level/flow at the maximum elevation of the hardwood swamps, which is the ecotone between hardwood swamp and higher elevation, infrequently flooded wetlands such as hydric hammocks. This level is flooded for 30 continuous days with a 5-year return interval.

FH Magnitude Components

A recommended FH elevation of 40.8 ft NGVD was calculated by transferring the maximum elevations of the hardwood swamp communities surveyed at Transects 3, 5, 7, and 9 to the USGS 02239501 gaging station and then averaging the four transferred elevations (Table 9). The FH elevation was then converted to a recommended flow using a rating curve which resulted in a FH flow of 828 cfs (Appendix B). The FH event influences the following physical, biological, and biogeochemical processes:

- Supports hydrophytic vegetation and hydric soils of hardwood swamps and emergent marshes.
- Connects the entire floodplain to the river thereby providing opportunities for aquatic fauna to feed, spawn, and seek refuge.
- Promotes denitrification and nutrient cycling processes and promotes organic soil accrual by providing long duration floods at lower elevations in the floodplain.
- The FH elevation approximates the extent of the active floodplain at Silver River. Floods structure the physical environment of riverine ecosystems by creating geomorphic features and establishing boundaries with adjacent uplands.

FH Duration Component

The recommended FH duration of 30 days continuous inundation is derived from scientific literature indicating that seasonally flooded hardwood swamps are inundated for one to two months during the growing season (Mitsch and Gosselink 1993). A 30-day continuous flood event is sufficiently long to protect the structure and functions of seasonally flooded wetland plant communities (Hill et al. 1991). Junk et al. (1989) reported that short-term flooding events are important to redistribute plant seeds within aquatic habitats. The life cycles of many fishes are related to seasonal water level fluctuations, particularly annual flood patterns (Guillory 1979).

The 30-day flooding duration at the target elevation of 40.8 ft NGVD will also provide longer duration flooding for lower hardwood swamp elevations. For example, the average of the mean elevations of the hardwood swamps located on each MFLs transect (elevation range 37.4 [T3] to 39.7 [T9] ft NGVD) will have flooding durations of 180 to greater than 365 days when the FH event is achieved, albeit for a slightly reduced return interval when compared to the baseline condition. Therefore, the 30-day duration allows the majority of the floodplain habitat to be exploited by fish and other aquatic fauna to feed, reproduce, and/or use the available floodplain habitat for refuge.

In addition, the 30-day flooding duration is sufficient to cause the mortality of young upland plant species that have become established in the hardwood swamps during low water events, maintaining the hydrophytic structure and diversity of the hardwood swamp communities

(Ahlgren and Hansen 1957; Menges and Marks 2008). Research shows that abundant hypertrophied lenticels and adventitious roots develop in loblolly pine and pond pine after 30 continuous days of anaerobic conditions (Topa and McLeod 1986). Bell and Johnson (1974) found that species intolerant of flooding exhibited severe effects with less than 50 days of flooding during the growing season.

The 30-day flooding duration roughly corresponds to the durations of saturation that define the upper boundaries of many wetlands. From a regulatory standpoint, the U.S. Army Corps of Engineers uses durations of saturation between 5 and 12.5% of the growing season in most years as the standard in its wetland delineation manual (Environmental Laboratory 1987). Given the year-round growing season in Florida, this corresponds to durations of 18 to 46 days. However, the National Research Council (1995) has recommended a shorter duration hydroperiod to define wetland hydrology: saturation within 1 ft of the soil surface for a duration of two weeks (14 days) or more during the growing season in most years. This shorter duration hydroperiod may approximate the hydrology of the transitional wetland communities that occur upslope of the hardwood swamps along much of the Silver River floodplain.

FH Return Interval Component

Rule 40C-8.021(18), *F.A.C.*, describes the "temporarily flooded" hydroperiod category as follows: "…where surface water is present or the substrate is flooded for brief periods (up to several weeks) approximately every five years." This supports the proposed 5-year return interval for the FH along the Silver River. In contrast, the "seasonally flooded" hydroperiod category in Rule 40C-8.021 (16), *F.A.C.*, is more applicable to the average elevation of hardwood swamp, which should recur more frequently (i.e. every 1 to 2 years).

A SWIDS dataset for maximum elevations of nine hardwood swamps at Silver River (Figure 40) was evaluated to select an appropriate return interval for the FH. The recommended 5-year return interval (20%probability) occurs in the second driest quartile. The driest three systems (HS #1 and 2 at Transect 9, HS #2 at Transect 7) may be inappropriate reference sites because they appear influenced by seepage from the adjacent uplands, which have highly permeable, deep sandy soils (Figures 34-37; Freese, 2010; SCS, 1979) that contribute seepage to the floodplain. In contrast, the remaining hardwood swamps in the SWIDS dataset are adjacent to uplands with impermeable clay soils (Paisley series) that contribute little seepage. Therefore, the recommended 5-year return interval is near the driest margin of those sites that are most directly influenced by the river. This return interval is an estimate of the minimum frequency of flooding that this vegetation feature and associated functions can sustain.

Flow frequency analysis (Figure 41) shows that the FH flooding event under no-pumping conditions has a probability of approximately 39% (2.6-year return interval) while under baseline conditions, it has a probability of 35% (2.9-year return interval), a decrease of four flooding events per century. The recommended FH return interval of 20%

Table 9. Elevations (feet NGVD) of Silver River floodplain features transferred from MFLs transects to USGS 02239501 gaging station

Level	Transect	Feature	Elevation at Transect	Elevation at 02239501 Gage	Mean MFLs Elevation at 02239501 Gage
FH	3	Avg max HS*	39.02	41.13	40.81
FH	5	Avg max HS*	38.94	40.61	
FH	7	Avg max HS*	40.26	40.78	
FH	9	Avg max HS*	40.64	40.70	
MA	3	Avg organic soil —0.3 ft	36.22	39.06	39.01
MA	5	Avg organic soil —0.3 ft	37.02	38.86	
MA	7	Avg organic soil —0.3 ft	38.01	38.53	
MA	9	Avg organic soil —0.3 ft	39.49	39.57	
MFLs #1	3	Avg max Nuphar	34.22	38.18	37.85
MFLs #1	5	Avg max Nuphar	35.49	38.13	
MFLs #1	7	Avg max Nuphar	36.72	37.27	
MFLs #2	3	Avg organic soil —1.67 ft	34.85	38.17	37.92
MFLs #2	5	Avg organic soil —1.67 ft	35.65	38.14	
MFLs #2	7	Avg organic soil —1.67 ft	36.64	37.15	
MFLs #2	9	Avg organic soil —1.67 ft	38.12	38.22	

*HS= Hardwood Swamp

(5-year return interval) would allow 15 fewer events per century from baseline conditions and a decrease of approximately 19 events relative to the no-pumping condition.

The 5-year return interval represents a flow of 926 cfs under 2010 conditions and a flow of 828 cfs under MFLs conditions, a difference of 98 cfs. This represents the allowable reduction (i.e. freeboard) in Silver Springs flow that can occur before the FH flow is not achieved. However, since the FH is much less sensitive than the other two MFLs, it does not set the limit to further groundwater withdrawals.

Benefits of the FH for Ecological Structure and Function

<u>Physical Processes</u>

Flood events structure the physical environment of riverine ecosystems (Hill et al. 1991, Leopold 1995, Ritter et al. 1995, Poole 2002). They remove debris and redeposit sediment to create microtopographic features that support biological diversity as well as maintaining geomorphic features and establishing boundaries with adjacent uplands. Since the maximum elevations of hardwood swamps occur near the landward edge of the active floodplain at the four transects, the FH ensures that the dynamic flood processes that shape the physical environment will continue.

<u>Wetland Vegetation and Hydric Soils</u>

Flooding events at the FH elevation also support hydrophytic vegetation and hydric soils of hardwood swamps and emergent marshes (Appendix A). Hydric hammock and transitional wetlands located upslope of the FH elevation are supported by infrequent flooding and by seepage from adjacent uplands. The FH protects the spatial extent of seasonally flooded wetlands by killing upland species that encroach into wetlands during droughts. For example, the FH will flood mean elevations of hardwood swamps by more than 1.0 foot and flood emergent marshes along the channel to an even greater depth.

Swamps are naturally subjected to high water table levels/flows, soil saturation, periodic and/or continuous flooding at various times of the year. The relative duration and level of flooding plays a key and often critical role in the occurrence and growth rate of tree species and other plants from seed germination, early seedling growth and survival, and later tree growth. Schneider and Sharitz (1986) and Junk et al. (1989) reported that short-term flooding events are important to the redistribution of plant seeds within aquatic habitats. The species composition and structural development of floodplain plant communities are influenced by the duration of floods occurring during the growing season (Huffman 1980). The resulting anaerobic soil condition within wetland communities favors hydrophytic vegetation that are tolerant of longer periods of soil saturation and flooding, and mortality of young upland (flood-intolerant) plant species that may have become established during low water events (CH2M Hill 2005).

Seedlings of different species exhibit different levels of tolerance to soil saturation or shallow flooding. For example, water tupelo, ash, and willow are very tolerant while oaks, American elm, sweetgum, and hackberry are intolerant (Hosner and Boyce 1962; McAlpine 1961).

These flood tolerant characteristics in seedlings are often the factor determining occurrence of a given species on a given site.

Exclusion of oxygen from the flooded soil leads to a decrease or cessation of aerobic respiration in plant roots, resulting in decreased root growth, decreased transpiration, decreased translocation, and accumulation of toxic metabolic products in root tissues (Gill 1970). Observations suggest that mature, vigorous individuals suffer less flooding damage than either seedlings or over-mature specimens of the same species. Species differ remarkably in their resistance to flooding (Gill 1970).

Soil inundation creates stresses that affect physical, chemical, and biological processes. These stresses select for a suite of species adapted to frequent floods. This occurs via decrease in or depletion of oxygen, accumulation of carbon dioxide, increased solubility of mineral substances, reduction of iron and manganese, and anaerobic decomposition of organic matter (Ponnamperuma 1972, 1984). In addition, many potential toxic compounds accumulate in flooded soils such as hydrogen sulfide, ethanol, acetaldehyde, and cyanogenic compounds (Rowe and Catlin 1971).

Wildlife Habitat

The FH gives aquatic fauna access to the entire floodplain for feeding, spawning, and refugia habitat (Guillory 1979; Ross and Baker 1983). Nutrient pulses from floodwaters and decomposition of dead plant litter stimulate primary and secondary production (Crow and McDonald 1978; Wharton et al. 1982). The life cycles of many fish are related to seasonal water level and flow fluctuations, particularly the annual flood pattern (Guillory 1979). This FH water level/flow may be exceeded during wet years, and may not occur during dry years; most aquatic fauna are adapted to year-to-year variation of the natural hydrologic regime.

The FH greatly expands the aquatic habitat for fauna. The inundation of the floodplain swamp allows sufficient flows and water depths for fish and other aquatic organisms to feed and spawn on the river floodplain. Flooding events redistribute and concentrate organic particulates (i.e., decomposing plant and animal parts, seeds, etc.) across the floodplain (Junk et al. 1989). This organic matter is assimilated by bacteria and invertebrate populations (Cuffney 1988), which, in turn, serves as food for larger fauna.

Surface water connections of the river to the floodplain are important to animal productivity and fecundity (Bain 1990; Poff et al. 1997). The life cycles of many fish are related to seasonal water level and flow fluctuations, particularly the annual flood pattern (Guillory 1979). Inundation periods encompassing peak spawning periods can potentially enhance stream fish diversity and production (Knight et al. 1991). As water levels continue to rise, the amount of vegetative structure available to aquatic organisms increases greatly as large areas of the floodplain are inundated (Light et al. 1998). This FH water level/flow may be exceeded during wet years, and may not occur during dry years; most aquatic fauna are adapted to year-to-year variation of the natural hydrologic regime.

<u>Biogeochemical and Water Quality Functions</u>

The interaction of floodwaters with biologically and chemically reactive substrates (e.g., soils, vegetation, detritus, microbial mats, etc.) promotes denitrification and nutrient cycling processes across the floodplain. The FH also affects carbon sequestration by providing long duration floods that promote organic soil accrual, which balance losses of organic matter that may occur during droughts. Although the FH event occurs for only 30 days at the maximum elevation of hardwood swamp, it occurs for a much greater duration at the mean elevation of hardwood swamp, and for a still greater duration at the mean elevation of deep organic soils.

Floodplain soils alternate between aerobic and anaerobic conditions depending on the balance of atmospheric oxygen supply and oxygen demand of the soils. Wharton and Brinson (1979) emphasized that temporal changes between reducing and oxidizing conditions at the soil surface is one of the most unique attributes of wetlands. The cyclic wet/dry regime imparts a unique chemical environment that has profound effects on nutrient cycling (Wharton et al. 1982). Reducing conditions favor metabolic pathways such as methanogenesis, sulfate reduction, and denitrification, while ammonium and phosphate will tend to diffuse from the soils to overlying water (Wharton et al. 1982). Aerobic conditions favor soil decomposition, and many of the products of anaerobic metabolism are oxidized (Wharton et al. 1982). This has important implications for nutrient cycling in floodplains.

Stream ecologists have long recognized that nutrient dynamics in lotic systems reflect the interaction of biotic processing and hydrologic transport, a foundational concept of the nutrient spiraling concept in streams (Webster and Patten 1979; Newbold et al. 1982). The overall performance or the efficiency of a wetland to retain or remove nutrients is a factor of loading rate, hydraulic residence time, and availability of substrate for microbial communities (Heffernan et al. 2010). Alluvial floodplains efficiently remove nitrogen (N) and phosphorus (P) and act as pollutant sinks (Kitchens et al. 1975; Wharton and Brinson 1979). Because the Silver River is designated as a nutrient impaired water body (specifically with regard to nitrogen loading), protection of the nutrient removal functions of floodplain wetlands is an important consideration in the development of MFLs.

Although autotrophic and heterotrophic assimilation account for most nitrogen removal in many rivers, researchers have frequently identified denitrification as the most important mechanism of NO_x removal in wetlands (Arango et al. 2008). Denitrifiers are heterotrophic bacteria that only use nitrate as an electron acceptor when oxygen is absent. Denitrification involves the reduction of NO_3 to NO_2, which is further reduced to gaseous nitrogen forms (e.g., nitric oxide [NO], nitrogen gas [N_2]) that are lost to the atmosphere (Reddy and DeLaune 2008).

Data collected by Heffernan et al. (2010) and Cohen et al. (2011) indicate that autotrophic assimilation (i.e., plant uptake) accounts for a small proportion of observed NO_x removal in Florida spring run rivers, including Silver River. Additionally, they found the rate of NO_x removal by denitrification was 3 to 5 times greater than the rate of NO_x removal by autotrophic assimilation in all spring runs assessed. Additionally, sharp declines in NO_x

concentrations coincided with spikes in river stage associated with flooding. The mass of NO_x removed within the spring runs exhibited strong positive relationships with both river flow and stage. Increased NO_x removal at elevated stage is consistent with studies from other large rivers, in which floodplains are important sites of NO_x removal via denitrification (Wharton and Brinson 1979; Pinay et al. 2000; Hendrickson 2012).

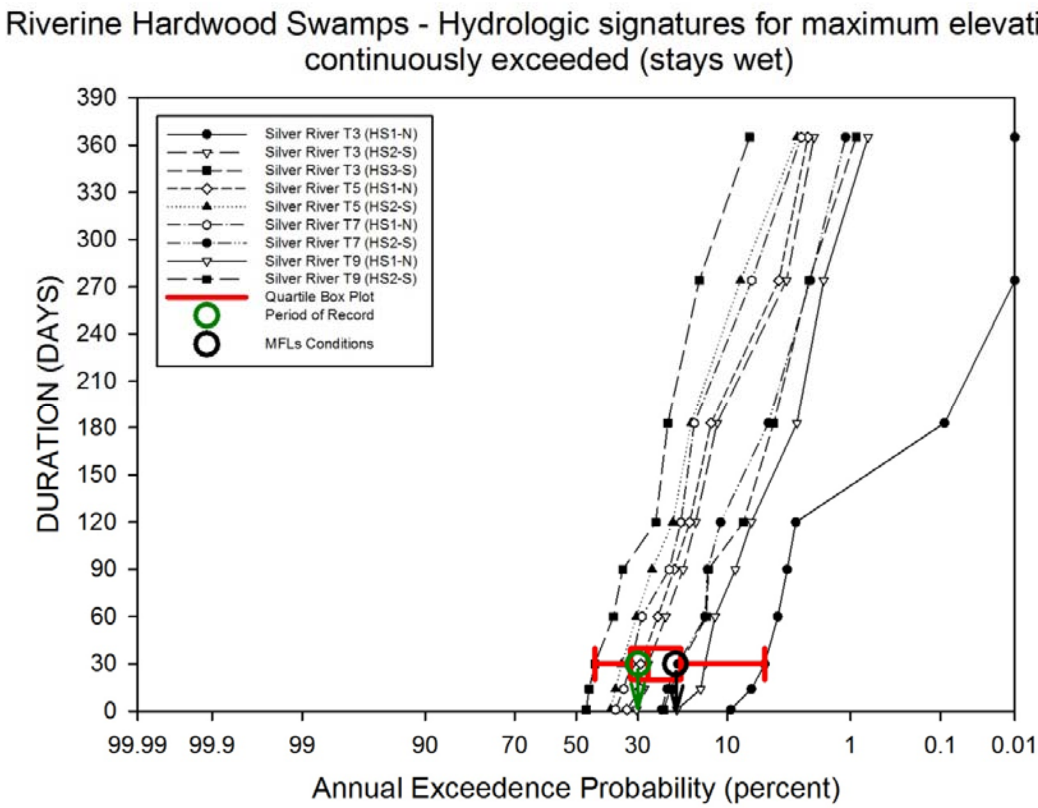


Figure 40. Hydrologic signatures for maximum elevations of nine hardwood swamps at Silver River

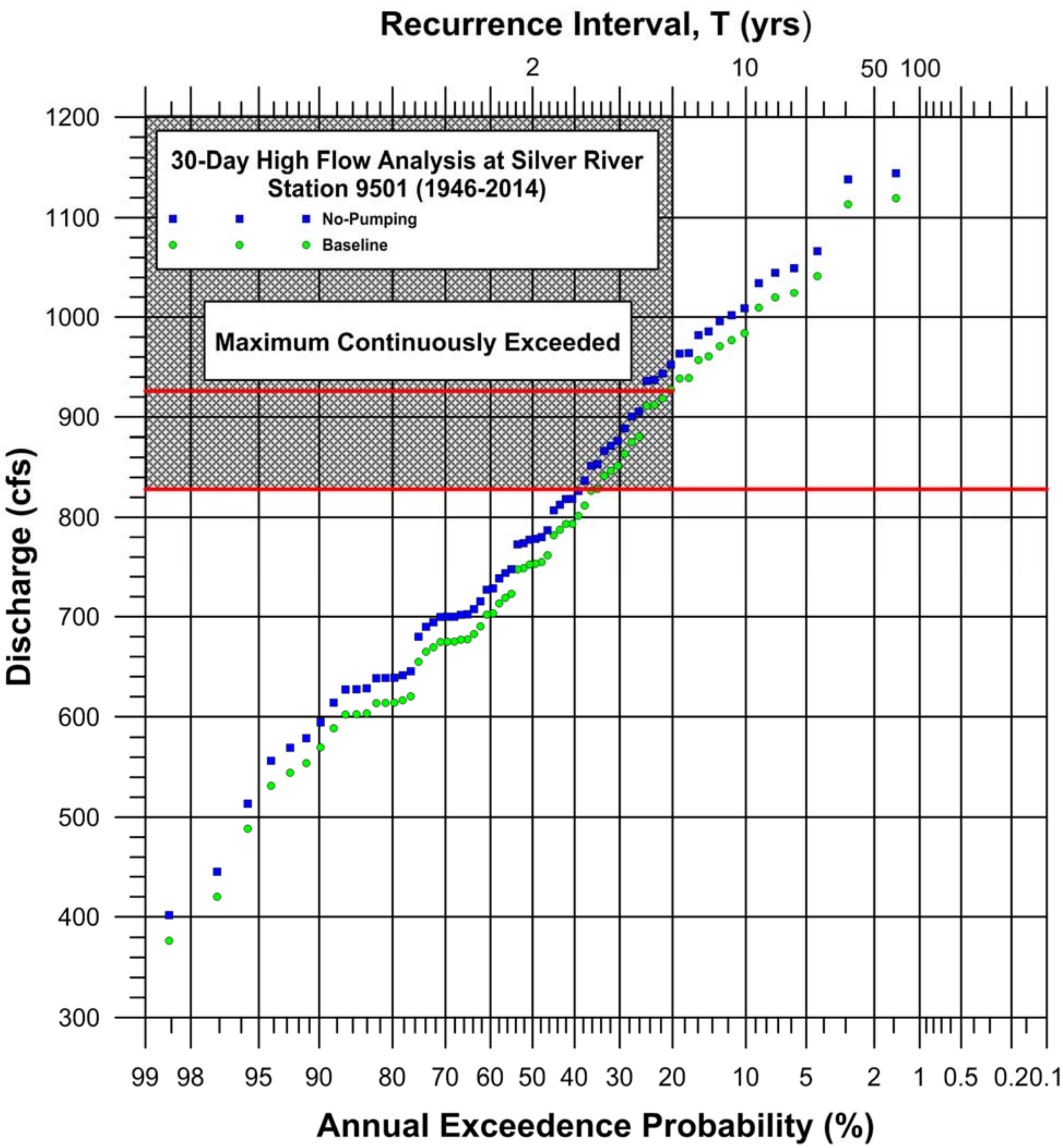


Figure 41. Flow frequency analysis for the FH, depicting no-pumping and baseline conditions relative to recommended minimum flow (bottom red line).

Minimum Average (MA) Flow: 638 cfs, 180-day mean nonexceedence duration, 1.7-year return interval at the USGS 02239501 gaging station.

The goal of the recommended MA is to prevent excessive drying of deep organic soils of the floodplain, which could cause their oxidation and subsidence and other adverse environmental impacts.

The general indicator of protection is a low water level in the river during typical years that, while exposing the surface of organic soils, keeps their average elevation saturated. These events are usually associated with dry season conditions during periods of normal precipitation. The MA event recurs, on average, every year or two for approximately six months during the dry season. Groundwater withdrawals should not increase the number of these low water events beyond the return interval threshold of the MA.

The specific indicator of protection is a low water level that is 0.3-foot below the average surface elevation of Histosols and histic epipedons (i.e. soils with organic layers $\geq$ 8 inches thickness) at Silver River Transects 3, 5, 7, and 9. This level is dewatered for a 180-day mean duration with a 1.7-year return interval.

MA Magnitude Component

The MA elevation of 39.0 ft NGVD was calculated by transferring mean elevations (Appendix B) of organic soils minus 0.3 foot from each transect (Appendix A, Table A-2) to the USGS 02239501 gage using regression equations, and averaging the four elevations. Finally, the recommended MA level was converted to a recommended flow using a rating curve, which resulted in a flow of 638 cfs. The MA is a low water threshold that maintains the following functions:

- Maintenance of soil organic matter protects integrity of tree roots in swamps.
- Intermittent ponding across lower elevations of the floodplain favors wetland species adapted to very long hydroperiods (e.g. bald cypress). Intermittent ponds may also favor certain wildlife species adapted to long-term flooding or soil saturation.
- Sequestration of carbon and nutrients within floodplain soils prevents nutrient pulses that degrade water quality.
- The presence of both aerobic and anaerobic soil zones across the floodplain enhances processes of nitrification and denitrification, which remove nitrogen from the system and protect water quality.

The 0.3-foot offset from the mean elevation of deep organic soils is an adjustment that accounts for the zone of soil saturation above the water table known as the capillary fringe. The thickness of the capillary fringe depends on the type of soil material, distribution of roots, and varies temporally. It cannot be precisely defined (Hillel, 1998). However, redox profiles have been used to estimate the thicknesses of saturated and anaerobic zones above the water table. Saturated soils are typically anaerobic and microbial breakdown of organic matter is very slow under these conditions. Low redox potentials (200 to -400 millivolts [mV]) are associated with reduced, anaerobic submerged soils; aerobic soils have redox potentials of about 300 to 800 mV (Ponnamperuma 1972).

Reddy et al. (2006) measured redox potentials *in situ* in organic soils of the upper St. Johns River marsh, as well as in soil cores subjected to lowered water tables in the laboratory. These data can be used to infer capillary fringe thickness. The capillary fringe estimate was 5 to 10 cm (0.2 to 0.3 ft) above the static water level. Deeper water table depths (e.g., -30cm [1 ft]) appeared to have even greater rises (+10 cm [0.3 ft]) in the capillary fringe (Reddy et al. 2006). This research indicates that a water level 0.3 feet below the surface elevation of organic soils is sufficient to produce anaerobic conditions in that surface layer and thereby prevent oxidation of soil carbon.

The MA levels are 36.2, 37.0, 38.0, and 39.5 ft NGVD at Transects 3, 5, 7, and 9, respectively. These levels maintain inundation or soil saturation across much of the hardwood swamp and throughout emergent marsh plant communities (Appendix A, Table A-2). Spatterdock beds (Table 10) will be completely inundated and remain physically connected to the Silver River channel thereby providing important refugia for aquatic faunal.

MA Duration Component

The recommended 180-day mean nonexceedence duration is supported by information in county soil surveys that describe hydrologic characteristics of organic soils. These include soil series such as Gator, Terra Ceia, and Okeelanta mucks, which were identified in the Silver River floodplain (Stoddard 2009; Freese 2010; Appendix G). Official series descriptions and interpretations are available from the USDA/NRCS (U.S. Department of Agriculture/Natural Resources Conservation Service) website. These sources indicate water tables in organic soils are typically at or above the soil surface for six to nine months in most years and presumably below that elevation during the remaining months.

The 180-day mean nonexceedence duration accounts for the numerous, short duration, alternating aerobic/anaerobic conditions near the organic soil surface. Field and laboratory experiments by Reddy et al. (2006) in organic soils of the Upper St. Johns River Basin indicated that shorter duration dewatering (alternating aerobic and anaerobic conditions) events are less likely to result in oxidation of organic matter, possibly due to the wicking action of the capillary fringe. Additionally, wetland soils are a medium for denitrification, a process important in maintaining aquatic/wetland water quality. The denitrification process is most effective in wetlands subject to alternating aerobic and anaerobic conditions because the aerobic conditions allow for conversion of ammonium to nitrate (nitrification), which is then subject to denitrification (Payne 1981; Reddy and DeLaune 2008).

The 180-day mean nonexceedence duration will also maintain wetland communities by a combination of inundation and dewatering. Studies of marshes in the Upper St. Johns River Basin (Brooks and Lowe 1984; Hall 1987) determined that the elevation corresponding to the 0.3 ft organic soil water table drawdown criterion had a hydroperiod of approximately 219 days. Studies of the Wekiva River system found this hydrologic condition can also be expressed as the low stage occurring on the average every 2-years (i.e., 50 events per century), with a duration of less than or equal to 180 days (Hupalo et al. 1994).

In a baseline study from Water Conservation Area 3A of the Everglades, Zafke (1983) reported that saw grass, a species that generally occurs on organic soils, tolerated annual durations of inundation ranging from 15% to 94% (~55 to 343 days, respectively). Similarly, Sincock (1958) noted that saw grass in the upper basin of the St. Johns River usually

Table 10. Shallow and deep marsh elevations at Silver River transects.

	Ground Elevation (ft NGVD)					
	Shallow Marsh (Pickerelweed)			Deep Marsh (Nuphar)		
Transect	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**	**Minimum**
T2	35.7	37.6	33.9	32.4	33.9	30.8
T3	36.1	37.2	35.0	-	-	-
	35.8	37.6	34.6	34.0	34.6	33.4
	35.6	36.9	33.9	33.3	33.9	32.4
T3 (mean)					**34.2**	
T5	35.9	37.2	34.4	-	-	-
	36.1	37.0	35.0	34.2	35.0	32.9
	36.3	37.4	35.7	35.1	36.0	33.0
T5 (mean)					**35.5**	
T6	36.6	37.3	35.6	-	-	-
	-	-	-	36.0	37.9	34.3
T7	37.5	38.4	36.6	34.8	36.6	32.2
	37.6	38.2	36.8	36.1	36.8	35.4
T7 (mean)					**36.7**	

occurred where there was annual duration of saturation of 45% (~164 days). These data suggest that organic soils may form under widely ranging durations of saturation. The average of the annual range provided by Zafke (1983) is 54%, approximately equal to the 180-day annual duration specified for the MA at Silver River.

MA Return Interval Component

MA mean non-exceedence events typically occur for long durations with brief return intervals and are usually described by the “typically saturated” hydroperiod category:

"…where for extended periods of the year the water level should saturate or inundate. This results in saturated substrates for periods of one-half year or more during non-flooding periods of typical years. Water levels causing inundation are expected to occur 50 to 60% of the time over a long-term period of record. This water level is expected to have a recurrence interval, on the average, of one or two years over a long-term period of record." (Rule 40C-8.021(18), *F.A.C.*)

Two SWIDS datasets were evaluated to select an appropriate return interval for the MA. They represent mean dewatering probabilities for mean elevations of deep organic soils minus 0.3 ft at: (1) 21 lakes in northeast Florida (Figure 42) and, (2) eight areas along the Silver River (Figure 43). The recommended 1.7-year return interval (59% probability) occurs near the highest dewatering probability (driest signature) of both datasets. This is an estimate of the maximum frequency of dewatering that this soil feature and associated functions can sustain.

Figure 44 indicates that deep organic soils at Transect 9 dry more frequently (63% mean nonexceedence) than the recommended MA conditions while these soils at Transects 3, 5, and 7 dry less frequently ($\geq$48% mean nonexceedence) than the recommended MA. One possible explanation for this discrepancy is that Transect 9 is bordered by uplands with highly permeable, deep, sandy soils (SCS, 1979), which contribute seepage to the floodplain. The three downstream transects are generally bordered by uplands with impermeable clay soils (Paisley series) that contribute little seepage.

Flow frequency analysis (Figure 45) shows that the MA dewatering event under the no-pumping condition has a probability of approximately 46% (2.2-year return interval) while under baseline conditions, it has a probability of 54& (1.9-year return interval), an increase of eight dewatering events per century. The recommended MA return interval of 59% (1.7-year return interval) would allow five additional events per century from baseline conditions and an increase of approximately 13 events relative to the no-pumping condition. It is important to note that the recommended return interval represents 3 years in 5 when this event would be expected to occur, over the long term, not an even distribution of events over time (i.e., not every 20 months).

The 1.7-year return interval represents a flow of 657 cfs under 2010 conditions and a flow of 638 cfs under MFLs conditions, a difference of 19 cfs (Figure 45). This represents the allowable reduction (i.e. freeboard) in Silver Springs flow that can occur before the MA flow is not achieved. However, since the MA is slightly less sensitive than the FL, it is not the most restrictive limit on further groundwater withdrawals.

Benefits of the MA for Ecological Structure and Function

Maintain Deep Organic Soils

Of particular concern is the decomposition of soil organic matter (loss of soil carbon) that occurs when wetlands soils are drained or sufficiently hydrologically altered, resulting in lowered land surface elevations (i.e., subsidence). Soil subsidence is a function of two processes termed primary and secondary subsidence (Stephens 1984; Vepraskas and Ewing 2006). Primary subsidence results from loss of soil buoyancy provided by soil pore water. Once pore water leaves the soil, the support it provided to the overlying soil particles is lost. When air fills these pore spaces, the soil compacts under its own weight. Secondary subsidence is caused by the direct oxidation of the soil organic carbon to inorganic carbon, which may be lost to the atmosphere as carbon dioxide (CO_2) and methane emissions (Vepraskas and Ewing 2006; Parent et al. 1977). In addition, aerobic soil decomposition can also lead to the release of inorganic nutrients (e.g., nitrogen and phosphorus), metals, and toxic materials that might otherwise remain sequestered in the soil under flooded (anaerobic) conditions (Reddy and DeLaune 2008; Osborne et al. 2011).

An appropriate mean nonexceedence event (i.e., average dewatering) is necessary to conserve the hydric nature and the aforementioned (see FH level/flow discussion in the Magnitude Component section) ecological functions of the floodplain organic soils. The presence of deep organic soils ($\geq$8 in. thick, Histic Epipedon and Histosols) are indicative of long-term soil saturation and/or inundation (NRCS 2010). Stephens (1974) reported that the oxidation and subsidence of Everglades peat soils occurred when the long-term average elevation of the water table was greater than 0.3 ft below the soil surface. The 0.3 ft organic soil drawdown criterion is also supported by studies in organic soils in the Blue Cypress Water Management area in the Upper St. Johns River Basin (Reddy et al. 2006). Field and laboratory experiments suggested that the top 10 centimeters (4 in. [0.33 ft]) is the most reactive (i.e., labile) soil area with respect to microbial oxidation. Therefore, this layer of reactive soil is most susceptible to oxidation and requires protection (Reddy et al. 2006). Where deep organic soils are observed, a 0.3 ft organic soil water table drawdown criterion is typically employed when developing the MA level (Mace 2006, 2007).

Support Biogeochemical Cycles

Wetlands soils play an important role in global biogeochemical cycles, particularly as reservoirs of carbon (Mitsch and Gosselink 1993). Soil organic matter in wetlands provides long-term nutrient storage for plant growth. Accumulation of soil organic carbon is a function of the balance between primary productivity and decomposition. When wetland primary productivity exceeds decomposition and erosion rates, soil organic matter accumulates by the stratified build-up of partially decomposed plant remains (Reddy and DeLaune 2008). Soil organic matter produces dissolved organic carbon to support downstream aquatic systems. It is also a source of exchange capacity for cations in soils and the large surface area of organic colloids present in organic soils plays an important role in the bioavailability of various metals and toxins in wetlands (Reddy and DeLaune 2008).

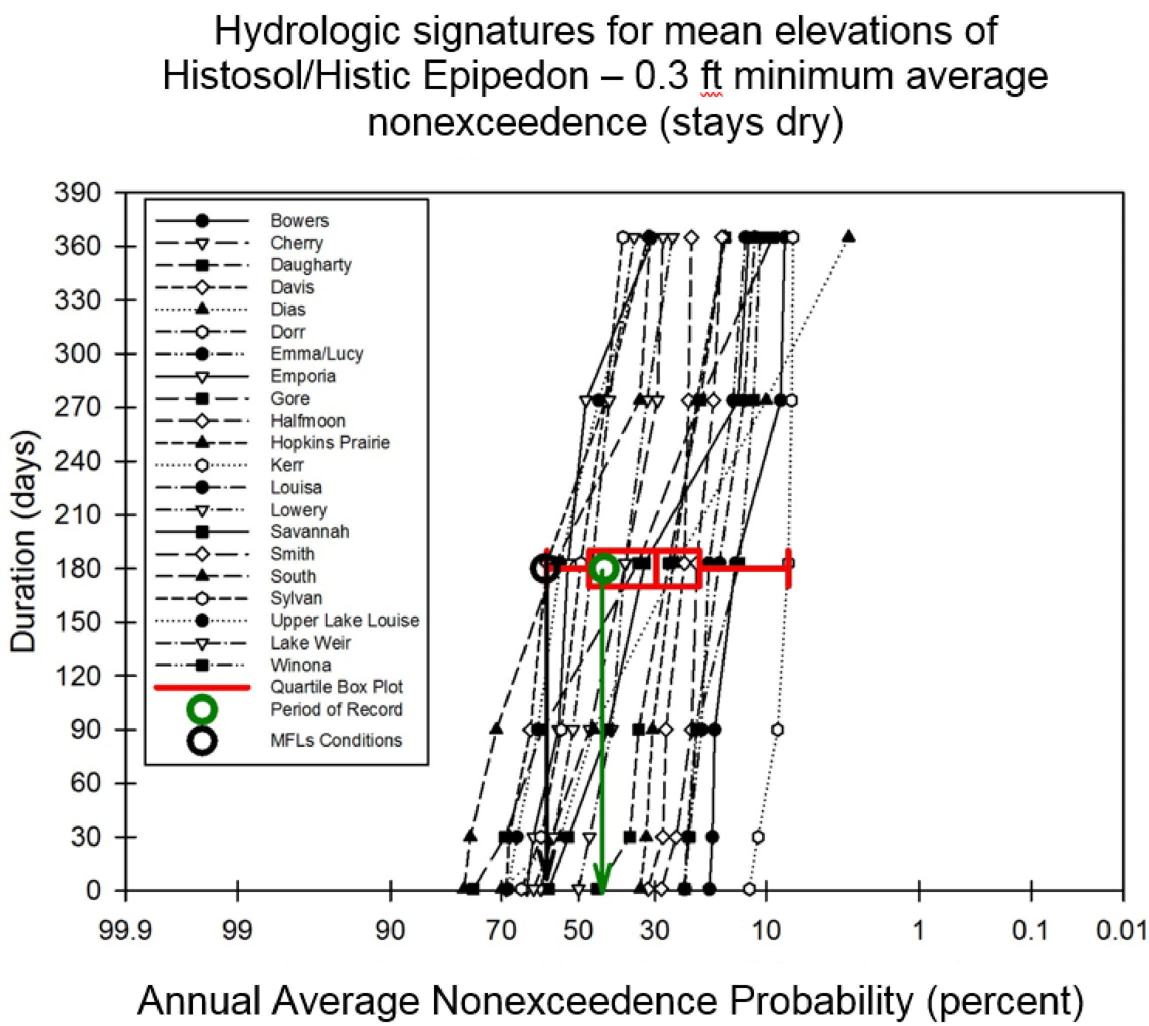


Figure 42. SWIDS plot of the distribution of hydrologic signatures for the annual average nonexceedence elevation for selected durations of deep organic soils minus 0.3 ft sampled on 21 lakes

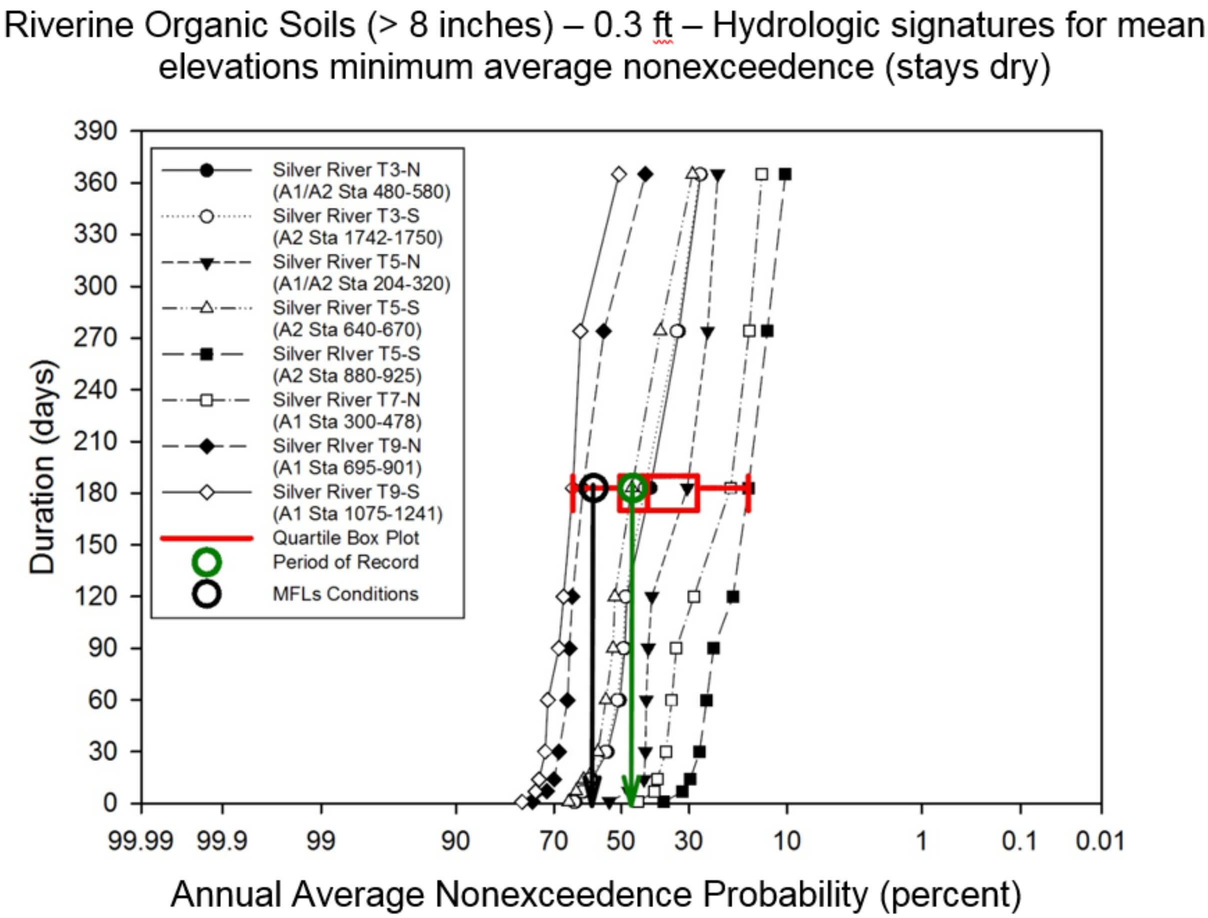
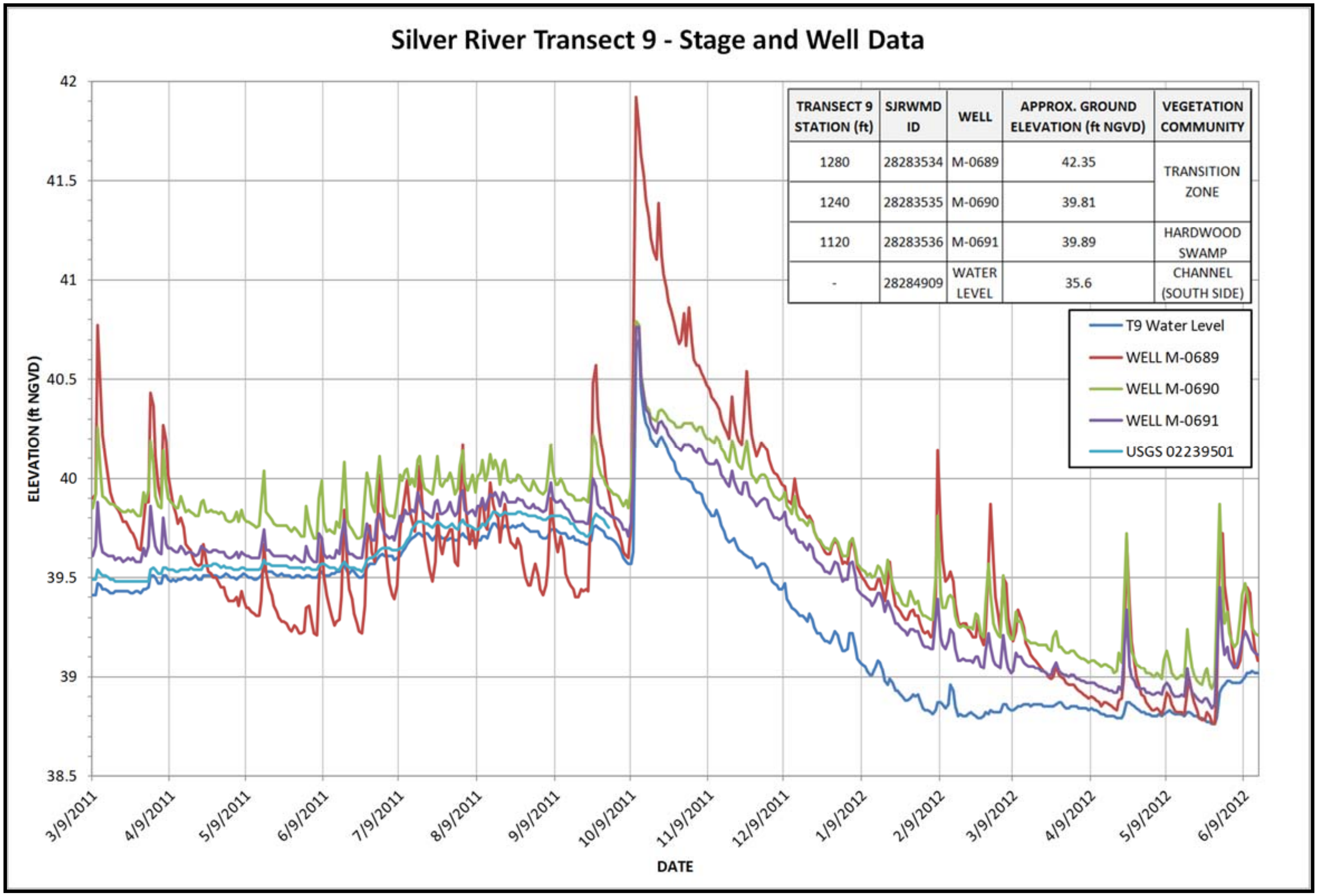


Figure 43. SWIDS plot of the distribution of hydrologic signatures for the annual average nonexceedence elevation for selected durations of eight deep organic soils minus 0.3 ft sampled on Silver River



TRANSECT 9 STATION (ft)	SJRWMD ID	WELL	APPROX. GROUND ELEVATION (ft NGVD)	VEGETATION COMMUNITY
1280	28283534	M-0689	42.35	TRANSITION ZONE
1240	28283535	M-0690	39.81	
1120	28283536	M-0691	39.89	HARDWOOD SWAMP
-	28284909	WATER LEVEL	35.6	CHANNEL (SOUTH SIDE)

Figure 44. Silver River minimum flows and levels (MFLs) Transect 9 (T9) river stage and USGS 02239501 gaging station and floodplain well water levels, Marion County, Florida

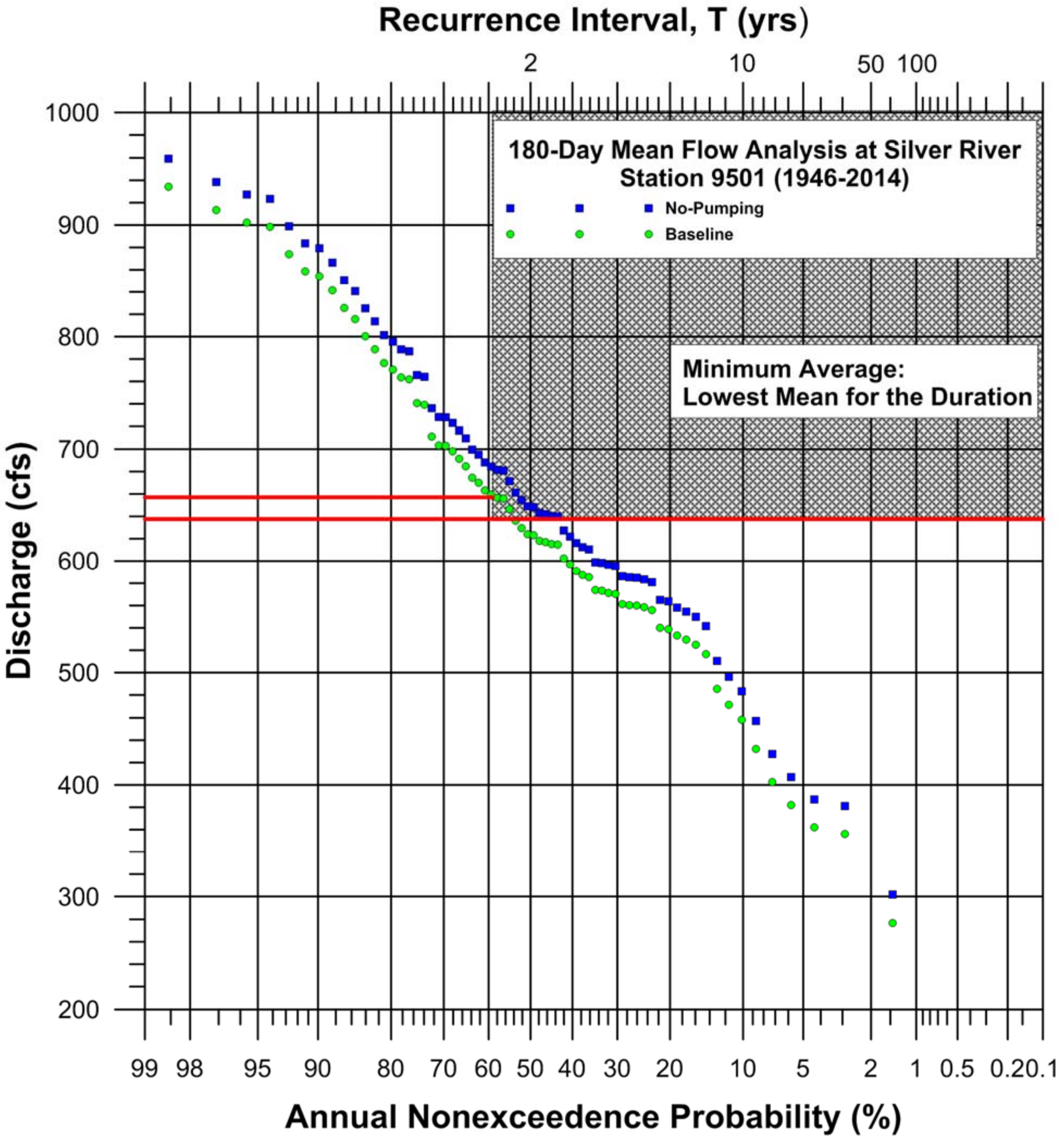


Figure 45. Flow frequency analysis for the MA, depicting no-pumping and baseline conditions relative to recommended minimum flow (bottom red line).

Minimum Frequent Low (FL) Flow: 572 cfs, 120-day continuous nonexceedence duration, 3-year return interval at the USGS 02239501 gaging station.

The goal of the recommended FL level/flow is to prevent excessive drying of the floodplain, the adjoining channel, and associated vegetation. Periodic drawdowns are beneficial because they allow regeneration of wetland plants, enhance nutrient cycling, and allow utilization of the floodplain by upland fauna. However, these drawdowns should not occur so frequently that the extent of the marsh ecotone or natural range of water table fluctuations are disrupted.

The general indicator of protection is a low water level in the river that maintains marsh ecotones and a natural fluctuation range of floodplain water tables. The FL is typically associated with the "semi-permanently flooded" hydroperiod category (Rule 40C-8.021(16), *F.A.C.*), such that "when surface water is absent, the water table is usually near the land surface…this water level is near the lower elevation that supports emergent marsh or floating vegetation and peat substrates, or other highly organic hydric substrates." These low water level events occur during moderate droughts. Groundwater withdrawals should not increase the number of these low water events beyond the return interval threshold of the FL.

The specific indicator of protection is a low water level/flow at the maximum elevation of spatterdock (*Nuphar advena*) beds at Silver River transects 3, 5, and 7. Spatterdock is a floating-leaved species characteristic of deep marshes. This level is also a low water level/flow approximately 1.67 feet (20-inches) below the average surface elevation of deep organic soils (e.g. Histosols and histic epipedons) in the hardwood swamps. This level is continuously dewatered for 120-day durations with a 3-year return interval.

FL Magnitude Components

The recommended FL elevation of 37.85 ft NGVD at the USGS 02239501 gaging station was calculated by measuring the maximum elevations of spatterdock beds, transferring these elevations to the 02239501 gage, and then averaging the values. Finally, the recommended FL level was converted to a flow with a rating curve (Appendix B), resulting in a FL of 572 cfs. The FL is a low water threshold that maintains the following functions:

- Marsh ecotones along the edge of the Silver River are protected from excessive dewatering since the recommended level would allow occasional dewatering of emergent marsh vegetation such as pickerelweed while ensuring long-term inundation of floating-leaved vegetation such as spatterdock.
- Water table levels within organic soils of hardwood swamps are maintained within an acceptable range of fluctuation as indicated by scientific research, and soil survey data. Plant and animal species that occupy the hardwood swamp are specifically adapted to these hydrologic conditions.
- Potentially significant archaeological remains are present in many soils bordering spring runs, often at some depth. Due to long-term saturated and anaerobic conditions, these

areas are unique repositories for artifacts of organic origin that are not preserved elsewhere.

A common FL criterion is the maximum elevation of deep marsh. This criterion distinguishes between frequently dewatered wetland such as shallow marsh and hardwood swamp and those that stay inundated for very long periods. Infrequent dewatering selects for flora such as water lilies and the related spatterdock species (family: Nymphaceae), which can germinate under water (Gerritsen and Greening, 1989). Protection of deep marsh vegetation is important since the dense vegetation and extended inundation provide important refugia for fish. This FL criterion maintains the long-term ecotone between deep marsh and shallow marsh, thereby preventing downhill shift in species, possible channel encroachment, and loss of open water. Table 10 shows the elevations of deep marsh features collected at or near Transects 3, 5, and 7. Deep marsh features from Transects 2 and 6 were not used in this determination since these sites do not have gages and the elevations could not be transferred to the 02239501 gage.

Another common FL criterion is the low water table level characteristic of organic soils near the water body of interest. Typically, as part of a FL event, a 1.67 feet (i.e. 20 inches) offset from the surface elevation of organic soils has been used. When organic soil elevations minus 1.67 feet from Transects 3, 5, 7, and 9 are transferred to the gage, the elevation of 37.92 is nearly the same as that of the maximum elevation of deep marsh from Transects 3, 5, and 7. This criterion supports the primary criterion based on the maximum elevation of spatterdock.

The 20-inch offset criterion is supported by data in a literature review of 17 studies of wetland hydroperiods in south Florida (ESE 1991). The average maximum water table depth for eight freshwater (sawgrass) marshes was 22 inches (range: 13 to 51 inches). The average maximum water table depth for seven bald cypress swamps was 27 inches (range: 14 to 60 inches). Both these wetland types commonly have deep organic soils and are therefore appropriate references for organic soils along Silver River. Anecdotal support is also provided in some soil survey reports (SCS 1974), which describe a low water table range of 10 to 30 inches for common organic soils during moderate drought. The 20-inch offset is the mean of this range.

FL Duration Component

The recommended 120-day continuous nonexceedence duration corresponds to the length of a normal dry season period (i.e., mid-February through mid-June; ~ four months) in north central Florida between the end of winter rains and the start of the summer rainy season. This duration allows seed germination of wetland plants, which generally require saturated but not inundated substrates (Kushlan 1990). This duration also allows time for these seedlings to grow sufficiently tall to survive subsequent flooding (Ware 2003).

FL Return Interval Component

The SWIDS dataset for the maximum elevation of spatterdock and water lily at 16 sites was the basis for the recommended 3-year FL return interval (Figure 46). Although not based on the driest signature, a three-year return interval does occur within the driest quartile of hydrologic signatures. This quartile represents a cluster of dewatering signatures from four water bodies in central Florida (Savannah, Big, Johns, and Hires Lakes). By using species-based SWIDS we remove some of the uncertainty about whether we are comparing similar systems with similar communities. We are comparing beds of the same species that have the same physiological tolerances. Further, much of the data for SWIDS was collected pre-2000, prior to some of the unusually severe droughts/ hydrologic perturbations of the last 16 years. This SWIDS analysis provides an estimate of the maximum frequency of dewatering that this vegetation feature and associated functions can sustain.

Flow frequency analysis (Figure 47) shows that the FL dewatering event under no-pumping conditions has a probability of 20% (5.0-year return interval) while under baseline conditions, it has a probability of 29% (3.5-year return interval), an increase of nine dewatering events per century. The recommended FL return interval of 33% (3.0-year return interval) would allow four additional events per century from baseline conditions and an increase of 13 events relative to the no-pumping condition.

Benefits of FL Criterion for Ecological Structure and Function, and Other Values

<u>Marsh Ecotones along Channel Margin</u>

The emergent marsh and floating-leaved vegetation common along the banks of the Silver River is a distinct ecotone between the frequently dewatered hardwood swamps of the floodplain and the permanently flooded SAV beds of the channel. We term it an ecotone because it occupies a relatively steep gradient between the two adjoining communities. This ecotone increases in prominence downstream of the headspring. It is absent at Transect 9, present but not delineated at Transect 7, and delineated as “shallow marsh” at Transects 5 and 3 where it ranges from 18 to 36 feet in width. The ecotone is dominated by pickerelweed at the nearshore edge and grades into stands of floating-leaved spatterdock at the lower margins. Although occasional patches of buttonbush are present, these areas are generally too wet to support woody shrubs and trees of the hardwood swamp but, unlike the SAV beds, are still subject to some degree of dewatering.

The distinct vegetation structure and hydrologic conditions of this ecotone likely provide habitat resources different from either of the adjoining communities. For example, wading birds, which are widely appreciated by visitors traveling by boat, often concentrate in these areas. The recommended FL will play an important role in preventing excessive dewatering of these marshes.

<u>Hardwood Swamp Vegetation Composition and Structure</u>

The hydrophytic vegetation of the Silver River floodplain is adapted to conditions of long-term wetness in both high and low water conditions. Vegetation in wetland areas tend to have shallow root systems and certain species may be sensitive to water table drawdowns below their normal rooting range. This may favor invasions of facultative species that are competitive in both wet and dry environments. This lower depth of the water table is a supporting criterion for the FL.

However, low water levels/flows in seasonally flooded wetlands are also a natural consequence of drought and have ecological benefits as long as the events do not occur too frequently. Drawdown conditions enable seeds of emergent wetland plants to germinate from the soil seed banks of the floodplain. Seeds of many wetland plant species require exposed soils to germinate (Van der Valk 1981). For example, cypress trees have rigorous hydrologic seed germination and seedling establishment requirements; seeds will not germinate underwater and seedlings can be killed by submergence (Demaree 1932; Watson 1983; Ware 2003). Dewatering the floodplain and the upper fringes of the Silver River littoral zone (i.e., some portions of the shallow marsh zone) for suitable durations, maintains the composition of emergent plant species and increases plant diversity within seasonally flooded wetlands.

Oxygenation of floodplain sediments during dry phases increases organic matter decomposition, and processing to more labile forms (Junk et al. 1989). Increased organic matter processing and transport, coupled with increased nutrient regeneration and availability, results in increased primary and secondary production (Junk et al. 1989, Welcomme et al. 2006, Arthington 2012).

Wildlife Habitat (Refugia, Nesting and Foraging)

Depressions in the floodplain can hold water even during drought periods and may be important for wildlife habitat. The recommended FL elevation ensures that at least some pools of water will remain on the floodplain at Transects 3, 5, 7, and 9 except during extreme drought. Water table data from Transect 9 (Figure 44) show that floodplain water tables track river levels but are often slightly higher. Although there is not always a 1:1 correspondence between river and water table levels, the recommended FL provides a conservative level of protection for wildlife that use the floodplain and marsh ecotones.

Low water levels/flows can also benefit wildlife as long as they do not occur too frequently. Dewatering allows for decomposition and compaction of surficial flocculent organic sediments. Increased populations of bacteria and fungi are basal food resources for micro- and macro-invertebrates, which in turn support higher trophic levels. Sunlight also heats, dries, and compacts exposed sediment into firmer substrates. Normally, on reflooding, habitat conditions are improved for fish nesting and foraging since the floodplain surface has consolidated, structural cover has increased, and forage resources (terrestrial and aquatic invertebrates) are abundant (Kushlan and Kushlan 1979; Merritt and Cummins 1984). Seasonal drying is considered essential to maintain energy and nutrient flows within the system (Kushlan 1990).

As water levels recede across the hardwood swamps at the Silver River, ideal water depths for wading bird foraging will occur. Wading birds follow the receding water levels and may feed in new areas as the wetland dries (Bancroft et al. 2002). Wading birds can only forage in relatively shallow water. Great egrets need water depths of less than 10 in. and the small herons need depths of less than 6 in. (Bancroft et al. 2002). Declining water levels cause fish and macroinvertebrates to be concentrated in isolated pools throughout the floodplain (Kushlan 1990). Birds may then exploit these concentrations (Bancroft et al. 1990), possibly enhancing nesting success (Kushlan 1990).

Archaeological Wet Sites and Associated Soil-embedded Artifacts

Virtually everything that is known about past human occupation in Florida (Preceramic Archaic Period 4000–9000 years ago) has been recovered from or near water bodies (Purdy 1991). Florida's springs and other water resources are often "archaeological wet sites" that contain plant, animal and human remains, which have survived for thousands of years. The artifacts are significant in that they paint a picture of human presence in Florida more than 12,000 years ago that is found nowhere else in the state (Purdy and Austin 2016). This situation is unique in the Western Hemisphere and provides an unprecedented opportunity to study resources available and utilized by humans in a warm climate (Purdy 2004). Similar information of this nature comes primarily from acidic, peatland bogs of northern Europe.

Archaeological wet sites are found in permanently saturated deposits that entomb and preserve organic objects that seldom survive elsewhere. Archaeological wet sites are often located along old shorelines and provide more diverse information about early human presence than does an upland site in the same area (Purdy 1988). The survival of organic materials entombed in a waterlogged context can be attributed to anaerobic (oxygen-free) conditions that inhibit or minimize activities of aerobic (oxygen-requiring) bacteria.

When an archaeological wet site is dewatered, the air enters the soil and aerobic bacteria accelerate decomposition of wooden artifacts and ecofacts (biological artifacts indicative of human occupation) (Purdy 1988). If these dry-out periods are periodic or prolonged, the organic remains and artifacts are destroyed (Willis 2004). Thousands of years of human history and uniquely preserved environmental data will be lost if MFLs are set too low on spring runs, such as Silver River. The recommended FL allows periodic dewatering of the surface soil layer but maintains long-term saturation and anaerobic conditions in deeper soil layers.

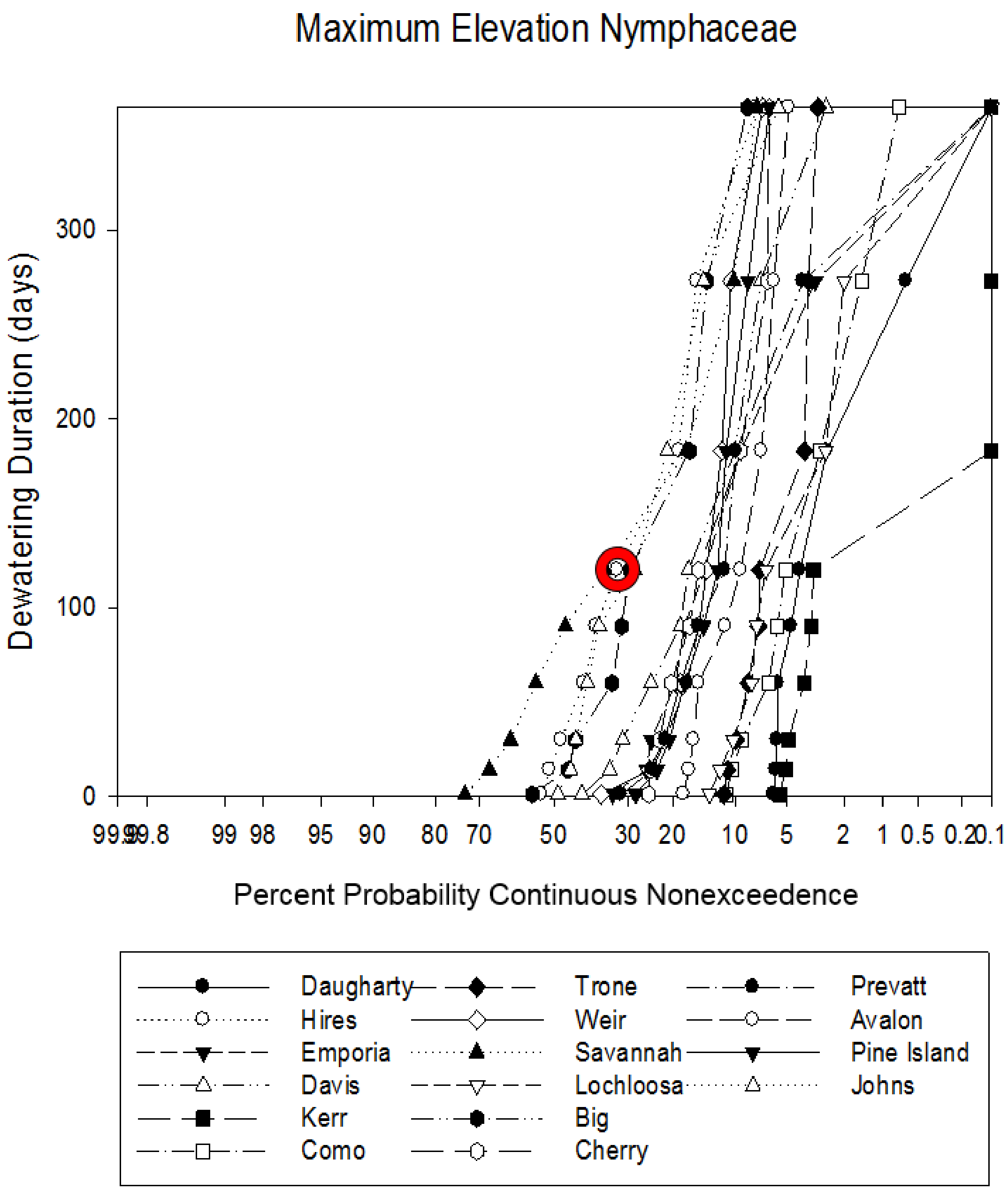


Figure 46. Hydrologic signatures for dewatering of maximum elevation of spatterdock and water lily. (The FL return interval is shown by the red circle.)

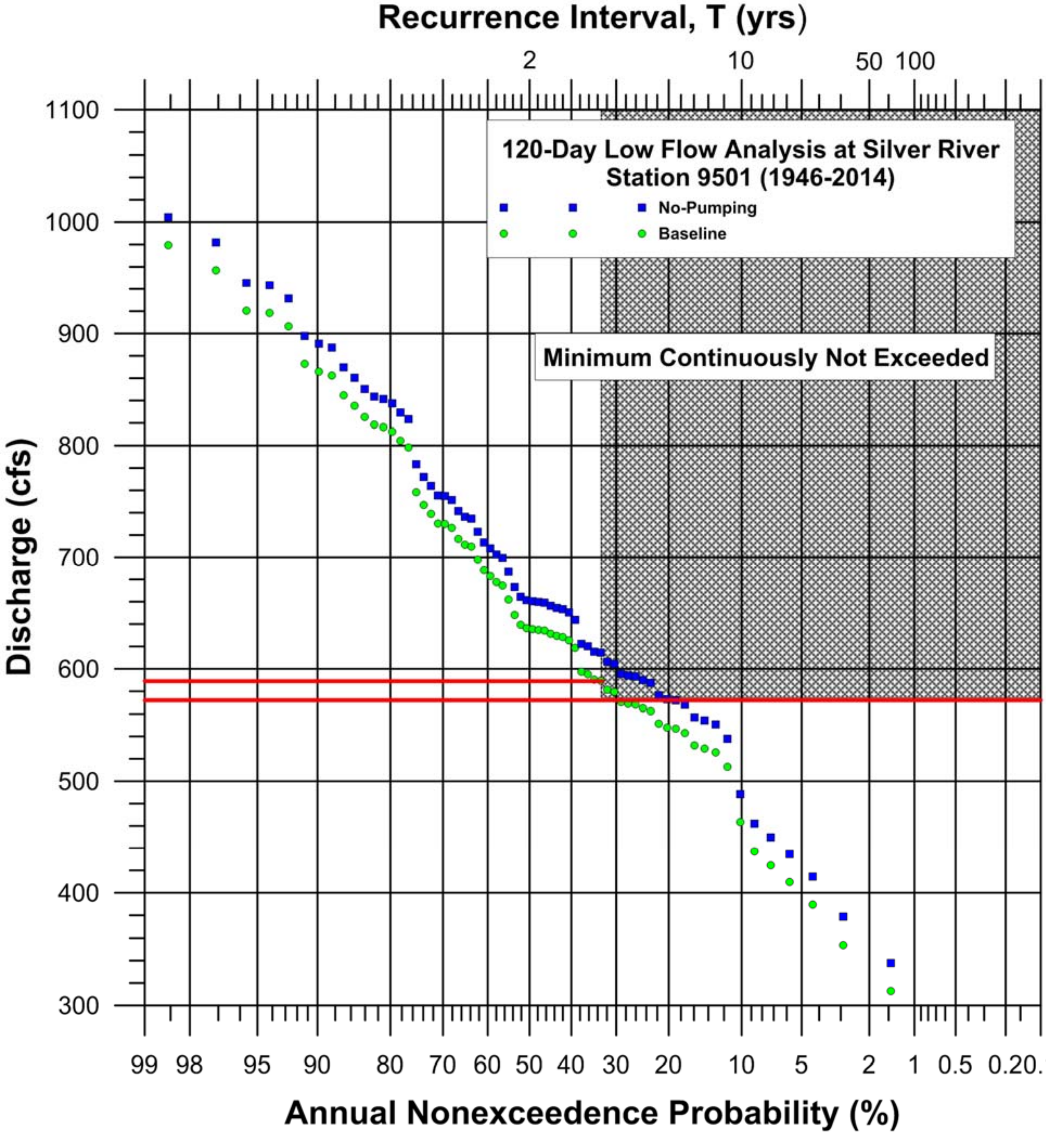


Figure 47. Frequency analysis plot for the Silver Springs FL, depicting no-pumping and baseline conditions relative to recommended minimum flow (bottom red line).

IMPORTANCE OF FLOW AND STAGE FOR THE SILVER SPRINGS ECOSYSTEM

The importance of both flow and stage regimes to the long-term maintenance of a river's physical structure, biogeochemistry and ecological integrity is widely recognized (Junk et al. 1989, Poff et al. 1997, Lytle and Poff 2004, Tockner et al. 2008, Arthington 2012). For riverine ecosystems, flow is considered a master variable that shapes physical habitat, drives key physicochemical processes, influences life history strategies and as a result affects the composition, distribution and interactions of biological communities. While water level (i.e., stage) is linked with flow, it is mechanistically distinct, and each influence related but different aspects of riverine form and function. Therefore, the maintenance and long-term integrity of lotic ecosystems is largely determined by the range of both flows and stages that comprise their "natural flow regime" (Hill et al. 1991, Poff et al. 1997, Richter et al. 1997, Poff and Zimmerman 2010, Arthington 2012).

Appendix H provides a detailed summary of the importance of and negative effects of alterations to flows and stages within riverine environments.

The recommended minimum flows for Silver Springs are intended to protect the range of flow and stage fluctuations required to maintain Silver River floodplain ecological habitats (i.e., hardwood swamp, shallow and deep marshes), functions (e.g., fish and wildlife habitat, nitrogen assimilation, denitrification, etc.), and prevent the oxidation and subsidence of organic soils caused by changes in the hydrology resulting from water withdrawals. The recommended minimum flows were determined based on critical water stages necessary to protect these environmental values.

While flows have been reduced since 2000, likely due primarily to flow suppression and drought, stages have increased to the point that floodplain swamps may be too wet (i.e., flooded for too long). Preliminary evidence suggests that cypress recruitment on the floodplain may be declining due to the increased stages post-2000. There is evidence to suggest that this is primarily due to an increase in the abundance and areal extent of the native SAV beds below the USGS 02239501 gaging station and the increase in the invasive exotic, *Hydrilla*, in the river channel. The combined effect of this vegetative damming may be higher stages than previously seen during low flow conditions, resulting in a negative impact on the recruitment of native floodplain tree species. Because of uncertainty regarding the permanence of post-2000 stages and the effects on tree recruitment, it is not clear whether this is part of a long-term cycle or constitutes harm to floodplain species.

However, given the importance of both flows and stages in this system, and because the relationship between stage and flow has changed over time, it is critical to monitor river stage to ensure that the recommended minimum flows continue to be protective over the long term. This is discussed further in the Conclusions and Recommendations.

EFFECTS OF RECOMMENDED MINIMUM FLOWS ON IN-CHANNEL VELOCITIES

Effect of Post-2000 Stage-Flow Shift on Velocities

Velocity data for Silver River show a marked difference between pre- and post-2000 periods, and are related to the changing stage-flow relationship. As flow declines, in-channel velocities are expected to also decline, with fewer high-flow and high shear stress events occurring that would be able to scour and transport sediment, algae, detritus, and SAV.

Velocities above 0.25 m^{-s} appear to influence vegetation community structure (Biggs 1996, Hoyer et al. 2004, Franklin 2008, King 2014). A 2004 study of three southwest Florida rivers identified a velocity threshold of 0.82 ft/s below which river substrates were suitable for colonization of SAV (Hoyer et al. 2004). A current velocity of 1.15 ft/s has been estimated as a threshold above which filamentous algal abundance was minimal due to active scouring of algal biomass in Gum Slough Spring (King 2014). Increased velocity increases both shear stress and frictional stress on attached algae, enhancing sloughing from macrophyte leaves. Above a critical velocity, macrophyte leaf breakage and sloughing, and even uprooting, occurs. These perturbations physically restructure the vegetation community by creating bare patches and shifting community composition. High stream flow events will generally shift community composition toward macrophytes dominance.

During the period 1933–1997 velocity in the Silver River exceeded 0.25 m^{-s} approximately 70% of the time, but only about 20% of the time after 2001 (Kaplan and Sucsy 2016). The altered velocity distribution likely changed plant community structure in Silver River. The earliest observations showed much less vegetation in the river when flows were relatively high (Whitford 1956, Odum 1957). While SAV has been present throughout the river since at least 1990 (Duarte et al. 1990), relatively low flow through the 1990s and early 2000s may have allowed SAV to reconfigure, filling in channel areas previously devoid of vegetation. Preliminary modeling suggests that vegetation can have a pronounced effect on stage and velocity through increased channel friction. If SAV reconfiguration occurred in Silver River, it established a positive feedback: reduced flow allowed vegetation to expand, reducing velocity and allowing vegetation to persist and further expand.

Field measurements of average flow velocity were collected from the USGS 02239510 station located near the confluence of the Silver and Ocklawaha rivers from 2003 until 2010. This same site was used between 1976 and 1995. At this location, a range of velocity conditions have been documented near the rivers' confluence. This is also the location with the longest available period of record (more than 34 years) for flow at Silver River. A time series plot of this record (Figure 48) indicates lower channel cross section average velocities since 2000 compared with earlier years, with a statistically significant difference of 0.509 ft/s between pre-2000 (1.505 ft/s) and post 2000 (0.996 ft/s). The pre- and post-2000 comparison was chosen due to patterns seen for other hydrologic changes in Silver River, as well as a gap in available measurements between 1997 and 2001. Most of the velocity measurements prior to 2000 were above thresholds for algae growth and SAV (King 2014; Hoyer et al. 2004). In contrast, there was a reduced range of velocity after 2000, with the maximum observation of 1.31 ft/s after 2000 being lower than the pre-2000 mean. If the change in stage-flow relationship is due to increased channel roughness from SAV growth, this may act as a positive feedback loop, further suppressing flow and creating a lower shear-stress environment within which SAV or algae may persist more easily.

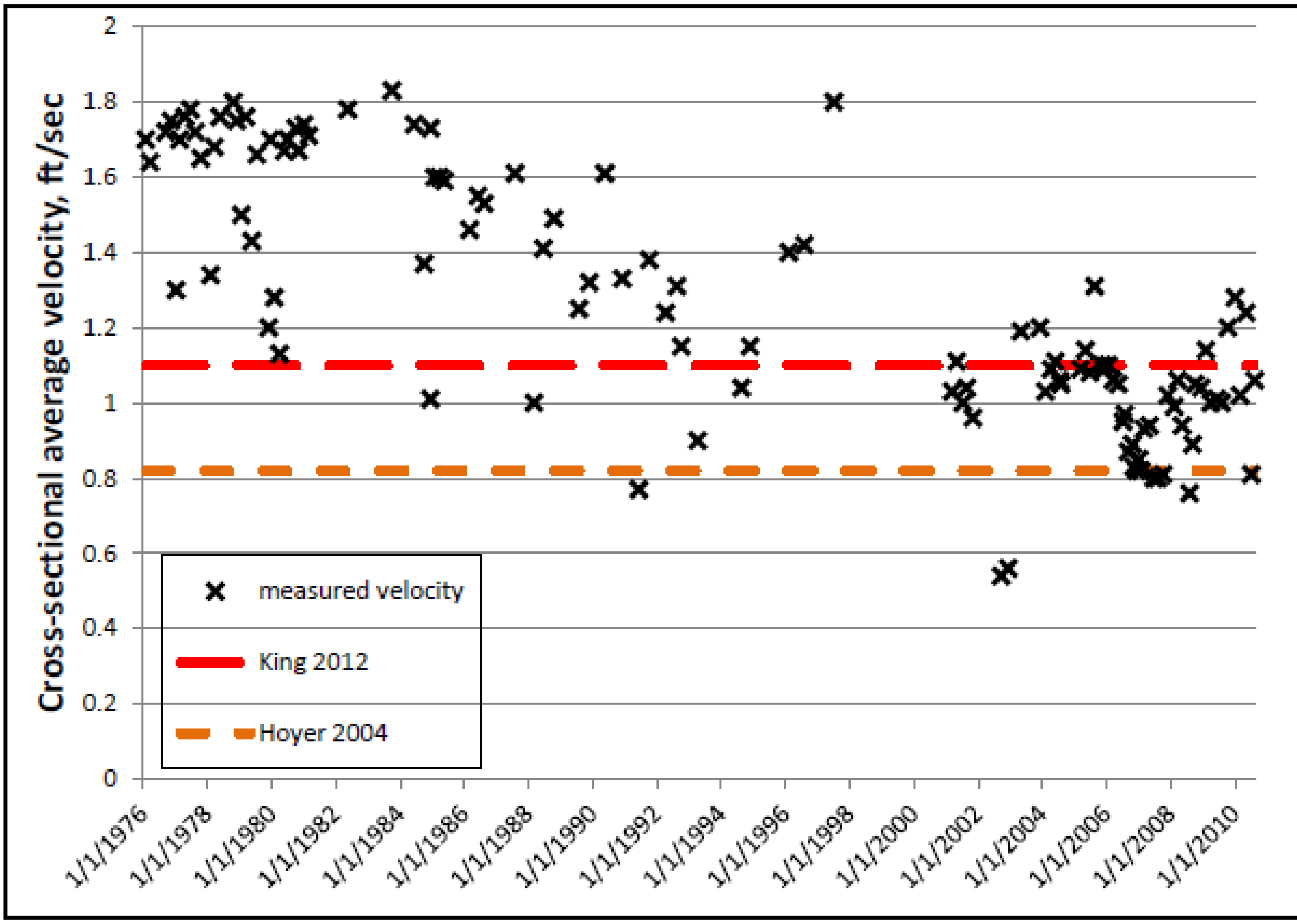


Figure 48. Comparison of average cross-sectional velocity near the Silver-Ocklawaha rivers confluence with thresholds for algae removal. Velocity data from USGS.

To understand and try to simulate the effects of the changing stage-flow relationship on velocities, SJRWMD modeled the effects of changing in-channel roughness coefficients (Manning's *n*-values) on water surface levels for similar flows pre- and post-2000 (Table 11). Spatial variability of in-channel average velocities and water surface levels within Silver River was simulated using the Silver River Hydrologic Engineering Centers River Analysis System (HEC-RAS) model for five different 30-day high flow events and two different observed periods of record: 1947 to 1999 and 2000 to 2010. The Manning's n-value (roughness coefficient) was 0.057 for the POR 1947 to 1999 and 0.10 for the POR 2000 to

2010. Simulated average velocity profiles indicated that only about one-half of the Silver River has an average channel velocity greater than the algal flushing threshold of 1.15 ft/s (King 2014) for the flow events tested. Velocities exceed this threshold just downstream from the boil (~26,030 ft above the confluence), then generally drop below this threshold for the majority of the spring run, increasing above the threshold again near the confluence with the Lower Ocklawaha River.

In contrast, the 30-day high flow frequency analysis of the Silver River adjusted POR flow data for the POR 2000 to 2010 (German 2010; USGS 2012) was completed and 1.05-year, 1.25-year, 2-year, 5-year, and 10-year flows were estimated graphically as 370, 500, 630, 740, and 790 cfs, respectively. The HEC-RAS model simulated in-channel average velocity profiles indicated a marked reduction in average velocities for 2000–2010 conditions, relative to 1947 – 1999 conditions. The majority of the Silver River is predicted to fall below the 1.15 ft/s velocity threshold (King 2014) for these flow events under the 2000 to 2010 in-stream conditions. Only portions of the lower spring run within ~5,000 ft of the confluence with the Ocklawaha River achieved the threshold velocity (Table 11). The physical morphologies (channel Manning's *n*-values—roughness coefficients) were markedly different in the model simulations for the 1947 to 1999 POR and the 2000 to 2010 POR.

Increased roughness values (i.e., based on the calibration of the HEC-RAS for the pre- and post-2000 years) support the conclusion that channel roughness may have been high enough post-2000 to change the stage-discharge relationship of the river. These results support that increased in-channel roughness is a probable cause of increased stages and the resultant decreased flows and velocities for the post-2000 period.

When coupled with observations of increasing SAV (native and exotic) abundance in the lower Silver River, and groundwater mounding (see *Silver Springs MFLs Overview* section for more information) it seems likely that a probable explanation for an increase in channel roughness is the increase of SAV in the Silver River channel, which is having a damming effect on flow. Possible factors accounting for noted change in vegetation include:

- A scarcity of large flood events on the Ocklawaha River since 2000 means there have been fewer occasions when that river back-floods dark, tannin-stained water into the Silver River thereby disrupting stands of SAV;
- Fewer large flood events on the Silver River since 2000 have produced fewer high-energy scour events to physically remove SAV;
- Enriched levels of nitrogen have stimulated production of submerged vegetation; and
- Patches of the invasive species hydrilla (*Hydrilla verticellata*) have become more prevalent in recent years and may be altering flow patterns (see *Silver Springs MFLs Overview* section for more information).

The effects of changing channel morphology/roughness on the stage-flow relationship within Silver River is currently being investigated more closely as part of the CRISPS project.

SJRWMD and University of Florida engaged in a research project, in part, to assess and quantify the importance of flow velocity as an ecosystem driver in Silver River. A series of *in situ* experiments was also conducted as part of SJRWMD's continuing data collection and improvement of assessment tools to measure effects of velocity on SAV and algae, including experiments to monitor long-term SAV growth and productivity across a gradient of physical forcings (e.g., light, velocity, epiphyte cover) and manipulation of flow velocity through patches of SAV to define critical velocity thresholds resulting in epiphytic algal sloughing, SAV sloughing and uprooting. These experimental data, along with morphometric and flow data, are being used to calibrate a three-dimensional hydrodynamic model, constructed by SJRWMD staff, that will test different hydrologic/hydraulic distributions. The model will be a powerful tool to assess how spring flow, stage and corresponding velocity distributions interact to drive ecosystem states in Silver River.

Table 11. Comparison of 30-day high flow velocities (ft/s) simulated using a HEC-RAS model at 11 cross-sections, five flows, and two periods of record.

Period of Record	Flow (cfs)	Stream Channel Cross-section (Distance in feet from HEC-RAS cross-section CS-1 near the Confluence with Ocklawaha River)										
		CS 11 (26,030	CS 10 (22,760	CS 9 (21,600	CS 8 (19,380	CS 7 (17,370	CS 6 (13,990	CS 5 (9,770	CS 4 (7,500	CS 3 (4,490	CS 2 (2,640	CS 1 (0)
1947–1999	1.05-yr: 600 cfs	1.31	0.45	0.63	0.69	0.52	0.99	0.87	1.07	1.33	0.52	1.31
	1.25-yr: 680 cfs	1.34	0.48	0.67	0.73	0.56	1.04	0.94	1.17	1.49	0.59	1.49
	2-yr: 820 cfs	1.38	0.54	0.75	0.80	0.61	1.11	1.06	1.34	1.79	0.72	1.83
	5-yr: 960 cfs	1.41	0.61	0.83	0.86	0.67	1.19	1.11	1.50	2.10	0.86	2.34
	10-yr: 1040 cfs	1.46	0.63	0.87	0.88	0.70	1.23	1.13	1.56	2.23	0.92	2.51
2000–2010	1.05-yr: 370 cfs	0.76	0.27	0.38	0.41	0.31	0.58	0.52	0.65	0.81	0.32	0.81
	1.25-yr: 500 cfs	0.81	0.32	0.44	0.46	0.36	0.64	0.62	0.79	1.06	0.43	1.10
	2-yr: 630 cfs	0.90	0.36	0.49	0.50	0.40	0.70	0.62	0.89	1.26	0.52	1.33
	5-yr: 740 cfs	0.96	0.39	0.54	0.51	0.43	0.74	0.62	0.97	1.43	0.60	1.59
	10-yr: 790 cfs	0.98	0.40	0.55	0.52	0.44	0.76	0.61	1.00	1.51	0.64	1.73

Note: Shaded values meet or exceed velocity threshold of 1.15 feet per second (King, 2014)

Importance of In-channel Velocity as an Ecological Driver

Water velocity is the main factor in regulating aquatic macrophyte distribution, composition, biomass, and metabolism in rivers (Haslam 1978; Riis and Biggs 2003; Franklin et al. 2008; WSI 2010). Increased current velocity can also physically affect the ability of macrophytes to colonize or survive in certain area (Riis and Biggs 2003). Current velocity can benefit aquatic macrophyte growth by enhancing carbon dioxide and nutrient supply, or be detrimental to growth due to mechanical stress. Typically both abundance and diversity of macrophytes are stimulated by low to medium velocities, and growth restricted at higher velocities (Madsen et al. 2001). Riis and Biggs (2003) reported that macrophyte abundance peaked at velocities of 0.98 to 1.64 ft/s. Above a certain threshold, there may also be a negative relationship between flow and recruitment of macrophytes (Arthington 2012). As water velocities increase the flora becomes more restricted to species capable of resisting the current and when velocity is rapid only a few species can survive (Riis and Biggs 2003). Nilsson (1987) reported that peak macrophyte species diversity was observed at surface velocities of 0.98 ft/s. As velocity increases, the ability of macrophytes to remain attached to the substrate is reduced and mechanical stress is increased. Detrimental aspects of flow are generally encountered at higher velocities and aquatic macrophytes are only present in negligible quantities or completely absent when velocities exceed 3.28 ft/s (Chambers et al. 1991).

WSI (2010) examined ecosystem metabolism parameters in 12 Florida springs. The ecosystem metabolism parameters measured for each spring included: gross primary productivity (GPP), net primary productivity, community respiration, productivity to respiration ratio, photosynthetically active radiation, and ecosystem efficiency. Ecosystem metabolism is an estimate of the overall function of an aquatic ecosystem. The consumption and production of oxygen by all spring flora and fauna are included in these measurements (WSI 2010). As a part of this assessment, WSI examined the relationship between GPP and spring velocity and flow and supported the research findings discussed above with regard to SAV and stream velocity. Modeled GPP was positively correlated to average spring velocity; at current velocities up to about 0.82 ft/s GPP increased, while at velocities greater than this, GPP declined (WSI 2010).

In spring ecosystems, SAV and the epiphytic algal community are the key components of the primary producer community, and are likely of equal importance (WSI 2010). Spring run in-channel velocities also strongly influence the epiphytic algal community. Horner et al. (1983) found that velocity enhanced epiphyton accrual between 0.16 and 0.82 ft/s, apparently by maximizing the nutrient concentration gradient between surrounding water and the cell surface. Velocity increases up to approximately 1.64 ft/s enhanced diatom accrual, however, accrual declined with successive velocity increments above 1.64 ft/s. It was hypothesized that velocity increase created new opposing effects: improved turbulent diffusion of nutrients to algal cell surfaces, predominant at velocities under 1.64 ft/s, and increasing frictional shear stress, which becomes dominant at higher velocities (Horner et al. 1983). Sudden increases in velocity raised instantaneous loss rates by an order of magnitude or more (Horner et al. 1983). Increased velocity alone removed benthic algal biomass, and high suspended sediment concentrations further increased algal removal. The erosive action of suspended sediments may have a much greater influence on periphyton export than does velocity shear (Horner et al. 1983).

Filamentous algae have become a conspicuous component of the SAV communities in many of Florida's springs, including Silver Springs (Stevenson et al. 2004; Munch et al. 2006; Hand 2009; WSI 2010; Hicks and Holland 2012, draft). With increased nutrient loading and reduced flows, filamentous algae (predominantly the cyanobacterium, *Lyngbya*) have expanded to the point of displacing macrophyte biomass by overgrowing (smothering) the macrophytes and outcompeting them for available light energy. King (2014) studied velocity regimes in a Florida spring and in laboratory studies and estimated a current velocity of 1.15

ft/s as a threshold above which filamentous algal abundance is minimal due to active scouring of algal biomass. This velocity threshold is used as a point of reference in the analyses presented in the following section.

The maintenance of the spring run in-channel velocity regime (i.e., magnitude, spatial distribution, and fluctuation) is, therefore, paramount to the protection of the Silver River ecological health. Without such maintenance, water depths, physical channel morphology, ecological habitats, and ecosystem metabolism functions (i.e., gross primary productivity, community respiration, net primary productivity, and ecosystem efficiency) may not be adequately protected.

Magnitude and Spatial Variability of Average In-Channel Velocities Between Baseline and MFLs Hydrologic Conditions

As noted above, the recommended minimum hydrologic regime is intended to protect the flows and stages necessary to maintain structure and function. A question remains, however, whether the hydrologically sensitive criteria developed based on riparian floodplain structure and functions will also protect the in-stream portions of the aquatic ecosystem from significant ecological harm. The following summarizes the results of analyses conducted by ATM to evaluate the potential effects of the recommended MFLs on Silver River in-channel velocities (Appendix E). It was assumed that maintenance of in-channel surface water levels and velocities will adequately protect water depths, physical channel morphology, ecological habitats, and ecosystem metabolism functions.

This evaluation utilized the Silver River HEC-RAS model to simulate average in-stream channel velocities at 11 Silver River channel cross sections for 10 flows corresponding to a 30-day continuously exceeded flow event under two hydrologic regimes: baseline conditions (i.e., 1946 to 2014 USGS-adjusted flow time series); and MFLs conditions (i.e., baseline flow time series adjusted to include the flow reduction allowed by the most constraining minimum flow). The objective was to examine how the recommended MFLs affect in-channel velocities and potentially affects ecosystem function. Channel roughness coefficients and configuration were identical in the model simulations for the baseline and MFLs conditions (Appendix E).

The analysis shows that the amount of flow reduction allowed by the Silver River MFLs does not appreciably impact the magnitude or spatial distribution of in-channel velocities or water levels. The magnitudes of the in-channel velocities are predicted to be only slightly lower under MFLs conditions, relative to baseline, and the spatial distributions for velocities and water levels are identical for the two hydrologic regimes (Table 12). As a point of reference on Table 12, current velocities ≥1.15 ft/s (a velocity threshold above which filamentous algal abundance is minimal due to active scouring of algal biomass in spring run streams [King 2014]) are shaded to more clearly show the velocity distributions for the two hydrologic conditions. Results are similar for velocities necessary for maximum gross primary production (critical threshold of 0.82 ft/s). There was very little difference in spatial distribution or magnitude of velocities necessary for maximum GPP.

Based on these results, it is concluded that the recommended MFLs hydrologic conditions developed based on riparian floodplain structure and ecological functions will also protect the in-stream portions of the aquatic ecosystem from significant ecological harm. Because the amount of flow reduction allowed by the Silver River MFLs does not appreciably impact the magnitude or spatial distribution of in-channel velocities, physical channel morphology, ecological habitats (i.e., the presence or absence of submerged aquatic macrophyte beds), and ecosystem metabolism parameters (i.e., gross primary productivity, community respiration, and net primary productivity), will be maintained.

Table 12 In-channel, average velocities (feet per second [ft/s]) simulated by the Silver River HEC-RAS model at different river reaches for 10 different flows (cubic feet per second [cfs]) events and two different hydrologic regimes (Baseline and MFLs condition)

Hydrologic Regime	Flow Percentile (%)	Flow (cfs)	Velocities (cfs) at 11 Stream Channel Cross Sections (Distance in feet [ft] from Cross Section CS-1 Near the Confluence with the Ocklawaha River)										
			CS 11 (26,030)	CS 10 (22,760)	CS 9 (21,600)	CS 8 (19,380)	CS 7 (17,370)	CS 6 (13,990)	CS 5 (9,770)	CS 4 (7,500)	CS 3 (4,490)	CS 2 (2,640)	CS 1 (0)
Baseline Condition	10	1007	1.25	0.49	0.67	0.65	0.53	0.92	0.78	1.1	1.5	0.68	1.43
	20	950	1.22	0.48	0.65	0.64	0.52	0.89	0.77	1.08	1.47	0.66	1.41
	30	873	1.18	0.46	0.63	0.62	0.5	0.86	0.75	1.05	1.41	0.62	1.38
	40	815	1.16	0.45	0.61	0.62	0.5	0.85	0.75	1.04	1.41	0.6	1.34
	50	762	1.14	0.43	0.6	0.61	0.49	0.84	0.76	1.02	1.38	0.58	1.31
	60	725	1.13	0.42	0.58	0.61	0.48	0.84	0.76	1.01	1.35	0.57	1.29
	70	682	1.11	0.41	0.57	0.6	0.47	0.82	0.79	0.99	1.32	0.55	1.26
	80	626	1.11	0.4	0.55	0.59	0.46	0.82	0.78	0.97	1.28	0.52	1.22
	90	576	1.14	0.39	0.55	0.59	0.45	0.84	0.77	0.96	1.23	0.48	1.17
	95	517	1.15	0.38	0.53	0.58	0.44	0.85	0.75	0.92	1.19	0.46	1.13

Hydrologic Regime	Flow Percentile (%)	Flow (cfs)	Velocities (cfs) at 11 Stream Channel Cross Sections (Distance in feet [ft] from Cross Section CS-1 Near the Confluence with the Ocklawaha River)										
			CS 11 (26,030)	CS 10 (22,760)	CS 9 (21,600)	CS 8 (19,380)	CS 7 (17,370)	CS 6 (13,990)	CS 5 (9,770)	CS 4 (7,500)	CS 3 (4,490)	CS 2 (2,640)	CS 1 (0)
MFLs Condition	10	967	1.23	0.48	0.66	0.64	0.52	0.9	0.77	1.09	1.48	0.67	1.42
	20	910	1.2	0.47	0.64	0.63	0.51	0.88	0.76	1.07	1.44	0.64	1.4
	30	834	1.17	0.45	0.62	0.62	0.5	0.86	0.76	1.05	1.42	0.61	1.35
	40	777	1.15	0.44	0.6	0.61	0.49	0.85	0.76	1.03	1.39	0.59	1.32
	50	736	1.14	0.43	0.59	0.61	0.48	0.84	0.76	1.01	1.36	0.57	1.29
	60	686	1.12	0.41	0.57	0.6	0.47	0.82	0.79	0.99	1.33	0.55	1.26
	70	658	1.12	0.41	0.56	0.6	0.46	0.82	0.78	0.98	1.3	0.53	1.24
	80	597	1.11	0.39	0.54	0.58	0.45	0.82	0.77	0.95	1.26	0.51	1.2
	90	550	1.14	0.38	0.54	0.59	0.45	0.85	0.76	0.94	1.21	0.47	1.15
	95	492	1.16	0.37	0.52	0.57	0.44	0.85	0.74	0.92	1.17	0.45	1.12

Note: Shaded cells meet or exceed velocity threshold of 1.15 ft/s

Relevant 62-40.473, *F.A.C.*, Environmental Values

Based on a screening analysis (Appendix F), the following environmental values (Rule 62-40.473, *F.A.C.*) were determined to be relevant to identify the limiting conditions for MFLs development for Silver Springs:

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

According to the screening criteria, two environmental values: “fish and wildlife habitats and the passage of fish” and “filtration and adsorption of nutrients and other pollutants,” were determined to be the most limiting environmental values to the further development of consumptive uses of surface and/or regional groundwater, and the primary criteria on which the Silver Springs minimum flow was developed.

All of the environmental values (Rule 62-40.473, *F.A.C.*) for Silver Springs and Silver River were evaluated relative to the allowable flow reduction from the no-pumping flow time series, in a report by ATM (Appendix E). ATM determined that the flow reduction associated with the recommended MFLs hydrologic conditions would not have a significant impact on the 10 environmental values for the spring or spring run.

Water Quality

Regarding environmental value #8: Water Quality, recent research suggests there is little evidence that variations in spring flow rates will demonstrably affect spring water quality. ATM assessed the effects of the flow reduction associated with the recommended Silver Springs MFLs hydrologic conditions on water quality and found no important relationships between flow rates or water levels and water quality trends in the Silver River. While there are clearly issues with substantially increased NOx concentrations in Silver Springs, ATM found no evidence that the flow reduction associated with the recommended MFLs hydrologic conditions would have any significant effect on NOx concentrations within the spring or spring run. ATM concluded that the majority of the variability in water quality for all parameters was not explained by variability in Silver Springs flow (ATM 2017).

In addition, Heyl (2012) examined the relationship between spring flow and NOx concentrations in the Chassahowitzka River, Homosassa River, Silver Springs, Pumphouse and Trotter springs, Gum Springs, and Rainbow Springs systems. NOx concentrations had markedly increased in all of these springs. Heyl evaluated the relationship between flow and NOx concentration in each system with standard statistical techniques. In all six systems, the increase in NOx concentration was determined to be independent of flow, but strongly dependent on time (i.e., date). Regarding their research on springs in the Suwannee River Water Management District, Upchurch et al. (2007) state: “The clear conclusion from this analysis is that minimum flow and levels (MFLs) cannot be utilized to mitigate NOx discharging from the springs by promoting high flow.” Upchurch et al. (2007) further stated, “In order to maintain an optimal pattern of flow from the springs through the use of minimum discharge and levels, discharge of high NOx concentrations in spring water is likely to result unless NOx sources are reduced.”

CONCLUSIONS AND RECOMMENDATIONS

RECOMMENDED MINIMUM FLOWS

Recommended minimum flows were developed for Silver Springs using an event based approach. The three recommended flows (FH, MA and FL) are based on criteria developed from vegetation, soils and topography data (Table 13).

Table 13. Recommended minimum flows for Silver Springs, Marion County, Florida

Minimum Flows	Flow (cfs)	Duration (days)	Return Interval (years)
Frequent high	828	30	5
Average	638	180	1.7
Frequent low	572	120	3

The recommended FH (828 cfs, 30-days, with a 5-year return interval) is based on providing a sufficient number of flood events to protect the entire extent of floodplain wetlands and their wildlife habitat values. These flood events also promote filtration and absorption of nutrients and other pollutants on the floodplain. The recommended MA (638 cfs, 180-days, with a 1.7-year return interval) prevents an excessive number of dewatering events in order to protect organic soils from oxidation and subsidence and avoid adverse impacts to habitat and water quality. The recommended FL (572 cfs, 120-days, with a 3-year return interval) prevents an excessive number of dewatering events in order to protect marsh ecotones along the Silver River and their associated wildlife values. The FL also maintains an appropriate water table level in soils of the floodplain during periodic droughts. By maintaining the essential characteristics of the natural seasonal flooding and drying regimes, the basic structure and functions of a given environmental system will be maintained.

Although the recommended MFLs were developed based on riparian floodplain ecological criteria, they will also protect the in-stream aquatic ecosystem from significant harm. HEC-RAS model simulations indicate that the amount of flow reduction allowed by the Silver Springs MFLs will not appreciably impact the magnitude or spatial distribution of in-channel velocities. Physical channel morphology, submerged aquatic macrophyte beds, and ecosystem metabolism parameters will be maintained.

Because the MFLs for Silver Springs are based on flows, once they are adopted, they can more readily be used to support SJRWMD’s water supply planning and water use regulation programs. The MFLs can be used to determine future/projected and ongoing compliance status for consumptive use permitting through a compliance assessment analysis. Groundwater model projections are used to estimate the future impact of individual and cumulative consumptive use permits on MFLs. By setting the Silver Springs MFLs as a series of minimum flows, it enables SJRWMD to use groundwater modeling to estimate spring flow reduction, and thus readily perform a compliance assessment to ensure the MFLs will be met. The recommended minimum flows were developed based on the flows necessary to protect critical water stages. As such, the critical stages within the Silver Springs ecosystem are protected by the recommended minimum flows.

MFLs status was assessed using frequency analysis to compare the frequency of critical ecological events under baseline conditions to the frequency of those same events based on the recommended MFLs. The baseline condition represents a best estimate of current impacted condition, and for the Silver Springs MFLs is defined as the 2010-pumping condition. Impact on the UFA due to groundwater withdrawals was estimated using the best available tool, the NDMv5 regional groundwater model. The NDMv5 flow reduction estimate of 26 cfs represents the change in Silver Springs flow from a no-pumping condition to the baseline condition (see Appendix B for more details).

The recommended MFLs events set the limit of available water, beyond which further water withdrawals would be significantly harmful to the ecological structure and/or function, or other beneficial uses of a given water body. These events are based on the hydrologic regime necessary to protect environmental functions and values over the long term. As such, the recommended return intervals are the average number of events required over the long term, recognizing that event frequency may vary between long periods of wet and drought conditions. Because the recommended MFLs events are long-term averages, they were also assessed using the full long-term POR for Silver Springs.

To complete the status assessment of the MFLs for Silver Springs, it is necessary to determine if the MFLs are being met under current pumping conditions and under projected pumping conditions for the 20-year planning horizon. Frequency analyses indicate that all three recommended MFLs for Silver Springs are currently being achieved under baseline conditions. Freeboards of 98 cfs, 19 cfs, and 17 cfs were calculated for the FH, MA and FL, respectively. The most constraining MFL is the FL, with a freeboard of 17 cfs. Although it was determined that the MFLs are being met under current pumping conditions, based on the best available information, the predicted flow reduction resulting from projected water use for the 20-year planning horizon is more than 17 cfs of freeboard available for the most constraining MFL. Therefore, without the implementation of an appropriate prevention strategy, the proposed FL flow for Silver Springs will not be met for the entire 20-year planning horizon. Based on the best available data, an estimated ~3.5% change has occurred from a no-pumping to baseline condition due to groundwater pumping. The recommended minimum flow allows an additional ~2.5% reduction, for a total of ~6% reduction from groundwater pumping before the FL flow will no longer be met. The analyses also indicate that, based upon current water use projections, groundwater pumping will cause the FL flow to no longer be met in approximately 2025. Therefore, a prevention strategy is recommended for adoption concurrent with the MFLs that includes the necessary projects and regulatory measures to ensure that the MFLs will be met for the 20-year planning horizon.

SJRWMD concludes that the recommended MFLs, which have been developed primarily for the protection of significant harm to "fish and wildlife habitats and the passage of fish" and "filtration and absorption of nutrients and other pollutants," will protect all other relevant Rule 62-40.473, *F.A.C.*, environmental values. Because these MFLs protect the structure and function of wetlands and aquatic habitats, other functions and values related to ecological integrity (e.g., nutrient filtration, detrital transport) will likely be protected from significant ecological harm caused by withdrawals, if the FH, MA and FL criteria are protected (Appendix E). The recommended MFLs presented in this report are preliminary and will not become effective until adopted by the SJRWMD Governing Board, as directed in Rule 40C-8.031, *F.A.C.*

Future Monitoring and Adaptive Management

Incorporating New Physical and Ecological Information

To ensure that the minimum flows recommended herein maintain critical physical characteristics, and protect critical environmental functions and values, SJRWMD will continue to monitor hydrological, physical and ecological characteristics of Silver Springs and Silver River.

SJRWMD has initiated systematic physical streambed morphology and in-channel vegetation mapping with Acoustic Doppler Current Profilers (ADCP). As a part of SJRWMD's Springs Protection Initiative and development of restoration strategies for Silver Springs, routine in-channel, quantitative vegetation monitoring and velocity profiling at selected Silver River channel cross sections were conducted from 2014 through February 2017.

Additionally, SJRWMD continues data collection and improvement of assessment (such as the Silver River Environmental Fluid Dynamic Code (EFDC) hydrodynamic model), which will allow a more thorough assessment of cause and effect relationships between abiotic and biotic stream properties. Upon completion, the model can be used to confirm the conclusions regarding the MFLs protection of in-channel structure and function.

SJRWMD recommends reevaluating the Silver Springs minimum flows within 10 years of rule adoption.

Monitoring Stage-Flow Relationship

The stage-flow relationship within Silver River (USGS gage 02239501) has changed over time. Since 2000 there are, on average, higher water levels per unit flow relative to pre-2000. In addition, the recommended minimum flows are based on providing sufficient river stages to protect the most sensitive environmental values.

Because of these two factors it is critical that both stages and flow be monitored over time to: 1) evaluate whether the stage-flow relationship has permanently changed; and 2) verify that sufficient stages are being maintained to protect critical environmental values.

Periodic reassessments of the recommended MFLs based on future monitoring data would assure that critical environmental thresholds are being achieved and providing the expected levels of protection of the water resources and ecology. Reassessments may include analysis of baseline flow and stage time series, updated and newly developed models, and/or periodic monitoring of the river channel, floodplain vegetation communities, and soil water tables.

Vegetation Management

While the FDEP Basin Management Action Plan (BMAP) process is focused on achieving total maximum daily loads (TMDLs) by reducing nutrient loading to the springshed (e.g., nitrogen in particular), physical management of the Silver River channel and/or the Ocklawaha River (e.g., SAV harvesting) may need to be further explored if it is determined that it is necessary to alter the changes in channel roughness and increased friction affecting Silver Springs and Silver River flows that have occurred.

Ongoing Status Assessment

As previously described, a critical part of future monitoring will be the assessment of MFLs compliance. MFLs will be assessed on a 5-year interval, or when permit applications are considered. A screening level analysis that incorporates climatic factors and uncertainty will be used to determine whether minimum flows are being achieved. If this screening level analysis suggests that they are not being achieved, further analyses will be undertaken to determine the cause. See *MFLs Status Assessment* section for more details.

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APPENDICES

APPENDIX A—SILVER SPRINGS MFLS VEGETATION AND SOILS COLLECTION AND ANALYSIS METHODS, TRANSECT DESCRIPTIONS AND FIELD DATA

FIELD DATA COLLECTION AND ANALYSIS

Site Preparation and Survey

On selection of a transect site at Silver River, vegetation was trimmed to allow a line of sight along the length of the transect. A measuring tape was then laid out along the transect's length. Elevations were surveyed by SJRWMD Bureau of Public Works survey staff, in accordance with Chapter 5J-17, *F.A.C.*, Section 472.027 F.S., at various length intervals (5 ft, 10 ft, 20 ft, etc.) to adequately characterize the topography and transect features. Additional elevations were measured, including obvious elevation changes, vegetation community changes, soil changes, high water marks, elevations of adventitious roots or lichen lines, and other features of interest (e.g., tree bases).

Latitude and longitude data were also collected with a global positioning system (GPS) receiver at selected points along the transects. These data were used to accurately locate specific features along each transect and will facilitate future recovery of transect locations (e.g., MFLs biological monitoring efforts).

Soil Sampling Procedures

Detailed soil profiles were described to gain an understanding of past and present hydrologic, geologic, and anthropogenic processes that have occurred, resulting in the observed transect soil features. Soil borings were taken at various points on the transect lines to sample all significant geomorphic features, landscape positions, and plant communities. Soil profiles were described following standard NRCS procedures (NRCS 2010). Each soil horizon (unique layer) was generally described with respect to texture, thickness, Munsell color (Kollmorgen Corp. 1992), structure, consistency, boundary, and presence of roots. Soil series were determined by using taxonomic keys (SSS 1999) to determine soil classification and by consulting series criteria found in official series descriptions (SCS 1979; NRCS 2012). The primary soil criteria considered in the MFLs determinations were the presence and depth of organic soils, as well as the extent of hydric soils observed along the field transects. Additional soil sampling procedures are documented in SJRWMD's MFLs methods manual (SJRWMD 2006, draft).

Vegetation Sampling Procedures

Plant associations are well-documented groupings of vegetation stands that have relatively consistent floristic composition, uniform physiognomy, and a distribution that is characteristic of a particular habitat (Barbour et al. 1999). For purposes of the MFLs program, plant associations are referred to as communities. Ecotones are transition zones between two plant communities containing the characteristic species of both communities. Community boundaries are spatial localities where the magnitude of change in species composition is greatest (Fagan et al. 2003).

The spatial extent of plant communities or transition zones (i.e., ecotones) between plant communities was determined using reasonable scientific judgment. Reasonable scientific judgment involves the ability to collect and analyze information using technical knowledge, and personal skills and experience to serve as a basis for decision making (Gilbert et al. 1995). In this case, such judgment was based on field observations of relative abundance of dominant plant species, occurrence and distribution of soils and hydric soils indicators (HIs), and changes in land slope or elevation along the hydrologic gradient. Plant communities and transition zones were delineated along a specialized line transect called a belt transect. A belt transect is a line transect with width (belt width) to form a long, thin, rectangular plot divided into smaller sampling areas called quadrats that correspond to the spatial extent of plant communities or transitions between plant communities (Figure A1). The belt transect width will vary depending on the type of plant community to be sampled (SJRWMD 2006, draft). For example, a belt width of 10 ft (5 ft on each side of the transect line) may suffice for sampling herbaceous plant communities of a floodplain marsh. However, a belt width of 50 ft (25 ft on each side of the line) may be required to represent a forested community adequately (e.g., hardwood swamp, Figure A1).

Plants were identified and the percent cover of plant species was estimated if they occurred within the established belt width for the plant community under evaluation (quadrat). Percent cover is defined as the vertical projection of the crown or shoot area of a plant to the ground surface and is expressed as a percentage of the quadrat area. Percent cover as a measure of plant distribution is often considered as being of greater ecological significance than density, largely because percent cover gives a better measure of plant biomass than the number of individuals. The canopies of the plants inside the quadrat will often overlap each other, so the total percent cover of plants in a single quadrat will frequently sum to more than 100% (SJRWMD 2006, draft). Percent cover was estimated visually using cover classes (ranges of percent cover).

The cover class and percent cover ranges (Table A1) are a variant of the Daubenmire method (Mueller-Dombois and Ellenberg 1974) and are summarized in SJRWMD’s MFLS methods manual (SJRWMD 2006, draft). Plant species, plant communities, and percent cover data were recorded on field vegetation data sheets. The data sheets are formatted to facilitate field data collection and computer transcription.
In an effort to confirm expert observations and identify discontinuities, a line intercept sampling technique was also used at Silver River to measure plant cover and distribution. Line intercept is a quantitative method that involves measuring by plant species the lengths of vegetation that overlap the transect line. Cover intervals are measured to the nearest foot. Vines and floating species are not reliable indicators of site hydrology and are excluded.

Plant Community Delineation

Plant communities are identified in the field as described above using vegetation characteristics supplemented by soil and landscape features. Delineation of communities is a matter of reasonable scientific judgment refined by extensive experience in a particular region. Split Moving Window (SMW) gradient analysis was also used to detect vegetation breaks and support field delineations of vegetation communities. SMW is described by Cornelius and Reynolds (1991), Hennenberg et al. (2005), and Boughton et al. (2006) and was modified by Epting (2010) for use at SJRWMD.

The SMW procedure views vegetation abundance along the line transect through a series of 3-foot wide windows. Plant species composition is compared between adjacent window pairs, which may range from 2 to 20 windows in width. For each window pair, the mean dissimilarity coefficient for species composition (z-score) is calculated. Z-scores are the sum of squared differences standardized by the mean and standard deviation for each window mid-point position. Average z-scores are plotted against transect length and peaks in the z-scores are generally deemed to be vegetation breaks if they exceed one standard deviation. Moving Window Regression Analysis (MWRA) calculates the slope of the z-score line. Vegetation breaks are defined as those points where regression slope has a maximum value >0 or a minimum value <0 between a break and the next change of sign (or hitting zero).

All discontinuities identified by the SMW procedure were re-investigated in the field for verification. Some vegetation breaks identified by the SMW procedure were the result of a change in vegetation composition, such as decreased groundcover or overstory that did not signal a habitat change. Field notes were taken and reviewed in conjunction with the initial vegetation breaks, cover estimates, elevation and soils data to determine appropriate habitats and vegetation community breaks for the transect.

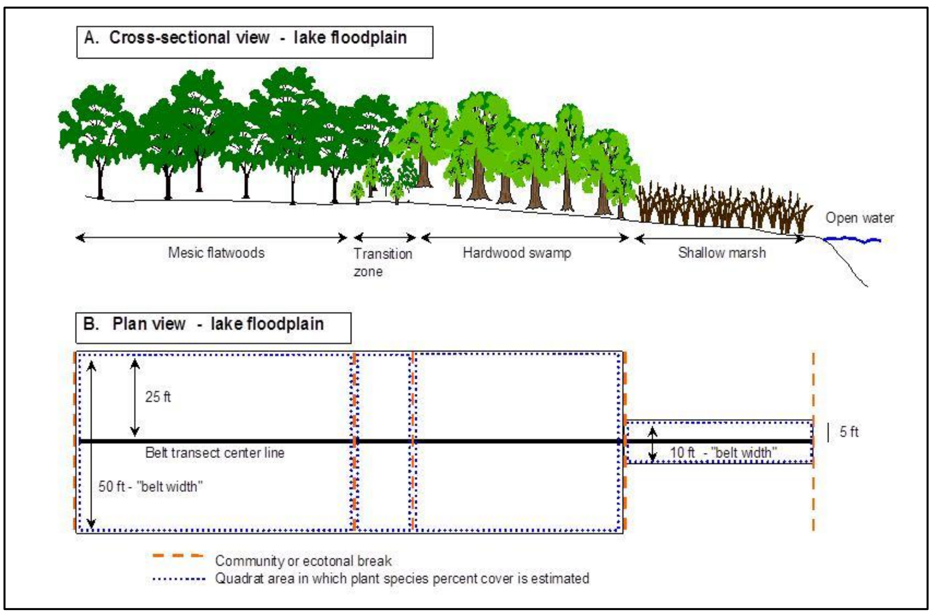

Figure A1. Generalized belt transect through forested and herbaceous plant communities

Table A1. Summary of vegetation cover classes and percent cover ranges

Cover Class	Percentage Cover Range	Descriptor
0	< 1 %	Rare
1	1%–10%	Scattered
2	11%–25%	Numerous
3	26%–50%	Abundant
4	51%–75%	Co-dominant
5	> 75 %	Dominant

Source: Mueller-Dombois and Ellenberg 1974

TRANSECT DESCRIPTIONS

Transect 3 Vegetation

Upland–North (Stations 0 to 215 [minimum elevation 44.9 ft NGVD]). Transect 3 began in the upland community on the north side of the Silver River. The overstory was dominated by cabbage palm (*Sabal palmetto*) with abundant sweet gum (*Liquidambar styraciflua*) and numerous American elm (*Ulmus americana*) and swamp chestnut oak (*Quercus michauxii*). The understory was mainly composed of abundant dwarf palmetto (*Sabal minor*) and numerous long-leaf spikegrass (*Chasmanthium sessiliflorum*).

Transition Zone (Stations 215 [44.9 ft NGVD] to 275 [40.2 ft NGVD]). A transition zone occurred on the slope from upland to hardwood swamp. The overstory was dominated by cabbage palm, with numerous sweet gum and sugarberry (*Celtis laevigata*) and occasional American elm. The midstory was comprised of numerous musclewood (*Carpinus caroliniana*). The understory had abundant dwarf palmetto with numerous Florida paspalum (*Paspalum floridanum*).

Hardwood Swamp (Stations 275 [40.2 ft NGVD] to 728 [37.2 ft NGVD]). The hardwood swamp began at Station 275 (40.2 ft NGVD) and continued to the edge of channel where the shallow marsh community began (Station 728, 37.2 ft NGVD). The overstory of the northern hardwood swamp was composed of abundant cypress (*Taxodium* spp.) with numerous sweet gum, cabbage palm, black gum (*Nyssa sylvatica*), red maple (*Acer rubrum*), and ash (*Fraxinus* spp.*)*. American elm was sparse within this community, as was sweet bay (*Magnolia virginiana*). There was minimal midstory and only an occasional understory comprised of occasional savannah panicum (*Panicum gymnocarpon*), beakrush, false nettle (*Boehmeria cylindrica*), red ludwigia (*Ludwigia repens*), nut sedge (*Cyperus esculentus*), lizard's tail (*Saururus cernuus*), and water hemlock (*Cicuta mexicana*).

Shallow Marsh (Stations 728 [37.2 ft NGVD] to 746 [35.0 ft NGVD]). A thin band of shallow marsh vegetation occurred at the edge of the hardwood swamp before the river channel deepened at Station 746, 35.0 ft NGVD). The shallow marsh was characterized by abundant pickerelweed (*Pontederia cordata*), with sparse spatterdock (*Nuphar advena*) and eelgrass (*Vallisneria americana*) and an occasional buttonbush (*Cephalanthus occidentalis*), false nettle, or arrowhead (*Sagittaria sp.*).

Aquatic Bed–River Channel (Stations 746 [35.0 ft NGVD] to 826 [38.3 ft NGVD]). The channel of the Silver River and its submerged aquatic bed extended from Stations 746 to 826 (35.0 to 38.3 ft NGVD). Arrowhead (*Sagittaria kurziana*) dominated this portion of the Silver River's submerged aquatic vegetation, with numerous eelgrass (*Vallisneria americana*) and scattered hornwort (*Ceratophyllum demersum*). Algae covered the majority of the submerged vegetation.

Hydric Hammock (Stations 826 [38.3 ft NGVD] to 1325 [38.2 ft NGVD]). On the south side of the river, the elevation increases sufficiently to support a hydric hammock community. The overstory of this community had abundant cabbage palm and red maple, with numerous ash and sparse American elm. The midstory had some cabbage palm with numerous dogwood trees (*Cornus foemina*), with sparse wax myrtle (*Myrica cerifera*), dahoon holly (*Ilex cassine*), small leaf viburnum (*Viburnum obovatum*), red cedar (*Juniperus silicicola),* and sea myrtle (*Baccharis sp.*). The understory was composed of numerous false nettle with sparse dwarf palmetto, frog fruit (*Phyla nodiflora*), bluestem (*Andropogon sp.*), fingergrass (*Eustachys glauca*), camphorweed (*Pluchea longifolia*), dotted smartweed (*Polygonum punctatum*), hornpod (*Mitreola petiolata*), and others.

Hardwood Swamp (Stations 1325 [38.2 ft NGVD] to 1426 [37.6 ft NGVD]). The hydric hammock community decreased in elevation and sharply transitioned into a hardwood swamp community. The overstory of the hardwood swamp community was dominated by cypress, ash, red maple, and cabbage palm. There was minimal midstory within this community, but the understory was composed of tall panicum (*Panicum longifolium*), pennywort (*Hydrocoytle sp.*), hornpod, red ludwigia, false nettle, smartweed, pickerelweed, horned beaksedge, and camphorweed.

Transition Zone (Stations 1426 [37.6 ft NGVD] to 1538 [37.8 ft NGVD]). The hardwood swamp increased in elevation, changing into a drier transitional area before dropping again into hardwood swamp. This transitional area had an overstory still dominated by bald cypress, with abundant ash, and sparse red maple, cabbage palm, and cypress. There was minimal midstory, but the understory consisted of sparse hornpod, lateflowering thoroughwort (*Eupatorium serotinum*), false nettle, camphorweed, and yellow nutgrass.

Hardwood Swamp (Stations 1538 [37.8 ft NGVD] to 1826 [38.7 ft NGVD]). This hardwood swamp crosses a distributary channel that branches off of Silver River on a 90 degree bend between MFLs Transect 3 and hydrologic modeling cross section T-4. This channel is an established channel that is visible on aerial maps and traverses the southern part of the Silver River floodplain from just west of Transect 3 and flows to the east, independently connecting to the Ocklawaha River at the point where it becomes channelized upstream of the Silver River confluence. Hardwood swamp continued from the transition community to the hydric hammock. The overstory was dominated by bald cypress, with numerous ash, and sparse cypress, blackgum, and cabbage palm. The midstory was minimal with only very sparse willow (*Salix caroliniana*) and some cabbage palm. The understory consisted of sparse hornpod, pickerelweed, pimpernel (*Samolus parviflorus*), yellowcress (*Rorippa sp.*), and spider lily (*Hymenocallis sp.*).

<u>Hydric Hammock (Stations 1826 [38.7 ft NGVD] to 2025 [56.9 ft NGVD]).</u> The hydric hammock sloped up from the hardwood swamp floodplain to a transition zone below the plateaued upland edge. The overstory consisted of abundant cabbage palm, sweet gum, and sugarberry, with numerous live oaks (*Quercus virginiana*) and sparse sweet bay, American elm, and slash pine (*Pinus elliottii*). There was some midstory cabbage palm, with the understory being composed of sparse caesarweed (*Urena lobata*), yellow nutgrass, Florida paspalum, woodsgrass (*Oplismenus hirtellus*), and forked bluecurls (*Trichostema dichotomum*).

<u>Transition Zone (Stations 2025 [56.9 ft NGVD] to 2120 [58.1 ft NGVD])</u>. A transition zone encompassing a trail and a gradient of vegetation existed between the sloped hydric hammock and the plateaued upland edge. The overstory of this zone consisted of abundant sweet gum, with scattered cabbage palm, laurel oaks, and loblolly pines. The midstory consisted of abundant cabbage palm, with an understory of numerous Bahia grass and Baldwin's flatsedge (*Cyperus croceus*).

<u>Upland–South (Station 2120 [58.1 ft NGVD] to 2200 [58.1 ft NGVD])</u>. The uplands consisted of an overstory of abundant sweet gum, with numerous loblolly pine, and scattered cabbage palm, laurel oak, sweet bay, cedar elm, white ash, and swamp chestnut oak. The midstory was comprised of numerous cabbage palm and scattered hackberry. The understory consisted of woodsgrass, with scattered panic grass, dwarf palmetto, and long-leaf spikegrass. Transect 3 terminated at Station 2200 (58.1 ft NGVD).

Transect 3 Hydric Soil Indicators

Ten primary HIs (NRCS 2010) were observed: Depleted Matrix (F3), Thick Dark Surface (A12), Muck Presence (A8), Stratified Layers (A5), Umbric Surface (F13), Depleted Below Dark Surface (A11), 5 cm Mucky Mineral (A7), Redox Dark Surface (F6), Histic Epipedon (A2), and Histosol (A1). Elevation summary statistics for HIs and their estimated extents are shown in Figure 29 and Appendix A. More detailed information can be found in the soils report (Freese 2010; Appendix G).

The landward HI (F3 Depleted Matrix) north of the river was at Station 314 (39.4 ft NGVD in the hardwood swamp. HIs extended across the floodplain to the river channel. However, on the south side of the river channel, HIs were absent from most the hydric hammock community. HIs began again at Station 1205 (38.3 ft NGVD) in hydric hammock where F3 Depleted Matrix and A11 Depleted Below Dark Surface were both observed. The southern landward extent of HIs (F3 Depleted Matrix) was at Station 1830 (38.9 ft NGVD) near the start of a second hydric hammock.

Muck Presence (A8) occurred in five area of Transect 3: Stations 468 (36.9 ft NGVD) to 480 (36.1 ft NGVD), 580 (36.9 ft NGVD) to 640 (37.4 ft NGVD), 1345 (37.6 ft NGVD) to 1445 (37.9 ft NGVD), 1567 (37.1 ft NGVD) to 1670 (37.1 ft NGVD), and 1715 (36.8 ft NGVD) to 1742 (36.8 ft NGVD).

Deep organics were less extensive at Transect 3 relative to other transects. A1 Histosol and A2 Histic Epipedon (A2) occurred on the north side of the floodplain from Stations 480 (36.1 ft NGVD) to 580 (36.9 ft NGVD). A small area of A2 Histic Epipedon also occurred on the south floodplain near the toe-slope (Stations 1742 [36.8 ft NGVD] to 1750 [35.8 ft NGVD]). Due to the small extent of these HIs, no soil series were identified.

Transect 5 Vegetation

Upland—North (Stations 0 to 88 [minimum elevation 48.5 ft NGVD]). Transect 5 began in the upland community on the north side of the Silver River. The overstory was composed of numerous cabbage palm, sweet gum, pignut hickory (*Carya glabra*), shumard oak (*Quercus shumardii*), and swamp chestnut oak (*Quercus michauxii*) with scattered American elm, water oak, and ash. The midstory consisted of hackberry (*Celtis laevigata*), with scattered American hornbeam (*Carpinus caroliniana*) and giant cane (*Arundinaria gigantea*). The understory was composed of numerous dwarf palmetto (*Sabal minor*), with scattered beautyberry (*Callicarpa americana*), shield fern (*Thelypteris* sp.), and various herbaceous grasses.

Transition Zones 1 and 2 (1: Stations 88 [48.5 ft NGVD] to 116 [43.8 ft NGVD]; and 2: Station 116 [43.8 ft NGVD] to 167 [39.0 ft NGVD]). The initial transition zone (1) that occurred from the upland to the slope descending into hardwood swamp contained a mixture of upland and wetland species. This 28 ft zone was not assessed individually via the cover estimate method because it was designated after review of the original cover estimates, the line intercept data, as well as field reconnaissance. The second transition zone (2) occurred at the base of the bluff slope and included more wetland species. The overstory was composed of abundant cypress with numerous sweet gum and cabbage palm. The mid- and understories were composed of various scattered or rare species, such as American elm, ash, swamp tupelo (*Nyssa sylvatica* var. *biflora*), American hornbeam, dwarf palmetto, shield fern, basket grass, various panicums, and marsh fleabane (*Pluchea camphorata*).

Hardwood Swamp (Stations 167 [39.0 ft NGVD] to 494 [33.1 ft NGVD]). Hardwood swamp began at the bottom of the slope where coverage of the cypress trees and knees became more dense and the dense cabbage palm ended. This community crossed a narrow slough on the north side of the floodplain. At times of high water levels, this slough has some flow through the floodplain. The overstory consisted of numerous cypress, red maple (*Acer rubrum*), and ash, with scattered cypress, American elm, sweet gum, swamp tupelo, and cabbage palm. The midstory consisted mainly of smaller overstory trees, with the understory being sparse and consisting of scattered false nettle (*Boehmeria cylindrica*), southern hemlock (*Cicuita mexicana*), thoroughwort (*Eupatorium sp.*), pennywort (*Hydrocoytle sp.*), red ludwigia (*Ludwigia repens*), dotted smartweed (*Polygonum punctatum*), pickerelweed (*Pontederia cordata*), miterwort (*Mitreola petiolata*), and various panicums.

Aquatic Bed–River Channel (Stations 494 [33.1 ft NGVD] to 568 [34.4 ft NGVD]). The channel of the Silver River and its submerged aquatic bed extended from Stations 494 to 568. Springtape dominated this portion of the Silver River's submerged aquatic vegetation, with numerous eelgrass and scattered hornwort.

Shallow Marsh (Stations 568 [34.4 ft NGVD] to 604 [37.2 ft NGVD]). The thin shallow marsh community at the edge of the river channel had numerous pickerelweed, with scattered spatterdock (*Nuphar advena*) and some submerged hornwort.

Hardwood Swamp (Stations 604 [37.2 ft NGVD] to 1333 [38.7 ft NGVD]). The hardwood swamp on the south side of the transect began at the edge of the shallow marsh, and continued until the transition zone to hydric hammock. The hardwood swamp overstory consisted of mainly ash and cypress with numerous red maple and scattered swamp tupelo, sweet bay, and cabbage palm. The midstory consisted mainly of smaller overstory trees, with the understory being sparse and consisting of scattered false nettle (*Boehmeria cylindrica*), southern hemlock (*Cicuita mexicana*), thoroughwort (*Eupatorium sp.*), pennywort (*Hydrocoytle sp.*), red ludwigia (*Ludwigia repens*), pickerelweed (*Pontederia cordata*), miterwort (*Mitreola petiolata*), beakrush (*Rhynchospora corniculata*), nut sedge (*Cyperus esculentus*), water pimpernel (*Samolus parviflorus*), lizard's tail (*Saururus cernuus*), and various panicums.

Transition Zone (Stations 1333 [38.7 ft NGVD] to 1400 [39.7 ft NGVD]). Between the hardwood swamp and uplands occurred a transition zone on the lower slope that graded into a hydric hammock. This Transition Zone had an overstory consisting of numerous cabbage palm, sweet gum, and cypress, with scattered red maple, southern red cedar (*Juniperus silicicola*), and swamp tupelo. The midstory consisted mainly of smaller overstory trees, with the understory being composed of numerous Savannah panicum (*Panicum gymnocarpon*) and tall panicum, with scattered basketgrass, southern cut grass (*Leersia virginica*), dwarf palmetto, variable panic grass (*Panicum commutatum*), marsh fleabane, and lizard's tail.

Hydric Hammock (Stations 1400 [39.7 ft NGVD] to 1490 [45.4 ft NGVD]). The hydric hammock located on the back slope of the floodplain was dominated by cabbage palm in the overstory, with numerous southern red cedar, and sweet gum, with scattered water hickory (*Carya aquatic*), American elm and laurel oak (*Quercus laurifolia*). The midstory consisted of smaller overstory trees, with the understory being composed of dwarf palmetto, woodsorrel (*Oxalis* sp.), variable panic grass, tall panicum, Florida paspalum (*Paspalum floridanum*), nut sedge, thoroughwort, and pennywort.

Upland–South (Stations 1490 [45.4 ft NGVD] to 1600 [47.3 ft NGVD]). The uplands on the south side of Transect 5 consisted of an overstory dominated by cabbage palm and sweet gum, with numerous water hickory, southern red cedar, American elm, and laurel oak, and scattered hackberry and water oak. The midstory consisted mainly of small cabbage palm and sweet gum. The sparse understory is composed of Cherokee sedge, variable panic grass, and dwarf palmetto.

Transect 5 Hydric Soil Indicators

There were nine primary HIs (NRCS 2010) at Transect 5: Depleted Matrix (F3), Muck Presence (A8), Histic Epipedon (A2), Histosol (A1), Stratified Layers (A5), 5cm Mucky Mineral (A7), Umbric Surface (F13), Organic Bodies(A6), and Redox Dark Surface (F6) (Freese 2010; Appendix G; NRCS 2010). Elevation summary statistics for HIs and their estimated extents are shown in Figure 30 and Appendix A. More detailed information is found in the soils report (Freese 2010; Appendix G).

On the north side of Transect 5, HIs began in the transition zone and extended to the river. The landward extent of HIs (F3 Depleted Matrix) was at Station 140 (40.1 ft NGVD. On the south side, the HIs extended from the river through the hardwood swamp community. The southern landward extent of HIs (F3 Depleted Matrix) was at Station 1460 (41.7 ft NGVD) in the hydric hammock.

A8 Muck Presence occurred in seven areas: Stations 170 (38.7 ft NGVD) to 204 (37.4 ft NGVD), 320 (38.0 ft NGVD) to 370 (38.9 ft NGVD), 405 (38.9 ft NGVD) to 460 (37.5 ft NGVD), 670 (37.6 ft NGVD) to 700 (37.9 ft NGVD), 760 (38.6 ft NGVD) to 880 (36.9 ft NGVD), 925 (36.6 ft NGVD) to 1150 (38.0 ft NGVD), and 1193 (38.4 ft NGVD) to 1320 (38.5 ft NGVD).

Deeper organic soils occurred in three areas. A1 Histosol extended 116 linear feet (Stations 204 [37.4 ft NGVD] to 320 [38.0 ft NGVD]). A2 Histic Epipedon (A2) occurred from Stations 640 [37.9 ft NGVD] to 670 [37.6 ft NGVD] and 880 [36.9 ft NGVD] to 925 [36.6 ft NGVD]) for a combined length of 75 feet. Soil series included Histosols such as Gator and Okeelanta mucks and Denaud muck, a histic epipedon series.

Transect 7 Vegetation

Upland–North (Stations 0 to 70 [minimum elevation 50.3 ft NGVD]). Transect 7 began in the upland community on the north side of the Silver River. The overstory was composed of abundant loblolly pine (*Pinus taeda*), numerous cabbage palm and sweet gum, with scattered southern red cedar and laurel oak. The midstory consisted of scattered wax myrtle and smaller overstory trees species. The understory was composed of scattered dwarf palmetto, with various scattered herbs (i.e., hammock throughwort (*Ageratina jucunda*), bluestem (*Andropogon sp*.), Cherokee sedge, long-leaf spikegrass (*Chasmanthium sessiliflorum*), etc.). The upland vegetation community ended at the waterward station for loblolly pine.

Hydric Hammock (Stations 70 [50.3 ft NGVD] to 250 [39.7 ft NGVD]). Hydric hammock continued from upland to the hardwood swamp. This community had an overstory that was composed of abundant sweet gum, with numerous cabbage palm and hackberry, and scattered ash and box elder (*Acer negundo*). The midstory consisted of smaller overstory tree species, American hornbeam, and southern red cedar. The understory was composed of scattered dwarf palmetto, various grasses (*Muhlenbergia schreberi*, *Panicum spp*.) and other herbaceous species.

Hardwood Swamp (Stations 250 [39.7 ft NGVD] to 747 [37.9 ft NGVD]). The hardwood swamp began where mature cabbage palm ended and hardwood swamp tree species began. This community crossed a wide but relatively shallow area on the north side of the floodplain. At times of high water levels, this area does have some flow through the floodplain. The overstory consisted of abundant cypress and ash, with numerous red maple and swamp tupelo. The midstory was composed of numerous scattered immature cabbage palm. The understory was composed of numerous beakrush with various scattered herbaceous species, such as southern water hemlock, false nettle, pennywort, spiderlily (*Hymenocallis sp*.), red ludwigia, miterwort, spatterdock, pickerelweed, smartweed, camphorweed, etc. The hardwood swamp ended at the termination of hardwood swamp tree trunks into the river channel.

Aquatic Bed–River Channel (Stations 747 [37.9 ft NGVD] to 934 [36.4 ft NGVD]). The aquatic bed began where the elevation drops into the river channel. This area of submerged aquatic vegetation was dominated by arrowhead (springtape) and eelgrass with numerous hornwort. The edges of the channel had scattered southern water hemlock, spatterdock, and pickerelweed.

Hardwood Swamp (Stations 934 [36.4 ft NGVD] to 1390 [40.1 ft NGVD]). The hardwood swamp began at the termination of hardwood swamp tree trunks into the river channel. This portion of hardwood swamp has an overstory with abundant cypress, numerous ash and cabbage palm, with scattered red maple and American elm. The understory consisted of numerous tall panicum and beakrush, with scattered false nettle, southern water hemlock, buttonweed, pennywort, whitegrass (*Leersia virginica*), alligatorweed, spatterdock, basketgrass, variable panic grass, Savannah panicum, camphorweed and marsh fleabane, dotted smartweed, lizard’s tail, water pimpernel, and pickerelweed.

Transition Zone 2 (Stations 1516 [40.7 ft NGVD] to 1790 [40.9 ft NGVD]). This open transitional area was a disturbed area of an abandoned old pasture, as evident by aerial photography, its habitat characteristics, and a couple relict fence posts with barbed wire. There was little to no overstory, with a midstory consisting of numerous wax myrtle, with scattered red maple, swamp dogwood, and southern red cedar. The understory consisted of abundant dogfennel, ragweed (*Ambrosia artemisiifolia*), and broomsedge, numerous frog fruit (*Phyla nodiflora*), paspalum grass (*Paspalum sp.*), and scattered panicums, false nettle, coinwort, nut sedge (*Cyperus esculentus*), ponysfoot (*Dichondra* sp.), and white-topped sedge. Rooting from feral hog (*Sus scrofa*) activity in this area was evident to staff on several different field collection days.

Hydric Hammock (Stations 1790 [40.9 ft NGVD] to 2025 [41.2 ft NGVD]). The hydric hammock begins where overstory begins again online, in conjunction with a small decrease in elevation. This hydric hammock community has an overstory of numerous red maple, sweet gum, cabbage palm, cypress, and American elm, with scattered box elder, ash, and laurel oak. The midstory consisted of some saplings of overstory trees, with scattered swamp dogwood and wax myrtle. The understory was composed of scattered ragweed, broomsedge, false nettle, coinwort, long-leaf spikegrass (*Chasmanthium sessiliflorum*), ponysfoot, white-topped sedge, pennywort, various panicums, frogfruit, Florida paspalum (*Paspalum floridanum*), camphorweed, and fleabane (*Pluchea rosea*).

<u>Upland–South (Stations 2025 [41.2 ft NGVD] to 2175 [45.1 ft NGVD]).</u> The hydric hammock ended and the upland community began at the start of the loblolly pine (*Pinus taeda*) trees. This community continued until the transect ended at Station 2175 (45.1 ft NGVD) in dense saw palmetto. The overstory of this southern upland community consisted of numerous loblolly pine, cabbage palm, sweet gum and laurel oak, with scattered American holly (*Ilex opaca*), southern magnolia (*Magnolia grandiflora*). The midstory of this community was composed of scattered wax myrtle and few rusty lyonia (*Lyonia ferruginea*). Although near the end of the transect, saw palmetto formed a dense monospecific stand, it was only rated with a coverage estimate of 1 (sparse or scattered) because it did not exist at lower elevations in this community and its overall coverage for this vegetation section was less than 10%. The understory was comprised of numerous long-leaf spikegrass, with scattered beauty berry (*Calicarpa americana*), gallberry (*Ilex glabra*), nimblewill muhly (*Muhlenbergia schreberi*), and variable panic grass (*Panicum commutatum*).

Transect 7 Hydric Soil Indicators

There were nine primary HI (NRCS 2010) at Transect 7: Depleted Matrix (F3), Redox Dark Surface (F6), Muck Presence (A8), Mucky Mineral (A7), Organic Bodies (A6), Histosol (A1), Depleted Below Dark Surface (A11), Umbric Surface (F13), and Stripped Matrix (S6) (NRCS 2010). Descriptive statistics for HIs and their estimated extents are shown in Figure 31 and Appendix A. More detailed site information can be found in the soils report (Freese 2010; Appendix G).
On the north side of Transect 7, HIs began in the hydric hammock and continued to the river channel. The landward HI at Station 200 (42.0 ft NGVD) was F3 Depleted Matrix. On the south side of the channel, the HIs extended through hardwood swamp , hydric hammock, and disturbed transition zone communities. The southern landward extent of HIs was S6 Stripped Matrix at Station 2035 (41.1 ft NGVD) at the edge of the uplands.

A8 Muck Presence occured in the following four areas: Stations 245 (40.7 ft NGVD) to 300 (37.8 ft NGVD), 478 (38.8 ft NGVD) to 575 (39.6 ft NGVD), 666 (39.7 ft NGVD) to 725 (38.6 ft NGVD), and 960 (39.2 ft NGVD) to 1150 (39.8 ft NGVD) .

One area of deep organic soils was found along Transect 7. A1 Histosol occurred with an estimated extent of 178 ft (Stations 300 [37.8 ft NGVD] to 478 [38.8 ft NGVD]). The average of deep organic soils along Transect 7 was 38.3 ft NGVD, with a median of 38.4 ft NGVD and a 1.5 ft elevation range (37.3 to 38.8 ft NGVD). Soil series in this area include Gator and Okeelanta mucks.

Transect 9 Vegetation

<u>Upland–North (Station 0 to 202 [minimum elevation 54.4 ft NGVD]).</u> Transect 9 began in the upland community on the north side of the Silver River. The overstory was dominated by

abundant pignut hickory, with numerous sweet gum, southern magnolia (*Magnolia grandiflora*), bastard white oak (*Quercus austrina*), and laurel oak. This community also had scattered sand live oak (*Quercus geminata*), cabbage palm, loblolly pine, and southern red cedar. The midstory consisted of numerous hop hornbeam (*Ostrya virginiana*), with scattered wild black cherry (*Prunus serotina*), highbush blueberry (*Vaccineum corymbosum*), beautyberry, sparkleberry (*V. arboreum*), and Hercule's club (*Zanthoxylum clava-herculis*). The understory was composed of numerous saw palmetto and long-leaf spikegrass, with scattered prickly pear cactus (*Opuntia humifusa*), bluestem, basketgrass, variable panic grass, tall panicum, Florida paspalum, nut sedge, globe sedge (*Cyperus globulosus*), Heller's witchgrass (*Dichanthelium oligosanthes*), partridgeberry (*Mitchella repens*), and various other species.

<u>Transitional Zone (Stations 202 [54.4 ft NGVD] to 300 [41.1 ft NGVD])</u>. At Station 202, there was a change in elevation gradient and overstory composition. Two transition areas were designated from Stations 202 to 300. The first transition area (Stations 202 to 255) had an overstory of abundant cabbage palm, with numerous pignut hickory and swamp chestnut oak, with scattered sweet gum. The midstory consisted of numerous hop and American hornbeam, with scattered beautyberry. The understory consisted of scattered false nettle, long-leaf spikegrass, nut sedge, dog fennel (*Eupatorium compositifolium*), partridgeberry, basketgrass, variable panic grass, Savannah panicum, marsh fleabane, dotted smartweed, dwarf palmetto, various fern species, and others.

The second transitional area (Stations 255 to 300) had an overstory of numerous sweet bay and cypress, with scattered sweet gum, cabbage palm, and swamp tupelo. Cypress overstory and cypress knees began in this zone, but rooted cypress tree trunks did not begin until after Station 300. The midstory consisted of scattered wax myrtle, salt myrtle (*Baccharis halimifolia*), and American hornbeam. The understory was composed of scattered basketgrass, alligatorweed, false nettle, dog fennel, pennywort, whitegrass, soft rush (*Juncus effusus*), red ludwigia, variable panic grass, Savannah panicum, Florida paspalum, marsh fleabane, dotted smartweed, lizard's tail, dwarf palmetto, floodplain beakrush (*Rhynchospora miliacea*), harsh verbena (*Verbena scabra*), various sedges and ferns, and other herbaceous species.

<u>Hardwood Swamp (Stations 300 [41.1 ft NGVD] to 916 [36.0 ft NGVD])</u>. The hardwood swamp community began at the base of the slope, where cypress trees began. The overtory was composed of abundant swamp tupelo and ash, with numerous cypress and American elm, and scattered red maple and cabbage palm. There was little to no midstory within this community, and the understory was mainly composed of numerous Savannah panicum and floodplain beakrush, with scattered alligatorweed, false nettle, southern water hemlock, buttonweed, dog fennel, pennywort, whitegrass, red ludwigia, miterwort, tall panicum, marsh fleabane, dotted smartweed, pickerelweed, beakrush, and lizard's tail. The hardwood swamp transitioned abruptly into the river channel at Station 916.

<u>Aquatic Bed—River Channel (Stations 916 [36.0 ft NGVD] to 1053 [38.2 ft NGVD])</u>. There was an abrupt elevation change at the edge of the floodplain hardwood swamps and the river channel. This area had minimal overstory on the edges of the river channel from adjacent hardwood swamps. The channel was dominated by submerged arrowhead or springtape, with

numerous eelgrass and scattered hornwort, with an occasional naiad (*Najas sp.*). Floating-leaved vegetation consists of an occasional spatterdock at the edge of the channel.

Hardwood Swamp (Stations 1053 [38.2 ft NGVD] to 1210 [40.0 ft NGVD]). This hardwood swamp community began on the south side of the river channel and continued until the end of cypress knees near the base of the slope. The overstory was comprised of abundant red maple with numerous ash, swamp tupelo, and cypress, and scattered sweet bay, cabbage palm, and American elm. The midstory consisted of scattered dahoon holly and some cabbage palm. The sparse understory consisted of alligatorweed, false nettle, southern water hemlock, buttonweed, dog fennel, pennywort, whitegrass, red ludwigia, miterwort, Savannah panicum, tall panicum, marsh fleabane, dotted smartweed, beakrush, floodplain beakrush, water pimpernel, lizard's tail, and shield fern.

Transitional Zone (Stations 1210 [40.0 ft NGVD] to 1283 [42.6 ft NGVD]). The transitional zone began at the end of cypress knees at the base of the slope and continued until loblolly pines began on the slope. The overstory was dominated by cabbage palm with abundant red maple and numerous sweet gum. The midstory consisted of scattered overstory species trees, mainly cabbage palm, with some scattered beautyberry. The understory was composed of false nettle, thoroughwort, pennywort, variable panic grass, dwarf palmetto, and tall nutgrass.

Upland–South (Stations 1283 [42.6 ft NGVD] to 1400 [52.2 ft NGVD]). The upland community began at the waterward loblolly pine on the slope, and continued upslope until it neared the Silver Springs Theme Park trail/road that runs along the upland edge of the floodplain at that site. The vegetation in this area was divided into two sections. The first 100 ft of this community has wetter species on the slope than the last upper 15 ft of the transect where the wetter species drop out and drier species become more dominant (i.e., sand live oak).

Transect 9 Hydric Soil Indicators

There were five primary HI observed at Transect 9: A8 Muck Presence, A1 Histosol, F13 Umbric Surface, S6 Stripped Matrix, and S7 Dark Surface (NRCS 2010). Summary statistics of elevations for HIs as well as estimated extents are shown in Figure 32 and Appendix A. More detailed soils information is found in Freese (2010; Appendix G).

North of the river, the landward HI (S6 Stripped Matrix) was at Station 243 (45.7 ft NGVD) in the transition zone between upland and hardwood swamp. Hydric indicators extended across the entire floodplain. South of the river, the landward HI (S7 Dark Surface) was at Station 1275 (41.9 ft NGVD) in the transition zone between upland and hardwood swamp.

A8 Muck Presence occured between Stations 325 (40.0 ft NGVD) and 695 (39.7 ft NGVD), and between Stations 1241 (39.7 ft NGVD) and 1262 (41.1 ft NGVD). Two areas of deep organic soil were also found: A1 Histosol occurred on each side of the floodplain with an estimated extent between Stations 695 (39.7 ft NGVD) and 901 (40.3 ft NGVD) and Stations 1075 (39.8 ft NGVD) to 1241 (39.7 ft NGVD). Soil series observed in these areas include Terra Ceia, which has very deep organic accumulations, and Gator and Okeelanta, which have moderately deep organic accumulations.

FIELD DATA

Table 1. Statistical summary of vegetation and soils features at Silver River minimum flows and levels (MFLs) transects, Marion County, Florida

VEGETATION HABITATS BY TRANSECT									
TRANSECT	FEATURE	STATION (ft)		ELEVATION (ft NGVD)					
		START	STOP	MEAN	MEDIAN	RANGE	MIN	MAX	N
3	UPLAND (UP-NORTH)	0	215	-	-	10.2	44.9	-	44
3	TRANSITION ZONE (TZ1)	215	275	42.6	42.6	4.7	40.2	44.9	13
3	HARDWOOD SWAMP (HS1)	275	728	37.7	37.6	4.1	36.1	40.2	92
3	SHALLOW MARSH (SM)	728	746	36.1	36.0	2.2	35.0	37.2	5
3	CHANNEL AQUATIC BED (AB)	746	826	31.2	32.8	14.7	23.6	38.3	15
3	HYDRIC HAMMOCK (HH1)	826	1325	39.5	39.7	2.2	38.0	40.2	101
3	HARDWOOD SWAMP (HS2)	1325	1426	37.4	37.5	1.2	37.0	38.2	22
3	TRANSITION ZONE (TZ2)	1426	1538	38.0	38.0	0.7	37.6	38.3	24
3	HARDWOOD SWAMP (HS3)	1538	1826	36.9	36.9	3.0	35.7	38.7	60
3	HYDRIC HAMMOCK (HH2)	1826	2025	48.7	49.6	18.2	38.7	56.9	41
3	TRANSITION ZONE (TZ3)	2025	2120	57.7	57.6	1.4	56.9	58.3	20
3	UPLAND (UP-SOUTH)	2120	2200	58.4	58.3	0.8	58.0	58.8	17
5	UPLAND (UP-NORTH)	0	88	-	-	3.9	48.5	-	19
5	TRANSITION ZONE (TZ1)	88	116	46.9	47.4	4.7	43.8	48.5	7
5	TRANSITION ZONE (TZ2)	116	167	40.4	40.0	4.8	39.0	43.8	12
5	HARDWOOD SWAMP (HS1)	167	494	37.7	37.8	5.9	33.1	39.0	65
5	CHANNEL AQUATIC BED (AB)	494	568	28.7	28.0	13.6	20.8	34.4	15
5	SHALLOW MARSH (SM)	568	604	35.9	36.1	2.8	34.4	37.2	6
5	HARDWOOD SWAMP (HS2)	604	1333	37.7	37.6	2.2	36.6	38.8	146
5	TRANSITION ZONE (TZ3)	1333	1400	39.3	39.3	1.2	38.7	39.9	15
5	HYDRIC HAMMOCK (HH)	1400	1490	41.5	40.8	5.7	39.7	45.4	19
5	UPLAND (UP-SOUTH)	1490	1600	-	-	2.8	34.4	-	6
7	UPLAND (UP-NORTH)	0	70	-	-	0.4	50.3	-	15
7	HYDRIC HAMMOCK (HH1)	70	250	45.9	46.5	10.7	39.7	50.4	37
7	HARDWOOD SWAMP (HS1)	250	747	38.9	38.9	2.7	37.3	40.0	97
7	CHANNEL AQUATIC BED (AB)	747	934	32.6	34.4	12.3	25.6	37.9	21
7	HARDWOOD SWAMP (HS2)	934	1390	39.7	39.9	4.1	36.4	40.5	92
7	TRANSITIONAL ZONE (TZ1)	1390	1516	40.5	40.5	0.6	40.1	40.7	27
7	TRANSITIONAL ZONE (TZ2)	1516	1790	41.3	41.3	1.0	40.7	41.7	56
7	HYDRIC HAMMOCK (HH2)	1790	2025	40.6	40.5	1.4	39.9	41.3	48
7	UPLAND (UP-SOUTH)	2025	2175	-	-	4.1	41.0	-	31
9	UPLAND (UP-NORTH)	0	202	-	-	6.6	54.4	-	42
9	TRANSITION ZONE (TZ1&TZ2)	202	300	46.2	44.9	13.3	41.1	54.4	21
9	HARDWOOD SWAMP (HS1)	300	916	39.8	39.8	5.1	36.0	41.1	124
9	CHANNEL AQUATIC BED (AB)	916	1053	31.5	30.6	10.9	27.3	38.2	26
9	HARDWOOD SWAMP (HS2)	1053	1210	39.7	39.8	2.0	38.2	40.2	33
9	TRANSITION ZONE (TZ3)	1210	1283	40.6	40.2	3.1	39.5	42.6	16
9	UPLAND (UP-SOUTH)	1283	1400	-	-	9.6	42.6	-	25

Table A2—*Continued*

ESTIMATED EXTENTS OF HYDRIC SOIL INDICATORS (HI) BY TRANSECT									
T3 - STATISTICS OF ESTIMATED HI EXTENTS									
TRANSECT	**HI**	**EST. EXTENT [STATION (ft)]**		**ELEVATION (ft NGVD)**					
		START	**STOP**	**Mean**	**Median**	**Range**	**Minimum**	**Maximum**	**N**
3	NONE	0	314	-	-	15.7	39.4	-	64
3	F3	314	369	39.0	38.8	0.7	38.7	39.4	12
3	A12	369	468	37.9	37.9	1.9	36.9	38.8	22
3	A8	468	480	36.7	36.8	0.8	36.1	36.9	4
3	A1/A2	480	580	36.5	36.5	0.9	36.1	37.0	21
3	A8	580	640	37.0	36.9	0.8	36.6	37.4	13
3	A5	640	728	37.8	37.8	1.1	37.2	38.3	19
3	NONE	814	1205	39.7	39.8	2.5	37.7	40.2	79
3	F3/A11	1205	1330	38.6	38.7	1.5	37.7	39.2	26
3	A7	1330	1345	37.7	37.7	0.1	37.6	37.7	4
3	A8	1345	1445	37.5	37.4	1.0	37.0	38.0	21
3	A7	1445	1464	38.0	38.0	0.3	37.8	38.1	5
3	A5	1464	1495	38.1	38.1	0.3	38.0	38.3	7
3	F3	1495	1567	37.8	37.9	1.1	37.1	38.2	16
3	A8	1567	1670	36.3	36.2	1.4	35.7	37.1	22
3	A7	1670	1715	37.3	37.3	0.8	36.8	37.6	10
3	A8	1715	1742	36.8	36.8	0.3	36.7	37.0	7
3	A2	1742	1750	36.5	36.8	1.1	35.8	36.9	3
3	A7	1750	1790	36.8	36.8	1.4	35.8	37.2	9
3	F3	1790	1830	37.9	38.0	2.3	36.6	38.9	9
3	NONE	1830	2000	-	-	17.6	38.9	-	35
T3 - SUMMARY OF ALL ORGANIC HI ESTIMATED EXTENT ELEVATIONS									
TRANSECT	**HI**	**EST. EXTENT [STATION (ft)]**		**ELEVATION (ft NGVD)**					
		START	**STOP**	**MEAN**	**MEDIAN**	**RANGE**	**MIN**	**MAX**	**N**
3	A8	468	480	36.9	36.9	2.3	35.7	38.0	67
		580	640						
		1345	1445						
		1567	1670						
		1715	1742						
3	A1/A2	480	580	36.5	36.5	0.9	36.1	37.0	21
3	A2	1742	1750	36.5	36.8	1.1	35.8	36.9	3
3	A1/2&A2	480	580	36.5	36.6	1.2	35.8	37.0	24
		1742	1750						

Table A2—*Continued*

ESTIMATED EXTENTS OF HYDRIC SOIL INDICATORS (HI) BY TRANSECT									
T5 - STATISTICS OF ESTIMATED HI EXTENTS									
TRANSECT	**HI**	**EST. EXTENT [STATION (ft)]**		**ELEVATION (ft NGVD)**					
		START	**STOP**	**Mean**	**Median**	**Range**	**Minimum**	**Maximum**	**N**
5	NONE	0	140	-	-	12.3	40.1	-	29
5	F3	140	170	39.6	39.9	1.4	38.7	40.1	7
5	A8	170	204	38.1	38.1	1.3	37.4	38.7	8
5	A1/A2	204	320	37.4	37.5	3.7	34.5	38.2	24
5	A8	320	370	38.4	38.4	0.9	38.0	38.9	11
5	A5	370	405	38.9	38.9	0.2	38.8	39.0	8
5	A8	405	460	38.0	37.7	1.4	37.5	38.9	12
5	A6/F13	600	640	37.9	38.0	1.7	36.8	38.5	9
5	A2	640	670	37.7	37.6	0.7	37.3	38.0	7
5	A8	670	700	37.5	37.5	0.6	37.3	37.9	7
5	A6	700	760	38.5	38.6	0.9	37.9	38.8	13
5	A8	760	880	37.7	37.5	1.7	36.9	38.6	25
5	A2	880	925	37.0	37.0	0.6	36.6	37.2	10
5	A8	925	1150	37.3	37.4	1.4	36.6	38.0	46
5	A7	1150	1193	38.5	38.5	0.8	38.0	38.8	10
5	A8	1193	1320	38.0	38.0	1.2	37.3	38.5	27
5	F13/F6	1320	1365	38.9	38.9	0.8	38.5	39.3	10
5	F6	1365	1420	39.7	39.7	0.7	39.3	40.0	12
5	F3	1420	1460	40.7	40.5	1.7	40.0	41.7	9
5	NONE	1460	1600	-	-	5.6	41.7	-	29
T5 - SUMMARY OF ALL ORGANIC HI ESTIMATED EXTENT ELEVATIONS									
TRANSECT	**HI**	**EST. EXTENT [STATION (ft)]**		**ELEVATION (ft NGVD)**					
		START	**STOP**	**MEAN**	**MEDIAN**	**RANGE**	**MIN**	**MAX**	**N**
5	A8	170	204	37.7	37.6	2.3	36.6	38.9	136
		320	370						
		405	460						
		670	700						
		760	880						
		925	1150						
		1193	1320						
5	A1	204	320	37.4	37.5	3.7	34.5	38.2	24
5	A2	640	670	37.3	37.2	1.4	36.6	38.0	17
		880	925						
5	A1 &A2	204	320	37.3	37.4	3.7	34.5	38.2	41
		640	670						
		880	925						

Table A2—*Continued*

ESTIMATED EXTENTS OF HYDRIC SOIL INDICATORS (HI) BY TRANSECT									
T7 - STATISTICS OF ESTIMATED HI EXTENTS									
TRANSECT	**HI**	**EST. EXTENT [STATION (ft)]**		**ELEVATION (ft NGVD)**					
		START	**STOP**	**MEAN**	**MEDIAN**	**RANGE**	**MIN**	**MAX**	**N**
7	NONE	0	200	-	-	8.7	42.0	-	42
7	F3	200	235	41.5	41.6	1.1	40.9	42.0	9
7	F6	235	245	40.7	40.7	0.5	40.4	40.9	3
7	A8	245	300	38.8	38.6	2.9	37.8	40.7	14
7	A1	300	478	38.3	38.4	1.5	37.3	38.8	38
7	A8	478	575	39.2	39.1	0.8	38.8	39.6	22
7	A7	575	596	39.7	39.7	0.3	39.5	39.8	6
7	F3	596	666	39.8	39.9	0.4	39.7	40.0	16
7	A8	666	725	39.3	39.3	1.1	38.6	39.7	13
7	A8	960	1150	39.4	39.4	1.3	38.8	40.1	39
7	A11/F3	1150	1520	40.2	40.1	0.9	39.8	40.7	75
7	NONE	1520	1668	41.3	41.3	1.0	40.7	41.7	31
7	F3	1668	1790	41.4	41.5	0.7	40.9	41.6	26
7	F13/A6	1790	1915	40.6	40.5	1.1	40.0	41.1	26
7	A7	1915	1980	40.3	40.3	0.7	39.9	40.6	15
7	S6	1985	2035	41.0	41.0	0.8	40.5	41.3	11
7	NONE	2035	2175	-	-	4.0	41.1	-	29
T7 - SUMMARY OF ALL ORGANIC HI ESTIMATED EXTENT ELEVATIONS									
TRANSECT	**HI**	**EST. EXTENT [STATION (ft)]**		**ELEVATION (ft NGVD)**					
		START	**STOP**	**MEAN**	**MEDIAN**	**RANGE**	**MIN**	**MAX**	**N**
7	A8	245	300	39.3	39.3	2.9	37.8	40.7	88
		478	575						
		666	725						
		960	1150						
7	A1	300	478	38.3	38.4	1.5	37.3	38.8	38

Table A2—*Continued*

ESTIMATED EXTENTS OF HYDRIC SOIL INDICATORS (HI) BY TRANSECT									
T9 - STATISTICS OF ESTIMATED HI EXTENTS									
TRANSECT	**HI**	**EST. EXTENT [STATION (ft)]**		**ELEVATION (ft NGVD)**					
		START	**STOP**	**MEAN**	**MEDIAN**	**RANGE**	**MIN**	**MAX**	**N**
9	NONE	0	243	-	-	15.3	45.7	-	50
9	S6	243	260	44.9	44.9	1.6	44.1	45.7	5
9	F13	260	325	41.8	41.7	4.1	40.0	44.1	14
9	A8	325	695	39.9	39.9	1.2	39.2	40.4	75
9	A1	695	901	39.8	39.7	0.9	39.4	40.3	43
9	A1	1075	1241	39.8	39.8	0.7	39.5	40.2	35
9	A8	1241	1262	40.5	40.4	1.4	39.7	41.1	6
9	S7	1262	1275	41.4	41.3	0.8	41.1	41.9	4
9	NONE	1275	1400	-	-	10.3	41.9	-	26
T9 - SUMMARY OF ALL ORGANIC HI ESTIMATED EXTENT ELEVATIONS									
TRANSECT	**HI**	**EST. EXTENT [STATION (ft)]**		**ELEVATION (ft NGVD)**					
		START	**STOP**	**MEAN**	**MEDIAN**	**RANGE**	**MIN**	**MAX**	**N**
9	A8	325 1241	695 1262	39.9	39.9	1.9	39.2	41.1	81
9	A1	695 1075	901 1241	39.8	39.8	0.9	39.4	40.3	78
ELEVATIONS OF INTEREST									
TRANSECT	**FEATURE**	**EST. EXTENT [STATION (ft)]**		**ELEVATION (ft NGVD)**					
		START	**STOP**	**MEAN**	**MEDIAN**	**RANGE**	**MIN**	**MAX**	**N**
6B	SUMMARY LICHEN LINES [north of channel]	-	-	42.1	42.1	0.2	42.0	42.2	9
11C	SUBMERGED BOAT (HIGH POINT)	-	-	-	-	-	-	37.9	1
11J-11K	SUBMERGED ROCK (HIGH POINT	-	-	-	-	-	-	37.4	1
11B-GROUND	Shallow Areas of Concern (Glass Bottom Boat Tours)	85	240	35.7	35.3	3.7	34.0	37.7	32
11C-GROUND	Shallow Areas of Concern (Glass Bottom Boat Tours)	10	85	35.1	35.0	3.9	33.4	37.3	16
11C-BOAT	Shallow Areas of Concern (Glass Bottom Boat Tours)	50	60	36.0	35.6	3.0	34.9	37.9	4
11E-GROUND	Shallow Areas of Concern (Glass Bottom Boat Tours)	115	240	37.1	37.2	2.3	36.0	38.3	26
11F-GROUND	Shallow Areas of Concern (Glass Bottom Boat Tours)	0	220	36.8	37.0	2.6	34.9	37.5	45
TRANSECT	**FEATURE**	**EST. EXTENT [STATION (ft)]**		**ELEVATION (ft NGVD)**					
		START	**STOP**			**RANGE**	**MIN MIN**	**MAX MAX**	**N**
11B, C, E, & F	Shallow Areas of Concern (Glass Bottom Boat Tours)	-	-	-	-	4.9	33.4	38.3	5

Table A3. Vegetation cover estimates and community breaks from Silver River minimum flows and levels (MFLs) Transect 3, Marion County, Florida

		Vegetation Community										
		Name	**UP**	**TZ1**	**HS1**	**SM**	**AB**	**HH1**	**HS2**	**TZ2**	**HS3**	**HH2**
		Start (ft)	**0**	**215**	**275**	**728**	**746**	**826**	**1325**	**1426**	**1538**	**1826**
		Stop (ft)	**215**	**275**	**728**	**746**	**826**	**1325**	**1426**	**1538**	**1826**	**2000**
Species	**Common Name**	**FUWDM Code[1]**	**Plant Species Cover Estimates[2]**									
Acer rubrum	Red maple	FACW			2			3	1	1		
Aeschynomene sp.	Joint-vetch	UL										0
Ageratina jucunda	Hammock throughwort	UL	1									
Ampelopsis arborea	Pepper vine	UL			0			0		1		
Andropogon sp.	Bluestem grass	UL						1				
Arundinaria gigantea	Giant cane	FACW	1									
Aster carolinianus	Climbing aster	OBL			0			0				
Baccharis sp.	Falsewillow	UL						1				
Berchemia scandens	Rattan vine	UL			0			1				
Boehmeria cylindrica	False nettle	OBL			1	0		2	1	1		
Callicarpa americana	Beautyberry	UL	1	0								
Carex cherokeensis	Cherokee sedge	FACW	1	1	1							
Carex comosa	Bristly sedge	OBL									0	
Carpinus caroliniana	American hornbeam	FACW	1	2	0							
Carya glabra	Pignut hickory	UL	1									
Celtis laevigata	Hackberry	FACW	1	2								3
Cephalanthus occidentalis	Buttonbush	OBL				0			0			
Ceratophyllum demersum	Hornwort	UL					1					
Chasmanthium sessiliflorum	Long-leaf spikegrass	FAC	2	0	0							
Cicuta mexicana	Southern water hemlock	OBL			1				0			
Clematis sp.	Virgin's bower	UL	0									
Cornus foemina	Swamp dogwood	FACW						2	0		0	
Cyperus distinctus	Sedge	OBL						0				

Table A3—*Continued*

Species	Common Name	Vegetation Community										
		Name	**UP**	**TZ1**	**HS1**	**SM**	**AB**	**HH1**	**HS2**	**TZ2**	**HS3**	**HH2**
		Start (ft)	**0**	**215**	**275**	**728**	**746**	**826**	**1325**	**1426**	**1538**	**1826**
		Stop (ft)	**215**	**275**	**728**	**746**	**826**	**1325**	**1426**	**1538**	**1826**	**2000**
Species	**Common Name**	**FUWDM Code[1]**	**Plant Species Cover Estimates[2]**									
Cyperus esculentus	Nut sedge	FAC	1	1	1					1		1
Cyperus globulosus	Globe sedge	FAC	0									
Dichondra sp.	Ponysfoot	UL	1					1				1
Dichromena colorata	White-topped sedge	FACW						0				
Diodia virginiana	Buttonweed	FACW			0							
Echinochloa crusgalli	Barnyardgrass	FACW						1		1		
Erechtites hieracifolia	Fireweed	FAC										0
Eupatorium serotinum	Late boneset	FAC						0	0	1	0	
Eupatorium sp.	Thoroughwort	FAC			0			1	1	1		
Eustachys glauca	Saltmarsh fingergrass	FACW						1				
Fraxinus sp.	Ash	UL			2			2	1	3	2	
Galium sp.	Bedstraw	UL										0
Galium tinctorium	Bedstraw	FACW									0	
Hydrocotyle sp.	Pennywort	FACW		0	1			1	1			
Hymenocallis sp.	Spider-lily	OBL			0				0		1	
Ilex cassine	Dahoon holly	OBL						1				
Iris virginica	Southern blue flag	OBL			0					0		
Juniperus silicicola	Southern red cedar	UL						1				
Kosteletzkya virginica	Saltmarsh mallow	OBL							0			
Liquidambar styraciflua	Sweet gum	FACW	3	2	2							3
Ludwigia repens	Red ludwigia	OBL			1				1			
Lycopus rubellus	Bugleweed	OBL			0							
Magnolia virginiana	Sweet bay	OBL			1							1
Mikania scandens	Hempweed	UL	1	0	0			1	1		1	

Table A3—*Continued*

Species	Common Name	Vegetation Community										
		Name	**UP**	**TZ1**	**HS1**	**SM**	**AB**	**HH1**	**HS2**	**TZ2**	**HS3**	**HH2**
		Start (ft)	**0**	**215**	**275**	**728**	**746**	**826**	**1325**	**1426**	**1538**	**1826**
		Stop (ft)	**215**	**275**	**728**	**746**	**826**	**1325**	**1426**	**1538**	**1826**	**2000**
		FUWDM Code[1]	**Plant Species Cover Estimates[2]**									
Mitreola petiolata	Miterwort	FACW			1			1	1	1	1	
Muhlenbergia schreberi	Nimblewill muhly	FACW	1	1				0				
Myrica cerifera	Wax myrtle	FAC						1				
Nuphar luteum	Spatter-dock	OBL				1						
Nyssa sylvatica var. biflora	Tupelo, swamp	OBL			2						1	
Oplismenus hirtellus	Basket grass	FAC		1	0					0		1
Oxalis sp.	Woodsorrel	UL	1									
Panicum commutatum	Variable panic grass	FAC	1	1	1			1		1		
Panicum gymnocarpon	Savannah panicum	OBL			1							
Panicum longifolium	Tall panicum	OBL	1		1			1	1			
Parthenocissus quinquefolia	Virginia creeper	UL	1	0								
Paspalum floridanum	Florida paspalum	FACW	1	2								1
Phyla nodiflora	Frog-fruit	FAC						1				
Pilea microphylla	Rockweed	FACW	1	0								
Pinus elliottii	Slash pine	UL										1
Pinus taeda	Loblolly pine	UL	1									
Pisita stratiotes	Water-lettuce	UL			0							
Pluchea camphorata	Marsh fleabane	FACW		1	1							
Pluchea longifolia	Camphorweed	FACW						1	1	1		
Polygonum punctatum	Dotted smartweed	OBL			0			1	1			
Polygonum sp.	Smartweed	UL							0			
Pontederia cordata	Pickerelweed	OBL			1	3			1		1	
Quercus laurifolia	Laurel oak	FACW	1		0							
Quercus michauxii	Swamp chestnut oak	FACW	2									

Table A3—*Continued*

Species	Common Name	Vegetation Community										
		Name	**UP**	**TZ1**	**HS1**	**SM**	**AB**	**HH1**	**HS2**	**TZ2**	**HS3**	**HH2**
		Start (ft)	**0**	**215**	**275**	**728**	**746**	**826**	**1325**	**1426**	**1538**	**1826**
		Stop (ft)	**215**	**275**	**728**	**746**	**826**	**1325**	**1426**	**1538**	**1826**	**2000**
Species	**Common Name**	**FUWDM Code[1]**	**Plant Species Cover Estimates[2]**									
Quercus shumardii	Shumard oak	UL	1									
Quercus virginiana	Live oak	UL										2
Rhynchospora caduca	Beakrush	FACW						0				
Rhynchospora corniculata	Beakrush	OBL			1			0	1			
Rorippa sp.	Yellow-cress	OBL									1	
Sabal minor	Dwarf palmetto	FACW	3	3	1			1				
Sabal palmetto	Cabbage palm	FAC	4	4	2			3	1	1	1	3
Sagittaria kurziana	Arrowhead	OBL				0	4					
Salix caroliniana	Carolina willow	OBL			0					1	1	
Samolus parviflorus	Water pimpernel	OBL									1	
Saururus cernuus	Lizard’s tail	OBL			1							
Scleria sp.	Nutrush	FACW	0									
Sicyos angulatus	Oneseed burr cucumber	UL	0									
Smilax spp.	Greenbrier	UL	1		0							1
Spilanthes americana	Spot flower	FACW						1		1		
Stenotaphrum secundatum	St. Augustine grass	UL						1				
Taxodium sp.	Cypress	OBL		1	3				1	1	1	
Taxodium distichum	Bald cypress	OBL			2			0	4	4	4	
Thelypteris sp.	Shield fern	FACW	1	1	0			1			0	
Trichostema dichotomum	Blue-curls	UL										1
Ulmus americana	American Elm	FACW	2	1	1			1				1
Urena lobata	Caesar-weed	UL	1	0	1			1			0	1
Vallisneria americana	Eel grass	OBL				1	2					
Verbena scabra	Harsh verbena	FACW						0				

Table A3—*Continued*

		Vegetation Community										
		Name	**UP**	**TZ1**	**HS1**	**SM**	**AB**	**HH1**	**HS2**	**TZ2**	**HS3**	**HH2**
		Start (ft)	**0**	**215**	**275**	**728**	**746**	**826**	**1325**	**1426**	**1538**	**1826**
		Stop (ft)	**215**	**275**	**728**	**746**	**826**	**1325**	**1426**	**1538**	**1826**	**2000**
Species	**Common Name**	**FUWDM Code[1]**	**Plant Species Cover Estimates[2]**									
Viburnum obovatum	Small viburnum	FACW						1				
Vitis rotundifolia	Muscadine grape	UL	1	1				1				

UP = Upland, TZ = Transition Zone, HS = Hardwood Swamp, SM = Shallow Marsh, AB = Aquatic Bed, HH = Hydric Hammock

[1]**FWDM** codes are taken from Ch. 62-340.450, *F.A.C.* as established in Florida Wetlands Delineation Manual (Gilbert et al. 1995). Species not in the rule are listed as Unlisted (UL) unless they are obvious aquatics; unlisted aquatic species are designated as obligates (OBL). **Unlisted (UL)**—Plants that are not listed in the Florida Wetlands Delineation Manual. **Facultative (FAC)**—Plants with similar likelihood of occurring in both wetlands and uplands. **Facultative Wet (FACW)**—Plants that typically exhibit their maximum cover in areas subject to surface water flooding and/or saturation, but may also occur in uplands. **Obligate (OBL)**—Plants that are found or achieve their greatest abundance in an area that is subject to surface water flooding and/or saturation; rarely occur in uplands.

[2]**Plant Species Cover Estimates:** Areal extent of vegetation species along the transect within a given vegetation community where 0 = <1% (rare), 1 = 1% to 10% (scattered), 2 = 11% to 25% (numerous), 3 = 26% to 50% (abundant), 4 = 51% to 75% (co-dominant), 5 = > 75% (dominant).

Table A42. Vegetation cover estimates and community breaks from Silver River minimum flows and levels (MFLs) Transect 5, Marion County, Florida

		Vegetation Community										
		Name	**UP-N**	**TZ1**	**TZ2**	**HS1**	**AB**	**SM**	**HS2**	**TZ3**	**HH**	**UP-S**
		From (ft)	**0**	**88**	**116**	**167**	**494**	**568**	**604**	**1333**	**1400**	**1490**
		To (ft)	**88**	**116**	**167**	**494**	**568**	**604**	**1333**	**1400**	**1490**	**1600**
Species	**Common Name**	**FUWDM Code[1]**	**Plant Species Cover Estimates[2]**									
Acer rubrum	Red maple	FACW		-		2			2	1		
Ageratina jucunda	Hammock throughwort	UL		-								0
Alternanthera philoxeroides	Alligator weed	OBL		-					0			
Ampelopsis arborea	Pepper vine	UL		-						1	1	
Arundinaria gigantea	Giant cane	FACW	1	-								
Baccharis halimifolia	Salt myrtle	FAC		-						0		
Boehmeria cylindrica	False nettle	OBL		-		1			1			
Callicarpa americana	Beautyberry	UL	1	-								
Carex cherokeensis	Cherokee sedge	FACW	1	-								1
Carpinus caroliniana	American hornbeam	FACW	1	-	1							
Carya aquatica	Water hickory	OBL		-						1	1	2
Carya glabra	Pignut hickory	UL	2	-								
Celtis laevigata	Hackberry	FACW	2	-						1	1	1
Ceratophyllum demersum	Hornwort	UL		-			1	1				
Chasmanthium sessiliflorum	Long-leaf spikegrass	FAC	1	-								
Cicuta mexicana	Southern water hemlock	OBL		-		1			1			
Conyza canadensis	Dwarf horseweed	UL		-						0		
Cyperus esculentus	Nut sedge	FAC	1	-	1				1		1	

Table A4—*Continued*

Species	Common Name	Vegetation Community										
		Name	**UP-N**	**TZ1**	**TZ2**	**HS1**	**AB**	**SM**	**HS2**	**TZ3**	**HH**	**UP-S**
		From (ft)	**0**	**88**	**116**	**167**	**494**	**568**	**604**	**1333**	**1400**	**1490**
		To (ft)	**88**	**116**	**167**	**494**	**568**	**604**	**1333**	**1400**	**1490**	**1600**
Species	**Common Name**	**FUWDM Code[1]**	**Plant Species Cover Estimates[2]**									
Cyperus globulosus	Globe sedge	FAC	1	-								
Decumaria barbara	Climbing hydrangea	UL		-		0			0			
Dichondra carolinensis	Dichondra	FAC		-							1	0
Diodia virginiana	Buttonweed	FACW		-					1			
Eichornnia sp.	Water hyacinth	UL		-		1			1			
Elytraria caroliniensis	Carolina scalystem	FAC		-							1	0
Erechtites hieraciifolius	Fireweed	FAC		-					0			
Eupatorium serotinum	Late boneset	FAC	1	-	0					1		
Eupatorium sp.	Thoroughwort	UL	1	-	1	1			1		1	
Fraxinus sp.	Ash	UL	1	-	1	2			3	1		
Galium sp.	Bedstraw	UL	1	-								
Hydrocotyle sp.	Pennywort	UL		-	1	1			1	1	1	
Hymenocallis sp.	Spiderlily	OBL		-		1			1			
Hypoxis curtissi	Common yellow stargrass	FACW		-						0		
Ilex cassine	Dahoon holly	OBL		-		0						
Iris sp.	Iris	UL		-					1			
Juniperus silicicola	Southern red cedar	UL		-						1	2	2
Leersia hexandra	Southern cut grass	OBL		-					0	1		
Leersia virginica	Whitegrass	OBL		-								0
Liquidambar styraciflua	Sweet gum	FACW	2	-	2	1				2	2	4

Table A4—*Continued*

Species	Common Name	Vegetation Community										
		Name	**UP-N**	**TZ1**	**TZ2**	**HS1**	**AB**	**SM**	**HS2**	**TZ3**	**HH**	**UP-S**
		From (ft)	**0**	**88**	**116**	**167**	**494**	**568**	**604**	**1333**	**1400**	**1490**
		To (ft)	**88**	**116**	**167**	**494**	**568**	**604**	**1333**	**1400**	**1490**	**1600**
Species	**Common Name**	**FUWDM Code[1]**	**Plant Species Cover Estimates[2]**									
Ludwigia repens	Red ludwigia	OBL		-		1			1			
Magnolia virginiana	Sweet bay	OBL		-		0			1			
Mikania scandens	Hempweed	UL		-		1			1			
Mitreola petiolata	Miterwort	FACW		-		1			1	0		
Muhlenbergia schreberi	Nimblewill muhly	FACW	0	-	0							
Nuphar luteum	Spatter-dock	OBL		-				1				
Nyssa sylvatica var. biflora	Tupelo, swamp	OBL		-	1	1			1	1		
Oplismenus hirtellus	Basket grass	FAC	1	-	1				0	1	0	
Oxalis sp.	Woodsorrel	UL	0	-	0				0		1	
Panicum commutatum	Variable panic grass	FAC	1	-	1				1	1	1	1
Panicum gymnocarpon	Savannah panicum	OBL		-		1			1	2		
Panicum longifolium	Tall panicum	OBL	1	-	1				1	2	1	
Panicum sp.	Panicum	UL		-		1						
Paspalum floridanum	Florida paspalum	FACW	1	-	1	0					1	
Persea palustris	Swamp bay	OBL		-		0						
Pluchea camphorata	Marsh fleabane	FACW		-	1	1			1	1		
Pluchea longifolia	Camphorweed	FACW		-					1			
Polygonum punctatum	Dotted smartweed	OBL		-		1						
Pontederia cordata	Pickerelweed	OBL		-		1		3	1			
Quercus laurifolia	Laurel oak	FACW		-						0	1	2

Table A4—*Continued*

Species	Common Name	Vegetation Community										
		Name	UP-N	TZ1	TZ2	HS1	AB	SM	HS2	TZ3	HH	UP-S
		From (ft)	0	88	116	167	494	568	604	1333	1400	1490
		To (ft)	88	116	167	494	568	604	1333	1400	1490	1600
		FUWDM Code[1]	Plant Species Cover Estimates[2]									
Quercus michauxii	Swamp chestnut oak	FACW	2	-								
Quercus nigra	Water oak	FACW	1	-								1
Quercus shumardii	Shumard oak	UL	1	-								
Rhynchospora corniculata	Beakrush	OBL		-					1			
Rorippa sp.	Yellow-cress	OBL		-					1			
Sabal minor	Dwarf palmetto	FAC	3	-	1					1	1	1
Sabal palmetto	Cabbage palm	FAC	2	-	2	1			1	2	3	4
Sacciolepis striata	American cupscale	OBL		-					0			
Sagittaria kurziana	Arrowhead	OBL		-			4					
Samolus parviflorus	Water pimpernel	OBL		-					1			
Saururus cernuus	Lizard's tail	OBL		-		1			1	1		
Sicyos angulatus	Oneseed burr cucumber	UL		-						1		
Smilax bona-nox	Greenbrier	UL		-							1	1
Taxodium sp.	Cypress	OBL		-	3	2			3	2		
Taxodium distichum	Bald cypress	OBL		-		1						
Thelypteris sp.	Shield fern	FACW	1	-	1	1				1		
Toxicodendron radicans	Poison ivy	UL	1	-	1	1			1		1	
Ulmus americana	American Elm	FACW	1	-	1	1					1	2
Urena lobata	Caesar-weed	UL	1	-						1		
Vallisneria americana	Eel grass	OBL		-			3					

Table A4—*Continued*

Species	Common Name	Vegetation Community										
		Name	**UP-N**	**TZ1**	**TZ2**	**HS1**	**AB**	**SM**	**HS2**	**TZ3**	**HH**	**UP-S**
		From (ft)	**0**	**88**	**116**	**167**	**494**	**568**	**604**	**1333**	**1400**	**1490**
		To (ft)	**88**	**116**	**167**	**494**	**568**	**604**	**1333**	**1400**	**1490**	**1600**
		FUWDM Code[1]	**Plant Species Cover Estimates[2]**									
Verbena scabra	Harsh verbena	FACW		-					1			

NOTE: TZ 88–116 not assessed for vegetation. Designation made after reviewing vegetation, line intercept notes, and landscape characteristics in relation to cover estimate and line intercept breaks.

UP = Upland, TZ = Transition Zone, HS = Hardwood Swamp, SM = Shallow Marsh, AB = Aquatic Bed, HH = Hydric Hammock

[1]**FWDM** codes are taken from Ch. 62-340.450, *F.A.C.* as established in Florida Wetlands Delineation Manual (Gilbert et al. 1995). Species not in the rule are listed as Unlisted (UL) unless they are obvious aquatics; unlisted aquatic species are designated as obligates (OBL). **Unlisted (UL)**—Plants that are not listed in the Florida Wetlands Delineation Manual. **Facultative (FAC)**—Plants with similar likelihood of occurring in both wetlands and uplands. **Facultative Wet (FACW)**—Plants that typically exhibit their maximum cover in areas subject to surface water flooding and/or saturation, but may also occur in uplands. **Obligate (OBL)**—Plants that are found or achieve their greatest abundance in an area that is subject to surface water flooding and/or saturation; rarely occur in uplands.

[2]**Plant Species Cover Estimates:** Areal extent of vegetation species along the transect within a given vegetation community where 0 = < 1% (rare), 1 = 1% to 10% (scattered), 2 = 11% to 25% (numerous), 3 = 26% to 50% (abundant), 4 = 51% to 75% (co-dominant), 5 = > 75% (dominant).

Table A5. Vegetation cover estimates and community breaks from Silver River minimum flows and levels (MFLs) Transect 7, Marion County, Florida

Species	Common Name	Vegetation Community									
		Name	**UP-N**	**HH1**	**HS1**	**AB**	**HS2**	**TZ1**	**TZ2**	**HH3**	**UP-S**
		Start (ft)	**0**	**70**	**250**	**747**	**934**	**1390**	**1516**	**1790**	**2025**
		Stop (ft)	**70**	**250**	**747**	**934**	**1390**	**1516**	**1790**	**2025**	**2175**
Species	**Common Name**	**FUWDM Code [1]**	**Plant Species Cover Estimates[2]**								
Acer negundo	Box elder	FACW		1				1		1	
Acer rubrum	Red maple	FACW			2		1	2	1	2	
Ageratina jucunda	Hammock throughwort	UL	1	1						0	
Alternanthera philoxeroides	Alligator weed	OBL			1		1				
Ambrosia artemisiifolia	Ragweed	UL						0	3	1	
Ampelopsis arborea	Pepper vine	UL					0	1	0	1	
Andropogon sp.	Bluestem grass	UL	1					1	2	1	
Andropogon virginicus	Broomsedge	FAC						1	3	1	
Bignonia capreolata	Crossvine	UL	1	1							
Boehmeria cylindrica	False nettle	OBL			1		1	1	1	1	
Callicarpa americana	Beautyberry	UL	0								1
Carex cherokeensis	Cherokee sedge	FACW	1	1							
Carex comosa	Bristly sedge	OBL			0						
Carpinus caroliniana	American hornbeam	FACW		1							
Celtis laevigata	Hackberry	FACW		2						0	
Centella asiatica	Coinwort	FACW							1	1	0
Cephalanthus occidentalis	Buttonbush	OBL					0				
Ceratophyllum demersum	Hornwort	UL				2					
Chasmanthium sessiliflorum	Long-leaf spikegrass	FAC	1							1	2
Cicuta mexicana	Southern water hemlock	OBL			1	1	1				
Conyza canadensis	Dwarf horseweed	UL		0							

Table A5—*Continued*

Species	Common Name	Vegetation Community									
		Name	**UP-N**	**HH1**	**HS1**	**AB**	**HS2**	**TZ1**	**TZ2**	**HH3**	**UP-S**
		Start (ft)	**0**	**70**	**250**	**747**	**934**	**1390**	**1516**	**1790**	**2025**
		Stop (ft)	**70**	**250**	**747**	**934**	**1390**	**1516**	**1790**	**2025**	**2175**
Species	**Common Name**	**FUWDM Code [1]**	**Plant Species Cover Estimates[2]**								
Cornus foemina	Swamp dogwood	FACW						1	1	1	
Crataegus sp.	Hawthorne	UL						1			
Cyperus distinctus	Sedge	OBL						0			
Cyperus esculentus	Nut sedge	FAC		1					1	1	
Decumaria barbara	Climbing hydrangea	UL			1		1				
Desmodium sp.	Tricktrefoil	UL	1	1							
Dichondra sp.	Ponysfoot	UL	1	1			1	1	1	1	
Dichromena colorata	White-topped sedge	FACW						1	1	1	
Diodia virginiana	Buttonweed	FACW			1		1				
Echinochloa crusgalli	barnyardgrass	FACW					0				
Erechtites hieraciifolius	Fireweed	FAC					1				
Erianthus giganteus	Sugarcane plumegrass	OBL						1	0		
Eupatorium sp.	Thoroughwort	UL			1		1	1	3	1	
Euphorbia sp.	Spurge	UL	0								
Eustachys glauca	Saltmarsh fingergrass	FACW						1	0		
Fraxinus sp.	Ash	UL		1	3		2	2	0	1	
Galium sp.	Bedstraw	UL	1						0	0	
Hydrocotyle sp.	Pennywort	UL			1	0	1	1	0	1	
Hymenocallis sp.	Spiderlily	OBL			1		1				
Hypericum hypercoides	St Andrew's cross	FAC	1								
Ilex cassine	Dahoon holly	OBL			0					0	
Ilex glabra	Gallberry	UL									1
Ilex opaca	American holly	FAC									1
Juniperus silicicola	Southern red cedar	UL	1	1					1		
Leersia virginica	Whitegrass	OBL	1				1			0	

Table A5—*Continued*

		Vegetation Community										
		Name	**UP-N**	**HH1**	**HS1**	**AB**	**HS2**	**TZ1**	**TZ2**	**HH3**	**UP-S**
		Start (ft)	**0**	**70**	**250**	**747**	**934**	**1390**	**1516**	**1790**	**2025**
		Stop (ft)	**70**	**250**	**747**	**934**	**1390**	**1516**	**1790**	**2025**	**2175**
Species	**Common Name**	**FUWDM Code** [1]	**Plant Species Cover Estimates**[2]								
Liquidambar styraciflua	Sweet gum	FACW	2	3						2	2
Lobelia cardinalis	Cardinal flower	OBL					0				
Ludwigia repens	Red ludwigia	OBL			1					0	
Lyonia ferruginea	Rusty lyonia	UL									0
Magnolia grandiflora	Southern magnolia	UL									1
Mikania scandens	Hempweed	UL			1		1	1		0	
Mitreola petiolata	Miterwort	FACW			1		1		0	0	
Muhlenbergia schreberi	Nimblewill muhly	FACW	1	1							1
Myrica cerifera	Wax myrtle	FAC	1		0				2	1	1
Nuphar luteum	Spatter-dock	OBL			1	1	1				
Nyssa sylvatica var. biflora	Tupelo, swamp	OBL			2						
Oplismenus hirtellus	Basket grass	FAC	1	1			1				
Panicum commutatum	Variable panic grass	FAC	1	1			1	1		1	1
Panicum gymnocarpon	Savannah panicum	OBL		1	1		1			1	
Panicum longifolium	Tall panicum	OBL	1	1			2	1	1	1	
Paspalum floridanum	Florida paspalum	FACW	1	1	0			1	0	1	
Paspalum sp.	Paspalum grass	UL							2	1	
Phyla nodiflora	Frog-fruit	FAC						1	2	1	0
Pinus taeda	Loblolly pine	UL	3								2
Pluchea camphorata	Marsh fleabane	FACW			1		1				
Pluchea longifolia	Camphorweed	FACW			1		1	1		1	
Pluchea rosea	Fleabane	FACW								1	
Polygonum punctatum	Dotted smartweed	OBL			1		1			0	
Pontederia cordata	Pickerelweed	OBL			1	1	1				
Pteridium aquilinum	Bracken fern	UL									0

Table A5—*Continued*

Species	Common Name	Vegetation Community									
		Name	**UP-N**	**HH1**	**HS1**	**AB**	**HS2**	**TZ1**	**TZ2**	**HH3**	**UP-S**
		Start (ft)	**0**	**70**	**250**	**747**	**934**	**1390**	**1516**	**1790**	**2025**
		Stop (ft)	**70**	**250**	**747**	**934**	**1390**	**1516**	**1790**	**2025**	**2175**
Species	**Common Name**	**FUWDM Code [1]**	**Plant Species Cover Estimates[2]**								
Quercus laurifolia	Laurel oak	FACW	1							1	2
Quercus nigra	Water oak	FACW									0
Rhynchospora corniculata	Beakrush	OBL			2		2				
Rivina humilis	Roughplant	UL		1							
Sabal minor	Dwarf palmetto	FAC	1	2							1
Sabal palmetto	Cabbage palm	FAC	2	2	2		2	3	2	2	2
Sacciolepis striata	American cupscale	OBL					0				
Sagittaria kurziana	Arrowhead	OBL				4					
Samolus parviflorus	Water pimpernel	OBL			1		1				
Saururus cernuus	Lizard's tail	OBL			1		1			1	
Scleria sp.	Nutrush	FACW	1								
Senna marilandica	Southern wild senna	UL							1	1	
Serenoa repens	Saw palmetto	UL									1
Smilax bona-nox	Greenbrier	UL	1								1
Spermacoce sp.	False buttonweed	UL	0	1							
Spilanthes americana	Spot flower	FACW					1	1	0	1	1
Taxodium sp.	Cypress	OBL			3		3	2	0	2	
Ulmus americana	American Elm	FACW					1	1	0	2	
Vaccinium corymbosum	Highbush blueberry	FACW									1
Vallisneria americana	Eel grass	OBL				3					
Verbena scabra	Harsh verbena	FACW						1	1		
Viburnum obovatum	Small viburnum	FACW						1			
Woodwardia areolata	Net-vein chain fern	OBL			1						

UP = Upland, TZ = Transition Zone, HS = Hardwood Swamp, AB = Aquatic Bed, HH = Hydric Hammock

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[2]**Plant Species Cover Estimates:** Areal extent of vegetation species along the transect within a given vegetation community where 0 = < 1% (rare), 1 = 1% to 10% (scattered), 2 = 11% to 25% (numerous), 3 = 26% to 50% (abundant), 4 = 51% to 75% (co-dominant), 5 = > 75% (dominant).

Table 3. Vegetation cover estimates and community breaks from Silver River minimum flows and levels (MFLs) Transect 9, Marion County, Florida

Species	Common Name	Vegetation Community									
		Name	**UP-N**	**TZ1**	**TZ2**	**HS1**	**AB**	**HS2**	**TZ3**	**UP-S**	**UP-S**
		Start (ft)	**0**	**202**	**255**	**300**	**916**	**1053**	**1210**	**1283**	**1385**
		Stop (ft)	**202**	**255**	**300**	**916**	**1053**	**1210**	**1283**	**1385**	**1400**
Species	**Common Name**	**FUWDM Code[1]**	**Plant Species Cover Estimates[2]**								
Acer rubrum	Red maple	FACW				1		3	3		
Ageratina jucunda	Hammock throughwort	UL	1	0	0					0	
Alternanthera philoxeroides	Alligator weed	OBL			1	1		1			
Andropogon sp.	Bluestem grass	UL	1	0	0			0			
Aster carolinianus	Climbing aster	OBL				1		1			
Baccharis halimifolia	Salt myrtle	FAC			1						
Boehmeria cylindrica	False nettle	OBL		1	1	1		1	1		
Bumelia tenax	Tough bumelia	UL									0
Callicarpa americana	Beautyberry	UPL	1	1	1				1	1	1
Cardamine pensylvanica	Pennsylvania bitter-cress	OBL			1						
Carpinus caroliniana	American hornbeam	FACW		2	1						
Carya glabra	Pignut hickory	UL	3	2						3	2
Cephalanthus occidentalis	Buttonbush	OBL						0			
Ceratophyllum demersum	Hornwort	UL					1				
Chasmanthium sessiliflorum	Long-leaf spikegrass	FAC	2	1							
Cicuta mexicana	Southern water hemlock	OBL				1		1			
Conyza canadensis	Dwarf horseweed	UL		0	0						

Table A6—*Continued*

Species	Common Name	Vegetation Community									
		Name	UP-N	TZ1	TZ2	HS1	AB	HS2	TZ3	UP-S	UP-S
		Start (ft)	0	202	255	300	916	1053	1210	1283	1385
		Stop (ft)	202	255	300	916	1053	1210	1283	1385	1400
		FUWDM Code[1]	Plant Species Cover Estimates[2]								
Cyperus distinctus	Sedge	OBL			1			0			
Cyperus esculentus	Nut sedge	FAC	1	1	1					1	1
Cyperus globulosus	Globe sedge	FAC	1					0			
Decumaria barbara	Climbing hydrangea	UL						0			
Dichanthelium oligosanthes	Heller's witchgrass	UL	1	0	0					1	1
Diodia virginiana	Buttonweed	FACW				1		1			
Dryopteris ludoviciana	Southern shield-fern	FACW		1	1						
Eichhornia crassipes	Waterhyacinth	OBL				1					
Elephantopus sp	Elephantsfoot	UL			1						
Eupatorium compositifolium	Dog fennel	FAC		1	1	1		1			
Eupatorium sp.	Thoroughwort	UL	1	0	0	1		1	1		
Eustachys glauca	Saltmarsh fingergrass	FACW	1							1	0
Fraxinus sp.	Ash	UL				3		2			
Galium sp.	Bedstraw	UL	1								0
Gelsemium sempervirens	Yellow jessamine	UL								0	1
Hydrocotyle sp.	Pennywort	UL		0	1	1		1	1		
Hymenocallis sp.	Spiderlily	OBL				0					
Ilex cassine	Dahoon holly	OBL				0		1			
Juncus effusus	Soft rush	OBL			1						
Juniperus silicicola	Southern red cedar	UL	1								
Leersia virginica	Whitegrass	OBL			1	1		1			

Table A6—*Continued*

		Vegetation Community									
		Name	**UP-N**	**TZ1**	**TZ2**	**HS1**	**AB**	**HS2**	**TZ3**	**UP-S**	**UP-S**
		Start (ft)	**0**	**202**	**255**	**300**	**916**	**1053**	**1210**	**1283**	**1385**
		Stop (ft)	**202**	**255**	**300**	**916**	**1053**	**1210**	**1283**	**1385**	**1400**
Species	**Common Name**	**FUWDM Code[1]**	**Plant Species Cover Estimates[2]**								
Liquidambar styraciflua	Sweet gum	FACW	2	1	1	0		0	2	3	
Ludwigia leptocarpa	Ludwigia	OBL				0					
Ludwigia repens	Red ludwigia	OBL			1	1		1			
Lycopus rubellus	Bugleweed	OBL				0					
Magnolia grandiflora	Southern magnolia	UL	2							3	
Magnolia virginiana	Sweet bay	OBL			2	0		1			
Mikania scandens	Hempweed	UL			1	1		1			
Mitchella repens	Partridgeberry	UL	1	1						0	0
Mitreola petiolata	Miterwort	FACW				1		1			
Myrica cerifera	Wax myrtle	FAC			1						
Najas sp.	Naiad	UL					0				
Nuphar luteum	Spatter-dock	OBL					0				
Nyssa sylvatica var. biflora	Tupelo, swamp	OBL			1	3		2			
Oplismenus hirtellus	Basket grass	FAC	1	1	1				0	1	1
Opuntia humifusa	Prickley-pear cactus	UL	1								
Osmunda cinnamomea	Cinnamon fern	FACW		1	1						
Osmunda regalis	Royal fern	OBL						0			
Ostrya virginiana	Hop hornbeam	UL	2	2							
Oxalis sp.	Woodsorrel	UL		1	1	1		1			
Panicum commutatum	Variable panic grass	FAC	1	1	1				1	1	
Panicum gymnocarpon	Savannah panicum	OBL		1	1	2		1			

Table A6—*Continued*

Species	Common Name	Vegetation Community									
		Name	**UP-N**	**TZ1**	**TZ2**	**HS1**	**AB**	**HS2**	**TZ3**	**UP-S**	**UP-S**
		Start (ft)	**0**	**202**	**255**	**300**	**916**	**1053**	**1210**	**1283**	**1385**
		Stop (ft)	**202**	**255**	**300**	**916**	**1053**	**1210**	**1283**	**1385**	**1400**
Species	**Common Name**	**FUWDM Code[1]**	**Plant Species Cover Estimates[2]**								
Panicum longifolium	Tall panicum	OBL	1			1		1			
Paspalum floridanum	Florida paspalum	FACW	1		1						
Persea palustris	Swamp bay	OBL				0		0			
Pinus elliottii	Slash pine	UL									2
Pinus taeda	Loblolly pine	UL	1	0						1	
Pluchea camphorata	Marsh fleabane	FACW		1	1	1		1			
Polygonum punctatum	Dotted smartweed	OBL		1	1	1		1			
Pontederia cordata	Pickerelweed	OBL				1		0			
Prunus serotina	Wild black cherry	UL	1							1	
Prunus sp	Cherry	UL	1								
Ptilimnium capillaceum	Mock bishop's weed	FACW	1								
Quercus austrina	Bastard white oak	UL	2								
Quercus geminata	Sand live oak	UL	1								3
Quercus laurifolia	Laurel oak	FACW	2							2	3
Quercus michauxii	Swamp chestnut oak	FACW		2							
Quercus nigra	Water oak	FACW								2	
Rhynchospora corniculata	Beakrush	OBL				1		1			
Rhynchospora miliacea	Floodplain beakrush	OBL			1	2		1			
Sabal minor	Dwarf palmetto	FAC		1	1				1	1	
Sabal palmetto	Cabbage palm	FAC	1	3	1	1		1	4	2	2
Sagittaria kurziana	Arrowhead	OBL					4				

Table A6—*Continued*

Species	Common Name	Vegetation Community									
		Name	**UP-N**	**TZ1**	**TZ2**	**HS1**	**AB**	**HS2**	**TZ3**	**UP-S**	**UP-S**
		Start (ft)	**0**	**202**	**255**	**300**	**916**	**1053**	**1210**	**1283**	**1385**
		Stop (ft)	**202**	**255**	**300**	**916**	**1053**	**1210**	**1283**	**1385**	**1400**
Species	**Common Name**	**FUWDM Code[1]**	**Plant Species Cover Estimates[2]**								
Sagittaria sp.	Arrowhead	OBL				0		0			
Salix caroliniana	Carolina willow	OBL						0			
Samolus parviflorus	Water pimpernel	OBL			1			1			
Saururus cernuus	Lizard's tail	OBL			1	1		1			
Scleria triglomerata	Tall nutgrass	FACW	1	1					1	1	
Serenoa repens	Saw palmetto	UL	2							2	2
Smilax bona-nox	Greenbrier	UL	1	0							
Smilax pumila	Sarsaparilla vine	UL	1	0							
Solanum viarum	Tropical soda apple	UL		1							
Solidago odora	Sweet goldenrod	UL	1							1	
Taxodium sp.	Cypress	OBL			2	2		2			
Thelypteris sp.	Shield fern	FACW		1	1	1		1			
Tilia americana	Basswood	FACW	1							1	
Trichostema dichotomum	Blue-curls	UL	1								
Ulmus americana	American Elm	FACW				2		1			
Urena lobata	Caesar-weed	UL				0					
Vaccinium arboreum	Sparkleberry	UL	1							1	
Vaccinium corymbosum	Highbush blueberry	FACW	1								
Valisneria americana	Eel grass	OBL					2				
Verbena scabra	Harsh verbena	FACW			1						
Vitus sp.	Grapevine	UL	1	1	1						

Table A6—*Continued*

Species	Common Name	Vegetation Community									
		Name	UP-N	TZ1	TZ2	HS1	AB	HS2	TZ3	UP-S	UP-S
		Start (ft)	0	202	255	300	916	1053	1210	1283	1385
		Stop (ft)	202	255	300	916	1053	1210	1283	1385	1400
		FUWDM Code[1]	Plant Species Cover Estimates[2]								
Woodwardia areolata	Net-vein chain fern	OBL		1	1						
Yucca filamentosa	Adam's needle	UL	1								
Zanthoxylum clava-herculis	Hercules club	UL	1								

UP = Upland, TZ = Transition Zone, HS = Hardwood Swamp, AB = Aquatic Bed, HH = Hydric Hammock

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[2]**Plant Species Cover Estimates:** Areal extent of vegetation species along the transect within a given vegetation community where 0 = < 1% (rare), 1 = 1% to 10% (scattered), 2 = 11% to 25% (numerous), 3 = 26% to 50% (abundant), 4 = 51% to 75% (co-dominant), 5 = > 75% (dominant).

Soils Taxonomy

Transect 3 Soils Taxonomy. Soils were mapped as Bluff series for all floodplain communities, with the northern uplands being mapped as Holopaw series and the southern uplands being mapped as Paisley series. Field samples did not verify all three soil series classifications and varied from the SSURGO (SSS 2008a) map delineation due to the mapping scale. Thirteen soil stations were fully profiled along Transect 3 (Figure 22) and are detailed in Freese (2010; Appendix G). Five of the thirteen profiled stations were not able to be keyed to a soil series, but were keyed to either the soil suborder or great group.

The Paisley taxajunct soil series was observed at four of the thirteen profiled stations (Stations 0, 130, 245, and 1950, elevations 55.1, 49.7, 42.6, and 52.1 ft NGVD, respectively). Paisley soils are deep soils that formed in clayey marine sediments influenced by underlying calcareous material (SSS 2008b). They are poorly drained, slowly permeable soils on nearly level, low broad flood plains with slopes of less than 1% (SSS 2008b). The water table of Paisley soils is at a depth of 10 in. or less for 2 to 6 months during most years, with water being on the surface of the soil for less than one month (SSS 2008b).

The Nittaw soil series or a Nittaw taxajunct series was observed at two of the twelve profiled stations (Stations 310 and 390, elevations 39.4 and 38.2 ft NGVD, respectively). Nittaw soils are very poorly drained, slowly permeable soils that formed in thick deposits of clayey marine sediments found in well-defined drainageways or broad (nearly level) swamps and marshes (SSS 2010). These soils usually have slopes less than 2% and are usually subject to flooding and have standing water for 6 months or more in most years (SSS 2010).

The Aquent soil suborder is wet entisols, meaning they have little or no evidence of pedogenic development and are saturated for some time of the year (SSS 1999). Many of these soils form in recent sediments and support vegetation tolerant of permanent or periodic saturation and/or flooding (SSS 1999). The Fluvaquent soil great group is a member of the Aquent soil suborder and is normally wet soils on floodplains and deltas, stratified from sediment deposition due to changing currents and shifting channels (SSS 1999). These soils are found extensively along rivers and often support forests, deciduous or coniferous (SSS 1999). Mollic Fluvaquents (Stations 640 and 875, 37.4 and 39.4 ft NGVD) have a high base saturation and many are found on floodplains along streams (SSS 1999). Typic Fluvaquents (Stations 900 and 1270, elevations 39.8 and 39.0 ft NGVD, respectively) are young fluvial deposits usually in wet areas on floodplains (SSS 1999). Most Typic Fluvaquents are nearly level, and can support forest vegetation.

The other profiles located within the Silver River’s southern floodplain were keyed as Fluvaquentic Endoaquoll (Station 1495, elevation 38.1 ft NGVD). These soils are keyed as part of the Endoaquoll great group, of the Aquoll suborder of the Mollisol soil order. Aquolls are wet Mollisols that commonly develop in low areas of ponded water, but can develop on broad flats of hillsides (SSS 1999). Endoaquolls have a fluctuating depth to groundwater, depending on season (SSS 1999). Fluvaquentic Endoaquoll soils form mostly in recent alluvium on flood plains and usually have an irregular decrease in organic carbon content with increasing depth (SSS 1999).

The Bluff soil series or a Bluff taxajunct series was observed at two of the twelve profiled stations (Stations 1817 and 1885, elevation 38.3 and 44.2 ft NGVD, respectively). Bluff series soils are sandy-clay soils that formed in thick beds of alkaline loamy marine sediments and consist of very deep, very poorly drained, slowly permeable soils found in marshes and broad low terraces along river flood plains with slopes ranging from 0% to 2% (SSS 2008b; SCS 1979). The natural vegetation for Bluff soils is hardwood swamp, with soils usually being flooded for 1 month or more annually and having a water table at less than 10 in. deep for 6 or more months of the year and rarely less than 20 in. deep (SCS 1979, SSS 2008b). Bluff soils are subject to frequent long duration flooding, but do not receive appreciable sediments (SSS 2008b). Bluff soils meet the hydric soil criteria of flooding and saturation in Marion County (FAESS 2000, 2007).

Transect 5 Soil Taxonomy. Soils were mapped as Bluff series for all floodplain communities, with the northern uplands being mapped as Bluff series and the southern uplands being mapped as Paisley series. Field samples did not verify all soil series classifications and varied from the SSURGO (SSS 2008a) map delineation due to the mapping scale. Twelve soil stations were fully profiled along Transect 5 (Figure 23) and are detailed in Freese (2010; Appendix G). Six different soil series were keyed on this transect. One of the twelve profiled stations was not able to be keyed to a soil series, but was keyed to the soil great group.

The Paisley, Nittaw, Bluff soil series, as well as the Fluvaquent and Endoaquoll great groups were previously described for Transect 3. Paisley (Station 1430, elevation 40.2 ft NGVD) and Paisley taxajunct series (Stations 40 and 1555, elevation 51.2 and 46.8 ft NGVD, respectively) were described on the northern and southern ends of Transect 5. The Nittaw series (Stations 140 and 1310, elevation 40.1 and 38.3 ft NGVD, respectively) was described downslope from Paisley soils. Bluff soils were described at Station 201 (37.5 ft NGVD), in the hardwood swamp. A Typic Fluvaquent (Station 765, 38.4 ft NGVD) soil was keyed in the hardwood swamp community, closer to the main channel.

The Gator taxajunct soil series were identified at profiled Stations 206 and 240 (37.4 and 37.3 ft NGVD, respectively). Gator soils are very poorly drained orgnaic soils that formed in moderately thick beds of hydrophytic plant material overlying beds of loamy and sandy marine sediments in depressions and floodplains with slopes of less than 1% (SSS 2010). These soils are have a Histic Epipedon and are usually saturated with water at or above the surface except during extended droughts, with floodplains being flooded for very long durations (SSS 2010).

A Okeelanta taxajunct soil series was identified at Station 285 (37.8 ft NGVD). The Okeelanta series was keyed out at Station 318 (37.9 ft NGVD). Okeelanta soils are very deep, very poorly drained, rapidly permeable soils found in large freshwater marshes and small depressions that formed in decomposed hydrophytic nonwoody organic material overlying sand (SSS 2010). These soils usually occur in areas with a slope ranging from 0% to 2% and have a Histic Epipedon (A2; SSS 2010). The water table is usually at depths of less than 10 in. below the surface and the soil is usually covered by water for 6 to 12 months during most years (SSS 2010).

The Denaud series was identified at Station 300 (37.8 ft NGVD). The Denaud series soils are very deep, very poorly drained, moderately permeable soils with a thin organic layer over sandy and loamy material in depressions (original established series found on the fringes of the Everglades) (SSS 2010). These organic soils have a Histic Epipedon (A2) formed in sandy and loamy marine sediments and have slopes of less than 2% (SSS 2010). Under unaltered conditions, these soils are normally ponded for 6 to 9 months and saturated to the surface for the rest of the time during most years (SSS 2010).

Transect 7 Soil Taxonomy. At Transect 7, the soils on the northern uplands of the floodplain were mapped as Paisley series, while floodplain itself was mapped as Bluff series. The southern portions of Transect 7 were mapped as Anclote-Tomoka association and Placid soil series. Field samples did not verify all soil series classifications and varied from the SSURGO (SSS 2008a) map delineation due to the mapping scale.

Eighteen soil stations were fully profiled along Transect 7 (Figure 24) and are detailed in Freese (2010; Appendix G). Nine of the eighteen profiled stations were not able to be keyed to a soil series, but were keyed to the soil great group (Mollic and Typic Fluvaquents [Stations 1315, 1500, 1668, and 1700, elevation 39.9, 40.7, 41.6, and 41.4 ft NGVD, respectively] and Fluvaquentic Endoaquolls [Stations 294, 484, 1000, and 1920, elevation 38.2, 39.2, 39.3, and 39.9 ft NGVD, respectively]).

The remaining nine profiled stations were able to be keyed to a soil series or its taxajunct designation. The Paisley soil series or Paisley taxajunct series were identified at Stations 20, 24, 135, and 235 (elevation 50.6, 50.7, 48.6, and 40.9 ft NGVD, respectively). A Bluff taxajunct series was identified at Station 279 (38.5 ft NGVD). Gator taxajunct and Gator soil series were identifed at Stations 306 and 400 (elevation 37.3 and 38.7 ft NGVD, respectively). Station 470 (38.7 ft NGVD) was keyed to an Okeelanta taxajunct series. A Pomona series was identified at Station 2145 (44.3 ft NGVD). The Fluvaquent and Endoaquoll great groups, Paisley, Gator, Okeelanta and Bluff series soils were described above for the previous transects. Pomona series soils are described below.

Pomona soils (Station 2145, 44.3 ft NGVD) are sandy soils that formed in sandy and loamy marine sediments, consisting of very deep, poorly and very poorly drained, moderate to moderately slowly permeable soils found on broad lower ridges of the Lower Coastal Plain (SSS 2008b). The water table is within 10 in. of the surface for 1 to 3 months and between 10 and 40 in. for 6 or more months during most years (SCS 1979). During dry periods, the water table recedes to below 40 in. in depth (SCS 1979). Native vegetation of these soils consists of slash and/or longleaf pine with an understory of saw palmetto (*Serenoa repens*), wax myrtle (*Myrica cerifera*), and gallberry (*Ilex glabra*) (SCS 1979). Pomona soils are listed as partially hydric (SSS 2008a) and can meet the hydric soil criteria of saturation (FAESS 2007) and ponding (FAESS 2000, 2007) for Marion County.

Transect 9 Soil Taxonomy. Soils on the uplands were mapped as Tavares series soils, while the northern floodplain was mapped as Bluff series and the southern floodplain was mapped as Anclote series. Field samples did not verify all soil series classifications and varied from the SSURGO (SSS 2008a) map delineation due to the mapping scale.

Seventeen soil stations were fully profiled along Transect 9 (Figure 25) and are detailed in Freese (2010; Appendix G). Five of the seventeen profiled stations were not able to be keyed to a soil series, but were keyed to the soil great group [Thapto-Histic Endoaquoll at Station 325 (40.0 ft NGVD), Fluvaquentic Haplosaprist at Stations 700, 800, 825, and 856 (39.9, 39.7, 39.7, and 39.7 ft NGVD, respectively)]. The remaining twelve profiled stations were able to be keyed to a soil series or its taxajunct designation: Sparr (Station 10, 60.9 ft NGVD), Jumper (Station 180, 56.5 ft NGVD), Bluff (Station 600, 40.0 ft NGVD), Terra Ceia taxajunct (Station 775, 39.6 ft NGVD), Terra Ceia (Stations 858 and 884, 39.7 and 39.7 ft NGVD, respectively), Gator (Station 1110, 39.8 ft NGVD), Okeelanta (Station 1235, 39.6 ft NGVD), Anclote taxajunct (Station 1245, 40.1 ft NGVD), Pompano (Station 1275, 41.9 ft NGVD), and Tavares (Station 1365, 49.9 ft NGVD). Gator, Bluff, and Okeelanta soil series were previously described at other transects.

Sparr soils (Station 10, 60.9 ft NGVD) are very deep, somewhat poorly drained, and moderately slowly to slowly permeable soils on uplands of the coastal plain that formed in thick beds of sandy and loamy marine sediments and have slopes ranging from 0% to 8% (SSS 2008). The water table for Sparr series soils is at depths of 20- to 40 in. for periods of 1 to 4 months, with water normally being perched on the surface of the loamy layers, though loamy layers may also be saturated (SSS 2008). Native vegetation of these soils consists of longleaf, slash, and loblolly pine, as well as magnolia, dogwood, hickory, and live, laurel, and water oak.

Jumper soils (Station 180, 56.5 ft NGVD) are deep and somewhat poorly drained, moderately permeable soils formed in loamy and sandy marine sediments that are found on the uplands of central Florida, with slopes ranging from 0% to 5% (SSS 2012). Natural vegetation on Jumper series soils includes loblolly, slash, and longleaf pines, water and willow oaks, sweetbay and magnolia, with understories of bluestem, panicums, and beautyberry (SSS 2012).

Terra Ceia (Stations 858 and 884, elevation 39.7 and 39.7 ft NGVD, respectively) and Terra Ceia taxajunct (Station 775, 39.6 ft NGVD) soil series consist of very deep, very poorly drained, rapidly permeable soils in freshwater marshes that formed in more than 50 in. of well decomposed hydrophytic, herbaceous plant remains, with slow to ponded runoff that occur on slopes from 0% to 1% (SSS 2008). These deep organic (muck) hydric soils have water tables at or above the soil surface except during extended dry periods and are flooded for long durations, when undrained (SSS 2008). Terra Ceia soils meet the hydric soil criteria for Marion County for saturation and flooding (FAESS 2007).

The Anclote soil series (Anclote taxajunct soil profile identified at Station 1245, 40.1 ft NGVD) are very deep, very poorly drained, rapidly permeable soils found in depressions, poorly defined drainways, and floodplains that formed in thick beds of sandy marine sediments and have slopes ranging from 0% to 1% (SSS 2008). The water table is within 10 in. of the surface for 6 or more months during most years and recedes to depths of more than 20 in. during the driest season, while depressional areas may remain ponded. Native vegetation consists of cypress, bay, pop ash, pond pine, cabbage palm red maple and Juncus species (SSS 2008). Anclote soils meet the hydric soil criteria for Marion County for saturation, ponding, and flooding (FAESS 2007).

Pompano soil series (Station 1275, 41.9 ft NGVD) consist of very deep, very poorly drained, rapidly permeable soils in depressions, drainageways, and broad flats that formed in thick beds of marine sands and have slopes ranging form 0% to 2% (SSS 2008). The water table of these soils is at depths of less than 10 in. for 2 to 6 months each year, above the soil surface for more than 3 months each year in depressed areas, and is within 30 in. of the surface more than 9 months each year during drier months (SSS 2008). Native vegetation consists of palmetto, occasional cypress, gum, and slash pine with and understory of native grasses (SSS 2008). The Pompany soil series meets the hydric soil criteria for Marion County for saturation, and also meets the hydric soil criteria for ponding in depressional areas (FAESS 2007).

The Tavares soil series (Station 1365, 49.9 ft NGVD) consists of very deep, moderately well drained, rapidly or very rapiddly permeable soils on lower slopes of hills and knolls of the lower Coastal Plain that formed in sandy marine or eolian deposits, with slopes of 0% to 8% (SSS 2007). The water table is between 40 to 80 in. from the soil surface for more than 6 months during most years, but can recede to depths greater than 80 in. during drought periods for this series (SSS 2004). Native vegetation on this soil series consists of slash and longleaf pine with occasional blackjack, turkey, and post oak and an understory of pineland threeawn (SSS 2007). The Tavares soil series itself does not meet the hydric soil criteria for Marion County, but inclusions of Pompano soils (described above) do (FAESS 2007).

A profile on the north end of the transect keyed to Thapto-Histic Endoaquoll (Station 325, 40.0 ft NGVD). These soils are part of the Endoaquoll great group, of the Aquoll suborder of the Mollisol soil order. Aquolls are wet Mollisols that commonly develop in low areas of ponded water, but can develop on broad flats of hillsides (SSS 1999). Endoaquolls have a fluctuating depth to groundwater, depending on season (SSS 1999). Thapto-Histic Endoaquoll soils are poorly drained and have a buried Histosol within 100cm of the mineral soil surface (SSS 1999).

Several profiles on the north side of the transect near the river were keyed to Fluvaquentic Haplosaprist (Stations 700, 800, 825, and 856, 39.9, 39.7, 39.7, and 39.7 ft NGVD, respectively). These soils are part of the Haplosaprist great group, of the Saprist suborder of the Histosol soil order. Haplosaprists are wet for more than 30 days during normal years, unless drained (SSS 1999). Fluvaquentic Haplosaprists are a subgroup that have either one mineral layer (5 to 30 cm thick) or two or more mineral layers (of any thickness) within the organic materials control section below the surface tier (SSS 1999).

PHOTOS OF MFLS TRANSECTS

Silver River MFLs Transect 3 (S3)

MFL Transect 3 Station 0+00 Start

MFL Transect 3 Station 3+00

MFL Transect 3 Station 5+00

MFL Transect 3 – Silver River

Facing North **Facing South**

MFL Transect 3 Station 9+00

MFL Transect 3 Station 13+25

Facing North **Facing South**

MFL Transect 3 Station 14+00

Facing North **Facing South**

MFL Transect 3 Station 16+00


Facing North **Facing South**

MFL Transect 3 Station 18+00


Facing North **Facing South**

MFL Transect 3 Station 20+00 End

Silver River MFLs Transect 5 (S5)-2008

MFLs Transect 5 Station 1+68

MFLs Transect 5 Station 2+00

MFLs Transect 5 Station 3+00

MFLs Transect 5 Station 4+00

MFLs Transect 5 Station 5+00

MFLs Transect 5 Station 10+35 (looking south: started east, stopped west)

MFLs Transect 5 - 2008

MFLs Transect 5 Station 40 Panorama (started/ended facing north)

MFLs Transect 5 Station 100 Panorama (started/ended facing north)

MFLs Transect 5 Station 180 Panorama (started facing north, ended facing west-northwest)

MFLs Transect 5 Station 568 Panorama (started/ended facing north)

MFLs Transect 5 Station 568 Panorama (started/ended facing north)

MFLs Transect 5 - 2008

MFLs Transect 5 Station 1305 Panorama (started/ended facing north)

MFLs Transect 5 Station 1455 Panorama (started facing north, ended facing east)

MFLs Transect 5 Station 1560 Panorama (started/ended facing east-northeast)

Silver River MFLs Transect 7 (S7)—2008

MFLsTransect 7 - 2008

MFLs Transect 7 Station 10 Panorama (started/ended facing north)

MFLs Transect 7 Station 260 Panorama (started/ended facing north)

MFLs Transect 7 Station 350 Panorama (started/ended facing north)

MFLs Transect 7 Station 380 Panorama (started/ended facing north)

MFLs Transect 7 Station 515 Panorama (started/ended facing north)

MFLs Transect 7 - 2008

MFLs Transect 7 Station 700 Panorama (started/ended facing north)

MFLs Transect 7 Station 990 Panorama (started/ended facing north)

MFLs Transect 7 Station 1390 Panorama (started/ended facing north)

MFLs Transect 7 Station 2050 Panorama (started/ended facing north)

Silver River MFLs Transect 9 (S9)–2006

MFLs Transect 9 Station 0+00 Start

MFLs Transect 9 Station 2+00

MFLs Transect 9 Station 3+00

MFLs Transect 9 Station 6+00

MFLs Transect 9 Station 9+00

MFLs Transect 9 Station 11+00

MFLs Transect 9 Station 13+00

MFLs Transect 9 Station 14+00

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APPENDIX B – HYDROLOGIC DATA ANALYSIS TECHNICAL MEMORANDUM

Date: March, 2017

By: Awes Karama, PhD., Jian Di and Fatih Gordu. P.E

Subject: Silver Springs MFL Hydrologic Data Analysis

Introduction

In addition to extensive work conducted to understand the ecological structure and function of priority water bodies, establishing minimum flow and levels (MFLs) and evaluating the status of water bodies require substantial hydrologic analysis of available data. Several steps were involved in performing the hydrologic data analysis for determination of the Silver Springs MFLs.

1. Review of available data
2. Determination of period-of record (POR) for data analysis
3. Transferring MFL field transect data to the gage location where long-term measured flow data are available
4. Development of a stage-flow relationship for converting MFL stages to MFL flows
5. Groundwater pumping impact assessment
6. Development of synthetic flow time series representing no-pumping and current-pumping conditions
7. Estimating available water (freeboard or deficit)

This document describes each of the above steps in the hydrologic analysis and associated results.

Hydrologic Analysis

1 Data Review

Flow data for the period of 1/1/1946 to 12/31/2014 was used for the Silver Springs MFLs development. Two sets of flow data were available. One is the original USGS dataset, which can be retrieved directly from the USGS website and the other is the dataset developed by Edward R. German (former USGS hydrologist) by adjusting the USGS dataset, which is referred to as the USGS-adjusted data set in this document (German, 2010).

SJRWMD contracted with Edward German to address issues related to the USGS estimation of flow, and to create a dataset that could be used as the basis for MFLs analyses. There were two main reasons German determined that adjustments were needed to the USGS dataset. The first reason was that the original USGS data was based on measured and estimated flow from various locations downstream from the main spring vents before October 2003. The USGS computation of flow did not consider the effect of flow measurement location. Because there are inflows from several small spring vents as well as from surface tributaries between the main spring vents and the mouth of the Silver River, the location of flow measurements is very important. By not considering measurement location, the USGS dataset would not account for all additional inflows when developing the flow rating curves.

The second reason was that the USGS computation of flow was only based on groundwater level measurements at a well near the spring until August 2002. It did not take the spring pool elevation into account. This would be a reasonable assumption if spring pool elevation was relatively constant. However, spring pool elevation has been significantly influenced by backwater from the Ocklawaha River and Half-mile Creek. The water level difference between the pool elevation and the groundwater level should have been used to calculate spring flow so that the backwater effect could be considered.

The USGS-adjusted dataset includes adjustments to the USGS data collected prior to October 2003 to address the aforementioned issues related to the USGS dataset. These adjustments resulted in the following improvements to the original USGS dataset.

- Improved the data consistency by normalizing the flow collected from various locations to one station, the 3900 ft station.
- Minimized the errors caused by the backflow events associated with the vegetation build up in the channel and the high-water level in the Ocklawaha river.
- Increased accuracy of the estimated flows by using the hydraulic head difference between the groundwater level and the spring pool elevation.

Since October 2003, all flow data have been collected at the USGS 02239501-gauge station, also referred to as the ‘3900-ft’ station since it is located at about 3900 ft downstream of the main spring boils. In addition, flows since September 2002 are estimated using the difference between the groundwater level and the spring pool elevation.

A comparison of the USGS and USGS-adjusted datasets was conducted for the period of 1/1/1946 to 9/30/2003. Mean flow was 733 cfs and 775 cfs respectively for USGS-adjusted and USGS original datasets. On average the USGS data was 42 cfs greater than the USGS-adjusted for that period (Table B1, Figures B1 and B2). This is due to the fact that the USGS estimates are based on rating curves developed at cross-sections farther downstream of 02239501 station, which would include additional flows coming from several small spring vents as well as from surface tributaries.

Table B1. Statistics of USGS original and USGS- adjusted flow (cfs) for the period of 1/1/1946 – 9/30/2003.

	Mean	Std. Dev	Minimum	Maximum
USGS-adjusted	733	152	320	1217
USGS Original	775	156	350	1290

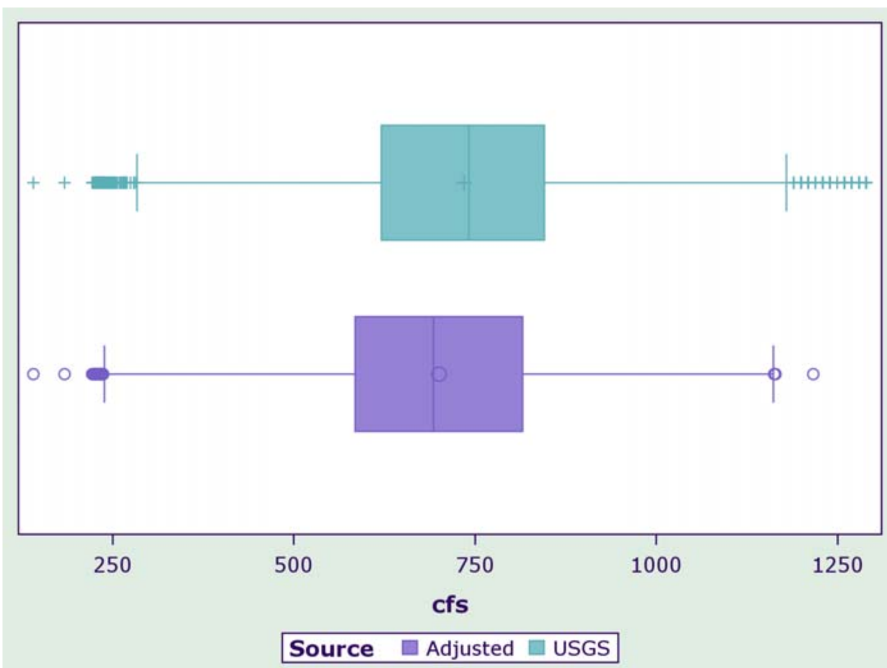


Figure B1. Distribution of USGS original and USGS- adjusted flow (cfs) for the period of 1/1/1946 – 9/30/2003.

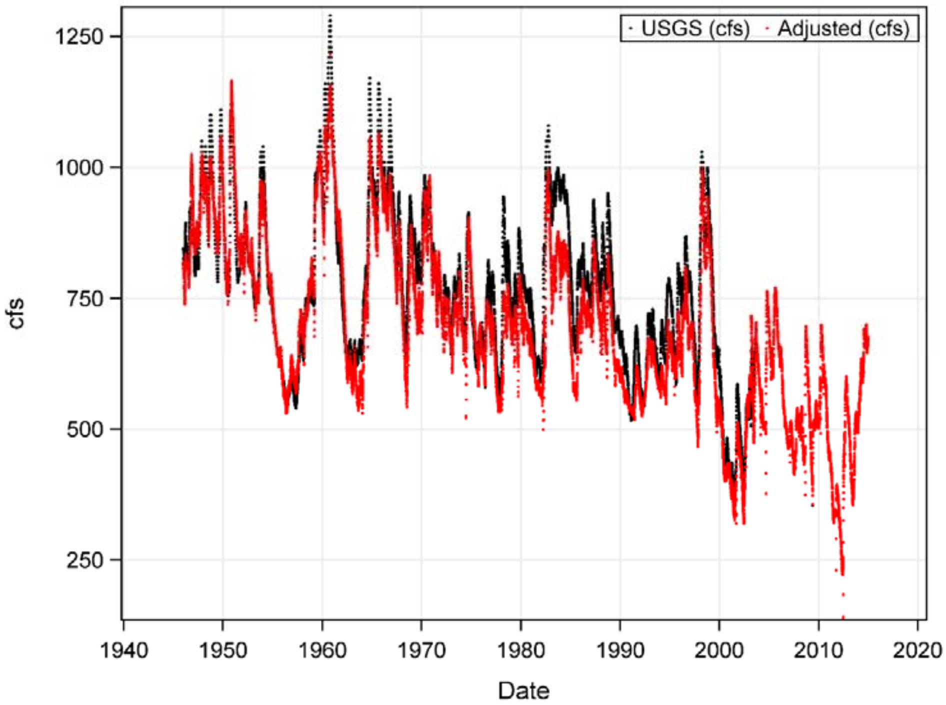


Figure B2. USGS original and USGS- adjusted daily flow (cfs) for the period of 1/1/1946 – 12/31/2014.

2 Period of Record

A review of the historical stage-flow relationship indicated there was a significant change in the relationship after 2000 (See Section 4 for details). However, it was difficult to determine whether this change was caused by anthropogenic influences. In addition, due to a lack of long-term data, it can not be determined whether the post-2000 condition is permanent or a part of the long-term natural behavior of the spring system. The stage-flow relationship may have changed after 2000 due to a flourishing submerged aquatic vegetation (SAV), which could have resulted from natural factors such as a reduction in the number of backwater events and reduction in scour and dark water due to large flooding events, etc. As a result, SJRWMD decided that using the full POR for MFL determination was appropriate.

3 Transferring MFL field transect data to 501 gage

The MFLs field determinations were carried out at MFLs transects S3, S5, S7, and S9 along the Silver River (Figure B3). However, the recommended MFLs regime is set at USGS 02239501 gauging station because this station has a long period of record. MFLs transect elevation data were transferred to the USGS 02239501 gauging station using regression analysis.

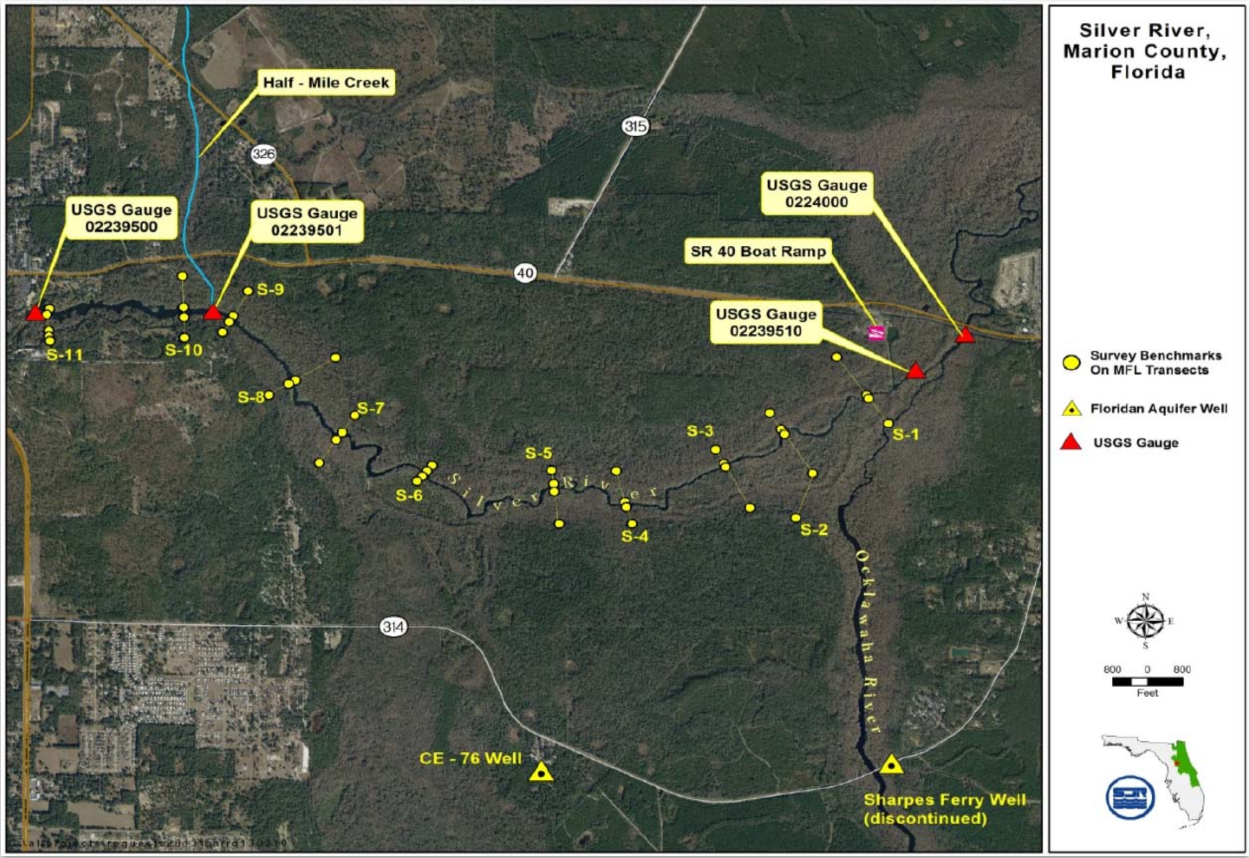


Figure B3. MFL transect locations

Observed stages from 6/4/2007 to present at the USGS Station 02239501 and each MFLs transect were used to develop regression equations. It should be noted that the further the distance of an MFL transect from the USGS 02239501 gauging station, the less linear the relationship is. Backwater and within-channel friction effects complicate these relationships, particularly for further downstream MFL stations. Hence, the regressions equations were developed sequentially between MFL transects from downstream to upstream (S3 versus S5, S5 versus S7, and S7 versus S9) and between transect S9 and the USGS 02239501 gauging station. Figures B4 to B7 show the graphs and associated regression equations. Table B2 presents the MFLs stage transects and corresponding computed stages at USGS 02239501 station.

The elevation relationships between field transects and USGS 02239501 were developed to normalize the MFLs stage levels at one location. The relationship can be appropriately expressed by using a non-linear relationship in some cases (Figures B4 and B5) while in others, a simple linear relationship can be sufficient (Figures B6 and B7) for transferring the elevation data from one transect to another.

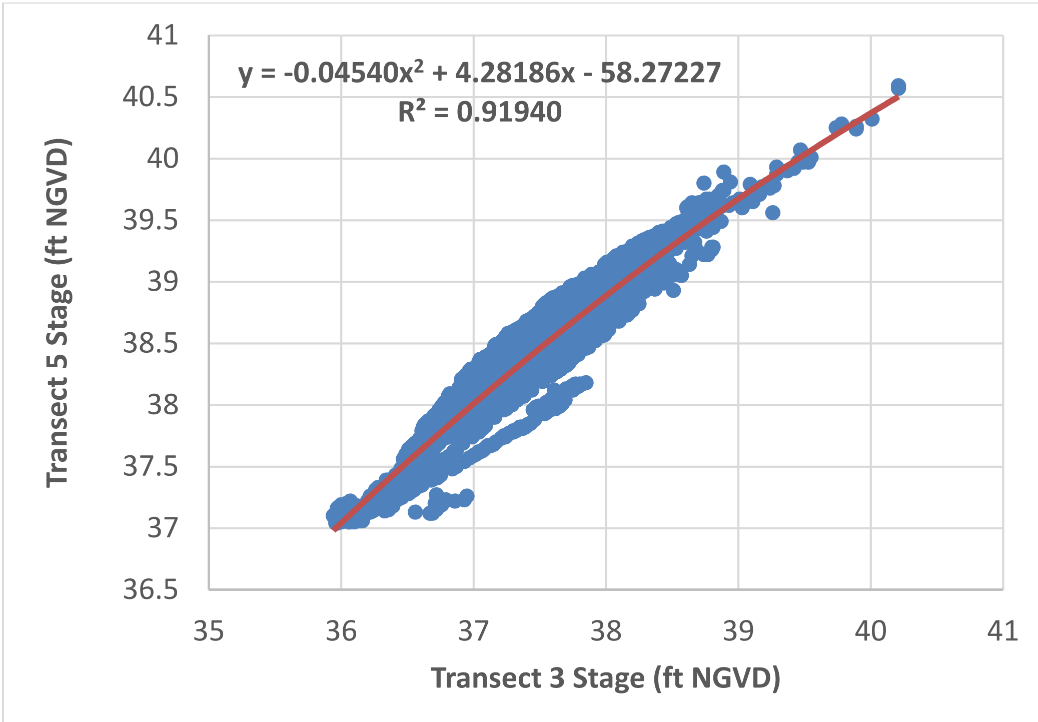


Figure B4. Relationship between transects 3 and 5.

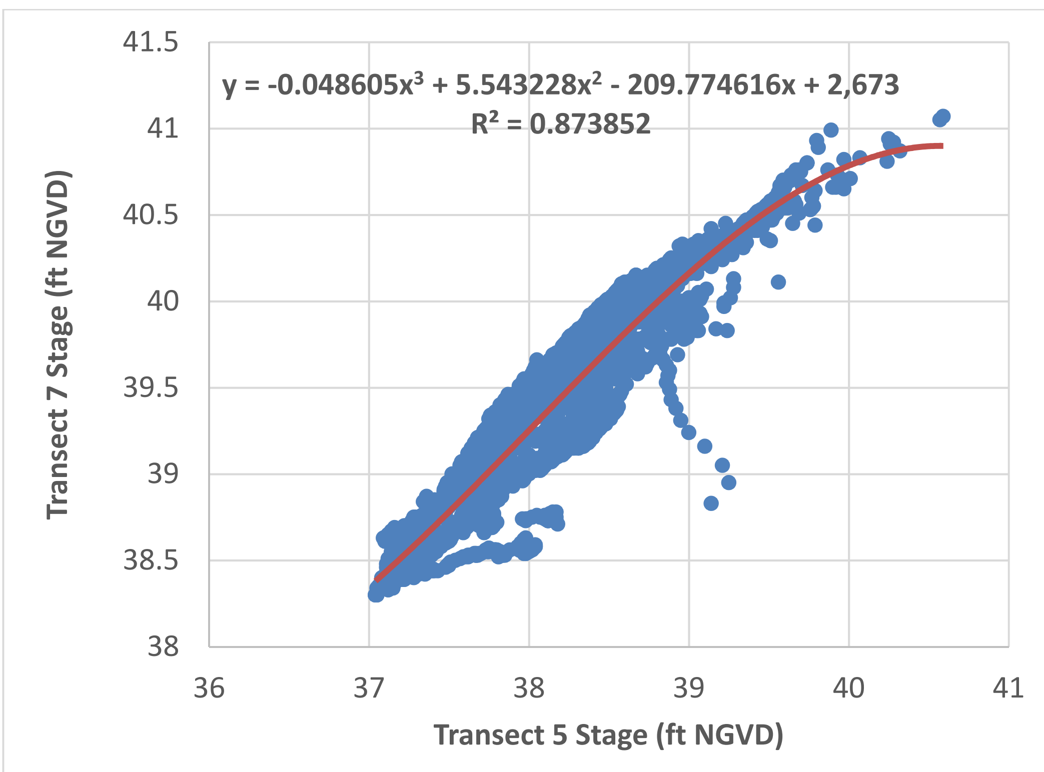


Figure B5. Relationship between transects 5 and 7.

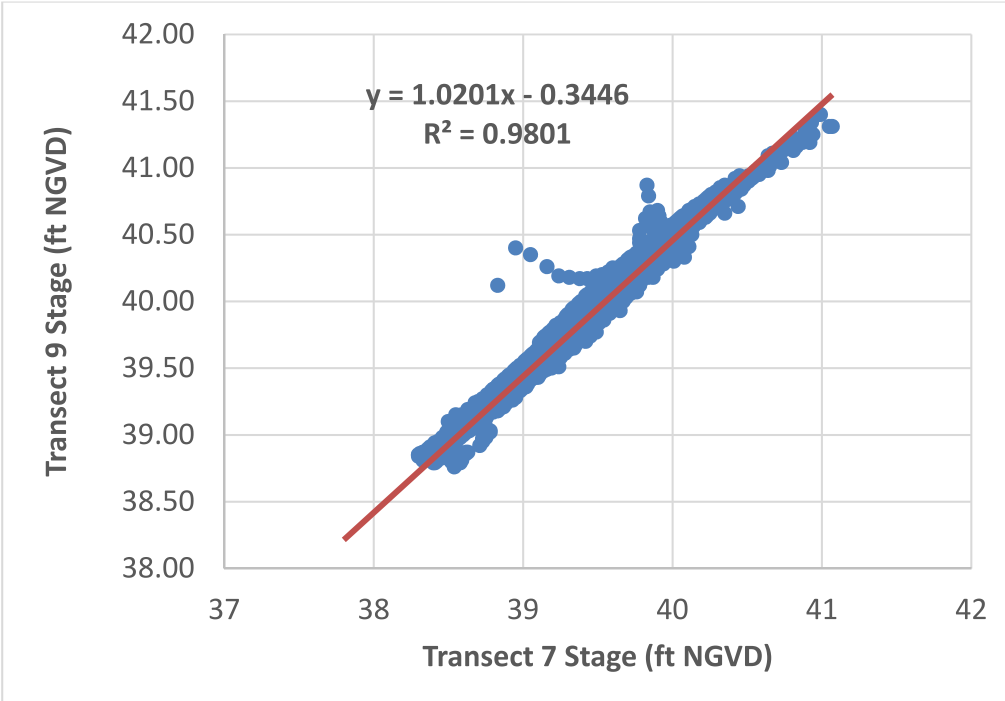


Figure B6. Relationship between transects 7 and 9.

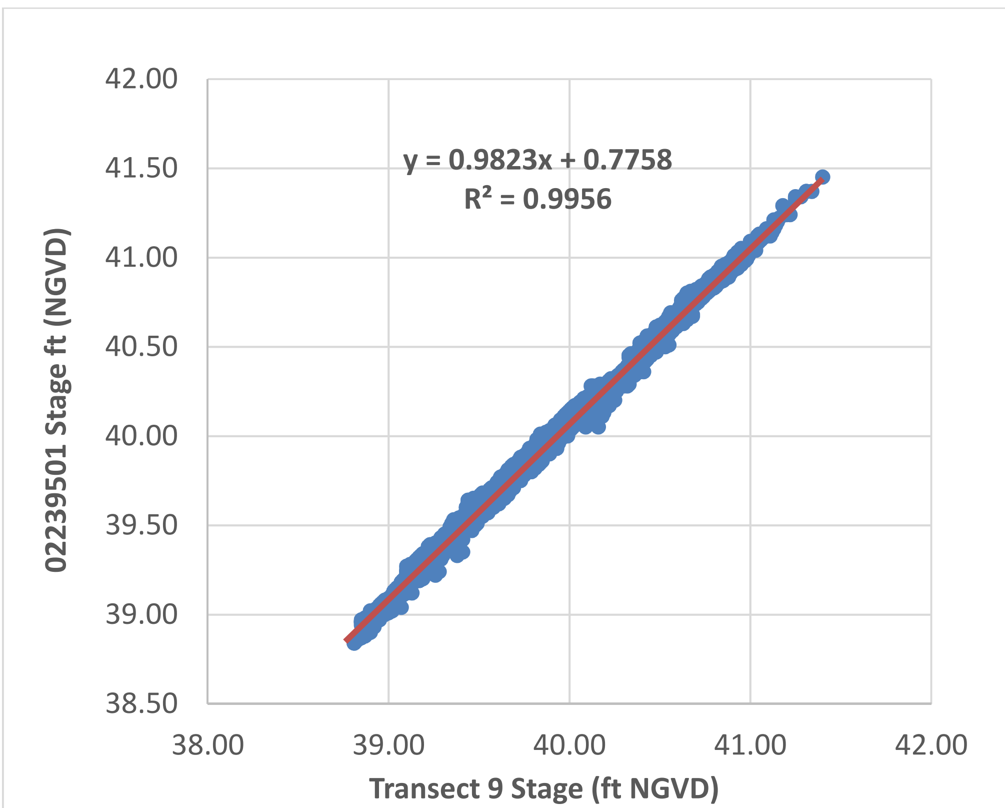


Figure B7. Relationship between transect 9 and 02239501 site.

The relationship functions shown on the Figures B4 through B7 were used to transfer the minimum levels at each of the four transects (Column E in Table B2) to levels at USGS 02239501 station (Column F in Table B2). The final minimum levels for the Frequent High (FH), Mean Average (MA) and Frequent Low (FL) for Silver Springs were calculated as the average of the elevations at USGS 02239501 (Column G in Table B2) estimated from the transects (Column F).

Table B2. The minimum levels at the four MFL transects and at the USGS 02239501gauge station.

Column A	Column B	Column C	Column E	Column F	Column G
MFLs(1)	**Transect**	**Feature**	**Elevation at transect (FT NGVD)**	**Estimated elevation at 02239501 based on transect elevation (FT NGVD)**	**Estimated minimum levels at 02239501 (FT NGVD)**
FH	3	avg max HS	39.02	41.13	
FH	5	avg max HS	38.94	40.61	
FH	7	avg max HS	40.26	40.78	
FH	9	avg max HS	40.64	40.7	**40.81**
MA	3	avg org soil (A1/2&A2) - 0.3 FT	36.22	39.06	
MA	5	avg org soil (A1/2&A2) - 0.3 FT	37.02	38.86	
MA	7	avg org soil (A1) - 0.3 FT	38.01	38.53	
MA	9	avg org soil (A1) - 0.3 FT	39.49	39.57	**39.01**
FL	3	avg max nuphar	34.22	38.18	
FL	5	avg max nuphar	35.49	38.13	
FL	7	avg max nuphar	36.72	37.23	**37.85**

FH: minimum frequent high, MA: minimum average, and FL: minimum frequent low.

4 Stage-flow relationships

It is necessary to translate MFL stages (estimated in the previous step) to flows, so that the frequencies of current and recommended spring flows can be calculated based on a long-term flow time series. At any given stage, the flow varies for various reasons including measurement error, climatic conditions, increase in in-channel vegetation, backwater effect etc. As illustrated in Figure B8, the stage-flow relationships are significantly different between the pre- and post-2000 periods. The variation in flow for a given stage over the POR reflects different conditions occurring in the system (e.g dry, wet, climatic, low flow, high flow, backwater) that they could all be part of the natural system. Since the flow to be estimated should be representative of the natural system for a given stage, the entire POR was used to develop the stage/flow relationship (Figure B9).

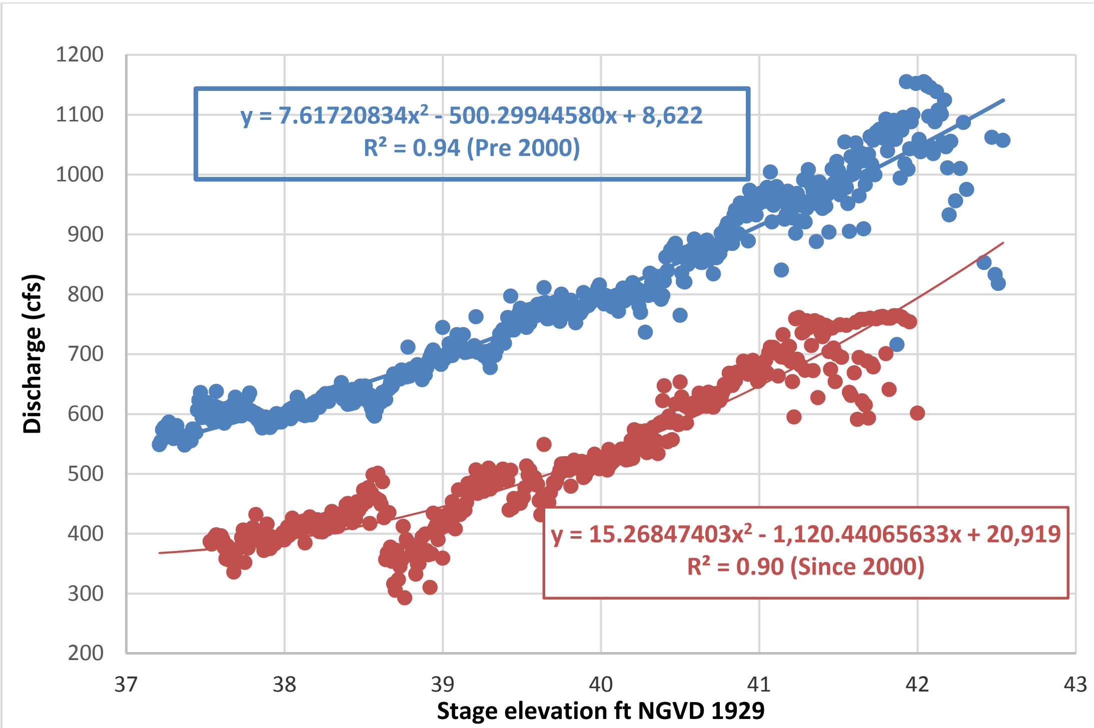


Figure B8. Stage and flow rating curves based on the USGS-adjusted dataset for pre and post 2000 periods.

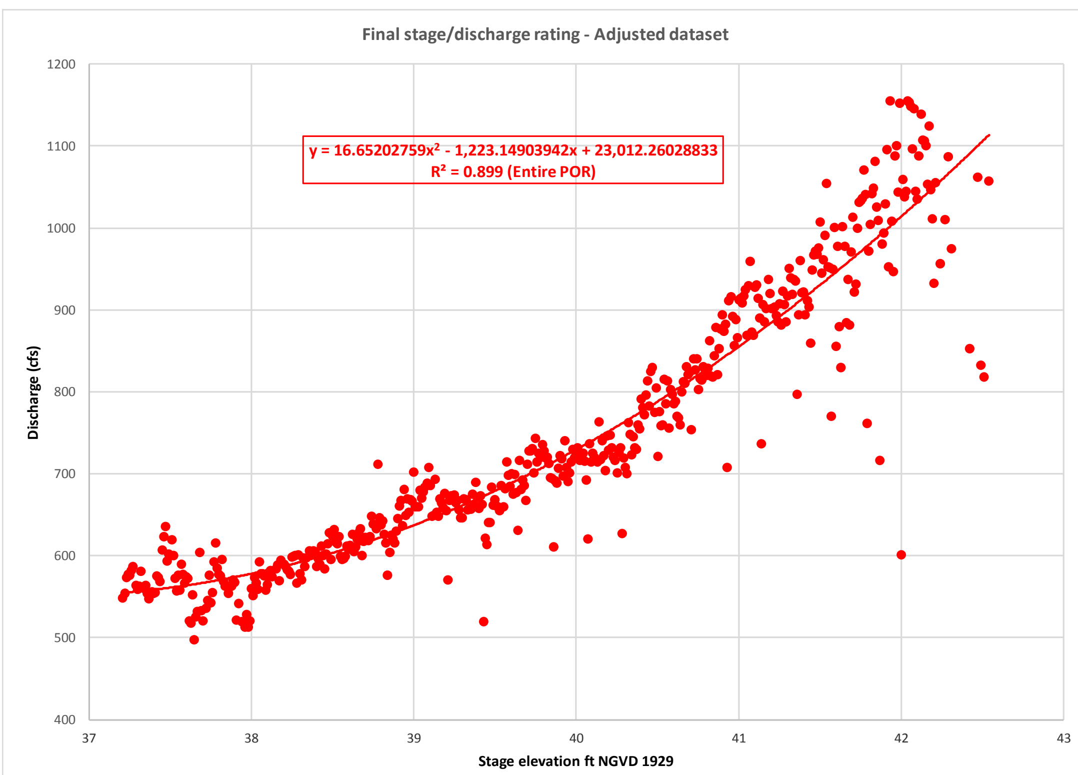


Figure B9. Stage and flow rating curves based on the 1946 -2014 period of USGS- adjusted dataset.

5 Groundwater pumping impact assessment

The determination of MFLs is based on the concept of maintaining a critical frequency of some ecologically important event. To assess the current status of the MFLs (whether an MFL is currently being met or not), the current frequency of this critical event is compared to the recommended frequency of this event, using frequency analysis (discussed in Section 7). To calculate the current frequency of an MFL, a “baseline condition” flow time series is first developed. This represents the frequency distribution of high and low flows during the POR, but as if there had been current pumping throughout the same period. The first step in creating the “baseline condition” flow time series, which in this case is the “2010-pumping condition” flow time series, is to create a “no-pumping condition” flow time series. The no-pumping condition flow time series was created by adding an estimate of impact due to historical pumping (i.e., change in spring flows due to pumping) to each year in the observed record. This annual estimate of reduction in flows due to pumping was developed by first estimating historical groundwater pumping from 1930 to present using both historical population and available actual water use in Marion County (see Figure B10).

Because historical population and water use data was available only at county level before 1995, the estimated groundwater use in Marion county was used as a surrogate to estimate impact on spring flows due to historical pumping. Since most of the groundwater contributing area of the spring is within Marion County, this should be considered a reasonable assumption.

The actual groundwater use for Marion County was available for every year from 1978 to present. The population data for the county was available for every ten years from 1930 to 1970 and for every year thereafter. An average groundwater use per capita was calculated by dividing the average groundwater use by average population using the data from the earliest three years (1978, 1979 and 1980) for which groundwater use data was available. To estimate the groundwater use from 1930 to 1977, the population data was multiplied by the estimated average groundwater use per capita (see Figure B10)

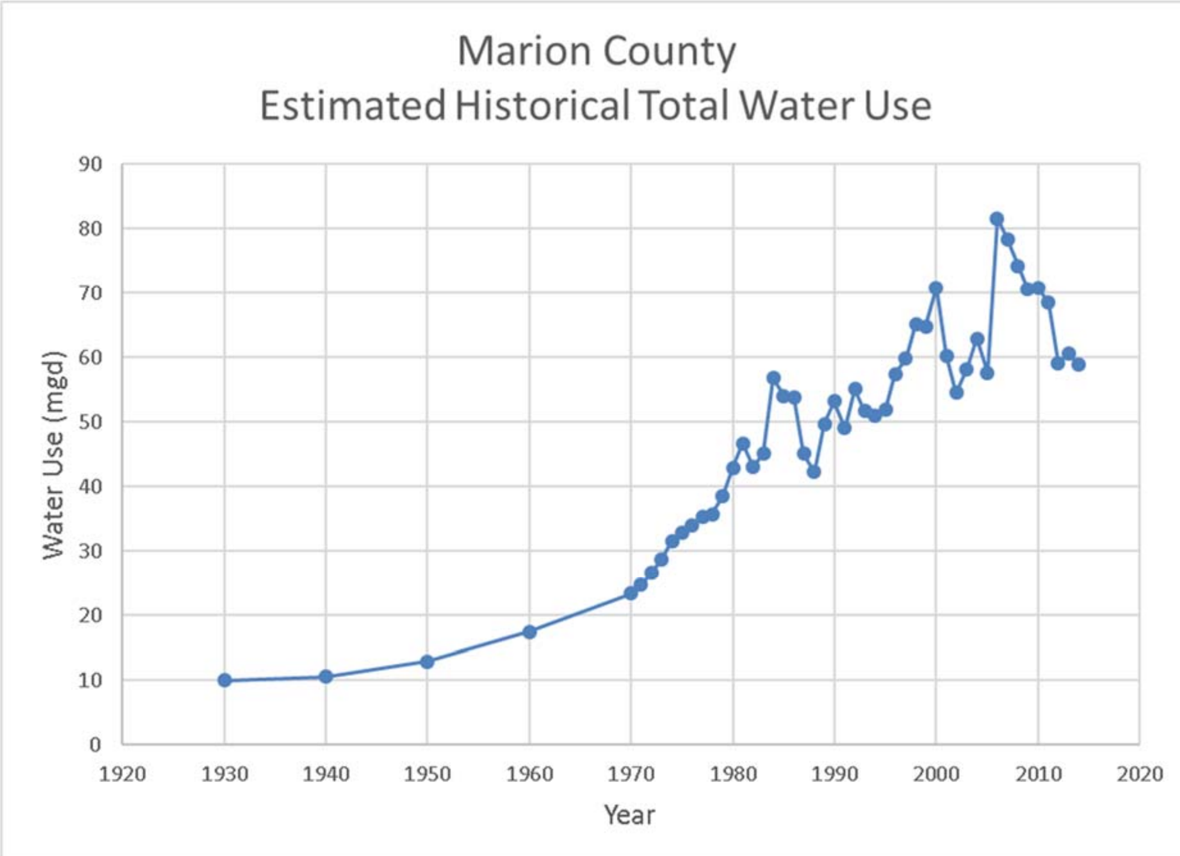


Figure B10. Estimated historical groundwater use in Marion county

Next, the relationship between groundwater pumping and the reduction in spring flow was developed using version 5.0 of the Northern District Groundwater Flow Model (NDMv5 model) (HGL and Dynamic Solutions, 2016). To develop the relationship, three model simulations were performed for three different pumping conditions. For each pumping condition, reduction in spring flow was estimated using the NDMv5 model simulation results. A polynomial relationship between the total pumping in the model and the reduction in flow was later developed (see Figure B11). The ratio of the pumping in Marion county to the total pumping in the NDMv5 model is estimated at 16.4%. Thus, the estimated groundwater pumping from 1930 to present shown in Figure B10 was divided by 16.4% to estimate the total pumping within the model domain over time. Using the polynomial function shown in Figure B11 and the estimated total pumping in the model over time, annual impact to the spring flow from historical pumping was estimated (see Figure B12).

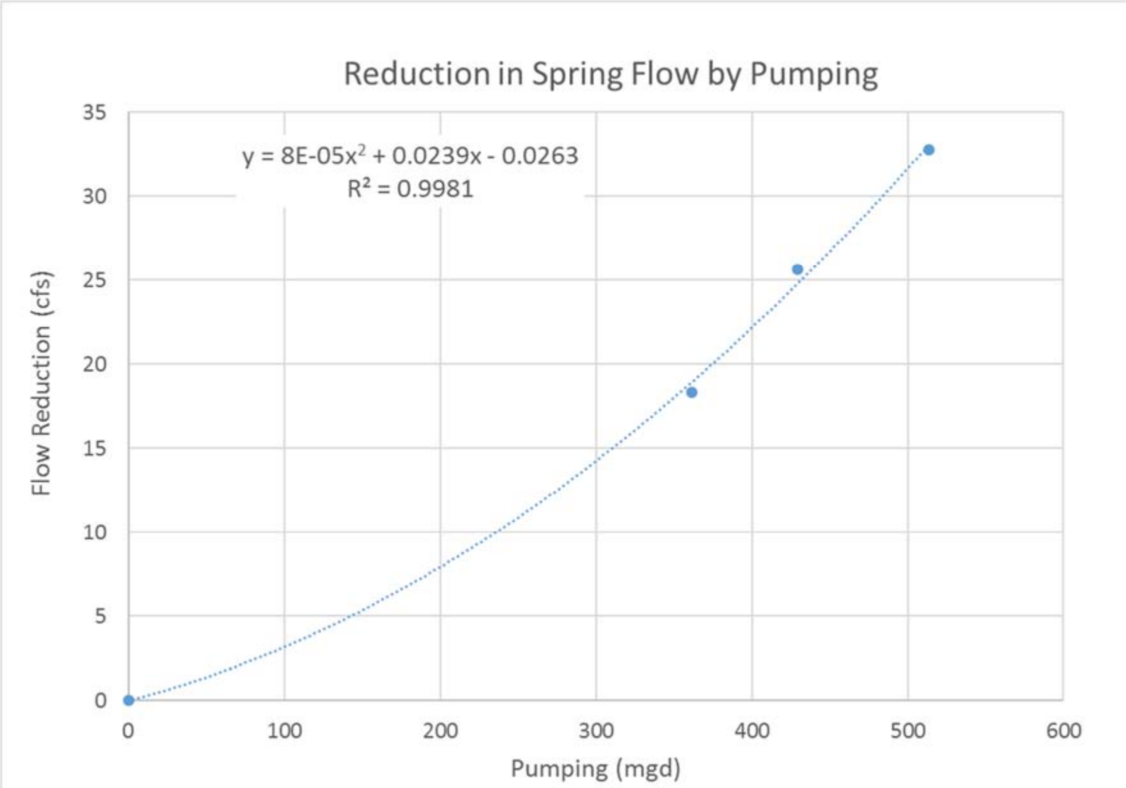


Figure B11. Relationship between pumping and reduction in spring flow

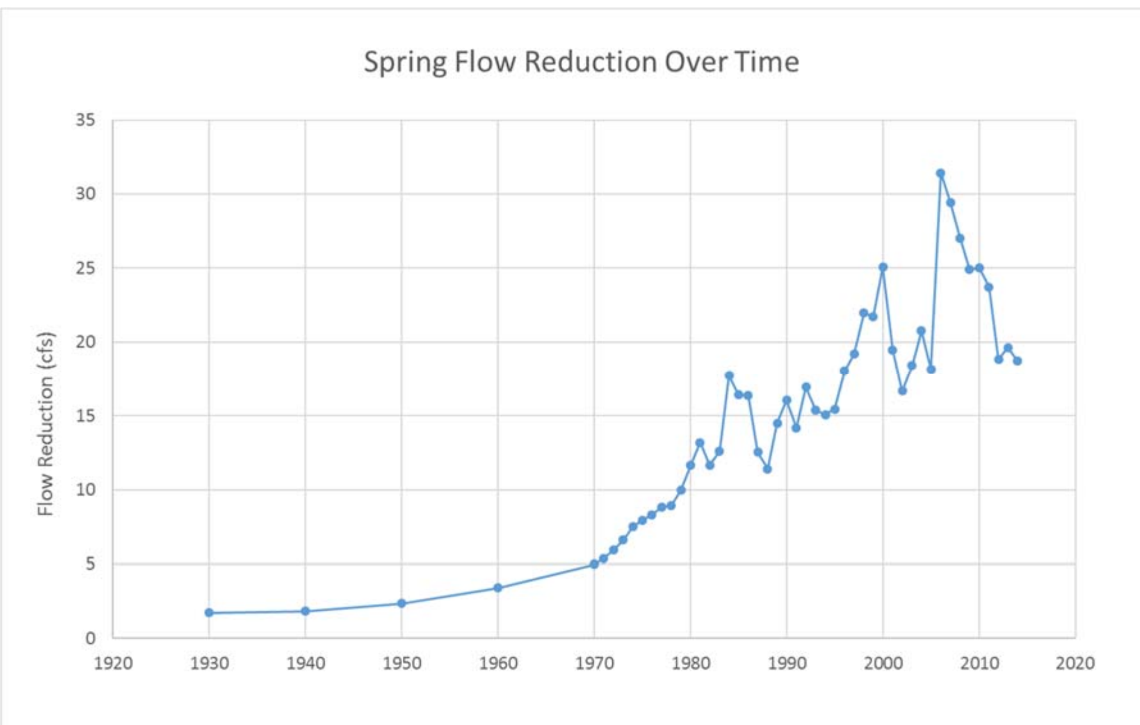


Figure B12. Impact of pumping on spring flow over time

6 Development of synthetic flow time series

6.1 "No-pumping condition" flow time series

The estimated annual historical pumping impact (shown in Figure B12) was added to the USGS-adjusted flows at USGS 02239501 station to create a no-pumping flow time series. This synthetic time series constitutes a reference hydrologic condition of the spring system in which the impact from groundwater pumping is assumed to be minimal.

6.2 "Baseline condition" flow time series

The NDMv5 groundwater model estimated a reduction of Silver Springs flow of 26 cfs in 2010 due to pumping. This amount was subtracted from daily synthetic no-pumping condition flow time series to estimate the baseline condition, which represents the best estimate of the current impacted condition flow time series for Silver Springs. The synthetic baseline flow time series represents a reference hydrologic condition of the spring system in which the impact from groundwater pumping on spring flows is constant over time at a rate of 26 cfs. The baseline-condition is the latest pumping and hydrologic condition NDMv5 was calibrated to. Therefore, it represents the best available information regarding the impact of current withdrawal on spring flow at Silver Springs. If Silver Springs experiences the same long-term climate present during the entire observed POR (including long wet and dry periods), plus the current best estimate of pumping (2010) then we expect to see, over the long-term, the same frequency distribution of flooding and drying events represented by the baseline condition. The baseline condition also provides a reference point from which future pumping can be compared. Figure B13 shows the observed, no-pumping and baseline condition flow time series.

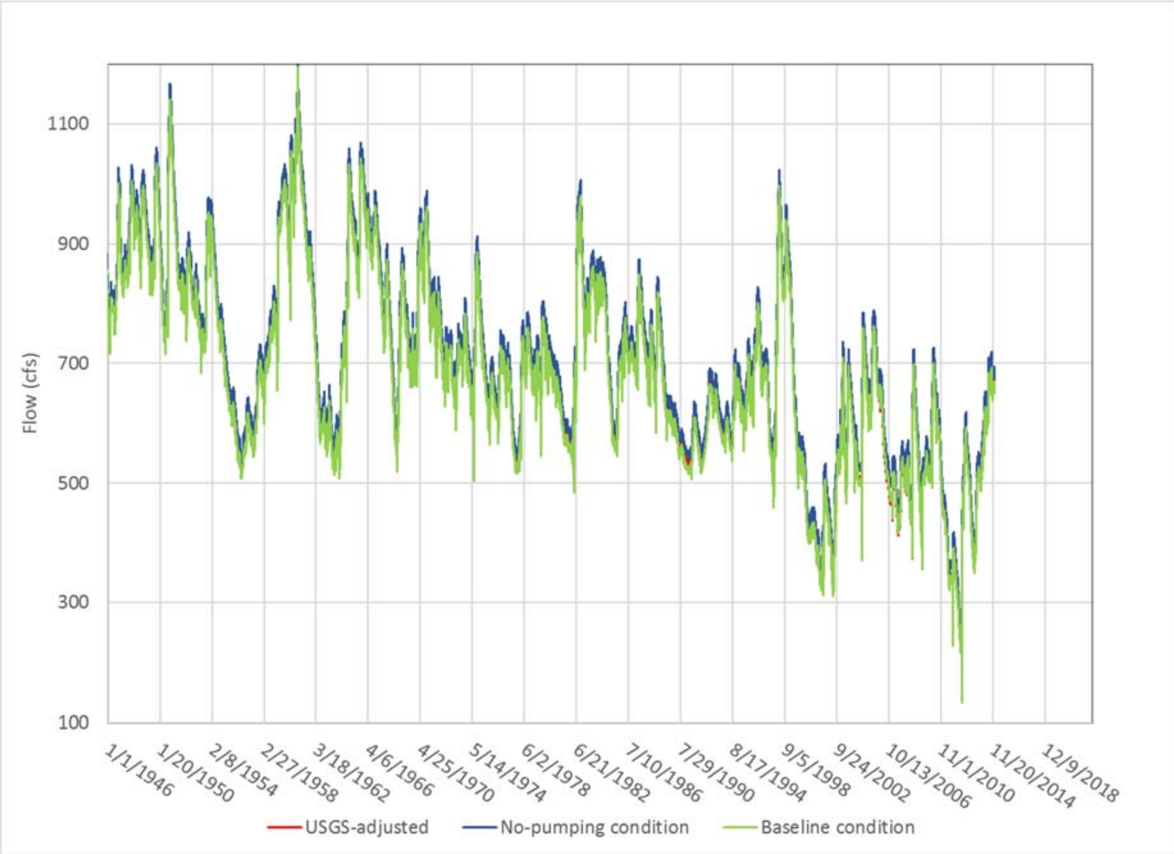


Figure B13. Observed and Synthetic spring flow time series

7 Estimating freeboard/deficit

Minimum flows can be used to assess the hydrologic condition of Silver River system at the time of MFLs adoption. The stage-flow relationship at USGS 02239501 station, which was described in Section 4, was used to compute the minimum flows corresponding to the recommended minimum stages in Table B3. Table B3 shows the computed MFLs.

SJRWMD's MFLs method is an event based method (Neubauer *et al*. 2008). An event is characterized by a defined magnitude, duration, and return interval. Statistical frequencies of stage and flow time series are analyzed. Three MFLs were recommended for the Silver River. They are the minimum frequent high (FH), minimum average (MA), and the minimum frequent low (FL). The annual frequencies are based on the baseline condition time series for period of record from 1946 to 2014. Figures B14 to B16 show the annual frequency graphs of FH, MA, and FL.

Table B3. Recommended MFLs

Recommended MFLs	Level (ft., NGVD29)	Flow (cfs)	Duration (days)	Return Interval (years)	Probability (%)
Minimum Frequent High	40.81	828	30.0	5.0	20.0
Minimum Average	39.01	638	180.0	1.7	59.0
Minimum Frequent Low	37.85	572	120.0	3.0	33.0

In each of the below figures (Figures B14 through B16), the shaded area indicates the region where MFLs are met. The shaded area is bounded by minimum flow and return interval for each specific duration. The MFLs region determines if a specific MFL (FH, MA, or FL) is met or not and by how much. The annual flow frequency plot of baseline condition flow time series is overlaid in each figure. Each of the minimum flows has an allowable change that can be read directly from a plot relating annual flow frequencies to the minimum flows. The intersection of baseline condition flow frequency curve and return interval specific to each MFL determines baseline condition flow at that return interval. The difference between baseline condition flow and minimum flow at the return interval specific to each MFL (shown in Table B3) constitutes the allowable flow reduction (or necessary recovery before the MFLs is achieved) and is referred to as “freeboard”. Table B4 presents the freeboard computation of Silver Springs.

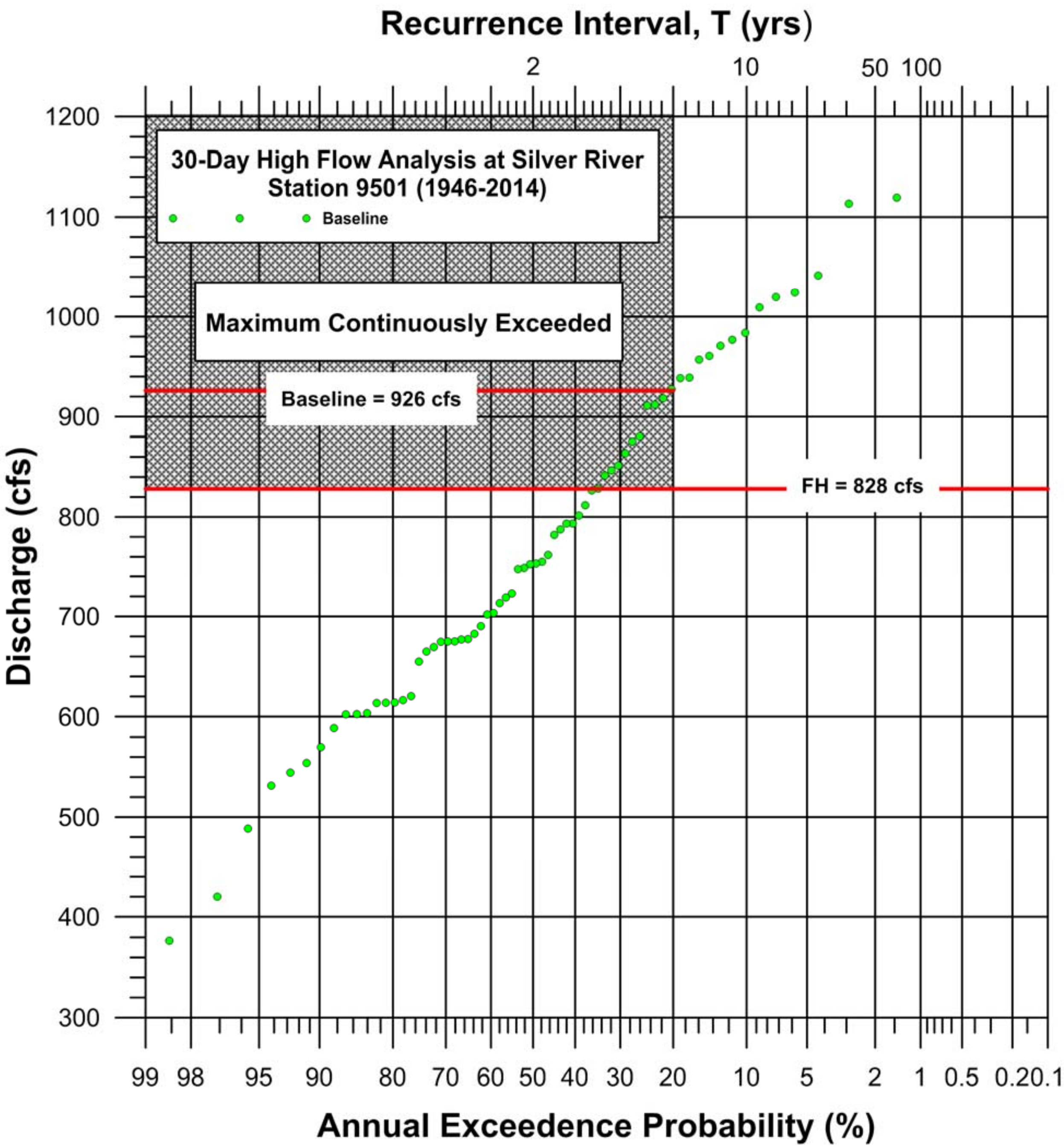


Figure B14. Annual frequency graph of FH

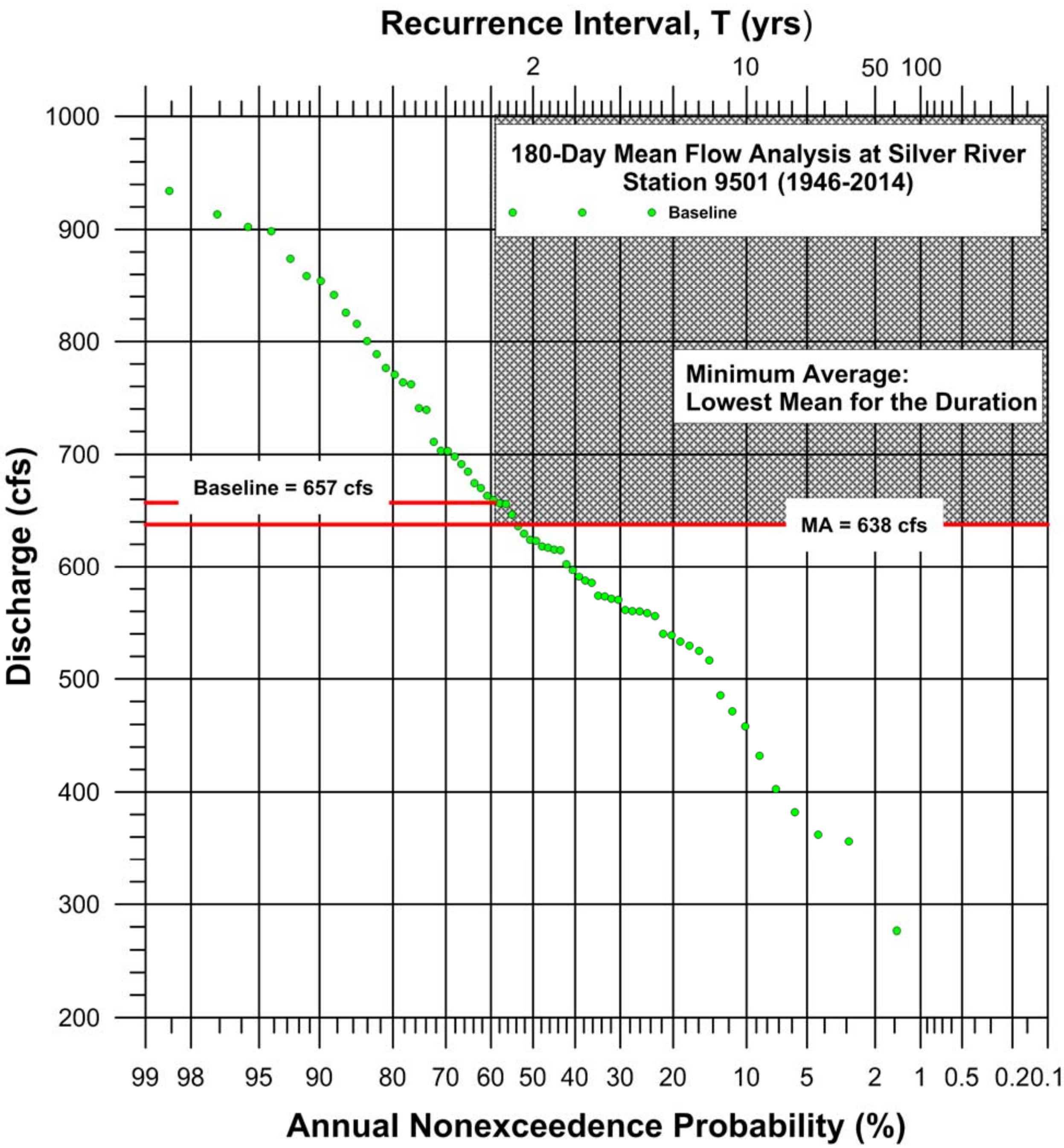


Figure B15. Annual frequency graph of MA

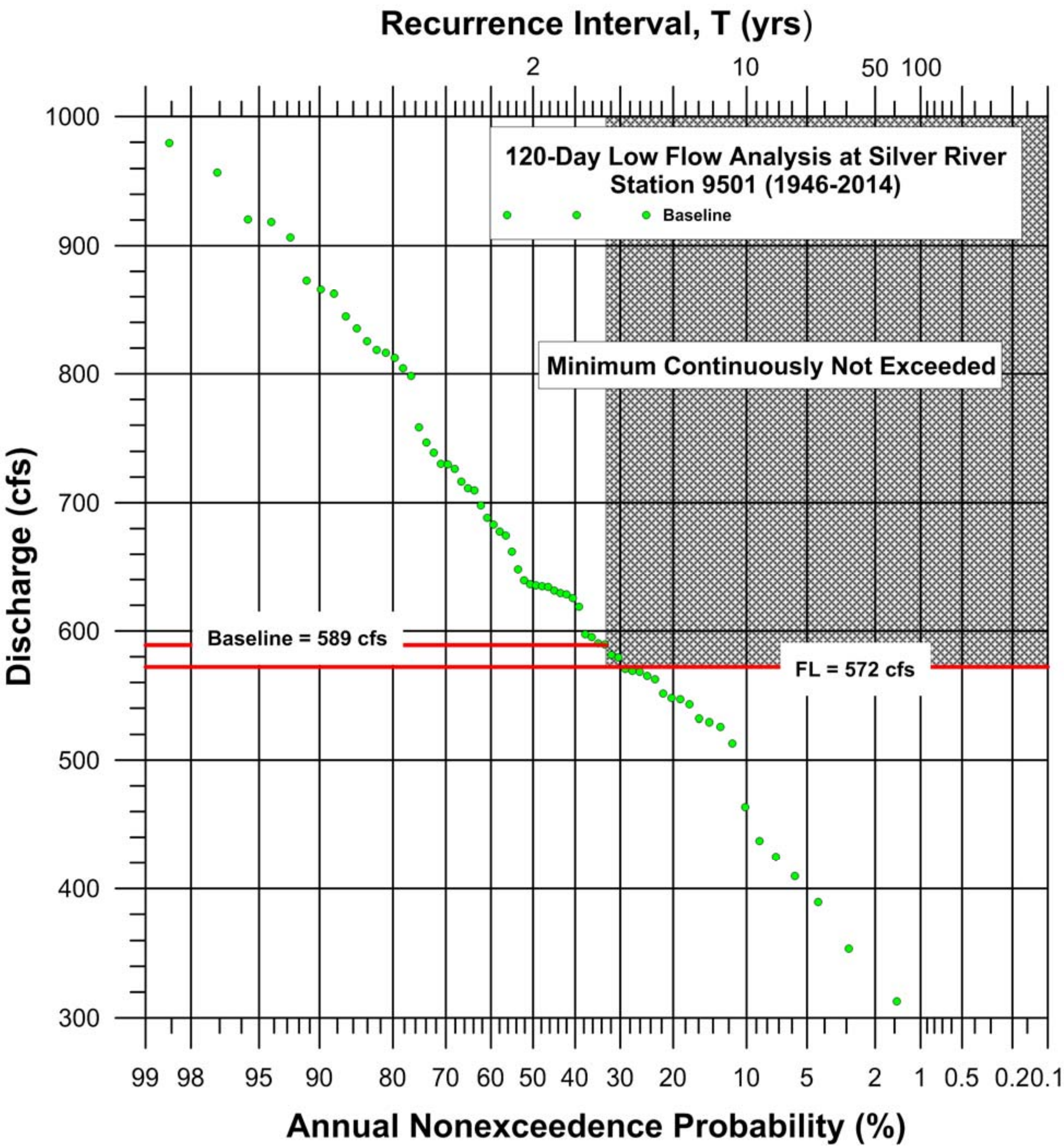


Figure B16. Annual frequency graph of FL

Table B4. Estimation of Freeboard

Period of Record	MFLs	Baseline Condition Flow (cfs)	MFLs Flow (cfs)	Freeboard (cfs)
1946 - 2014	**FH**	926	828	98
	MA	657	638	19
	FL	589	572	17

References

German, E. R. 2010. Evaluation and recomputation of daily flow for Silver Springs near Ocala, Florida. Special Publication. SJ2010-SP9. St. Johns River Water Management District, Palatka, Fl.

HGL and Dynamic Solutions, 2016. Northern district groundwater flow model version 5.0. Report prepared for the St Johns River Water Management District and Southwest Florida Water Management District.

Neubauer, C.P., G.B. Hall, E.F. Lowe, C.P. Robison, R.B. Hupalo, and L.W. Keenan. 2008. Minimum Flows and Levels Methods of the St. Johns River Water Management District, Palatka, Fla. Environmental Management, DOI.

APPENDIX C—SHALLOW WATER CROSS-SECTIONS

Glass Bottom Boats

Several shallow areas of the river were investigated for the potential of restricting boat traffic during low flows. Areas within the Silver Springs Theme Park were profiled topographically to determine at what river stage the operation of glass bottom boats may be affected by lowered stages (see Appendix D, Table D1–glass bottom boat physical dimensions).

Twelve shallow cross sections were profiled for elevations in the upper Silver Springs Theme Park (Figure C-1) on January 24 and 25 in 2007. Eight of these cross sections were located along the glass bottom boat tour routes along the main channel to assess shallow areas that may cause spatial and depth restrictions at low water levels. For example, route alterations may be required in shallow waters if boats were to try to pass one another, to have to wait for one another to get out of the way before continuing on their tours, or impede touring of underwater viewing features (e.g., sunken boats). The elevations of two potential obstructions (high stationary points along the run: a (normally) submerged boat wreck and a limestone rock outcropping) were measured to determine the water levels that these may become obstructions to boat traffic.

Of the twelve areas profiled, four yielded shallow areas of concern with extreme shallows or underwater obstructions that may force the glass bottom boats to alter their normal route (Transects 11B, 11C, 11E, and 11F; Figures C-2 through C-5, respectively). The glass bottom boats that tour this section of the spring run are the fully enclosed, heavier boats that require a minimum water depth of 2.5 ft for clearance and motor operation when fully loaded (Appendix D).

Water depths at Transects 11B and 11C (Figures C-2 and C-3) affect access to the following spring vents: Catfish Reception Hall and Ladies Parlor. The shallow areas of concern for these transects are to the side of spring vents, which are much deeper and would allow for continued boat passage and viewing of the springs. However, an attraction in this area is the underwater boat wreck along Transect 11C (maximum elevation 37.9 ft NGVD, Figure C-3). If spring pool water levels fall below 40.4 ft NGVD (wreck maximum elevation 37.9 ft NGVD + 2.5 ft clearance for glass bottom boats), the glass bottom boats would be unable to fully view the submerged boat wreck at this location and would have to slightly alter the usual tour route. However, it is still possible for the glass bottom of the boat to partially pass over the underwater wreck, so long as the motor does not come into contact with the obstructing portion of the wreck.

Water depths at Transects 11E and 11F (Figure C-4 and C-5) affect access to the Blue Grotto spring vent. During times of higher water, the glass bottom boats enter through the west side and exit the east side of Transect 11E. During periods of water levels lower than 39.6 ft NGVD (37.1 ft NGVD + 2.5 ft clearance), the glass bottom boats may need to alter normal tour routes for this area. Transect 11F bisects the main channel (Figure C-5). The elevation depth in this shallow area of concern is 37.3 ft NGVD, meaning that if water levels fall below 39.8 ft NGVD glass bottom boat traffic may become restricted to the narrower, deeper portion of the channel or potentially cause damage to the submerged aquatic vegetation along the shallow portions of the spring run.

Canoes, Kayaks, and Small Motorboats

Other areas along the Silver River within the Silver Springs Theme Park property were profiled to determine whether stage in relation to channel morphology may affect the navigation or passage of other boat traffic. Four shallow-water cross sections investigated in the Silver Springs Theme Park focused passage by canoes, kayaks, or small motorboats along oxbows or side springs. Elevations for cross sections upstream of the USGS 02239501 Silver River near Ocala (3900 ft station) were transferred via water level and prorated from the nearest hydrologic model cross-sectional benchmarks (Table B-1). Cross-sections are shown in Figures C-6 through C-12.

Seven shallow cross sections were surveyed for profile elevations in the Silver River State Park portion of the river from the Silver Springs Theme Park to the confluence with the Ocklawaha River on January 17 and 18 in 2007. Sites were selected based on shallow areas of the river, as well as areas where underwater obstructions (i.e., downed trees) would force boaters into shallow areas. All graphs of these shallow water cross-sections can be found in Figures C6 to C12.

Having surveyed several shallow sections of the Silver River and having observed it through several seasons and after many storm events, SJRWMD staff determined that the in-channel downed trees are the main obstruction for navigation, not shallow areas of the river. The smallest maximum channel depth surveyed was approximately 29.0 to 30.0 ft NGVD (Appendix B). Transect 1A had a maximum channel depth of approximately 29.0 ft NGVD and at the time of survey in 2007 had 7 ft of water depth above that point. Transects 1B and 2A had maximum channel depths of approximately 30.0 ft NGVD and had 6 ft of water depth above that point at the time of survey.

Most areas identified in 2007 as shallow areas of concern along the main river were no longer shallow areas of concern in 2012 due to the movement of floating mats and coarse large woody debris since then. Occasionally a downed tree in the channel may force a motorboat to the shallow side of the spring run, thereby potentially restricting navigation for some vessels. These in-channel downed trees are often shifted during periods of high flows and during storm events. The remaining shallow areas are not shallow enough across the channel to obstruct navigation; however, there are areas where motorboats may cause ‘prop scarring’ and damage to the SAV beds in the shallower portions if caution is not exercised and the prop is not trimmed up. Silver River State Park staff and Friends of the Silver River volunteers periodically minimally clear navigational obstructions in the main channel to allow for the passage of canoes, kayaks, small motorboats, and larger ecotour pontoon or deck boats.

Table C1. Silver Springs and Silver River prorated water levels, Marion County, Florida (source: SJRWMD, D. Becker)

Date Surveyed	**From Station**	**To Station**	**Distance In Feet**	**Water Level Difference (Ft)**	**Water Level Change By Ft Between Stations**	**Correction**	**From Station Elevation (Ft Ngvd)**	**Prorated W/L @ To Station (Ft NGVD)**
1/17/07	SR 1	SR2	2712	0.499	0.000184			
1/17/07	SR 1	1A	1733			0.319	35.70	36.02
1/17/07	SR 1	1B	2364			0.435	35.70	36.14
1/17/07	SR5	SR6	4139	0.682	0.000165			
1/17/07	SR5	5A	506			0.083	37.38	37.46
1/17/07	SR5	5B	1885			0.311	37.38	37.69
1/17/07	SR5	5C	4043			0.666	37.38	38.04
1/18/07	SR6	SR7	3327	0.587	0.000176			
1/18/07	SR6	6A	2850			0.503	38.06	38.56
1/24/07	STAFF GAUGE	11-A	3772	0.342	0.000091			
1/25/07	STAFF GAUGE	11-K	54			0.005	39.24	39.24
1/25/07	STAFF GAUGE	ROCK	485			0.044	39.24	39.28
1/25/07	STAFF GAUGE	SR10	516			0.047	39.24	39.29
1/25/07	STAFF GAUGE	11-J	760			0.069	39.24	39.31
1/25/07	STAFF GAUGE	11-I	1225			0.111	39.24	39.35
1/24/07	STAFF GAUGE	11-H	1757			0.159	39.24	39.40
1/25/07	STAFF GAUGE	11-L	2507			0.227	39.24	39.47

1/24/07	STAFF GAUGE	11-G	2658			0.241	39.24	39.48
1/24/07	STAFF GAUGE	11-F&E	2935			0.266	39.24	39.51
1/24/07	STAFF GAUGE	11-D	3242			0.294	39.24	39.53
1/24/07	STAFF GAUGE	11-B&C	3508			0.318	39.24	39.56
1/24/07	STAFF GAUGE	11-A	3772			0.342	39.24	39.58

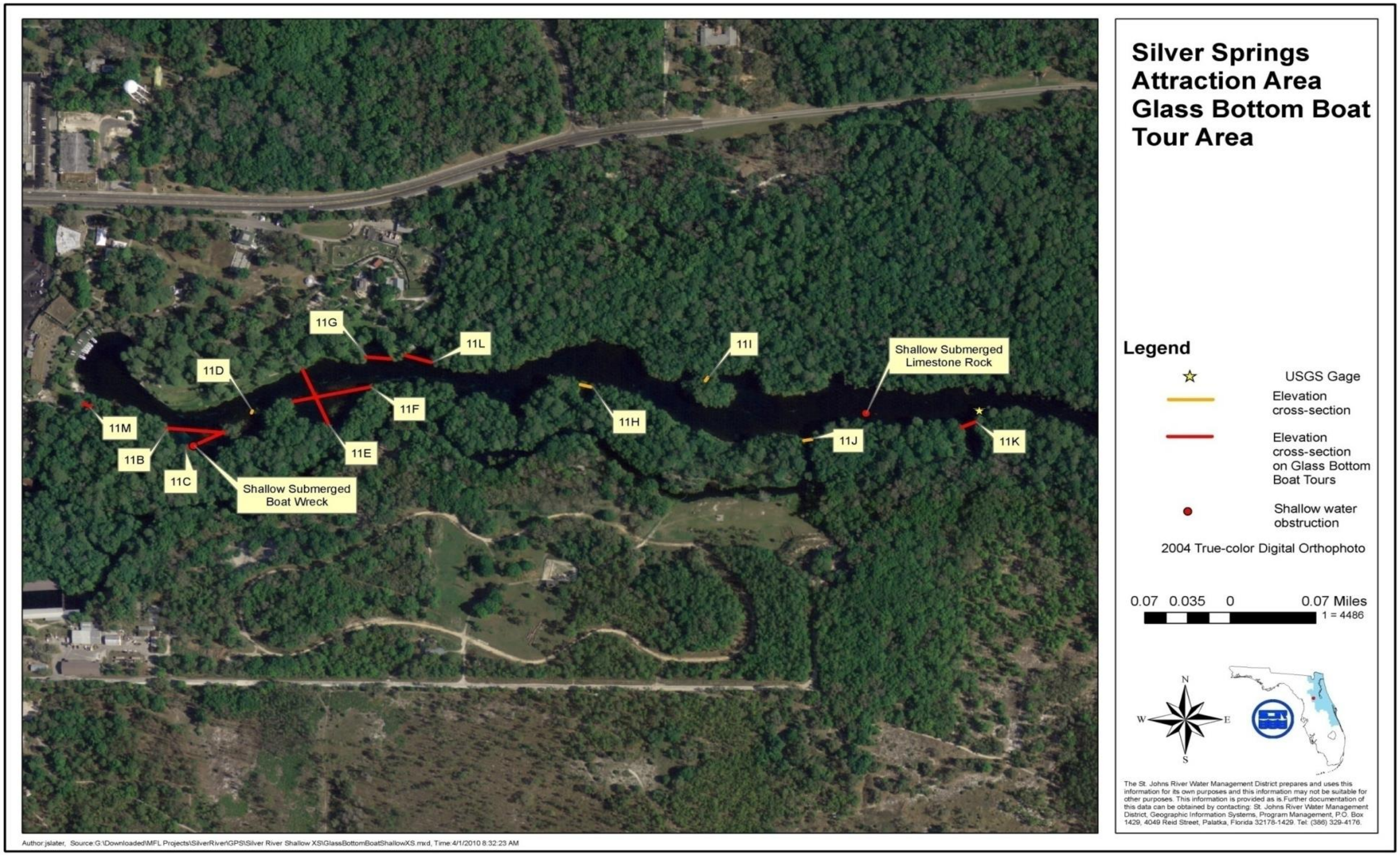


Figure C-1. Location of shallow water cross sections

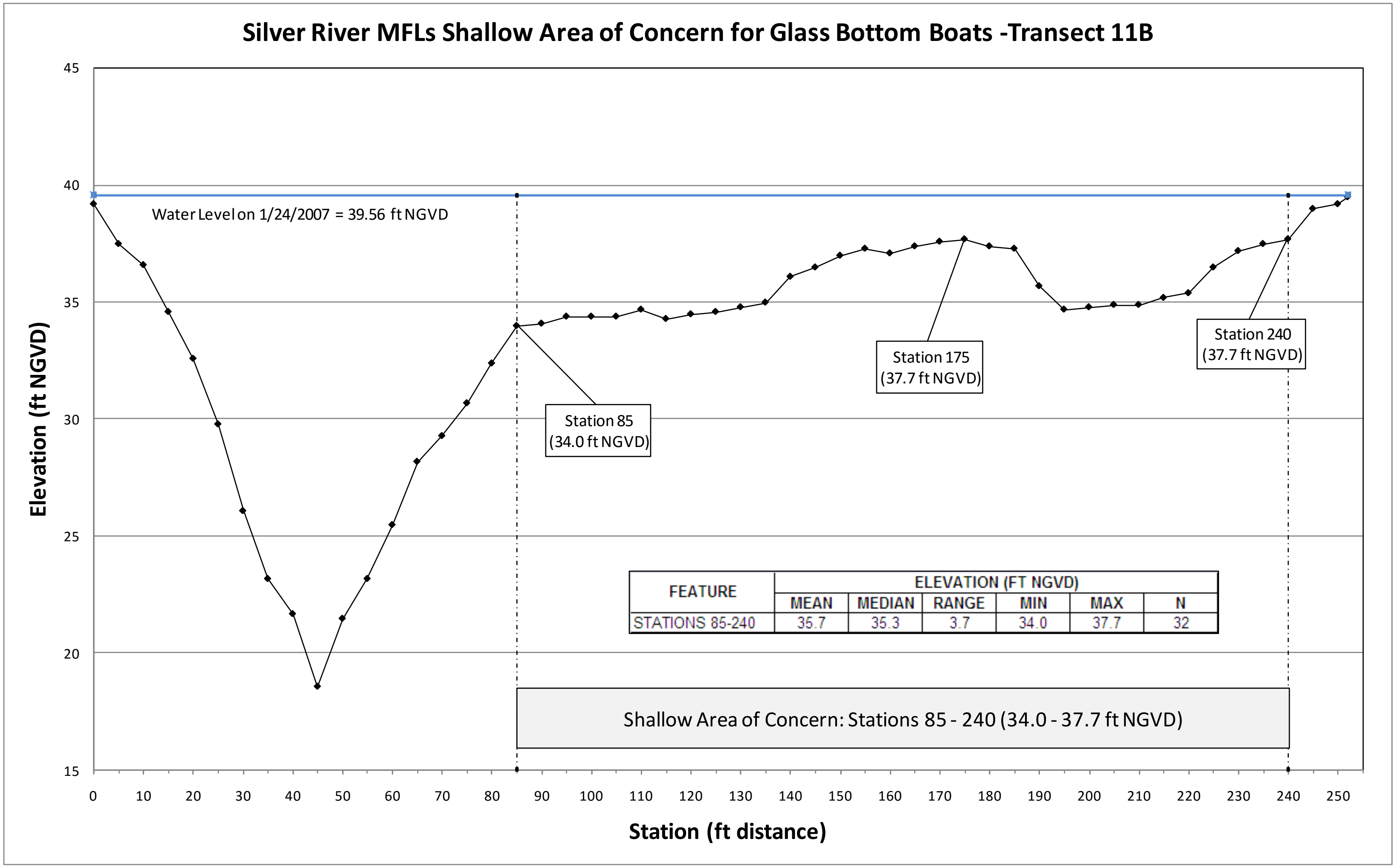
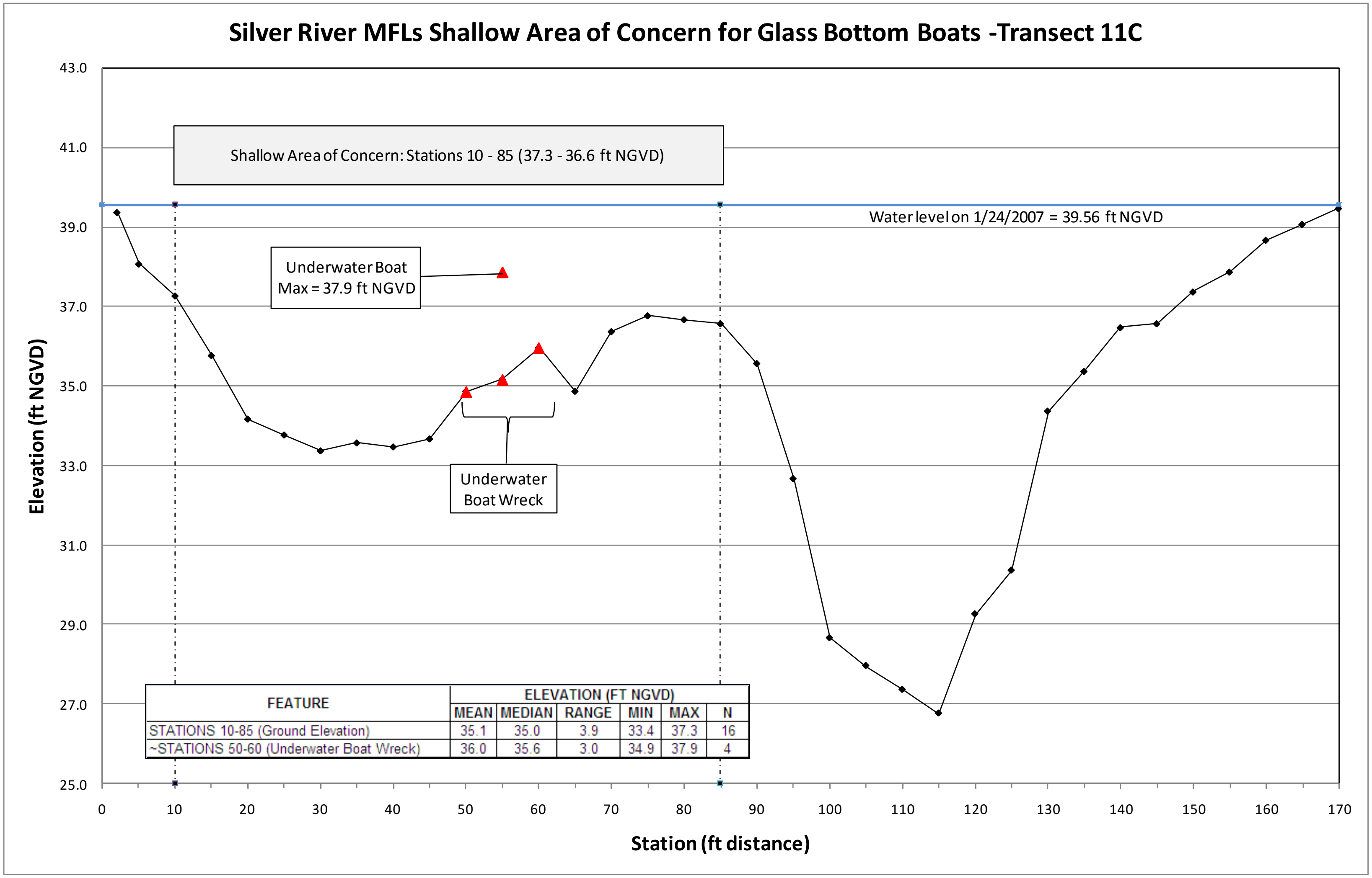
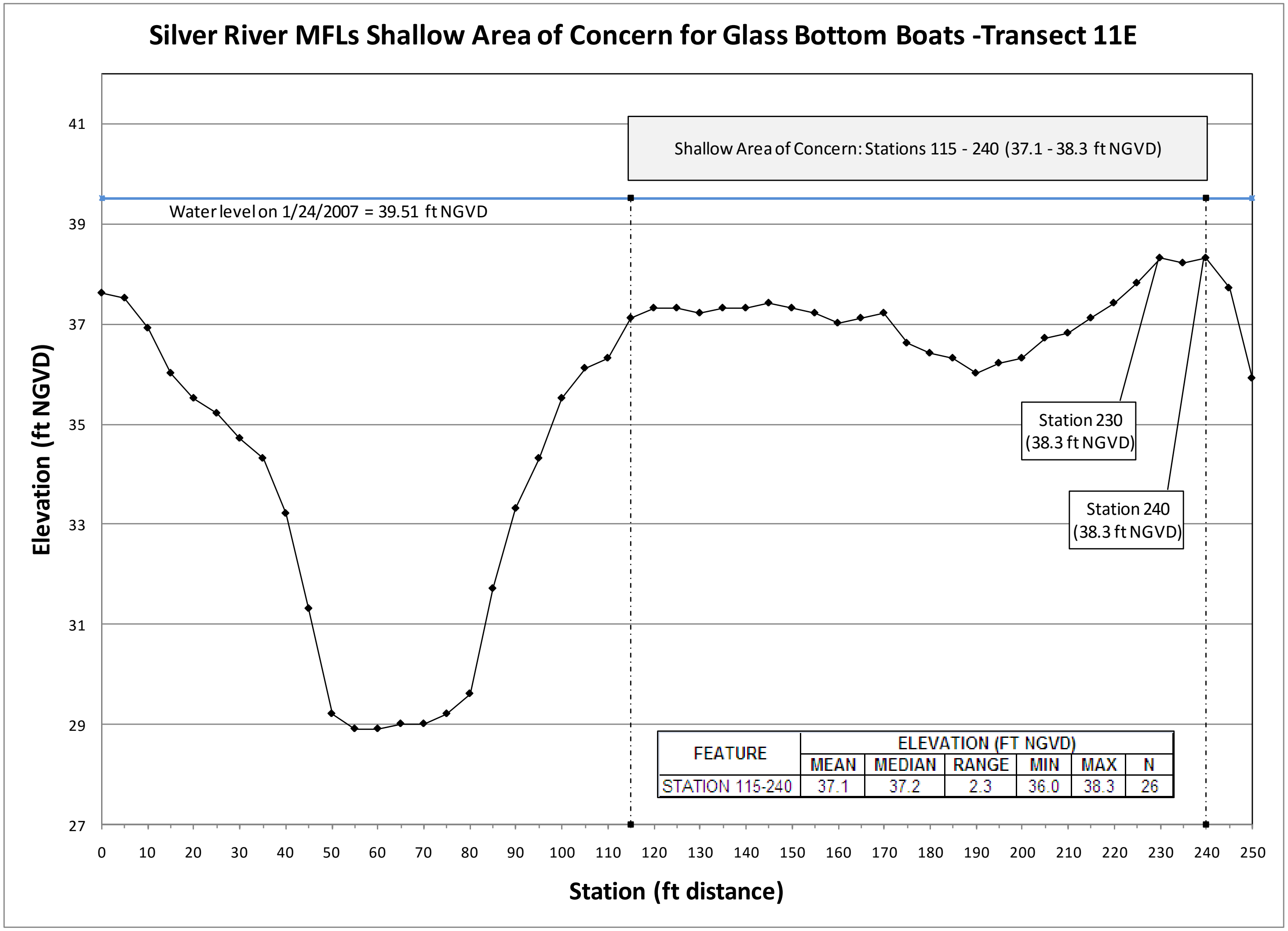


Figure C-2. Shallow water cross section 11B



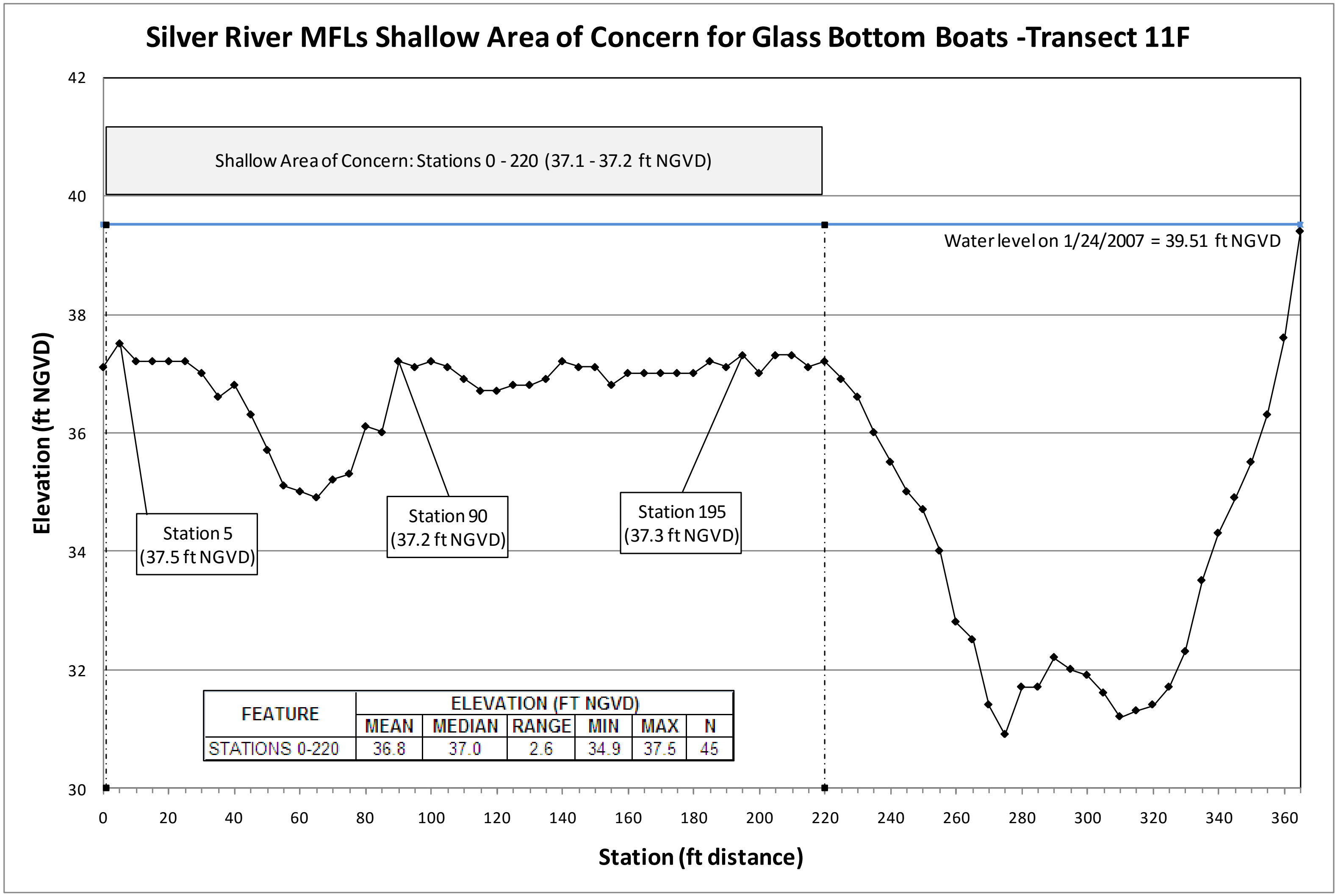
FEATURE	ELEVATION (FT NGVD)					
	MEAN	MEDIAN	RANGE	MIN	MAX	N
STATIONS 10-85 (Ground Elevation)	35.1	35.0	3.9	33.4	37.3	16
~STATIONS 50-60 (Underwater Boat Wreck)	36.0	35.6	3.0	34.9	37.9	4

Figure C-3. Shallow water cross section 11C



FEATURE	ELEVATION (FT NGVD)					
	MEAN	MEDIAN	RANGE	MIN	MAX	N
STATION 115-240	37.1	37.2	2.3	36.0	38.3	26

Figure 1. Shallow water cross section 11E



FEATURE	ELEVATION (FT NGVD)					
	MEAN	MEDIAN	RANGE	MIN	MAX	N
STATIONS 0-220	36.8	37.0	2.6	34.9	37.5	45

Figure C-5. Shallow water cross section 11F

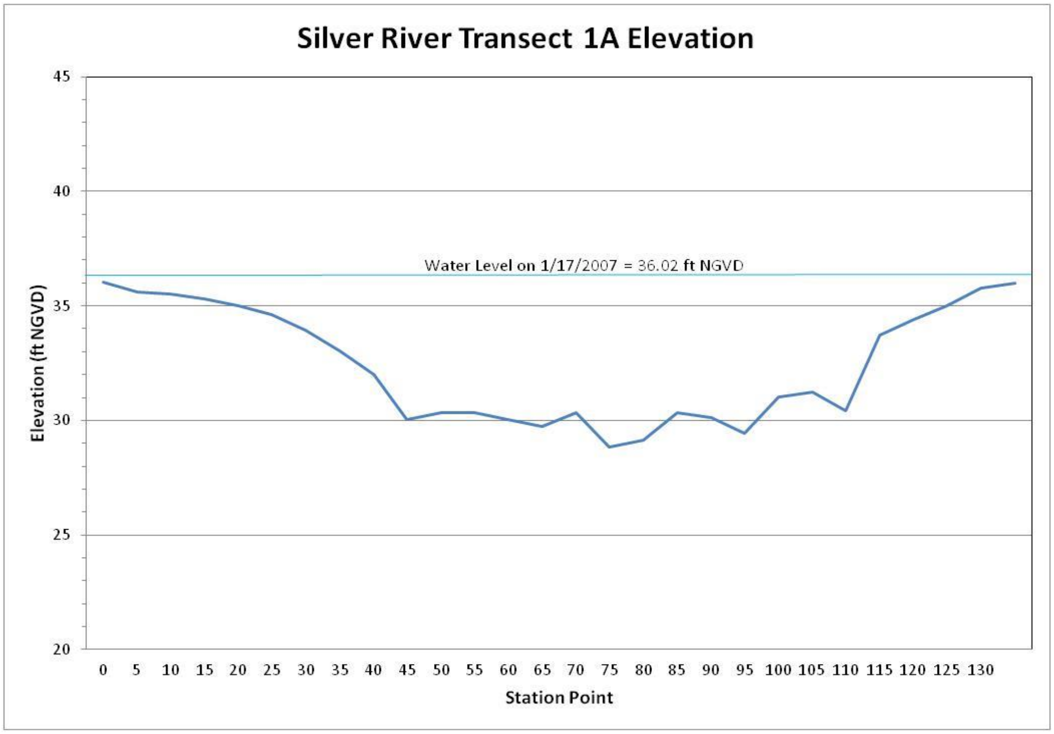


Figure C-6. Shallow water cross section 1A

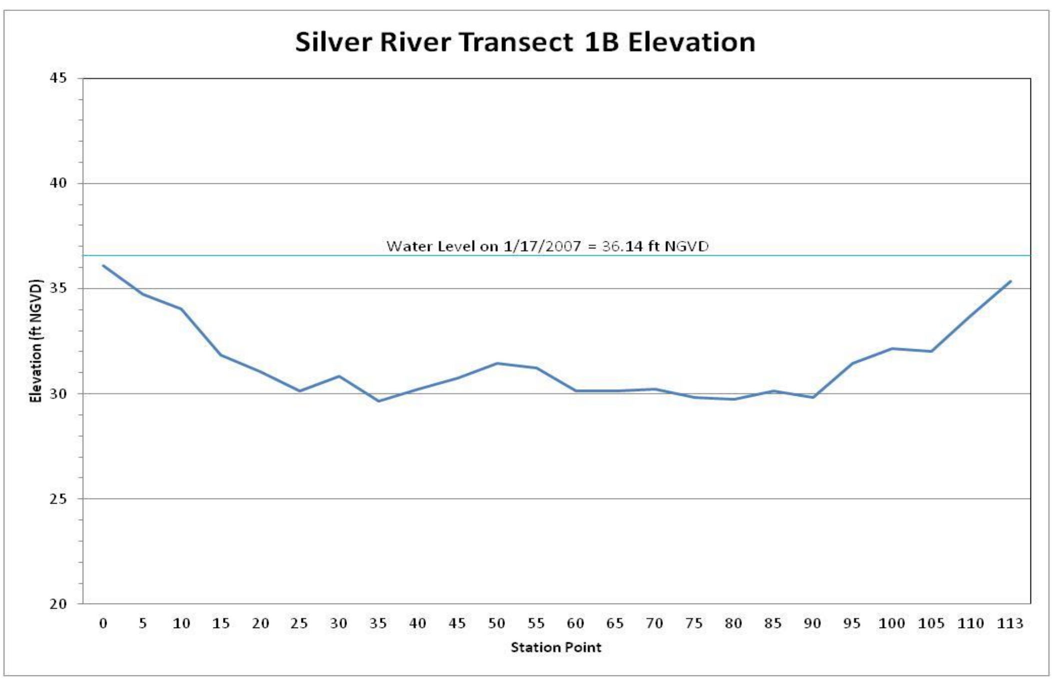


Figure C-7. Shallow water cross section 1B

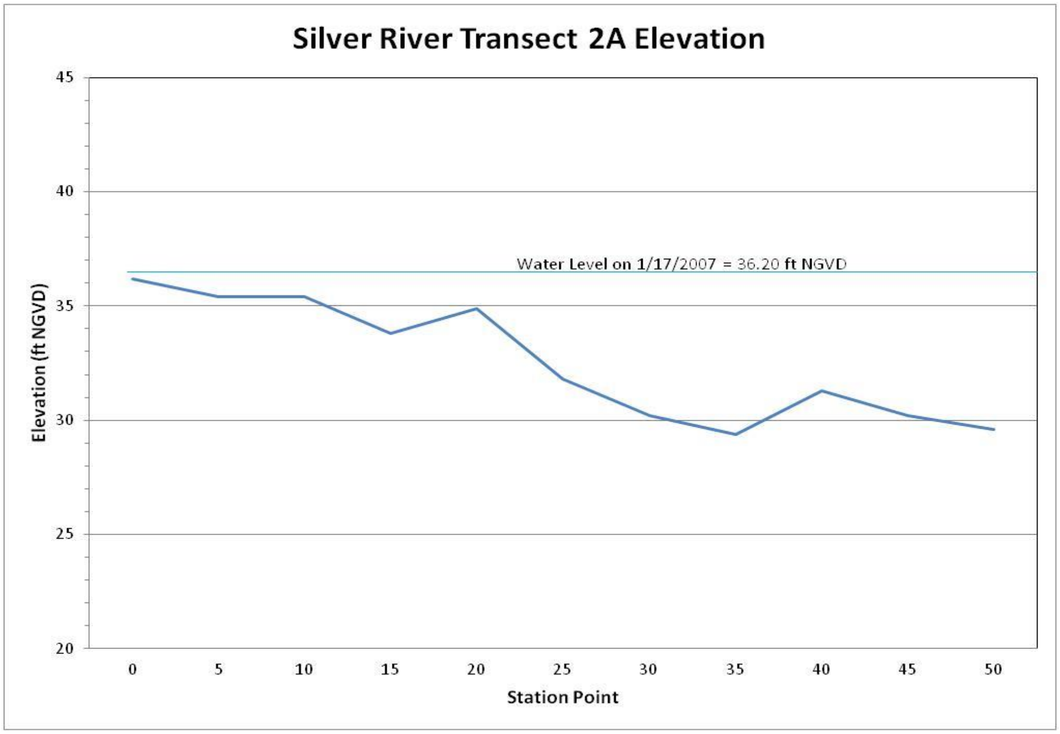


Figure C-8. Shallow water cross section 2A

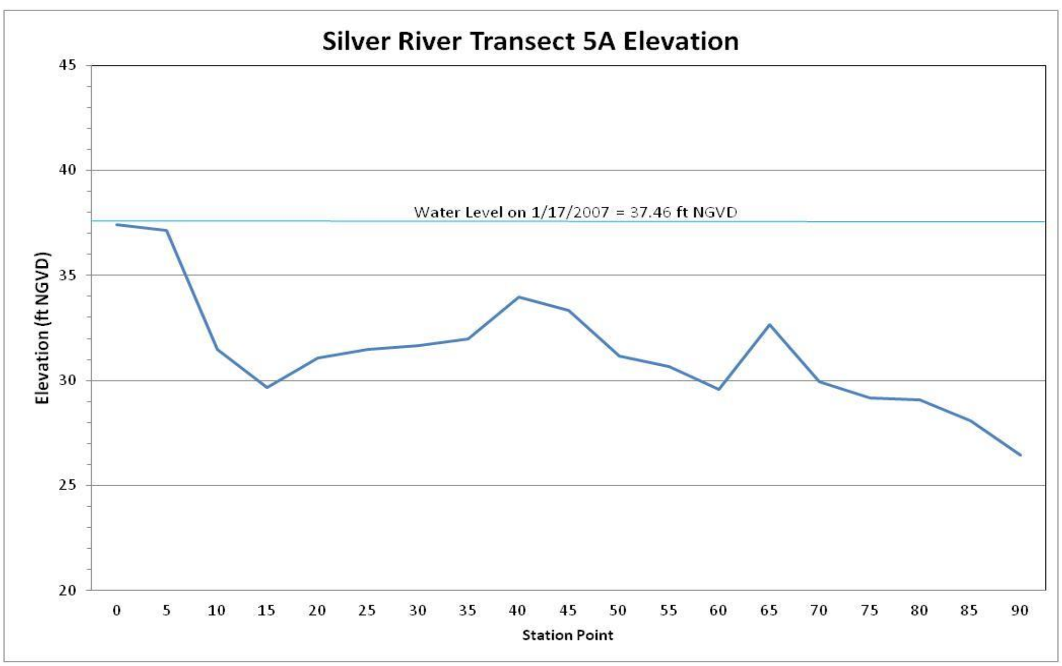


Figure C-9. Shallow water cross section 5A

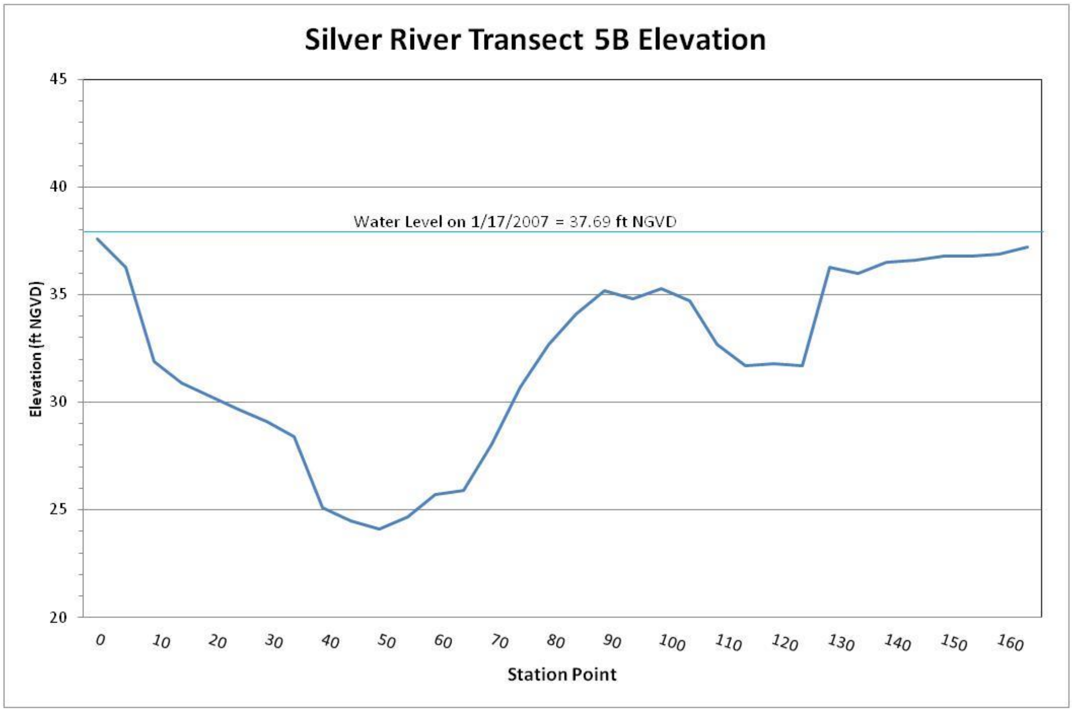


Figure C-10. Shallow water cross section 5B

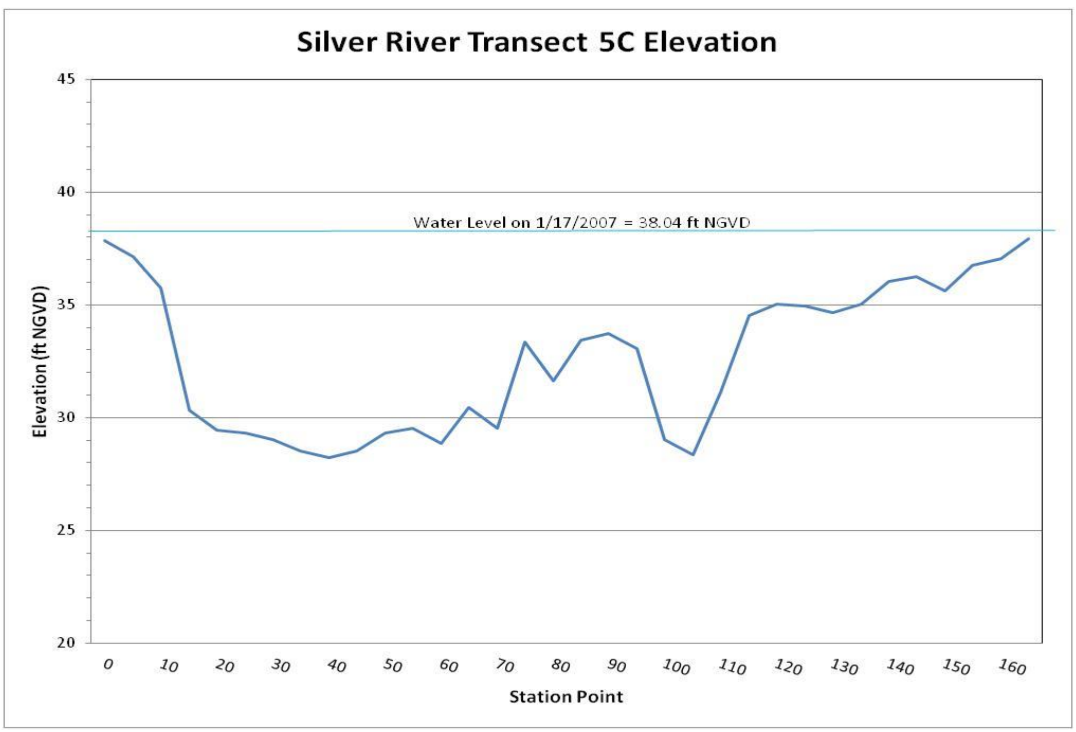


Figure C-11. Shallow water cross-section 5C

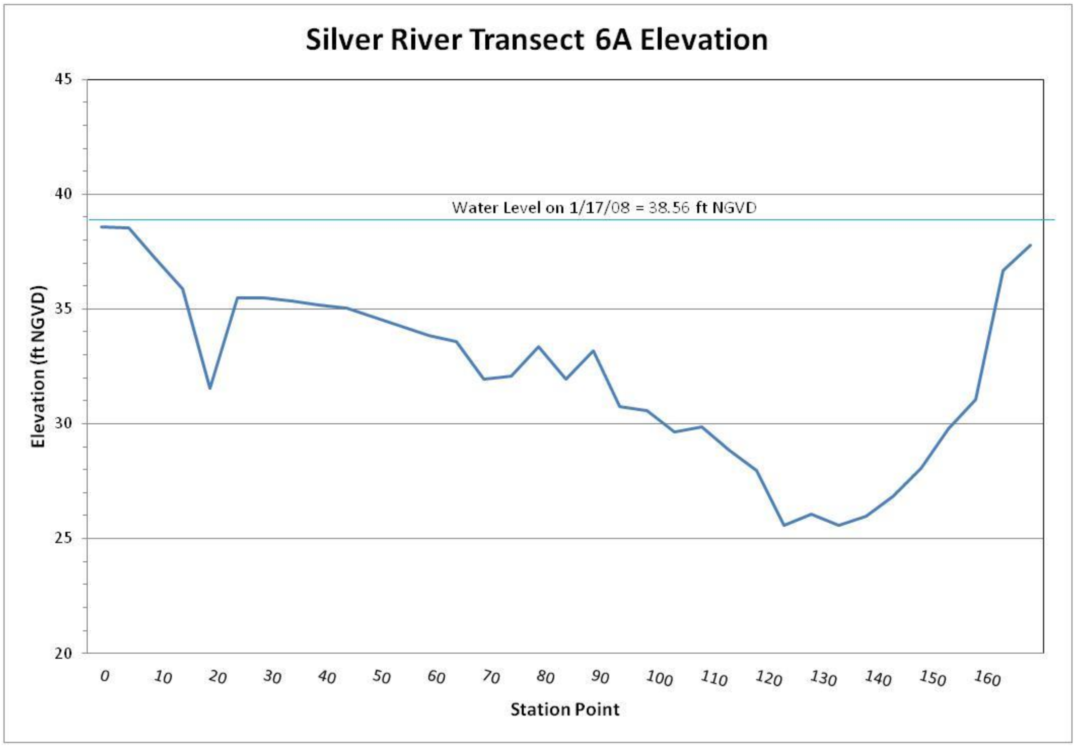


Figure C-12. Shallow water cross-section 6A

APPENDIX D—GLASS BOTTOM BOAT DIMENSIONS

The Glass Bottom Boats of the Silver Springs Theme Park

The Silver Springs Theme Park uses glass bottom boats within the upper 3,900 ft of the Silver River to showcase the headwater springs. These boats are electrically powered by rechargeable batteries that are stored under the seats and are recharged after use. These electric glass bottom boats are used within the park to showcase the various springs from the main spring boil to the Silver Springs Attraction raptor center, located near the USGS gauging station (Figure D1).

Although two different looking boats are used in the park, the base construction of each are the same, consisting of the same glass bottom hull for each version (Figure D2). Each boat has a glass bottomed aluminum hull that is 31 ft long (Figure D3) and 11.5 ft wide (Figure D4), weighing 20 gross tons (net tons). These glass bottom boats are Coast Guard rated to use a 10 horsepower electric motor. The foot of the motor sits 3.1 ft below the hull gunnel (Figures D3 and D5). The main spring tour uses fully enclosed boats with windows and a solid roof (Figure D6). The raptor cruise tour consists of unenclosed glass bottom boats with a canvas canopy and sides (Figure D7). Table D1 details the glass bottom boat physical measurements for each boat format — enclosed vs open.

Due to their cabin differences, the main spring tour enclosed boats are heavier and sit lower in the water than the canvas Fort King River Cruise and the Raptor Center Tour boats (0.4 ft difference in draft). In the heavier enclosed boat (main spring tour), the bottom of the motor sits 2.3 ft below the top of the water when the boat is empty. In the lighter open canopy boat, the bottom of the motor sits 1.9 ft below the top of the water when the boat is empty. When at full capacity, the boats only draft 0.2 ft more than when empty. The minimum depth of water necessary for a full capacity enclosed glass bottom boat to operate freely is at least 2.5 ft. The minimum depth of water necessary for a full capacity unenclosed glass bottom boat with a canvas canopy and sides is at least 2.1 ft.

Each boat is inspected and certified by the United States Coast Guard. Table D2 details the Coast Guard specifications for the Silver Springs glass bottom boats. The allowed capacity for each boat is 36 people. The navigation of these glass bottom boats is limited to the Silver River and is also limited to daylight hours.

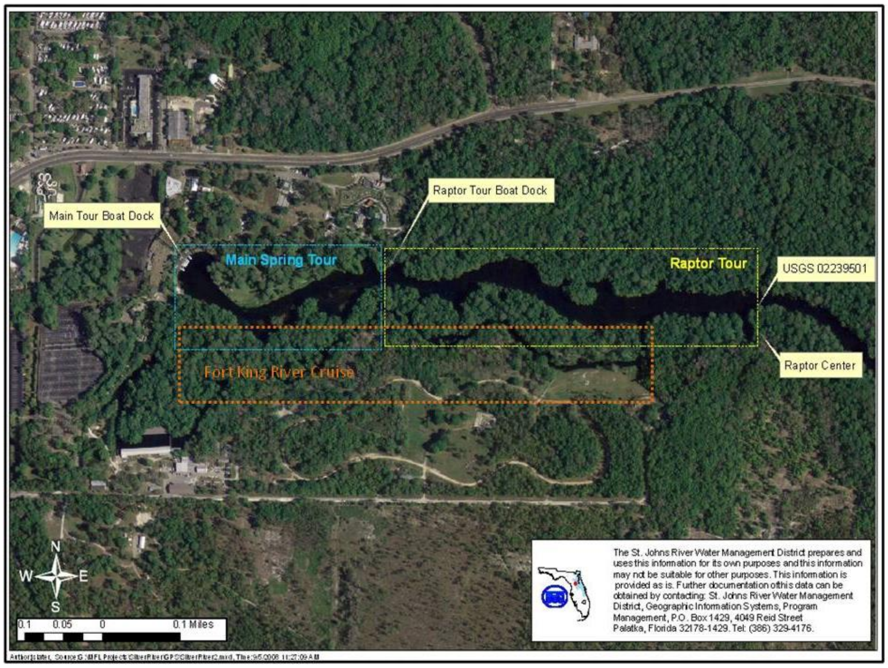


Figure D1. Map of Silver Springs Theme Park (Marion County, Florida) showing glass bottom boat tours: main spring tour (fully enclosed boat), raptor tour (canvas canopy boat), and the Fort King River Cruise (canvas canopy boat)

Figure D2. The inside of a Silver Springs glass bottom boat consists of seats along each side, with the glass bottom insert in the middle allowing passengers to see below the boat (Marion County, Florida)

Figure D3. Silver Springs Attraction glass (Marion County, Florida) bottom boat in dry dock out of the water, illustrating the length of the hull (red line) and the height of the boat cabin (blue line)

Figure D4. Silver Springs Attraction (Marion County, Florida) glass bottom boat in dry dock out of the water, illustrating the width of the deck (blue line) and the depth of the motor below the gunnel (red line)

Figure D5. Silver Springs Attraction (Marion County, Florida) glass bottom boat measurements for hull height (red line) and gunnel (blue line)

Figure D6. Fully enclosed Silver Springs Attraction main spring tour glass bottom boat (Marion County, Florida)

Figure D7. Silver Spring Attraction Raptor Tour and Fort King River Cruise glass bottom boat with canvas canopy and sides (Marion County, Florida)

Table D1. Silver Springs Theme Park (Marion County, Florida) glass bottom boat physical measurements for each boat format — enclosed vs open

MEASUREMENTS	MEASUREMENTS ARE IN FEET	
	ENCLOSED BOAT FORMAT	OPEN BOAT FORMAT
LENGTH (same)	31	31
WIDTH (same)	11.5	11.5
HEIGHT (TOTAL)	9.95	7.85
HEIGHT (TOP OF GUNNEL TO TOP OF CABIN/CANVAS)	7	5.7
HEIGHT (TOP OF CABIN TO TOP OF VENT)	0.8	-
HEIGHT (HULL BOTTOM TO BOTTOM OF GUNNEL) (same)	1.9	1.9
GUNNEL (ROLLED ALUMINUM) (same)	0.25	0.25
GUNNEL (BOTTOM) TO FOOT OF MOTOR (same)	3.1	3.1
GUNNEL (BOTTOM) TO TOP OF WATER (EMPTY)	0.8	1.2
GUNNEL (BOTTOM) TO TOP OF WATER (FULL CAPACITY)	0.6	
GUNNEL (BOTTOM) TO TOP OF WATER (EST 1/2 CAPACITY)	0.7	

Table D2. Coast Guard specifications for the custom built Silver Springs Theme Park glass bottom boats (Marion County, Florida)

COAST GUARD SPECIFICATIONS	ENCLOSED BOAT FORMAT	OPEN BOAT FORMAT
LENGTH (FT)	31.0	31.0
GROSS/NET TON	20.0	20.0
HORSEPOWER (ELECTRIC MOTOR PROPULSION)	10	10
HULL MATERIAL	ALUMINUM	ALUMINUM
CAPACITY (MAXIMUM # OF PEOPLE)	36	36

APPLIED TECHNOLOGY & MANAGEMENT
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Gainesville, FL 32605
386-256-1477
www.appliedtm.com

MEMORANDUM

Janicki Environmental, Inc.
1155 Eden Isle Drive NE
St. Petersburg, FL 33704
727-895-7722
/janickienvironmental.com/

To: Andrew Sutherland, Ph.D.

From: Robert Burleson, P.E.
Tony Janicki, Ph.D.

Re: Addendum to address specific peer reviewer comments

Date: March 7, 2017

The purpose of this memorandum is to describe additional analyses performed following and in response to comments received from one of the peer reviewers. Specifically, the comment was made about whether it was appropriate to perform the Water Resource Values (WRV) assessment based on the entire 1946-2014 period-of-record, when so much of that record is not dependent on climate and reflects a flow-stage relationship and hydrologic regime that has changed over time. Some concern was also expressed about what was considered relatively large changes in the frequency of flooding events for some of the WRVs.

In response to these comments, additional analyses were performed for the WRVs of concern, using a split period-of-record, a record that extended from 1946-2000 (Pre-2000) and from 2001-2014 (Post-2000). St. Johns River Water Management District (SJRWMD) developed time series and frequency statistics for flow and stage for each of the periods-of-record using flow-stage relationships developed from data from each period. Time series and frequency statistics were developed for the no-pumping and minimum flows and levels (MFLs) hydrologic regimes. These time series and frequency statistics were then applied to the critical metrics for the WRVs of concern.

The results of the analyses for the two periods are presented in tables attached to this memo, along with frequency analysis graphs used in the assessment. The following observations were noted following completion of this assessment:

- There is an increase in flooding events in the Post-2000 period as compared to the Pre-2000 period for both the no-pumping and MFL hydrologic regimes.
- There was recognition of a change in this relationship that occurred near the year 2000.

- The change in this relationship was largely attributed to a significant increase in the distribution of submerged aquatic vegetation (SAV) in the spring run. Recent field observations have documented floodplain inundation even during the current dry season.
- As part of the peer review of this report, a peer reviewer questioned the use of the entire baseline period to establish the MFL.
- At many transects, the number of flooding events in the Post-2000 period under the MFL hydrologic regime is comparable to the number of flooding events in the Pre-2000 period under the no-pumping hydrologic regime.
- With respect to WRVs where water level is most critical, the preliminary MFL recommended in Sutherland et al. (2017) is even more protective in the Post-2000 period.
- There were slightly fewer flooding events in the Pre-2000 period than for the 1946-2014 period-of-record for both the no-pumping and the MFL hydrologic regimes.

While there is uncertainty as to whether the flow-stage relationships in the Post-2000 period will continue or the system will move toward a Pre-2000 condition, the preliminary MFL should be protective of WRVs. Continued monitoring of the system through on-going research as part of the Collaborative Research Initiative on Sustainability and Protection of Springs (CRISPS) initiative and reassessment of the MFL through the regulatory process and MFL program are important for determining causes of changes that have occurred in the system and for assessing trends.

Table 5-13a. Pre-2000 frequency analysis of criteria (30-days continuously exceeded) for the protection of fish, wading birds, and wetland vegetation (before October 1, 2000)				
Transect	**Critical Stage (ft-NGVD)**	**Number of Events/100 years No-Pumping Condition**	**Number of Events/ 100 Years MFL Regime**	**Decrease in Number of Events under the MFLs Hydrologic Regime**
T3	37.3	91	61	30
T5	37.7	115	85	30
T7	39.4	89	72	17
T9	39.8	91	80	11

Table 5-13b. Post-2000 frequency analysis of criteria (30-days continuously exceeded) for the protection of fish, wading birds, and wetland vegetation (after October 1, 2000)				
Transect	**Critical Stage (ft-NGVD)**	**Number of Events/100 years No-Pumping Condition**	**Number of Events/ 100 Years MFL Regime**	**Decrease in Number of Events under the MFLs Hydrologic Regime**
T3	37.3	136	100	36
T5	37.7	129	171	-42
T7	39.4	157	129	28
T9	39.8	171	129	42

Table 5-14a. Pre-2000 seasonal frequency analysis results for the criterion of protection of fish during spawning season (March through September) (30-days continuously exceeded) (before October 1, 2000)

Transect	Critical Stage (ft-NGVD)	Number of Events/100 years No-Pumping Condition	Number of Events/ 100 Years MFL Regime	Decrease in Number of Events under the MFLs Hydrologic Regime
T3	37.3	74	44	30
T5	37.7	100	76	24
T7	39.4	76	57	19
T9	39.8	76	63	13

Table 5-14b. Post-2000 seasonal frequency analysis results for the criterion of protection of fish during spawning season (March through September) (30-days continuously exceeded) (after October 1, 2000)

Transect	Critical Stage (ft-NGVD)	Number of Events/100 years No-Pumping Condition	Number of Events/ 100 Years MFL Regime	Decrease in Number of Events under the MFLs Hydrologic Regime
T3	37.3	86	86	0
T5	37.7	114	107	7
T7	39.4	93	93	0
T9	39.8	107	93	14

Table 5-16a. Pre-2000 frequency analysis results of floodplain inundation criteria (180-day low stage continuously not exceeded) for the protection of organic soils (before October 1, 2000)

Transect	Critical Stage (ft-NGVD)	Number of Events/100 Years No-Pumping Condition	Number of Events/ 100 Years MFL Regime	Increase in Number of Events under the MFLs Hydrologic Regime
T3	37.77	83	93	10
T5	37.67	44	57	13
T7	39.67	74	85	11
T9	39.77	57	74	17

Table 5-16b. Post-2000 frequency analysis results of floodplain inundation criteria (180-day low stage continuously not exceeded) for the protection of organic soils (after October 1, 2000)

Transect	Critical Stage (ft-NGVD)	Number of Events/100 Years No-Pumping Condition	Number of Events/ 100 Years MFL Regime	Increase in Number of Events under the MFLs Hydrologic Regime
T3	37.77	79	93	14
T5	37.67	14	29	15
T7	39.67	64	79	15
T9	39.77	29	64	35

Table 5-24a. Pre-2000 frequency analysis results for the protection of detrital transfer—7-day duration high stage continuously exceeded

Transect	Critical Stages (ft-NGVD)	Statistic[1]	Hydrologic Scenario	
			No-Pumping Condition	MFL
T3	38 (mean)	Events/100 yr	44	30
		Difference	-	-14
	38.3 (overflow)	Events/100 yr	36	24
		Difference	-	-12
	40.2 (max)	Events/100 yr	6	4
		Difference	-	-2
T5	38.4 (mean)	Events/100 yr	62	47
		Difference	-	-15
	39 (overflow)	Events/100 yr	40	28
		Difference	-	-12
	40.2 (max)	Events/100 yr	10	6
		Difference	-	-4
T7	39.8 (mean)	Events/100 yr	59	43
		Difference	-	-16
	40 (overflow)	Events/100 yr	51	36
		Difference	-	-15
	41.7 (max)	Events/100 yr	4	2
		Difference	-	-2
T9	39.9 (mean)	Events/100 yr	76	60
		Difference	-	-16
	40.3 (overflow/max)	Events/100 yr	60	44
		Difference	-	-16

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and MFLs hydrologic regimes.

Table 5-24b. Pre-2000 frequency analysis results for the protection of detrital transfer—30-day duration high stage continuously exceeded

Transect	Critical Stages (ft-NGVD)	Statistic[1]	Hydrologic Scenario	
			No-Pumping Condition	MFL
T3	38 (mean)	Events/100 yr	33	24
		Difference	-	-9
	38.3 (overflow)	Events/100 yr	25	17
		Difference	-	-8
	40.2 (max)	Events/100 yr	6	3
		Difference	-	-3
T5	38.4 (mean)	Events/100 yr	52	38
		Difference	-	-14
	39 (overflow)	Events/100 yr	32	21
		Difference	-	-11
	40.2 (max)	Events/100 yr	8	5
		Difference	-	-3
T7	39.8 (mean)	Events/100 yr	45	35
		Difference	-	-10
	40 (overflow)	Events/100 yr	38	29
		Difference	-	-9
	41.7 (max)	Events/100 yr	3	2
		Difference	-	-1
T9	39.9 (mean)	Events/100 yr	64	52
		Difference	-	-12
	40.3 (overflow/max)	Events/100 yr	48	37
		Difference	-	-11

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and MFLs hydrologic regimes.

Table 5-24d. Post-2000 frequency analysis results for the protection of detrital transfer—30-day duration high stage continuously exceeded

Transect	Critical Stages (ft-NGVD)	Statistic[1]	Hydrologic Scenario: No-Pumping Condition	Hydrologic Scenario: MFL
T3	38 (mean)	Events/100 yr	49	26
		Difference	-	-23
	38.3 (overflow)	Events/100 yr	33	19
		Difference	-	-14
	40.2 (max)	Events/100 yr	8	5
		Difference	-	-3
T5	38.4 (mean)	Events/100 yr	77	58
		Difference	-	-19
	39 (overflow)	Events/100 yr	46	23
		Difference	-	-23
	40.2 (max)	Events/100 yr	10	7
		Difference	-	-3
T7	39.8 (mean)	Events/100 yr	72	48
		Difference	-	-24
	40 (overflow)	Events/100 yr	60	31
		Difference	-	-29
	41.7 (max)	Events/100 yr	6	5
		Difference	-	-1
T9	39.9 (mean)	Events/100 yr	83	73
		Difference	-	-10
	40.3 (overflow/max)	Events/100 yr	73	53
		Difference	-	-20

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and MFLs hydrologic regimes.

Table 5-29a. Pre-2000 frequency analysis results for the protection of filtration and absorption of nutrients and other pollutants – 14–day duration high stage continuously exceeded

Transect	Critical Stages ft-NGVD	Statistic[1]	Hydrologic Scenario	
			No-Pumping Condition	MFL
T3	38 (mean)	Events/100 yr	40	28
		Difference	-	-12
	38.3 (overflow)	Events/100 yr	33	22
		Difference	-	-11
	40.2 (max)	Events/100 yr	6	3
		Difference	-	-3
T5	38.4 (mean)	Events/100 yr	58	45
		Difference	-	-13
	39 (overflow)	Events/100 yr	38	26
		Difference	-	-12
	40.2 (max)	Events/100 yr	9	6
		Difference	-	-3
T7	39.8 (mean)	Events/100 yr	55	40
		Difference	-	-15
	40 (overflow)	Events/100 yr	47	33
		Difference	-	-14
	41.7 (max)	Events/100 yr	3	2
		Difference	-	-1
T9	39.9 (mean)	Events/100 yr	72	58
		Difference	-	-14
	40.3 (overflow/max)	Events/100 yr	56	42
		Difference	-	-14

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and MFLs hydrologic regimes.

Table 5-29b Pre-2000 frequency analysis results for the protection of filtration and absorption of nutrients and other pollutants –30–day duration high stage continuously exceeded

Transect	Critical Stages ft-NGVD	Statistic[1]	Hydrologic Scenario: No-Pumping Condition	Hydrologic Scenario: MFL
T3	38 (mean)	Events/100 yr	33	24
		Difference	-	-9
	38.3 (overflow)	Events/100 yr	25	17
		Difference	-	-8
	40.2 (max)	Events/100 yr	6	3
		Difference	-	-3
T5	38.4 (mean)	Events/100 yr	52	38
		Difference	-	-14
	39 (overflow)	Events/100 yr	32	21
		Difference	-	-11
	40.2 (max)	Events/100 yr	8	5
		Difference	-	-3
T7	39.8 (mean)	Events/100 yr	45	35
		Difference	-	-10
	40 (overflow)	Events/100 yr	38	29
		Difference	-	-9
	41.7 (max)	Events/100 yr	3	2
		Difference	-	-1
T9	39.9 (mean)	Events/100 yr	64	52
		Difference	-	-12
	40.3 (overflow/max)	Events/100 yr	48	37
		Difference	-	-11

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and MFLs hydrologic regimes.

Table 5-29c. Post-2000 frequency analysis results for the protection of filtration and absorption of nutrients and other pollutants – 14–day duration high stage continuously exceeded

Transcect	Critical Stages ft-NGVD	Statistic[1]	Hydrologic Scenario	
			No-Pumping Condition	MFL
T3	38 (mean)	Events/100 yr	54	31
		Difference	-	-23
	38.3 (overflow)	Events/100 yr	40	21
		Difference	-	-19
	40.2 (max)	Events/100 yr	9	6
		Difference	-	-3
T5	38.4 (mean)	Events/100 yr	80	64
		Difference	-	-16
	39 (overflow)	Events/100 yr	52	27
		Difference	-	-25
	40.2 (max)	Events/100 yr	11	8
		Difference	-	-3
T7	39.8 (mean)	Events/100 yr	77	55
		Difference	-	-22
	40 (overflow)	Events/100 yr	60	42
		Difference	-	-18
	41.7 (max)	Events/100 yr	6	5
		Difference	-	-1
T9	39.9 (mean)	Events/100 yr	84	77
		Difference	-	-7
	40.3 (overflow/max)	Events/100 yr	76	56
		Difference	-	-20

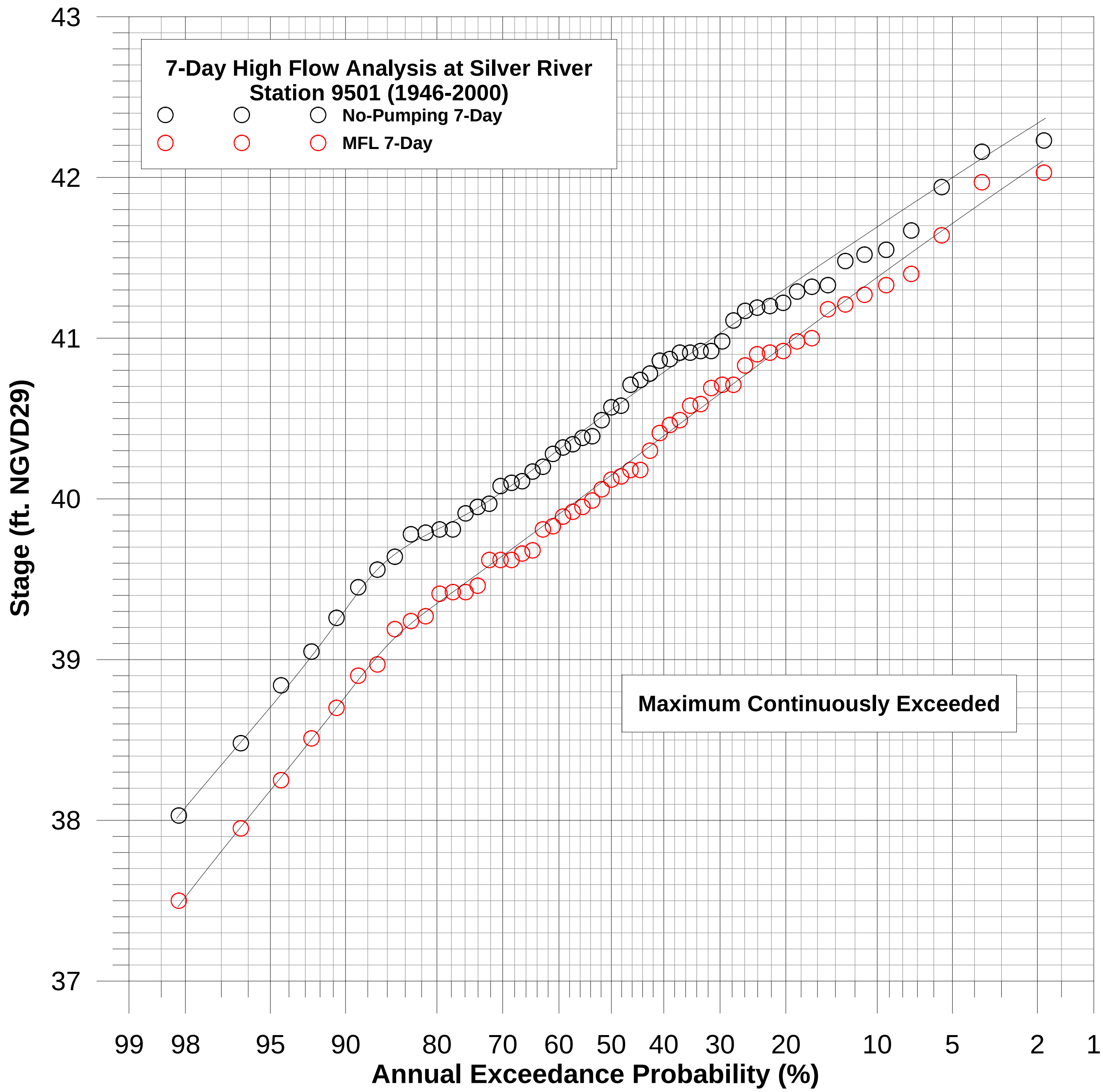
1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and MFLs hydrologic regimes.

Table 5-29d Post-2000 frequency analysis results for the protection of filtration and absorption of nutrients and other pollutants –30–day duration high stage continuously exceeded

Transect	Critical Stages ft-NGVD	Statistic[1]	Hydrologic Scenario: No-Pumping Condition	Hydrologic Scenario: MFL
T3	38 (mean)	Events/100 yr	49	26
		Difference	-	-23
	38.3 (overflow)	Events/100 yr	33	19
		Difference	-	-14
	40.2 (max)	Events/100 yr	8	5
		Difference	-	-3
T5	38.4 (mean)	Events/100 yr	77	58
		Difference	-	-19
	39 (overflow)	Events/100 yr	46	23
		Difference	-	-23
	40.2 (max)	Events/100 yr	10	7
		Difference	-	-3
T7	39.8 (mean)	Events/100 yr	72	48
		Difference	-	-24
	40 (overflow)	Events/100 yr	60	31
		Difference	-	-29
	41.7 (max)	Events/100 yr	6	5
		Difference	-	-1
T9	39.9 (mean)	Events/100 yr	83	73
		Difference	-	-10
	40.3 (overflow/max)	Events/100 yr	73	53
		Difference	-	-20

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and MFLs hydrologic regimes.

Pre-2000
Frequency Graphs


7-Day High Flow Analysis at Silver River
Station 9501 (1946-2000)
No-Pumping 7-Day
MFL 7-Day
Maximum Continuously Exceeded
Stage (ft. NGVD29)
Annual Exceedance Probability (%)
43
42
41
40
39
38
37
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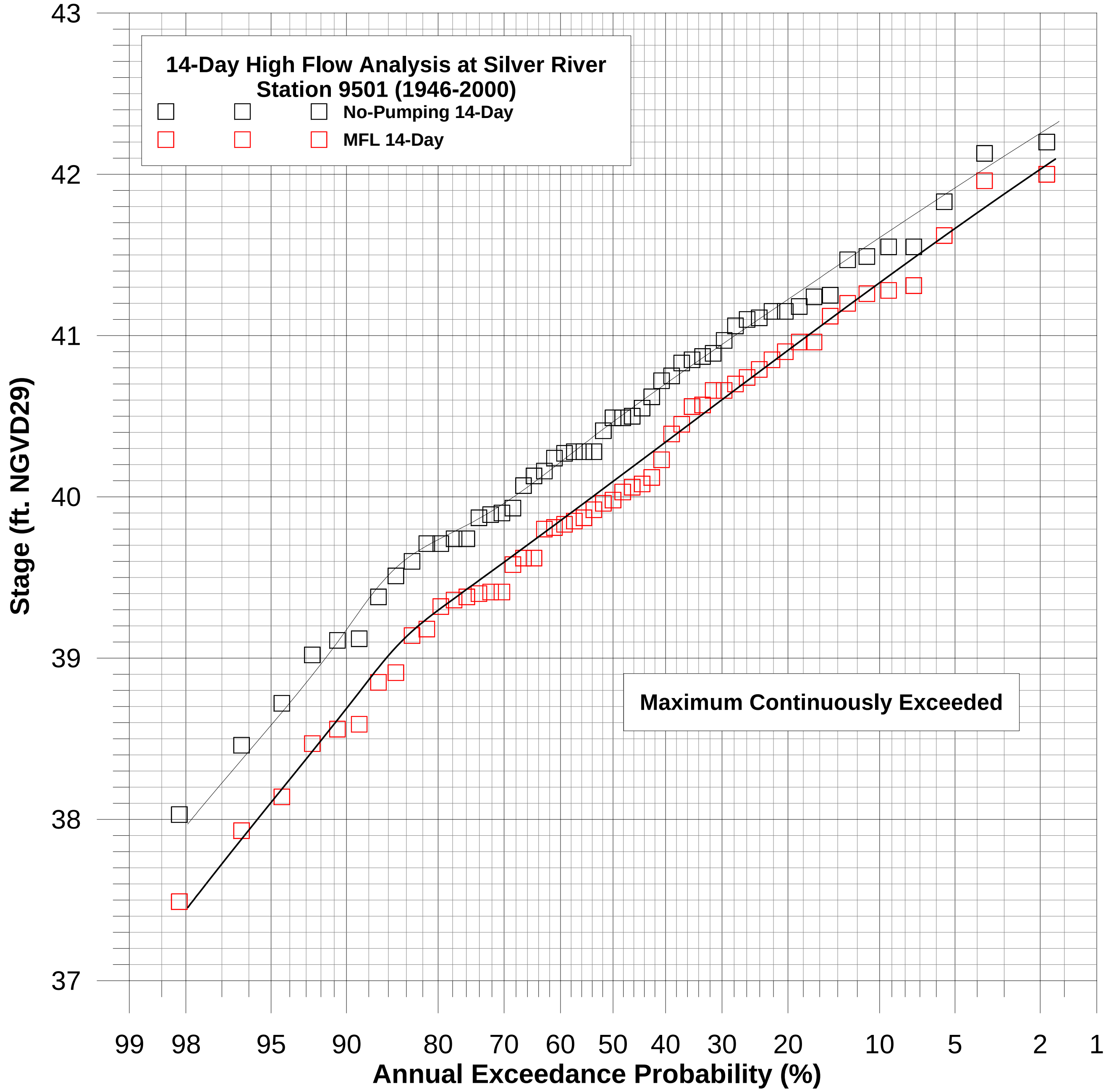
14-Day High Flow Analysis at Silver River
Station 9501 (1946-2000)
No-Pumping 14-Day
MFL 14-Day
Maximum Continuously Exceeded
Stage (ft. NGVD29)
43
42
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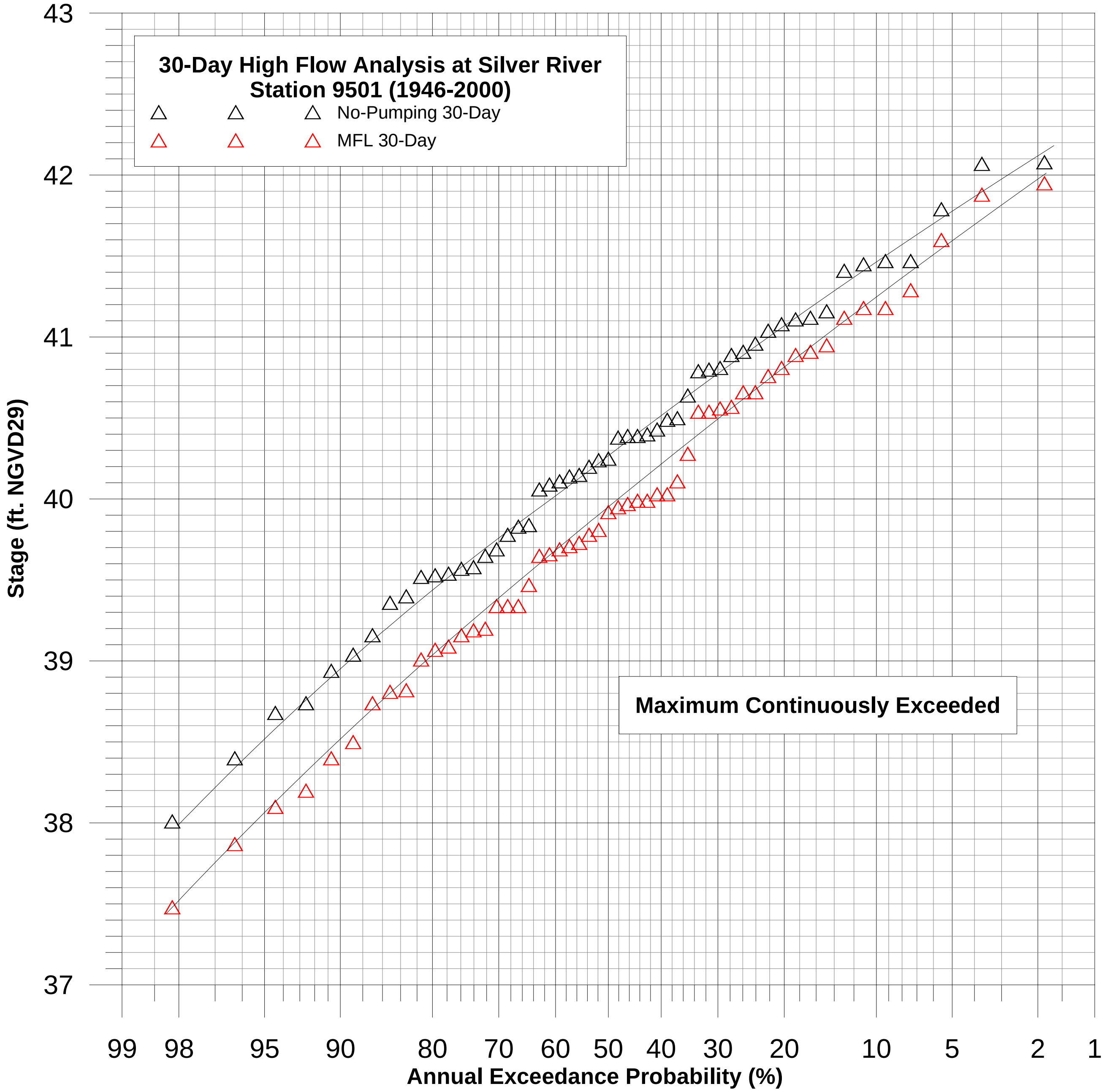
Annual Exceedance Probability (%)



30-Day High Flow Analysis at Silver River
Station 9501 (1946-2000)
No-Pumping 30-Day
MFL 30-Day
Maximum Continuously Exceeded
Stage (ft. NGVD29)
43
42
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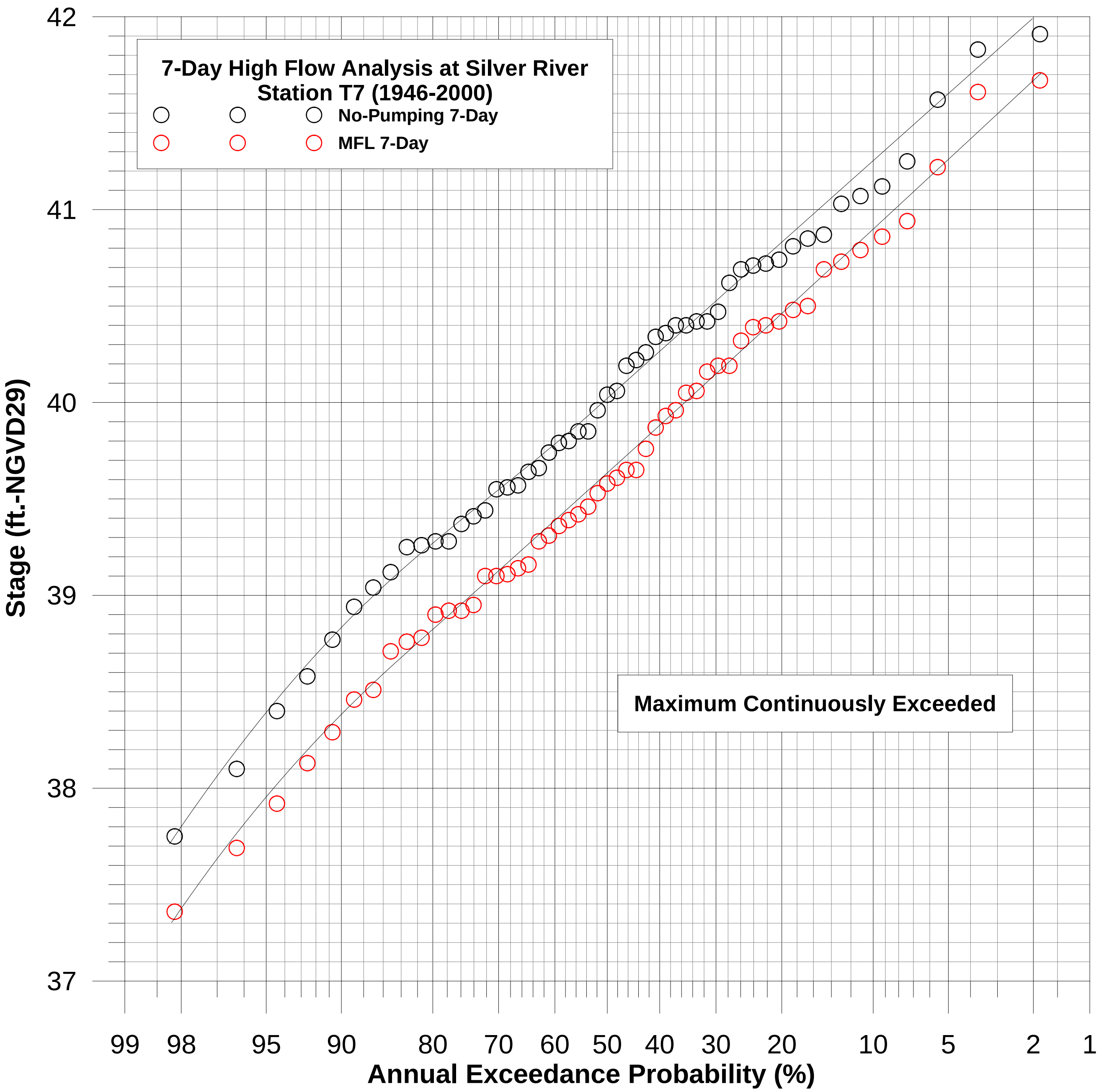
Annual Exceedance Probability (%)



7-Day High Flow Analysis at Silver River
Station T7 (1946-2000)
No-Pumping 7-Day
MFL 7-Day
Maximum Continuously Exceeded
Stage (ft.-NGVD29)
42
41
40
39
38
37
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98
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20
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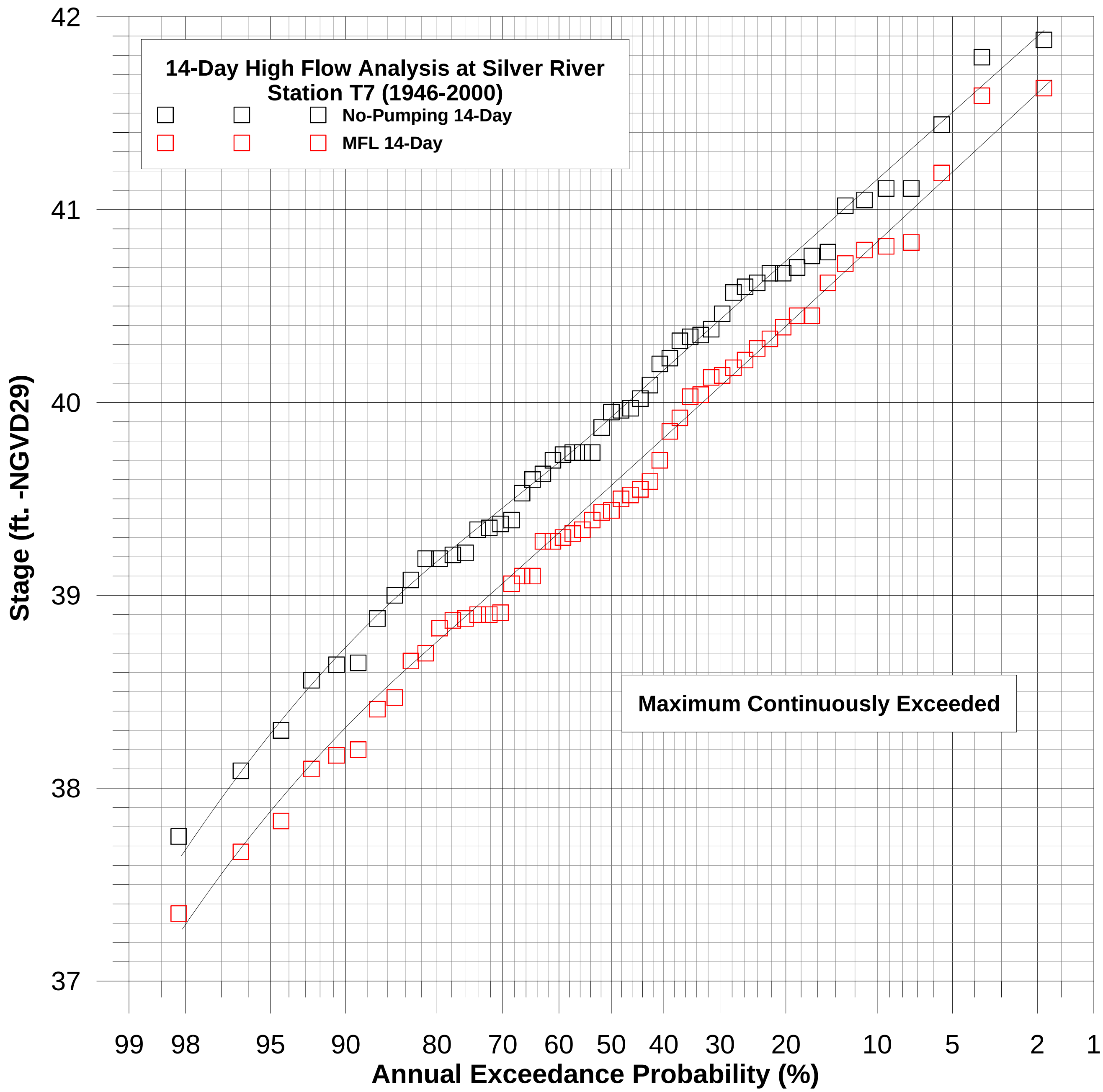
1
Annual Exceedance Probability (%)


14-Day High Flow Analysis at Silver River
Station T7 (1946-2000)
No-Pumping 14-Day
MFL 14-Day
Maximum Continuously Exceeded
Stage (ft. -NGVD29)
42
41
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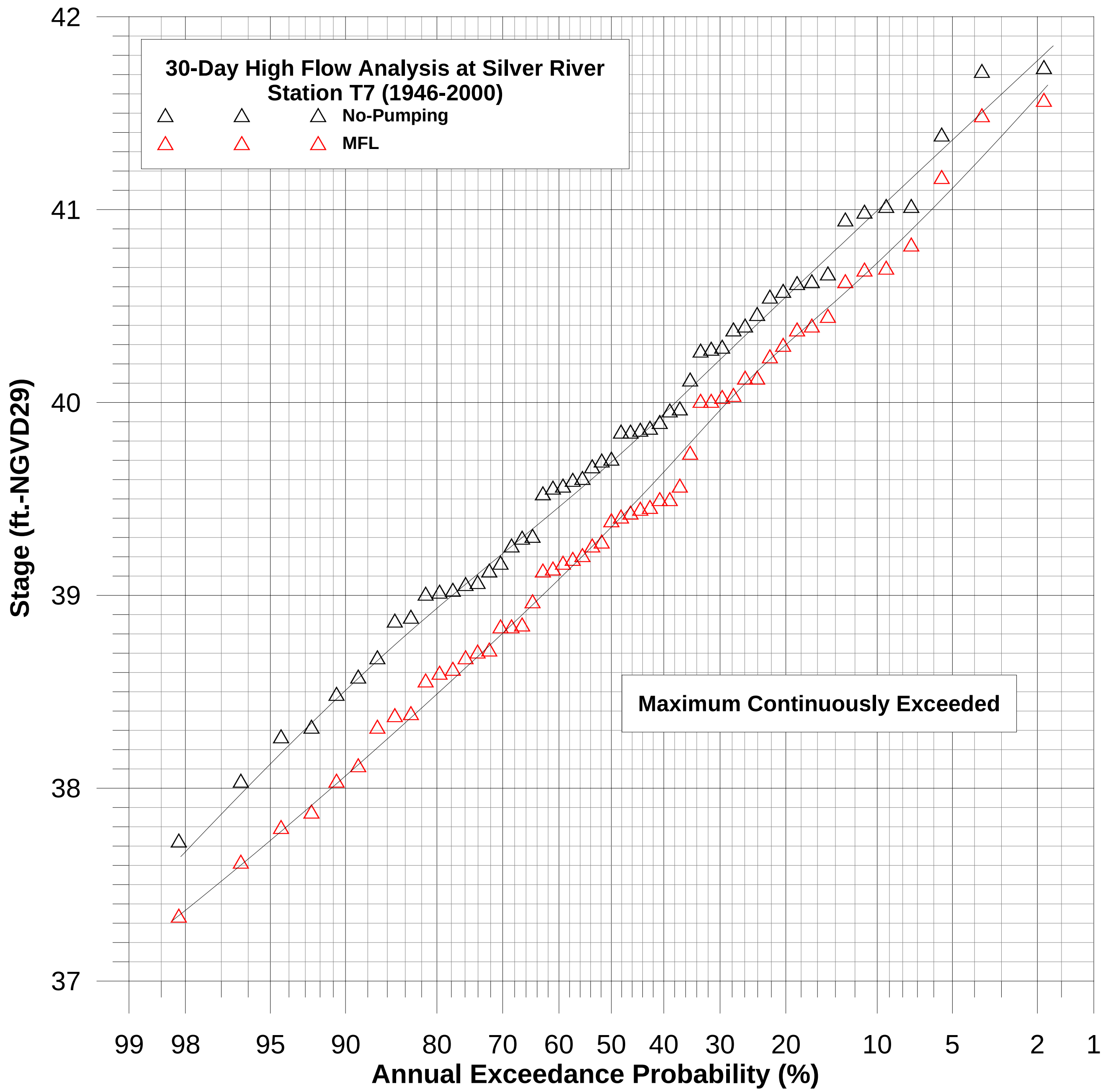
Annual Exceedance Probability (%)



30-Day High Flow Analysis at Silver River
Station T7 (1946-2000)
No-Pumping
MFL
Maximum Continuously Exceeded
Stage (ft.-NGVD29)
37
38
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40
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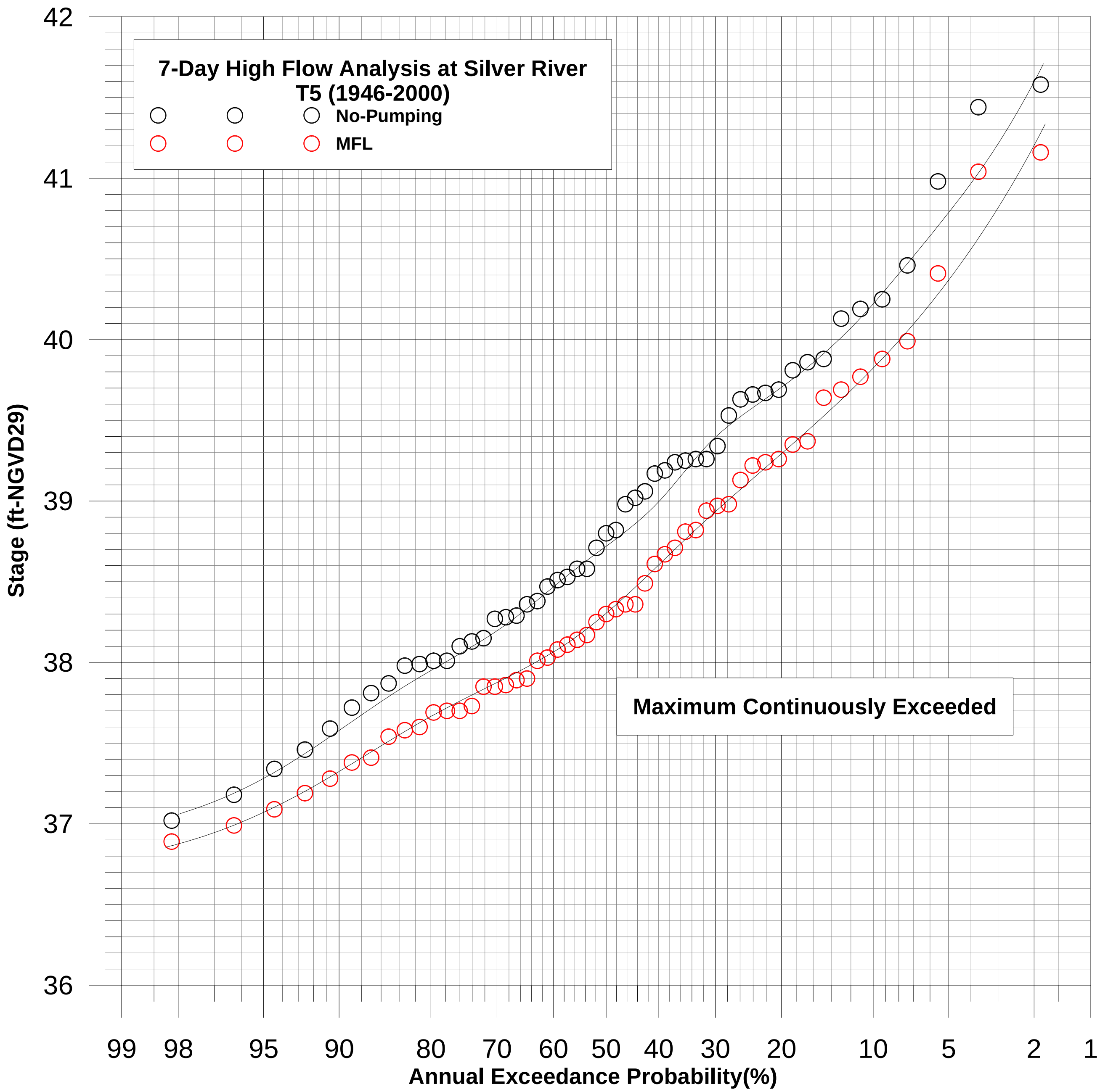
1
Annual Exceedance Probability (%)


7-Day High Flow Analysis at Silver River
T5 (1946-2000)
No-Pumping
MFL
Maximum Continuously Exceeded
Stage (ft-NGVD29)
42
41
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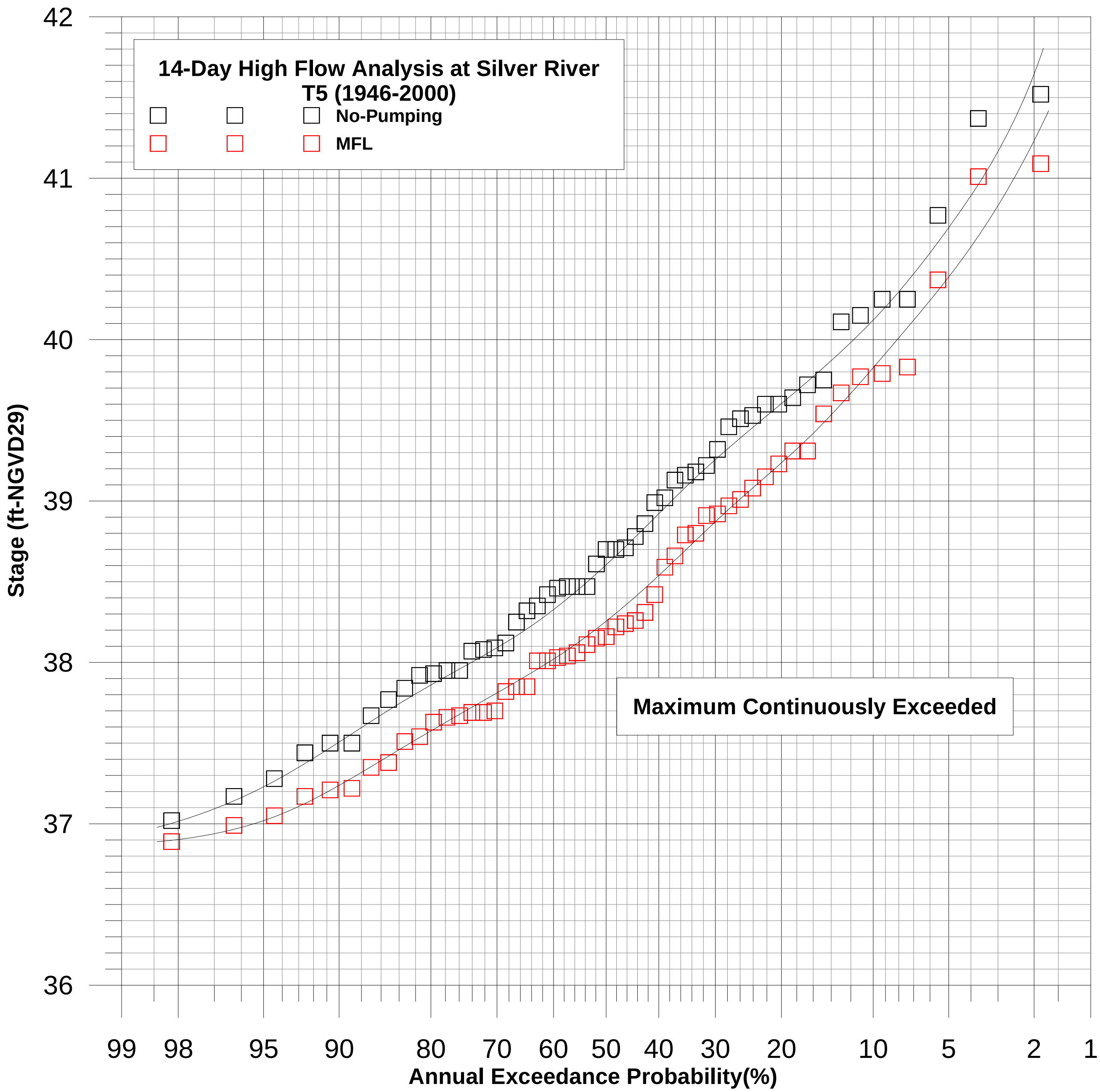
1
Annual Exceedance Probability(%)


14-Day High Flow Analysis at Silver River
T5 (1946-2000)
No-Pumping
MFL
Maximum Continuously Exceeded
Stage (ft-NGVD29)
42
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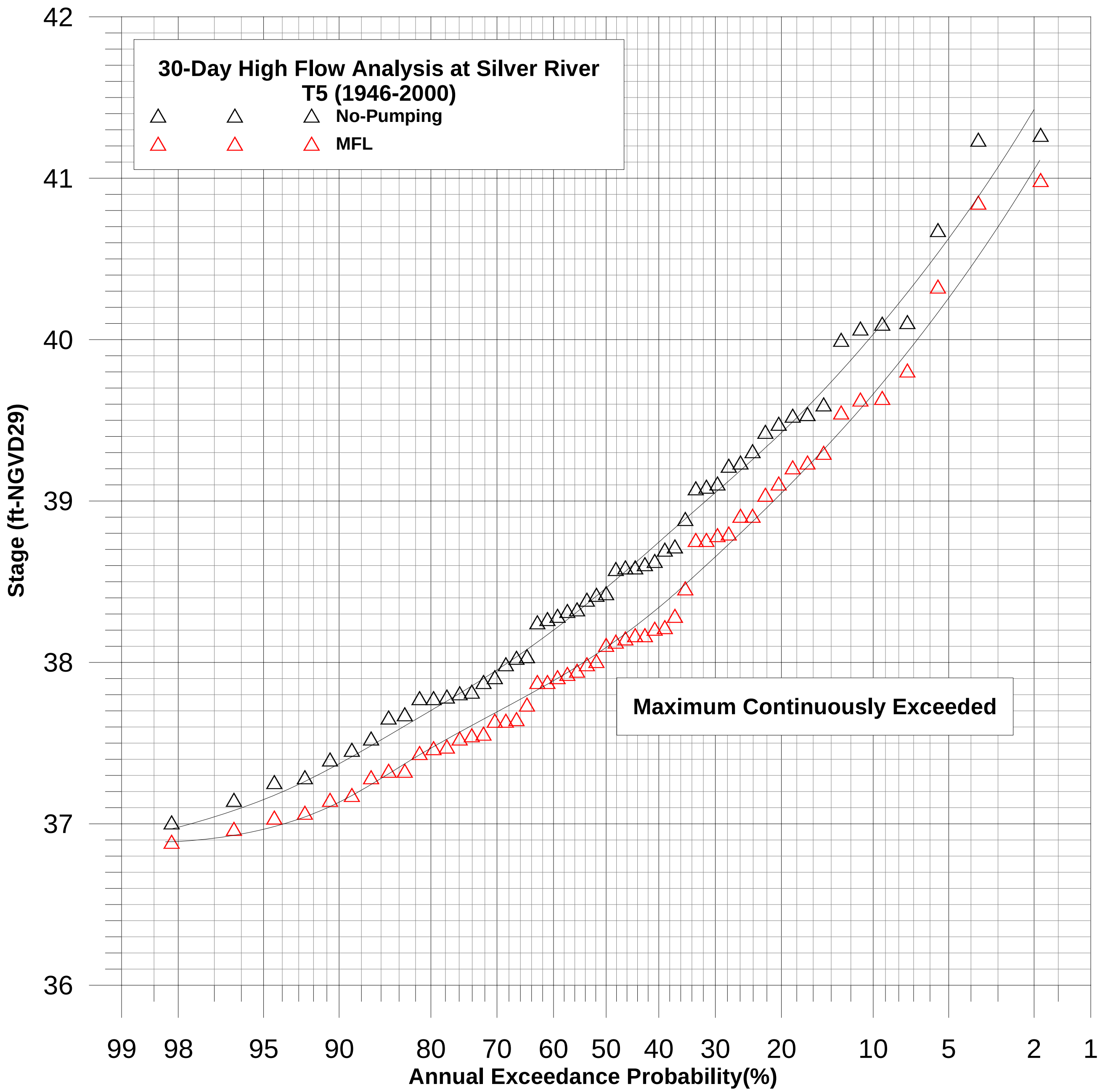
Annual Exceedance Probability(%)



30-Day High Flow Analysis at Silver River
T5 (1946-2000)
No-Pumping
MFL
Maximum Continuously Exceeded
Stage (ft-NGVD29)
42
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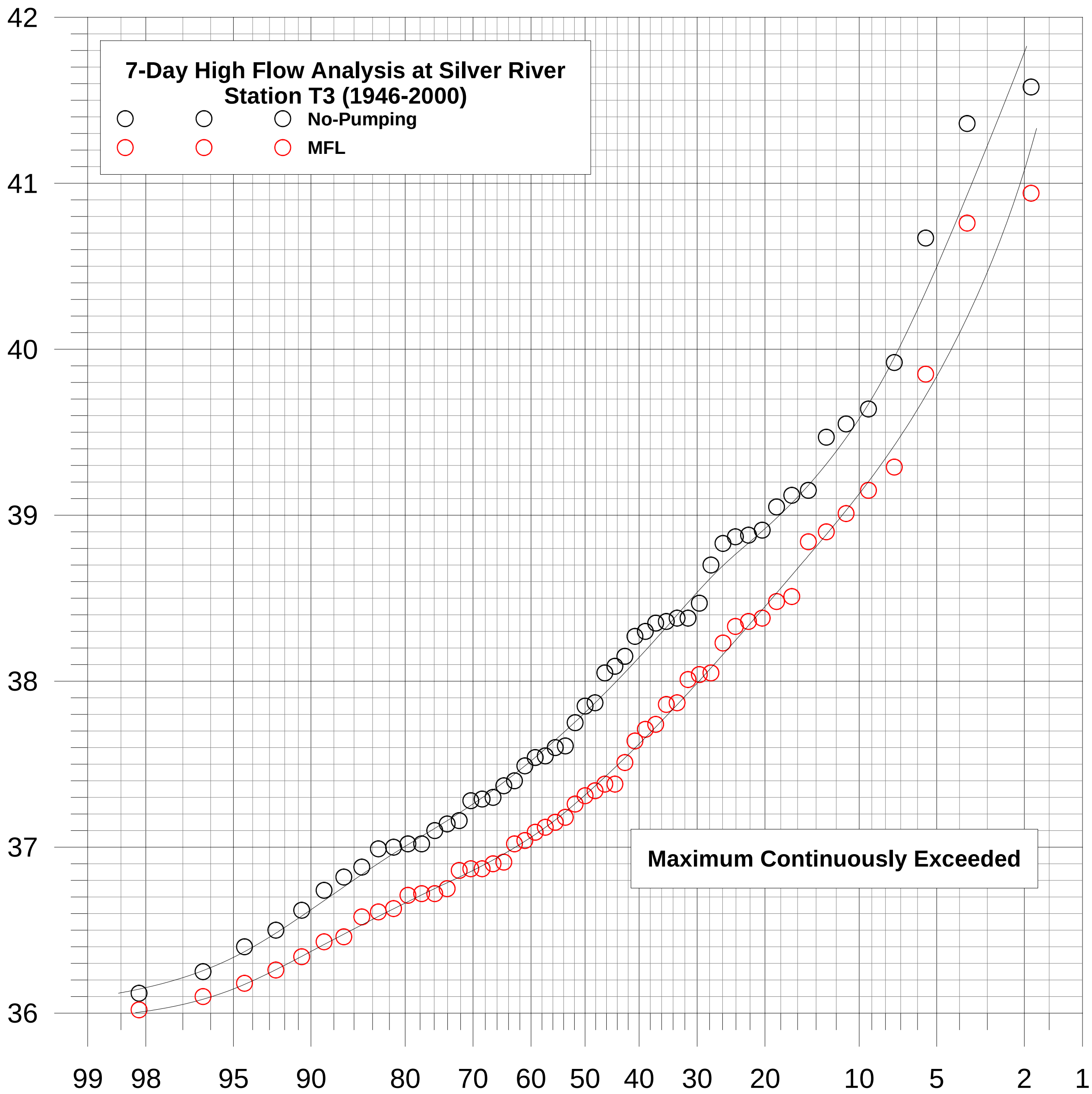
Annual Exceedance Probability(%)


7-Day High Flow Analysis at Silver River
Station T3 (1946-2000)
No-Pumping
MFL
Maximum Continuously Exceeded
42
41
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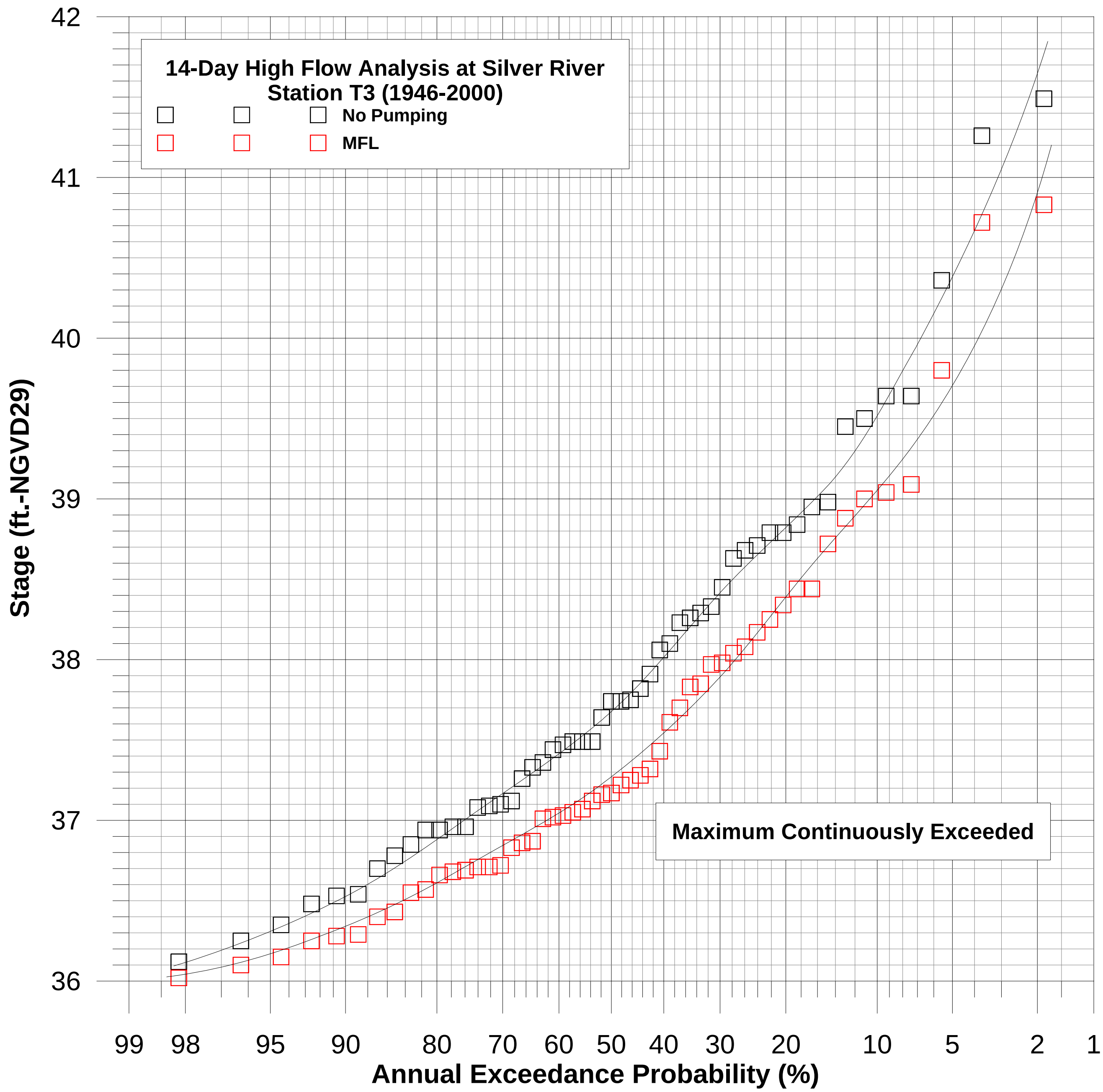
14-Day High Flow Analysis at Silver River
Station T3 (1946-2000)
No Pumping
MFL
Maximum Continuously Exceeded
Stage (ft.-NGVD29)
42
41
40
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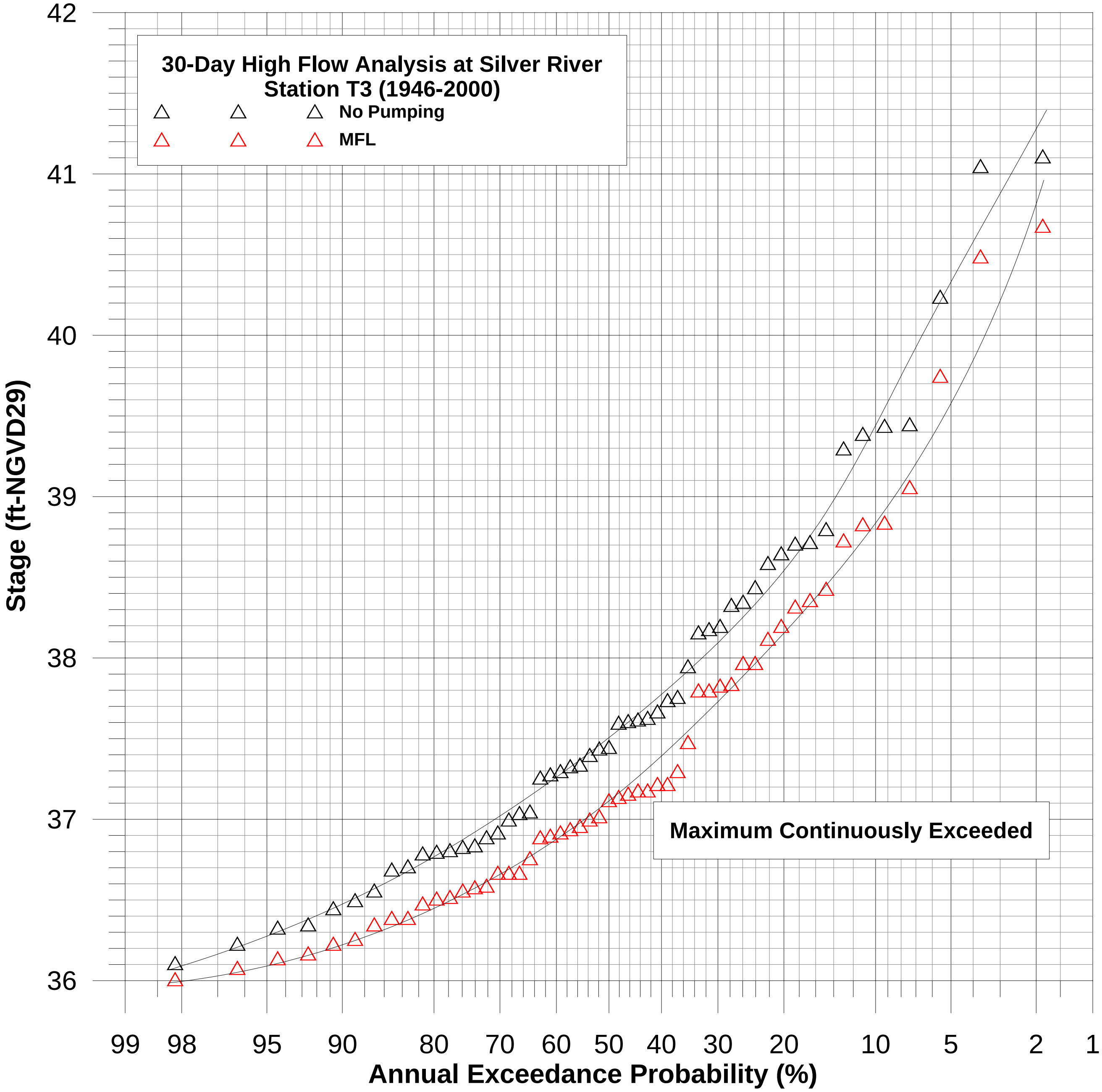
Annual Exceedance Probability (%)



30-Day High Flow Analysis at Silver River
Station T3 (1946-2000)
No Pumping
MFL
Maximum Continuously Exceeded
Stage (ft-NGVD29)
42
41
40
39
38
37
36
99
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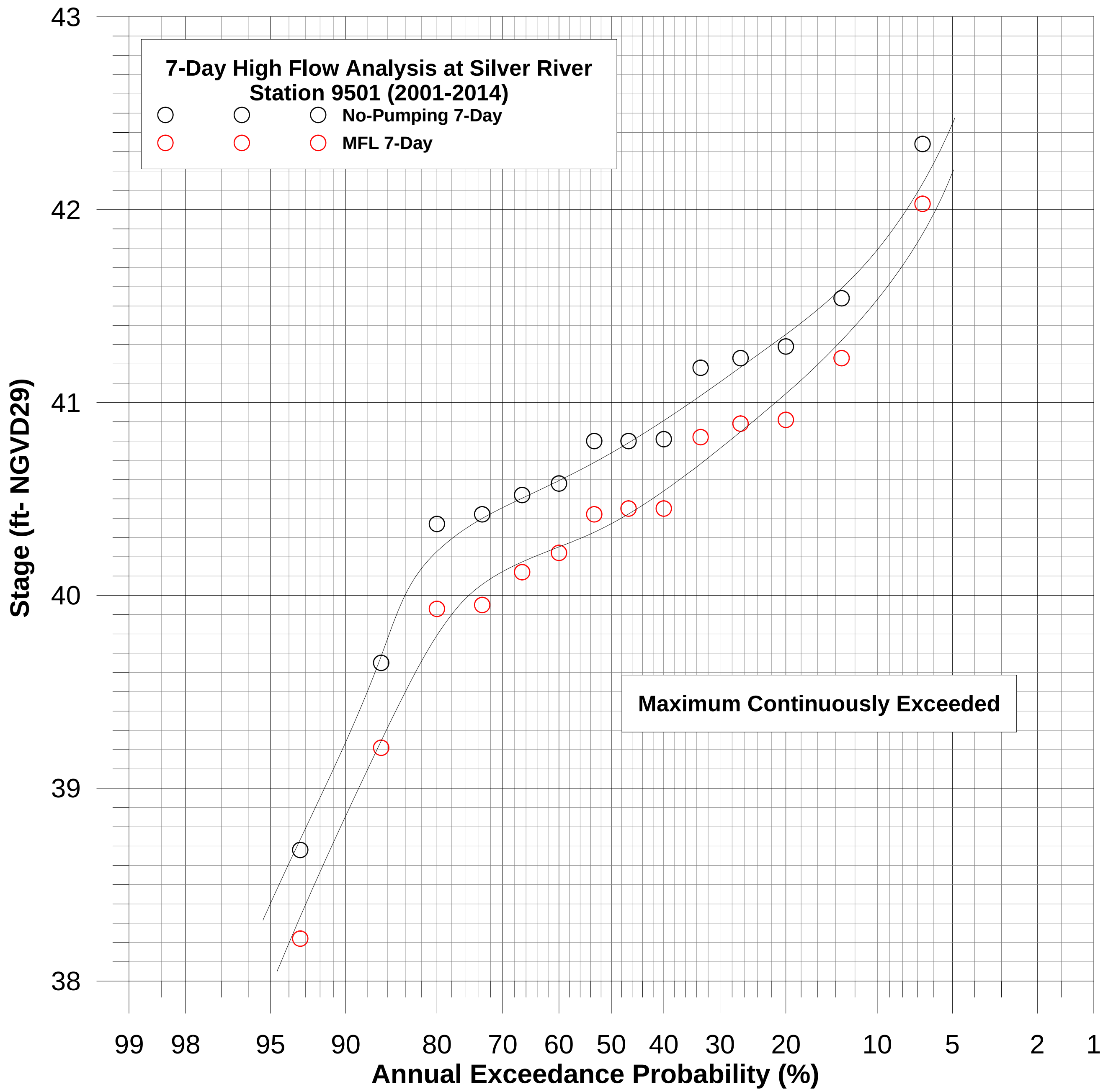
1
Annual Exceedance Probability (%)

Post-2000
Frequency Graphs



7-Day High Flow Analysis at Silver River
Station 9501 (2001-2014)
No-Pumping 7-Day
MFL 7-Day
Maximum Continuously Exceeded
43
42
41
40
39
38
Stage (ft- NGVD29)
99
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95
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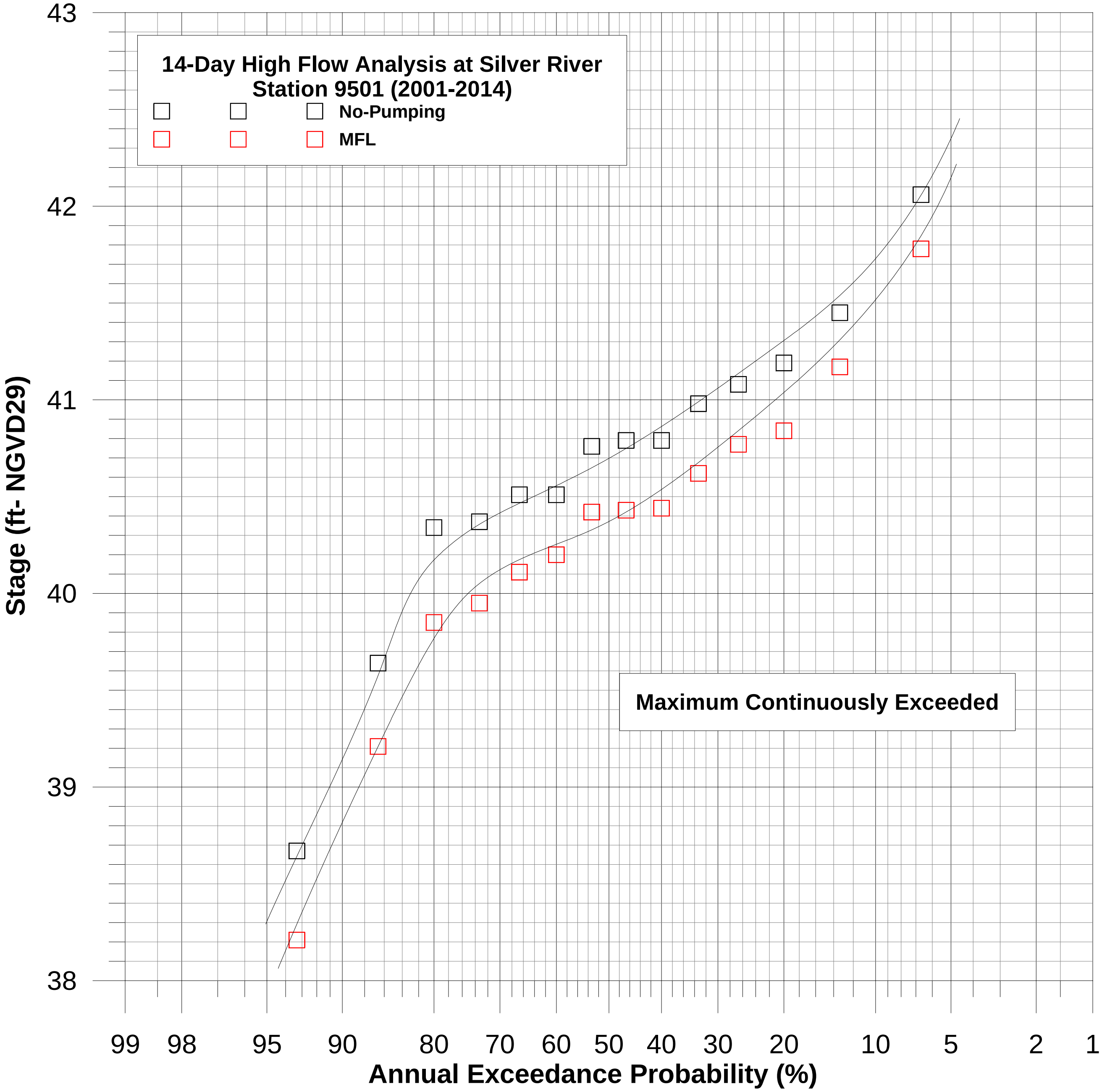
5
2
1
Annual Exceedance Probability (%)



14-Day High Flow Analysis at Silver River
Station 9501 (2001-2014)
No-Pumping
MFL
Maximum Continuously Exceeded
Stage (ft- NGVD29)
43
42
41
40
39
38
99
98
95
90
80
70
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50
40
30
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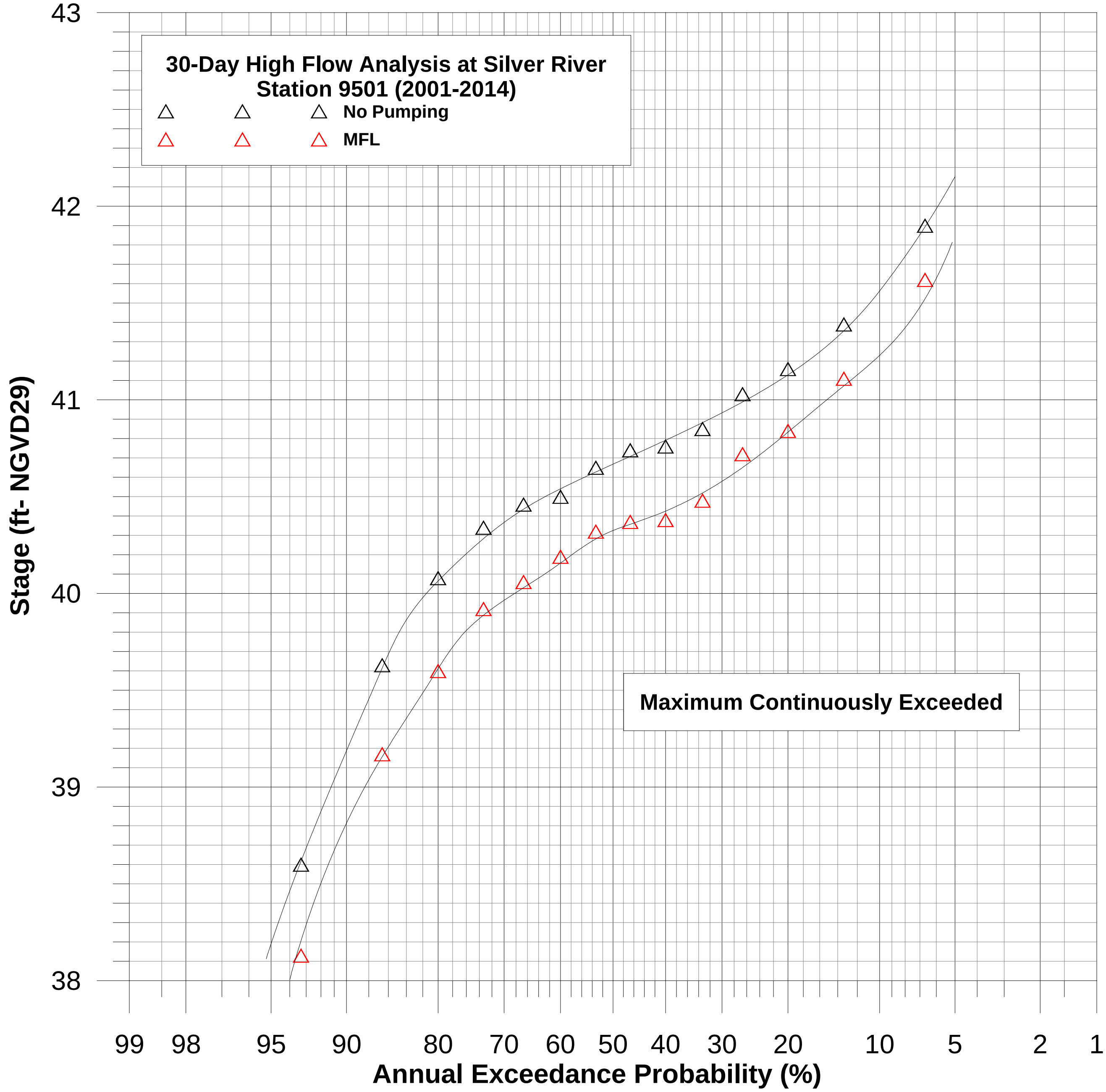
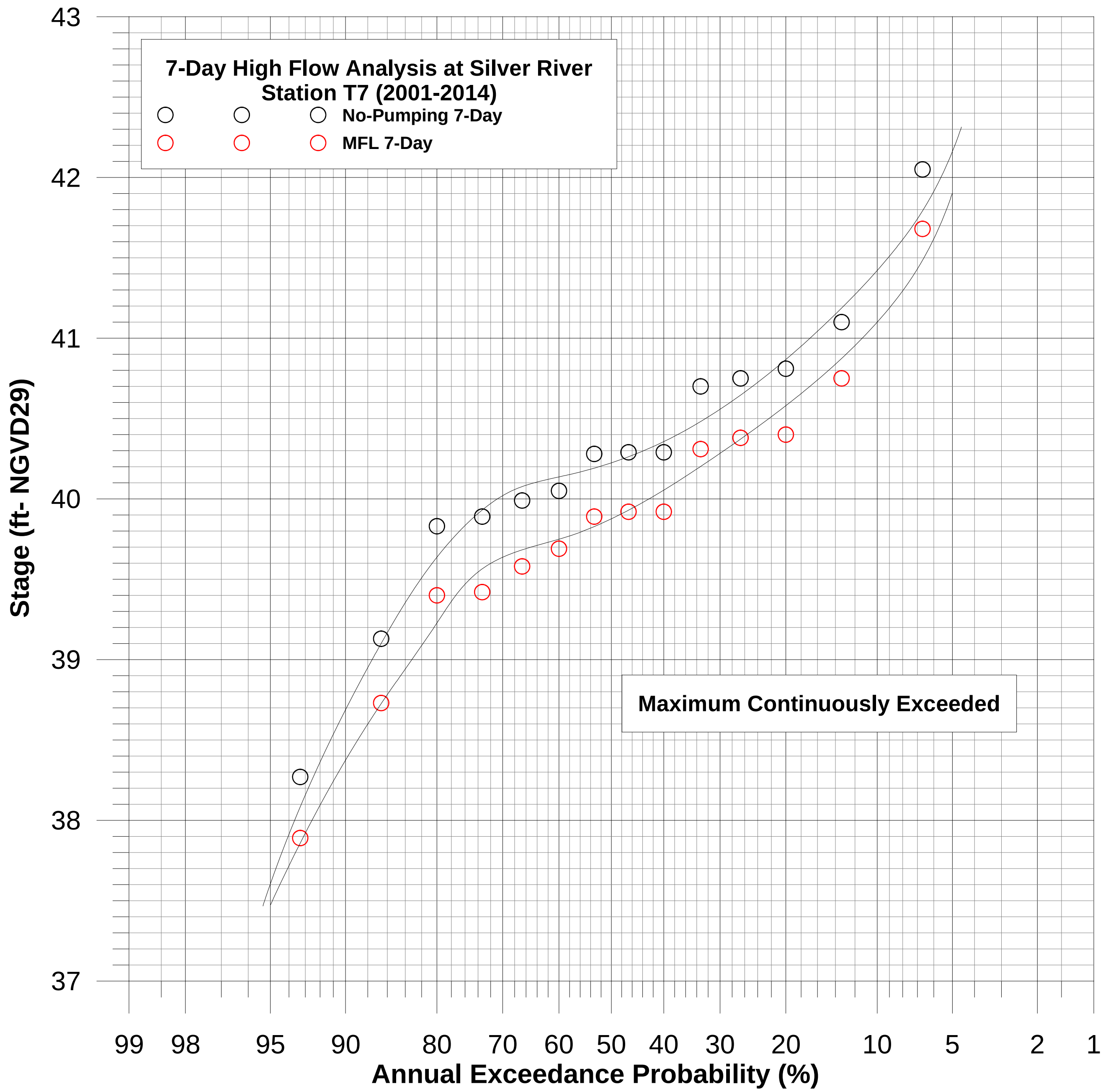
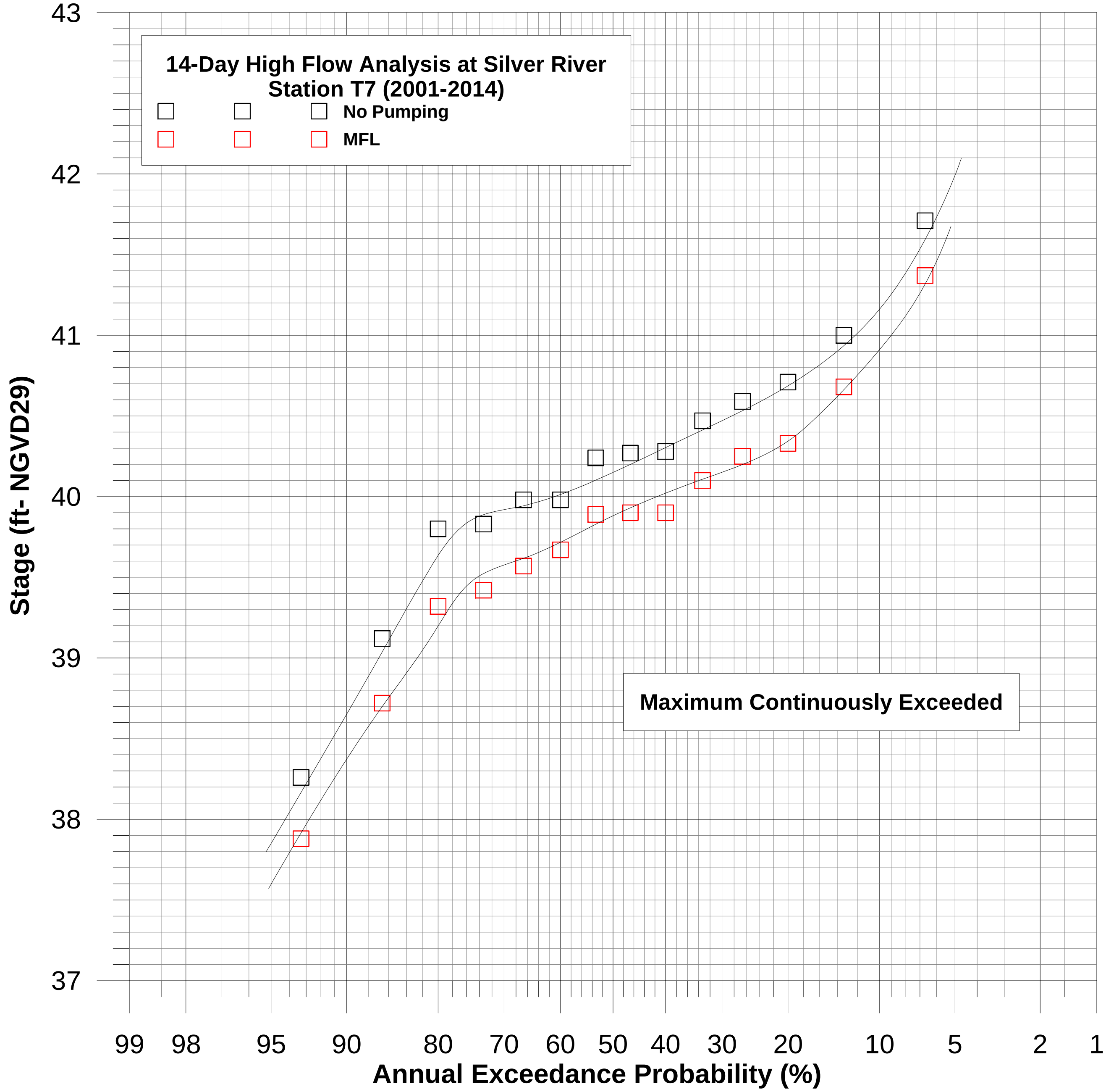
10
5
2
1
Annual Exceedance Probability (%)



30-Day High Flow Analysis at Silver River
Station 9501 (2001-2014)
No Pumping
MFL
Maximum Continuously Exceeded
Stage (ft- NGVD29)
43
42
41
40
39
38
99 98 95 90 80 70 60 50 40 30 20 10 5 2 1
Annual Exceedance Probability (%)



7-Day High Flow Analysis at Silver River Station T7 (2001-2014)
No-Pumping 7-Day
MFL 7-Day
Maximum Continuously Exceeded
Stage (ft- NGVD29)
Annual Exceedance Probability (%)
43
42
41
40
39
38
37
99 98 95 90 80 70 60 50 40 30 20 10 5 2 1



14-Day High Flow Analysis at Silver River
Station T7 (2001-2014)
No Pumping
MFL
Maximum Continuously Exceeded
43
42
41
40
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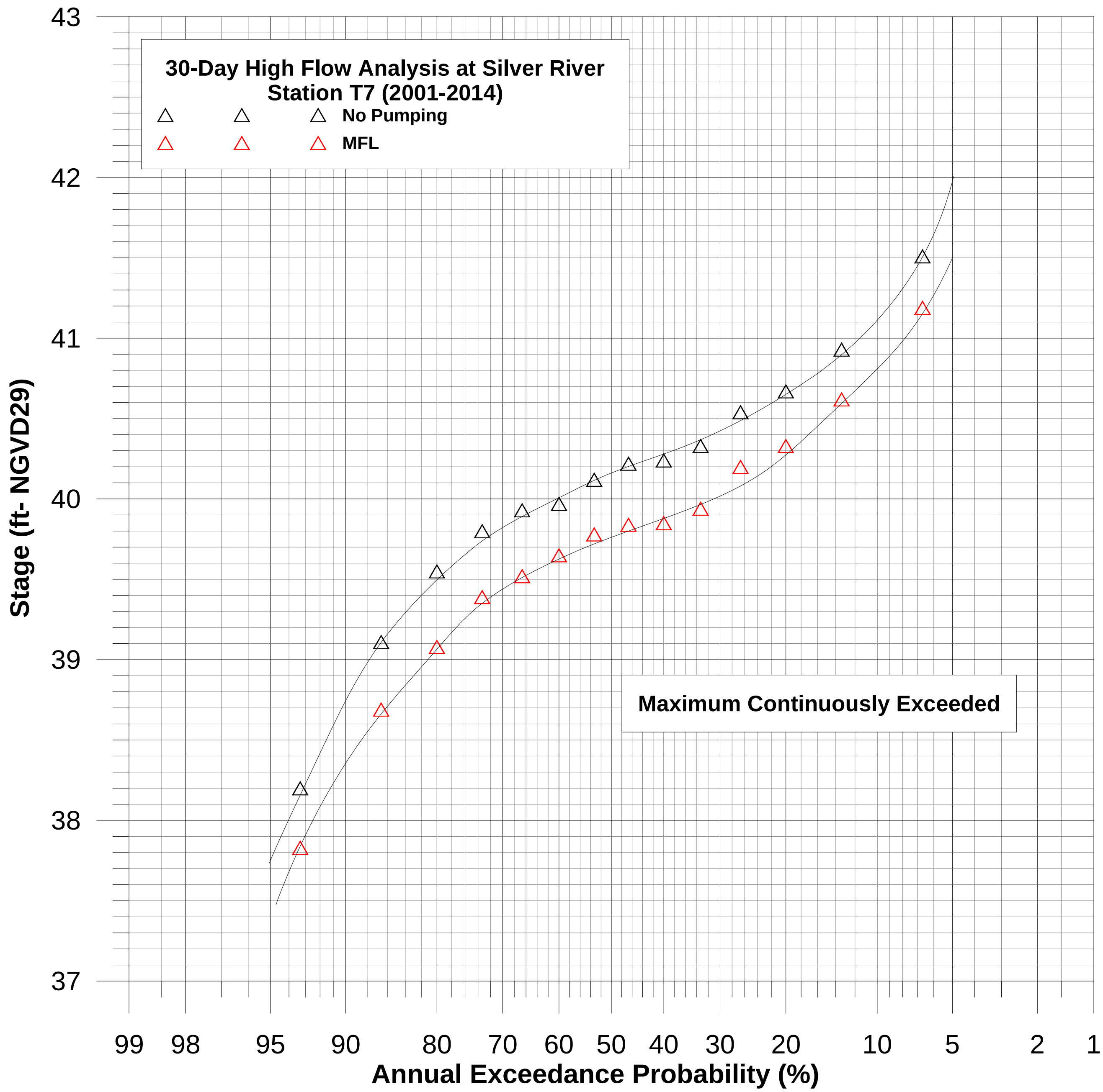
38
37
Stage (ft- NGVD29)
99 98 95 90 80 70 60 50 40 30 20 10 5 2 1
Annual Exceedance Probability (%)


30-Day High Flow Analysis at Silver River
Station T7 (2001-2014)
No Pumping
MFL
Maximum Continuously Exceeded
Stage (ft- NGVD29)
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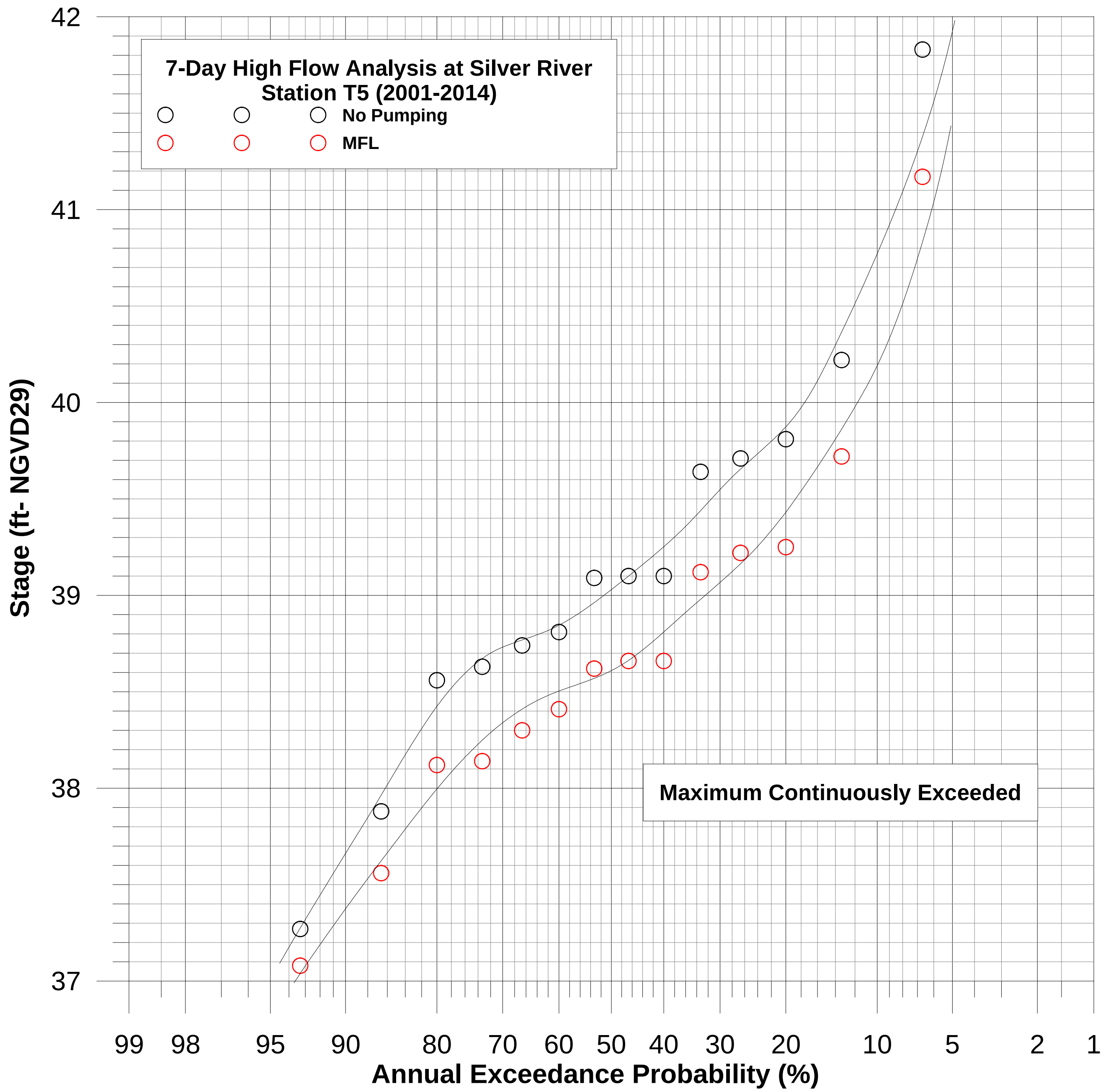
Annual Exceedance Probability (%)



7-Day High Flow Analysis at Silver River
Station T5 (2001-2014)
No Pumping
MFL
Maximum Continuously Exceeded
Stage (ft- NGVD29)
42
41
40
39
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37
Annual Exceedance Probability (%)
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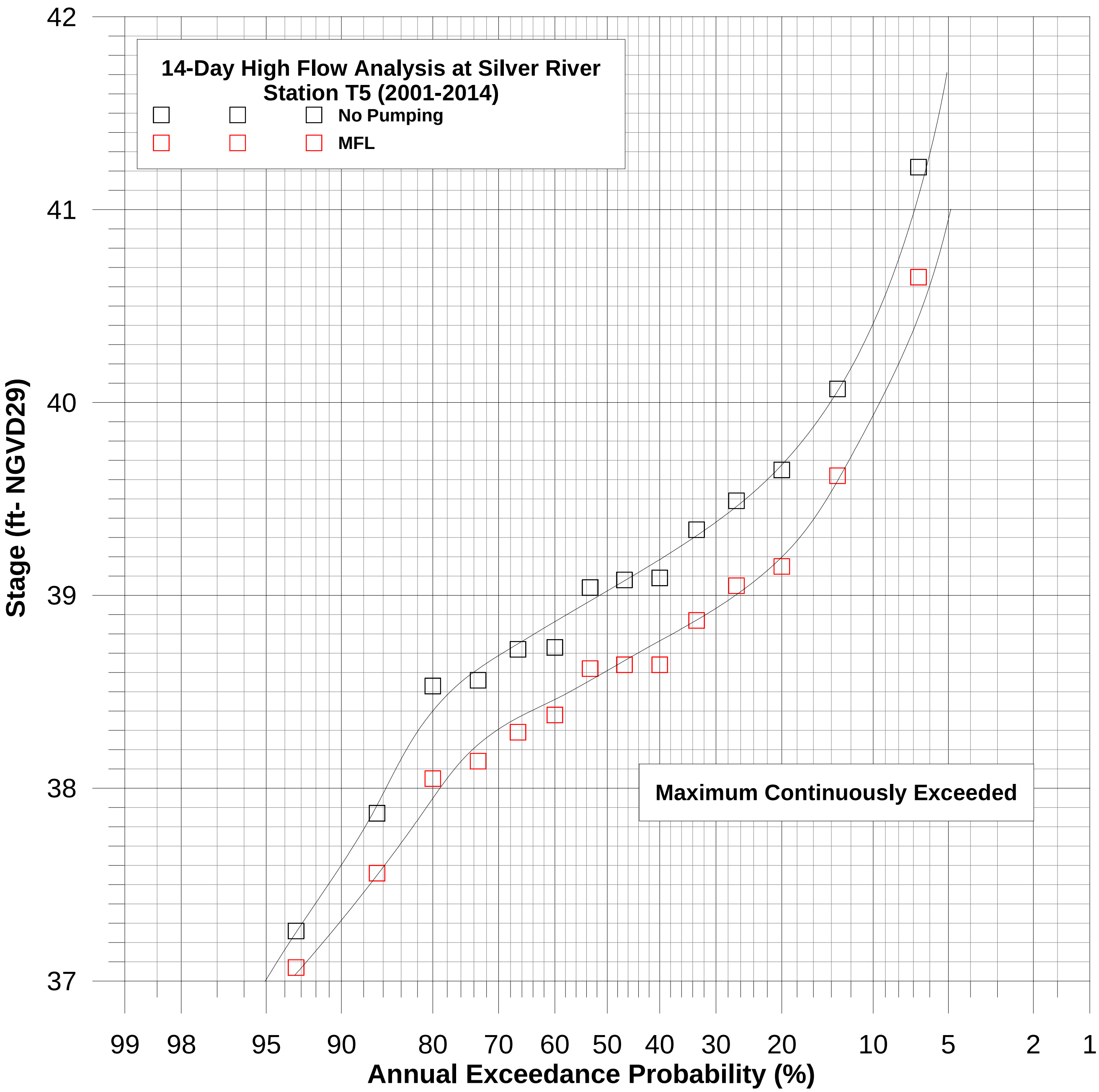
14-Day High Flow Analysis at Silver River
Station T5 (2001-2014)
No Pumping
MFL
Maximum Continuously Exceeded
Stage (ft- NGVD29)
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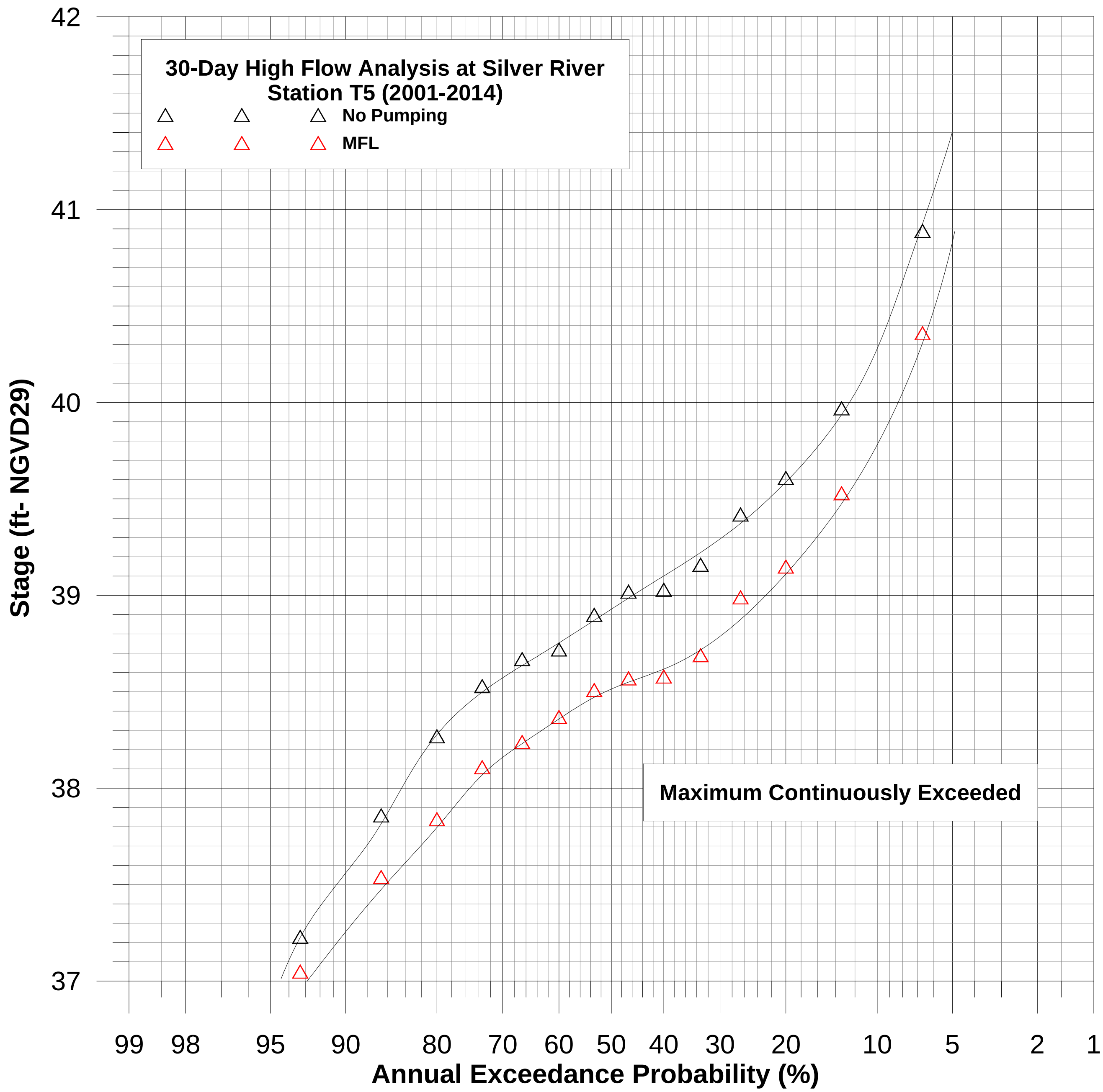
Annual Exceedance Probability (%)


30-Day High Flow Analysis at Silver River
Station T5 (2001-2014)
No Pumping
MFL
Maximum Continuously Exceeded
Stage (ft- NGVD29)
Annual Exceedance Probability (%)
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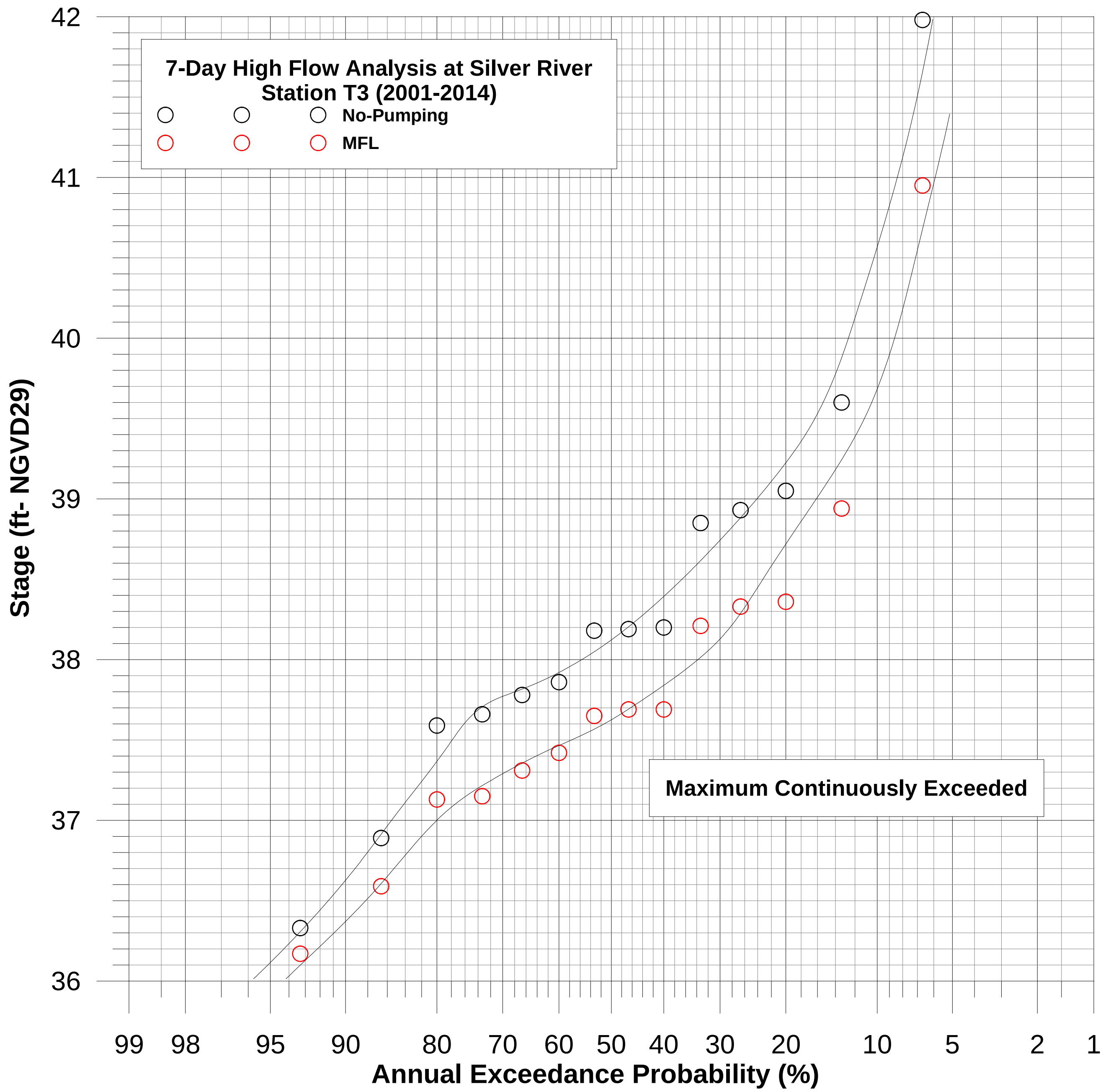
7-Day High Flow Analysis at Silver River
Station T3 (2001-2014)
No-Pumping
MFL
Maximum Continuously Exceeded
Stage (ft- NGVD29)
36
37
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39
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41
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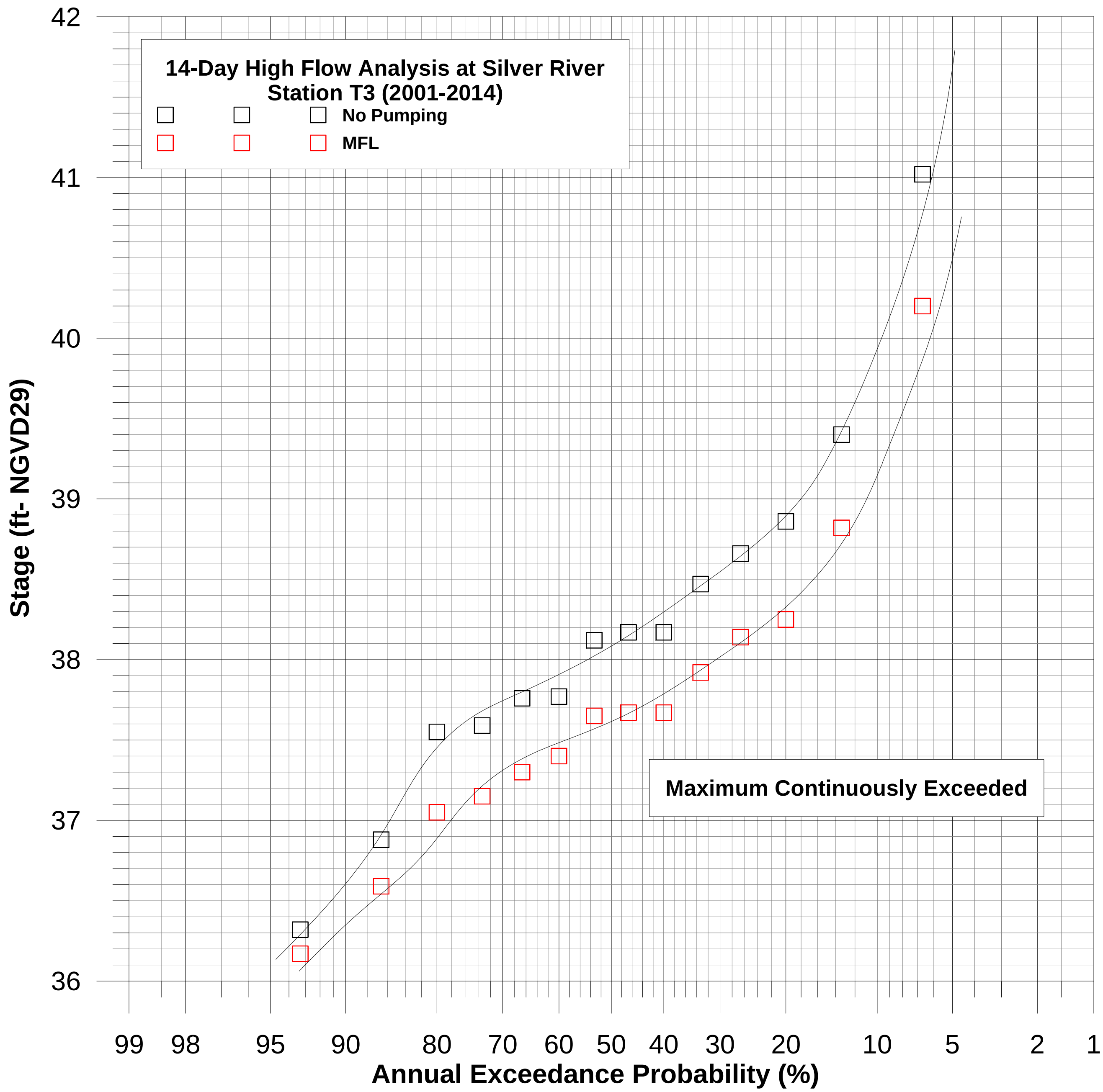
10
5
2
1
Annual Exceedance Probability (%)



14-Day High Flow Analysis at Silver River
Station T3 (2001-2014)
No Pumping
MFL
Maximum Continuously Exceeded
Stage (ft- NGVD29)
Annual Exceedance Probability (%)
42
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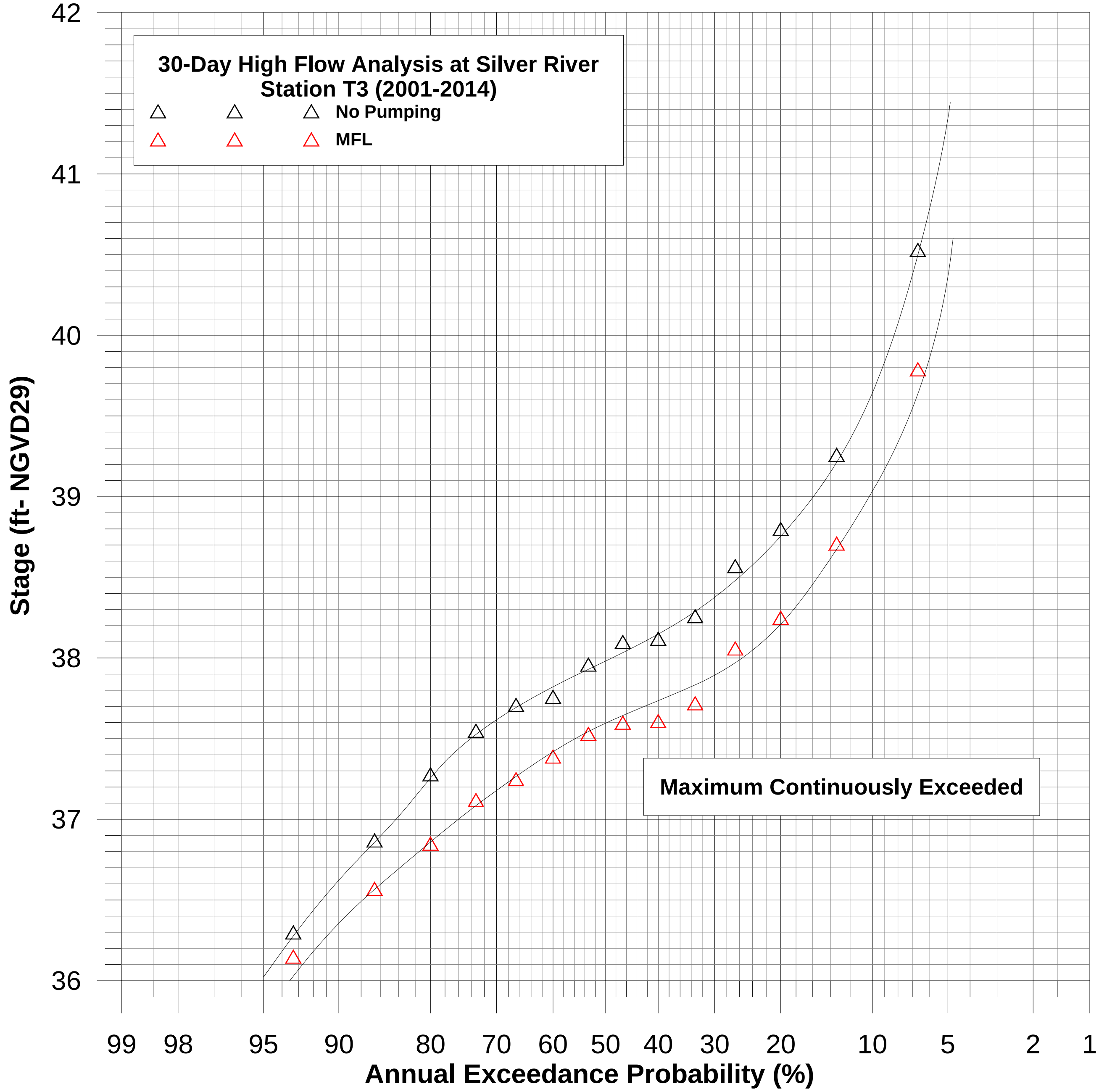

30-Day High Flow Analysis at Silver River
Station T3 (2001-2014)
No Pumping
MFL
Maximum Continuously Exceeded
Stage (ft- NGVD29)
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1
Annual Exceedance Probability (%)

WATER RESOURCES AND HUMAN USE VALUE ASSESSMENT OF SILVER SPRINGS AND THE SILVER RIVER, MARION COUNTY

MARCH 2017

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT
PALATKA, FLORIDA

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ACKNOWLEDGMENTS

Applied Technology and Management, Inc., and Janicki Environmental, Inc. would like to express sincere gratitude to the staff at the St. Johns River Water Management District for all of their help in the preparation of this document. Their suggestions and comments contributed greatly to improving the quality of the final report.

Funds for this study were provided by the St. Johns River Water Management District.

EXECUTIVE SUMMARY

An evaluation was conducted to determine if the recommended minimum flows for Silver Springs, in Marion County, Florida, protects the 10 water resource values (WRVs) defined in Rule 62-40.473, Florida Administrative Code (*F.A.C.).* The determination of the recommended MFLs for Silver Springs is presented in Sutherland et al. (2016) and is summarized in Table ES-1.

Table ES-1. Recommended minimum flows for Silver Springs, Marion County, Florida

Minimum Flows	Flow (cfs)	Duration (days)	Return Interval (years)
Frequent high (FH)	828	30	5
Average (MA)	638	180	1.7
Frequent low (FL)	572	120	3

The most constraining MFL is the FL, with a freeboard of 17 cfs. Based on the best available information, including the NDMv5 groundwater model, the predicted flow reduction resulting from projected water use for the 20-year planning horizon is more than 17 cfs. Therefore, the proposed MFLs for Silver Springs are not achieved for the 20-year planning horizon, and a prevention strategy is required. Based on the best available data, approximately 3.5% has already occurred from a no-pumping to baseline condition. The recommended minimum flow allows an additional 2.5 percent reduction, for a total of 6 percent reduction from no-pumping to the MFLs condition.

The WRV evaluations for the Silver River were conducted using an event-based analysis of changes in return intervals for critical flow events between no-pumping conditions, which define conditions without anthropogenic effects from groundwater pumping, and the recommended MFLs hydrologic regime. The development of the two hydrologic regimes is discussed in detail in Sutherland et al. (2017). More specifically, the return intervals (frequency of occurrence) of hydrologic conditions from which one may infer protection of the WRVs were evaluated under no-pumping conditions and under the MFLs hydrologic regime. The WRV was determined to be protected if the frequency of occurrence of these key events under the MFLs hydrologic regime did not differ unacceptably from the no-pumping condition based on available data, literature research and professional judgment where necessary. The term *unacceptably* implies a professional judgment that the reduction or increase in frequency of a critical hydrologic event results in an adverse impact to a WRV function. Table ES-2 provides a summary of the WRV assessment.

WRV 1 (*Recreation In and On Water*), and WRV 10 (*Navigation*) are considered protected. Given that the relative frequency of the low-water events remains on average once every 1 to 2 years, this WRV is considered protected under the proposed MFLs hydrologic regime.

WRV-2 (*Fish and Wildlife Habitats and the Passage of Fish*) was considered to be one of the more sensitive WRVs. The analysis concluded that it is protected with respect to fish and manatee passage and velocities to protect fish and shellfish habitats. The analysis with respect to floodplain inundation to protect hydric soils concluded that hydric soils would be protected under the proposed Silver Springs MFLs. Wetland communities and associated fauna within the floodplain were also determined to be protected. Manatee refugia was considered protected with respect to water temperature and depth.

WRV-3 (*Estuarine Resources*) and WRV-5 (*Maintenance of Freshwater Storage and Supply*) were found. For WRV-3, the contribution of the Silver River to downstream estuarine resources is contained within the cumulative contributions of other flow reductions evaluated in the St. Johns River Water Supply Impact Study (WSIS) for which estuarine resource protection is one of the major considerations. The WSIS concluded that the proposed and assessed flow reductions do not cause harm to estuarine resources. Therefore, flow reductions associated with Silver River MFL will be protective of WRV-3 since the Silver River's future contribution to flow reductions to the lower St. Johns River will have been accounted for. Under any circumstances flows from the Silver River are small relative to flows of the entire St. Johns River system. Protection of WRV-5 under the draft Silver River MFLs is related to non-consumptive uses and environmental values. This WRV is encompassed in the other nine (9) WRVs.   Given that those evaluations concluded that all nine WRVs are protected, it is concluded that WRV-5 is also protected by the draft MFLs.

WRV-4 (*Transfer of Detrital Material*) and WRV-7 (*Filtration and Absorption of Nutrients and Other Pollutants*) were also considered to be two of the more sensitive WRVs evaluated. The sensitivities are primarily related to a lowering in floodplain inundation frequency. The major factor that would be affected by flow reductions allowed under the recommended MFLs would be the reduction in the frequency of physical contact of water with riparian, or floodplain vegetation. The draft MFL was considered to be protective as it prevents unacceptable reductions in contact time with the floodplain, which is important for maintaining these characteristics.

Changes in velocities associated with flow reductions allowed under the draft MFLs were also evaluated. WRV-8 (Sediment Loads), Algal Scour and aspects of WRV-4 (*Transfer of Detrital Material*) and WRV-7 (*Filtration and Absorption of Nutrients and Other Pollutants*) have a velocity dependence associated with their function. were considered protected under all scenarios with respect to velocity. Given the small decrease, 0.05 ft/sec or less, in average in-channel velocities anticipated, these WRVs should be protected under the draft Silver Springs MFLs.

WRV9 (*Water Quality*) found no important relationships between flow rates or water levels and water quality trends in the Silver River.

The Silver River faces a number of water quality issues, chiefly an increase in nitrates, a documented decrease in water transparency over the past 50 years, and a concomitant increase in attached algae. However, evaluations performed indicate that the water quality parameters at issue are independent of Silver River flow and stage. Consequently, water quality would be generally unaffected by flow reductions. Source control within the groundwater basin was identified by the Florida Department of Environmental Protection (FDEP) as the primary means to reduce nitrate concentrations in the Silver River. The FDEP is addressing nitrate source control in the Silver Springs Basin Management Action Plan (BMAP). St. Johns River Water Management District (SJRWMD) has also embarked on a Springs Protection Initiative that will focus resources on the study of springs within the SJRWMD, including Silver Springs that will provide information critical to the development of sound restoration strategies.

Table ES-2. Summary results for WRV evaluation of the recommended MFLs Hydrologic Regime	
Water Resource Value (WRV)	**MFLs Hydrologic Regime Protective?**
WRV-1: Recreation In and On the Water	Yes
WRV-2: Fish and Wildlife Habitats and the Passage of Fish	
Fish Passage	Yes
Fish/Shellfish Habitat (flow velocity related issues)	Yes
Floodplain Inundation (wetland communities)	Yes
Floodplain Inundation (hydric soils)	Yes
Manatee Protection (temperature, water depth)	Yes
WRV-3: Estuarine Resources	Yes
WRV-4: Transfer of Detrital Material	Yes
WRV-5: Maintenance of Freshwater Storage and Supply	Yes
WRV-6: Aesthetic and Scenic Attributes	Yes
WRV-7: Filtration and Absorption of Nutrients and Other Pollutants	Yes
WRV-8: Sediment Loads	Yes
WRV-9: Water Quality	Yes
WRV-10: Navigation	Yes

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1.0 INTRODUCTION

The Silver Springs and Silver River in Marion County, Florida, are listed as priority waterbodies on the State of Florida's Minimum Flows and Levels (MFLs) Priority Water Body List. Pursuant to Section 373.042(2) of the Florida Statutes (*F.S.*), the St. Johns River Water Management District (SJRWMD) must therefore establish MFLs for these systems.

The methodology for determining these recommended MFLs is detailed in two SJRWMD draft reports: *Minimum Flows Determination for Silver Springs, Marion County, Florida* (Sutherland et al. 2017), and *Development of Flow and Stage Time Series at MFL Transects of Silver Spring*s (Karama et al. 2016). The recommended MFLs will remain preliminary until the SJRWMD Governing Board formally adopts them by rule (rule 40C-8, Florida Administrative Code [*F.A.C.*]). Prior to its consideration by the Governing Board, an assessment may be conducted to determine whether the recommended MFLs hydrologic regime will protect designated natural resource and environmental values. This document provides such an assessment.

Because of the existing amount of groundwater pumping and other consumptive uses in the Silver Springs groundwater basin, it has been questioned whether the existing flow represents the true historical flow in the river or is already representative of some reduced flow percentage. Accordingly, an additional flow scenario, called the *no-pumping scenario*, was developed to represent spring discharge and river flow that would occur in the absence of the existing groundwater withdrawals. Details of how the no-pumping hydrologic scenario was developed including methods used by SJRWMD to develop the discharge and stage time series as well as the frequency analysis are summarized in Karama et al. (2016). The MFLs hydrologic scenario was developed in relation to the no-pumping hydrologic scenario.

Neubauer et al. (2008) provides an overview of the SJRWMD's MFLs program, which establishes MFLs for lakes, streams and rivers, wetlands, springs, and groundwater aquifers, as mandated by state water policy (section 373.042, *F.S.*). The establishment of MFLs gives priority to waters that are located within: (a) an outstanding Florida water, (b) an aquatic preserve, (c) an area of critical state concern, or (d) an area subject to Chapter 380 Resource Management Plans (rule 62-40.473(3), *F.A.C.*).

According to Rule 62-40.473(1)*, F.A.C.*, in establishing MFLs pursuant to Section 373.042 and Section 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 (62.40.473 (1) (a), *F.A.C.*)
b. Fish and wildlife habitats and the passage of fish (62.40.473 (1) (b), *F.A.C.*)
c. Estuarine resources (62.40.473 (1) (c), *F.A.C.*)
d. Transfer of detrital material (62.40.473 (1) (d), *F.A.C.*)
e. Maintenance of freshwater storage and supply (62.40.473 (1) (e), *F.A.C.*)
f. Aesthetic and scenic attributes (62.40.473 (1) (f), *F.A.C.*)
g. Filtration and absorption of nutrients and other pollutants (62.40.473 (1) (g), *F.A.C.*)
h. Sediment loads (62.40.473 (1) (h), *F.A.C.*)
i. Water quality (62.40.473 (1) (i), *F.A.C.*)
j. Navigation (62.40.473 (1) (j), *F.A.C.*)

It is these 10 natural resource and environmental values that are the focus of this assessment, and the assessment will determine how these values may be affected under the proposed MFLs hydrologic regime.

2.0 SILVER RIVER BACKGROUND INFORMATION

The Silver River is located in Marion County, east of the City of Ocala (Figure 2-1). The Silver River is the spring run for Silver Springs, which is the largest of Florida's first magnitude springs, (Scott et al. 2004; Osburn et al. 2006; Rosenau et al. 1977; as cited in Munch et al. 2006) and the focal point for the iconic Florida tourist attraction noted for its glass-bottom boats.

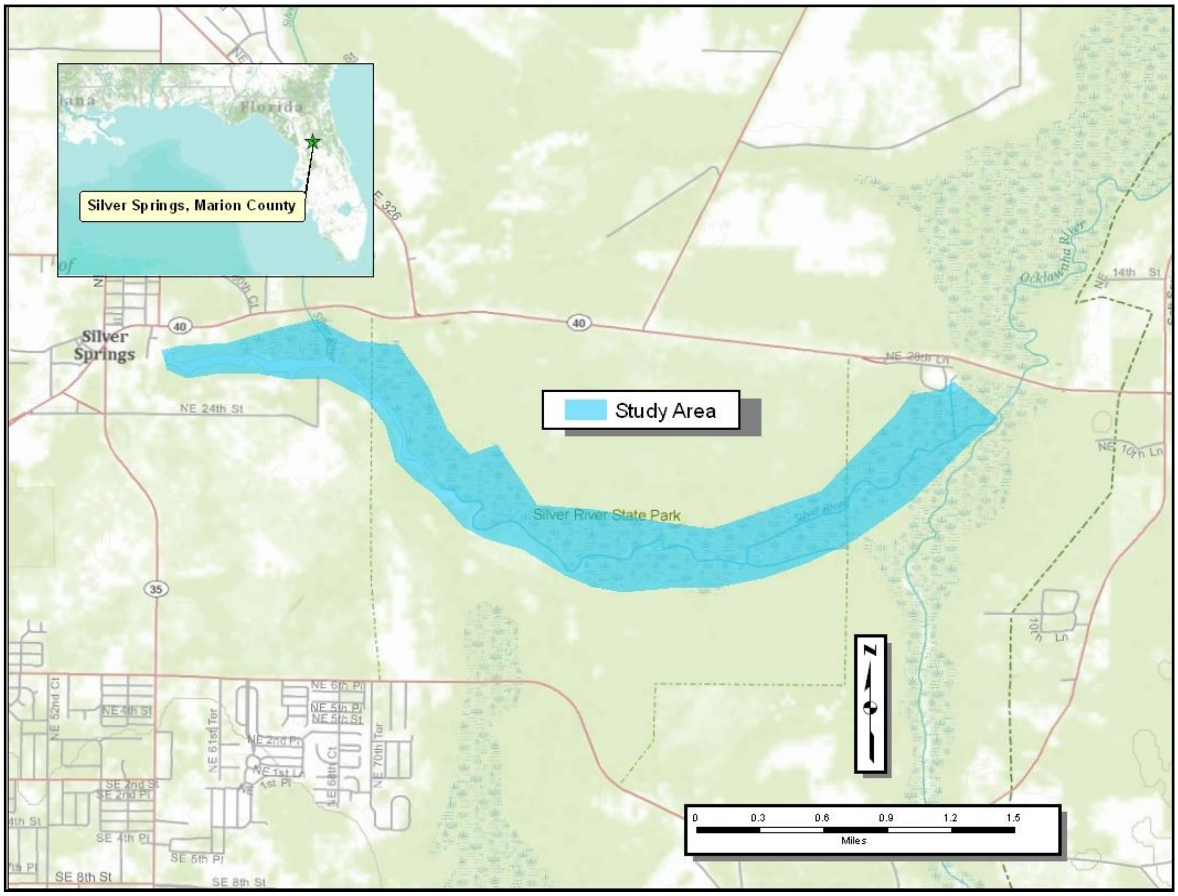


Figure 2-1. Location map for the Silver Springs study site in Marion County, Florida Source: ESRI 2011 (map), ATM 2012.

Karama et al. (2016) details the development of flow and stage time series at MFL transects on Silver Springs and the Silver River. Figure 2-2 presents the flow time series for the USGS-adjusted (German, 2010), observed, no-pumping and MFL hydrologic regimes at the 9501 station. Table 2-1 presents summary statistics for flow for the three hydrologic regimes. Figure 2-3 presents the observed stage time series st the 9501 station. Table 2-2 presents summary statistics for observed stages at the 9501 station.

A review of the historical stage-flow relationship indicated there was a significant change in the relationship after 2000. As discussed in Sutherland et al. (2017), evidence suggests that this condition is largely due to SAV-related flow suppression caused primarily by the 112” rainfall deficit (from 1970s to the present). While there is still uncertainty about the permanence of SAV and the current stage-discharge relationship, SJRWMD concluded that it is possible pre-2000 conditions will return when above average rainfall and large flooding events (with associated high scour from the Silver River, dark water from the Ocklawaha River, reduced SAV, and lower stages) return for a sufficient period. While the long-term deficit rainfall condition persists, it is appropriate to include the post-2000 dry period as part of a long-term climatic cycle. As a result of the considerations described above, SJRWMD decided that using the full POR for MFLs determination was appropriate.

Figure 2-4 provides a regional map locating the Silver River in relation to the Lower Ocklawaha River drainage basins. The Silver River is within the Ocklawaha Basin, which, in turn, discharges to the Lower St. Johns River Basin and ultimately to the Atlantic Ocean.

Table 2-1. Summary statistics for flow at the 9501 Station for the three flow regimes (cfs)

	Flow Regime		
Statistic	**USGS-adjusted**	**No-Pumping**	**MFL**
Mean	701	712	670
Median	693	704	662
Range	1076	1061	1061
Minimum	141	160	118
Maximum	1217	1220	1178

Table 2-2. Summary statistics for stage at the 9501 Station for the three flow regimes (Elevations are in FT. NGVD)

	Flow Regime		
Statistic	**Observed**	**No-Pumping**	**MFL**
Mean	39.56	39.70	39.23
Median	39.56	39.73	39.24
Range (ft)	5.33	5.55	5.87
Minimum	37.21	37.25	36.59
Maximum	42.54	42.80	42.46

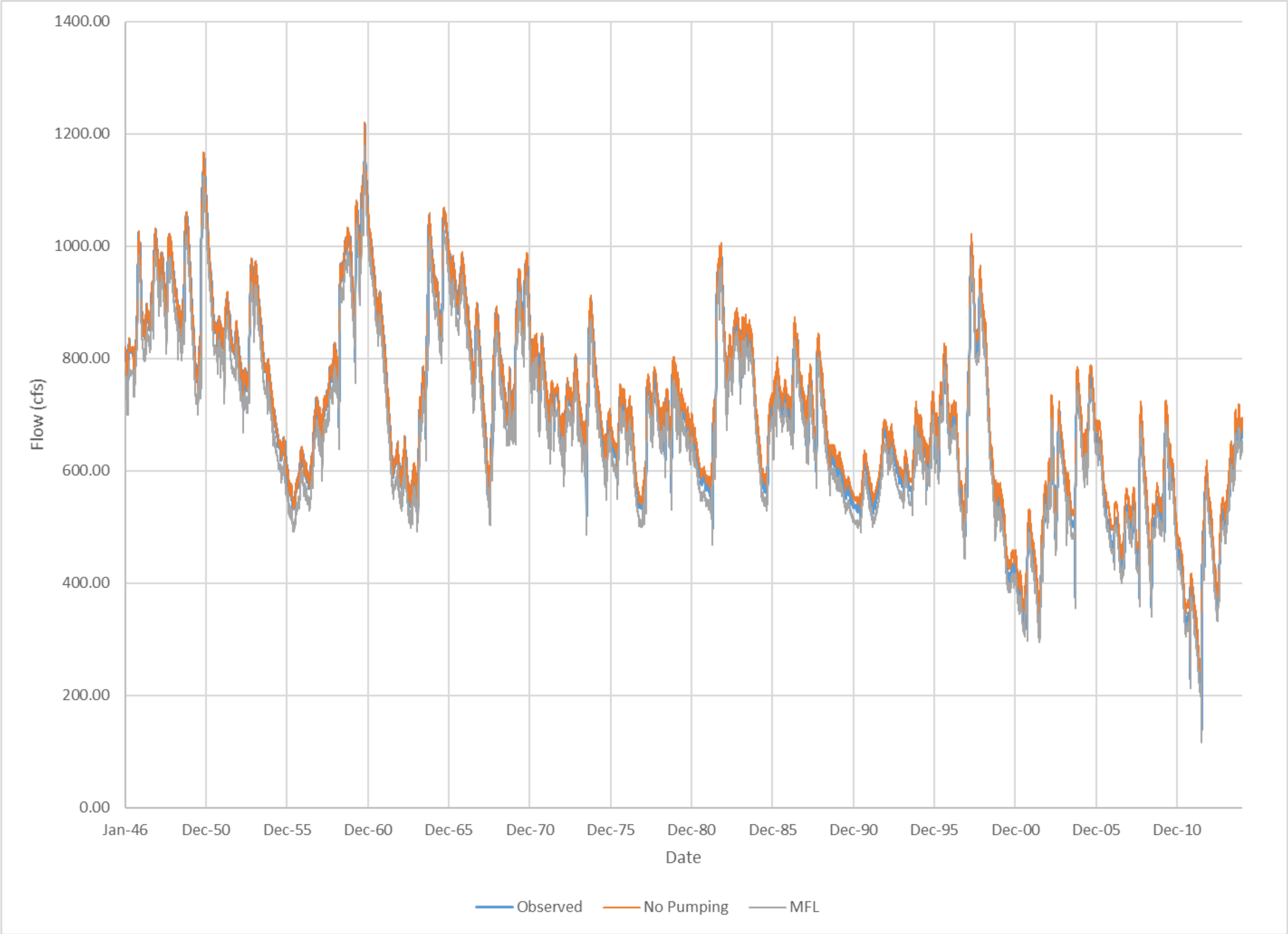


Figure 2-2. Flow time series for the USGS-adjusted, no-pumping and MFL hydrologic regimes at the 9501 station

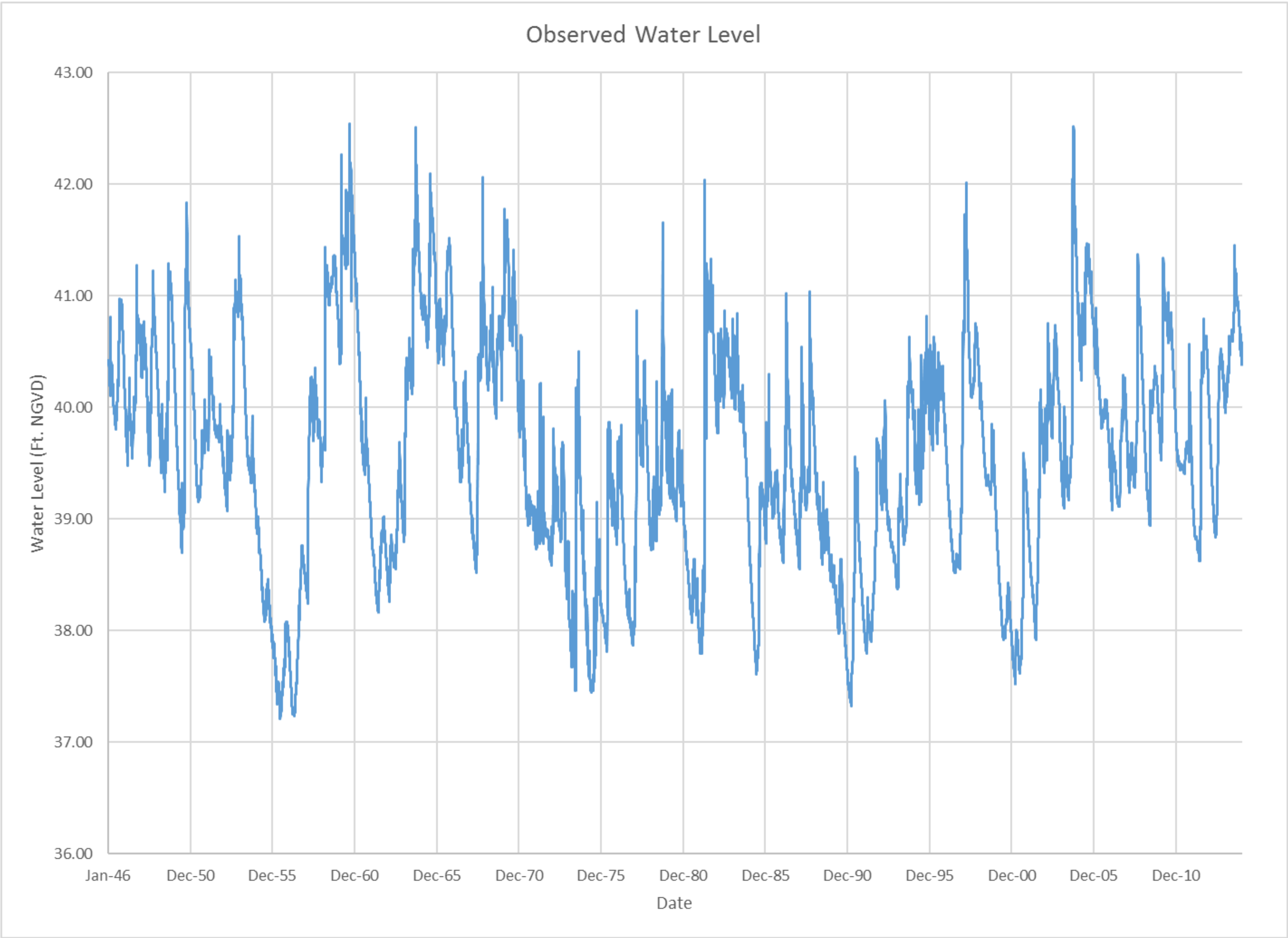


Figure 2-3. Observed stage time series at the 9501 station

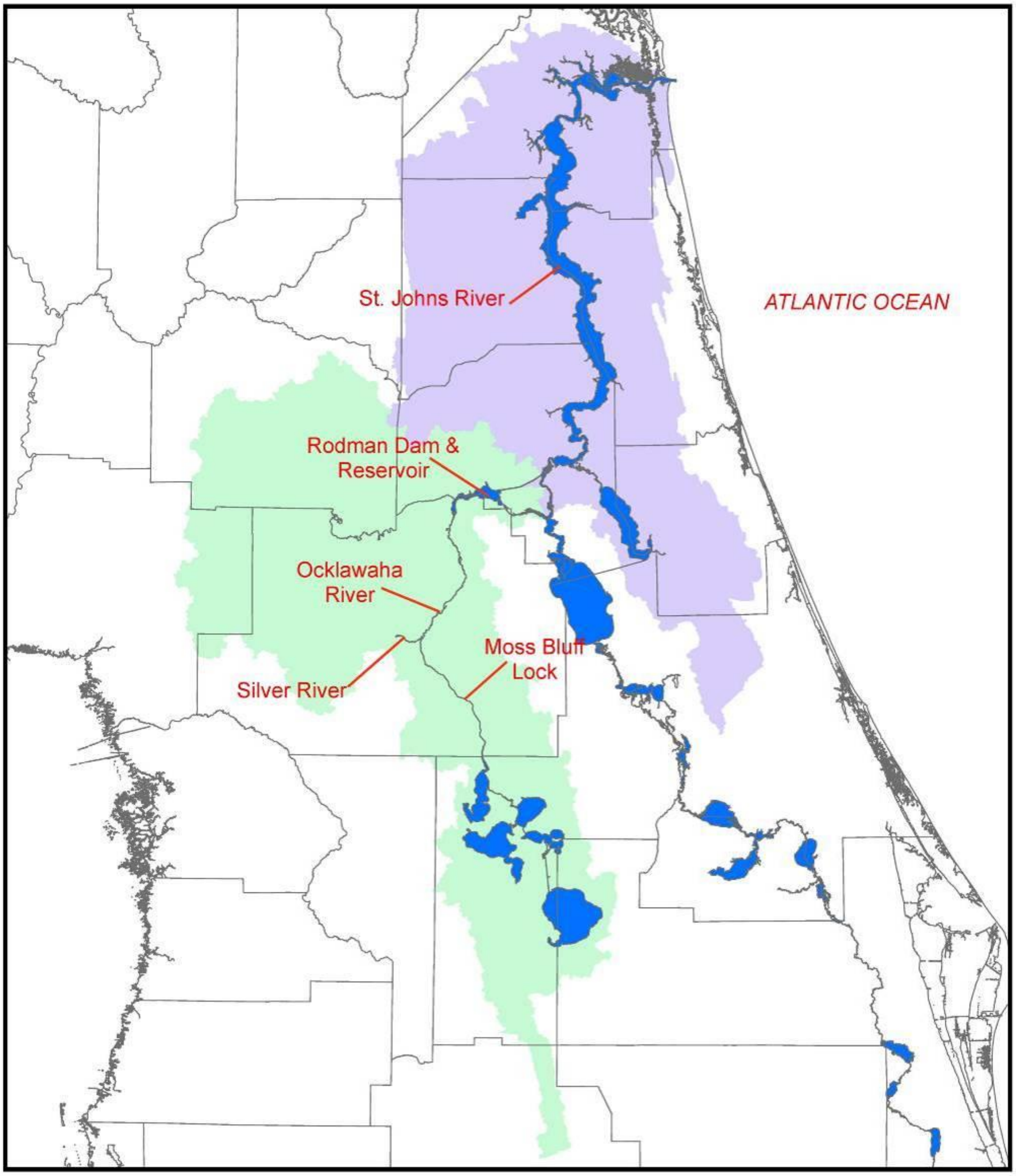
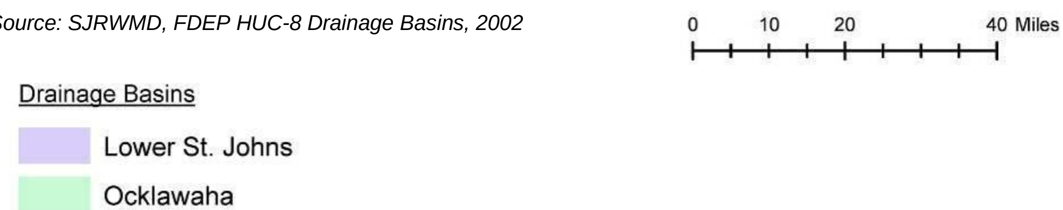


Figure 2-4. Drainage basins in relation to Silver River.

Data Source: SJRWMD, FDEP HUC-8 Drainage Basins, 2002



The Silver River has its headwaters at Silver Springs and then flows approximately 5.3 miles eastward to its confluence with the northward flowing Ocklawaha River. The Rodman dam, reservoir, and lock complex is approximately 22 river miles down the Ocklawaha River (to the north) from the Silver River-Ocklawaha River confluence and the Moss Bluff lock is located 12 river miles upstream to the south (Figure 2-4). Figure 2-5 provides a more detailed overview of the Silver River water resource value (WRV) assessment project area. Descriptions for the three U.S. Geological Survey (USGS) gaging stations located along the Silver River (Figure 2-5) are included in Appendix A.

Figure 2-6 provides a more detailed overview of the Rodman dam, which, as will be discussed in later sections of this report, is a major obstacle for fish and wildlife, particularly manatees, to move between the St. Johns River and the Ocklawaha River.

Water discharged from Silver Springs to form the Silver River exits through at least 30 spring vents distributed along the river's first 3,900 feet (ft) (Osburn et al. 2006) (Figure 2-7). Surface water runoff, while a smaller portion of the river's long-term water budget, can be significant at times. Half Mile Creek is the major surface water inflow (Figure 2-5) that has been sporadically monitored in the past. Beginning in May 2013, Half Mile Creek (at SR40) and the Marion County Stormwater Treatment overflow are gauged and monitored (USGS 02239600 and 02239601). While the data record is very limited, it indicates that flow occurs intermittently and only during large storm events.

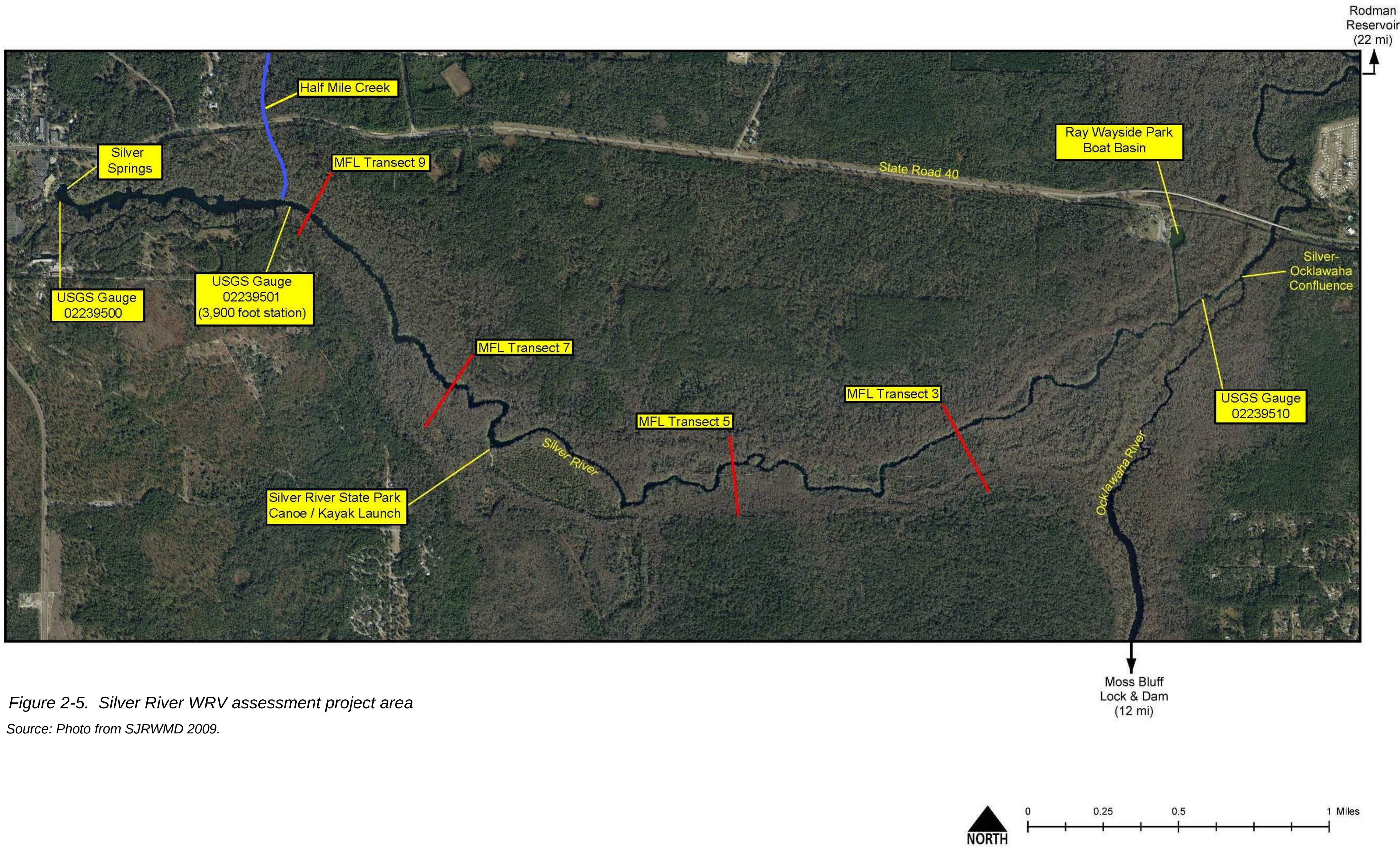
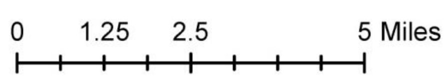


Figure 2-5. Silver River WRV assessment project area

Source: Photo from SJRWMD 2009.

Figure 2-6. Rodman Dam and reservoir complex.

Source: SJRWMD 2009.



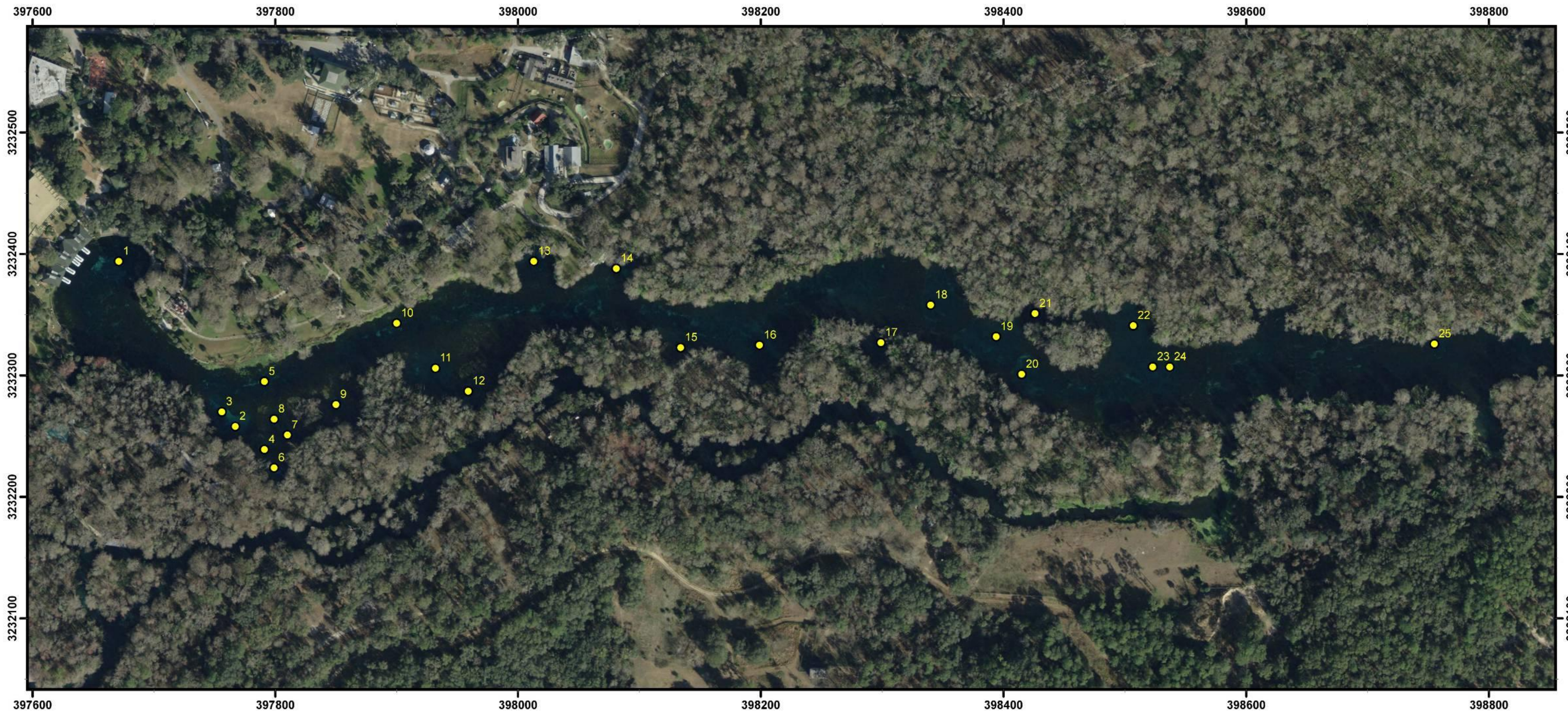


Figure 2-7. Multiple vents comprising Silver Springs and discharging to the Silver River.

Source: Osburn et al. 2006.

Key

1. Mammoth Spring
2. Catfish Reception Hall Spring
3. Jacobs Well Spring
4. Bridal Chamber Spring
5. Oscar Spring
6. Ladies Parlor Spring
7. Devils Kitchen Spring A
8. Devils Kitchen Spring B
9. Alligator Hole Spring
10. Mastodon Bone Spring
11. Geyser Spring
12. Blue Grotto Spring
13. Christmas Tree Spring
14. Garden of Eden Spring
15. Indian Cave Spring
16. First Fishermans Paradise Spring
17. No Name Cove Spring
18. Turtle Meadows Spring
19. Second Fishermans Paradise Spring
20. Catfish Hotel Spring
21. Turtle Nook Spring
22. Raccoon Island Spring
23. Shipwreck Spring
24. Catfish Convention Hall Spring
25. Timber Spring

0 50 100 200 Meters

The 10 WRVs are assessed at four locations along the Silver River, indicated in red on Figure 2-5 as MFLs Transects 9, 7, 5, and 3, referred to as T9, T7, T5 and T3, respectively. T9 is the farthest upstream and T3 the furthest downstream. As will be discussed in more detail in the following sections, the WRV assessments will consider how changes in the frequency of high or low water events may affect WRVs in both the river channel and the adjacent floodplain at each of the four MFLs transects.

Figure 2-8 provides a land cover map of areas adjacent to the Silver River. The MFLs transects are indicated in red. All transects include both the main river channel and the forested floodplain on each side of the river. Each transect is oriented roughly perpendicular to the river channel, extending outward across the riparian floodplain until higher elevation uplands are encountered.

Land cover types are indicated by a code, with the riparian floodplain being predominantly classified as 6170, or Mixed Wetland Hardwoods (SJRWMD 2004). SJRWMD staff surveyed topographic cross-sections at the four MFLs transects (presented in Section 4). Floodplain plant-community types are delineated and annotated on each MFLs transect. Appendix B provides a detailed analysis of hydric soils located along the MFLs transects.

H.T. Odum conducted the first extensive ecological study of Silver Springs in the mid-1950s. The results of that study were published in the journal *Ecological Monographs* as the now-classic paper, *Trophic Structure and Productivity of Silver Springs, Florida* (Odum 1957), and provided a detailed analysis of the spring's biological and ecosystem metabolism. Some 25 years later, Knight (1980) conducted a doctoral dissertation study, under H.T. Odum's supervision, that built upon Odum's original 1950s work.

Recently, and as a follow-up to the earlier work of Odum (1957) and Knight (1980), the *Fifty-Year Retrospective Study of the Ecology of Silver Springs, Florida* (Munch et al. 2006) was conducted. The retrospective study assessed land use and water quality changes in Silver Springs over the decades since Odum's original work, with a goal to develop cause-and-effect relationships, if any, regarding the spring's ecology. The study's scope was to review available data for the upper 0.75 mile [1,200 meters (m)] of the Silver River, collect additional data as needed for comparison to historical data, and develop linkages between springshed land-use changes and the Silver Springs ecology. The study was limited to the upper 1,200 m of the

Silver Springs run beginning at the main spring boil (Mammoth Spring) and included all the major spring boils Odum (1957) and Knight (1980) studied.

Currently, SJRWMD and the University of Florida (UF), are conducting a large and multi-disciplinary study of Silver Springs, Silver River, and it is springshed as part of the Collaborative Research Initiative on Sustainability and Protection of Springs (CRISPS), As part of the SJRWMD/UF collaborative CRISPS project, numerous individual studies are currently being conducted to improve our understanding of the physical, chemical and biological dynamics within Silver Springs and Silver River. The results of these studies, when completed, will be most valuable for future MFL and WRV assessments of Silver Springs and Silver River.

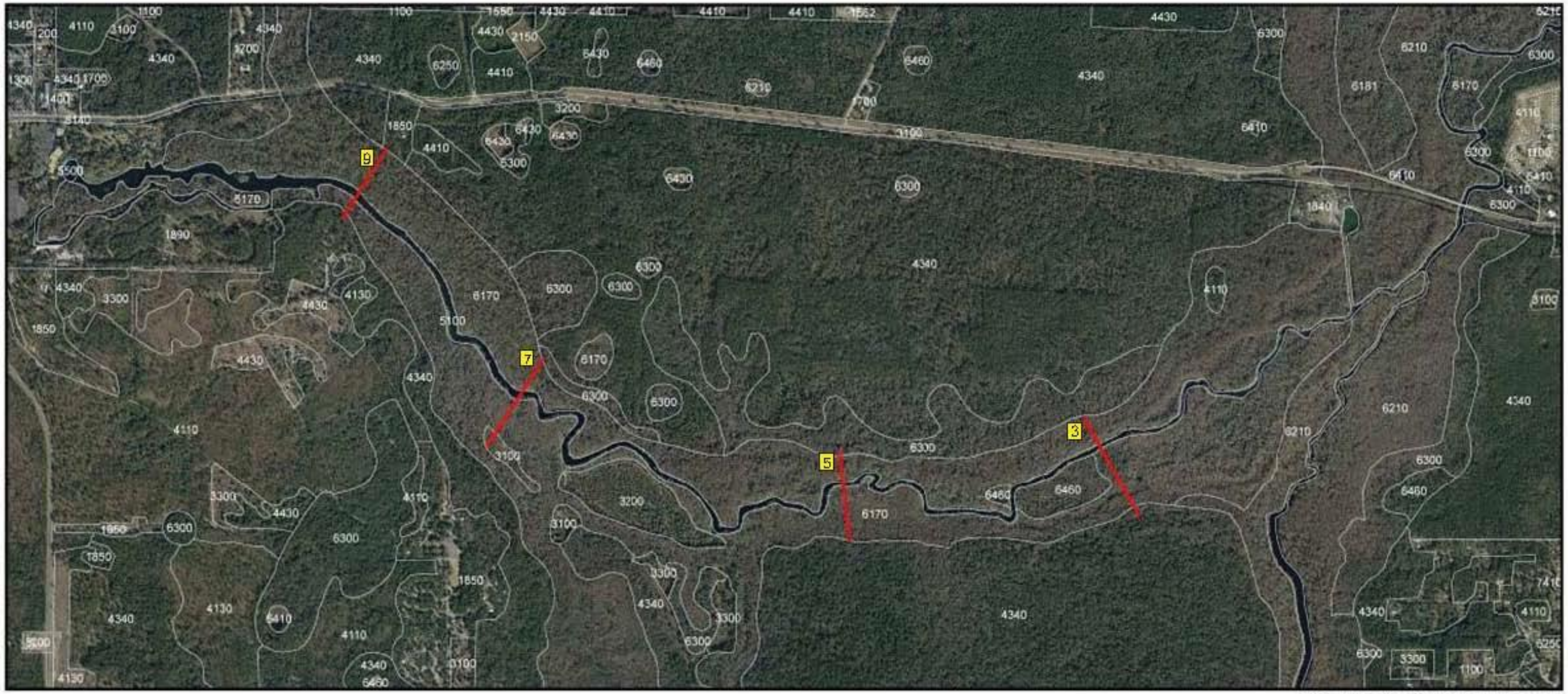


Figure 2-8. Silver River land use and land cover.

(MFL transects noted in red)

Source: SJRWMD 2004.

0 0.25 0.5 1 Miles

Key to Land Use and Land Cover Codes Contiguous to Silver River or within MFL Transects	
3000: Upland Nonforested	6000: Wetlands
3100: Herbaceous upland nonforested	6100: Wetland hardwood forests
3200: Shrub and brushland (wax myrtle or saw palmetto, occasionally scrub oak)	6170: Mixed wetland hardwoods
4000: Upland Forests (25% forested cover)	6200: Wetland coniferous forests
4340: Upland mixed coniferous/hardwood	6210: Cypress
5000: Water	6300: Wetland forested mixed
5100: Streams and waterways	6400: Vegetated non-forested wetlands
5500: Major springs	6460: Mixed scrub-shrub wetland

3.0 BACKGROUND ON MFLS DEVELOPMENT

Sutherland et al. (2017) provides a detailed description of the methodology for determining the recommended MFLs for Silver Springs. This section provides background on the MFLs determination process for Silver Springs.

Minimum Flows and Levels (MFLs) provide an effective tool to assist in making sound water management decisions that prevent significant adverse impacts due to water withdrawals to the water resources or ecology of the area. MFLs at SJRWMD are established as multiple hydrologic events to protect an ecosystem's natural hydrologic variability and the resources that depend on these inter-annual fluctuations. Minimum flows, which are set for springs and riverine systems, are events with three components: magnitude (flow, in cfs), duration (in days) and frequency (in years). These critical events set the limit of available water, beyond which further water withdrawals would be significantly harmful to the ecological structure and/or function, or other beneficial uses of a given water body. These recommended MFLs events are based on the hydrologic regime necessary to protect environmental functions and values over the long-term. As such, the recommended return intervals are the average number of events required over the long-term, recognizing that event frequency may vary between long periods of wet and drought conditions. Because the recommended MFLs events are long-term averages, they were also assessed using the long-term period of record for Silver Springs.

Recommended minimum flows were developed for Silver Springs using an event based approach. Three minimum flows are recommended (Table 3-1), based on criteria developed from vegetation, soils and topography data.

Table 3-1. Recommended minimum flows for Silver Springs, Marion County, Florida

Minimum Flows	Flow (cfs)	Duration (days)	Return Interval (years)
Frequent high (FH)	828	30	5
Average (MA)	638	180	1.7
Frequent low (FL)	572	120	3

The recommended FH (828 cfs, 30-days, with a 5-year return interval) is based on providing a sufficient numbers of flood events to protect the entire extent of floodplain wetlands and their wildlife habitat values. These flood events also promote filtration and absorption of nutrients and other pollutants on the floodplain.

The recommended MA (638 cfs, 180-days, with a 1.7-year return interval) prevents an excessive number of dewatering events in order to protect organic soils from oxidation and subsidence and avoid adverse impacts to habitat and water quality.

The recommended FL (572 cfs, 120-days, with a 3-year return interval) prevents an excessive number of dewatering events in order to protect marsh ecotones along the Silver River and their associated wildlife values. The FL also maintains an appropriate water table level in soils of the floodplain during periodic droughts. It is assumed that if the essential characteristics of the natural seasonal flooding and drying regimes are maintained, then the basic structure and functions of a given environmental system will be maintained.

Although the recommended MFLs were developed primarily to protect riparian floodplain ecological functions, they will also protect the in-stream aquatic ecosystem from significant harm. HEC-RAS model simulations indicate that the amount of flow reduction allowed by the Silver Springs MFLs will not appreciably impact the magnitude or spatial distribution of in-channel velocities. Physical channel morphology, submerged aquatic macrophyte beds, and ecosystem metabolism parameters should be maintained.

The SJRWMD is charged with determining the threshold of significant harm caused by water withdrawals, and to separate the effects of groundwater withdrawals from those of climate (i.e., drought) on the hydrology of priority water bodies. Impact on the Upper Floridan Aquifer (UFA), estimated as flow reduction due to groundwater withdrawals, was estimated using the best available tool, version 5 of the Northern District Model (NDMv5) regional groundwater model. A flow reduction of 26 cfs was estimated, based on the NDMv5, to be the flow reduction currently occurrings do to groundwater withdrawals.

The NDMv5 estimate of flow reduction represents the change from a no-pumping condition to the baseline condition. The baseline condition represents a best estimate of current impacted condition, and for the Silver Springs MFL is defined as the 2010-pumping condition. The baseline condition incorporates the natural variability of the spring flow time series, as if impacted by flow reduction equal to that caused by 2010 water use.

MFLs status was assessed using frequency analysis (described in detail below) to compare the frequency of critical ecological events under baseline conditions to the frequency of those same events based on the recommended MFLs. Frequency analyses indicate that all three recommended MFLs for Silver Springs are currently being achieved under baseline conditions. Freeboards of 98 cfs, 19 cfs, and 17 cfs were calculated for the FH, MA and FL, respectively. The most constraining MFL is the FL, with a freeboard of 17 cfs. Based on the best available information, including the NDMv5 groundwater model, the predicted flow reduction resulting from projected water use for the 20-year planning horizon is more than 17 cfs. Therefore, the proposed MFLs for Silver Springs are not achieved for the 20-year planning horizon, and a prevention strategy is required. Based on the best available data, approximately 3.5% has already occurred from a no-pumping to baseline condition. The recommended minimum flow allows an additional 2.5 percent reduction, for a total of 6 percent reduction from no-pumping to the MFLs condition.

The SJRWMD concludes that the recommended MFLs, which have been developed primarily for the protection of significant harm to “fish and wildlife habitats and the passage of fish” and “filtration and absorption of nutrients & other pollutants”, will protect all other relevant Rule 62-40.473, F.A.C., environmental values. Because these MFLs protect the structure and function of wetlands and aquatic habitats, other functions and values related to ecological integrity (e.g., nutrient filtration, detrital transport) will likely be protected from significant ecological harm caused by withdrawals, if the FH, MA and FL criteria are protected. The recommended MFLs presented in this report are preliminary and will not become effective until adopted by the SJRWMD Governing Board as rule, in Rule 40C-8.031, F.A.C.

4.0 PROCEDURE FOR EVALUATING WATER RESOURCE VALUES

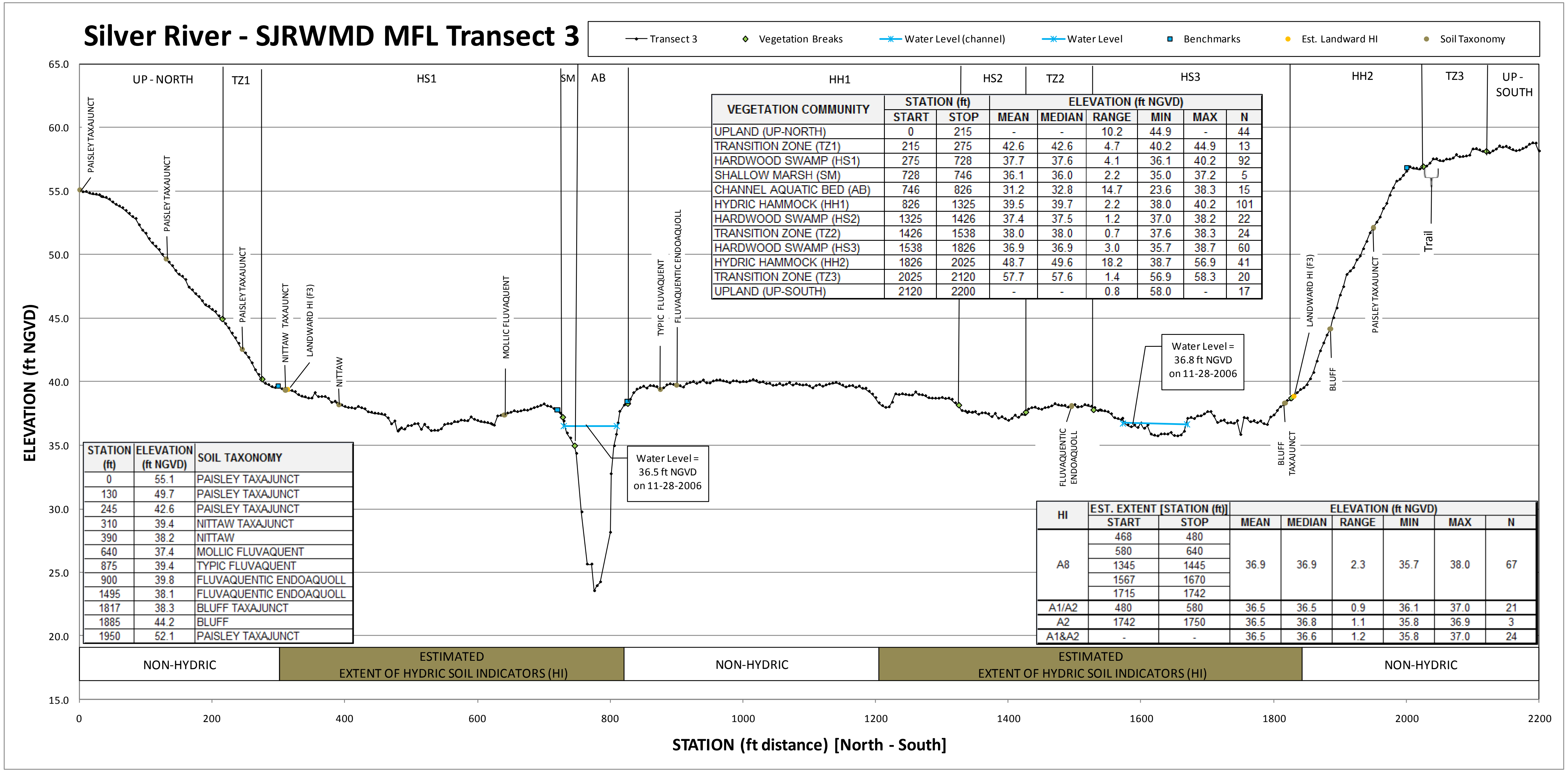
Applied Technology and Management, Inc. (ATM) was contracted by the SJRWMD to evaluate whether or not the minimum flows for Silver Springs recommended by Sutherland et al. (2017) will protect the 10 WRVs for Silver Springs and Silver River. This section describes the method for evaluating the WRVs in the context of the draft MFLs. The WRV evaluation was conducted using no-pumping conditions, and MFLs hydrologic regimes.

The 10 WRVs were assessed at numerous locations along the Silver River (Figure 2-5). As discussed in more detail in subsequent sections, the WRV assessments consider how changes in the frequency of high or low water events (stage and/or flow) may affect both the river channel and the adjacent floodplain at each of the four MFLs transects (Figures 4-1 through 4-4) and at other locations surveyed along the river's reach.

The four MFLs transects correspond to cross-sections surveyed across the river channel and the width of the adjacent floodplain. Eleven cross-sections were surveyed for use in the Silver River Hydrologic Engineering Center's River Analysis System (HEC-RAS) model (Figure 4-5). The HEC-RAS transects resulting from this effort are presented in Appendix C. SJRWMD selected four of these cross-section locations (S9, S7, S5, and S3), which correspond to MFLs transects T9, T7, T5, and T3, as the MFLs evaluation points.

SJRWMD staff performed shallow-water soundings in shallow-water areas both within the Silver Springs attraction area (now Silver Springs State Park) and in areas downstream to describe bathymetry in areas particularly at risk during low river stages. Figure 4-6 presents the location of shallow-water soundings in the upper Silver River within the Silver Springs State Park. The shallow-water sounding transects resulting from this effort are presented in Appendix D.

The analytical approach for this work effort is frequency analysis and parallels SJRWMD methods to develop the MFLs (i.e., by identifying ecologically meaningful thresholds defined by magnitude, duration, and return interval components). Working definitions of protection of WRVs proposed for this project are as follows.

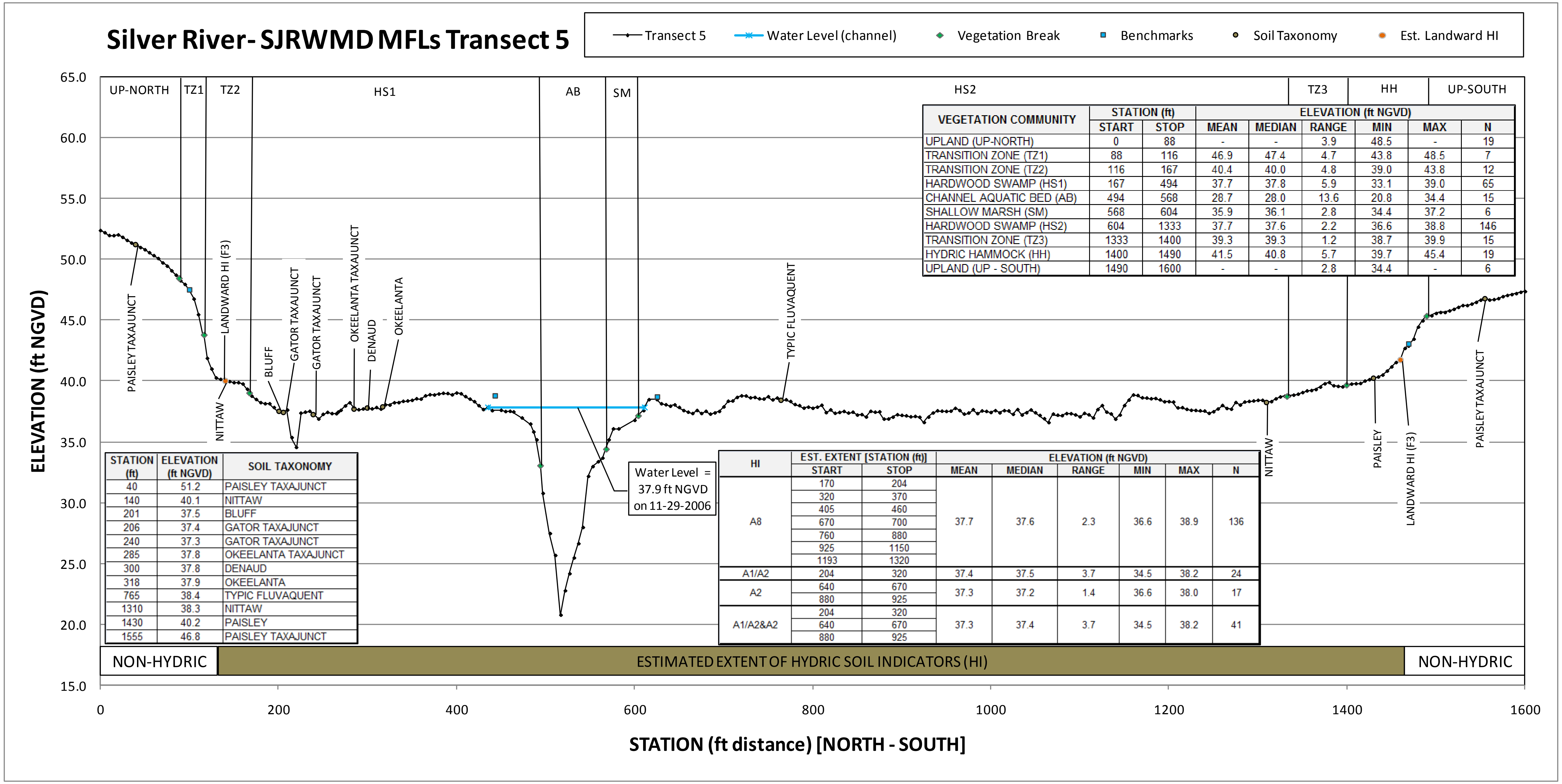


VEGETATION COMMUNITY	STATION (ft)		ELEVATION (ft NGVD)					
	START	STOP	MEAN	MEDIAN	RANGE	MIN	MAX	N
UPLAND (UP-NORTH)	0	215	-	-	10.2	44.9	-	44
TRANSITION ZONE (TZ1)	215	275	42.6	42.6	4.7	40.2	44.9	13
HARDWOOD SWAMP (HS1)	275	728	37.7	37.6	4.1	36.1	40.2	92
SHALLOW MARSH (SM)	728	746	36.1	36.0	2.2	35.0	37.2	5
CHANNEL AQUATIC BED (AB)	746	826	31.2	32.8	14.7	23.6	38.3	15
HYDRIC HAMMOCK (HH1)	826	1325	39.5	39.7	2.2	38.0	40.2	101
HARDWOOD SWAMP (HS2)	1325	1426	37.4	37.5	1.2	37.0	38.2	22
TRANSITION ZONE (TZ2)	1426	1538	38.0	38.0	0.7	37.6	38.3	24
HARDWOOD SWAMP (HS3)	1538	1826	36.9	36.9	3.0	35.7	38.7	60
HYDRIC HAMMOCK (HH2)	1826	2025	48.7	49.6	18.2	38.7	56.9	41
TRANSITION ZONE (TZ3)	2025	2120	57.7	57.6	1.4	56.9	58.3	20
UPLAND (UP-SOUTH)	2120	2200	-	-	0.8	58.0	-	17

STATION (ft)	ELEVATION (ft NGVD)	SOIL TAXONOMY
0	55.1	PAISLEY TAXAJUNCT
130	49.7	PAISLEY TAXAJUNCT
245	42.6	PAISLEY TAXAJUNCT
310	39.4	NITTAW TAXAJUNCT
390	38.2	NITTAW
640	37.4	MOLLIC FLUVAQUENT
875	39.4	TYPIC FLUVAQUENT
900	39.8	FLUVAQUENTIC ENDOAQUOLL
1495	38.1	FLUVAQUENTIC ENDOAQUOLL
1817	38.3	BLUFF TAXAJUNCT
1885	44.2	BLUFF
1950	52.1	PAISLEY TAXAJUNCT

HI	EST. EXTENT [STATION (ft)]		ELEVATION (ft NGVD)					
	START	STOP	MEAN	MEDIAN	RANGE	MIN	MAX	N
A8	468	480	36.9	36.9	2.3	35.7	38.0	67
	580	640						
	1345	1445						
	1567	1670						
	1715	1742						
A1/A2	480	580	36.5	36.5	0.9	36.1	37.0	21
A2	1742	1750	36.5	36.8	1.1	35.8	36.9	3
A1&A2	-	-	36.5	36.6	1.2	35.8	37.0	24

Figure 4-1. Graph of Silver River SJRWMD MFLs Transect 3 with vegetation cover estimate breaks, landward hydric soil indicator, profiled soil taxonomy, and organic soils (if present)
Source: SJRWMD 2011b

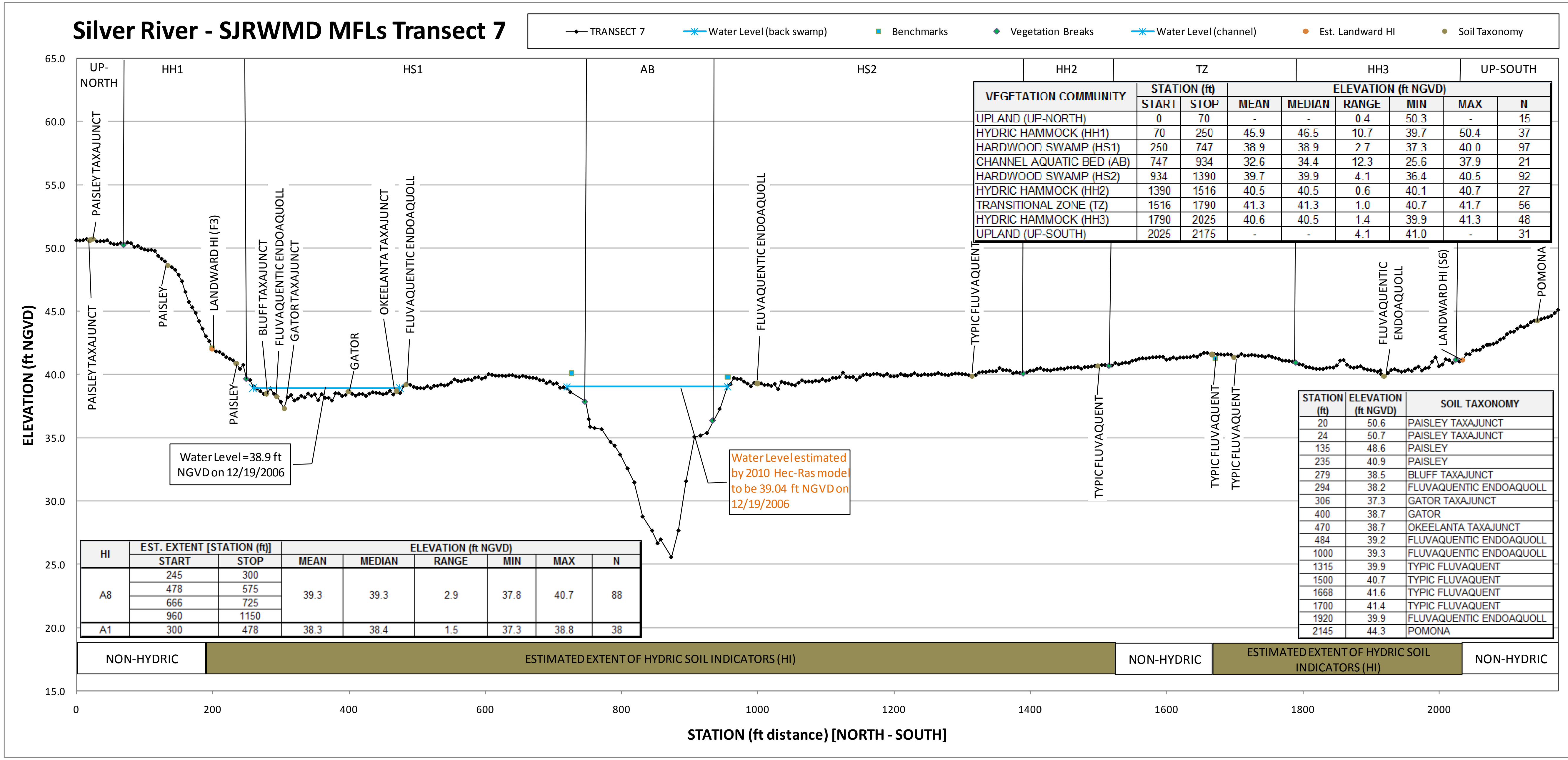


VEGETATION COMMUNITY	STATION (ft)		ELEVATION (ft NGVD)					
	START	STOP	MEAN	MEDIAN	RANGE	MIN	MAX	N
UPLAND (UP-NORTH)	0	88	-	-	3.9	48.5	-	19
TRANSITION ZONE (TZ1)	88	116	46.9	47.4	4.7	43.8	48.5	7
TRANSITION ZONE (TZ2)	116	167	40.4	40.0	4.8	39.0	43.8	12
HARDWOOD SWAMP (HS1)	167	494	37.7	37.8	5.9	33.1	39.0	65
CHANNEL AQUATIC BED (AB)	494	568	28.7	28.0	13.6	20.8	34.4	15
SHALLOW MARSH (SM)	568	604	35.9	36.1	2.8	34.4	37.2	6
HARDWOOD SWAMP (HS2)	604	1333	37.7	37.6	2.2	36.6	38.8	146
TRANSITION ZONE (TZ3)	1333	1400	39.3	39.3	1.2	38.7	39.9	15
HYDRIC HAMMOCK (HH)	1400	1490	41.5	40.8	5.7	39.7	45.4	19
UPLAND (UP - SOUTH)	1490	1600	-	-	2.8	34.4	-	6

STATION (ft)	ELEVATION (ft NGVD)	SOIL TAXONOMY
40	51.2	PAISLEY TAXAJUNCT
140	40.1	NITTAW
201	37.5	BLUFF
206	37.4	GATOR TAXAJUNCT
240	37.3	GATOR TAXAJUNCT
285	37.8	OKEELANTA TAXAJUNCT
300	37.8	DENAUD
318	37.9	OKEELANTA
765	38.4	TYPIC FLUVAQUENT
1310	38.3	NITTAW
1430	40.2	PAISLEY
1555	46.8	PAISLEY TAXAJUNCT

HI	EST. EXTENT [STATION (ft)]		ELEVATION (ft NGVD)					
	START	STOP	MEAN	MEDIAN	RANGE	MIN	MAX	N
A8	170	204	37.7	37.6	2.3	36.6	38.9	136
	320	370						
	405	460						
	670	700						
	760	880						
	925	1150						
	1193	1320						
A1/A2	204	320	37.4	37.5	3.7	34.5	38.2	24
A2	640	670	37.3	37.2	1.4	36.6	38.0	17
	880	925						
A1/A2&A2	204	320	37.3	37.4	3.7	34.5	38.2	41
	640	670						
	880	925						

Figure 4-2. *Graph of Silver River SJRWMD MFLs Transect 5 with vegetation cover estimate breaks, landward hydric soil indicator, profiled soil taxonomy, and organic soils (if present)*
Source: SJRWMD 2011b.

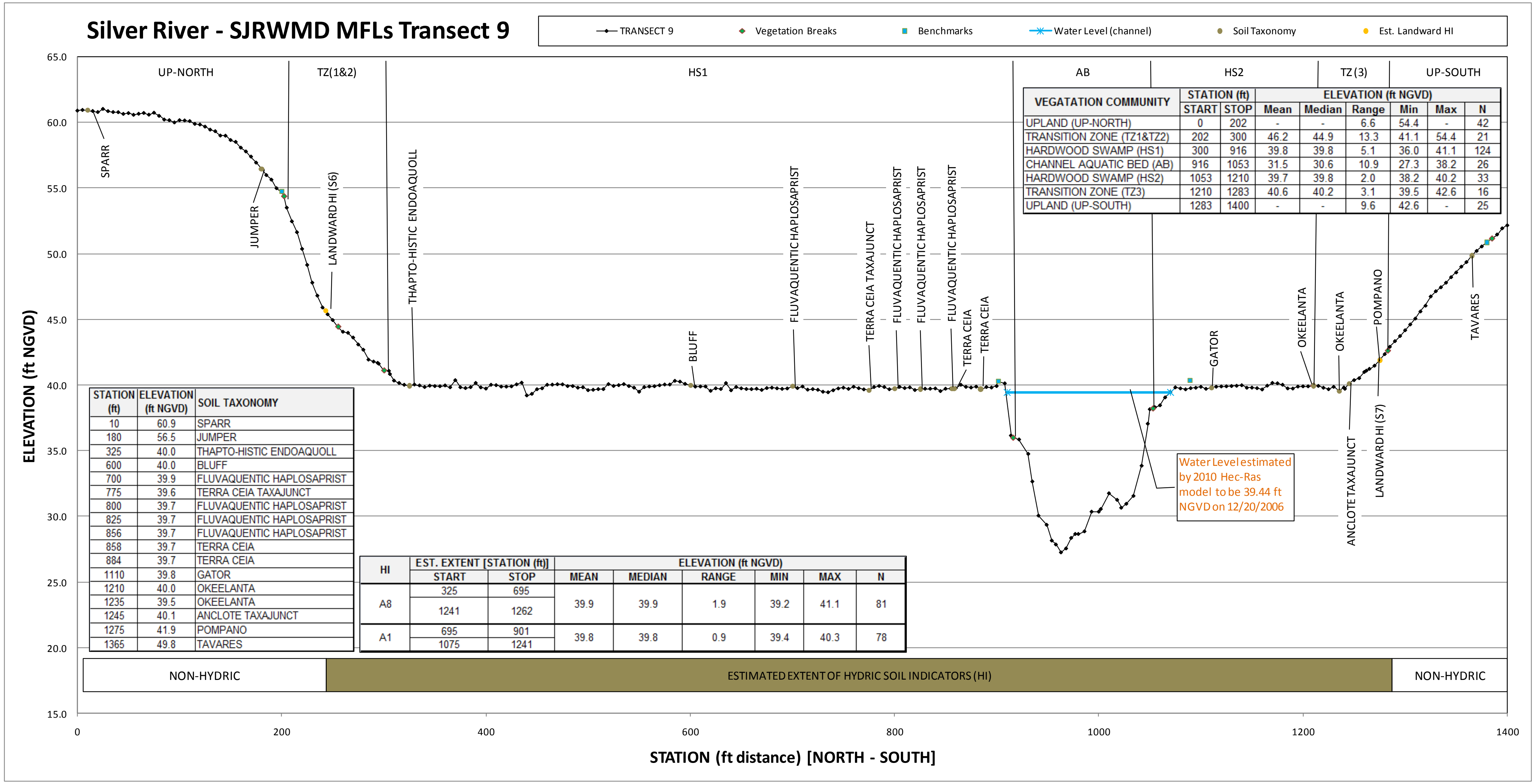


VEGETATION COMMUNITY	STATION (ft)		ELEVATION (ft NGVD)					
	START	STOP	MEAN	MEDIAN	RANGE	MIN	MAX	N
UPLAND (UP-NORTH)	0	70	-	-	0.4	50.3	-	15
HYDRIC HAMMOCK (HH1)	70	250	45.9	46.5	10.7	39.7	50.4	37
HARDWOOD SWAMP (HS1)	250	747	38.9	38.9	2.7	37.3	40.0	97
CHANNEL AQUATIC BED (AB)	747	934	32.6	34.4	12.3	25.6	37.9	21
HARDWOOD SWAMP (HS2)	934	1390	39.7	39.9	4.1	36.4	40.5	92
HYDRIC HAMMOCK (HH2)	1390	1516	40.5	40.5	0.6	40.1	40.7	27
TRANSITIONAL ZONE (TZ)	1516	1790	41.3	41.3	1.0	40.7	41.7	56
HYDRIC HAMMOCK (HH3)	1790	2025	40.6	40.5	1.4	39.9	41.3	48
UPLAND (UP-SOUTH)	2025	2175	-	-	4.1	41.0	-	31

HI	EST. EXTENT [STATION (ft)]		ELEVATION (ft NGVD)					
	START	STOP	MEAN	MEDIAN	RANGE	MIN	MAX	N
A8	245	300	39.3	39.3	2.9	37.8	40.7	88
	478	575						
	666	725						
	960	1150						
A1	300	478	38.3	38.4	1.5	37.3	38.8	38

STATION (ft)	ELEVATION (ft NGVD)	SOIL TAXONOMY
20	50.6	PAISLEY TAXAJUNCT
24	50.7	PAISLEY TAXAJUNCT
135	48.6	PAISLEY
235	40.9	PAISLEY
279	38.5	BLUFF TAXAJUNCT
294	38.2	FLUVAQUENTIC ENDOAQUOLL
306	37.3	GATOR TAXAJUNCT
400	38.7	GATOR
470	38.7	OKEELANTA TAXAJUNCT
484	39.2	FLUVAQUENTIC ENDOAQUOLL
1000	39.3	FLUVAQUENTIC ENDOAQUOLL
1315	39.9	TYPIC FLUVAQUENT
1500	40.7	TYPIC FLUVAQUENT
1668	41.6	TYPIC FLUVAQUENT
1700	41.4	TYPIC FLUVAQUENT
1920	39.9	FLUVAQUENTIC ENDOAQUOLL
2145	44.3	POMONA

Figure 4-3. Graph of Silver River SJRWMD MFLs Transect 7 with vegetation cover estimate breaks, landward hydric soil indicator, profiled soil taxonomy, and organic soils (if present)
Source: SJRWMD 2011b.

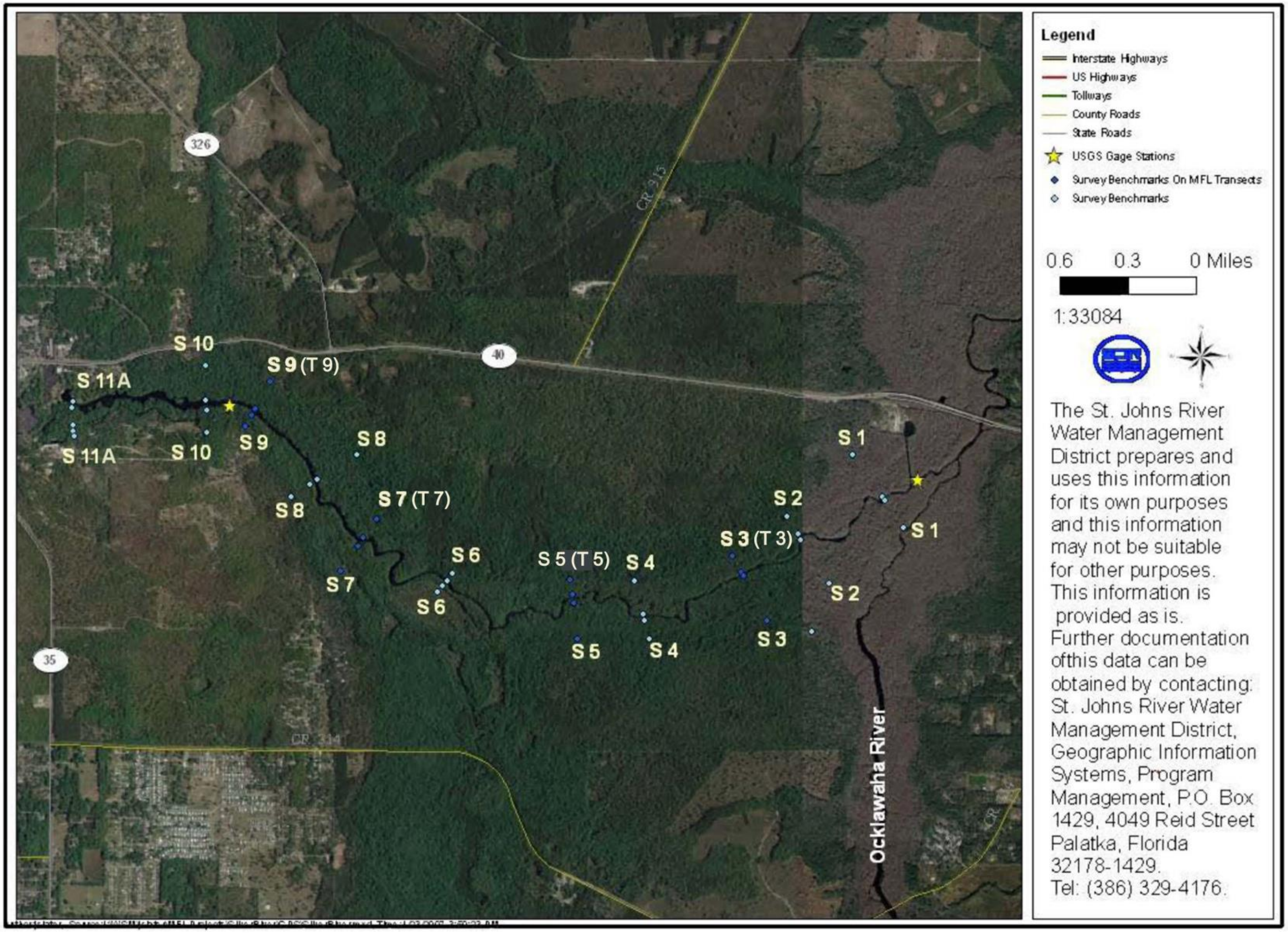


VEGATATION COMMUNITY	STATION (ft)		ELEVATION (ft NGVD)					
	START	STOP	Mean	Median	Range	Min	Max	N
UPLAND (UP-NORTH)	0	202	-	-	6.6	54.4	-	42
TRANSITION ZONE (TZ1&TZ2)	202	300	46.2	44.9	13.3	41.1	54.4	21
HARDWOOD SWAMP (HS1)	300	916	39.8	39.8	5.1	36.0	41.1	124
CHANNEL AQUATIC BED (AB)	916	1053	31.5	30.6	10.9	27.3	38.2	26
HARDWOOD SWAMP (HS2)	1053	1210	39.7	39.8	2.0	38.2	40.2	33
TRANSITION ZONE (TZ3)	1210	1283	40.6	40.2	3.1	39.5	42.6	16
UPLAND (UP-SOUTH)	1283	1400	-	-	9.6	42.6	-	25

STATION (ft)	ELEVATION (ft NGVD)	SOIL TAXONOMY
10	60.9	SPARR
180	56.5	JUMPER
325	40.0	THAPTO-HISTIC ENDOAQUOLL
600	40.0	BLUFF
700	39.9	FLUVAQUENTIC HAPLOSAPRIST
775	39.6	TERRA CEIA TAXAJUNCT
800	39.7	FLUVAQUENTIC HAPLOSAPRIST
825	39.7	FLUVAQUENTIC HAPLOSAPRIST
856	39.7	FLUVAQUENTIC HAPLOSAPRIST
858	39.7	TERRA CEIA
884	39.7	TERRA CEIA
1110	39.8	GATOR
1210	40.0	OKEELANTA
1235	39.5	OKEELANTA
1245	40.1	ANCLOTE TAXAJUNCT
1275	41.9	POMPANO
1365	49.8	TAVARES

HI	EST. EXTENT [STATION (ft)]		ELEVATION (ft NGVD)					
	START	STOP	MEAN	MEDIAN	RANGE	MIN	MAX	N
A8	325	695	39.9	39.9	1.9	39.2	41.1	81
	1241	1262						
A1	695	901	39.8	39.8	0.9	39.4	40.3	78
	1075	1241						

Figure 4-4. *Graph of Silver River SJRWMD MFLs Transect 9 with vegetation cover estimate breaks, landward hydric soil indicator, profiled soil taxonomy, and organic soils (if present) Source: SJRWMD 2011b.*



Note: T9, T7, T5, and T3 are MFL transects.

Figure 4-5. HEC-RAS model cross sections
Source: SJRWMD 2010a.

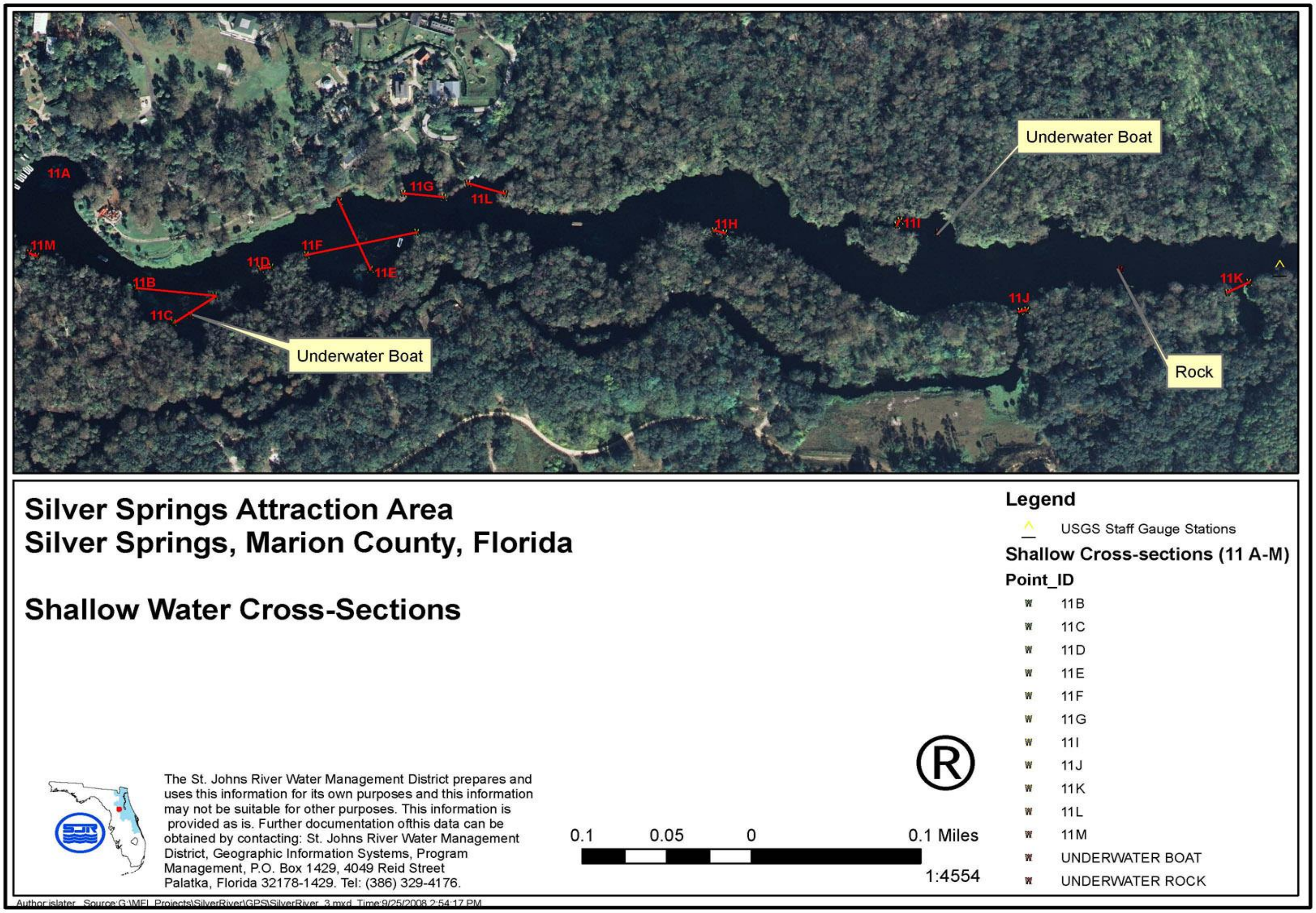


Figure 4-6. *Silver Springs shallow water cross-sections 11A-M*
Source: SJRWMD (2013)

High flow (flooding): related WRVs are considered protected if, under a MFLs flow regime, a critical high-flow event of a specified magnitude and duration does not occur too infrequently when compared to the high-flow event frequency under long-term no-pumping conditions.

Low flow (dewatering) - related WRVs are considered to be protected if, under a MFLs flow regime, the low-flow event of a specified magnitude and duration does not occur too frequently compared to the low-flow event frequency under long-term no-pumping conditions.

Each WRV represents a broad class of functions, processes and/or activities that require consideration of protection. A four-level hierarchical approach was utilized to assess whether the MFLs hydrologic regime was protective of each WRV. This approach, described below, moves from broad, general definitions to more specific criteria of protection, then to general indicators of protection and, finally, to specific indicators of protection that can be measured and assessed. The indicators should reflect characteristics that are most sensitive to changes in hydrology and should be applied to the most sensitive portion of the system being evaluated.

Level 1- Restate the WRV in terms of criteria that are specific to the water body being evaluated. Include the definition of the WRV as provided by the SJRWMD.

Level 2- Identify a representative function, process, or activity that should be very sensitive or possibly the most sensitive to changes in the return interval of high or low flow or stage events. This function, process, or activity should be one for which data resources are available.

Level 3- Identify a general indicator for the protection of that function, process, or activity.

Level 4- Identify a specific indicator of protection in terms of magnitude, duration, and return interval or frequency. Include an assessment of the change in the number of events per century under the no-pumping condition and the MFLs hydrologic regimes.

An example with WRV 1 for the Silver River follows:

Level 1- Recreation in and on the water is defined as the active use of water resources and associated natural systems for personal activity and enjoyment. The criteria for protection of this WRV are "legal water sports and activities."

Level 2- Recreational boat passage for canoes, kayak, and motor boats is the representative function used to assess protection of this WRV.

Level 3- Sufficient water depth in the main channel and shallow-water areas in the upper part of the run to allow safe recreational boat passage is the general indicator to protect this WRV.

Level 4- The specific indicator is a low water level event, of the specific magnitude and specific duration, resulting in insufficient depth and cross-sectional areas at hydraulic controls in the main channel and shallow-water areas in the upper part of the run. The WRV is considered protected if the return interval of this event does not increase beyond the return interval of the threshold value selected to protect this WRV.

The 10 WRVs are present at varying levels in each waterbody, taking on different levels of importance. In a no-pumping condition, they will naturally occur at some level although it is possible for a water body to not exhibit all 10 WRVs (i.e. navigation in a very shallow spring run). The WRV is considered protected if there is not an unacceptable change in the frequency of threshold violations (i.e., Level 4) between the no-pumping condition hydrologic regime and the MFLs hydrologic regime that would indicate loss of that WRV at whatever level or importance from what existed in the no-pumping or natural condition. This hierarchical approach was applied to all WRVs.

Frequency analysis, as it is applied to evaluating WRV protection, involved the following five steps. The details for Steps 1 through 3 are discussed in Karama et al. (2016).

1. Generate hydrographs for the river flows and stages based on the existing flow and stage record.
2. Generate synthetic hydrographs for the river flow and stages for the no-pumping hydrologic condition.
3. Generate synthetic hydrographs for river flow and stage for the MFLs scenario.
4. For each WRV, select a key water resource criterion (e.g., boat passage, fish passage, sediment transport) that is most sensitive to changes in hydrology.

5. Develop relevant high- and low-flow/stage frequency statistics curves from hydrographs developed in Steps 1 and 2 and evaluate the return intervals of a specific critical event under the no-pumping condition and MFLs hydrologic regimes to determine if the WRV is protected.

Karama et al. (2016) developed daily stage and flow time series for the Silver River for the no-pumping and MFLs hydrologic regimes covering the time period from 1946 through 2014, from which the high- and low-flow/level frequency statistics were developed. SJRWMD provided the frequency analysis, which encompasses three types of events: (1) minimum average stages or flows, (2) maximum stages or flows continuously exceeded, and (3) minimum stages or flows continuously not exceeded. Frequency statistics were developed at T9, T7, T5, and T3 for each of these event-types for the no-pumping condition and MFLs hydrologic regimes for 1-, 7-, 14-, 30-, 60-, 90-, 120-, 183-, 273-, and 365-day durations (Appendix E).

For each WRV, the difference in the frequencies of the selected WRV event between the no-pumping condition and the MFLs hydrologic regimes was evaluated. Each of the WRVs was evaluated by identifying key hydrologic conditions that were relevant to that WRV. Through analyses of all the WRVs, using a common quantitative approach, including WRVs that involved more complex processes (e.g., fish and wildlife and the passage of fish), along with supporting literature and discussion, a professional judgment was made for whether the WRV is protected under the MFLs hydrologic regime.

Available information was researched to support the selection of the specific indicator parameter(s) and duration(s) for each WRV assessment. This consideration dictated that the selection of general and specific indicators of WRV protection (Level 3 and 4) be conducted by a team of senior professionals with in-depth knowledge of biology, ecology, hydrology, and cultural practices. Table 4-1 summarizes the WRV hierarchy for evaluating the MFLs hydrologic scenarios for the Silver River.

Table 4-1. WRV hierarchy for hydrologic scenarios evaluation for the Silver River						
WRV		Criteria	Representative Functions	General Indicator	Specific Indicator	Event
1.	Recreation in and on the Water	Legal water sports and activities	Recreational boat passage for canoes, kayak, and motor boats	Water depth in river channel and shallow-water areas	Sufficient water level in river channel and shallow-water areas to accommodate canoes, kayaks, and motor boats	1- and 7-day low stage continuously not exceeded
2.	Fish and Wildlife Habitat and the Passage of Fish	Aquatic and wetland environments required by fish and wildlife	Fish Passage	Water depth in river channel	0.8 ft water depth across 25% of channel cross-section	7-day low flow continuously not exceeded
			Fish/Shellfish Habitat	Water flow in river channel	Minimal (< 0.1 ft/sec) reduction in water flow velocity	1-day low flow continuously not exceeded
			Floodplain inundation for fish, birds, and wetland vegetation	Floodplain inundation duration	Inundation to hardwood swamp mean elevation	30-day critical water level continuously exceeded
			Floodplain inundation to protect hydric soils	Floodplain inundation duration	Inundation to 0.3 ft below organic soil mean elevation	180-day critical water level not exceeded
			Manatee protection (warm water refuge)	Water temperature & depth	Bottom water temperature exceeds 68°F and water depth exceeds 5.0 ft	1-day critical water level not exceeded
3.	Estuarine Resources	Coastal systems and associated natural resources	Salinity fluctuations in the estuary	Large salinity zone shifts that are associated with changes in the hydrologic regime.	Flow variations in the subject section of the river that may influence the occurrence of extreme salinity events.	Not applicable. Utilized findings of the St. Johns River Water Supply Impact Study (Draft Final Report, 2011)
4.	Transfer of Detrital Material	The movement of loose organic material and debris and associated decomposing biota	Water depth and floodplain inundation in the spring run	Water stage to maintain detrital transfer to the Silver River	Stage associated with depth and area of inundation for transfer of detrital material into suspension in the Silver River	7- and 30-day high stage continuously exceeded
5.	Maintenance of Freshwater Storage and Supply	The amount(s) of surface water and groundwater needed for non-consumptive uses	The maintenance of adequate surface water levels, flows, and aquifer levels in the area adjacent to the water body.	Aquifer levels, surface water levels and flows that do not result in adverse impacts to the water body.	Evaluation as to whether the groundwater-surface water interactions will change because of flow reductions in Silver River to the extent that WRVs are not protected	Protection of this WRV is dependent on the other WRV assessments. No event specific to this WRV is used.
6.	Aesthetics and Scenic Attributes	Passive recreation	Visual setting at selected points	Water level and clarity	Water level associated with optimal scenic and wildlife viewing	30- and 90-day low stage continuously not exceeded
7.	Filtration and Absorption of Nutrients and Other Pollutants	The process of absorption and filtration	Ability of water to promote nutrient removal in the river and adjacent wetlands	Depth and duration of floodplain inundation and residence time	Return intervals of stages associated with selected duration sufficient to maintain contact with riparian vegetation and residence time similar to no-pumping conditions	14-day and 30-day high stage continuously exceeded
8.	Sediment Loads	The process of sediment movement and deposition	Water velocities and flow	Changes in velocity and bed shear stress	Flows associated with velocity and bed shear stress necessary for sediment mobilization and transport	7-day and 30-day high flows continuously exceeded

Table 4-1. WRV hierarchy for hydrologic scenarios evaluation for the Silver River

WRV		Criteria	Representative Functions	General Indicator	Specific Indicator	Event
9.	Water Quality	Chemical and physical properties of the water	The concentration of key chemicals/ indicators in the springs.	Maintenance of discharge events for maintenance of acceptable water quality to support a healthy aquatic community	Differences in frequency, duration and return interval of events within the water column necessary to maintain adequate protection of water resource	1-day low flow continuously not exceeded
10.	Navigation	Legal operation of eco-tourism and commercial fishing vessels	Area access	Water depth in river	Water level associated with minimum river channel depth and clearance over shallow-water areas for ecotourism vessel operation	1-day and 7-day low stage continuously not exceeded

5.0 EVALUATION OF WATER RESOURCE VALUES

5.1 WRV-1: RECREATION IN AND ON THE WATER

Recreation in and on the Water is defined as the active use of water resources and associated natural systems for personal activity and enjoyment. The criterion for protection for *Recreation in and on the Water* is all legal water sports and activities (Table 4-1). The Silver River is entirely contained within the boundaries of Silver Springs State Park and the state park rules, in turn, dictate allowable water sports and activities, which, at Silver Springs State Park, is limited to boating (http://floridastateparks.org/silverriver/default.cfm). Accordingly, the representative function used to assess the effect of the MFLs hydrologic regime is recreational boat passage, specifically pontoon boats, motorboats, and canoes/kayaks. The water depth at the four MFLs transects (Figure 2-5) and the sounding transects in the upper spring run (Figure 4-6) provides both the general and specific indicators regarding protection of the boating function.

The former Silver Springs theme park was combined with the Silver River State Park and opened on October 1, 2013 as the Silver Springs State Park. There are on-going efforts to transition the park to native landscapes, develop interpretive programs, improve stormwater quality treatment, and to restore portions of the area to their former physical state. Storm water improvements have been installed and impervious paving areas reduced. Available activities at the park include canoeing and kayaking, boat tours including the famous glass-bottomed boats, nature viewing, concessions, camping, hiking, mountain biking and equestrian trails and event hosting. Fishing and swimming are not allowed at this time.

Boating access to the Silver River is provided at three points (Figure 2-5). Boats on trailers access the river through Marion County's Ray Wayside Park boat basin, located at the western end of the Ocklawaha River Bridge on State Road 40. The park provides boat ramps and a canoe/kayak launch. Access from the boat basin to the Silver River is through an excavated 1,200-ft-long channel, which connects to the Silver River approximately 1,300 ft. upstream from its confluence with the Ocklawaha River. Boats may also enter the Silver River via the Ocklawaha River. The final boating access option is to launch from the River Trail canoe and kayak dock inside the Silver River State Park. The River Trail launch point is limited to canoes and kayaks since the launch point is accessed via a 0.6-mile-long trail, and boats must be carried from the main parking lot (http://www.floridastateparks.org/silverriver/activities.cfm#17).

Motor-powered boats must observe no-wake speeds while on the Silver River. Boats may not land at any point along the Silver River, except the canoe/kayak put-in/take-out ramp at River Trail. Boats using the Silver River may travel all the way to the head of the river at the main spring boil, but may not land.

Protection of the recreational boating function is dependent on adequate water depths during low-flow conditions. River bottom elevations for the four MFLs transects were determined from field survey of these transects (Figures 4-1 through 4-4). Even during the lowest recorded water level, water depths at all four MFLs transects were in excess of 10 ft, and over 14 ft at T5. This illustrates that single boat passage in the river channel is not an issue.

While not a recreational boater, Captain Tom O'Lenick operates an ecotourism business that runs guided boat tours along the length of the Silver River. He uses an approximately 20-ft-long pontoon boat, with an outboard motor and a 15-inch draft (approximate total depth of 2 ft.) that would be typical of the size and type of many recreational boats on the Silver River. Further descriptions were provided by Mike Young, Operations Manager for the Silver Springs theme park (personal communication, 2010), who described typical recreational boats he sees on the river as canoes, kayaks, jon boats, small outboard-powered runabouts, and 18- to 24-ft pontoon boats. Mr. Young added that occasionally someone will navigate a surprisingly large vessel up the river to the main spring. In comparison, the enclosed glass-bottom boats associated with the Silver Springs attraction require a minimum depth of 2.5 ft. for propeller clearance, based on measurements taken by SJRWMD staff with assistance from attraction staff. These boats will be evaluated as part of WRV 10, *Navigation*.

With regard to water levels for recreational boating, Captain O'Lenick has been in business since 1983 and estimates he is on the Silver River 200 days per year, and perhaps more than 5,000 times in total. A typical Silver River ecocruise for Captain O'Lenick runs from the Ray Wayside Park boat basin to the head of the river and back, requiring approximately 3.5 hours.

For all the years Captain O'Lenick has been on the Silver River, he recalls the lowest water levels occurred in 2000/2001 (personal communication, August 19, 2010). This description is consistent with the water level stage record for that time period, but comparably low stages also occurred in 1990 and 1985, the early 1970s, and mid-1950s. However, even at the low water levels experienced by O'Lenick, he states that he had no problem navigating the river, and there was always sufficiently deep water in mid-river.

Protection of the recreational boating function is dependent on maintaining sufficient water level in river channel and shallow-water areas to accommodate canoes, kayaks, and motor boats Figure 5-1 presents an example of how the evaluation was performed. Two areas where these events would be most critical would be 1) in the shallow areas in the upper reaches of the river within the attraction area and 2) in narrow sections of the river where passage of two boats simultaneously would be made more difficult.

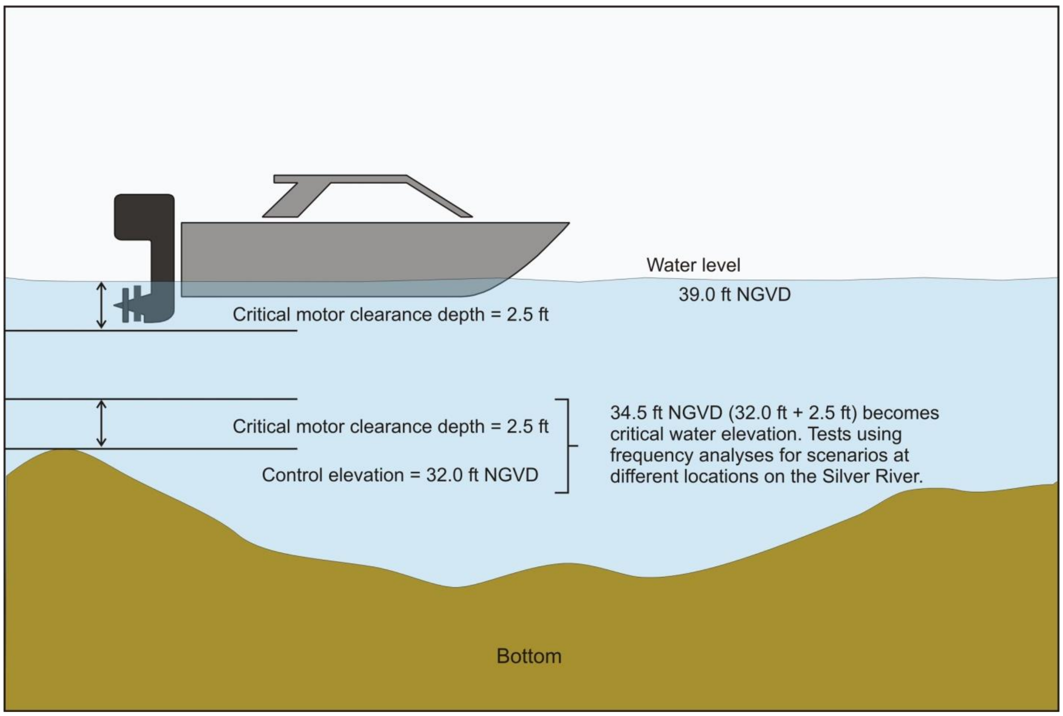


Figure 5-1. *Illustration of channel clearance critical stage for recreational boat passage (ATM 2012)*

Another scenario in which boat passage would be limited would be in areas where downed trees force boats into shallow areas of the river, potentially damaging submerged aquatic vegetation (SAV) with prop scars. This type of restriction is ephemeral and dependent upon management actions (clearing channel), and flow conditions, particularly high flows which shift downed trees into the channel and dislodge floating mats. Therefore, it was not investigated further.

Review of the shallow-water transects (Figure 4-6 and Appendix D) indicate that the most critical areas are located near the Reception Hall spring boil area and in the Blue Grotto area. The locations of these spring vent areas are presented on Figure 2-7. Specifically, shallow-water Transects 11B and11C (near the Reception Hall spring boil) and shallow-water Transects 11E and 11F (near Blue Grotto) are critical given their shallowness and the amount of regular boat traffic these areas experience. The critical stage threshold elevations (Table 5-1) were developed according to the example presented in Figure 5-1. The typical recreational motor boat has a critical motor clearance depth of approximately 2 ft as compared to a critical motor clearance depth of 2.5 ft for the Silver Springs attraction's glass-bottom boats. A 2.5-ft critical motor clearance depth was used in the calculation of the critical stage threshold elevation. The critical stage (ft-NGVD) was calculated by adding 2.5 ft. to the control elevation (typically the maximum elevation in the transect).

Table 5-1. Critical stage values at shallow-water sounding transects in Upper Silver River

Location	Shallow-Water Transect ID	Critical Stage (ft-NGVD)
Reception Hall	11B	40.2
	11C	39.3
Blue Grotto	11E	39.9
	11F	39.8

Comparison of the no-pumping condition stage levels to the MFLs hydrologic regime was conducted using the frequency analyses representing the 1-day minimum continuously not exceeded stage because the 1-day analyses have lower minimum stages than the longer duration analyses and, consequently, offer a worst-case scenario regarding water depths. Additionally, a 7-day minimum continuously not exceeded stage duration was evaluated as this duration of low water would have a greater impact on recreational boating accessibility. The critical stages were converted to comparable elevations at Station 9501 using the regression relationship between stages at USGS Station 9500 (which approximate those found at the critical shallow-water transects) and USGS Station 9501 developed by SJRWMD (Karama et al. 2016). Frequency statistics developed for Station 9501 were then used in the evaluation. SJRWMD provided the frequency analysis of stage for the two hydrologic regimes.

Tables 5-2a and 5-2b present the results of the frequency analysis of critical threshold stage for protection of recreational boating with respect to motor clearance depth. Currently, these critical events occur on average almost every year and once every 2 years at Transect 11C. This is consistent with discussions with Mr. Young and two Lost River Voyage boat captains, who indicated that they simply avoided shallow nearshore areas when necessary. Transect 11C experiences the largest increase in low-water critical events, with 19 more 7-day duration critical events per 100 years under the MFLs hydrologic regime. These critical low-water events will be occurring on average every 1.5 years. Given that the relative frequency of the low-water events remains on average once every 1 to 2 years, this WRV is considered protected under the proposed MFLs hydrologic regime.

The second condition where these low-stage events would be most critical would be in narrow sections of the river where passage of two boats simultaneously would be made more difficult. While the middle of the river channel has been shown to provide accessibility for recreational boats during all conditions, there are some locations where the river channel narrows, requiring more careful boat operation to avoid other passing boats while not impacting to shallow areas and riverbanks. The typical pontoon boat is approximately 12 ft. wide. Assuming that two similar-sized boats are passing each other, a minimum width of 50 ft is desired to provide for the two boat widths plus an additional 25 ft for buffers between the passing boats and from shallow areas and river banks.

Table 5-2a. Frequency analysis of critical threshold stage for protection of recreational boating – motor clearance depth—1-day duration low stage continuously not exceeded

Shallow-Water Sounding Transect	Critical Threshold Stage ft, NGVD	Statistic[1]	Hydrologic Scenario	
			No-Pumping Condition	MFL
11B	40.2	Events/100 yr	87	95
		Increase in Events	-	8
11C	39.3	Events/100 yr	50	71
		Increase in Events	-	21
11E	39.9	Events/100 yr	77	90
		Increase in Events	-	13
11F	39.8	Events/100 yr	73	89
		Increase in Events	-	15

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and the MFLs hydrologic regimes.

Table 5-2b. Frequency analysis of critical threshold stage for protection of recreational boating – motor clearance depth—7-day duration low stage continuously not exceeded				
Shallow-Water Sounding Transect	**Critical Threshold Stage ft, NGVD**	**Statistic[1]**	**Hydrologic Scenario**	
			No-Pumping Condition	**MFL**
11B	40.2	Events/100 yr	86	93
		Increase in Events	-	7
11C	39.3	Events/100 yr	49	68
		Increase in Events	-	19
11E	39.9	Events/100 yr	75	89
		Increase in Events	-	14
11F	39.8	Events/100 yr	71	86
		Increase in Events	-	15

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and the MFLs hydrologic regimes.

The critical threshold elevations that would provide for a minimum river-channel width of 50 ft and accommodate a 2.5-ft motor clearance depth were evaluated at the four MFLs transects so that a frequency analysis could be performed. Tables 5-3a and 5-3b present those critical threshold elevations at each of the four MFLs transects. Frequency statistics for 1- and 7-day duration continuously not exceeded stages were used to evaluate these critical threshold elevations. The results of the analysis, presented in Tables 5-3a and 5-3b, indicate that these elevations do not occur for either duration. The conclusion is that under the preliminary MFLs hydrologic scenario, the ability of two boats to pass in narrow sections of the river is protected.

Table 5-3a. Frequency analysis of critical threshold stage for protection of recreational boating – minimum river channel width—1-day duration low stage continuously not exceeded

MFL Transect	Critical Threshold Stage ft-NGVD	Statistic[1]	Hydrologic Scenario	
			No-Pumping	MFL
T3	33	Events/100 yr	0	0
		Increase in Events	-	0
T5	35.2	Events/100 yr	0	0
		Increase in Events	-	0
T7	34.6	Events/100 yr	0	0
		Increase in Events	-	0
T9	33.4	Events/100 yr	0	0
		Increase in Events	-	0

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and the MFLs hydrologic regimes.

Table 5-3b. Frequency analysis of critical threshold stage for protection of recreational boating – minimum river channel width—7-day duration low stage continuously not exceeded

MFL Transect	Critical Threshold Stage ft-NGVD	Statistic[1]	Hydrologic Scenario	
			No-Pumping	MFL
T3	33	Events/100 yr	0	0
		Increase in Events	-	0
T5	35.2	Events/100 yr	0	0
		Increase in Events	-	0
T7	34.6	Events/100 yr	0	0
		Increase in Events	-	0
T9	33.4	Events/100 yr	0	0
		Increase in Events	-	0

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and the MFLs hydrologic regimes.

5.2 WRV-2: FISH AND WILDLIFE HABITATS AND THE PASSAGE OF FISH

For this evaluation, "fish and wildlife habitat and the passage of fish" is defined as "*aquatic and wetland environments required by fish and wildlife, including endangered, endemic, listed, regionally rare, recreationally or commercially important, or keystone species, to live, grow, and migrate. These environments include hydrologic magnitudes, durations, and frequencies sufficient to support the life cycles of aquatic, wetland and wetland-dependent species*" (SJRWMD 2006). Although water quality including dissolved oxygen (DO) is an important element of fish and wildlife habitat, that component is discussed under WRV-9, *Water Quality*.

Thus, the criteria for the assessment of the protection of this WRV are "aquatic and wetland environments required by fish and wildlife."

The representative functions used to assess protection are:

1. Fish passage, and breeding and growth habitats for dominant species, based on current and historical species accounts; and
2. Habitat for other significant taxa as documented for the system, including birds and turtles.

The general indicators of protection are:

1. The relationships between dominant fish species and spring hydrology (flow and stage), and
2. The relationships between significant taxa other than fish and spring hydrology.

The specific indicators of protection are water levels and flows adequate to:

1. Allow the passage of larger dominant fish species such as the bowfin, largemouth bass, and Florida gar,
2. Provide for floodplain inundation of sufficient duration and frequency to maintain wetland habitats and organic soils,
3. Provide for floodplain inundation of sufficient duration and frequency to facilitate bird feeding and small fish breeding and growth, and
4. Maintain channel water depth and temperature sufficient for manatee refugia.

The multiple WRV criteria that are defined represent long-term minimum hydrologic requirements necessary for the protection of fish and wildlife habitat and passage of fish. The best available information was used for these analyses and was taken from the large body of scientific literature that describes the Silver Springs system. Some of the criteria have been developed to protect key umbrella species, under the assumption that protection of these representative species will also provide sufficient protection of other members of the ecological community.

Silver Springs and the Silver River have long been the subject of scientific examination and data collection. The first published reports on Silver Springs date from the 1860s, when early residents and visitors recorded accounts of the river. The first published works included a physical description of the main boil, discharge measurements, and the water's optical properties. Numerous studies were conducted in Silver Springs during the late 1940s and 1950s. Of particular importance was a program of extensive data collection and evaluation of Silver Springs and other Florida springs conducted by Dr. Howard T. Odum of the University of Florida. This multi-year springs research culminated with the publication of a landmark paper in 1957. Dr. Odum, along with numerous colleagues, quantified relationships between water quality, productivity, ecosystem structure, and energy flows for the Silver Springs system for the first time. During the late 1970s, Knight (1980, 1983) re-examined many of the relationships between system metabolism, productivity, and system structure of Silver Springs that Odum (1957) had established previously.

A recent major examination of the Silver Springs system was the *Fifty-Year Retrospective Study of the Ecology of Silver Springs, Florida* (Munch et al. 2006). Note that the CRISPS study is on-going. Water quality, flow, and ecological data collected during the study were compared to information obtained by Odum, Knight, and others to identify any changes that may have occurred during the previous 50 years. Numerous useful documents are listed at the Silver Springs Basin Working Group website (2010).

In addition to the above-listed works, numerous other researchers have examined Silver Springs, resulting in a library of peer-reviewed scientific journal publications, as well as unpublished data available from SJRWMD, USGS, the FDEP, the Florida Fish and Wildlife Conservation Commission (FWC), the U.S. Environmental Protection Agency (EPA), and the Florida Geological Survey (FGS).

Munch et al. (2006) provides a thorough description of ecological monitoring of vegetation, fish and wildlife of the Silver Springs system, which is summarized in the following sections. Water quality data collection programs are discussed under WRV-9, *Water Quality*.

Macroalgae

There have been several inventories of algae and aquatic vegetation completed for the Silver Springs system. Whitford (1954, 1956) recorded algae species in more than 100 springs in Florida. He identified five types of springs, each with different vegetation and water quality characteristics. Silver Springs was identified as a hard, freshwater spring. Dominant algae in Silver Springs were identified as *Cocconeis placentula*, *Synedra ulna, Achnanthes lanceolata, Gomphonema longiceps, Gomphonema sphaerophorum, Amphitrix* sp., and *Lyngbya wollei* (Munch et al. 2006). Whitford concluded that water velocity was the most important controlling factor for the distribution of algal plant communities in springs, rather than temperature or light effects.

Martin (1966) also inventoried vegetation in Silver Springs. He reported thick growths of the alga *Spirogyra* in the main boil and *Lyngbya* attached to exposed surfaces in the main spring boil. Stevenson et al. (2004) surveyed algae and nutrient levels in 28 springs in north and central Florida to compare algal communities in these springs and to relate those communities to nutrient (nitrogen and phosphorus) concentrations in those springs. General conclusions of Stevenson's study were that macroalgae are found in all springs (including low-nutrient sites such as Alexander Springs) and covered about half of the bottom area of all springs studied. *Vaucheria* and *Lyngbya* were the two most common macroalgae species observed. Percent cover by *Vaucheria* was related to total nitrogen concentrations in these springs but no similar relationship was found for *Lyngbya*. Traditional diatom indicators of water quality were not found to be predictive of spring nutrient conditions. It should be noted that despite the existing documentation of the link between nitrogen enrichment and algal biomass, other processes might have a significant effect on algal biomass as well (Heffernan et al. 2010).

Four seasonal algal surveys were completed for the 50-year retrospective study (Munch et al. 2006). Major benthic algae species observed during that work are presented in Table 5-4.

Additionally, Mattson (2009) examined the relationship between nitrogen levels, algae proliferation, and benthic invertebrate communities in several Florida springs. He noted that elevated levels of nutrients in Florida springs and spring run streams, principally nitrate, have been linked to increased algal abundance (as biomass, cell density, and/or chlorophyll *a*) and changes in algal community structure, mainly from a microalgal/diatom-dominated community to one dominated more by filamentous macroalgae (including blue-green, green and yellow-green algae). Mattson (2009) analyzed data from published studies of benthic algae and macroinvertebrates for the existence of relationships between the two. Increased algal abundance was associated with “positive” (increased invertebrate taxa richness and abundance) and “negative” changes (decreased evenness and diversity). Significant reductions in taxa richness and significantly increased contributions of percent dominance with increased proportions of blue-green and green algae in the algal community suggest that changes in algal community structure from a periphyton/microalgal dominance to one of filamentous macroalgae negatively affect macroinvertebrate community structure.

Table 5-4. Major benthic algal species encountered in Silver Springs, Florida, 2003 – 2005

Spring	Summer	Fall	Winter
Cyanophyta - blue green algae - cyanobacteria			
Lyngbya wollei *Phormidium* sp.	*Lyngbya wollei* *Oscillatoria* sp.	*Lyngbya wollei* *Oscillatoria* sp.	*Lyngbya wollei Oscillatoria* sp.
Chlorophyta - green algae			
Ulothrix sp.	*Cladophora* sp. *Mougeotia* sp.	*Cladophora* sp. *Mougeotia* sp.	*Cladophora* sp.
Xanthophyceae			
	Vaucheria sp.	*Vaucheria* sp.	*Vaucheria* sp.
Baccillariophyta - diatoms			
Pennate: *Gomphonema* sp., *Cymbella* sp., *Synedra ulna, Fragilaria crotoninsis, Fragilaria* sp.	*Synedra ulna, Cymbella* sp.,*Gomphonema* sp., *Navicula* sp., *Fragilaria sp.*	*Fragilaria* sp., *Cymbella* sp., *Gomphonema* sp., *Synedra ulna*	*Gomphonema* sp., *Fragilaria sp., Cymbella* sp., *Navicula* sp., *Synedra ulna*
Centric *Aulacoseira italica, Aulacoseira varians* *Aulacoseira* sp., *Terpsinoe musica*	*Cocconesis* sp., *Aulacoseira varians*	*Aulacoseira varians, Terpsinoe musica*	*Aulacoseira varians, Terpsinoe musica, Aulacoseira italica, Cocconesis* sp.
Source: Munch et al. 2006.			

Fishes

Surveys of fish and wildlife include publications by Ross, a herpetologist at the Silver Springs theme park. His book *Fishes of Silver Springs, Florida* (Allen 1946) provides information on most of the fish species found the spring run. Descriptions and photos of many of the fish are included. Hubbs and Allen (1943) also conducted sampling of fish and reported 25 species in the Silver River Museum records (Munch et al. 2006).

A large body of literature describe other Florida springs, much of which can be applied to Silver Springs. Odum and Caldwell (1955) and Caldwell et al*.* (1957) described fish respiration in Beecher Spring, an anaerobic spring located in Welaka, Florida. For this study, oxygen in the spring water was related to the density and species makeup of fish. This study provided information regarding the diffusion of oxygen in springs and the release of oxygen by plants.

Walsh and Williams (2003) surveyed fish and mussel populations in 16 springs and spring runs in north-central Florida. Their study was designed to provide a baseline inventory of variations in fish and mussel populations among springs. Museum data were also reviewed to establish occurrence of other fish and mussel species in individual springs.

Museum collections included 99 fish species from Florida springs. The most common species in these collections was the redeye chub (*Notropis harperi*), which has a recognized close association with spring habitats. Fish families in museum collections in order of abundance were minnow (Cyprinidae), sunfishes and basses (Centrarchidae), topminnows and livebearers (Fundulidae and Poecillidae), and seven other families. During their own sampling, Walsh and Williams (2003) collected 79 fish species, with 29 species collected in Silver Springs and the Silver River. The Silver River Museum collection includes 22 species.

A combined total of 41 different fish species have been identified in the Silver River, including a new exotic fish, the vermiculated sailfin catfish (*Pterygoplichys disjunctivus*) introduced from South America (Walsh and Williams 2003). The redeye chub was the dominant fish in both the museum collections and in the Walsh and Williams sampling.

Shellfish and Mollusks

Mussels had relatively low population densities in the Silver River (Walsh and Williams 2003). They observed five species of native mussels and the Asian clam (Table 5-5). Three of the mussel species are thought to be exclusive to the Silver River (Williams and Walsh, 2003). Other field sampling found no evidence of rare or protected snails in Silver Springs or Silver River (Shelton 2006).

Table 5-5. **Mussels collected in Silver River State Park and Ocklawaha River at the mouth of Silver River**			
Species	**Common Name**	**Sample Size**	**Percent of Total**
Corbicula fluminea	Asian clam	31	8.8
*Elliptio icterina**	Variable spike	1	0.3
Elliptio sp.	Unidentified spike	315	89.0
*Toxolasma paulus**	Iridescent lilliput	1	0.3
*Uniomerus carolinianus**	Florida pondhorn	2	0.6
Villosa amygdala	Florida rainbow	4	1.1
	Total number of specimens:	354	
*Note: these are found exclusively in Silver River			
Source: Williams and Walsh (2003).			

Selected Findings of the 50-Year Retrospective Study

Aquatic plants, including epiphytes, benthic algae mats, and macrophytes were sampled, characterized, and analyzed for the 50-year retrospective study (Munch et al. 2006). Some of the significant results of that work are as follows:

- *Sagittaria* remains the dominant submerged aquatic plant species in Silver Springs and represents one of the main physical features of the ecosystem.
- The populations of birds, fish, turtles and alligators at Silver Springs were assessed and compared to results of previous investigations. Table 5-6 summarizes bird and reptile species observed by Odum (1957) and Munch et al. (2006).
- Total species richness in 2004 for birds, fish, and reptiles was similar to historical records at the Silver River. Table 5-7 presents the number of vertebrates observed during the 50-year retrospective study.
- Visual observations of turtles present in Silver Springs found that dominant populations of cooters observed during the early 1950s were still present, as were smaller populations of soft-shelled turtles. However, musk turtles were observed during the Odum study and, although likely to be present today, were not observed recently.
- Alligator populations were not estimated by Odum (1957) but were estimated at a density of about 3.4 per hectare (ha) at night by Knight (1980) and at 0.91/ha in the day

Munch et al. (2006). Note that the time of day of sampling and methods, of Munch et al. and Knight were different and should not be compared.

Table 5-6. Species of birds and reptiles observed (indicated by "+") in the spring run of Silver River, Florida, studies by Odum (1957) and Munch et al. (2006)

Flora Category	Common Name	Species	Odum (1957)	Munch et al. (2006)
Birds	American coot	*Fulica americana*	+	
	Anhinga	*Anhinga anhinga*		+
	Common moorhen	*Gallinula chloropus*	+	+
	Double-crested cormorant	*Phalacrocorax auritus*		+
	Florida mottled duck	*Anas fulvigula*		+
	Grackle	*Quiscalus quiscula*		+
	Great blue heron	*Ardea herodias*	+	+
	Green heron	*Butorides virescens*	+	
	Little blue heron	*Egretta caerulea*	+	+
	Osprey	*Pandion haliaetus*		+
	Pied-billed grebe	*Podilymbus podiceps*		+
	Snowy egret	*Egretta thula*		+
	White ibis	*Eudocimus albus*		+
	Wood duck	*Aix sponsa*		+
Reptiles	Alligator	*Alligator mississippiensis*	+	+
	Common musk turtle	*Sternotheris odoratus*	+	
	Florida cooter	*Pseudemys floridana*	+	+
	Florida red-bellied cooter	*Pseudemys nelsoni*		
	Florida softshell turtle	*Apalone ferox*	+	+
	Loggerhead musk turtle	*Sternotheris minor*	+	+
	Snapping turtle	*Chelydra serpentina*	+	+

Source: Munch et al., 2006.

Table 5-7. Individual and total count of alligator, turtle and bird species visually observed on the spring run of Silver Springs, Florida					
		Number Observed on Date			
Common Name	**Scientific Name**	**3/4/2004**	**4/16/2004**	**6/4/2004**	**6/17/2004**
Reptiles					
American alligators	*Alligator mississippiensis*	7	3	13	6
Common snapping turtle	*Chelydra serpentina*	0	0	1	0
Florida red bellied cooter	*Pseudemys nelsoni*	8	4	5	5
Peninsula cooter	*Pseudemys peninsularis*	25	17	20	17
Soft shelled turtle	*Apalone ferox*	0	1	2	1
Unidentified turtle		11	12	9	7
	Total	44	34	37	30
Birds					
Anhinga	*Anhinga anhinga*	4	1	0	1
Common moorhen	*Gallinula chloropus*	4	2	3	2
Double crested cormorant	*Phalacrocorax auritus*	14	13	8	2
Florida mottled duck	*Anas fulvigula*	0	0	3	5
Grackle	*Quiscalus quiscula*	0	1	0	0
Great blue heron	*Ardea herodias*	3	1	2	2
Little blue heron	*Egretta caerulea*	2	1	3	1
Osprey	*Pandion haliaetus*	0	1	0	0
Pied-billed grebe	*Podilymbus podiceps*	2	0	0	0
Snowy egret	*Egretta thula*	2	1	3	2
White ibis	*Eudocimus albus*	13	0	1	2
Wood duck	*Aix sponsa*	0	2	4	0
	Total	54	23	27	17
Source: Munch et al. 2006.					

- Populations of fish-eating birds such as the double-crested cormorant have apparently increased at Silver Springs since the 1950s study period. Largemouth bass and bluegill sunfish continue to be among the most dominant larger fish present in Silver Springs (Munch et al. 2006).
- Catfish and mullet were present in high abundance in Silver Springs 50 years ago but had largely disappeared during Knight’s 1978-79 study and also were observed in low abundance in the Munch et al. (2006) study. Table 5-8 presents the fish species biomass estimates observed by Odum, Knight, and in the 50-year retrospective study.

Table 5-8. Comparison of biomass estimates (kg live weight/ha) of fishes in the Silver River, Florida, based on results of visual surveys from Odum (1957), Knight (1980), and Munch et al. (2006)

Family	Common Name	Scientific Name	Biomass (kg/ha)		
			Odum (1957)	Knight (1980)	Munch et al. (2006)
Amiidae	Bowfin	*Amia calva*		0.58	2.79
Anguillidae	American eel	*Anguilla rostrata*			0.01
Belonidae	Atlantic needlefish	*Strongylura marina*		0.01	
Catostomidae	Lake chubsucker	*Erimyzon sucetta*		1.97	1.10
Centrarchidae	Redbreast sunfish	*Lepomis auritus*			0.26
Centrarchidae	Bluegill	*Lepomis macrochirus*			10.99
Centrarchidae	Redear sunfish	*Lepomis microlophus*			2.42
Centrarchidae	Spotted sunfish	*Lepomis punctatus*			0.04
Centrarchidae	Sunfish sp.	*Lepomis* sp.	47.62	15.56	
Centrarchidae	Largemouth bass	*Micropterus salmoides*	27.14	18.65	11.10
Centrarchidae	Black crappie	*Pomoxis nigromaculatus*		0.02	0.01
Cichlidae	Blue tilapia	*Tilapia aurea*			0.23
Clupeidae	Gizzard shad	*Dorosoma cepedianum*		66.28	2.57
Cyprinidae	Golden shiner	*Notemigonus crysoleucas*		6.32	0.59
Cyprinodontidae	Golden Topminnow	*Fundulus chrysotus*			0.00007
Cyprinodontidae	Bluefin killifish	*Lucania goodei*	18.57		0.002
Esocidae	Chain pickerel	*Esox niger*		1.34	2.61
Ictaluridae	Channel catfish	*Ictalurus punctatus*			0.03
Lepisosteidae	Longnose gar	*Lepisosteus osseus*	1.43		2.06
Lepisosteidae	Florida gar	*Lepisosteus platyrhincus*	44.29	1.33	3.52
Mugilidae	Striped mullet	*Mugil cephalus*	266.67	2.57	1.55
Percidae	Swamp darter	*Etheostoma fusiforme*			0.00007
Poeciliidae	Gambusia sp	*Gambusia* sp.	21.43		0.00003
Poeciliidae	Least killifish	*Heterandria formosa*	3.33		0.00003
	Catfish		95.24		
	Shiners		0.95		0.01
		TOTAL FISH BIOMASS	526.7	114.6	41.90

Note: Methods used for visual surveys were different among studies. *Anguilla rostrata* was listed as *A. bostoniensis* in Odum (1957). Biomass derived from grams dry weight per m² estimates in Odum (1957) and Knight (1980) using standard wet weight/dry weight factors.

Source: Munch et. al. 2006.

- Knight found gizzard shad to be the most abundant fish species 25 years ago, whereas Munch et al. (2006) found much lower abundance of this species. Gizzard shad were not reported by Odum in the 1950s.
- Overall estimated annual average fish live-weight biomass in Silver Springs has declined by about 92 percent since Odum's study in the early 1950s, and by 61 percent since Knight's 1978-79 study. The declines in total biomass were due to large reductions in a few species (i.e., catfish, mullet, gizzard shad), but other species were found in similar abundance across the 50-year span (Munch et al 2006).
- Another recent examination of the hydrology, water chemistry, and aquatic communities of Silver Springs, Ponce de Leon Spring, Gemini Springs, and Green Springs ─ all in the SJRWMD ─ was conducted by USGS in 2004 (Phelps et al. 2006). Data of flow, water chemistry, and aquatic communities including benthic invertebrates, fishes, algae, and aquatic macrophytes that were collected by USGS, SJRWMD, and FDEP were used for the assessment. Macro-invertebrates were sampled at Ponce de Leon Spring, Gemini Springs, and Green Springs, but not Silver Springs.

Protected Species

The entire reach of the Silver River from the confluence with the Ocklawaha River upstream to the Silver Springs theme park and its surrounding floodplain is included in the Silver River State Park and Wilderness Preserve. The Ocklawaha River Aquatic Preserve extends from about 5 river miles upstream of the Silver River confluence to nearly 12 river miles downstream and includes the Silver River up to the Silver Springs Attraction Area [Florida Department of Natural Resources (FDNR) 1992, FDEP 2009].

Numerous protected species of flora and fauna have been observed in the aquatic preserve as shown in Table 5-9. Other descriptions of listed and rare species are provided in Florida Natural Areas Inventory (FNAI 2004) and Herring and Davis (2004).

The following sections summarize the specific criteria for maintaining channel water depths and flows for:

- The protection of fish passage and manatee refugia;
- Floodplain inundation for the protection of fish, wading birds, wetland vegetation, and organic soils; and
- Maintenance of channel water velocities.

Table 5-9. Listed species observed in Ocklawaha River Aquatic Preserve			
Common Name	**Scientific Name**	**State**	**Federal**
Reptiles			
American alligator	*Alligator mississipiensis*	SSC	T (s/a)
Eastern indigo snake	*Drymarchoncorais couperi*	T	T
Birds			
limpkin	*Aramus guarauna*	SSC	n/a
little blue heron	*Egretta caerulea*	SSC	n/a
snowy egret	*Egretta thula*	SSC	n/a
tricolor heron	*Egretta tricolor*	SSC	n/a
Florida sandhill crane	*Gruscanadensis pratensis*	T	n/a
wood stork	*Mycteria americana*	E	E
Mammals			
Sherman's fox squirrel	*Sciurus niger shermani*	SSC	n/a
Florida manatee	*Trichechus manatus*	E	E
Florida black bear	*Ursus americanus floridanus*	T	n/a
Plants			
Venus hair fern	*Adiantum capillus veneris*	T	n/a
star anise	*Illicium parviflorum*	T	n/a
pondspice	*Litsea aestivalis*	T	n/a
grass-of-parnassus	*Parnassia grandifolia*	E	n/a
whisk fern	*Psilotum nudum*	T	n/a
Florida willow	*Salix floridana*	T	n/a
Florida pinkroot	*Spigelia loganoides*	E	n/a
cardinal flower	*Lobelia cardinalis*	T	n/a
State listings are taken from the Florida Fish and Wildlife Conservation Commission or as with plants Florida Department of Agriculture. Federal listings are taken from the United States Fish and Wildlife Service. E= Endangered; T= Threatened; T (s/a)= Threatened due to similarity in appearance; SSC= Species of Special Concern; UR= Under review; n/a= information not available or no designation listed			
Source: FDEP 2009.			

Magnitude, duration, and frequency of selected hydrologic events are listed for the protection of Silver Spring and Silver River resources.

Methods used to examine how MFLs hydrologic scenarios may affect local fish and wildlife build on those SJRWMD (Munch et al. 2006) developed and applied to other Florida springs (HSW 2009). A literature review of the effects of water levels on fish populations is provided in Hill and Cichra (2002).

Specific Criteria for Channel Water Depth to Protect Fish Passage

One of the specific habitat criteria is to maintain a minimum water depth in stream channels required for passage of fish. An example of the SJRWMD indicator is a low water level and associated flow that corresponds to a water depth less than 0.8 ft [0.2 meter (m)] over 25 percent of the channel width, at a hydraulic control elevation of the river channel with a duration of 7 continuous days and 20-year return interval [i.e., five such dewatering events per 100 years, on average (SJRWMD 2006)]. This criterion is based on work by Everest et al. (1985) and others who recommended a minimum depth of 0.5 to 0.8 ft for salmon and trout. The relative size of these fishes is comparable to larger fish in the Silver River (e.g., largemouth bass and gar).

For this work, the critical return interval is the number of occurrences of the critical depth during the no-pumping condition period. The number of occurrences of the critical depth should not greatly exceed the no-pumping condition under the MFLs hydrologic regime. Thus, the specific criteria for fish passage used here is to maintain a water depth of 0.8 ft or more over at least 25 percent of the channel width for not less than 7 continuous days. An example is illustrated in Figure 5-2.

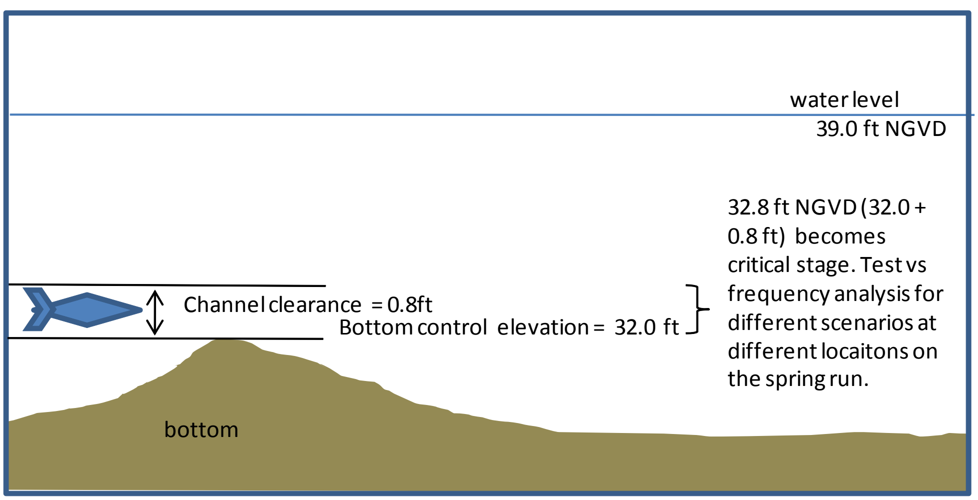


Figure 5-2. Illustration of channel clearance critical stage for fish passage (Figure from SJRWMD, 2011c)

Information used in the following analyses included:

- Land elevation, soil, and vegetation data collected at MFLs transects T3, T5, T7, and T9 on the Silver River.

- Bottom elevations for shallow-water sounding transects in the upper spring run (transect 11E)
- HEC-RAS computer output of Silver River flow (discharge), water level (stage), and/or velocity at sites T3, T5, T7, the shallow water transect 11E, and the USGS gauging station 9501, near T9. Discharge and stage estimates were developed for two scenarios: no-pumping and MFLs scenarios as discussed in Chapter 3.

Critical water depths that would afford fish passage were determined for each transect (Table 5-10). The locations of the transects are shown in Figure 2-5. Transect sections are presented in Figures 4-1 through 4-4.

Table 5-10. Specific channel water depth criteria for protection of fish passage, 7-day low stage continuously not exceeded

Transect	Critical Stage (Water Level ≥ ft-NGVD)	Frequency	Duration
T3	26.6	Minimize increase from no-pumping condition of 7-day continuously not exceeded water elevation less than 0.8 ft for 25% of channel cross-section	7 day
T5	27.4		
T7	29.2		
T9	29.3		

Table 5-11 presents the results of the frequency analysis for no-pumping condition and MFLs scenarios. The “Events” columns shows the number of times that the criterion was met, based on a 100-year cycle. Each transect has a critical elevation corresponding to the specific criterion. The “Increase” column in Table 5-11 shows the difference in number of occurrences of the critical hydrologic condition.

Table 5-11. Frequency analysis for water depth criteria for the protection of fish passage, 7-day low stage continuously not exceeded

Transect	Critical Stage (ft-NGVD)	Number of Events/ 100 Years No-Pumping Condition	Number of Events/ 100 Years MFL Regime	Increase in Number of Events under the MFLs Hydrologic Regime
T3	26.6	0	0	0
T5	27.4	0	0	0
T7	29.2	0	0	0
T9	29.3	0	0	0

The water depths at T3, T5, and T7, which were used in this analysis, were much deeper than the required minimum. Because the water level never falls below the critical stage, the event occurs zero times in a 100-year cycle. As can be seen, this condition did not change for the MFL scenario, meaning that the stage never fell below the critical level at any section.

A common cause of impedance to fish passage is shoaling at the mouth of tributaries, caused when high flows in the main river deposit sediment along the side of the channel. No severe shoaling at the confluence of the Silver River and Ocklawaha River that would impede fish passage has been observed (Jeff Sowards, Aquatic Preserve Manager, personal communication 2010). Finally, water from the Ocklawaha River can flow up the Silver River during high-flow periods, creating a backwater effect that causes higher stages in the spring run. Thus, it is concluded that passage of fish in the Silver River is protected under the recommended MFLs hydrologic regime.

It should be noted, however, that fish and manatee passage is likely impeded by the dam and lock at the Rodman Reservoir. This artificial impoundment is located on the Ocklawaha River about 30 river miles downstream of the confluence with the Silver River and was part of the now decommissioned Cross Florida Barge Canal Project, initiated in 1935. The dam and Buckman Lock were completed and the reservoir flooded in 1968. Although migratory fish such as striped bass, eels and mullet are reported to be found upstream of Rodman Reservoir (Save Our Rodman, Inc. 2010), it is likely that the dam and Buckman Lock impede the passage of fish such as mullet and striped bass and manatees. A drastic decline in the population of striped bass is attributed to the reservoir (Munch et al. 2006). As shown in Table 5-8, mullet had by far the highest biomass of any fish observed by Odum (1957) before the reservoir was built, but were seen in very modest amounts in studies completed after the reservoir was constructed.

Specific Criteria for Maintaining Channel Water Velocity to Protect Fish Habitat

The steady flow and transparent waters of Florida spring runs often support high biomass of submersed species, whose year-round productivity is limited by light (Odum, 1957). Water current serves as an important auxiliary energy source by increasing nutrient availability and exporting waste products. Within a range of slow currents for which flow is laminar [0.0007 - 0.02 foot per second (ft/sec)], photosynthesis of submersed plants has been shown to increase with increasing current velocity (Odum 1957). However, the high velocities that occur during flooding in most streams and rivers would represent stressful and often quite damaging conditions for macrophytes (Davis and Brinson 1980). Strong flow occurs at the main boil and other vents as well, providing significant circulation throughout the spring run. Maintaining flow velocities is beneficial by providing nutrient delivery and carrying away wastes.

Potential changes in river flow velocities that were simulated for all scenarios using the HEC-RAS model were examined at the four transects across the range of observed flows. The Silver River HEC-RAS model evaluated hydraulic characteristics at 11 cross-sections along the Silver River for a range of flow conditions. The HEC-RAS model contained two geometry plans, one for the 1947-1999 period (in-channel Manning's n = 0.057) and one for the post-2000 period in which denser vegetative growth in the channel created rougher flow conditions necessitating a higher in-channel Manning's n (in-channel Manning's n = 0.1). Discussions of these HEC-RAS models are also included in Sutherland et al. (2017). Because the current period-of-record encompasses the entire period (1946-2014) and frequency statistics were calculated for the 1946-2014 period, the HEC-RAS model needed to be modified through the creation of a third geometry plan which best matched flow-stage relationships developed from the entire 1946-2014 period-of-record. An in-channel Manning's n of 0.070 with a floodplain Manning's n of 0.3 provided the best match for the entire period.

Figure 5-3 shows velocity differences between the most extreme scenarios – the no-pumping condition and the MFL condition for each of the four transects. Very different trends in velocities at different transects are evident, which reflect the relative influence of the spring as a flowing water source and the Ocklawaha River as a tailwater, based on the locations of the transects in the spring run.

Two trends related to velocity patterns in the river are evident:

- Velocities for the entire range of flows that were examined generally increased at the more downstream transects. Transects T9 and T7, the more upstream transects, had the lower velocities, and Transect T3, closest to the river discharge, has the highest.
- The magnitude of difference between the no-pumping condition flows and the MFL scenario flows was most marked at the downstream transects, away from the spring. However, differences between the no-pumping condition and MFL scenario velocities were, qualitatively speaking, small at all transects. All changes in flow velocities were 0.1 foot per second (fps) (less than 10 percent) or less across the entire range of flows.

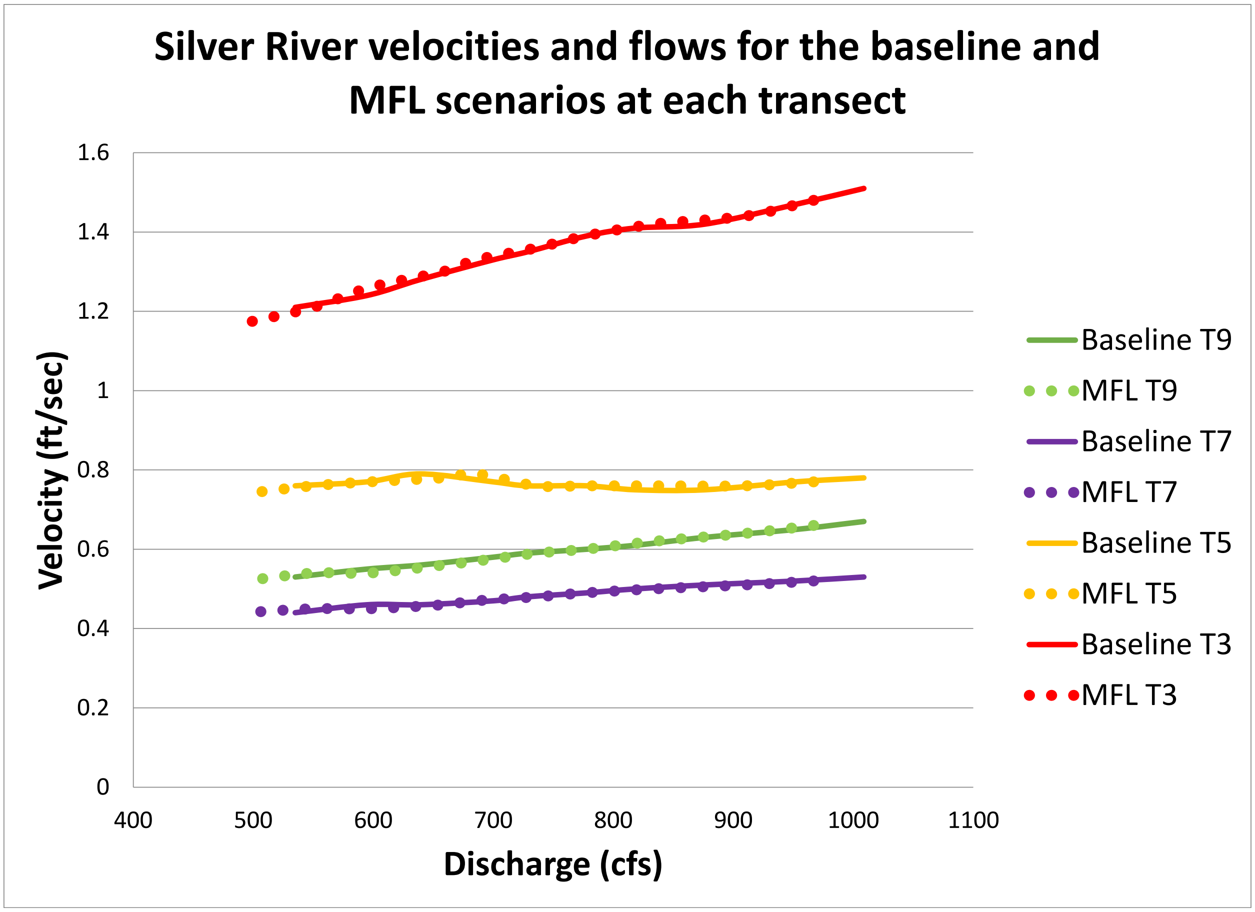


Figure 5-3. Simulated flow velocities at Silver River MFLs transects for POR (solid lines) and MFLs conditions (dotted lines)

As shown in Figure 5-3, the reductions are less than 0.05 feet per second across the range of flows. Therefore, velocities under the MFLs scenario are likely sufficient to provide aeration, nutrient delivery, and waste removal. Therefore, channel velocities required to protect fish and wildlife habitat are considered protected, based on the small magnitude of change in flow velocities under the MFLs hydrologic regime.

With respect to habitat requirements for local shellfish, Johnson et al. (2001) found that unionid mussel mortality can be highly correlated with water flow velocity and DO concentration. These findings in the Flint River in southern Georgia were observed during periods of extreme drought. Similar conditions are highly unlikely to occur in the Silver River. The minimal water velocity and DO reductions that could result under the MFLs hydrologic regime are not expected to affect mussel habitat quality.

Rogers et al. (2005) suggested that the abundance of spotted sunfish was positively related to river flow in the Ocklawaha River, downstream of the confluence with the Silver River. Munch et al. (2006) collected both spotted sunfish and redbreast sunfish in Silver River. These species tend to prefer lotic riverine environments (Rogers et al. 2005). The authors suggested that minimum flows in Florida should manage for low flow events to prevent sequential years of adverse conditions for population success; however, the determinants for population success were described as related more to floodplain inundation. Therefore, rather than evaluating the effects of velocities on these populations, specific floodplain inundation criteria were developed to evaluate protection of fish and wildlife habitat.

Specific Criteria for Floodplain Inundation to Protect Wetland Communities and Associated Fauna

The Silver River is surrounded by a wide, well-defined floodplain, largely composed of mineral-based soils with pockets of organic mucks. Vegetation communities transition from the open water river channel to shallow marsh, to broader hardwood swamp and hydric hammocks, before rising to the adjoining uplands. The width of organic soils and wetland vegetation that comprises the floodplain generally ranges from 1,300 to 1,900 ft. A wide variety of small fish and other vertebrates use the floodplain for feeding, reproduction, and refuge. Additionally, wading birds feed throughout the floodplain. Essential to this habitat is the vegetation that depends on the underlying organic soils that require periodic inundation to prevent oxidation. Thus, maintaining a proper range of flooding and dewatering events in the floodplain is essential for protecting these inter-dependent ecologic functions, recognizing that a wide range of extreme hydrologic conditions is to be expected in a naturally functioning ecosystem.

One important function of the floodplain is to provide protected spawning grounds for small fish. The literature supports a recommendation for a duration criterion of 30 continuous days for seasonal floodplain inundation. This period is sufficient to accommodate the reproductive cycle of small fish that would utilize the flooded area for spawning. For example, the bluegill has an incubation period of up to one week (Stuber et al. 1982), and adult males will guard the nest for an additional week until the fry can forage (Keenleyside 1971). Largemouth bass fry also require about 30 days to develop survival skills [Texas Department of Parks and Wildlife (TDPW) 2010].

The specific criteria to provide for floodplain inundation of sufficient frequency and duration to maintain wetland habitats is to minimize the difference between no-pumping conditions and the MFLs flow scenario of the inundation of the median elevation of the hardwood swamp community at sites T3, T5, T7, and T9 for a continuous duration of 30 days, as shown in Table 5-12. Floodplain topographic data were not available for shallow-water transect 11E, so that site is not included in this analysis. This hydrologic condition will result in some of the floodplain being flooded annually but will maintain a shallow enough water depth to facilitate wading bird feeding and to prevent large fish from easily preying on fry (HSW 2009).

Table 5-12. Specific floodplain inundation criteria (30-days high stage continuously exceeded) for protection of fish, wading birds, and wetland vegetation

Transect	Critical Stage (WL ≥ ft-NGVD)	Frequency	Duration
T3	37.3	Minimize the reduction in the frequency of 30-days high stage continuously exceeded inundation of hardwood swamp median elevation	30 days
T5	37.7		
T7	39.4		
T9	39.8		

Table 5-13 shows the results of the frequency analysis for floodplain inundation during an entire year. Again, the critical inundation elevation (median hardwood swamp elevation) varies across the landscape and is represented by a unique value at each transect. Thus, the frequency of inundation at each transect varies according to land elevation and water surface elevation. At all transects, there is a decrease in the number of times the 30-days high stage continuously exceeded occurred for the MFLs scenario. The largest decrease was found for Transect T3.

Table 5-13. Frequency analysis of criteria (30-days continuously exceeded) for the protection of fish, wading birds, and wetland vegetation

Transect	Critical Stage (ft-NGVD)	Number of Events/100 years No-Pumping Condition	Number of Events/ 100 Years MFL Regime	Decrease in Number of Events under the MFLs Hydrologic Regime
T3	37.3	96	62	34
T5	37.7	121	99	22
T7	39.3	100	79	21
T9	39.8	104	87	17

Floodplain inundation is especially important during fish spawning season. Many fish species, including pan fish and bass, spawn during spring through summer, so keeping the return interval of extreme events at an acceptable level during that time period is very important for fisheries survival. To determine seasonal effects from frequency of floodplain inundation events, a seasonal frequency analysis was conducted based on only the months important for fish spawning (i.e., March - September). The seasonal frequency analysis (March - September) duration analysis in Table 5-14 suggests there is little difference between no-pumping conditions and the MFLs scenario for this critical time period from that found for the entire year (Table 5-13).

Table 5-14. Seasonal frequency analysis results for the criterion of protection of fish during spawning season (March through September) (30-days continuously exceeded)

Transect	Critical Stage (ft-NGVD)	Number of Events/100 years No-Pumping Condition	Number of Events/ 100 Years MFL Regime	Decrease in Number of Events under the MFLs Hydrologic Regime
T3	37.3	74	47	27
T5	37.7	97	79	18
T7	39.3	78	65	13
T9	39.8	81	68	13

Piscivorous wading birds are intricately tied to their wetland habitats, which provide resources for all aspects of their existence. Foraging habitat requires prey – fish, frogs, and other small vertebrates – and adequate habitat to support the fish, as well as maintaining conditions that allow stalking. Numerous wading birds feed in the Silver River floodplains, including the great blue heron, little blue heron, tri-colored heron, snowy egret, and wood stork, all listed species (FDEP 2011a) as shown in Tables 5-6 and 5-9. It can be expected that foraging activity will be highest during the nesting season. In a nesting survey of portions of the SJRWMD jurisdiction, Sewell (2001) found the highest number of nests in June, but nesting peaked at different times of the year according to species. Great egret, great blue heron, and wood stork nests peaked in March and April (dry season), while other species peaked in June (Sewell 2001).

Conditions are best for the birds if the water has pooled and concentrated the fish, making capture easier. The criteria presented above in Table 5-12 for fish are likely beneficial for the birds as well. Inundation to the median hardwood wetland elevation for 30 days will provide the birds with shallow water and pools of fish for feeding. Deeper water would inhibit the birds' movement through the swamp and allow the fish to disperse. Shallower water or less frequent flooding may not produce sufficient fish to support the bird population. Thus, the same magnitude, frequency, and duration of floodplain inundation that was used to protect fish production are assumed to be appropriate for wading birds as well.

Wetland vegetation is necessary to support fish and birds, as well as other aquatic species. The hardwood swamps that make up much of the Silver River floodplain require frequent, but not continuous, inundation or saturation. Again, the criterion for magnitude of inundation of the floodplain to the median elevation of the hardwood swamp (the same as for protection of fish and wading birds) appears reasonable to sustain vegetation. From the results of the water level analysis, the scenarios using both annual and seasonally restricted data appear to be protective of the resource for the no-pumping condition and MFLs scenario.

Specific Criteria for Floodplain Inundation to Protect Organic Soils

A growing body of knowledge regarding soil properties and how they relate to ecological communities has resulted in soils becoming increasingly included in WRV and MFLs assessments [Brooks and Lowe 1984; Hall 2010; Mace 2007, 2006; SJRWMD 2011(a, b), 2006]. Organic soils (Histosols and Histic epipedons) that support floodplain vegetation are subject to oxidation/subsidence and lowered land surface elevation when they are drained/dewatered for extended periods. Thus, regular inundation/saturation is required to maintain these soils and associated wetland communities.

Specific indicators used by SJRWMD (2006) include inundation to the elevation corresponding to 0.3 ft below the surface of organic soils for an annual, mean non-exceedance duration of 180 days (not necessarily continuous) to minimize oxidation/subsidence. The magnitude component is based on field studies conducted by the U.S. Department of Agriculture and the University of Florida Everglades Agricultural Experiment Station (Stephens 1974).

In those studies, subsidence rates of organic soils in the Everglades were correlated with shallow groundwater depth. Higher water levels resulted in lower subsidence rates. Soil density and mineral content analyses showed that all losses took place above the water table. A regression model was developed that predicted that significant organic soil subsidence would not occur if the long-term average water table depth was maintained at 0.3 ft below the soil surface. Reddy et al (2006) investigated the influence of water levels on subsidence in the upper St. Johns River basin and found a similar result (10 cm, or 0.33 ft) with respect to long-term average water table below soil surface. This criterion was used for evaluation of the Silver River floodplain soils.

Detailed soils information for the Silver River transects included the delineation of the estimated extent of organic soils and organic soil indicators. At all transects, the organic soils extended from the river channel through the hardwood swamp and, in some cases, into the transition zone and organic hammock communities near the upland edge (Figures 4-1 through 4-4). The majority of the Silver River floodplain soils are mineral-based with pockets of muck (organics). The criterion to protect organic soils from possible oxidation/subsidence was the floodplain elevation corresponding to 0.33 ft below the mean elevation of the estimated extent of organic soils within the mixed hardwood swamp communities, with associated mean non-exceedance duration of 180 days per year (Table 5-15).

Table 5-15. Specific floodplain inundation criteria for protection of organic soils, 180-day low stage continuously not exceeded

Transect	Critical Stage (WL ≥ ft-NGVD)	Frequency	Duration
T3	37.77	Minimize increase from no-pumping conditions of years with less than 180-day non-exceedance water elevation of 0.33 ft below mean elevation of organic soils	180 days non-continuous
T5	37.67		
T7	39.67		
T9	39.77		

The SJRWMD uses the duration of 180 days per year (not necessarily continuous) for MFLs determinations and, although this WRV assessment is not a MFLs document, no substitute criterion was identified by this document's authors. Critical elevations range for this dewatering event from 37.77 feet reference to the National Geodetic Vertical Datum (ft-NGVD) at downstream site T3 to 39.77 ft-NGVD at upstream site T9/9501.

As with the other criteria, possible effects are assessed by evaluating the change in the number of events between the no-pumping conditions and the MFLs scenario (Table 5-16). An event is defined as the number of years out of 100 that the water table does not reach the desired elevation for at least 180 days, not necessarily consecutive. Effects are measured as the increase in the number of years that the minimum saturation conditions are not met.

Table 5-16. Frequency analysis results of floodplain inundation criteria (180-day low stage continuously not exceeded) for the protection of organic soils				
Transect	**Critical Stage (ft-NGVD)**	**Number of Events/100 Years No-Pumping Condition**	**Number of Events/ 100 Years MFL Regime**	**Increase in Number of Events under the MFLs Hydrologic Regime**
T3	37.77	82	91	9
T5	37.67	44	60	16
T7	39.67	74	84	10
T9	39.77	63	75	12

For the no-pumping condition, the number of dewatering events varies between 44 and 82 times per 100 years, dependent on which transect is evaluated. The evaluation of the frequency of attaining the soil protection criteria show relatively modest increases in dewatering events with the MFLs scenario of between 9 and 16 events per 100 years. As can be seen, Site T9 shows the largest increases in the number of dewatering events per century for the MFLs scenario.

Specific Criteria for Channel Water Depth to Protect Manatees

Although the existence of the Rodman Reservoir undoubtedly restricts access of manatees to the Silver River, these mammals are on the list of threatened and endangered species for the Ocklawaha River Aquatic Preserve that includes the Silver River, as well as state and national lists. A specific WRV criterion has been developed for manatee protection for Volusia County Blue Springs (Rouhani et al. 2007). That criterion was applied here and is consistent with manatee criteria for other Florida springs (Heyl 2008) (Figure 5-4).

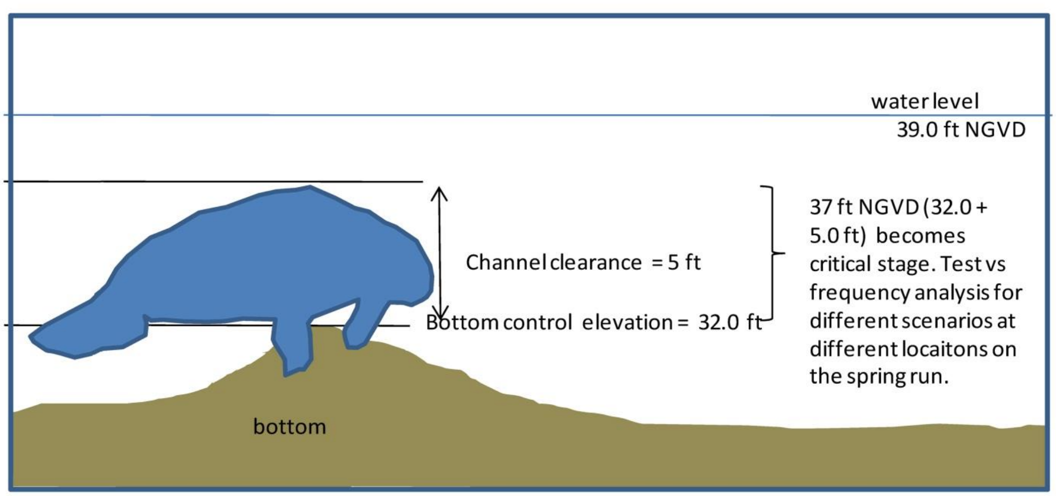


Figure 5-4. Illustration of channel clearance critical stage for manatee passage (Figure from SJRWMD, 2011c)

The sustainability of Florida’s manatee population depends on the availability of warm-water refuges during winter months. Manatees seek warmer waters when the temperature of the river drops below the high 60 degrees Fahrenheit (°F), typically between November and March. Prolonged exposure to lower water temperatures causes manatees to lose body heat and inadequately digest their food. This can lead to a condition classified as "cold stress" or death.

The temperature of Silver Springs and the entire length of the Silver River water remains above this threshold, with 99 percent of reported water temperature readings for the period of record above 69°F. Rouhani et al. (2007) reported the length of time for the presence of colder water to adversely affect manatees is 3 to 4 days. The actual carrying capacity of the spring as a manatee winter refuge is measured in terms of *the useable warm-water length* (UWWL), which is conservatively defined as the portion of the run with a bottom temperature greater than 68°F and a centerline water depth greater than or equal to 5 ft (Rouhani et al. 2007).

Table 5-17 shows the magnitude and duration of the specific criteria for manatee protection. The magnitude is a minimum water depth of 5 ft (expressed at each transect as a stage in ft-NGVD), relating to the minimum depth needed for manatee movement. The frequency is the number of occurrences (number of events per 100 years) and is assessed as the change in frequencies between the no-pumping condition and MFLs hydrologic regimes. The event duration is 1 day. Although a 3- to 4-day duration is reported to cause extreme hardships, the 1-day duration was used as a factor of safety. Transects 3 through 9 encompass the approach to the main boil, and transect 11E is within the spring pool, which would serve as the most proximal thermal refuge.

Table 5-17. Specific channel water temperature and depth criteria for the protection of manatees, 1-day low stage continuously not exceeded

Transect	Critical Stage (WL ≥ ft-NGVD)	Frequency	Duration
T3	28.6	Minimize reduction from no-pumping condition of useable warm-water length - The length of the Silver River for which bottom water temperature exceeds 68°F and water depth exceeds 5.0 ft (November through March)	1 day
T5	25.8		
T7	30.6		
T9	32.2		
11E	33.9		

Table 5-18 shows the results of the frequency analysis of water depth for manatee protection. As with the stage criteria for fish passage, the depth of the Silver River would not impact manatee movement under any scenario tested. The water level simulated using the HEC-RAS computer model did not reach the critical depth at any time under any scenario. In addition, the temperature of the spring and entire length of the river remained above the threshold temperature 99 percent of the time. Thus, the recommended MFLs hydrologic regime is protective of the WRV criteria for manatees.

Table 5-18. Frequency analysis of channel water depth criteria for the protection of manatees, 1-day low stage continuously not exceeded

Transect	Critical Stage (ft-NGVD)	Number of Events/ 100 Years No-Pumping Condition	Number of Events/ 100 Years MFL Regime	Increase in Number of Events under the MFLs Hydrologic Regime
T3	28.6	0	0	0
T5	25.8	0	0	0
T7	30.6	0	0	0
T9	32.2	0	0	0

5.3 WRV-3: ESTUARINE RESOURCES

Estuarine Resources are defined as coastal systems and their associated natural resources that depend on the habitat where oceanic salt water meets fresh water. These highly productive aquatic systems have properties, particularly salinity, that usually fluctuates between those of marine and freshwater habitats. There are no estuarine habitats in the Silver River, so this WRV analysis focused on downstream riverine systems including the St. Johns River as discussed below and the impact of the Silver Springs preliminary MFL on the downstream estuarine habitats.

The criterion for protection is "coastal systems and their associated natural resources." The representative function used to assess protection is "salinity fluctuations in the estuary." General indicators of protection include changes in the number of extreme high or low salinity events occurring that are associated with changes in the flow and hydrologic regime. The specific indicators of protection are flow variations in the subject section of the river that may influence the occurrence of extreme salinity events.

An estuary is a dynamic environment where freshwater inflows from the watershed mix with saline estuarine water. Mixing and circulation are driven by tides, freshwater flows, coastal geomorphometry, and meteorological forces. Estuarine resources including fish and wildlife, benthos, aquatic vegetation, and water quality are significantly influenced by this mix of fresh and salt water. Salinity conditions in an estuary can affect the biological community on either short term or long-term time scales. Changing the frequency of extreme salinity events can adversely impact the following resources:

- Vegetation communities (through osmotic and molecular stress)
- Water chemistry processes (denitrification, nitrogen fixation, metals and organic chemical fate, carbon dioxide (CO_2) uptake in water, etc.)
- Sediment processes
- Benthos
- Algae
- Fish and other vertebrates
- Pelagic invertebrates
- Bacteria community

Therefore, for this work it is important to examine whether or not the recommended MFLs hydrologic regime will result in unacceptable impacts to downstream estuarine resources resulting from changes in the salinity regime. This includes providing oligohaline (low salinity) habitat within the river system and providing for seasonality effects.

The flow of the Silver River under the MFLs hydrologic regime is 43 cfs less than under the no-pumping hydrologic regime. The Silver River flows into the Ocklawaha River, which flows into Rodman Reservoir, and then to the St. Johns River, which is estuarine in its lower reaches. Discharge out of the Rodman Reservoir is controlled by a dam. As a result, it is likely that downstream flows can be manipulated at the dam to maintain an acceptable flow regime (SJRWMD 2005).

Daily discharge data for the USGS gauge #02240000 (Ocklawaha River near Conner) and the USGS gauge #02244040 (St. Johns River at Buffalo Bluff) downstream of its confluence with the Ocklawaha River were obtained to examine the potential relative impact to stream flow that the MFLs flow regime could have, as shown in Table 5-19. The difference between the Silver River mean daily discharges for the Adjusted Period-of Record discharge and the MFLs hydrologic regime is approximately 17 cfs. The decrease in mean daily discharge under the

MFLs hydrologic regime for Silver River would result in approximately 2.0 percent decrease in mean daily discharge for the Ocklawaha River near Conner and approximately 0.4 percent decrease in mean daily discharge for the St. Johns River at Buffalo Bluff, if the Ocklawaha River was free-flowing.

Table 5-19. Estimated reduction in mean daily discharge at USGS gauges downstream of the Silver River under the recommended MFLs hydrologic regime if Rodman Reservoir Dam remained open

USGS Gauge	Mean Daily Discharge (cfs)	Predicted Percent Reduction
02240000 Ocklawaha River near Conner	879	2.0%
02244040 at St. Johns River at Buffalo Bluff	4725	0.4%

Hydrodynamic modeling conducted for the St. Johns River Water Supply Impact Study (SJRWMD 2010b) was also reviewed to identify any potential impacts to estuarine resources resulting from river flow reductions. The Environmental Fluids Dynamic Code (EFDC) hydrodynamic model was used to simulate water level and salinity differences in the St. Johns River between baseline conditions (scenario “Base1995NN” – 1995 conditions with no additional withdrawals) and a simulated 155 million gallon per day (mgd) withdrawal scenario, including 100 mgd from Rodman Reservoir (scenario “Full1995NN” – 1995 conditions with 155 mgd withdrawal). Model results suggest that the 155 mgd withdrawal would result in a drop in mean water level of less than 0.5 cm and a mean increase in salinity of less than 0.01 part per thousand (ppt) in the St. Johns River at Buffalo Bluff, about 10 river miles downstream of the mouth of the Ocklawaha River (SJRWMD 2010b).

It should be noted that mean salinity in the river remains at approximately 0.5 ppt (effectively freshwater) from upstream reaches to Shands Bridge, about 40 river miles downstream of Buffalo Bluff. It can therefore be assumed that any effects at Buffalo Bluff due to changes in Silver River discharges would be less in the estuarine downstream reaches. Also, a change in water level of 0.5 cm in a water body the size of the St. Johns River is within measurement error, as is a change in salinity of 0.01 ppt.

The criterion for assessing WRV-3 is changes in the number of extreme salinity events occurring downstream of Silver River that are associated with changes in flows. To examine the potential for changes to extreme events, cumulative distribution functions (CDFs) that were developed for the Water Supply Impact Study were reviewed.

Although a CDF for Buffalo Bluff was not plotted in the report, a CDF was included for the river at Shands Bridge, near the upstream extent of ocean intrusion. Infrequent high salinity events, above the 95th percentile of salinity, occur at that location and are the result of oceanic water intrusion. Differences in salinity at Shands Bridge between scenarios are evident only during these periods of ocean salinity intrusion and are not associated with changes in river flow due to withdrawals (SJRWMD 2010b). Also, estuarine biota are adapted to widely and rapidly changing environmental conditions including salinity, temperature, and water level. Table 5-20 shows the wide range of salinity preferences for a variety of common estuarine species.

Table 5-20. Salinity preferences for selected species (ppt)

Species	Lower Limit	Upper Limit
Adult oyster	11	33
Oyster Larval	11	31
Blue Crab, Megalopae	16	38
Blue Crab, Spawning Female	21	38
Sea Trout	15	34
Turtle grass	7	48
Bay Anchovy	10	20
Pinfish	20	25
Pink Shrimp	10	15

The St. Johns River Water Supply Impact Study Fisheries Working Group came to similar conclusions regarding the potential for impacts to fisheries due to the above potential withdrawals. The Fisheries Working Group's Draft Final Report (SJRWMD 2011e) states:

> *"Salinity—The EFDC hydrodynamic model output indicates that water withdrawals would have little effect on the overall spatial coverage of various salinity habitats in the Lower Basin estuary. This is consistent with the conclusions reached by other working groups."*

And:

> *"Based on these analyses we conclude that water withdrawals under the potential near-term and long-term withdrawal scenarios will have a negligible effect on the spatial coverage of the various salinity habitats as defined here."*

The St. Johns River Water Supply Impact Study Wetlands Working Group also came to similar conclusions regarding the potential for impacts to wetlands due to the above potential withdrawals. The Wetlands Working Groups Draft Final Report (SJRWMD 2011d) states:

> *Under Scenario Full1995NN* [or any others]*, no or only very small effects are projected to occur at the upper and lower wetland boundaries.*

The wetlands report states that in estuarine fringe habitats in downstream modeled reaches of the St. Johns River, salt marshes and hardwood swamps would have “very low” likelihood of effects based on changes in water level resulting from the “Full1995NN” scenario withdrawals. Also, salt marshes have a “low” likelihood of salinity effects from the “Full1995NN” scenario withdrawals, however hardwood swamps in downstream-most reach 1 have a “high” likelihood of salinity effects under the same scenario. Based on the modeling results and the assessment of fishery resources and wetlands, it appears likely that the scenario water withdrawals examined in the Water Supply Impact Study (SJRWMD 2010b) will have a negligible effect on estuarine resources.

The flow reduction allowed under the recommended MFLs hydrologic regime for the Silver River that is examined in this WRV assessment is less than the withdrawals examined in the Water Supply Impact Study and would be expected to have considerably milder effects on downstream river stage and salinity, and by inference, estuarine resources. Thus, estuarine resources as defined in WRV-3 would be protected under the recommended MFLs hydrologic regime.

5.4 WRV-4: TRANSFER OF DETRITAL MATERIAL

Transfer of Detrital Material is defined as the movement by water of loose organic material and debris and associated decomposing biota. The criterion for protection is “the movement of loose organic materials.” In addition, a distinction is made in the literature (Mehta et al. 2004) regarding the “transfer” of detrital material from the banks to the water column versus the “transport” of material (e.g., sediment, under WRV-8) within the run. The representative functions used to assess protection are water depth and floodplain inundation in the spring run. The general indicators of protection will be water stage events to maintain detrital transfer to the Silver River. Specific indicators of protection will be the number of events per 100 years associated with water depth and area of inundation necessary for adequate detrital transfer to the water column that does not differ unacceptably from no-pumping conditions.

Detrital material is an important component of the food web in aquatic ecosystems (Mitsch and Gosselink 1993). Detrital material transport is an important ecological function in many riverine systems (Wetzel 2001) including spring runs (Odum 1957). This detrital material forms the basis for a detritus food web, in which microbes and aquatic insects utilize the reduced carbon in the dead plant material from an upstream ecosystem to promote their own growth and metabolism. These organisms, in turn, are food for fish and wildlife in downstream segments.

Detrital transfer in the present context refers to the movement of organic-rich sedimentary material from the banks into the water column when high water levels occur (Mehta et al. 2004). Unlike systems dominated by stormwater runoff in which storm flows can be two orders of magnitude or more greater than base flows, the spring-fed-dominated Silver River receives most of its discharge from groundwater and does not experience large, flashy discharge and water level fluctuations.

It should be noted that Silver River water levels are affected by Ocklawaha River backwater, particularly in the lower half of the Silver River. T9 is representative of areas of the run that have relatively flat topography and more direct linkage to the floodplain. Based on transect information collected by the SJRWMD staff, some floodplain areas immediately adjacent to the channel and downstream of T9 show elevations at which overflow from the main channel into the floodplain can occur are often higher than those of the hardwood swamps in the floodplain.

Observations are that much of the spring run has a bank along the channel that would seem to allow direct flooding from the river at fairly high stages (T3, T5 and T7 are good examples). However, further observations indicate upstream flow does enter the floodplain and flow through back channels, re-entering the run further downstream. Also, flow reaches the back-swamps through bank levee breaks at various points along the channel and return flow to the channel by the same process, carrying detritus into the river channel. This is consistent with SJRWMD's Silver River Hydrologic Engineering Center-River Analysis System (HEC-RAS) model construction, in which overbank, or levee-type flow from the main channel into the floodplain, was not specified. The water level in the floodplain was allowed to fluctuate in concert with that in the main channel. Flow in the floodplain areas was limited through the specification of “ineffective flow areas” for floodplain areas below the overbank elevations and specification of a high roughness coefficient when water levels exceeded the overbank elevations.

Particulate export was measured periodically during the Silver Springs retrospective study (Munch et al. 2006) in an effort to quantify particulate organic carbon outputs to the Silver River system. Plant export traps were deployed and harvested 14 times during the study period June 2004 and January 2005. Particulate export was measured at three stations in the upper portion of the Silver River: just below the main spring boil, at the upstream end of Turtle Meadows, and downstream at the 3,900-ft (1,200-m) station. All measurements were made between June 2004 and January 2005. No seasonal patterns were evident; however, a slight diurnal pattern of increasing particulate export in the middle to late afternoon was observed that is likely correlated with increased human and animal activities during daylight hours. Although particulate export increased markedly downstream from about 9.3 kilograms dry weight per day (kg dw/d) just below the main spring boil to 78 kg dw/d at the 1,200-m station, the average particulate export on a per-area basis was higher just below the main spring boil, with an average of 1.15 grams dry weight per square meter per day (g dw/m^2/d) than the average rate of 0.67 g dw/m^2/d measured at the 1,200-m station (Munch et al. 2006).

Figure 5-5 illustrates the observed relationship between flow and total organic carbon (TOC). Detritus consists of all nonliving organic matter, in both dissolved and particulate forms. In aquatic ecosystems in general, nearly all the organic matter consists of dissolved organic carbon compounds (DOC), and particulate organic carbon compounds (POC) (Wetzel, 2001). These data were collected along the entire river reach and over a relatively narrow range of spring flows and are inconclusive concerning a relationship between flow and TOC. In the graph, TOC is used as a surrogate for detritus. Figure 5-6 presents the observed relationship between stage and TOC, with TOC used as a surrogate for detritus. While the graph shows a slight increase in TOC concentration with stage, there is still considerable scatter.

A summary of vegetation transect information can be found in Appendix F, including the mean elevations of the hardwood swamps and the hydric hammocks. The wetted perimeter (the portion of the channel that is inundated or wet) versus stage relationships at each transect are presented in Figures 5-7 through 5-10.

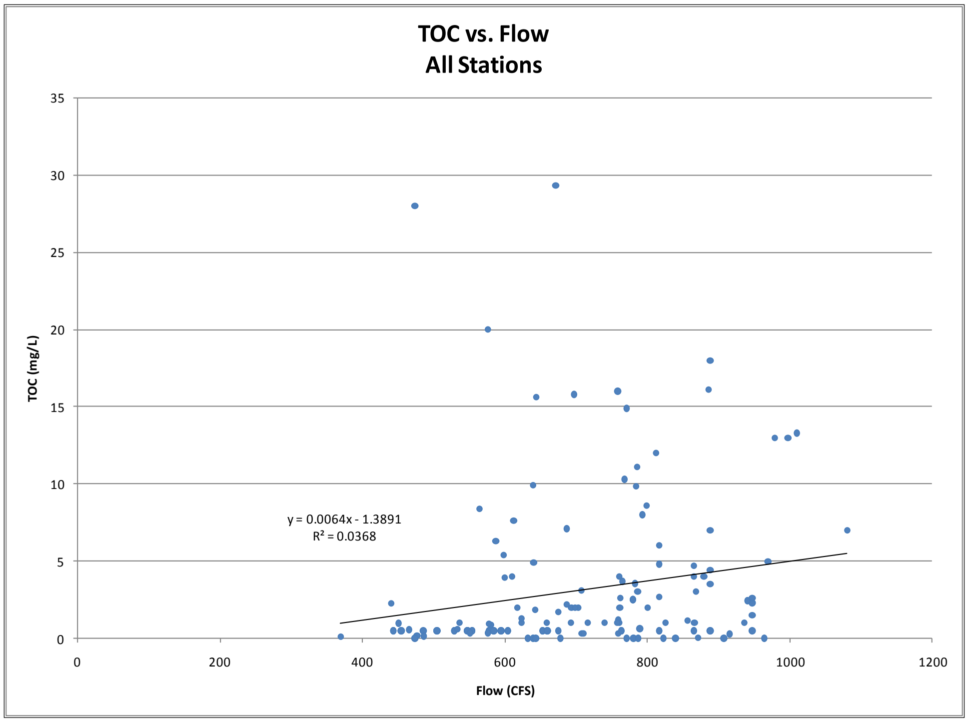


Figure 5-5. Relationship between flow and TOC for Silver River
Data Source: Munch et al. 2006.

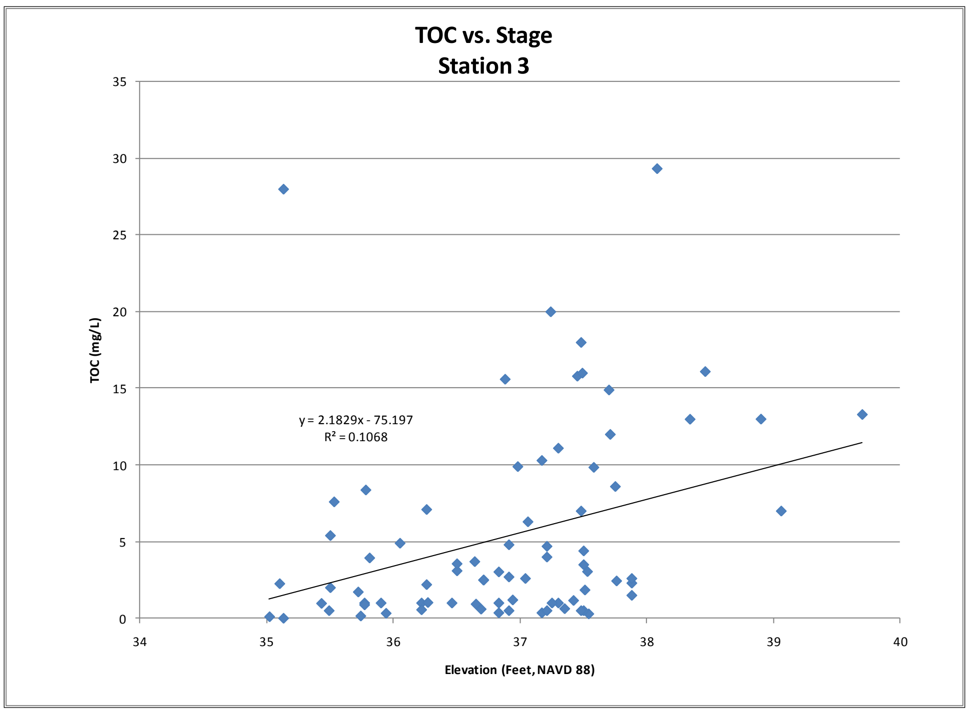


Figure 5-6. Observed relationship between stage and TOC for Silver River
Data Source: Munch et al. 2006

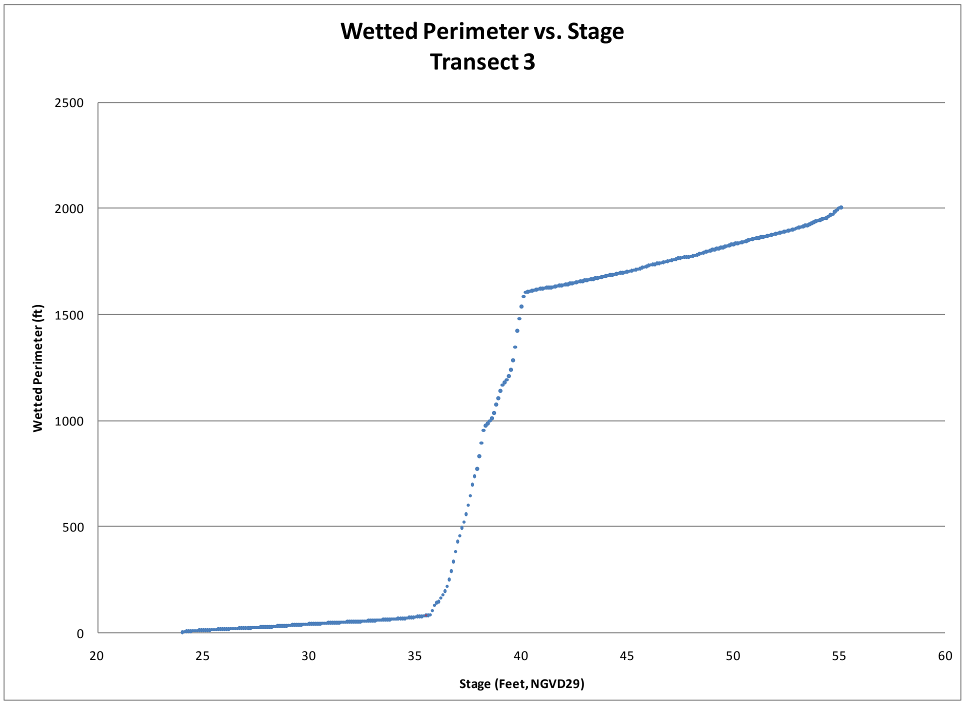


Figure 5-7. Wetted perimeter versus elevation for MFLs Transect 3

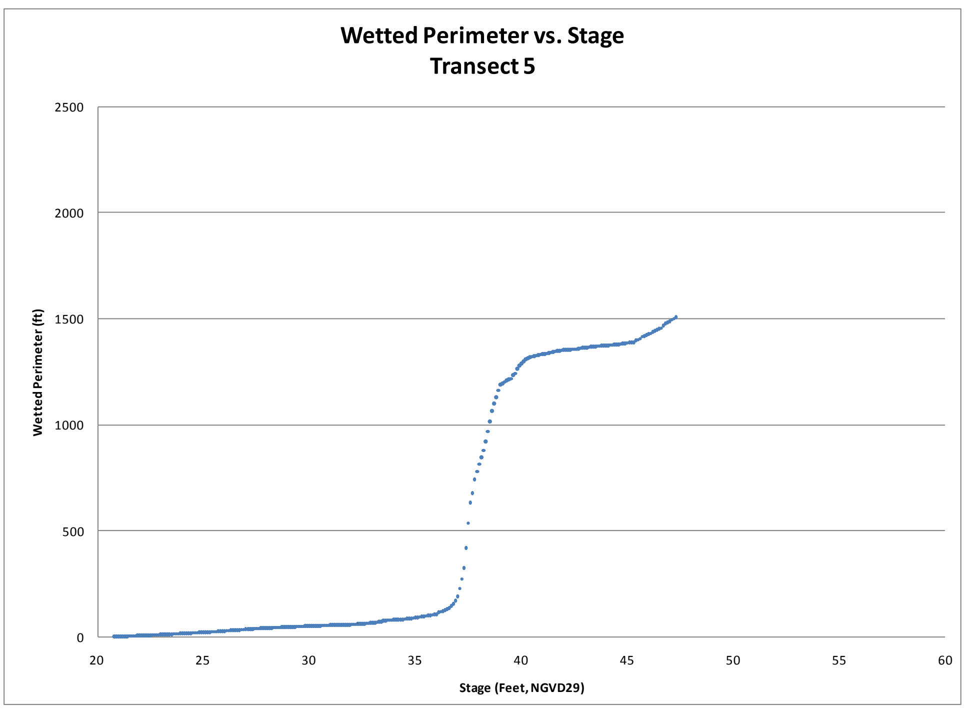


Figure 5-8. Wetted perimeter versus elevation for MFLs Transect 5

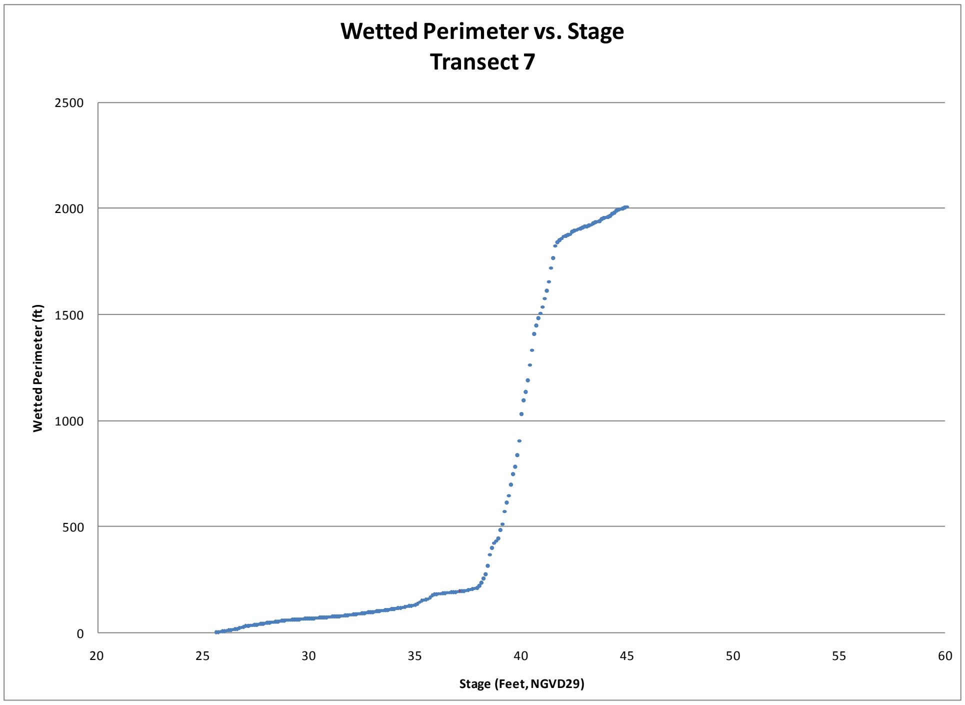


Figure 5-9. Wetted perimeter versus elevation for MFLs Transect 7

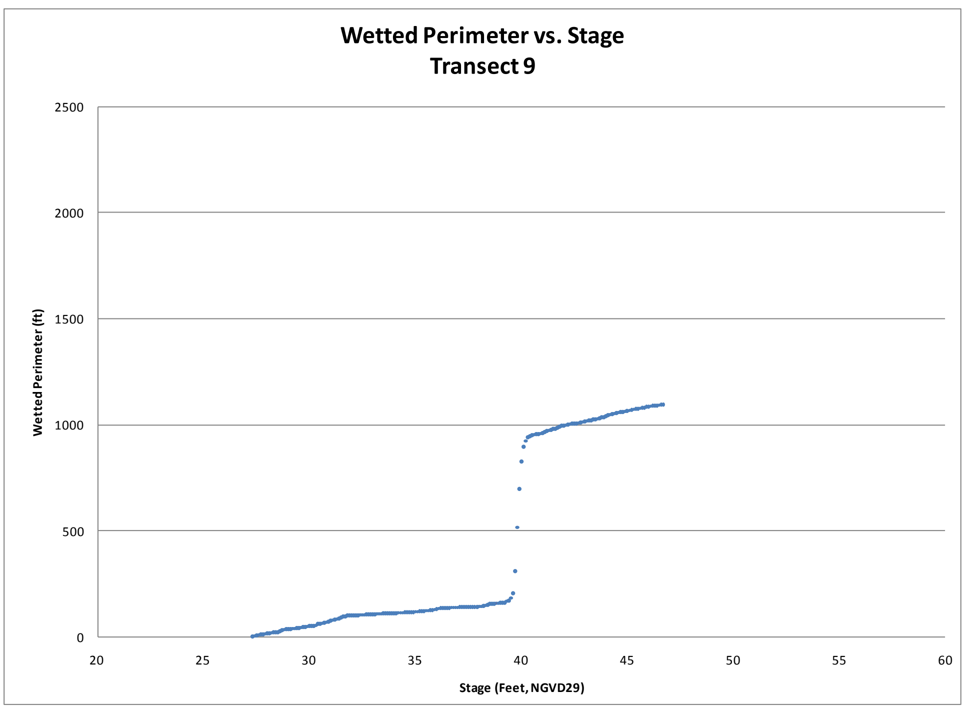


Figure 5-10. Wetted perimeter versus elevation for MFLs Transect 9

Two processes important to the transfer of detrital material are inundation of the floodplain, as that is the primary source of detritus that is mobilized by the inundation, and transfer of the material from the floodplain to the main channel, where it is transported to other locations. The important consideration is not necessarily the flow condition, but rather that the proposed MFLs would not cause a substantial shift in the occurrence of those critical flow events.

The SJRWMD developed the Silver River HEC-RAS model to evaluate hydraulic characteristics at 11 cross-sections along the Silver River for a range of flow conditions. The HEC-RAS model contained two geometry plans, one for the 1947-1999 period (in-channel Manning's n = 0.057) and one for the post-2000 period in which denser vegetative growth in the channel created rougher flow conditions necessitating a higher in-channel Manning's n (in-channel Manning's n = 0.1). Because the current period-of-record encompasses the entire period (1946-2014) and frequency statistics were calculated for the 1946-2014 period, the HEC-RAS model needed to be modified through the creation of a third geometry plan which best matched flow-stage relationships for the entire record. An in-channel Manning's n of 0.070 with a floodplain Manning's n of 0.3 provided the best match for the entire period.

An additional modification was made to the downstream boundary condition, which was changed from a static, fixed boundary to a Normal Depth assumption. The Normal Depth assumption is that the river flows under normal flow (uniform flow) conditions at the downstream boundary of the model. This allows specification of an energy slope, and then HEC-RAS will automatically back-calculate the depth using Manning's Equation. This method is used often in HEC-RAS applications and provides semi-dynamic properties for the downstream boundary (i.e., as the flow changes, so will the downstream boundary depth). This was deemed a more appropriate boundary condition as it better reflects the changing water levels in the Ocklawaha River, which serves as the water level boundary for the Silver River HEC-RAS model.

Table 5-21 presents in-channel average velocities at 11 cross-sections along the Silver River for a range of flow conditions. Given the small decrease, 0.05 ft/sec or less, in average in-channel velocities anticipated under the MFLs hydrologic regime from the period-of-record (POR) 1946-2014 hydrologic conditions, transport of detrital material from the banks of the Silver River should not change significantly under the MFLs hydrologic regime.

Table 5-21. In-channel, average velocities (feet per second, ft/s) simulated by the modified Silver River HEC-RAS model at different river reaches for 10 different discharge (cubic feet per second, cfs) events for the POR 1946-2014 no-pumping condition and the MFL hydrologic regime												
Exceedance Probability	**Discharge (cfs)**	**Stream Channel Cross-Section (Distance in feet from Confluence with Ocklawaha River)**										
		CS 11 (26,030 ft)	**CS 10 (22,760 ft)**	**CS 9 (21,600 ft)**	**CS 8 (19,380 ft)**	**CS 7 (17,370 ft)**	**CS 6 (13,990 ft)**	**CS 5 (9,770 ft)**	**CS 4 (7,500 ft)**	**CS 3 (4,490 ft)**	**CS 2 (2,640 ft)**	**CS 1 (0 ft)**
No-pumping condition												
10	1008.8	1.25	0.49	0.67	0.65	0.53	0.92	0.78	1.1	1.51	0.68	1.43
20	952.36	1.22	0.48	0.65	0.64	0.52	0.89	0.77	1.08	1.47	0.66	1.41
30	876.43	1.18	0.46	0.63	0.63	0.51	0.87	0.75	1.06	1.42	0.62	1.38
40	818.39	1.16	0.45	0.61	0.62	0.5	0.85	0.75	1.04	1.41	0.61	1.34
50	777.62	1.15	0.44	0.6	0.62	0.49	0.85	0.76	1.03	1.39	0.59	1.32
60	728.43	1.13	0.43	0.59	0.61	0.48	0.84	0.76	1.01	1.35	0.57	1.29
70	700	1.13	0.42	0.58	0.61	0.47	0.83	0.77	0.99	1.33	0.55	1.27
80	639	1.11	0.4	0.56	0.59	0.46	0.83	0.79	0.98	1.28	0.52	1.23
90	594.82	1.14	0.4	0.55	0.6	0.46	0.84	0.77	0.96	1.24	0.49	1.18
95	535	1.13	0.38	0.53	0.58	0.44	0.84	0.76	0.94	1.21	0.47	1.15
MFL												
10	967	1.23	0.48	0.66	0.64	0.52	0.9	0.77	1.09	1.48	0.67	1.42
20	910	1.2	0.47	0.64	0.63	0.51	0.88	0.76	1.07	1.44	0.64	1.4
30	834	1.17	0.45	0.62	0.62	0.5	0.86	0.76	1.05	1.42	0.61	1.35
40	777	1.15	0.44	0.6	0.61	0.49	0.85	0.76	1.03	1.39	0.59	1.32
50	736	1.14	0.43	0.59	0.61	0.48	0.84	0.76	1.01	1.36	0.57	1.29
60	686	1.12	0.41	0.57	0.6	0.47	0.82	0.79	0.99	1.33	0.55	1.26
70	658	1.12	0.41	0.56	0.6	0.46	0.82	0.78	0.98	1.3	0.53	1.24
80	597	1.11	0.39	0.54	0.58	0.45	0.82	0.77	0.95	1.26	0.51	1.2
90	550	1.14	0.38	0.54	0.59	0.45	0.85	0.76	0.94	1.21	0.47	1.15
95	492	1.16	0.37	0.52	0.57	0.44	0.85	0.74	0.92	1.17	0.45	1.12

The Silver HEC-RAS model was also used to assess mean flow velocities in the floodplains of the Silver River. Mean flow velocities in the floodplain are generally less than 0.1 ft/sec, with a few exceptions. Given that velocity reductions under the MFLs hydrologic regime are expected to be minimal, transport capacity within the floodplain areas is also expected to not change significantly.

Current velocity affects the composition of biological communities in streams, as well as being significant for channel erosion and downstream transport of materials. Studies of Florida springs have noted a possible relationship between reduced velocity and the proliferation of algae that may interact with algal response to nutrient increases (Stevenson et al., 2007). A recent study of three southwest Florida rivers identified a velocity threshold of 0.82 ft/sec below which river substrates were suitable for colonization of SAV (Hoyer et al., 2004). Recent studies at the Gum Slough spring system in Sumter County, FL identified a flow velocity threshold of 1.1 ft/sec above which algal abundance was minimal (King, 2012).

Using 30-day high flow frequency analysis of the Silver River adjusted POR discharge data for the period 1946 – 2014, in-channel, average velocities (feet per second, ft/s) simulated by the modified Silver River HEC-RAS model at different river reaches for 10 different discharge (cubic feet per second, cfs) events for the POR 1946-2014 no-pumping condition and the MFLs hydrologic regime was completed. The estimated discharges were inputted to the modified Silver River HEC-RAS model.

The simulated average velocity profiles (Table 5-22) indicate that less than half of the Silver River has an average channel velocity greater than 1.15 ft/second (ft/s) for these flow events. Velocities exceed the algal flushing threshold just downstream from the boil (~26,030 ft above the confluence), then generally drop below the threshold for the majority of the spring run, increasing above the threshold again near the confluence with the Lower Ocklawaha River (Table 5-22).

Given that velocity reductions under the MFL hydrologic regime is 0.05 ft/s or less, algal scour capacity will not change significantly.

Table 5-22. Algal Scour: In-channel, average velocities (feet per second, ft/s) simulated by the modified Silver River HEC-RAS model at different river reaches for 10 different discharge (cubic feet per second, cfs) events for the POR 1946-2014 no-pumping condition and the MFL hydrologic regime. Highlighted cells indicate locations where critical velocity of 1.1 fps was equaled or exceeded.

Exceedance Probability	Discharge (cfs)	Stream Channel Cross-Section (Distance in feet from Confluence with Ocklawaha River)										
		CS 11 (26,030 ft)	CS 10 (22,760 ft)	CS 9 (21,600 ft)	CS 8 (19,380 ft)	CS 7 (17,370 ft)	CS 6 (13,990 ft)	CS 5 (9,770 ft)	CS 4 (7,500 ft)	CS 3 (4,490 ft)	CS 2 (2,640 ft)	CS 1 (0 ft)
No-pumping condition												
10	1008.8	1.25	0.49	0.67	0.65	0.53	0.92	0.78	1.1	1.51	0.68	1.43
20	952.36	1.22	0.48	0.65	0.64	0.52	0.89	0.77	1.08	1.47	0.66	1.41
30	876.43	1.18	0.46	0.63	0.63	0.51	0.87	0.75	1.06	1.42	0.62	1.38
40	818.39	1.16	0.45	0.61	0.62	0.5	0.85	0.75	1.04	1.41	0.61	1.34
50	777.62	1.15	0.44	0.6	0.62	0.49	0.85	0.76	1.03	1.39	0.59	1.32
60	728.43	1.13	0.43	0.59	0.61	0.48	0.84	0.76	1.01	1.35	0.57	1.29
70	700	1.13	0.42	0.58	0.61	0.47	0.83	0.77	0.99	1.33	0.55	1.27
80	639	1.11	0.4	0.56	0.59	0.46	0.83	0.79	0.98	1.28	0.52	1.23
90	594.82	1.14	0.4	0.55	0.6	0.46	0.84	0.77	0.96	1.24	0.49	1.18
95	535	1.13	0.38	0.53	0.58	0.44	0.84	0.76	0.94	1.21	0.47	1.15
MFLs												
10	967	1.23	0.48	0.66	0.64	0.52	0.9	0.77	1.09	1.48	0.67	1.42
20	910	1.2	0.47	0.64	0.63	0.51	0.88	0.76	1.07	1.44	0.64	1.4
30	834	1.17	0.45	0.62	0.62	0.5	0.86	0.76	1.05	1.42	0.61	1.35
40	777	1.15	0.44	0.6	0.61	0.49	0.85	0.76	1.03	1.39	0.59	1.32
50	736	1.14	0.43	0.59	0.61	0.48	0.84	0.76	1.01	1.36	0.57	1.29
60	686	1.12	0.41	0.57	0.6	0.47	0.82	0.79	0.99	1.33	0.55	1.26
70	658	1.12	0.41	0.56	0.6	0.46	0.82	0.78	0.98	1.3	0.53	1.24
80	597	1.11	0.39	0.54	0.58	0.45	0.82	0.77	0.95	1.26	0.51	1.2
90	550	1.14	0.38	0.54	0.59	0.45	0.85	0.76	0.94	1.21	0.47	1.15
95	492	1.16	0.37	0.52	0.57	0.44	0.85	0.74	0.92	1.17	0.45	1.12

Multiple elevations needed to be examined in some locations to evaluate changes in critical events related to both floodplain inundation and detritus transport processes. For this evaluation, inundation of the maximum elevation and mean elevation of the floodplain and also the typical top-of-bank elevation at the stream channel edge, or overbank elevation, allowing sweeping of detritus by flow from the aquatic bed areas immediately adjacent to the river channel, were explored. This formulation is consistent with Silver River HEC-RAS model construction, in which overbank, or levee-type flow, from the main channel into the floodplain was not specified.

The water level in the floodplain was allowed to fluctuate in concert with that in the main channel. Conveyance in the floodplain areas was limited through the specification of *ineffective flow areas* for floodplain areas below the overbank elevations in which these areas functioned as floodplain storage, and specification of a high roughness coefficient when water levels exceeded the overbank elevations, allowing for direct water exchange with the main channel. These targets, summarized in Table 5-23, represent a range of flow conditions to compare across the two hydrologic regimes. Top-of-bank elevation target selection at each transect is discussed in the following paragraphs.

Table 5-23. Critical stage values and associated wetted perimeter length for detrital transfer

MFL Transect ID	Floodplain Elevation (ft-NGVD)		Overbank Elevation (ft-NGVD)		Wetted Perimeter at Overbank Elevation (ft)	
	Mean	Maximum	North	South	North	South
T3	38.0	40.2	38.3	40.2	974	1605
T5	38.4	40.2	39.0	38.8	1190	1131
T7	39.8	41.7	40.0	39.7	1287	1241
T9	39.9	40.3	40.3	40.2	940	900

For T3, a water surface elevation of 38.3 ft-NGVD will cause the river's main channel to overflow its north bank and greatly increase direct exchange with water in the floodplain (Figure 4-1). It appears that a water elevation of 40.2 ft-NGVD will cause the river to rise over its south bank and greatly increase direct exchange with water in the south floodplain. Evaluation of aerial photography and site reconnaissance indicates that the south floodplain in this area actually begins to receive Silver River flow at an elevation lower than 40.2 ft-NGVD. This occurs at a bend in the main river channel approximately 2,000 ft upstream of T3. From the SJRWMD Silver River HEC-RAS model, the overbank elevations for cross-section S4 (the closest to the overflow location) approximate those for T3. The results of the evaluation of the critical stages for detrital transfer at T3 should translate to this location. Therefore, only the north overbank will be evaluated for detrital transfer at T3.

For T5, a water surface elevation of 39.0 ft-NGVD will cause the river to rise over its north bank and greatly increase direct exchange with water in the floodplain (Figure 4-2). A water elevation of 38.8 ft-NGVD will cause the river to rise over its south bank and greatly increase direct exchange with water in the south floodplain. A water elevation of 39.0 ft-NGVD will be used to evaluate detrital transfer at T5 because it is a more conservative target.

For T7, a water surface elevation of 40.0 ft-NGVD will cause the river to rise over its north bank and greatly increase direct exchange with water in the floodplain (Figure 4-3). A water elevation of 39.7 ft-NGVD will cause the river to rise over its south bank and greatly increase direct exchange with water in the south floodplain. A water elevation of 40.0 ft-NGVD will be used to evaluate detrital transfer at T5 because it is a more conservative target.

For T9, a water surface elevation of 40.3 ft-NGVD will cause the river to rise over its north bank and greatly increase direct exchange with water in the floodplain (Figure 4-1). A water elevation of 40.2 ft-NGVD will cause the river to rise over its south bank and greatly increase direct exchange with water in the south floodplain. A water elevation of 40.3 ft-NGVD will be used to evaluate detrital transfer at T9 because it is a more conservative target.

Durations of 7 days and 30 days were examined as these durations will provide a range of sufficient contact times between the river and the adjacent floodplain to maintain connectivity and facilitate the transfer of detritus. Tables 5-24a and 5-24b present the frequency and duration parameter results for the evaluation of detrital transfer. SJRWMD provided the frequency analysis statistics.

Table 5-24a. Frequency analysis results for the protection of detrital transfer—7-day duration high stage continuously exceeded

Transect	Critical Stages (ft-NGVD)	Statistic[1]	Hydrologic Scenario: No-Pumping Condition	Hydrologic Scenario: MFL
T3	38 (mean)	Events/100 yr	50	32
		Difference	-	18
	38.3 (overflow)	Events/100 yr	41	24
		Difference	-	17
	40.2 (max)	Events/100 yr	7	5
		Difference	-	2
T5	38.4 (mean)	Events/100 yr	66	46
		Difference	-	20
	39 (overflow)	Events/100 yr	47	30
		Difference	-	17
	40.2 (max)	Events/100 yr	11	7
		Difference	-	4
T7	39.8 (mean)	Events/100 yr	62	42
		Difference	-	20
	40 (overflow)	Events/100 yr	57	36
		Difference	-	19
	41.7 (max)	Events/100 yr	5	3
		Difference	-	2
T9	39.9 (mean)	Events/100 yr	78	56
		Difference	-	22
	40.3 (overflow/max)	Events/100 yr	64	41
		Difference	-	23

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and MFLs hydrologic regimes.

Table 5-24b. Frequency analysis results for the protection of detrital transfer—30-day duration high stage continuously exceeded

Transect	Critical Stages (ft-NGVD)	Statistic[1]	Hydrologic Scenario: No-Pumping Condition	Hydrologic Scenario: MFL
T3	38 (mean)	Events/100 yr	38	26
		Difference	-	-12
	38.3 (overflow)	Events/100 yr	29	18
		Difference	-	-11
	40.2 (max)	Events/100 yr	6	4
		Difference	-	-2
T5	38.4 (mean)	Events/100 yr	58	39
		Difference	-	-19
	39 (overflow)	Events/100 yr	37	23
		Difference	-	-14
	40.2 (max)	Events/100 yr	7	6
		Difference	-	-1
T7	39.8 (mean)	Events/100 yr	54	34
		Difference	-	-20
	40 (overflow)	Events/100 yr	42	32
		Difference	-	-11
	41.7 (max)	Events/100 yr	3	2
		Difference	-	-1
T9	39.9 (mean)	Events/100 yr	69	48
		Difference	-	-21
	40.3 (overflow/max)	Events/100 yr	54	35
		Difference	-	-19

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and MFLs hydrologic regimes.

The frequency analysis indicates that all areas of the floodplain experience periodic inundation to allow detrital transfer to occur under the draft MFLs hydrologic scenario for both the 7-day and 30-day durations. The exception is MFLs transect T3, at the maximum floodplain elevation. Inundation of the floodplain up to the maximum floodplain elevation, except at T9, is a less frequent occurrence. The floodplain at T9 is flat, with the maximum floodplain elevation approximating the channel overbank elevation. Therefore, the critical elevations for evaluating detrital transfer are at the mean floodplain elevation and the channel overbank elevation.

The frequency of occurrence of critical events under the flow reduction scenarios for both 7-day and 30-day durations in which transfer of detritus to the river channel occurs is reduced from the no-pumping condition scenario. On average, these events occur once every 1.3 to 3.5 years, depending on the location along the river reach. The average for the no-pumping hydrologic regime for the mean floodplain and overbank elevations for the entire river is 1.8 and 2.25 years for the 7-day and 30-day durations respectively. The average for the MFL hydrologic regime for the mean floodplain and overbank elevations for the entire river is 2.8 and 3.4 years for the 7-day and 30-day durations respectively. Based on these data and the results of the frequency analysis, it is concluded this WRV is protected under the MFLs hydrologic regime.

5.5 WRV-5: MAINTENANCE OF FRESHWATER STORAGE AND SUPPLY

For this analysis, *Maintenance of Freshwater Storage and Supply* is defined as the protection of an adequate amount of freshwater for non-consumptive uses and environmental values associated with coastal, estuarine, riverine, spring, aquatic, and wetlands ecology. The analysis focuses on whether the proposed minimum levels or flows protect the capacity of wetlands, surface waters, or the aquifer to store and supply water for non-consumptive uses and environmental values. The criterion for protection is the amount(s) of surface water and groundwater that is needed for non-consumptive uses. The representative function used to assess protection is the maintenance of adequate surface water levels and aquifer levels in the area(s) adjacent to the water body. The general indicator of protection is aquifer levels, surface water levels and flows that do not result in adverse impacts to the water body. The specific indicator of protection includes an evaluation as to whether the groundwater-surface water interactions will change because of flow reductions in Silver River to the extent that WRVs are not protected.

The evaluation of this WRV is related to non-consumptive uses and environmental values. This WRV is encompassed in the other nine (9) WRVs. Their evaluation is presented in the other sections of Chapter 5. If the results of those evaluations conclude that the draft MFLs protect those WRVs, then WRV-5 is considered protected. Given that those evaluations concluded that all nine WRVs are protected, it is concluded that WRV-5 is also protect by the draft MFLs.

5.6 WRV-6: AESTHETIC AND SCENIC ATTRIBUTES

Aesthetic and Scenic Attributes, is defined as those features of a waterscape usually associated with passive uses such as bird watching, sightseeing, hiking, photography, contemplation, and painting, plus other forms of relaxation that usually result in human emotional responses of well-being and contentment. As access to the Silver River is primarily by boat, several of these passive uses, e.g., bird watching, photography, or contemplation, would be integrated with the recreational boating criteria in WRV-1, as well as the ecotourism aspects of WRV-10.

The criterion for protection is *passive recreation*. The representative function used to assess protection is the visual setting at representative points, which, in this case, are the four MFLs transects, as observed by a person on a boat. The general indicators of protection are changes in the visual setting at low flows under the no-pumping condition hydrologic regime versus low flows under the draft MFLs hydrologic regime. The specific indicators of protection are whether an obvious visual difference exists between the no-pumping low-flow hydrologic condition and the draft MFLs hydrologic regime and, if so, the extent to which these visual conditions may be changed (i.e., the extent of shifts in return interval at selected threshold water levels and duration).

The subject of aesthetics was specifically discussed with Capt. Tom O'Lenick, an ecotour operator who runs Silver River boat trips. As discussed in WRV-1, Capt. O'Lenick has run ecotour boat trips on the Silver River since 1983. He estimates he is on the river approximately 200 days per year and over 5,000 times in total. Capt. O'Lenick identified water clarity as the primary metric among his clients when describing their scenic priorities, i.e., the more clear and transparent the water, the "prettier" it is perceived and the easier it is to observe fish (O'Lenick, personal communication, August 19, 2010). The opportunity to view wildlife, specifically basking alligators, turtles, and the myriad water-dependent birds, was also a client priority.

Captain O'Lenick related his observation that water transparency in the Silver River tends to increase as river flow decreases (personal communication, August 19, 2010). The river water is clearer and more transparent when the water level is below the top of bank and water in the river is primarily the clear water flowing directly from the spring vents. Low water prevents introduction of tannic color from the floodplain. Capt. O'Lenick's observation of improved clarity with lower water levels was not validated in the evaluation of *Water Quality* (WRV-9) as most of the data related to water clarity (color and turbidity) were below detection limit, which limited the determination of such a relationship. At this point, the observation of such a relationship is anecdotal or “in the eye of the beholder.”

As indicated in Table 4-1, the specific indicator for the *Aesthetics* WRV is water level and clarity associated with desirable scenic and fish/wildlife viewing. The evaluation focused on the top-of-bank elevation, which optimizes wildlife viewing access and water clarity. The lower top-of-bank elevation at each of the MFLs transects was used as there were differences in these elevations between the north and south. Those elevations are presented in Table 5-25. The chosen events were the 30-day and 90-day low stage continuously not exceeded. These durations were chosen to reflect the durations of seasonal low-water level periods that currently exist and because longer durations will have a greater economic impact on ecotourism. Changes in the frequency of the 30-day and 90-day continuously not exceeded stage are summarized in Tables 5-26a and 5-26b.

Table 5-25. Critical stage thresholds for evaluation of aesthetics and scenic attributes

MFLs Transect ID	Critical Stage ft-NGVD
T3	38.3
T5	38.8
T7	39.7
T9	40.2

Table 5-26a. Frequency analysis results for the protection of aesthetics and scenic attributes—30-day duration low stage continuously not exceeded

Transect	Critical Stage ft-NGVD	Statistic[1]	Hydrologic Scenario: No-Pumping Condition	Hydrologic Scenario: MFLs
T3	38.3	Events/100 yr	100	100
		Difference	-	0
T5	38.8	Events/100 yr	94	99
		Difference	-	5
T7	39.7	Events/100 yr	89	95
		Difference	-	6
T9	40.2	Events/100 yr	88	95
		Difference	-	7

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and MFLs hydrologic regimes.

Table 5-26b. Frequency analysis results for the protection of aesthetics and scenic attributes—90–day duration low stage continuously not exceeded				
			Hydrologic Scenario	
Transect	Critical Stage ft-NGVD	Statistic[1]	No-Pumping Condition	MFLs
T3	38.3	Events/100 yr	95	100
		Difference	-	5
T5	38.8	Events/100 yr	91	94
		Difference	-	3
T7	39.7	Events/100 yr	80	90
		Difference	-	10
T9	40.2	Events/100 yr	79	90
		Difference	-	11

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and MFLs hydrologic regimes.

The results of the analysis indicate a small increase in the frequency of these events for all flow scenarios at the lower top-of-bank elevation where wildlife viewing and water clarity would be optimized at each transect. What is implied is that there are fewer of these events for the higher top-of bank elevation at each transect, which somewhat offsets this increase in desirable events. However, overall viewing experience should not be diminished. Also, as discussed, the water clarity in the Silver River is perceived to increase during lower water, so the aesthetics associated with clearer water and the ability to more clearly see fish are enhanced. Accordingly, WRV-6, *Aesthetics*, is protected under the draft MFLs hydrologic regime.

5.7 WRV-7: FILTRATION AND ABSORPTION OF NUTRIENTS AND OTHER POLLUTANTS

Filtration and Absorption of Nutrients and Other Pollutants is defined as the reduction in concentration of nutrients and other pollutants through the processes of filtration and absorption (i.e., the removal of suspended) and dissolved materials as these substances move through the water column, soil, or substrate and associated organisms. The criteria for protection are the processes of filtration and absorption. The representative function used to assess protection is the ability of water to promote nutrient removal in the river and adjacent wetlands. The general indicators of protection are the depth and duration of floodplain inundation. The specific indicators of protection are the return intervals of stages associated with selected duration sufficient to maintain contact with riparian vegetation similar to no-pumping conditions.

Filtration and absorption of nutrients and other pollutants are natural system processes associated with aquatic and wetland ecology and are protected under *F.A.C*. 62-40.470 (Natural Systems Protection and Management) and *F.A.C.* 60-40.473 (Minimum Flows and Levels). Filtration consists of physical, chemical and biological processes that occur as water flows through media such as soil, sediment, and vegetation. Absorption is a chemical process that occurs during filtration. In natural environments, filtration and absorption can take place at many points throughout the hydrologic cycle. Therefore, understanding where these processes occur is important in evaluating the protection of this WRV in terms of MFLs.

Battelle (2004) investigated the sensitivity of this WRV to alterations in hydrologic regimes. The report concluded that filtration and absorption of nutrients and other pollutants related to springs occur in the flow path through the aquifer from the recharge area to the point of discharge. Filtration is primarily a function of the soil porosity. Adsorption is also primarily a function of the soil properties. Geochemical reactions are driven by the water quality of the source water and the chemical constituents of the aquifer soils. Alteration of groundwater level by pumping or diversions from surface water bodies could have an indirect effect on filtration and absorption. Lowering of the groundwater level by pumping or river level declines may affect retention time of water in the aquifer, which is a factor in geochemical reactions involving absorption (Battelle 2004). Once the spring emerges, filtration and absorption can also occur on other biologically active surfaces on the floodplain.

The biogeochemical processing of dissolved constituents is controlled by complex interactions between the rate at which water flows through surface and subsurface flow paths and the rate at which dissolved constituents are processed by such processes as adsorption to sediments or uptake by microorganisms and vegetation (Hamilton and Helsel 1995). This processing of dissolved constituents typically occurs in the floodplains of streams and water bodies. Floodplain soils and sediments that comprise the boundaries of streams support abundant microorganisms and vegetation as well as low redox environments and/or steep redox gradients that are essential for numerous biogeochemical processes (Ponnamperuma 1972). Consequently, floodplain soils and sediments that comprise the boundaries of streams are areas in which a large proportion of the biogeochemical processing of dissolved constituents typically occurs (Hill et al. 1998, Hill and Lymburner 1998).

Filtration and absorption processes occur within the water column through contact with submerged aquatic vegetation and in riparian zones where major medium such as vegetation, sediments, and soils exist. The rates of these processes are functions of residence time, or contact time, with these media. The longer nutrient and pollutant particles exist within a water body, the more likely they will be filtered, absorbed, or assimilated. As corroborated by the HEC-RAS results, spring flow reductions will very slightly reduce the average in-channel flow velocity, which would allow more contact time for nutrients and pollutants within the water column. The increased residence time would allow more time for the nutrients and pollutants to be filtrated, absorbed, or otherwise assimilated by submerged aquatic vegetation (SAV), bottom sediments and organisms in water columns. Therefore, it may be reasonable to conclude that changes to hydraulic residence times associated with the MFLs hydrologic regime would benefit the filtration and absorption functional capacities of the SAV, which is abundant in portions of the Silver River.

The residence time of the Silver River was calculated at the lowest flow modeled in HEC-RAS, resulting in a mean channel velocity of approximately 0.3 ft/sec. The lowest mean channel velocity modeled along the river reach occurred at cross-section 10 (Figure 4-5) and was the minimum mean in-channel velocity for all flows and cross-sections. This velocity would result in an in-channel residence time of 0.96 day, if applied across the entire river reach. While not a realistic calculation of in-channel residence time, it does emphasize the point that water from the springs traverses the river reach in a relatively short time. The actual in-channel residence times are on the order of one-half day or less.

Cohen et al. (2011) investigated nitrogen removal mechanisms on a number of spring-fed rivers, including the Silver River. One conclusion was that significant nitrogen removal occurs in spring run streams and that denitrification was the dominant process across almost all the systems. They found that denitrification is strongly coupled to gross primary productivity (GPP) as is presented in Figure 5-11. GPP is one measure of ecosystem metabolism that provides insights into the overall function of an aquatic ecosystem.

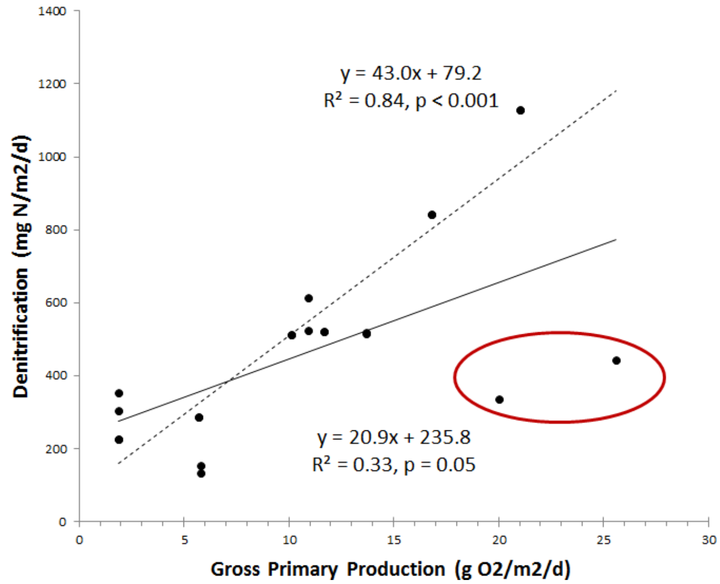


Figure 5-11. Relationship between denitrification (Uden) and gross primary production across rivers
The two outliers removed to yield the dashed line fit are both for upper river sites (Silver and Rainbow), which may not achieve the same level of denitrification as the rest of the river because of stronger hydraulic gradients (precluding water entering the sediments from the river) or because of reduced labile C availability. Source: Cohen et al. (2011)

WSI (2010) examined ecosystem metabolism parameters, including GPP, in 12 Florida springs. The consumption and production of oxygen by all spring flora and fauna are included in these measurements (WSI 2010). As part of this assessment, WSI examined the relationship between GPP and spring velocity and discharge. At current velocities up to about 0.82 ft/sec, GPP increased, whereas at velocities greater than this, GPP declined (WSI 2010). The decline in GPP above this velocity is likely related to physical conditions that reduce habitat suitability for SAV, which is a key component in primary production in spring ecosystems (WSI, 2010).

Table 5-21 presents in-channel average velocities at 11 cross-sections along the Silver River for a range of flow conditions. Depending on location along the river reach, in-channel average velocities can be above or below the 0.82 ft/s threshold where GPP is at a maximum. A decrease in average in-channel velocities can result in a decrease or an increase in GPP, depending on velocity conditions at a particular location along the river. Likewise, denitrification could decrease or increase in conjunction with shifts in GPP. Given the small decrease in average in-channel velocities (0.05 ft/s) anticipated under the MFL hydrologic regime from the POR 1946- 2014 condition as illustrated in Table 5-27, nitrogen removal, due to denitrification in the Silver River, is not anticipated to change significantly.

Table 5-27. Gross Primary Productivity - In-channel, average velocities (feet per second, ft/s) simulated by the modified Silver River HEC-RAS model at different river reaches for 10 different discharge (cubic feet per second, cfs) events for the POR 1946-2014 no-pumping condition MFLs hydrologic regime. Highlighted cells indicate locations where critical velocity of 0.82 fps was equaled or exceeded.

		Stream Channel Cross-Section (Distance in feet from Confluence with Ocklawaha River)										
Exceedance Probability	Discharge (cfs)	CS 11 (26,030 ft)	CS 10 (22,760 ft)	CS 9 (21,600 ft)	CS 8 (19,380 ft)	CS 7 (17,370 ft)	CS 6 (13,990 ft)	CS 5 (9,770 ft)	CS 4 (7,500 ft)	CS 3 (4,490 ft)	CS 2 (2,640 ft)	CS 1 (0 ft)
No-pumping condition												
10	1008.8	1.25	0.49	0.67	0.65	0.53	0.92	0.78	1.1	1.51	0.68	1.43
20	952.36	1.22	0.48	0.65	0.64	0.52	0.89	0.77	1.08	1.47	0.66	1.41
30	876.43	1.18	0.46	0.63	0.63	0.51	0.87	0.75	1.06	1.42	0.62	1.38
40	818.39	1.16	0.45	0.61	0.62	0.5	0.85	0.75	1.04	1.41	0.61	1.34
50	777.62	1.15	0.44	0.6	0.62	0.49	0.85	0.76	1.03	1.39	0.59	1.32
60	728.43	1.13	0.43	0.59	0.61	0.48	0.84	0.76	1.01	1.35	0.57	1.29
70	700	1.13	0.42	0.58	0.61	0.47	0.83	0.77	0.99	1.33	0.55	1.27
80	639	1.11	0.4	0.56	0.59	0.46	0.83	0.79	0.98	1.28	0.52	1.23
90	594.82	1.14	0.4	0.55	0.6	0.46	0.84	0.77	0.96	1.24	0.49	1.18
95	535	1.13	0.38	0.53	0.58	0.44	0.84	0.76	0.94	1.21	0.47	1.15
MFL												
10	967	1.23	0.48	0.66	0.64	0.52	0.9	0.77	1.09	1.48	0.67	1.42
20	910	1.2	0.47	0.64	0.63	0.51	0.88	0.76	1.07	1.44	0.64	1.4
30	834	1.17	0.45	0.62	0.62	0.5	0.86	0.76	1.05	1.42	0.61	1.35
40	777	1.15	0.44	0.6	0.61	0.49	0.85	0.76	1.03	1.39	0.59	1.32
50	736	1.14	0.43	0.59	0.61	0.48	0.84	0.76	1.01	1.36	0.57	1.29
60	686	1.12	0.41	0.57	0.6	0.47	0.82	0.79	0.99	1.33	0.55	1.26
70	658	1.12	0.41	0.56	0.6	0.46	0.82	0.78	0.98	1.3	0.53	1.24
80	597	1.11	0.39	0.54	0.58	0.45	0.82	0.77	0.95	1.26	0.51	1.2
90	550	1.14	0.38	0.54	0.59	0.45	0.85	0.76	0.94	1.21	0.47	1.15
95	492	1.16	0.37	0.52	0.57	0.44	0.85	0.74	0.92	1.17	0.45	1.12

The major factor that would be affected by flow reductions allowed under the recommended MFLs would be the reduction in the frequency of physical contact of water with riparian, or floodplain vegetation. The degree of nutrient release and assimilation in the wetlands, as well as the decomposition of the vegetation communities, depends to a large extent on the frequency and duration of inundation, because the process of filtration and absorption requires both wet and dry periods. If the selected threshold stages will not occur substantially less frequently under the MFLs scenario than under no-pumping conditions, it can be inferred that the process of filtration and absorption/adsorption in wetland soils, sediments, and vegetative communities, littoral vegetation, bottom sediments, and water column organisms would be protected. As such, this WRV is also protected by maintaining contact with the floodplain as was done in WRV-4 (Section 5-4) *Transfer of Detrital Material*.

The process of selecting the critical elevations for analysis was presented in Section 5-4. For this evaluation, inundation of the maximum elevation and mean elevation of the swamp and the typical top of bank elevation at the stream channel edge were assessed. These targets, which are summarized in Table 5-28 represent a range of flow conditions to compare across the two hydrologic regimes.

Table 5-28. Critical stage values and corresponding wetted perimeter length for filtration and absorption of nutrients and other pollutants

MFL Transect ID	Floodplain Elevation (ft-NGVD)		Overbank Elevation (ft-NGVD)		Wetted Perimeter at Overbank Elevation (ft)	
	Mean	Maximum	North	South	North	South
T3	38.0	40.2	38.3	40.2	974	1605
T5	38.4	40.2	39.0	38.8	1190	1131
T7	39.8	41.7	40.0	39.7	1287	1241
T9	39.9	40.3	40.3	40.2	940	900

A summary of vegetation transect information can be found in Appendix F, including the mean elevations of the floodplain. Their associated wetted perimeter versus stage relationships are presented in Figures 5-7 through 5-10.

Durations of 14 days and 30 days were evaluated to determine if sufficient contact time between the river and the adjacent hardwood swamps exists to maintain connectivity and facilitate the WRV-7, *Filtration and Absorption of Nutrients and Other Pollutants*. These durations were chosen as they approximate design residence time requirements for wet-detention systems as presented in Chapter 40C-42, *F.A.C.* (SJRWMD 2010c).

Tables 5-29a and 5-29b present the frequency and duration parameter results for the evaluation of WRV-7, *Filtration and Absorption of Nutrients and Other Pollutants*. SJRWMD provided the frequency analysis statistics. The frequency analysis indicates that all areas of the floodplain experience periodic inundation to allow filtration and absorption of nutrients and other pollutants to occur under the MFLs hydrologic regime for both the 14-day and 30-day durations. The exception is at MFLs transect T3.

Inundation of the floodplain up to the maximum floodplain elevation, except at T9, occurs infrequently under the no-pumping condition for the 14-day and 30-day durations. The floodplain at T9 is flat, with the maximum floodplain elevation approximating the channel overbank elevation. Therefore, the critical elevations for evaluating filtration and absorption of nutrients and other pollutants are at the mean floodplain elevation and the channel overbank elevation.

On average, these events occur once every 1.4 to 3.5 years, depending on the location along the river reach. The average for the no-pumping hydrologic regime for the mean floodplain and overbank elevations for the entire river is 2.0 and 2.2 years for the 14-day and 30-day durations respectively. The average for the MFL hydrologic regime for the mean floodplain and overbank elevations for the entire river is 3.0 and 3.4 years for the 7-day and 30-day durations respectively.

Based on these data and professional judgment, this WRV is protected under the recommended MFLs hydrologic regime.

Table 5-29a. Frequency analysis results for the protection of filtration and absorption of nutrients and other pollutants – 14–day duration high stage continuously exceeded

Transect	Critical Stages ft-NGVD	Statistic[1]	Hydrologic Scenario	
			No-Pumping Condition	MFL
T3	38 (mean)	Events/100 yr	44	30
		Difference	-	14
	38.3 (overflow)	Events/100 yr	34	21
		Difference	-	13
	40.2 (max)	Events/100 yr	6	4
		Difference		2
T5	38.4 (mean)	Events/100 yr	62	44
		Difference	-	18
	39 (overflow)	Events/100 yr	43	28
		Difference	-	15
	40.2 (max)	Events/100 yr	9	7
		Difference	-	2
T7	39.8 (mean)	Events/100 yr	59	37
		Difference	-	22
	40 (overflow)	Events/100 yr	51	35
		Difference	-	17
	41.7 (max)	Events/100 yr	5	3
		Difference	-	2
T9	39.9 (mean)	Events/100 yr	74	57
		Difference	-	17
	40.3 (overflow/max)	Events/100 yr	59	42
		Difference	-	17

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and MFLs hydrologic regimes.

Table 5-29b. Frequency analysis results for the protection of filtration and absorption of nutrients and other pollutants – 30–day duration high stage continuously exceeded				
			Hydrologic Scenario	
Transect	**Critical Stages ft-NGVD**	**Statistic[1]**	**No-Pumping Condition**	**MFL**
T3	38 (mean)	Events/100 yr	38	26
		Difference	-	12
	38.3 (overflow)	Events/100 yr	29	18
		Difference	-	11
	40.2 (max)	Events/100 yr	6	4
		Difference	-	2
T5	38.4 (mean)	Events/100 yr	59	39
		Difference	-	20
	39 (overflow)	Events/100 yr	37	23
		Difference	-	14
	40.2 (max)	Events/100 yr	6	6
		Difference	-	0
T7	39.8 (mean)	Events/100 yr	54	34
		Difference	-	15
	40 (overflow)	Events/100 yr	43	32
		Difference	-	11
	41.7 (max)	Events/100 yr	3	2
		Difference	-	1
T9	39.9 (mean)	Events/100 yr	69	54
		Difference	-	15
	40.3 (overflow/max)	Events/100 yr	54	35
		Difference	-	19

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and MFLs hydrologic regimes.

5.8 WRV-8: SEDIMENT LOADS

Sediment Loads is defined as the transport of inorganic materials, suspended in water, that may settle or rise, often depending on the volume and velocity of the water. The criterion for protection is the "transport of inorganic materials." The assessment focused on the effect of changing the return interval of events on the transport, erosion, and deposition of sediment. The representative function used to assess the protection of sediment loads is to maintain the transport of sediment in the Silver River. The general indicators of protection for high-water and low-water conditions are variations in stage, velocity, and bed shear stress between the no-pumping conditions and the MFLs hydrologic regimes. The specific indicators of protection are the minimum current velocities and bed shear stress, derived from the literature, required for adequate sediment transport, and the extent to which the number of events per 100 years for which intervals of these critical velocities will change under the MFLs hydrologic regime.

The movement or transport of sediment is a function of flow events, sediment material composition, and supply (i.e., source of particulate matter). Figure 5-12 depicts the classification categories (Mehta et al. 2004). Sediment transport amount, or “sediment load,” is conveyed as a mass or weight per unit time (e.g., tons/day or kg/sec). A more thorough discussion of sediment transport can be found in ATM (2008).

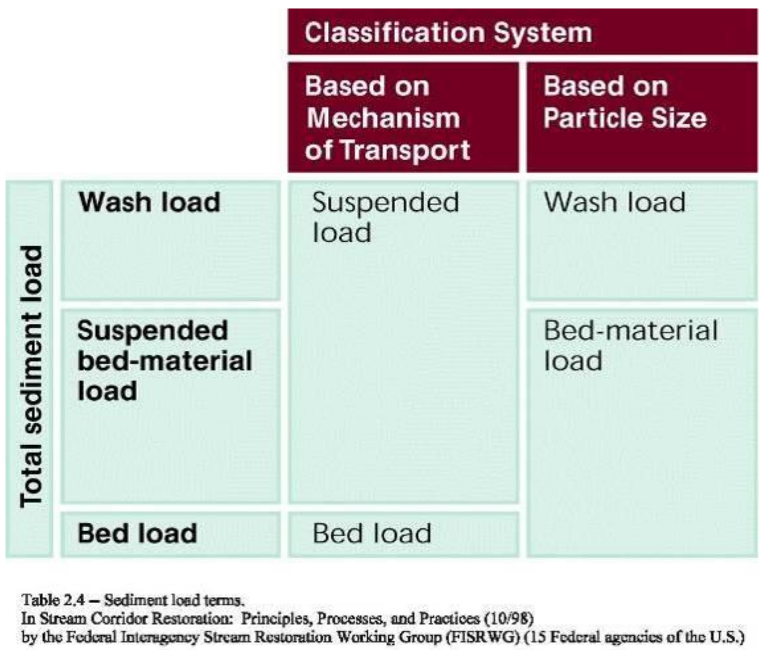


Figure 5-12. Sediment load classification categories (FISRWG 1998)

To protect this WRV, the effect of flow reductions allowed under the draft MFLs hydrologic regime on suspended load and bed material load (as defined in Figure 5-12), must be considered. The key variable is flow velocity, which transports the suspended particles (both organic and inorganic). If the number of critical flow velocity events per 100 years is not substantially changed under the recommended MFLs hydrologic regime, it can be inferred that this WRV will be protected.

Sediment Load Specific Criteria and Metrics

Figures 5-13 and 5-14 illustrate the observed relationship between flow and total suspended solids (TSS) and stage and TSS, respectively, using historical water quality data, specifically TSS, collected at Silver Springs and Silver River (Munch et al. 2006) as a surrogate for sediment load transport. These data were collected over a broad range of spring flows and are inconclusive concerning a relationship between flow and sediment transport. The goal of plotting these data was to determine if discernible patterns of transport exist where critical transport events, evidenced by slope changes in the flow and sediment load transport and stage and sediment load transport relationships specific to the Silver River system, may be identified.

Grain size analysis was not available for sediments within the Silver River main channel. Based on the NRCS Soil Survey for Marion County, the soils surrounding the Silver River are dominated by well- to moderately well-sorted medium to fine sand over a majority of its length. Based on the Unified Soil Classification System (USCS), fine to medium sand would have a median grain size diameter (D50) of approximately 0.5 millimeter (mm), with most particles being less than 2.0 mm in size.

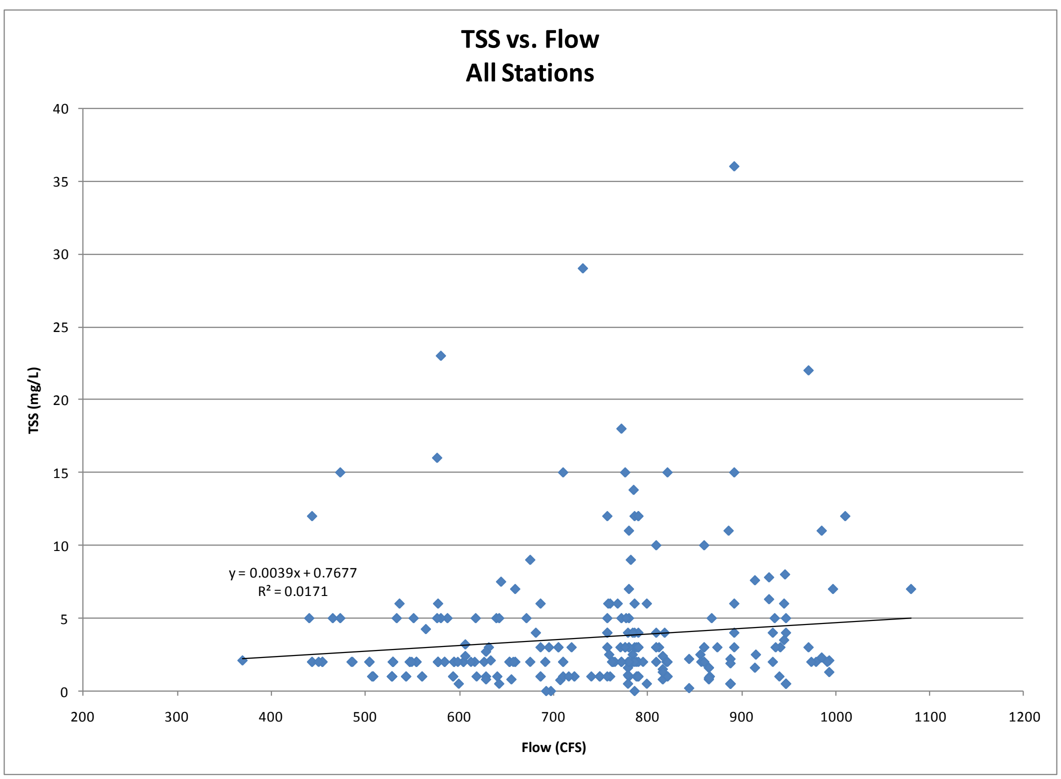


Figure 5-13. Relationship between flow and total suspended solids (TSS) for Silver River Data Source: Munch et al. 2006

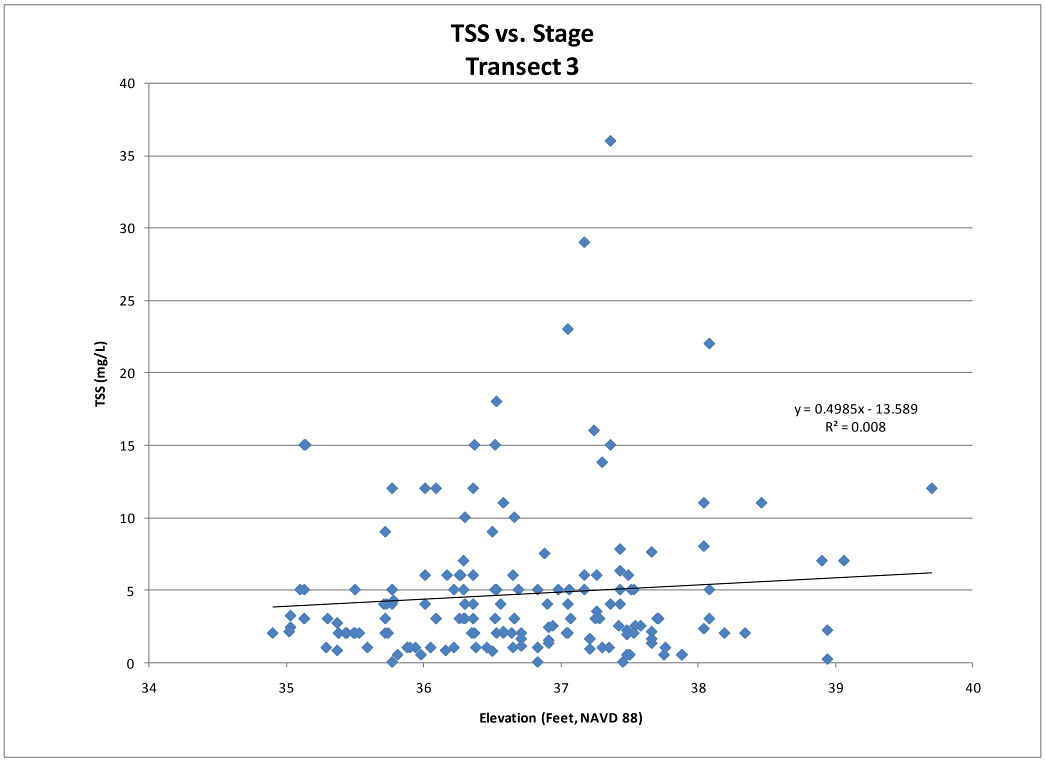


Figure 5-14. Relationship between stage and total suspended solids (TSS) for Silver River Data Source: Munch et al. 2006

As such, for sediment transport purposes, the bed material can be analyzed as non-cohesive inorganic fine sediment with a median grain size diameter (D50) of 0.50 mm. The initiation of motion of these particles is primarily a function of bed shear stress and particle size (Yang, 2006). Bed shear stress (τ) is computed as:

$$\tau = \gamma RS$$

where

γ = specific weight of water

R = hydraulic radius (cross-sectional flow area over wetted perimeter)

S = the slope of the energy grade line (which can be approximated by the bottom slope of the channel for uniform or gradually varied flow conditions)

A commonly accepted measure of the initiation of motion for uniform non-cohesive sediments can be determined using the Shields diagram (Shields 1936) presented in Figure 5-15. The Shields curve divides a region of motion from a region of no motion. By determining the dimensionless Shields parameter and dimensionless grain Reynolds number, a prediction of sediment motion may be obtained. For D50 sediment grain sizes of approximately 0.50 mm, the critical bed shear for motion is about 0.006 pound per square foot (lb/ft^2).

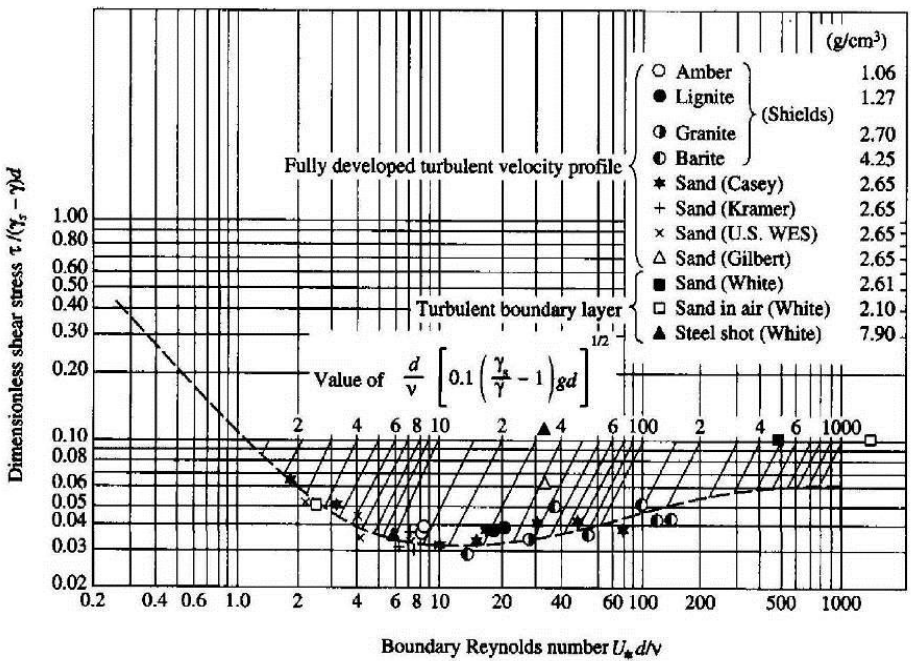


Figure 5-15. Incipient motion diagram (Shields, 1936)

SJRWMD's HEC-RAS results can be utilized to evaluate bed shear across the range of flows and along the river reach. Based on the HEC-RAS results provided by SJRWMD, Shields parameters were calculated for a range of flows at T3, T5, T7, and T9 to determine if the bed is mobilized and sediment transported across the entire range of flows and cross-sections per the Shields incipient motion diagram. For all flows and cross-sections evaluated under the 1947-1999 conditions, sediment motion occurs. A summary of modeled average in-channel velocities under two hydrologic regimes is presented in Table 5-30.

A key protection metric is whether the long-term transport of sediment will be influenced by withdrawals. Major changes in the sediment transport regime could cause net erosion or deposition of sediment in the channel, thereby changing the natural sediment regime. A simplified approach for this analysis is based on the work of Hjulstrom. Hjulstrom (1935) considered a wide range of uniform sediment size and flow conditions and developed a chart that indicates the regions of erosion, transport, and deposition (or sedimentation) (Figure 5-16). Therefore, sediment of a diameter of 0.5 mm would remain transported at a rate of between 3.7 centimeters per second (cm/sec) and 19 cm/sec (0.1 ft/sec and 0.6 ft/sec, respectively).

Table 5-30. Sediment - In-channel, average velocities (feet per second, ft/s) simulated by the modified Silver River HEC-RAS model at different river reaches for 10 different discharge (cubic feet per second, cfs) events for the POR 1946-2014 no-pumping condition and the MFLs hydrologic regime. Highlighted cells indicate locations where critical velocity of 0.60 fps was equaled or exceeded.

Weibull Plotting Position	Discharge (cfs)	Stream Channel Cross-Section (Distance in feet from Confluence with Ocklawaha River)										
		CS 11 (26,030 ft)	CS 10 (22,760 ft)	CS 9 (21,600 ft)	CS 8 (19,380 ft)	CS 7 (17,370 ft)	CS 6 (13,990 ft)	CS 5 (9,770 ft)	CS 4 (7,500 ft)	CS 3 (4,490 ft)	CS 2 (2,640 ft)	CS 1 (0 ft)
No-pumping condition												
10	1008.8	1.25	0.49	0.67	0.65	0.53	0.92	0.78	1.1	1.51	0.68	1.43
20	952.36	1.22	0.48	0.65	0.64	0.52	0.89	0.77	1.08	1.47	0.66	1.41
30	876.43	1.18	0.46	0.63	0.63	0.51	0.87	0.75	1.06	1.42	0.62	1.38
40	818.39	1.16	0.45	0.61	0.62	0.5	0.85	0.75	1.04	1.41	0.61	1.34
50	777.62	1.15	0.44	0.6	0.62	0.49	0.85	0.76	1.03	1.39	0.59	1.32
60	728.43	1.13	0.43	0.59	0.61	0.48	0.84	0.76	1.01	1.35	0.57	1.29
70	700	1.13	0.42	0.58	0.61	0.47	0.83	0.77	0.99	1.33	0.55	1.27
80	639	1.11	0.4	0.56	0.59	0.46	0.83	0.79	0.98	1.28	0.52	1.23
90	594.82	1.14	0.4	0.55	0.6	0.46	0.84	0.77	0.96	1.24	0.49	1.18
95	535	1.13	0.38	0.53	0.58	0.44	0.84	0.76	0.94	1.21	0.47	1.15
MFLS												
10	967	1.23	0.48	0.66	0.64	0.52	0.9	0.77	1.09	1.48	0.67	1.42
20	910	1.2	0.47	0.64	0.63	0.51	0.88	0.76	1.07	1.44	0.64	1.4
30	834	1.17	0.45	0.62	0.62	0.5	0.86	0.76	1.05	1.42	0.61	1.35
40	777	1.15	0.44	0.6	0.61	0.49	0.85	0.76	1.03	1.39	0.59	1.32
50	736	1.14	0.43	0.59	0.61	0.48	0.84	0.76	1.01	1.36	0.57	1.29
60	686	1.12	0.41	0.57	0.6	0.47	0.82	0.79	0.99	1.33	0.55	1.26
70	658	1.12	0.41	0.56	0.6	0.46	0.82	0.78	0.98	1.3	0.53	1.24
80	597	1.11	0.39	0.54	0.58	0.45	0.82	0.77	0.95	1.26	0.51	1.2
90	550	1.14	0.38	0.54	0.59	0.45	0.85	0.76	0.94	1.21	0.47	1.15
95	492	1.16	0.37	0.52	0.57	0.44	0.85	0.74	0.92	1.17	0.45	1.12

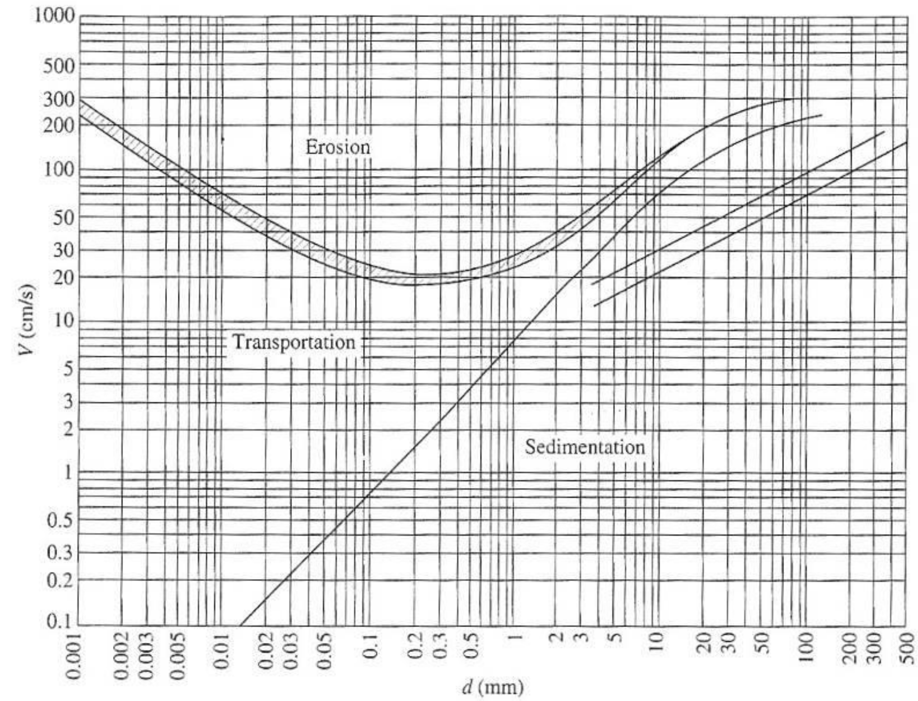


Figure 5-16. Erosion-deposition criteria for uniform particles (after Hjulstrom 1935) (USBR 2006)

The important consideration is not necessarily the flow condition (erosion versus transport), but rather that flow reductions allowed under the draft MFLs hydrologic regime would not cause a substantial shift in the occurrence of those critical flow events. If, for example, the flow condition at a particular location is erosive under the no-pumping condition hydrologic regime, then it should remain erosive under the recommended MFLs hydrologic regime to maintain the natural morphology of the river. Therefore, for the ranges of bed material sediment size present in this river, mean channel velocities between 0.1 and 0.6 ft/sec are critical for transport. A major shift in the frequency of occurrence of these velocities could cause morphological changes in the river.

The focus of the analysis is within the channel, since flow velocities in the floodplain are generally less than 0.1 ft/sec and are not sufficient for transport of inorganic sediments. Using HEC-RAS results, flow (Q) versus mean channel velocity (V) for the 11 HEC-RAS cross-sections were plotted. Six cross-sections show modeled velocities that exceed the critical transport velocity of 0.6 ft/sec across the range of flow conditions. The velocities for the remaining cross-sections were consistently in the critical velocity range. Those cross-sections included 2, 7, 8, 9, and 10 and are presented on Figure 5-17.

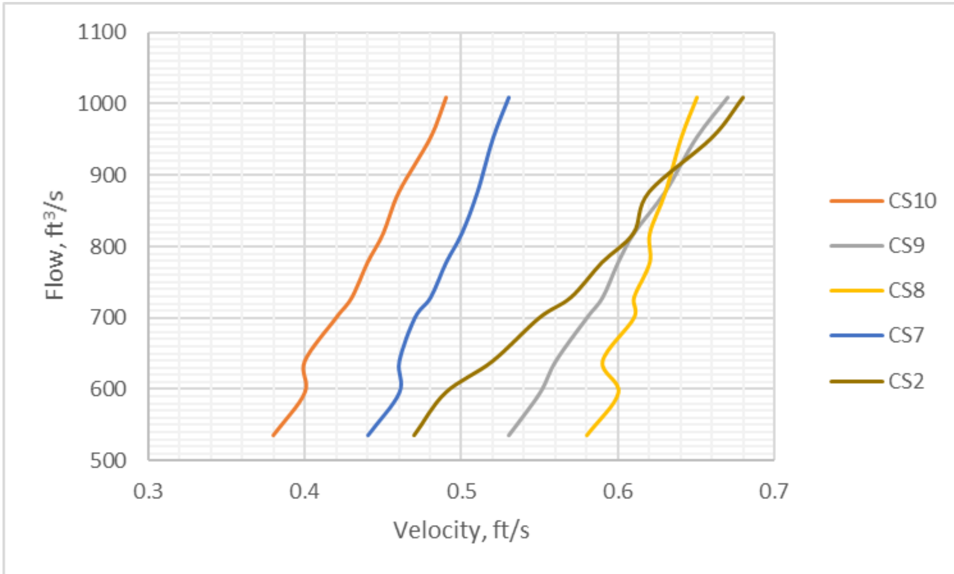


Figure 5-17. Flow versus velocity relationships for the Silver River based on HEC-RAS simulation results

Inspection of the velocity profiles for cross-sections 2 and 9 indicates that, at flows of 800 cfs and 775 cfs, respectively, velocities enter the critical velocity range. T9 has flow frequency-duration statistics developed for which changes in the occurrence of velocities critical to sediment transport can be evaluated. T3 has flow frequency-duration statistics developed for which changes in the occurrence of velocities critical to sediment transport can be evaluated at cross-section 2. The critical discharge values for evaluating sediment transport are presented in Table 5-31. A duration of 30 days was considered for the analysis. This duration provides sufficient time for normal sediment transport processes to occur. Extreme high-flow events of shorter duration (1 day) also contribute to sediment movement. These events are relatively infrequent and are not as important in spring-dominated systems, where flows are relatively constant and do not experience a wide range of flow rates.

Table 5-31. Critical discharge values for transport of sediment load

Transect	Flow (cfs)
CS2	800
CS9	775

Tables 5-32a and 5-32b present the frequency analysis results for sediment loads. SJRWMD provided the statistics from flow time series for the Silver River.

Table 5-32a. Frequency and duration parameters for sediment movement under the no-pumping condition and flow-reduction scenarios, (reduction in number of events per 100 years as compared to the no-pumping condition) – 7–day duration high flows continuously exceeded

Transect	Critical Threshold Flow (cfs)	Event/Difference	Scenario	
			No-Pumping Condition	MFL
			7-Day	7-Day
T3	800	Events/100 yr	61	54
		Decrease in Events	-	-7
T9	775	Events/100 yr	54	45
		Decrease in Events	-	-9

Table 5-32b. Frequency and duration parameters for sediment movement under the no-pumping condition and flow-reduction scenarios, (reduction in number of events per 100 years as compared to the no-pumping condition) – 30–day duration high flows continuously exceeded

Transect	Critical Threshold Flow (cfs)	Event/Difference	Scenario	
			No-Pumping Condition	MFL
			30-Day	30-Day
T3	800	Events/100 yr	57	48
		Decrease in Events	-	-9
T9	775	Events/100 yr	51	42
		Decrease in Events	-	-9

Flow events of a magnitude and duration identified as critical for maintaining sediment transport occur quite frequently on the Silver River. These events occur on average once every 2 years for the no-pumping condition and the MFL hydrologic regime. Given the small decrease, 0.05 ft/sec or less, in average in-channel velocities anticipated, sediment transport capacity should not change significantly.

5.9 WRV-9: WATER QUALITY

5.9.1 INTRODUCTION AND REGULATORY ACTIONS

Water Quality is defined as the chemical and physical properties of the aqueous phase (i.e., water) of a water body (lentic) or a flowing water course (lotic). The analyses presented for this WRV include water quality issues not addressed in WRV-7 (nutrients and other pollutants).

The criterion for protection was defined as the *chemical and physical properties of the water* that affect the aquatic community. The representative function used to assess protection of water resource values in Silver Springs and Silver River is defined as the concentration event of key chemicals/indicators in the water column. The general indicators of protection of WRVs in Silver Springs and the Silver River are maintenance of adequate discharge events to provide mixing/dilution and the maintenance of acceptable temperatures, nutrients, water clarity, bacteria, and DO levels. The specific indicators were defined as the differences in frequency of events within the water column necessary to maintain adequate protection of WRVs under no-pumping hydrologic conditions and the MFLs hydrologic regime.

A spring's water quality is determined by several factors. These include the chemical composition of the water entering the aquifer, the composition and solubility of the rocks with which the water comes into contact along flow paths, the length of time the water is in contact with the rocks as it moves from recharge to discharge areas, and the mixing of fresh groundwater with residual formation water or seawater. Land use activities in a spring's recharge basin and the upconing of poorer quality water from deeper zones due to groundwater withdrawals may also impact water quality.

Total Maximum Daily Load for Silver Springs

The Silver River faces a number of water quality issues, chiefly an increase in nitrates, a documented decrease in water transparency over the past 50 years and a concomitant increase in attached algae. To combat the increased nitrates and its associated effects, FDEP completed a total maximum daily load (TMDL) and instituted a BMAP to regulate the contribution of nitrates to upper Florida aquifer, the source of Silver Springs and the Silver River. However, the water quality parameters at issue are independent of Silver River flow and stage. Consequently, water quality would be generally unaffected by flow reductions allowed under the MFLs. Source control within the groundwater basin is the primary means to reduce nitrate concentrations in the Silver River.

In 2009, the Silver Springs (2772A), Silver Springs Group (2772C), and the Upper Silver River (2772E) waterbody segments (WBIDs) were listed as impaired for nutrients causing excessive algal growth (Figure 5-18). Due to the increasing trends in all three WBIDs, the causative pollutant was determined to be nitrate (NO_3).

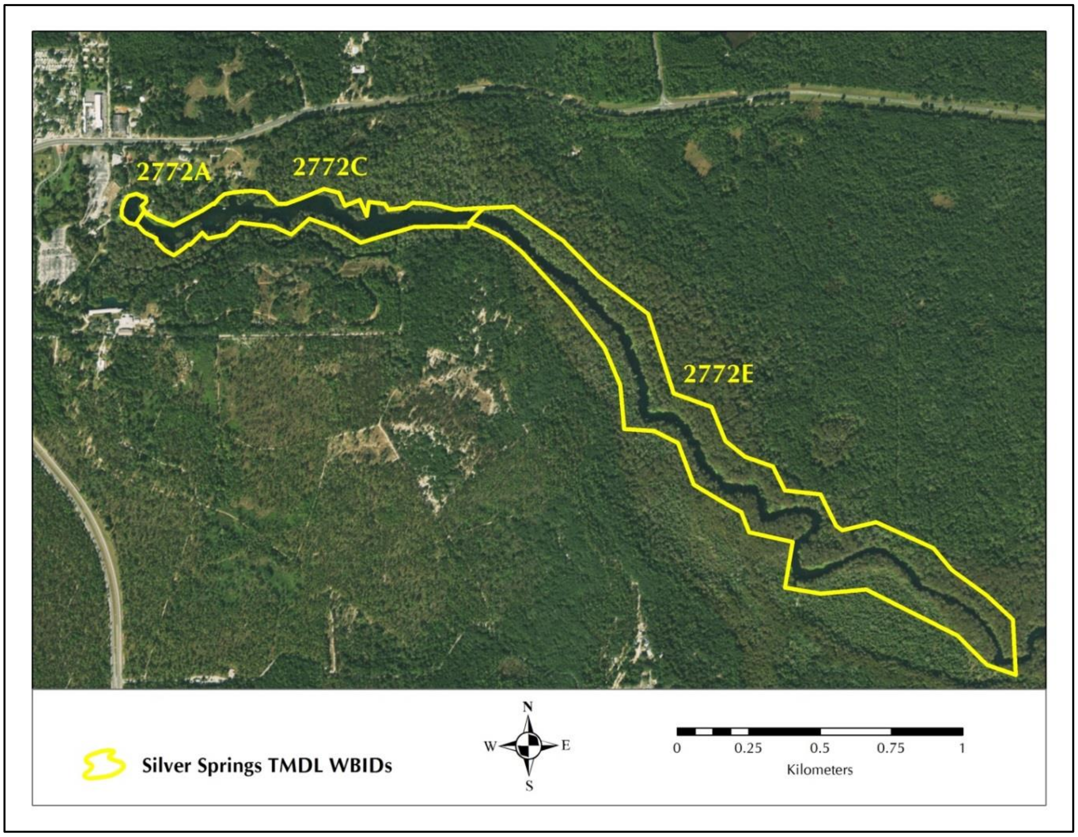


Figure 5-18. WBIDs addressed in the Silver Springs TMDL

The target nitrate concentration was set at 0.35 milligrams per liter (mg/L) (the current spring standard) and is expected not to cause an imbalance of the systems flora and fauna yet still reduce epiphytic and algal growth. To reach that concentration will require a 79 percent reduction in nitrates which is allocated to the National Pollutant Discharge Elimination System (NPDES) stormwater loads. EPA reviewed the final version of the TMDL and it was adopted in fall 2012.

<u>Basin Management Action Plan for Silver Springs</u>

To meet the TMDL, a BMAP is prepared and implemented, led by FDEP with stakeholder input. It was finalized in October, 2015. It provides the management priorities to meet the allocations for the first phase of BMAP implementation. The multi-phase approach is necessary to provide an adaptive management process until the TMDL is met. Due to the nature of these particular WBIDs, the State had to seek reductions from the surface water contributing area and, more importantly, from ground water contributions from the Upper Floridan Aquifer (UFA) which expanded the BMAP area considerably.

As part of this first phase, 140 projects and programs were identified that are expected to reduce the loading of nitrates to the UFA and ultimately discharging at Silver Springs. Projects include wastewater upgrades, local ordinance implementation (urban fertilizer, Florida Friendly Landscaping, pet waste), onsite treatment and disposal (septic system removal), stormwater treatment areas, and the purchasing of conservation lands. Estimated costs provided for about 50 percent of the projects are $216 million, including $54 million for wastewater improvements (80 percent reduction in wastewater loads) and $134 million for land conservation.

Local stakeholders have made commitments to implement this BMAP. A monitoring program has been designed to track the results of these management actions. The data will be use to guide the stakeholders and drive the adaptive management process so continual progress will be made to address the TMDL.

5.9.2 DESCRIPTION OF SILVER SPRINGS WATER QUALITY

The measured water quality data were investigated for relationships with existing conditions spring discharge rates as described in Karama et al. (2016). Threshold values for these key water quality characteristics have been identified as events to protect the aquatic habitat and ecological communities of the Silver River. It is the return interval of these events, given any statistically significant relationships, that is the subject of this evaluation.

Several datasets were combined to evaluate WRV-9. The first database was a compilation of numerous datasets from researchers and government agencies and included in the Munch et al. (2006). Munch et al. (2006) concluded that there has been a steady increase in nitrate-nitrogen concentrations in Silver Spring discharges since the 1950s, as well as decreases in nighttime DO concentrations and water transparency. While Silver Springs has long been appreciated for its exceptional water clarity, Munch et al. (2006) documented reduced horizontal Secchi distance and an increase in the light extinction coefficient. These factors contributed to a decision by the Florida Springs Task Force (FSTF) to list Silver Springs as a first magnitude spring requiring special protection (FSTF, 2000).

To extend the temporal extent of available data through 2014, the FDEP Impaired Waters Rule (IWR) Run 53 SAS dataset was queried for the WBIDs used to describe the Silver River system. The IWR dataset is a compilation of the data from Florida STORET that meets the stringent criteria used to assess waterbodies as directed by the Clean Water Act. FDEP used an earlier version of this dataset to determine the three waterbodies, Silver Springs, Silver Springs Group, and the Upper Silver River were impaired, requiring a TMDL to be developed along with the ensuing BMAP.

The study area was limited the WBIDs used by FDEP for assessment but were grouped into three reaches (Figure 5-19). The first reach, Reach 1, consists of Silver Springs and the Silver Springs Group, or WBIDs 2772A and 2772C, respectively. Reach 2 consists of the Upper Silver River and the Lower Silver River, or WBIDs 2772E and 2772D, respectively. Reach 3 is the upper 3.5 kilometers of the Ocklawaha River above Lake Ocklawaha, or WBID 2740C. Refer to Figure 5-19 for the location of the reaches in reference to the USGS flow gage.

The relationships between existing discharge and the key measured water quality parameters were investigated. The key water quality parameters included DO, acidity measured as pH, color, nitrate plus nitrite (NO_x), total nitrogen (TN), total phosphorus (TP), and turbidity. Daily means were calculated by reach for all water quality parameters and were plotted versus the discharge (in cfs) corresponding to the water quality sample collection dates.

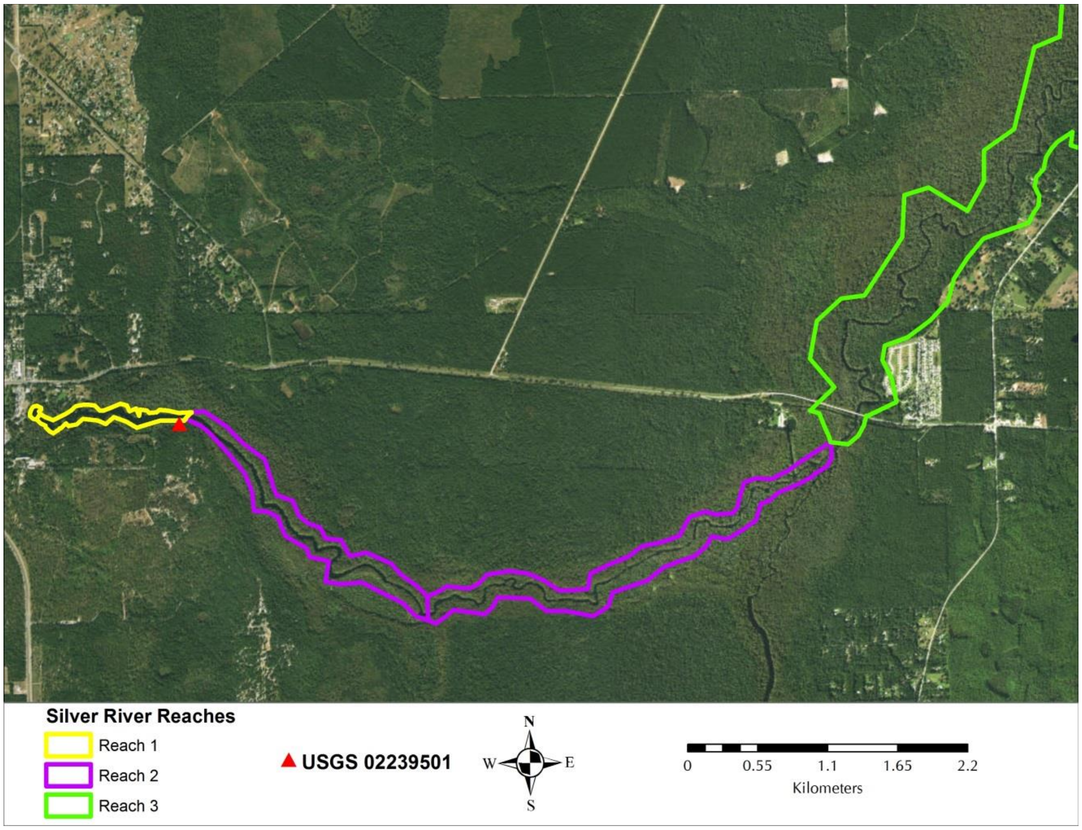


Figure 5-19. Extent of the three reaches used in the analysis along with the location of USGS flow gage

<u>Dissolved Oxygen</u>

The time series plots of the daily mean DO concentrations in each reach is presented in Figure 5-20. There is a general lack of a temporal trend in the DO in all three reaches.

Cumulative distributions plots of the DO collected in each reach are shown in Figure 5-21, providing a direct comparison of the distributions of the DO concentrations observed in each reach. While lower, the distribution of DO data from Reach 1 is strikingly similar to Reach 2. This is quite reasonable considering there is little additional hydrologic input to the system between these two reaches. Earlier reports compared the DO values to the previous freshwater 5 mg/L DO standard. Since anaerobic groundwater is the primary source of water to the system, lower DO values that fail to meet that or the current percent saturation standard are not unexpected. Data from Reach 3, representing the downstream waters of the Ocklawaha River, clearly reflect the mixing zone of upstream river water with waters from Silver River, resulting in a range of DO values. Plots of the relationship of DO with flow in Figure 5-22 show that for Reaches 1 (top) and 3 (bottom) there is a slight increase in DO concentration with increased flow.

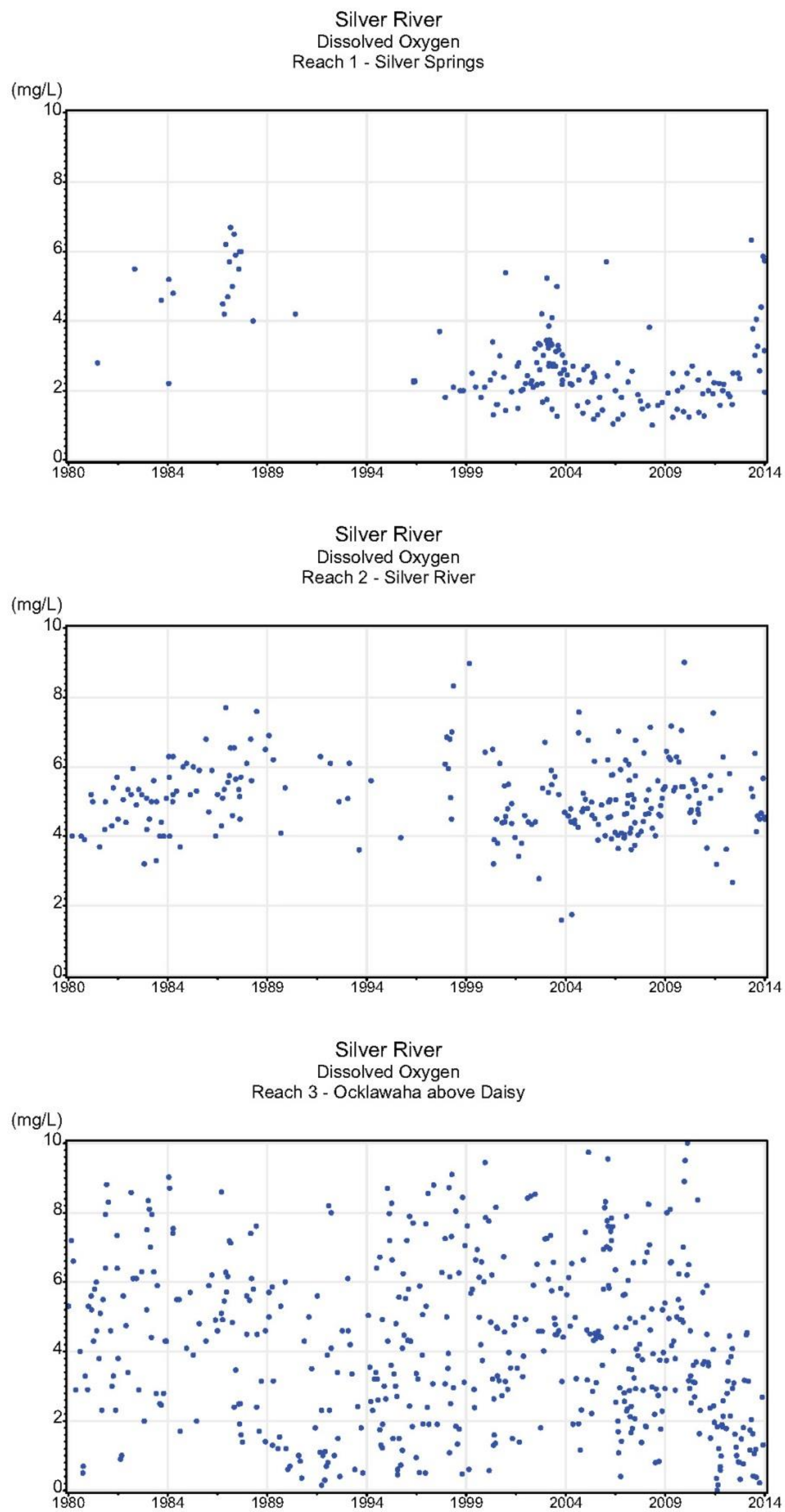


Figure 5-20. Time series plots of daily mean DO values for Reach 1 (top), Reach 2 (middle) and Reach 3 (bottom)
Data source: FDEP IWR Database.

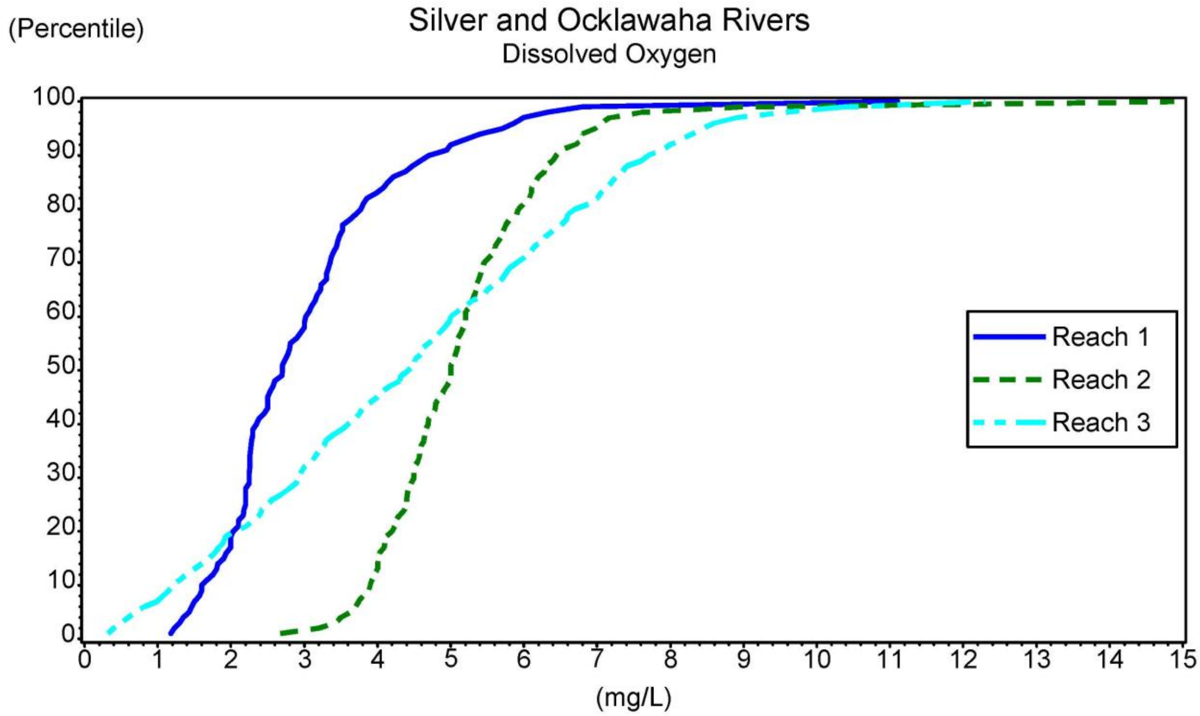


Figure 5-21. *Distributions of the DO data collected in each of the three reaches Data source: FDEP IWR Database.*

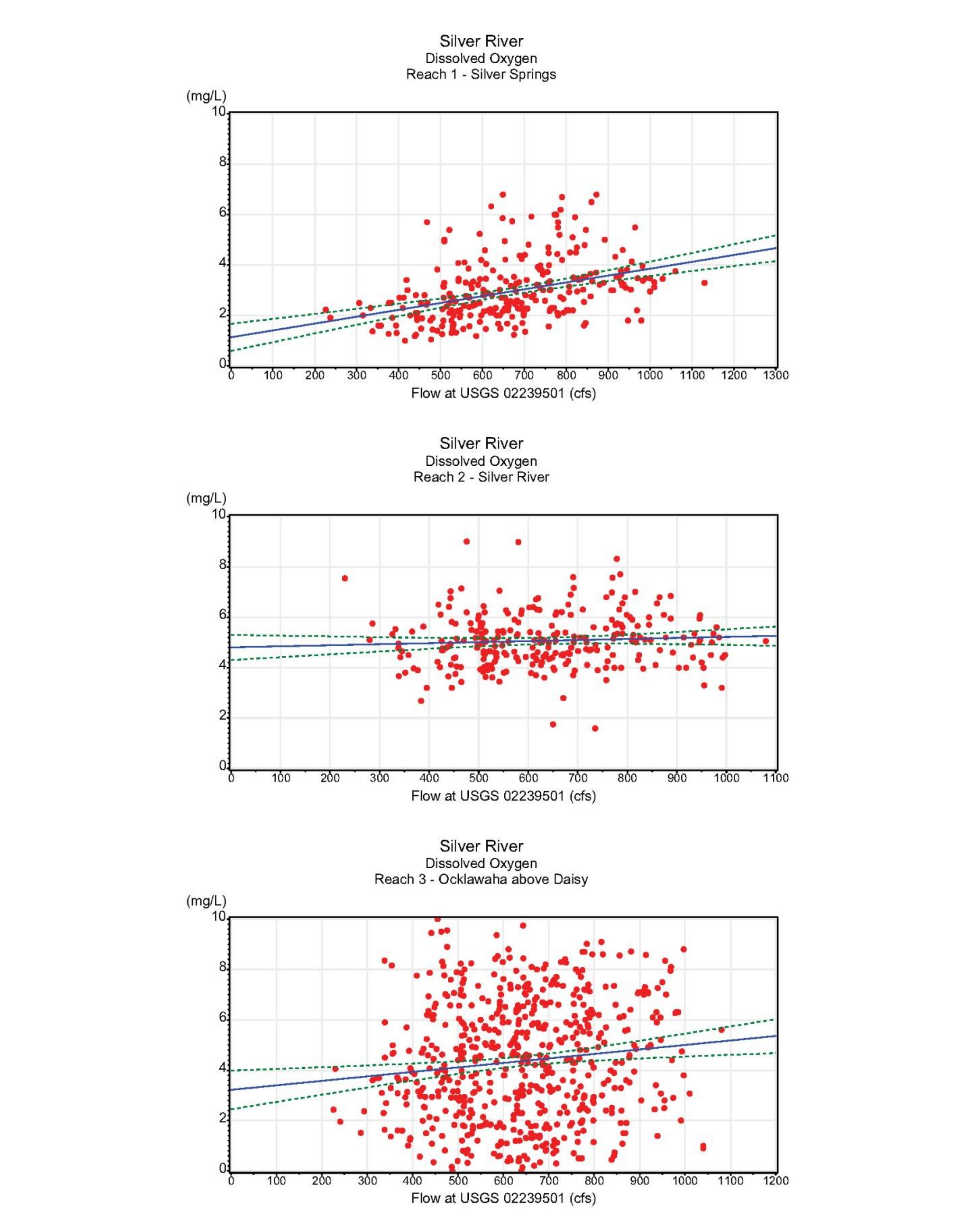


Figure 5-22. Plots of dissolved oxygen vs. flow for Reach 1 (top), Reach 2 (middle) and Reach 3 (bottom)
Data source: FDEP IWR Database.

pH

pH is a measure of the acidity or alkalinity of water and is reported on a logarithmic scale that represents the negative of the log of the concentration of hydrogen ions (H^+). The units of pH are expressed as laboratory standard units (SU). Values of pH less than 7.0 are considered acidic. Values of pH greater than 7.0 are considered alkaline (basic), and a pH = 7.0 is considered neutral. Acidity in water comes from two main natural sources, rainwater that contains carbonic acid resulting from reactions with atmospheric carbon dioxide (CO_2), and organic acids from soil, especially humic and tannic acids (Scott et al. 2004). Site geology also influences groundwater and spring discharge pH. Local groundwater is high in carbonates and bicarbonates, which should buffer the system to significant pH changes.

The pH of water is important to biochemical reactions such as the extraction of calcium from water for mollusks and crustaceans to produce shells. Experiments on freshwater bivalves such as *Corbicula* have shown dissolution of shells and mortality in acidic water (Kat 1972). Three molluskan species are thought to occur only in the Silver River (Walsh and Williams 2003), however, there is little evidence of the specific pH requirements for protection of these species.

Florida Class III surface water criteria for pH requires freshwater to be within the range of 6.0 to 8.5 (FDEP 2006). For this analysis, a minimum pH of 6.0 is used as the criterion to comply with the Florida state standard to maintain an acidity-alkalinity balance favorable to the natural fish and benthic fauna. In the absence of highly acidic or basic contaminants within the springshed, the pH in Florida spring discharges can be expected to remain within these limits.

Time series of mean daily pH values for the three reaches are shown in Figure 5-23. The majority of the data falls between 6 and 8 SU within all three reaches and shows a somewhat declining trend over time. Excursions below 6 SU are likely caused by the addition of surface water runoff and the associated detritus and organic acids such as tannins and lignins.

Cumulative distribution plots of the available data comparing the three reaches show a similarity between Reaches 1 and 2, being appreciably higher than in Reach 3 (Figure 5-24). This is likely due to the relative contribution of flows from the spring and other freshwater inputs. The pH in Silver Springs is largely groundwater driven, as opposed to the flows in Reach 3 that are largely affected by river flows driven by surface runoff. The lower pH can be attributed to the organic acid inputs typical of waters with wetland origins.

Plots of the relationship between pH with flow in each reach are shown in Figure 5-25. There is a slight increase in pH associated with increases in flows.

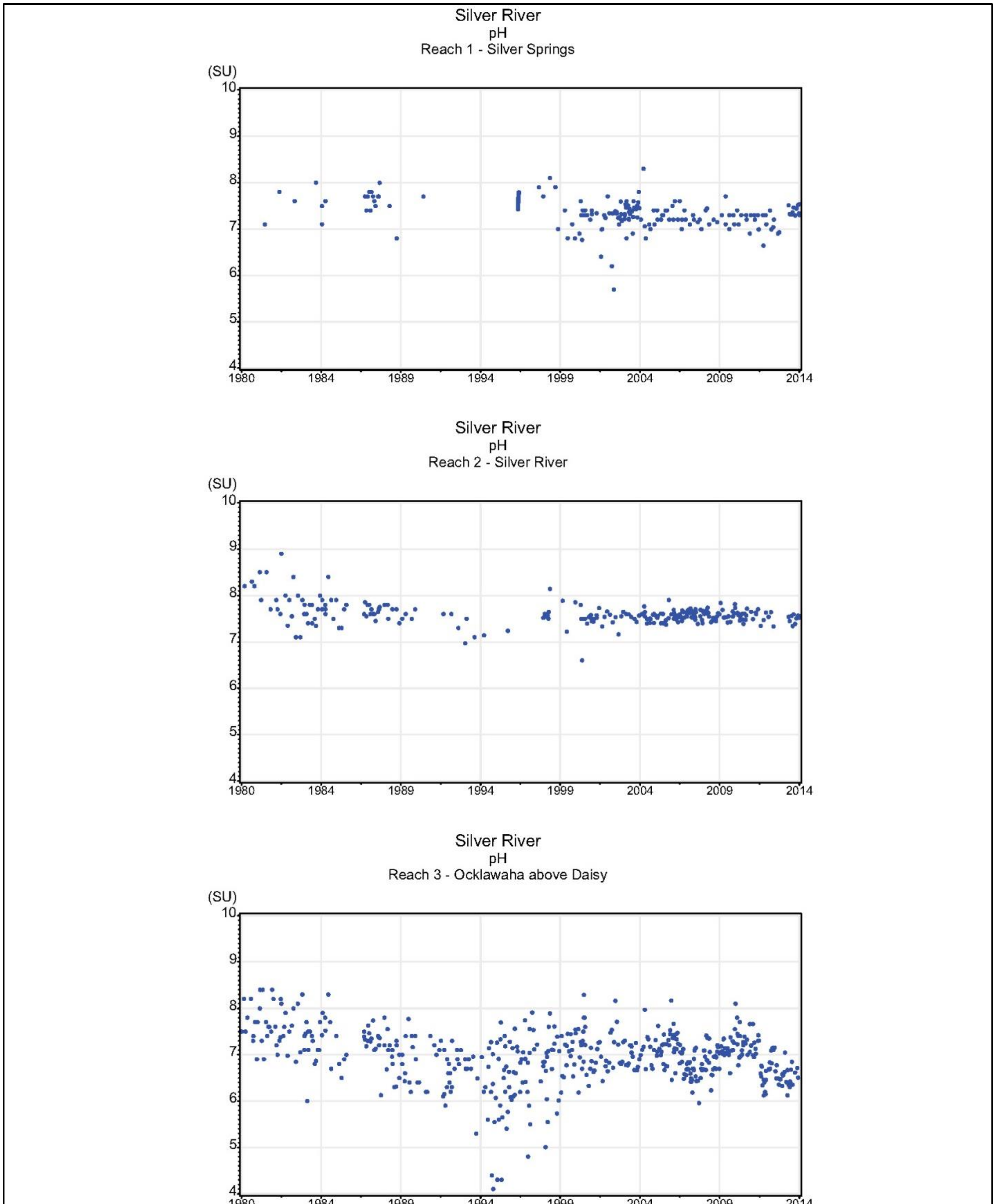


Figure 5-23. Time series plots of daily mean pH values for Reach 1 (top), Reach 2 (middle) and Reach 3 (bottom)
Data source: FDEP IWR Database.

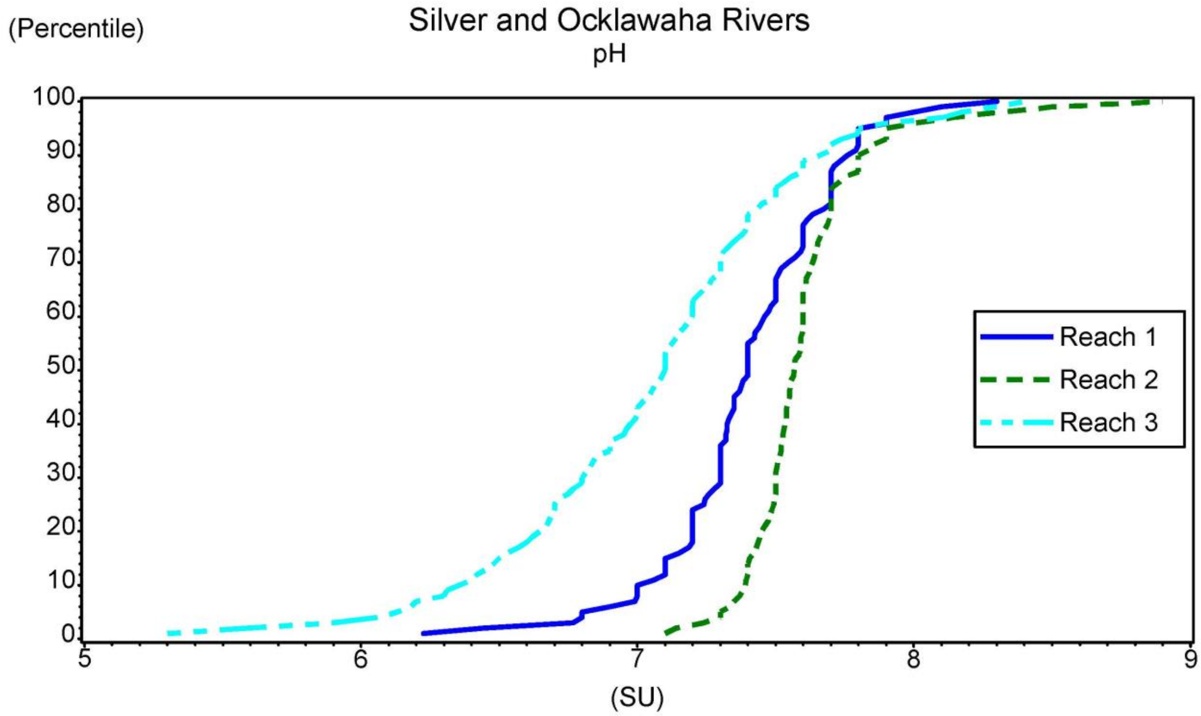


Figure 5-24. Distributions of the pH data collected in each of the three reaches Data source: FDEP IWR Database.

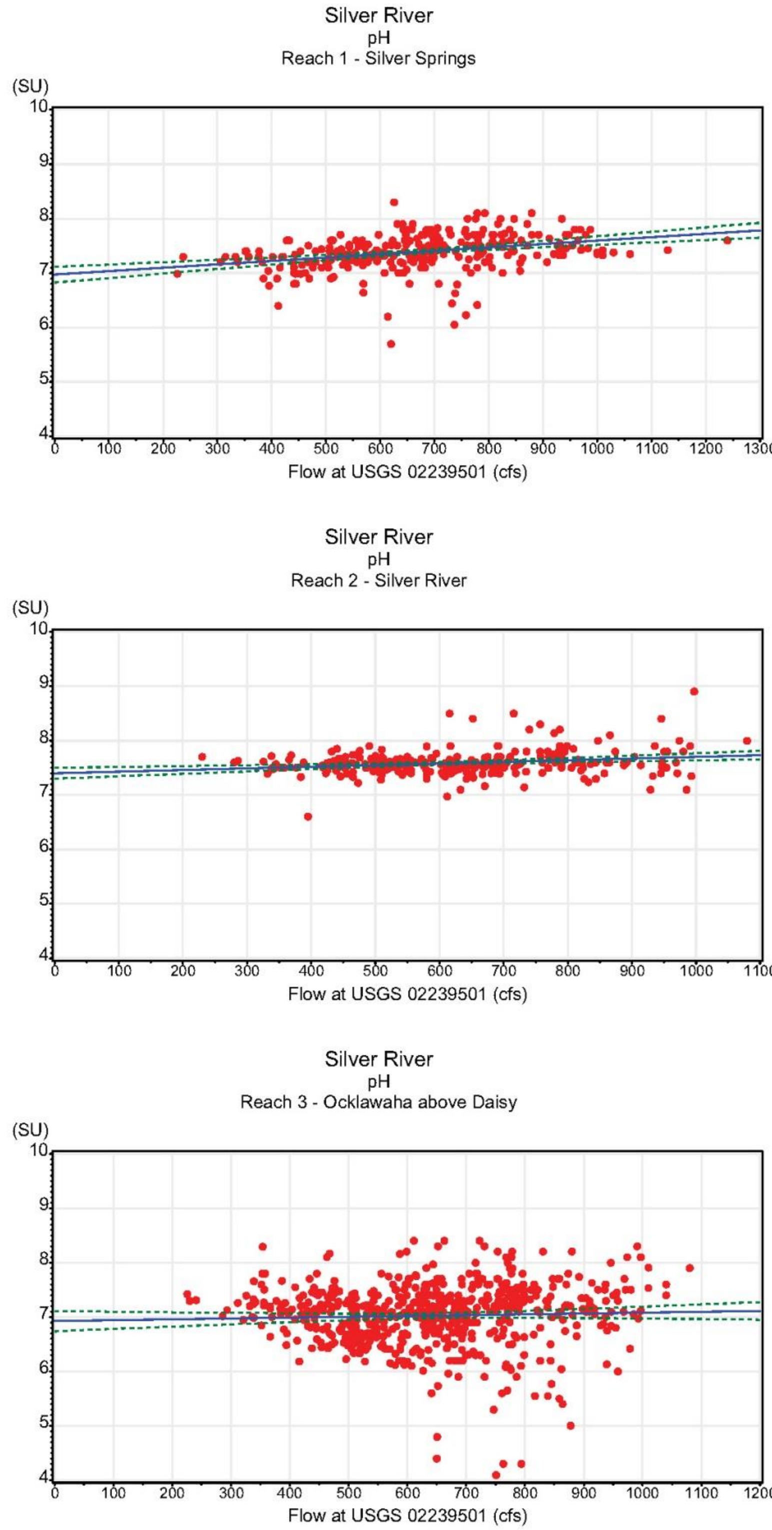


Figure 5-25. Plots of pH vs. flow for Reach 1 (top), Reach 2 (middle) and Reach 3 (bottom) Data source: FDEP IWR Database.

Nutrients

The nutrients nitrogen and phosphorus are two major constituents of aquatic plant tissues. As such, the amount of nitrogen and phosphorus in the water can control the rate of growth of aquatic macrophytes and algae (Odum 1971). In the aquatic environment, the forms of nitrogen and phosphorus that are the most soluble and easily absorbed by green plants are nitrate (NO_3) and orthophosphate (PO_4) (Wetzel 1975). In surface waters, the total amounts of TN and TP in the water column are often used as an indicator of the amount of nutrients available to fuel algae growth, since these also include particulate organic and inorganic forms. Scott et al. (2004) found the particulate form of nitrogen [total Kjeldahl nitrogen (TKN)] was in such low concentrations in the Silver River that it was undetectable at the method detection limit (MDL). Most of the nitrogen and phosphorus is incorporated in benthic macroalgae and microalgae including diatoms (Stevenson et al. 2007), epiphytes (periphyton), and macrophytes such as *Sagittaria* (Munch et al. 2006) rather than the phytoplankton community.

Studies of Florida springs by Stevenson et al. (2007) included bioassays to correlate nutrient additions and growth of macroalgae. Strong evidence was developed indicating that the growth of both *Vaucheria* and *Lyngbya* could be controlled by reducing nitrogen or phosphorus loads to the springsheds and springs. The researchers performed bioassay experiments on nutrient limitation of the growth rates of the benthic macroalgae *Vaucheria*, a filamentous green algae and Lyngbya, a colonial filamentous cyanobacteria.

Stevenson et al. (2007) took the work one step further by calculating the approximate amount of reduction in loads of nitrogen or phosphorus that may control the growth of the nuisance macroalgae in Florida springs. Field samples and laboratory experiments on *Lyngbya wollei* and subsequent mathematical models showed that the extent of cover of spring bottoms by algal mats of *Lyngbya* could be reduced if TN concentrations could be reduced below 0.25 mg/L or if TP concentration could be reduced below 0.035 mg/L. They also studied the possibility of reducing the cover of spring bottoms by *Vaucheria* mats, with similar results.

SRWMD sponsored field research that showed a relationship between nitrate and algae that reached a critical point at 0.44 mg/L NO_x, as presented by the FDEP (2008a) report, above which algae cell density would increase in a logistic growth curve pattern. FDEP (2008a, 2008b) used these and other studies to propose a standard for nitrate-nitrite concentration in spring waters equal to 0.35 mg/L. Nutrient cycling in the aquatic environment is discussed in

Section 5.7, on WRV-7. The following discussion focuses on chemical concentration in the water column in relation to flow rate.

Time series plots are presented by reach, depicting the mean daily nitrate-nitrite concentrations (Figure 5-26). In Reaches 1 and 2, there is a clear increasing trend over time, which is lacking in the observed nitrate-nitrite data from Reach 3. The increasing trend is largely responsible for the concern regarding the integrity of Silver Spring and Silver River.

Cumulative distribution plots of the available data comparing the three reaches are presented in Figure 5-27. The nitrate-nitrite concentrations are clearly higher in Reaches 1 and 2, where the median is approximately 1.0 mg/L as compared to a median of near 0.0 mg/L in Reach 3. As with pH and other water quality constituents, this difference is due to the difference in the relative contribution of spring flows in the three reaches, Reaches 1 and 2 being greater and Reach 3, much less. The lower concentrations in Reach 3 are indicative of the uptake of the inorganic nitrogen forms by the various algal communities there. Similar trends have been seen in nearby springs. These increases were identified as the cause of the excess algae in the spring and spring run that led to the TMDL.

Plots of the relationship between nitrate-nitrite with flows by reach are shown in Figure 5-28. There is a general trend of decreasing nitrate-nitrite with higher flows in Reaches 1 and 2. Conversely, there is little relationship between nitrate-nitrite and flows in Reach 3. Again, these results are likely due the difference in the relative contribution of spring flows in the three reaches, being greater in Reaches 1 and 2 and much less in Reach 3.

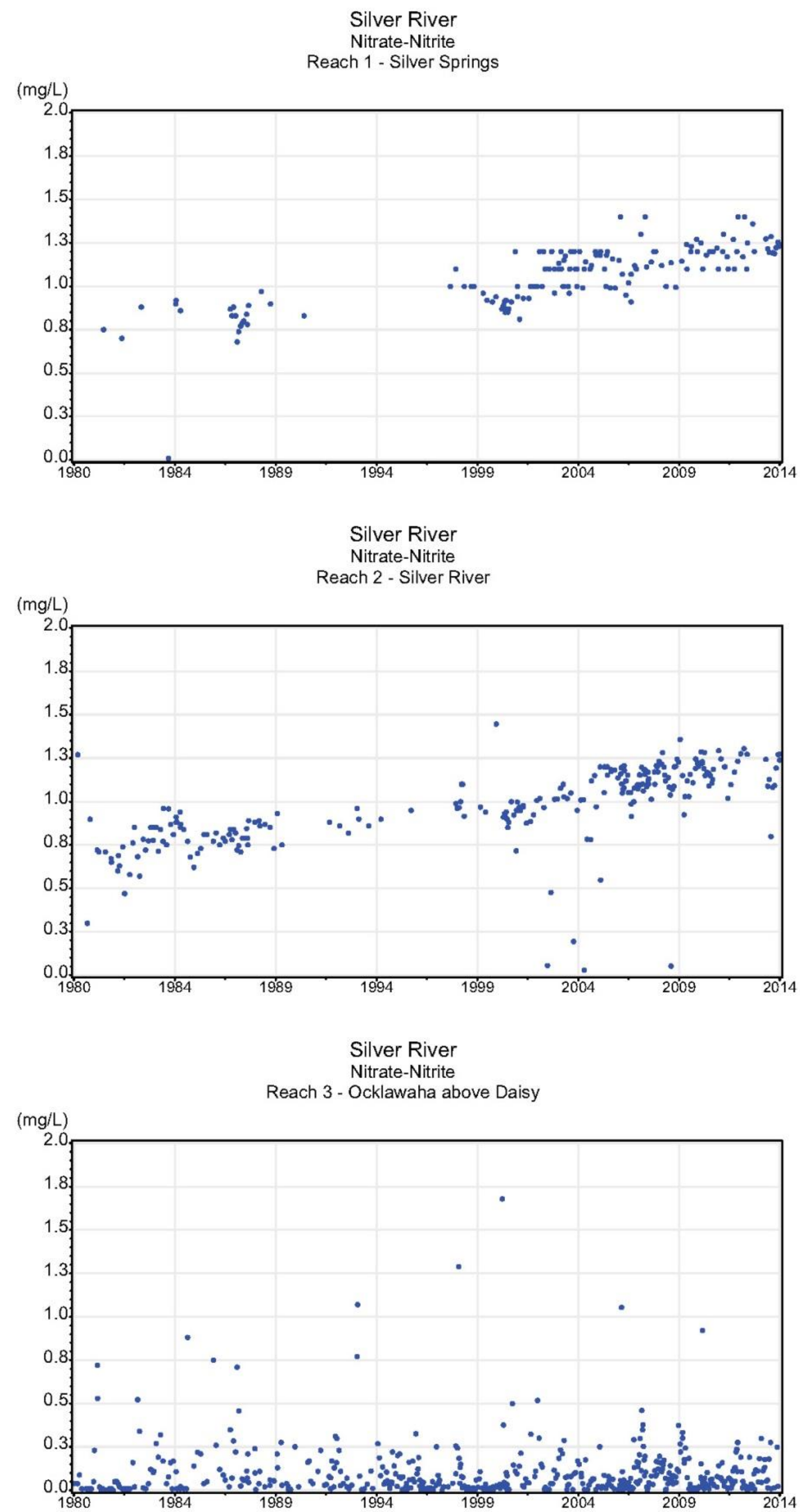


Figure 5-26. Time series plots of daily mean nitrate-nitrite values for Reach 1 (top), Reach 2 (middle) and Reach 3 (bottom)
Data source: FDEP IWR Database.

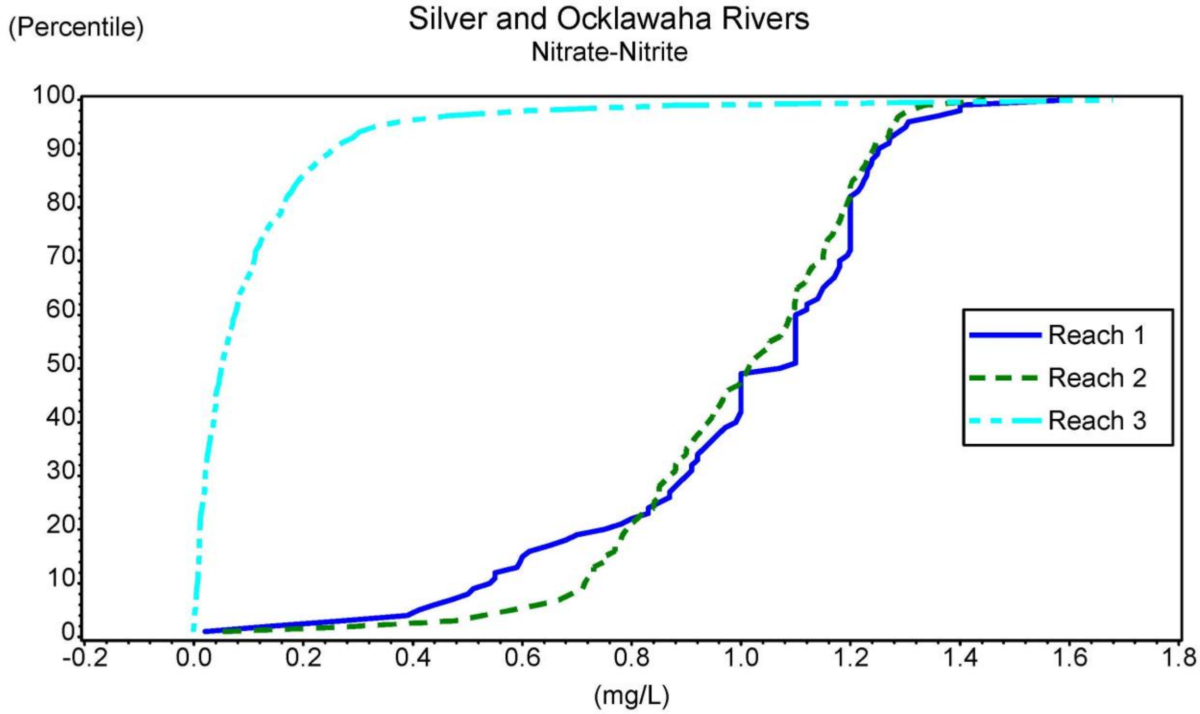


Figure 5-27. *Distributions of the nitrate-nitrite data collected in each of the three reaches Data source: FDEP IWR Database.*

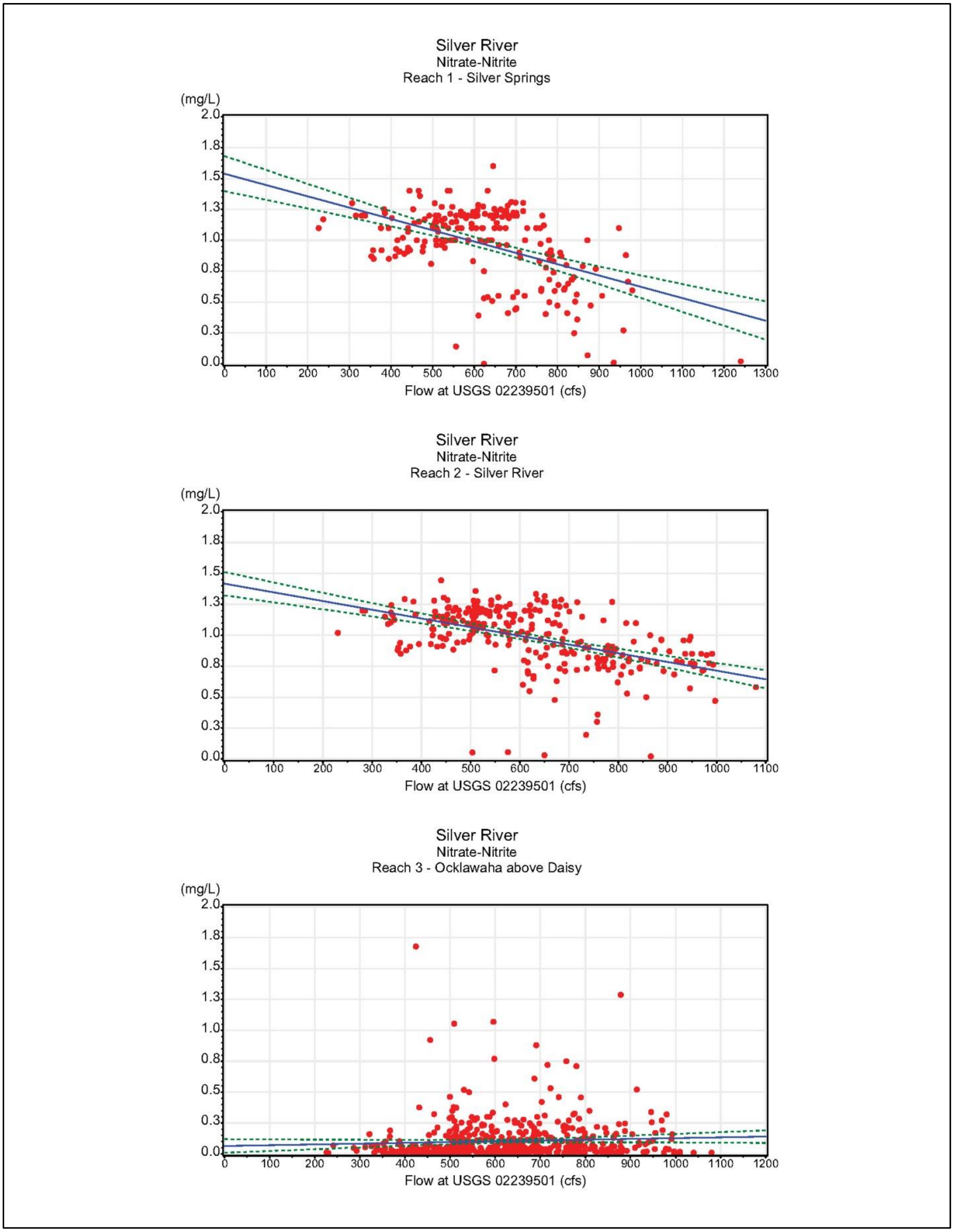


Figure 5-28. Time series plots of daily mean nitrate-nitrite values for Reach 1 (top), Reach 2 (middle) and Reach 3 (bottom)
Data source: FDEP IWR Database.

Phosphorus

The natural source of phosphorus in Florida springs comes from the large deposits of ancient marine sediments that contain a high concentration of phosphate compounds such as carbonate-fluorapetite, $Ca_5(PO_4 CO_3)_3F$ (Upchurch 1992). Phosphate can also come from agricultural fertilizers that infiltrate the aquifer or enter the river in surface runoff. Odum's early studies in the 1950s (Odum et al. 1953, Odum 1957) provided the first measurement of phosphorus in Silver Springs, recording a TP concentration of 0.05 mg/L. Scott et al. (2004) found an average TP equal to 0.042 mg/L in the main boil in 2001, and PO_4 equal to 0.03 mg/L and reported historical values recorded in 1972 as 0.14 mg/L for both TP and PO_4. Although a large amount of land area has been converted from forest to urban land uses, agriculture, and pasture in most of the springsheds of Florida, there has not been an increasing trend reported in the concentration of phosphate in Florida springs since the beginning of data collection in the 1950s (FDEP 2008a). In reviewing the phosphorus record, the authors of the 50-year retrospective study also found no trend in the Silver Springs system (Munch et al. 2006).

The distribution of TP observations in the database compiled by Munch et al. (2006) has a minimum value of TP = 0.01 mg/L, a maximum of TP = 0.22 mg/L, and a median of TP = 0.05 mg/L (Appendix C-1, Munch et al. 2006). The distribution of PO_4 observations has a minimum value of PO_4 = 0.01 mg/L, a maximum of PO_4 = 0.12 mg/L, and a median of PO_4 = 0.044 mg/L. Time series plots of TP, TP versus discharge, PO_4, and PO_4 versus discharge are shown in Appendix G. The plots do not suggest any correlation between discharge and TP or PO_4 at the main boil, or any other site within the study area.

The work of Stevenson et al. (2007) suggests that the coverage of mats of the nuisance algae *Lyngbya* can be controlled if TP concentration could be lowered below 0.033 mg/L. However, the earliest observations of phosphorus collected in the 1950s reported PO_4 in the main boil equal to 0.053 mg/L. These data suggest that concentrations of phosphorus have always been high and may always be high because of the ancient and extensive marine deposits that contain large amounts of phosphorus. For these reasons, neither TP nor PO_4 were investigated further.

Time series plots of TP for each of the reaches are shown in Figure 5-29. Very little change is shown over time. Cumulative plots by reach of the same data (Figure 5-30) again show the similarities between the first two reaches. Plots of the relationship of TP with flow for each reach only show the slightest increase in concentration with increased flow (Figure 5-31).

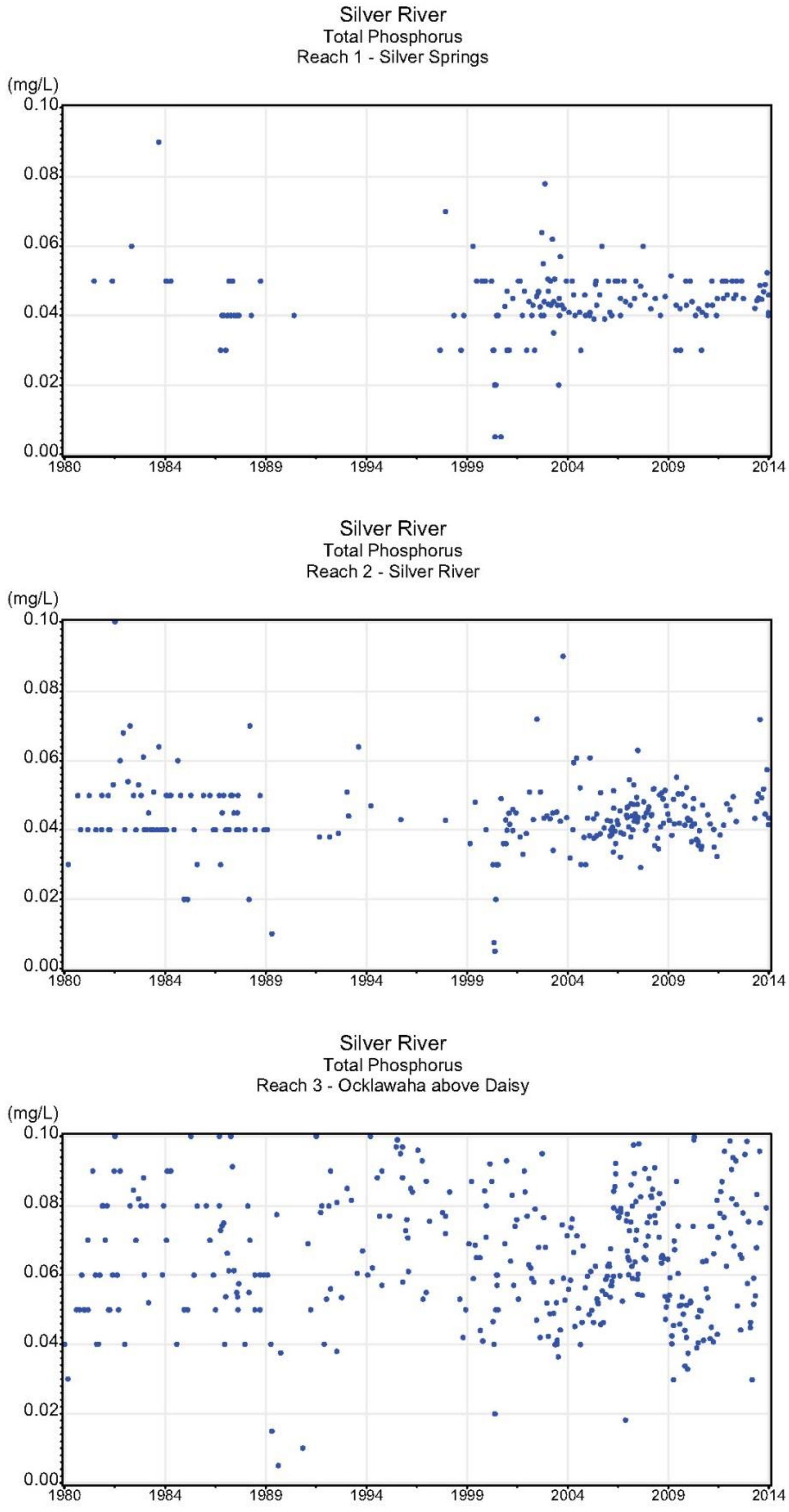


Figure 5-29. Time series plots of daily mean TP values for Reach 1 (top), Reach 2 (middle) and Reach 3 (bottom)
Data source: FDEP IWR Database.

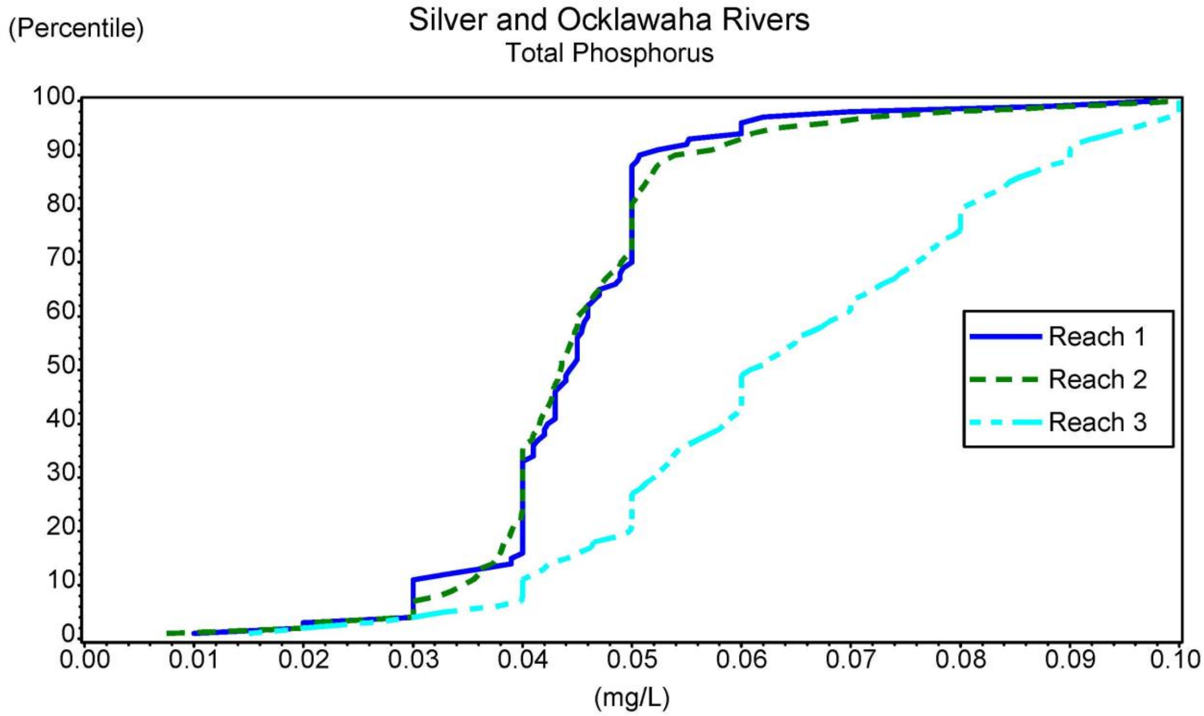


Figure 5-30. Distributions of the TP data collected in each of the three reaches Data source: FDEP IWR Database.

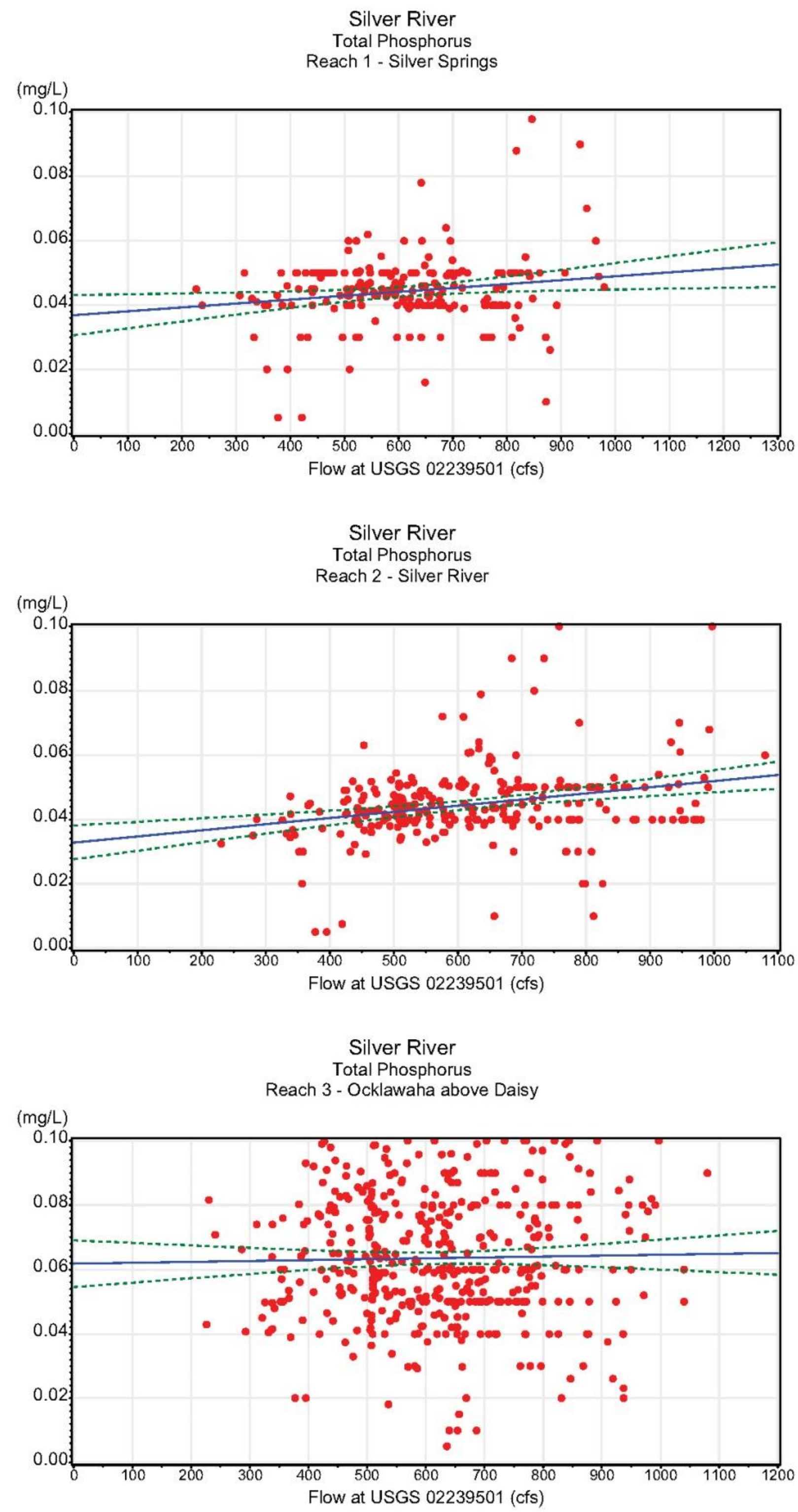


Figure 5-31. Plots of TP vs. flow for Reach 1 (top), Reach 2 (middle) and Reach 3 (bottom) Data source: FDEP IWR Database.

Water Clarity

The clarity of the Silver Springs system is a key issue of concern. Data for horizontal Secchi distance reported by Munch et al. (2006) indicated a possible decrease in water clarity between the 1950s and 2004. Water clarity is essential to allow the passage of light to aquatic vascular plants and algae for photosynthesis, as well as for aesthetic and recreational purposes.

Color, turbidity, dissolved and suspended solids, and chlorophyll concentrations are the primary determinants of a decline in water clarity when present in high concentration. The amount of light transmitted through water can be measured using a Secchi disc, or an electronic instrumentation that measures the attenuation and absorption of light in water, such as the LI-COR light sensor that was used by researchers who participated in the SJRWMD study of the Silver Springs system (Munch et al. 2006). Such sensors measure photosynthetically active radiation (PAR) and solar insolation, that is, incoming solar radiation (Wetzel 1975), and are used to calculate light extinction coefficients that define the rate of attenuation of light through the water column at increasing depth.

Color

Most of the spring run sampling sites do not have observations of color. Time series of the available color data for the three reaches are shown in Figure 5-32. While there is a great deal of temporal variation in the observed color data, there is no apparent temporal tend in the data from either reach.

Cumulative distribution plots of the color data from all three reaches are shown in Figure 5-33. There are clearly large differences between the three reaches (Figure 5-33). In Reach 1 the color is typically less than 5 platinum-cobalt units (PCUs)with somewhat higher values seen at times in Reach 2. However, in Reach 3, the color can be in excess of 1,000 PCUs. These differences are likely dependent on the relative influence of surface runoff from upstream regions of the Ocklawaha River that contributes colored, relatively acidic water typical of waters draining wetland areas.

There is a small relationship shown between the decrease in color values associated with an increase in flow in Reach 1, as shown in the top panel of Figure 5-34. This may be attributed to a potential backwater effect at low spring flows, allowing water from the Ocklawaha River to flow into the lower Silver River. No discernable relationships are exhibited in the other two reaches.

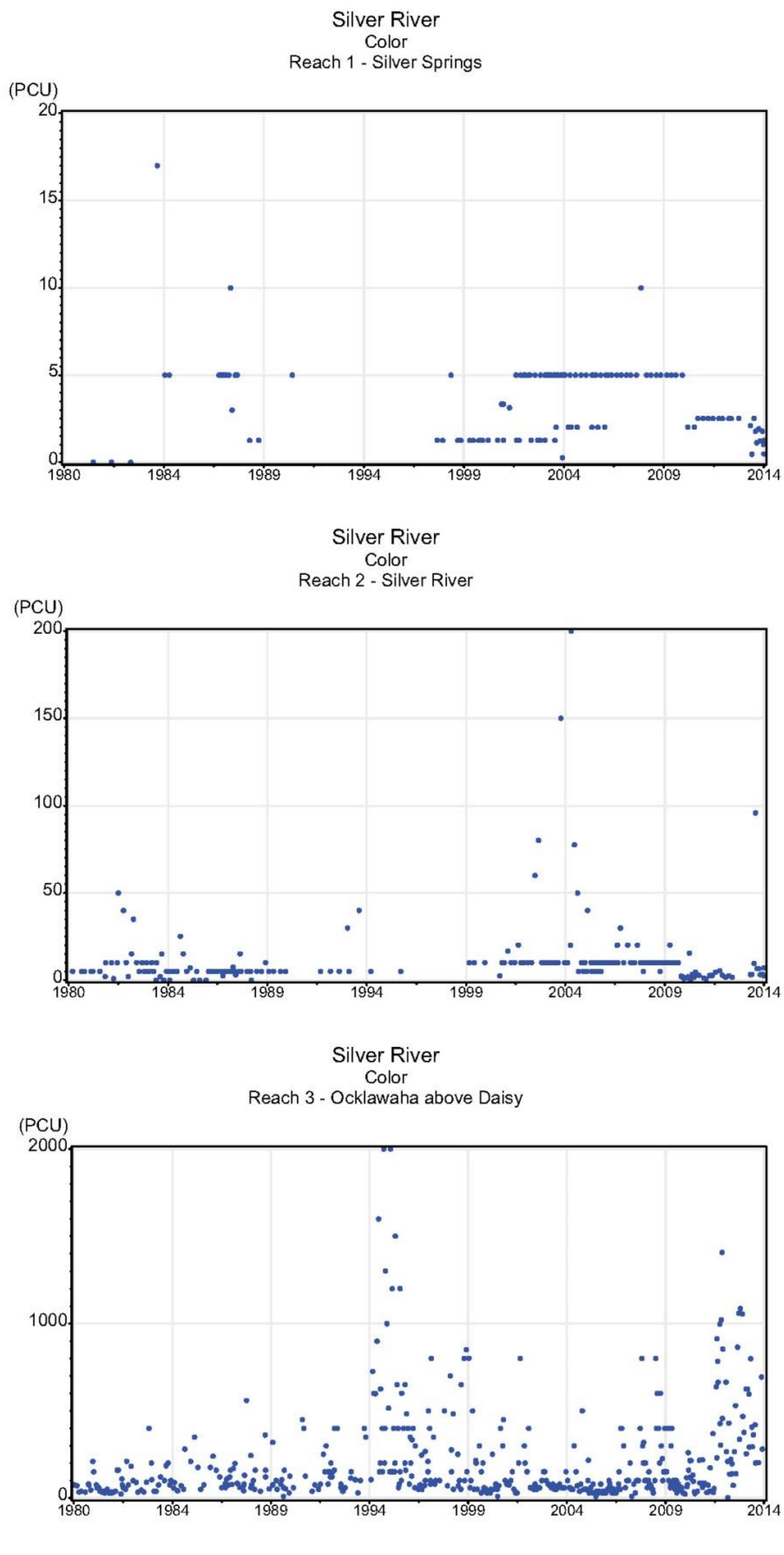


Figure 5-32. Time series plots of daily mean color values for Reach 1 (top), Reach 2 (middle) and Reach 3 (bottom)
Data source: FDEP IWR Database.

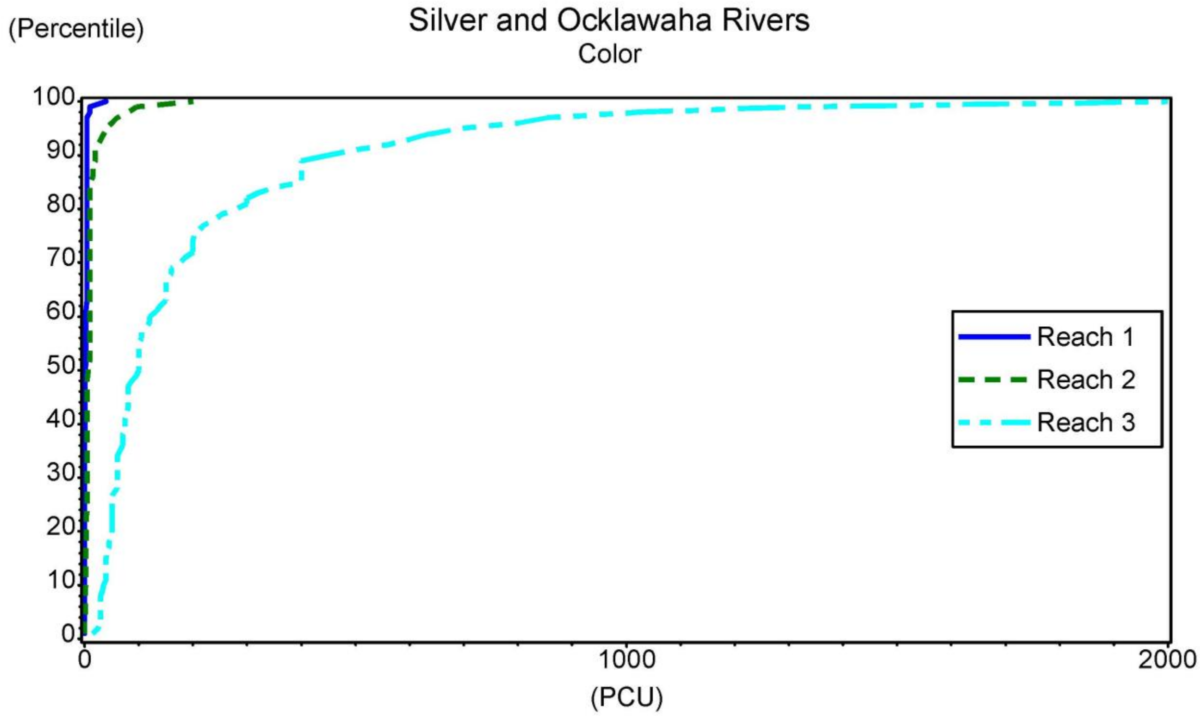


Figure 5-33. Distributions of the color data collected in each of the three reaches Data source: FDEP IWR Database.

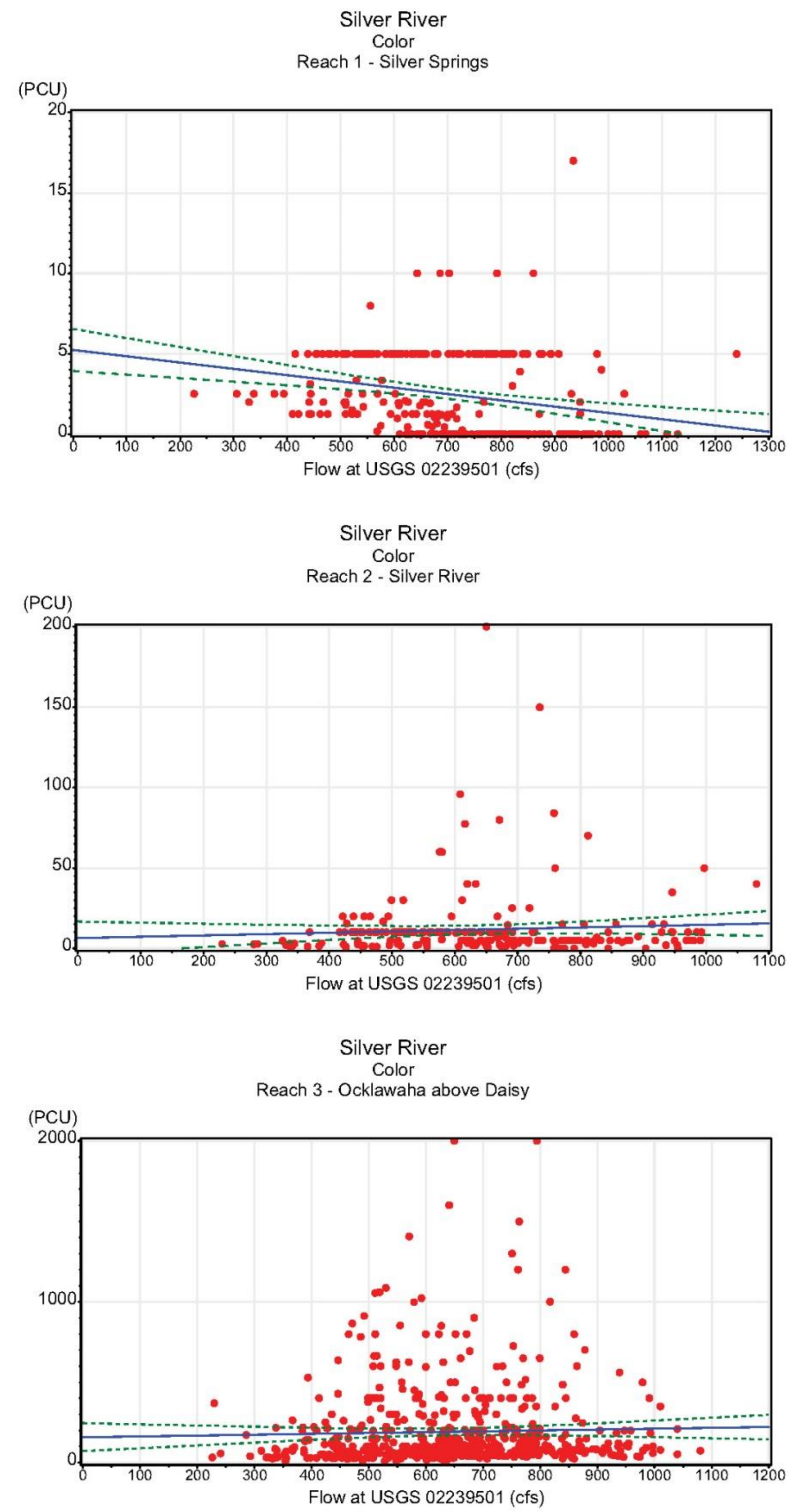


Figure 5-34. Plots of color vs. flow for Reach 1 (top), Reach 2 (middle) and Reach 3 (bottom) Data source: FDEP IWR Database.

Turbidity

Turbidity is a measure of the amount of very fine suspended particles in the water column in terms of the interference of light transmission by the particles. It is generally used to measure the amount of particulate material that interferes with light available to aquatic plants. During the 2001 survey of Silver Springs, Scott et al. (2004) reported the turbidity measured in water samples was below the MDL [0.05 nephelometric turbidity units (NTU)] at the main boil, Blue Grotto, and Reception Hall, all within 400 m (1,300 ft) of the head spring. The earliest measurement of turbidity in 1972, listed in the FGS (2004) report, also listed turbidity as zero. The historical measurements provided by Munch et al. (2006) found reports of turbidity ranging from 0.0 to 8.3 NTU, with a median of 0.30 NTU throughout the entire Silver River.

Data from the expanded dataset show similar results to the previous evaluation. Time series plots (Figure 5-35) indicate that turbidity value exceeded 5 NTU just once in Reach 1 and six times in Reach 2. Similar to the results found for color, there is a wide range of turbidity values over time but no apparent trend.

Cumulative distribution plots of the turbidity data from all three reaches are shown in Figure 5-36. As has been shown in many of the previous parameters, the Reaches 1 and 2 are similar, typically less than 1 to 2 NTU. In contrast, the turbidity in Reach 3 has a median of approximately 5 NTU and at times has exceeded 20 NTU. This again points to relative contribution of a groundwater in the upper two reaches driven system with little overland contributions.

All three reaches exhibit a slight increase in turbidity with increased flow (Figure 5-37). This result is not unexpected since turbidity increase at higher flows often results from both an increase in the delivery of materials via stormwater runoff and scour and displacement of smaller particles entrained by the increased velocities associated with the higher flows.

5.9.3 EFFECT OF THE PROPOSED MINIMUM FLOWS ON WATER QUALITY

Given the general lack of significant changes in water quality with changes in flows, there will be some improvement in such water quality constituents as inorganic nitrogen (NO_x) concentrations and no apparent degradation in other constituents. However, the increases in stage due to increased algal growth may be contributed to increases in nutrients, i.e., nitrate nitrogen.

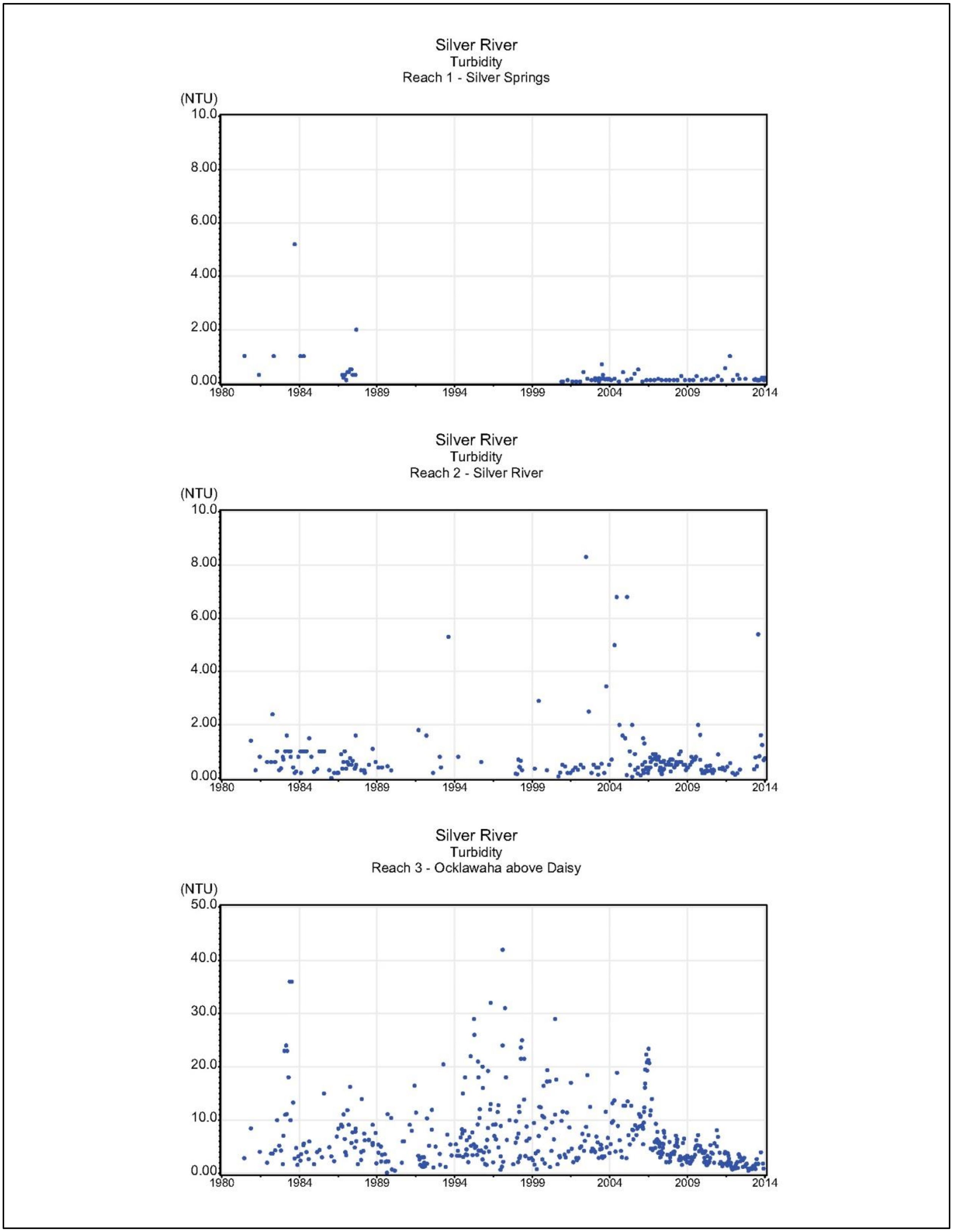


Figure 5-35. Time series plots of daily mean turbidity values for Reach 1 (top), Reach 2 (middle) and Reach 3 (bottom)

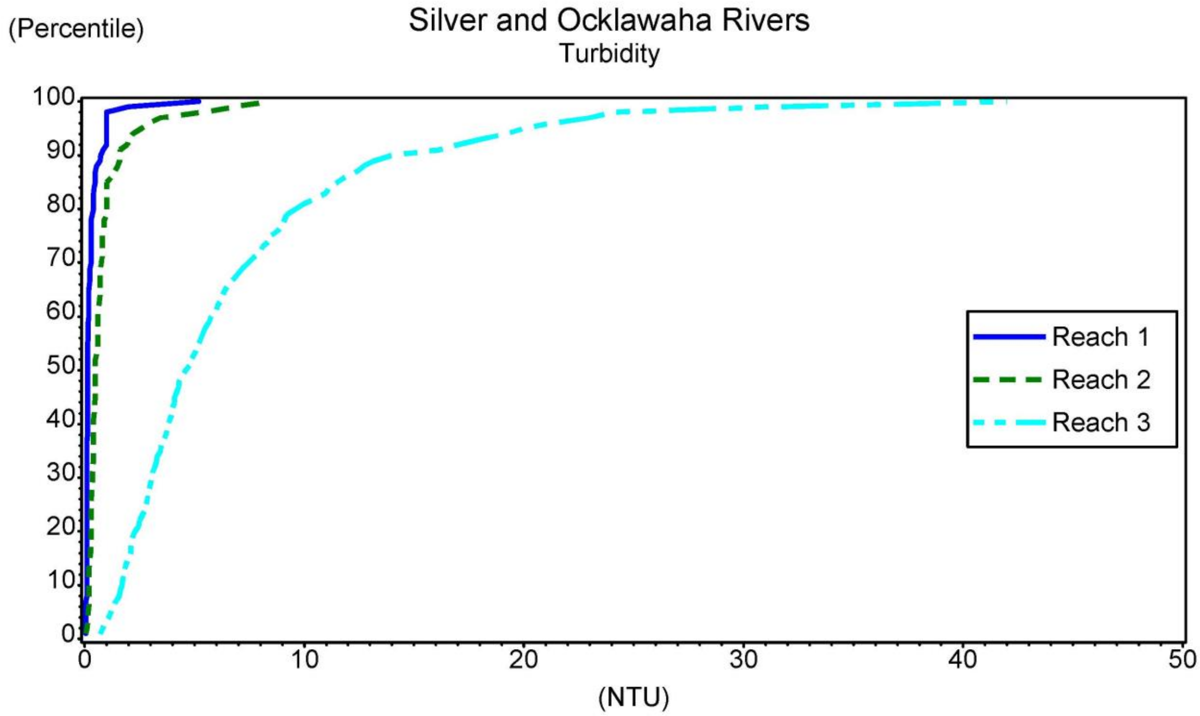


Figure 5-36. Distributions of the turbidity data collected in each of the three reaches

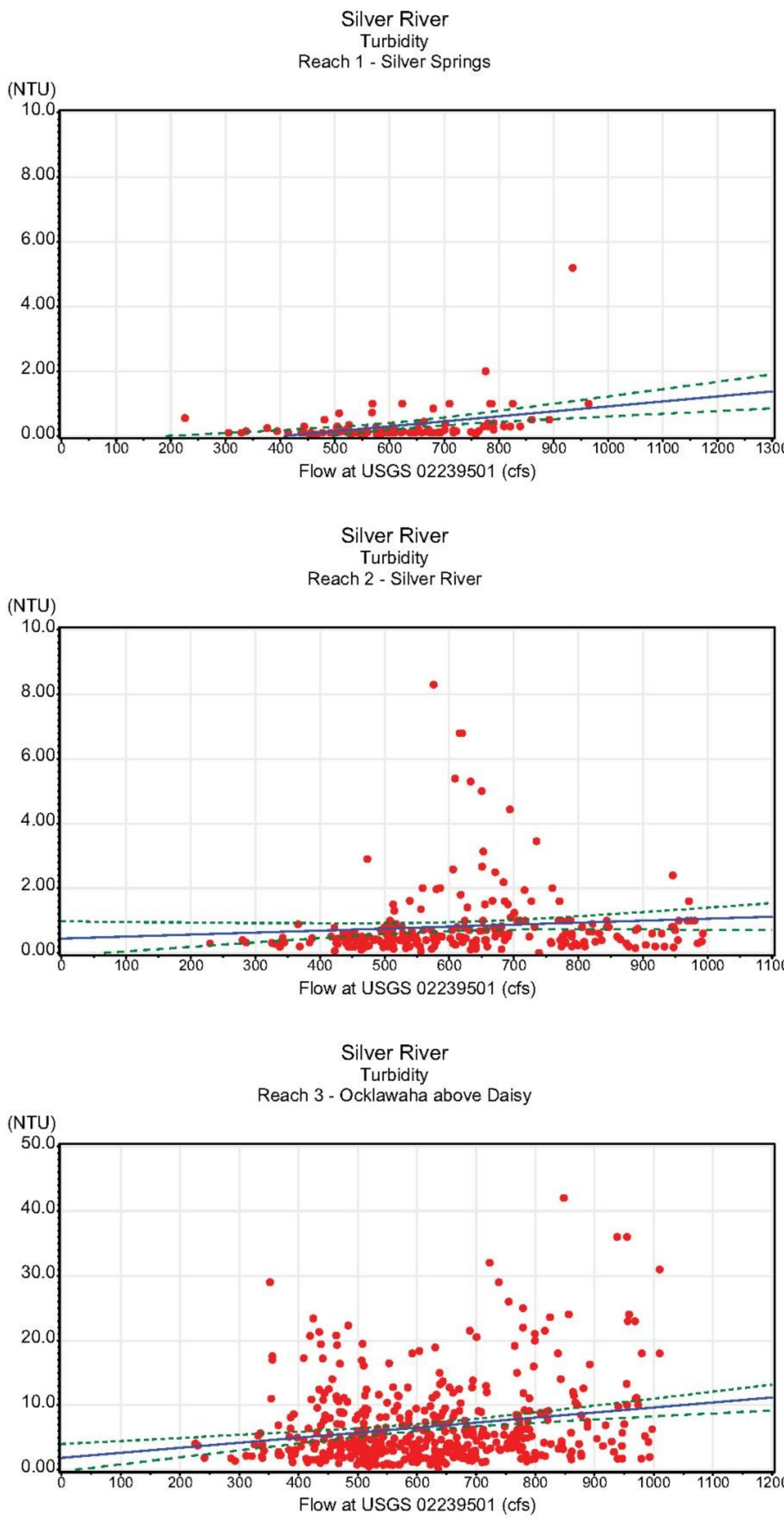


Figure 5-37. Plots of turbidity vs. flow for Reach 1 (top), Reach 2 (middle) and Reach 3 (bottom)

5.10 WRV-10: NAVIGATION

Navigation is defined as the safe passage for legal operation of ecotourism and commercial fishing vessels that are dependent on sufficient water depth, sufficient channel width, and appropriate water velocities. As discussed under WRV-1, boating access to the Silver River is provided at three points. Boat ramps and a canoe/ kayak launch are provided at the Ray Wayside Park boat basin located at the western end of the Ocklawaha River Bridge on State Road 40. Boats access the Silver River through an excavated 1,200-ft-long channel that connects to the Silver River approximately 1,300 ft upstream from its confluence with the Ocklawaha River.

Boats may also enter the Silver River directly from the Ocklawaha River, having first put into the Ocklawaha at some point upstream or downstream of its confluence with the Silver River. The final boating access option is to launch from the River Trail canoe and kayak dock inside Silver River State Park. The River Trail launch point is limited to canoes and kayaks because the launch point is accessed via a 0.6-mile-long trail, and boats must be carried from the main parking lot (http://www.floridastateparks.org/silverriver/activities.cfm#17).

There are no commercial fishing vessels on the Silver River since fishing is not allowed within the state park or the attraction limits. However, there are commercial ecotour operators that provide boat tours and paddle trips, accessing the Silver River at Ray Wayside Park, some of which are listed in Table 5-33. Kayaks may also be rented at Silver River State Park for launching at the River Trail launch point, but these may more appropriately be categorized as recreational use (WRV-1) than as part of an ecotourism operation.

Table 5-33. Links to tour operators offering Silver River boat/paddle trips
http://www.riverscapesboattours.com/book/TourBooking.php
http://discoverykayaktours.com/silverriver.aspx
http://www.captaintomscustomcharters.net/

The former Silver Springs theme park was combined with the Silver River State Park and opened on October 1, 2013 as the Silver Springs State Park. There are on-going efforts to transition the park to native landscapes, develop interpretive programs, improve stormwater quality treatment, and to restore portions of the area to their former physical state. Storm water improvements have been installed and impervious paving areas reduced. Available activities at the park include canoeing and kayaking, boat tours including the famous glass-bottomed boats, nature viewing, concessions, camping, hiking, mountain biking and equestrian trails and event hosting. Fishing and swimming are not allowed at this time.

As discussed under WRV-1, Captain Tom O'Lenick operates an ecotourism business that runs guided boat tours along the entire length of the Silver River. He uses an approximately 20-ft-long pontoon boat, with an outboard motor and a 15-inch draft. Captain O'Lenick has been in business since 1983 and estimates he is on the Silver River some 200 days per year, and perhaps over 5,000 times in total. A typical Silver River ecocruise for Captain O'Lenick runs from the Ray Wayside Park boat basin to the head of the river and back, lasting approximately 3.5 hours.

In all the years he has been on the Silver River, Captain O'Lenick says that the lowest water levels he has seen occurred in the 2000/2001 timeframe (personal communication, August 19, 2010). This description is consistent with the water level stage record for that time period, but comparable low stages also occurred circa 1990 and 1985, the early 1970s, and mid-1950s. However, even at the low water levels experienced by Captain O'Lenick, he states that he had no problem navigating the river, and that there was always sufficiently deep water in mid-river (personal communication, August 19, 2010). Again, this description is consistent with the data indicating 10 to 14 ft of water depth at the MFLs transects even during the most extreme low water event. It is unlikely that any of the reduced-flow scenarios would adversely affect an ecotourism operation such as Capt. O'Lenick's.

In addition to independent ecotour operators, the Silver Springs theme park formerly operated a fleet of boats that provide short tours around the vicinity of the main spring and a very short distance downriver. This is expected to continue when the former theme park reopens as Silver Springs State Park.

Figure 5-38 provides photographs of typical boats operated by the Silver Springs theme park. Appendix G provides glass-bottom boat measurements and photographs provided by SJRWMD staff. The glass bottom boats are 31 ft in length, 11.5 ft in width, and hold a maximum of 36 passengers. At full capacity, the hull draws less than 1 ft of water with the propeller extending approximately 2.5 ft. below the water surface.

Figure 5-38. *Typical glass-bottom boats used by the Silver Springs theme park Source Munch et al. 2006.*

Protection of navigation is a function of not significantly increasing the number of low-water level events associated with minimum river channel depth and clearance over shallow-water areas for ecotourism vessel operation when boats cannot pass because of flow reductions allowed under the draft MFLs. Figure 5-39 presents an example of how the evaluation was performed. Two areas where these events would be most critical would be 1) in the shallow areas in the upper reaches of the run within the attraction area and 2) in narrow sections of the run where passage of two boats simultaneously would be made more difficult.

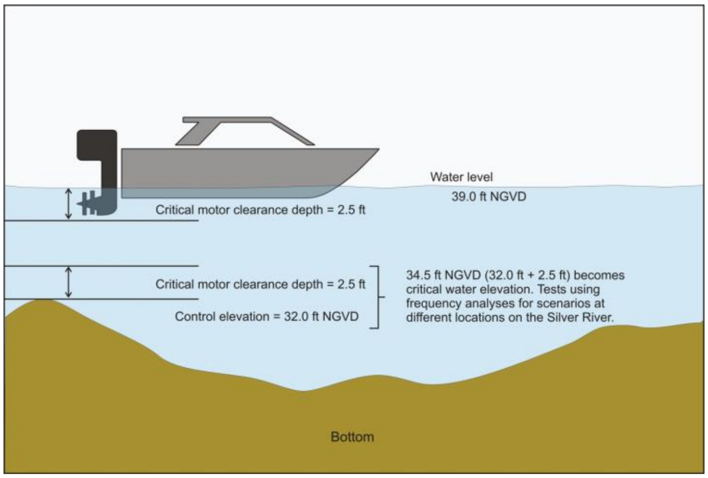


Figure 5-39. Illustration of channel clearance critical stage for ecotour boat passage (ATM 2012)

Review of the shallow-water transects indicate that the most critical areas are located near the Reception Hall spring boil area and in the Blue Grotto area (Figure 2-7). Specifically, Transects 11B, 11C, 11E and 11F are crucial given the shallowness and that these two areas are regular stops on the glass-bottom boat tours.

The critical stage threshold elevations evaluated are presented on Table 5-34. The elevations were developed according to the example presented in Figure 5-39. Based on the draft requirement calculated previously, a 2.5 ft critical draft was used in the calculation of the critical stage threshold elevation.

Table 5-34. Critical stage threshold elevations for the protection of ecotour operations

Location	Shallow-Water Transect ID	Critical Stage (ft-NGVD
Reception Hall	11B	40.2
	11C	39.3
Blue Grotto	11E	39.9
	11F	39.8

Embarkation points and downriver limits for each of the three Silver Springs theme park boat tours are provided on Figure 5-40. None of the boat tours operated by the Silver Springs theme park lasted longer than 25 minutes, with the downriver travel distance limited by that, requiring no more than a 15-minute return trip to the respective embarkation dock (Mike Young, personal communication, 2010). Because of their short trip durations, none of the three boat tours formerly offered by the Silver Springs theme park went as far downriver as T9.

Discussion with Mr. Young and two Lost River Voyage boat captains indicated that, even during the low water experienced during 2000/2001, there was no problem with navigation on the river. They simply avoided shallow nearshore areas. The main channel always had sufficient water. The primary low-water consideration for the boat tours is at the embarkation dock, where the boats can sit too low in relation to the passenger loading/unloading steps. If necessary, the steps can be adjusted to accommodate low water conditions. Also, a secondary loading dock is available that better facilitates passenger loading/unloading during extremely low water.

Comparison of the no-pumping condition stage levels to those under the draft MFLs hydrologic regime was conducted using the frequency analyses representing the 1-day minimum continuously not exceeded stage because the 1-day analyses have lower minimum stages than the longer duration analyses and, consequently, offer a worst-case scenario regarding water depths. Additionally, a 7-day minimum continuously not exceeded stage duration was evaluated as this duration of low water would have a greater impact on ecotour boating accessibility, not to mention the economic impact to the respective businesses.

Tables 5-35a and 5-35b present the results of the frequency analysis of critical threshold stage for protection of ecotour operations for the no-pumping condition stages and those stage values under the recommended MFLs hydrologic regime. Currently, these critical events occur almost every year and at most once, every 2 years at Transect 11C. This is consistent with discussions with Mr. Young and two Lost River Voyage boat captains who indicated that they simply avoided shallow nearshore areas when necessary.

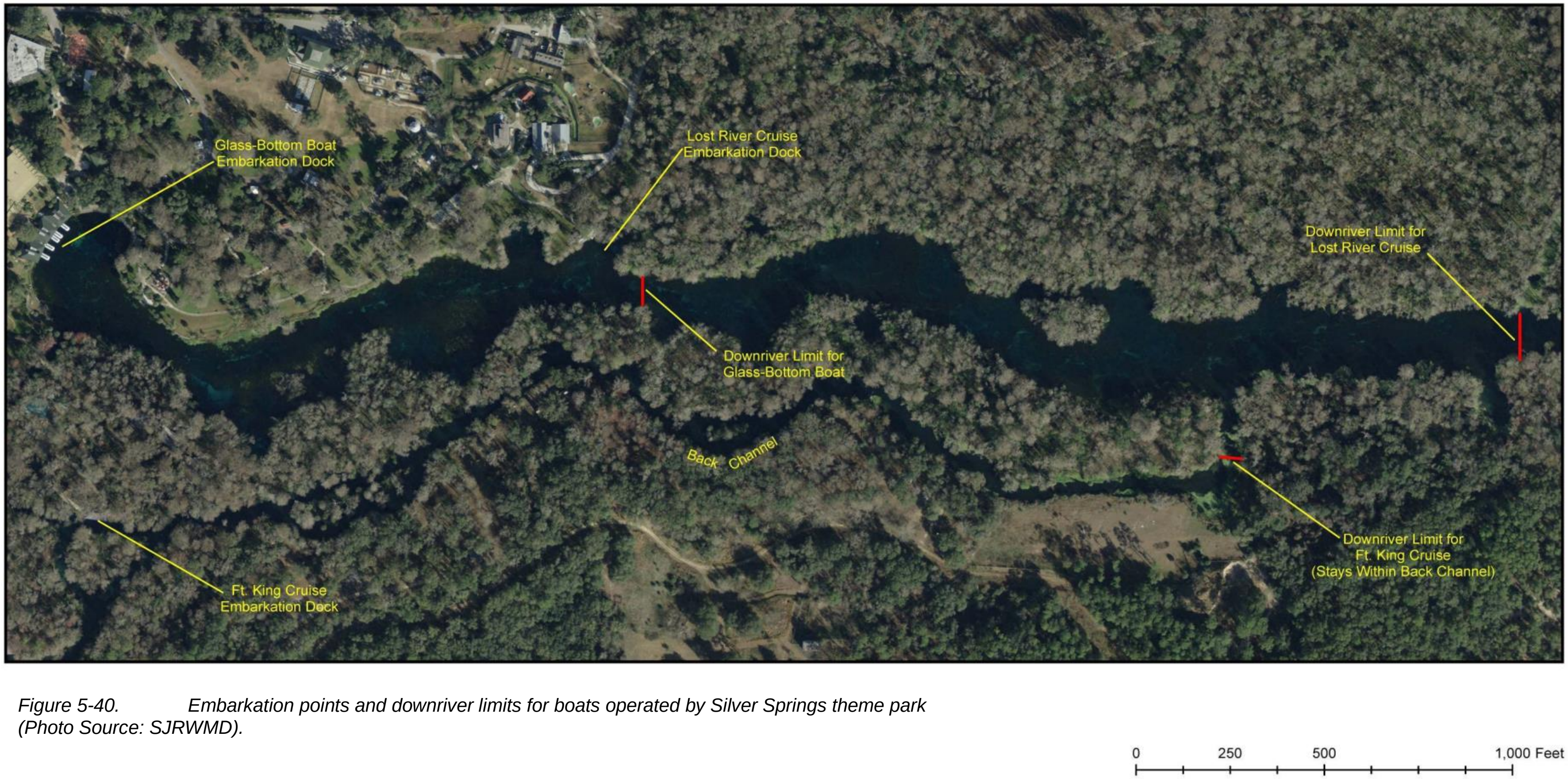


Figure 5-40. Embarkation points and downriver limits for boats operated by Silver Springs theme park (Photo Source: SJRWMD).

Table 5-35a. Frequency analysis of critical threshold stage for protection of recreational boating – motor clearance depth—1-day duration low stage continuously not exceeded

Shallow-Water Sounding Transect	Critical Threshold Stage ft, NGVD	Statistic[1]	Hydrologic Scenario	
			No-Pumping Condition	MFL
11B	40.2	Events/100 yr	87	95
		Increase in Events	-	8
11C	39.3	Events/100 yr	50	71
		Increase in Events	-	21
11E	39.9	Events/100 yr	77	90
		Increase in Events	-	13
11F	39.8	Events/100 yr	73	89
		Increase in Events	-	15

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and the MFLs hydrologic regimes.

Table 5-35b. Frequency analysis of critical threshold stage for protection of recreational boating – motor clearance depth—7-day duration low stage continuously not exceeded

Shallow-Water Sounding Transect	Critical Threshold Stage ft, NGVD	Statistic[1]	Hydrologic Scenario	
			No-Pumping Condition	MFL
11B	40.2	Events/100 yr	86	93
		Increase in Events	-	7
11C	39.3	Events/100 yr	49	68
		Increase in Events	-	19
11E	39.9	Events/100 yr	75	89
		Increase in Events	-	14
11F	39.8	Events/100 yr	71	86
		Increase in Events	-	15

1 Events /100 years= number of events per 100 years in which the critical stage event occurs. Difference = difference between the number of events occurring under no-pumping conditions and the MFLs hydrologic regimes.

Transect 11C experiences the largest increase in low-water critical events, with 19 more 7-day duration critical events per 100 years under the MFLs hydrologic regime. These critical low water events will still be occurring on average every 2 years. Given that the relative frequency of the low-water events remains on average once every 2 years, this WRV is considered protected under the recommended MFLs hydrologic regime. The experienced captains at the State Park and other ecotour operators will be able to navigate around the shallow areas while still accessing the view of the spring boils. Thus WRV-10, *Navigation*, is considered protected under all flow scenarios evaluated in the shallow areas of the river. FDEP is currently in discussions with the concessions operator to modify the glass-bottom boat tour route to avoid the shallower areas and will be isolating these areas more. This will further ensure protection of the shallow areas from possible impact damage.

As was presented in the discussion of recreational boating in Section 5-1, passage of two ecotour boats in narrow areas of the river channel is not affected under the recommended MFLs hydrologic regime.

6.0 CONCLUSIONS

An evaluation was conducted to determine if the recommended MFLs for the Silver River as presented in Sutherland et al. (2016) protects the 10 WRVs defined in Rule 62-40.473, *F.A.C.*

The WRV evaluations for the Silver River were conducted using an event-based analysis of changes in return intervals for critical flow events between no-pumping conditions and the recommended MFLs hydrologic regimes. The development of the two hydrologic regimes is discussed in detail in Karama et al. (2016). More specifically, the return intervals (frequency of occurrence) of hydrologic conditions from which one may infer protection of the WRVs were evaluated under no-pumping conditions and MFLs hydrologic regimes. The resource value was determined to be protected if the frequency of occurrence of these key events under the MFLs hydrologic regime did not differ unacceptably from the no-pumping condition based available data, literature research and professional judgment where necessary (Table 6-1). The term *unacceptably* implies a subjective evaluation. Table 6-1 provides a summary of the WRV assessment.

WRV 1 (*Recreation In and On Water*) and WRV 10 (Navigation) are considered protected. Given that the relative frequency of the low-water events remains on average once every 1 to 2 years, this WRV is considered protected under the proposed MFLs hydrologic regime.

WRV-2 (*Fish and Wildlife Habitats and the Passage of Fish*) was considered to be one of the more sensitive WRVs. The analysis concluded that it is protected with respect to fish and manatee passage and velocities to protect fish and shellfish habitats. The analysis with respect to floodplain inundation to protect hydric soils concluded that hydric soils would be protected under the proposed Silver Springs MFLs. Wetland communities and associated fauna within the floodplain were also determined to be protected. Manatee refugia was considered protected with respect to water temperature and depth.

WRV-3 (*Estuarine Resources*) and WRV-5 (*Maintenance of Freshwater Storage and Supply*) were found. For WRV-3, the contribution of the Silver River to downstream estuarine resources is contained within the cumulative contributions of other flow reductions evaluated in the St. Johns River Water Supply Impact Study (WSIS) for which estuarine resource protection is one of the major considerations. The WSIS concluded that the proposed and assessed flow reductions do not cause harm to estuarine resources. Therefore, flow reductions associated with Silver River MFL will be protective of WRV-3 since the Silver River's future contribution to flow reductions to the lower St. Johns River will have been accounted for. Under any circumstances flows from the Silver River are small relative to flows of the entire St. Johns River system. Protection of WRV-5 under the draft Silver River MFLs is related to non-consumptive uses and environmental values. This WRV is encompassed in the other nine (9) WRVs. Given that those evaluations concluded that all nine WRVs are protected, it is concluded that WRV-5 is also protected by the draft MFLs.

WRV-4 (*Transfer of Detrital Material*) and WRV-7 (*Filtration and Absorption of Nutrients and Other Pollutants*) were also considered to be two of the more sensitive WRVs evaluated. The sensitivities are primarily related to a lowering in floodplain inundation frequency. The major factor that would be affected by flow reductions allowed under the recommended MFLs would be the reduction in the frequency of physical contact of water with riparian, or floodplain vegetation. The draft MFL was considered to be protective as it prevents unacceptable reductions in contact time with the floodplain, which is important for maintaining these characteristics.

Changes in velocities associated with flow reductions allowed under the draft MFLs were also evaluated. WRV-8 (*Sediment Loads*), Algal Scour and aspects of WRV-4 (*Transfer of Detrital Material*) and WRV-7 (*Filtration and Absorption of Nutrients and Other Pollutants*) have a velocity dependence associated with their function. were considered protected under all scenarios with respect to velocity. Given the small decrease, 0.05 ft/sec or less, in average in-channel velocities anticipated, these WRVs should be protected under the draft Silver Springs MFLs.

WRV9 (*Water Quality*) found no important relationships between flow rates or water levels and water quality trends in the Silver River.

The Silver River faces a number of water quality issues, chiefly an increase in nitrates that has resulted in a documented decrease in water transparency over the past 50 years, and a concomitant increase in attached algae. However, the water quality parameters at issue are independent of Silver River flow and stage. Consequently, water quality would be generally unaffected by flow reductions as allowed under the draft MFLs. Source control within the groundwater basin was identified as the primary means to reduce nitrate concentrations in the Silver River. FDEP will address this during the Silver Springs TMDL and BMAP development efforts currently under way. SJRWMD has also embarked on a Springs Protection Initiative that will focus resources on the study of springs within the SJRWMD, including Silver Springs that will provide information critical to the development of sound restoration strategies.

Table 6-1. Summary results for WRV evaluation of the recommended MFLs hydrologic regime

Water Resource Value (WRV)	MFLs Hydrologic Regime Protective?
WRV-1: Recreation In and On the Water	Yes
WRV-2: Fish and Wildlife Habitats and the Passage of Fish	
Fish Passage	Yes
Fish/Shellfish Habitat (flow velocity related issues)	Yes
Floodplain Inundation (wetland communities)	Yes
Floodplain Inundation (hydric soils)	Yes
Manatee Protection (temperature, water depth)	Yes
WRV-3: Estuarine Resources	Yes
WRV-4: Transfer of Detrital Material	Yes
WRV-5: Maintenance of Freshwater Storage and Supply	Yes
WRV-6: Aesthetic and Scenic Attributes	Yes
WRV-7: Filtration and Absorption of Nutrients and Other Pollutants	Yes
WRV-8: Sediment Loads	Yes
WRV-9: Water Quality	Yes
WRV-10: Navigation	Yes

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APPENDIX F— ENVIRONMENTAL VALUES/WATER RESOURCE VALUES DECISION MATRIX FOR SILVER SPRINGS MFLS BASED ON RULE 62-40.473, *F.A.C.*

Table F1 - Environmental values/water resource values (WRV) decision matrix for Silver Springs and Silver River (Marion County, Florida) based on Rule 62-40.473, *F.A.C.*

Environmental Value (WRV)	Component	Score	Rationale
Recreation in and on the water	Level of resource risk[1]	1	There are sufficient water depths in the river channel (depth range 10-30 ft) to accommodate recreational use by small to medium-sized watercraft (i.e., canoes, kayaks, and motorized vessels less than 16 ft [Class A]) and larger commercial (ecotourism) and recreational watercraft (i.e., motorized vessels 16 to 26 ft [Class 1] and glass bottom boats [31 ft length] that operate near the main spring boils). Therefore, resource risk is low.
	Importance of resource value[2]	3	Significant regional economic importance, including but not limited to recreational outfitters, ecotourism, natural attractions (e.g., Silver River State Park), service providers (e.g., restaurants, gasoline service stations, grocery stores), etc. Therefore, resource importance is high.
	Resource legal constraint[3]	3	Silver River and Silver Springs designated as Outstanding Florida Waters (OFW), Rule 62-302.700(9) (i) and Rule 62-302.700(9) (c), *F.A.C.* Therefore, resource legal constraint is high.
	Screening value[4]	7	
	Criterion limiting[5]?	No	
Fish and wildlife habitats and passage of fish	Level of resource risk[1]	3	Reductions in floodplain inundation and channel (in-stream) velocities may negatively impact ecological structure (e.g., floodplain wetland plant community structure and composition, fish assemblages, hydric organic soils, algal community and in-stream submerged aquatic bed habitat) and functions (e.g., spawning, feeding, refugia for fish and other aquatic species that need access to the floodplain; aquatic fauna community composition and dynamics; in-stream primary productivity). Therefore, resource risk is high.
	Importance of resource value[2]	3	Habitats utilized by many faunal species that are state or federally threatened, endangered, or species of special concern (FDEP 2014 - http://www.dep.state.fl.us/parks/planning/SSAdvisory.htm, Table 2). These include the American alligator (Alligator mississipiensis), gopher tortoise (Gopherus polyphemus), the limpkin (Aramus guarauna), the little blue heron (Egretta caelulea), the snowy egret (Egretta thula) and the tricolor heron (Egretta tricolor). Federally endangered species include the wood stork (Mycteria Americana, also considered endangered by the FWC), and the Florida manatee (Trichechus manatus, also considered endangered by the FWC). Therefore, resource importance is high.
	Resource legal constraint[3]	3	Silver River and Silver Springs designated as Outstanding Florida Waters (OFW), Rule 62-302.700(9) (i) and Rule 62-302.700(9) (c), *F.A.C.* Therefore, resource legal constraint is high.
	Screening value[4]	9	
	Criterion limiting[5]?	Yes	

Table F1—*Continued*

Environmental Value (WRV)	Component	Score	Rationale
Estuarine resources	Level of resource risk[1]	1	The St. Johns River Water Supply Impact Study determined that upstream flow reductions allowed by MFLs would have minimal negative impacts to the Lower St. Johns River Estuary salinity regime (SJRWMD 2012b). Therefore, resource risk is low.
	Importance of resource value[2]	3	Silver River provides a major portion of the water budget to the Lower Ocklawaha River (especially during dry periods), a major tributary of the Lower St. Johns River. Freshwater discharge event are the source of dilution for oceanic salinities and result in preferred salinity zones with preferred habitats that can affect relative abundance of fish species and distributions of submerged aquatic vegetation in the Lower St. Johns Estuary (SJRWMD 2012b). Therefore, resource importance is high.
	Resource legal constraint[3]	1	Flows regulated by upstream (Moss Bluff) and downstream (Rodman) basin structures and defined water control regulation schedules. Therefore, legal constraint is low.
	Screening value[4]	5	
	Criterion limiting[5]?	No	
Transfer of detrital material	Level of resource risk[1]	2	A significant portion of the detrital material transfer occurs during periods of high water events when accumulated detrital materials on the floodplain are detached from the land surface due to buoyancy or turbulence, and moved by currents. Therefore, maintaining sufficient numbers of flooding events of the river floodplain is essential to the supply and transport of detrital material, and minimizes the potential for risk to this environmental value. Additionally, a significant portion of the detrital material in Silver River is produced directly in the instream channel as submerged aquatic vegetation (SAV) breaks down. Therefore, resource risk is moderate.
	Importance of resource value[2]	3	Important source of detrital material transported into the Silver and Ocklawaha rivers to support detrital foodwebs. Therefore, resource importance is high.
	Resource legal constraint[3]	3	Silver River and Silver Springs designated as Outstanding Florida Waters (OFWs), Rule 62-302.700(9) (i) and Rule 62-302.700(9) (c), *F.A.C.* Therefore, resource legal constraint is high.
	Screening value[4]	8	
	Criterion limiting[5]?	No	

Table F1—*Continued*

Environmental Value (WRV)	Component	Score	Rationale
Maintenance of freshwater storage and supply	Level of resource risk[1]	3	Consumptive use directly impacts an adequate amount of fresh surface water and groundwater to support non-consumptive uses and environmental values associated with coastal, estuarine, riverine, spring, aquatic, and wetlands ecology. Therefore, resource risk is high.
	Importance of resource value[2]	3	This environmental value encompasses all other environmental values identified in Rule 62-40.473 *F.A.C.* Therefore, resource importance is high.
	Resource legal constraint[3]	3	Silver River and Silver Springs designated as Outstanding Florida Waters (OFWs), Rule 62-302.700(9) (i) and Rule 62-302.700(9) (c), *F.A.C.* Therefore, resource legal constraint is high.
	Screening value[4]	9	
	Criterion limiting[5]?	No	
Aesthetics and scenic attributes	Level of resource risk[1]	1	There are sufficient water depths in river channel (depth range 10-30 ft) to accommodate recreational and commercial (ecotourism and outfitters) watercraft (i.e., canoes, kayaks, and motorized vessels up to 26 ft [Class 1]) access for scenic and wildlife viewing. Therefore, resource risk is low.
	Importance of resource value[2]	3	Significant regional economic importance, including but not limited to recreational outfitters, ecotourism, natural attractions (e.g., Silver River State Park), service providers (e.g., restaurants, gasoline stations, grocery stores), etc. Therefore, resource importance is high.
	Resource legal constraint[3]	3	Silver River and Silver Springs designated as Outstanding Florida Waters (OFWs), Rule 62-302.700(9) (i) and Rule 62-302.700(9) (c), *F.A.C.* Therefore, resource legal constraint is high.
	Screening value[4]	7	
	Criterion limiting[5]?	No	
Filtration and adsorption of nutrients and other pollutants	Level of resource risk[1]	3	Adequate inundation of the floodplain and maintenance of in-stream channel velocities support ecological structure (e.g., hydric organic soils and plant community composition) and functions (e.g., nutrient assimilation and denitrification) that are essential to the filtration and adsorption of nutrients and other pollutants. Therefore, resource risk is high.
	Importance of resource value[2]	3	System is an OFW and Aquatic Preserve. OFW requires no impairment in water quality. Potential increase in algal biomass as a result of nutrient loading. Therefore, resource importance is high.
	Resource legal constraint[3]	3	Silver River and Silver Springs designated as Outstanding Florida Waters (OFWs), Rule 62-302.700(9) (i) and Rule 62-302.700(9) (c), *F.A.C.* Therefore, resource legal constraint is high.
	Screening value[4]	9	
	Criterion limiting[5]?	Yes	
Sediment loads	Level of resource risk[1]	2	MFLs hydrologic conditions should have minimal impact on the in-stream channel velocities for sediment mobilization and transport. Therefore, resource risk is low.
	Importance of resource value[2]	3	Maintenance of in-stream channel velocities critical to sediment mobilization and transport, and maintenance of channel geomorphology. Therefore, importance of resource is high.
	Resource legal constraint[3]	3	Silver River and Silver Springs designated as Outstanding Florida Waters (OFWs), Rule 62-302.700(9) (i) and Rule 62-302.700(9) (c), *F.A.C.* Therefore, resource legal constraint is high.

Table F1—*Continued*

Environmental Value (WRV)	Component	Score	Rationale
	Screening value[4]	8	
	Criterion limiting[5]?	No	
Water quality	Level of resource risk[1]	1	Clear issues exist with substantially increased nitrate concentrations in the Silver Springs discharge. However, no important relationships appear to exist between flow rates or water levels and water quality trends in the Silver River (Upchurch et al. 2007; Appendix G). There is no evidence that flow reductions have significant effects on nitrate concentrations. Maintenance of adequate discharge and floodplain inundation events to provide filtration and adsorption of nutrients and other pollutants will protect instream water quality affected by existing and future water withdrawals. Therefore, resource risk is low.
	Importance of resource value[2]	3	System is an OFW and Aquatic Preserve. OFW requires no impairment in water quality. Potential increase in algal biomass as a result of nutrient loading. Therefore, resource importance is high.
	Resource legal constraint[3]	3	Silver River and Silver Springs designated as Outstanding Florida Waters (OFWs), Rule 62-302.700(9) (i) and Rule 62-302.700(9) (c), *F.A.C.* Florida's Impaired Waters Rule (Rule 62-303, *F.A.C.*) identified Silver Springs, the Silver Springs Group, and the Upper Silver River as impaired by nutrients. Therefore, resource legal constraint is high.
	Screening value[4]	7	
	Criterion limiting[5]?	No	
Navigation	Level of resource risk[1]	1	There are sufficient water depths in river channel and over shallow channel areas to accommodate larger commercial (ecotourism) and recreational watercraft (i.e., motorized vessels 16 to 26 ft [Class 1] and glass bottom boats [31 ft length] that operate near the main spring boils). Therefore, resource risk is low.
	Importance of resource value[2]	3	Important recreational boating area. Significant regional economic importance, including but not limited to recreational outfitters, ecotourism, natural attractions (e.g., Theme Park and Silver River State Park), service providers (e.g., restaurants, gasoline service stations, grocery stores), etc. Therefore, resource importance is high.
	Resource legal constraint[3]	3	Silver River and Silver Springs designated as Outstanding Florida Waters (OFWs), Rule 62-302.700(9) (i) and Rule 62-302.700(9) (c), *F.A.C.* Therefore, resource legal constraint is high.
	Screening value[4]	7	
	Criterion limiting[5]?	No	

Notes: 1. Evaluation of the level to which the resource is at risk. Score: 0 = none, 1 = low, 2 = medium, 3 = high
2. Evaluation of importance of the criterion with respect to resource. Score: 0 = none, 1 = low, 2 = medium, 3 = high
3. Legal constraints on resource, such as endangered species, Outstanding Florida Water, etc. Score: 0 = none, 1 = low, 2 = medium, 3 = high
4. Screening value = sum of Resource Risk, Resource Importance, and Resource Legal Constraint scores. Indicates overall importance of criterion to MFLs development.
5. Evaluation as to whether criterion is potentially limiting for MFLs development. (Y = Yes or N = No)

Technical Memorandum

Date: September 15, 2010

To: G. B. "Sonny" Hall, Ph.D., Technical Program Manager
Division of Water Supply Management

Copy: Jodi Slater, Environmental Scientist III
Division of Water Supply Management

From: Robert Freese, Ph.D., Soil Scientist
Division of Water Supply Management

Re: Summary of Soil Investigations at Silver River, Marion County, Florida, in Support of the MFLs Program

Introduction

This memorandum summarizes the results of two investigations of soil morphology conducted in 2006 and 2009 at four Minimum Flows and Levels (MFLs) transects at the Silver River, Marion County. These transects (identified as 3, 5, 7, and 9) traverse the floodplain from the uplands bordering the north side of the river to the uplands bordering the south side of the river. The transects are designed to detect the elevations at which various biologically significant features occur. Transect locations are shown in Figure 1, *Silver River MFLs Transect Locations*. The presence and distribution of deep organic soils (Histosols or histic epipedons) are of particular interest since they are important criteria for setting MFLs. The types of Hydric Soil Indicators (HI) are of interest since they are one factor determining wetland boundaries and are useful in interpreting hydrologic processes. Classification is necessary in order to assign soil series and thereby correlate field observations with soil survey data collected by the United States Department of Agriculture/ Natural Resources Conservation Service (USDA/NRCS).

Dr. G. B. "Sonny" Hall, Technical Program Manager, authorized the investigation in order to field check the work previously conducted by Dr. Albert Stoddard (AEV Consulting, LLC) at these same transects. Dr. Stoddard conducted his investigations over the course of nine field days from November 14 to December 20, 2006, and presented his findings in a report entitled, "*Silver River State Park, FL – Observed Soil Series and Hydric Soil Indicators on Selected Cross-Sectional Floodplain Transects*."

Methods

The soil reevaluation was conducted by Dr. Robert Freese, SJRWMD Soil Scientist, over the course of six field days from February 3 to April 9, 2009. Loss-on-ignition field data was collected in April 23, 2010. Field efforts focused on documenting soil characteristics within the wetland zones and on locating the hydric/ non-hydric soil boundaries. Relatively little effort was expended describing soil characteristics of the upland areas. The approach was to spot check the upland zones but to rely mainly on the 2006 work, provided the descriptions were consistent with the 2009 findings. Wetland areas were the focus of the reevaluation. There, the approach was to sample each distinct landscape or geomorphic position at an intensity such that stations were generally no further apart than 100 feet. The data from the two investigations are compared but presented separately. Inconsistencies in the findings of the two investigators, Albert Stoddard (AS) and Robert Freese (RF), are documented and resolutions are justified.

Histosols and histic epipedons are composed of soil material having a sufficient amount of organic carbon to qualify as muck, mucky peat, or peat and a sufficient thickness of these materials to meet standards defined by soil taxonomy[1]. In cases where there was uncertainty whether soil material had sufficient organic carbon to qualify as muck, soil samples were collected and analyzed in the University of Florida Environmental Pedology Lab by the "Loss on Ignition (LOI)" method[2]. Soil material with greater than 18 percent organic carbon is classified as muck while soil material with less than 5 percent organic carbon is classified as mineral soil. Soil material with intermediate levels of organic carbon may classify as either muck, mucky mineral, or mineral soil material depending on clay content. Clay content of the soil material was estimated based on the dominant textures from the soil profile. Soil samples were collected and analyzed in April 2010.

Soil profile descriptions follow standardized guidelines developed by the USDA/NRCS (Schoeneberger et al. 2002[3]). The conventional codes from this publication are the basis for the abbreviations used to describe morphologic features. These abbreviations refer to the size, abundance, and contrast of redoximorphic features; size and abundance of roots or other soil fragments; grade, size, and class of soil structure; and degree of stickiness and plasticity. All borings were evaluated for the presence of HI. Those soil pedons sampled to a sufficient depth were classified to the great group or subgroup level of Soil Taxonomy (Soil Survey Staff 1999[4]). Assumptions regarding soil chemistry were based on information in the Soil Survey of Marion County Area (Soil Survey Staff 1979[5]). Soil profile descriptions were inspected to determine the diagnostic surface/ subsurface horizons, and particle size class of the control section. This information was used to select a soil series of matching classification, where possible. If there were no established series with this classification, a taxajunct soil series was assigned. Taxajunct soil series indicate that the soil has a different classification from the named series but is otherwise similar. Taxajunct soil series were used in cases where the particle size class and drainage class matched that of an established series. Finally, some soil pedons had significant differences from all established series and were, therefore, designated with only a taxonomic category such as great group (e.g., Fluvaquent) or subgroup (e.g., Fluvaquentic Haplosaprist).

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[1] Soil Survey Staff, 1999. Soil Taxonomy, Second Edition. Natural Resources Conservation Service, national Soil Survey Center, Lincoln, NE.

[2] Nelson, D.W., and L.E. Sommers, 1996. Total carbon, organic carbon, and organic matter. *In* Methods of Soil Analysis – Part 3 (Chemical Methods), D.L. Sparks (ed). Soil Science Society of America, Inc. Madison, WI.

[3] Schoeneberger, P. J., Wysocki, D.A., Benham, E.C., and Broderson, W.D. (editors), 2002. Field book for describing and sampling soils, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

[4] Soil Survey Staff, 1999. Soil Taxonomy, Second Edition. Natural Resources Conservation Service, national Soil Survey Center, Lincoln, NE.

[5] Soil Survey Staff, 1979. Soil Survey of Marion County Area, Florida. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Due to constraints imposed by the scale of mapping, high variability, and a lack of anticipated land uses, the Marion County soil survey report did not accurately characterize the soils of the Silver River floodplain. Some taxonomic categories (e.g., Fluvaquents) do not have defined series. Although this reevaluation did not attempt to map the extent of soil series, an effort was made to delineate the lateral extent of HI, which the close spacing of borings made feasible. Landscape breaks such as changes in slope, elevation, or landform type were also relied upon when estimating HI breaks. The use of topography to map soil features is used extensively in soil surveys and is justified by the fact that topography is one of five factors influencing soil formation.

Results

The lateral extents of HI are shown in Table 1, *Soil Sample Locations and Primary HI Described in 2006 and 2009*. Although some stations had multiple HI, only those HI that were most strongly indicative of wetness were included in this summary (Hurt et al. 2007[6]). Soil morphology and landscape position are strongly correlated (Soil Survey Division Staff 1993[7]). Figure 2, *Transect 3: Hydric Soil Distribution*, Figure 3, *Transect 5: Hydric Soil Distribution*, Figure 4, *Transect 7: Hydric Soil Distribution*, and Figure 5, *Transect 9: Hydric Soil Distribution* show the distribution of HI at each of the four transects and demonstrate the relationship between soil properties and landscape position. For example, A8 (muck presence) occurs in slight depressions and on broad flat areas of the floodplain on all transects. A1 (Histosol) and A2 (histic epipedon) occur in narrow backswamp depressions of Transects 5 and 7 and in broad flat areas bordering the river at Transect 9. F3 (depleted matrix) and F6 (redox dark surface) are generally restricted to the terraces or toeslope areas that border the uplands. F13 (umbric surface) occurs in floodplain depressions at the edge of the uplands on Transects 5,7, and 9. In Transect 3, F13 occurs on toeslopes or in slight rises in backswamps. Non-hydric soil pedons occur in uplands and along berms or rises in the floodplain on all transects.

Deep organic soils (Histosols and histic epipedons) are most extensive at Transect 9 and occupy approximately 370 linear feet, occurring in two segments. These organic accumulations may be associated with Half Mile Creek, a small tributary creek located immediately upstream of Transect 9.The prevalence and depth of deep organic soils generally decreases downstream on the spring run, occupying approximately 180 linear feet of Transect 7, approximately 190 linear feet of Transect 5, and approximately 110 linear feet of Transect 3. This may be related to the progressive increase in floodplain microtopography at points downstream. At Transect 9, the deep organic soils occur on broad flat portions of the floodplain while at the other transects they are restricted to backswamp depressions.

Table 2, *Soil Taxonomy and Series as Determined in 2006 and 2009*, provides information on soil classification and assignment of soil series. Sixty-one soil descriptions had sufficient detail to identify diagnostic horizons and to classify according to soil taxonomy. Thirty-four were

[6] GW Hurt, FC Watts, and JM Galbraith. 2007. Using hydric soil indicators for identification of seasonal high saturation. *In* Hydric Soils of Florida Handbook. Ed. GW Hurt Florida Association of Environmental Soil Scientists. Gainesville FL

[7] Soil Survey Division Staff, 1993. Soil Survey Manual. United States Department of Agriculture Handbook No. 18. U.S. Government Printing Office, Washington DC.

described in 2006 and twenty-seven were described in 2009. Twenty of the soil pedons from 2006 were re-assigned to new series in 2009 based on soil taxonomic and series criteria shown in Table 2. In the 2009 study, diagnostic surface and subsurface horizons were determined first and were used in conjunction with the control section particle size class to determine the taxonomy.

Based on the 2009 revisions to the taxonomic status of the soil profiles, sixteen soil series or taxonomic equivalents occur on the four transects (Table 2). Each occupies a distinct landscape position. **Paisley**, a fine-textured and poorly-drained soil, occupies the uplands of Transects 3, 5, and the north side of Transect 7. Sandy, moderately well- to poorly-drained soils such as **Pomona**, **Sparr**, **Jumper**, and **Tavares** occupy the uplands of transect 9 and the south side of transect 7. **Nittaw** and **Bluff** are fine and fine-loamy textured, very poorly-drained soils that occupy low river terraces on Transects 3, 5, and 7. **Bluff** also occurs in the floodplain of transect 9. Coarse-loamy and coarse-silty **Fluvaquents** and **Fluvaquentic Endoaquolls,** for which there are no established series, occur extensively in the active floodplain of transects 3, 5, and 7. **Anclote**, a sandy and very poorly-drained soil, occurs in depressions bordering sandy uplands on transects 7 and 9. **Denaud**, a coarse-loamy soil with a histic epipedon, occurs as an inclusion within an area of Histosols in Transect 5. Shallow Histosols such as **Gator** and **Okeelanta** occur in backswamp areas of transects 5 and 7 and in a transition to deeper organic soils on transect 9. Deep Histosols such as **Terra Ceia** and **Fluvaquentic Haplosaprists** (no established series) occur extensively on the floodplain of transect 9. This latter category describes Histosols that have mineral layers interspersed within a profile dominated by organic horizons. These Histosols are similar to and grade into **Thapto-Histic Endoaquolls** (no established series), which are dominantly mineral soils that also contain thick, subsurface, organic horizons. The presence of such soils indicates that the Silver River has had a dynamic history with alternating episodes of organic accretion and mineral deposition.

Soil profile descriptions were collected from 133 soil pedons in 2006 and are shown in Appendix 1, *Soil Profile Descriptions from Silver River (2006)*. Soil profile descriptions were collected from 98 soil pedons in 2009 and are shown in Appendix 2, *Soil Profile Descriptions from Silver River (2009).* The level of detail of these descriptions ranges from brief comments to full soil profile descriptions. Observed HI included A1 (Histosol), A2 (histic epipedon), A4 (hydrogen sulfide), A5 (stratified layers), A6 (organic bodies), A7 (mucky mineral), A8 (muck presence), A11 (depleted below dark surface), A12 (thick dark surface), F3 (depleted matrix), F6 (redox dark surface), F13 (umbric surface), S6 (stripped matrix), and S7 (dark surface).

The results of LOI analysis for 13 soil samples from Transects 3, 5, and 7 are presented in Appendix 3, *Measured Organic Carbon Levels from Selected Horizons*. Four of the sampled soils qualified as muck with organic carbon levels ranging from 18.5 to 27.5 percent. Five of the sampled soils qualified as mucky mineral with organic carbon levels ranging from 9.9 to 12.1 percent. Four of the sampled soils qualified as mineral with organic carbon levels ranging from 4.2 to 8.0 percent.

Conclusions

The 2006 and 2009 soil investigations had different goals and focused on different aspects of the Silver River system. The 2006 investigation provided detailed soil descriptions, as well as brief comments regarding soils from both upland and wetland zones. The 2009 investigation focused more intensively on the wetland zones and on estimating the lateral extent of the various HI. In general, the findings of the two investigations are in good agreement. Some discrepancies occur due to the following reasons:

- Different sample locations (bore holes) were used for the two investigations.
- The 2009 study used soil-landscape relationships extensively in order to estimate and delineate the boundaries of HI, which had not been a goal in the 2006 study.
- Some field disturbances occurred in the years separating these studies. Extensive hog rooting and crayfish burrowing obliterated some thin, muck-based indicators. In most cases, other HI were present and the overall HI extent did not change.
- Additional bodies of deep organic soils were found that were previously not identified. Soils with interlayered muck and mineral horizons ("Fluvaquentic Haplosaprists") were much more extensive than anticipated. The depth of some borings from the 2006 study may have been insufficient to identify such soils.
- Additional wetland borings allowed refinement and/ or shifting of the lateral extent of HI.
- Soils series designations in the 2006 study were updated based on principles of soil taxonomy.

Some important findings are that the extent and depth of organic accumulations (Histosols and histic epipedons) in the Silver River floodplain system generally decrease downstream on the spring run and corresponds to an increase in floodplain microtopography. The deep and extensive organic accumulations at Transect 9 may be associated with nearby Half Mile Creek. The presence of interlayered muck and mineral horizons indicate that the Silver River has had a dynamic history with alternating episodes of organic accretion and mineral deposition. The soil series and HI in all transects occur in regular patterns that correspond to geomorphic landforms.

Table 1. Soil Sample Locations and Primary HI Described in 2006 and 2009

Transect	Station-HI (2006)	Station-HI (2009)	RF (2009) Evaluation of AS (2006) Descriptions	Estimated* extent of primary HI
3	0-none	0-none	Description confirmed.	
3	33-none		Descriptions consistent with findings at stations 0, 290 and 310. No HI expected in this upland area.	
3	130-none			
3	245-none			
3		290-none		
3	310-none	310-none	Description confirmed.	**none**: 0-314
3	314-F6		Descriptions consistent with findings at station 320. However, recent hog rooting has eliminated F6.	
3	320-F6	320-F3		
3	328-F6			
3	346-F6			**F3**: 314-369*
3		388-A12		
3	390-A12		Descriptions consistent with findings at station 388 and 465.	
3	415-A12			
3	432-A8		HI **not** consistent with findings at station 465.	
3		465-A12		**A12**: 369*-468
3	468-A8		HI not confirmed but A8 expected in this upper backswamp area.	**A8**: 468-480*
3		482-A8	(insufficient depth of boring)	
		500-A1		
3	515-A8		HI not consistent with findings at stations 500 and 550. Insufficient depth of boring.	
3		550-A2		
3	555-A8		HI not consistent with findings at stations 500 and 550. Insufficient depth of boring.	**A1/A2:** 480*-580*
3	586-A8			
3		600-A8		
3		622-A8		
3	640-A8			**A8**: 580-640
3		689-A5		
3	705-none		HI **not** consistent with findings at station 689 but otherwise similar; may be an inclusion of non-hydric soil	**A5**: 640-728
				river: 728-814
3		825-none		
3	875-none		Description consistent with findings at stations 825, 900, and 1006. HI not expected on berm.	
3		900-none		**none**: 814-1205*

Transect	Station-HI (2006)	Station-HI (2009)	RF (2009) Evaluation of AS (2006) Descriptions	Estimated* extent of primary HI
3		1006-none		
3		1215-F3/A11		
3		1256-F3/A11		
3	1270-F3/A11	1270-F3/A11	Description confirmed and consistent with findings at stations 1215 and 1256.	**F3/A11**: 1205*-1330
3	1330-A7	1330-A7	Description confirmed.	
3	1338-A7		Description consistent with station 1330.	**A7**: 1330-1345
3	1345-A8			
3	1350-A8			
3	1374-A8			
3	1385-A8		HI consistent with findings at station 1400.	
3	1395-A8			
3		1400-A8		
3	1420-A8		HI consistent with findings at station 1400.	
3	1445-A8			**A8**: 1345-1445
3	1464-A7/A5		HI not confirmed but dual HI expected in this transition area.	**A7**: 1445-1464
3	1495-A5		HI not confirmed.	**A5**: 1464-1495
3		1502-F13		
3	1504-A8		HI **not** consistent with findings at station 1502. LOI analysis at station 1540 indicates mineral texture. Muck not expected on convex landforms and rises in floodplain.	
3	1510-A8			
3	1540-A8			
3	1550-A8			
3	1555-A8			**F13**: 1495-1567*
3		1577-A8		**A8**: 1567*-1670*
3		1640-A8		
3		1680-A7		
3	1695-A8		Description **not** consistent with findings at station 1680. LOI analysis at station 1695 supports A7 (mucky mineral), not A8 (muck).	**A7**:1670*-1715
3	1715-A8		HI not confirmed but muck presence probable in depression.	
3	1722-A8			**A8**: 1715-1742
3	1742-A2		LOI analysis at station 1750 confirms A2 (histic epipedon).	
3	1750-A2			**A2**: 1742-1750
3		1755-A7		**A7**: 1750-1790

Transect	Station-HI (2006)	Station-HI (2009)	RF (2009) Evaluation of AS (2006) Descriptions	Estimated* extent of primary HI
3	1770-A8			
3	1790-A8		LOI analysis at station 1790 supports A7 (mucky mineral), not A8 (muck).	**A7**: 1750-1790
3	1805-A8	1805-F6	LOI analysis at station 1805 indicates mineral texture, not A8 (muck).	
3		1810-F6		
3	1817-F6			
3	1830-F6		Descriptions consistent with findings at station 1810.	**F6**: 1790-1830
3		1840-none		
3	1885-none			
3	1950-none		Descriptions consistent with findings at station 1840. No HI expected in this upland area.	**none:** 1830-2000
5	40-none		HI not expected in upland area but not confirmed.	**none**: 0-140
5	140-F6	140-F3	Description confirmed. Hog rooting in footslope area has eliminated F6.	
5	150-F6			
5	160-F6		Descriptions consistent with findings at station 140.	**F3**: 140-170
5	170-A8			
5	175-A8			
5	180-A8		Descriptions consistent with findings at station 201.	
5		201-A8		**A8**: 170-204*
5		206-A1		
5		240-A1		
5		285-A1		
5		300-A2		
5		318-A1		**A1**: 204*-320*
5	345-A8			
5	360-A8			
5	370-A8		Descriptions not confirmed. A8 (muck presence) likely based on landscape.	**A8**: 320*-370
5		377-A5		**A5**: 370-405
5	405-A8			
5	410-A8		Descriptions consistent with findings at station 412.	
5		412-A8		
5		446-A8		**A8**: 405-460

Transect	Station-HI (2006)	Station-HI (2009)	RF (2009) Evaluation of AS (2006) Descriptions	Estimated* extent of primary HI
5				**river**: 460-600
5		630-A6/F13		**A6/F13:** 600-640
5	640-A2		Description consistent with findings at station 641.	
5		641-A2		
5	670-A2		Description consistent with findings at station 641.	**A2**: 640-670
5	680-A8		HI not confirmed but consistent with landform.	
5	695-A8			**A8:** 670-700
5		700-A6		**A6**: 700-760*
5	765-A8			
5	800-A4		HI **not** consistent with findings at station 816; may be an ephemeral feature.	
5		816-A8		**A8**: 760*-880*
5		900-A2		**A2**: 880*-925*
5	960-A8		Description consistent with findings at station 1109. Muck expected on this broad flat in floodplain.	
5		1109-A8		
5	1120-A8		Description consistent with findings at station 1109. Muck expected on this broad flat in floodplain.	
5	1145-A4		Not consistent with findings at station 1109; may be an ephemeral feature.	**A8**:925*-1150*
5	1170-A8	1170-A7	Not consistent with findings at station 1170 (2009); muck not expected on this rise in floodplain.	**A7**: 1150*-1193*
5		1204-A8		
5	1295-A8		Descriptions consistent with findings at station 1204; Muck expected on this broad flat in floodplain.	
5	1310-A8/A12			
5	1315-A8			**A8**: 1193*-1320*
5	1330-F13/F6		Consistent with findings at station 1340.	
5		1340-F13/F6		
5	1345-F13/F6		Consistent with findings at station 1340.	
5	1355-F13/F6			**F13/F6**: 1320*-1365*

Transect	Station-HI (2006)	Station-HI (2009)	RF (2009) Evaluation of AS (2006) Descriptions	Estimated* extent of primary HI
5	1390-F6		HI not confirmed but expected and consistent with toeslope landform.	F6: 1365*-1420
5	1415-F6			
5	1420-F6			
5	1430-F3		Consistent with findings at station 1458; F3 expected on footslope.	F3: 1420-1460
5	1450-F3			
5		1458-F3		
5	1460-F3		Consistent with findings at station 1458; F3 expected on footslope.	
5		1500-none		none: 1460-1600
5	1555-none		Consistent with findings at station 1550. No HI expected in upland.	
7	20-none		Consistent with findings at station 24. Does not qualify for F13 due to upland landform.	none: 0-200
7		24-none		
7	135-none		Consistent with findings at station 24. Does not qualify for F13 due to upland landform.	
7	195-none			
7	200-F3		Consistent with findings at station 202.	F3: 200-235
7		202-F3		
7	215-F3		Consistent with findings at stations 202 and 220.	
7		220-F3		
7	230-F3		Consistent with findings at station 220.	
7	235-F3/F6		Consistent with findings at stations 220 and 240.	
7	240-F6	240-F6	Description confirmed.	F6: 235-245
7	245-F6/A8		Consistent with findings at stations 240 and 250.	
7		250-A8		A8: 245-300*
7		279-A8		
7		294-A8		
7		306-A1		A1: 300*-478*
7		400-A1		
7		470-A1		
7		484-A8		A8: 478*-575*
7		500-A8		
7		555-A8		
7		588-A7		A7: 575*-596*
7		620-F3		F3: 596*-666*

Transect	Station-HI (2006)	Station-HI (2009)	RF (2009) Evaluation of AS (2006) Descriptions	Estimated* extent of primary HI
7		673-A8		**A8**: 666*-725
7				**river**: 725-960
7		1000-A8		
7	1100-A8		Consistent with findings at station 1000.	**A8**: 960-1150*
7	1200-A8		Description consistent with findings at station 1201 but HI different due to crawfish disturbance, noted throughout this area.	
7		1201-A11/F3		
7	1217-A8			
7	1248-A8		Same comment as for station 1200.	
7	1255-no muck		Consistent with stations 1201 and 1315 (2009), which also lacked muck.	
7	1315-A8	1315-A11/F3	Description confirmed but HI different due to crawfish disturbance.	
7	1435-A8			
7	1490-A7/A5		Description consistent with findings at station 1500 (2009); HI different due to extensive crawfish disturbance to mucky mineral layer and thin strata.	
7	1500-A8	1500-A11/F3	Description confirmed but HI different due to crawfish disturbance.	
7	1515-A7		Description consistent with findings at station 1517; extensive crawfish disturbance has disrupted mucky mineral layer.	
7		1517-A11/F3		**A11/F3:** 1150*-1520*
7	1530-A7		HI **not** consistent with station 1542.	
7		1542-none		
7	1555-none		Description consistent with findings at station 1542.	
7	1600-A6		HI **not** consistent with findings at station 1628. HI not expected on rise in floodplain.	
7		1628-none		**none:** 1520*-1668

Transect	Station-HI (2006)	Station-HI (2009)	RF (2009) Evaluation of AS (2006) Descriptions	Estimated* extent of primary HI
7		1668-F3		F3: 1668-1790*
7	1670-A6		HI **not** consistent with station 1668.	
7	1700-A7	1700-F3	HI (2006) **not** consistent with findings at station 1700 (2009).	
7	1740-A6		HI **not** consistent with findings at station 1700 (2009).	
7		1792-F13/A6		**F13/A6**: 1790*-1915
7	1800-F13/A6		Description consistent with findings at stations 1792 and 1826.	
7		1826-F13/A6		
7	1830-F13/A6		Descriptions consistent with findings at station 1826.	
7	1875-F13			
7	1900-F13			
7		1915-A7		**A7**: 1915-1985
7	1920-none		HI **not** consistent with findings at stations 1915, 1960, 1985. HI expected in this depressional area.	
7	1940-none			
7		1960-A7		
7		1985-A7		
7	2000-none		Description **not** consistent with findings at station 2019.	**S6**: 1985-2035*
7		2019-S6		
7		2073-none		**none**: 2035*-2175
7	2145-none		Description consistent with findings at station 2073. No HI expected in upland.	
9	10-none	10-none	Description confirmed.	**none**: 0-243
9	180-none		HI consistent with station 10 findings. No HI expected in upland area.	
9	242-none			

Transect	Station-HI (2006)	Station-HI (2009)	RF (2009) Evaluation of AS (2006) Descriptions	Estimated* extent of primary HI
9	243-S6	243-S6	Description confirmed.	
9	255-S6		Consistent with findings at station 243 (2009).	**S6:** 243-260*
9	294-F13		HI consistent with findings at station 325 (2009).	
9	306-A8		HI **not** consistent with findings at station 325 (2009).	
9	325-A8/F13	325-A8/F13	Description confirmed.	**F13**: 260*-325
9		350-A8		
9		460-A8		
9		575-A8		**A8**: 325-695*
9		600-A8		
9		670-A8		
9		700-A1		
9		775-A1		
9		800-A1		
9		825-A1		
9		856-A1		
9		858-A1		
9		884-A1		**A1**: 695*-901
9				**river**: 901-1075
9	1110-A1		Descriptions consistent with findings at station 1235.	
9	1210-A1			
9		1235-A1		
9	1241-A1		Description consistent with findings at station 1235.	**A1**: 1075-1241
9	1245-A2		Description supports A8, not A2. Not confirmed.	
9	1255-A8		HI not confirmed but muck expected on this broad flat in floodplain.	
9	1262-A8			**A8**: 1241-1262
9	1275-S7	1275-S7	Description confirmed.	**S7**: 1262-1275
9	1280-none			
9	1365-none		No HI expected in this upland.	**none**: 1275-1400

* indicates ranges estimated based on landscape features rather than actual soil borings.

Table 2. Soil Taxonomy and Series as Determined in 2006 and 2009.

Transect-Station (Year)	Initially Designated Series(Taxonomy)	RF Comments and Revisions		
		Diagnostic Horizons	Taxonomic Class	Soil Series
3-0 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	mollic, argillic	fine Typic Argiaquoll	Texture and upland landform fit **Paisley** taxajunct - no ochric, no albic
3-0 (2009)	**Paisley** (fine, Typic Albaqualf)	mollic, argillic	fine Typic Argiaquoll	**Paisley** taxajunct - no ochric, no albic
3-130 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	mollic, argillic	fine Typic Argiaquoll	Texture and upland landform fit **Paisley** taxajunct - no ochric, no albic
3-245 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	ochric	fine Endoaquent	Texture and upland landform fit **Paisley** taxajunct – no albic, argillic
3-310 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	ochric	fine Endoaquent	Texture fits **Nittaw** taxajunct – no argillic
3-390 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	mollic, argillic	fine Typic Argiaquoll	Taxonomy fits **Nittaw** series
3-640 (2006)	(Aquent)	ochric	coarse-loamy Mollic Fluvaquent	No established series
3-875 (2006)	(Fluvaquent)	ochric	coarse-silty Mollic Fluvaquent	No established series
3-900 (2009)	(Fluvaquent)	ochric	coarse-silty Typic Fluvaquent	No established series
3-1270 (2006)	(Fluvaquent)	ochric	coarse-loamy Typic Fluvaquent	No established series
3-1495 (2006)	(Fluvaquent)	mollic	coarse-silty Fluvaquentic Endoaquoll	No established series
3-1817 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	mollic	fine Typic Endoaquoll	**Bluff** taxajunct - not fine-loamy
3-1885 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	mollic	fine-loamy Typic Endoaquoll	Taxonomy fits **Bluff** series
3-1950 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	mollic, argillic	fine Typic Argiaquoll	Texture and upland landform fit **Paisley** taxajunct - no ochric, no albic
5-40 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	ochric	fine Endoaquent	Texture and upland landform fit **Paisley** taxajunct - no albic, no argillic
5-140 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	mollic, argillic	fine Typic Argiaquoll	Taxonomy fits **Nittaw** series
5-201	**Bluff** (fine-loamy,	mollic	fine-loamy	Taxonomy fits **Bluff** series

Transect-Station (Year)	Initially Designated Series(Taxonomy)	RF Comments and Revisions		
		Diagnostic Horizons	Taxonomic Class	Soil Series
(2009)	Typic Endoaquoll)		Typic Endoaquoll	
5-206 (2009)	**Gator** (loamy, Terric Haplosaprist)	histic	loamy Fluvaquentic Haplosaprist	**Gator** taxajunct – Fluvaquentic not Terric
5-240 (2009)	**Gator** (loamy, Terric Haplosaprist)	mollic	loamy Fluvaquentic Haplosaprist	**Gator** taxajunct - no histic, Fluvaquentic not Terric
5-285 (2009)	**Okeelanta** (sandy, Terric Haplosaprist)	mollic	sandy Fluvaquentic Haplosaprist	**Okeelanta** taxajunct - no histic, Fluvaquentic not Terric
5-300 (2009)	**Denaud** (coarse-loamy, Histic Humaquept)	histic	coarse-loamy Histic Humaquept	Taxonomy fits **Denaud** series
5-318 (2009)	**Okeelanta** (sandy, Terric Haplosaprist)	histic	sandy, Terric Haplosaprist	Taxonomy fits **Okeelanta** series
5-765 (2006)	(Fluvaquent)	ochric	coarse-loamy Typic Fluvaquent	No established series
5-1310 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	mollic, argillic	fine, Typic Argiaquoll	Taxonomy fits **Nittaw** series
5-1430 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	ochric, argillic, albic	fine Typic Albaqualf	Taxonomy fits **Paisley** series
5-1555 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	mollic	fine Typic Endoaquoll	Texture and upland landform fit **Paisley** taxajunct – no albic, argillic
7-20 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	mollic, argillic	fine Typic Argiaquoll	Texture and upland landform fit **Paisley** taxajunct – no ochric, albic
7-24 (2009)	**Paisley** (fine, Typic Albaqualf)	mollic, argillic	fine Typic Argiaquoll	**Paisley** taxajunct - no ochric, no albic
7-135 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	ochric, argillic	fine Typic Albaqualf	Taxonomy fits **Paisley** series
7-235 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	ochric, argillic	fine Typic Albaqualf	Taxonomy fits **Paisley** series
7-279 (2009)	**Bluff** (fine-loamy, Typic Endoaquoll)	mollic	fine-loamy Fluvaquentic Endoaquoll	**Bluff** taxajunct – Fluvaquentic, not Typic
7-294 (2009)	(Endoaquoll)	mollic	coarse-loamy Fluvaquentic Endoaquoll	No established series
7-306	**Gator** (loamy,	mollic	loamy	**Gator** taxajunct - no histic,

Transect-Station (Year)	Initially Designated Series(Taxonomy)	RF Comments and Revisions		
		Diagnostic Horizons	Taxonomic Class	Soil Series
(2009)	Terric Haplosaprist)		Fluvaquentic Haplosaprist	not Terric
7-400 (2009)	**Gator** (loamy, Terric Haplosaprist)	histic	loamy Terric Haplosaprist	Taxonomy fits **Gator** series
7-470 (2009)	**Okeelanta** (sandy, Terric Haplosaprist)	mollic	sandy Fluvaquentic Haplosaprist	**Okeelanta** taxajunct – no histic, not Terric
7-484 (2009)	(Endoaquoll)	mollic	coarse-loamy Fluvaquentic Endoaquoll	No established series
7-1000 (2009)	(Endoaquoll)	mollic	coarse-loamy Fluvaquentic Endoaquoll	No established series
7-1315 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	ochric	coarse-loamy Mollic Fluvaquent	No established series
7-1315 (2009)	(Fluvaquent)	ochric	coarse-loamy Typic Fluvaquent	No established series
7-1500 (2006)	(Fluvaquent)	ochric	coarse-loamy Typic Fluvaquent	No established series
7-1668 (2009)	(Fluvaquent)	ochric	coarse-loamy Typic Fluvaquent	No established series
7-1700 (2006)	(Fluvaquent)	ochric	coarse-loamy Typic Fluvaquent	No established series
7-1920 (2006)	**Anclote** (Sandy, Typic Endoaquoll)	mollic	Coarse-loamy Fluvaquentic Endoaquoll	No established series
7-2145 (2006)	**Pomona** (Sandy Ultic Alaquod)	albic, spodic, argillic	sandy Ultic Alaquods	Taxonomy fits **Pomona** series
9-10 (2006)	**Sparr** (loamy Grossarenic Paleudult)	ochric, argillic	loamy Grossarenic Paleudult	Taxonomy fits **Sparr** series
9-180 (2006)	**Jumper** (loamy Arenic Plinthaquic Paleudult)	ochric, argillic	loamy Arenic Plinthaquic Paleudult	Taxonomy fits **Jumper** series
9-325 (2006)	**Bluff** (fine-loamy, Typic Endoaquoll)	mollic	Thapto-Histic Endoaquoll	No established series
9-600 (2009)	**Bluff** (fine-loamy, Typic Endoaquoll)	mollic	fine-loamy Typic Endoaquoll	Taxonomy fits **Bluff** series
9-700 (2009)	Fluvaquentic Haplosaprist	mollic	Fluvaquentic Haplosaprist	Insufficient depth to determine series

Transect-Station (Year)	Initially Designated Series(Taxonomy)	RF Comments and Revisions		
		Diagnostic Horizons	Taxonomic Class	Soil Series
9-775 (2009)	**Terra Ceia** (Typic Haplosaprist)	mollic	Fluvaquentic Haplosaprist	**Terra Ceia** taxajunct - no histic; Fluvaquentic, not Typic
9-800 (2009)	Fluvaquentic Haplosaprist	mollic	Fluvaquentic Haplosaprist	Insufficient depth to determine series
9-825 (2009)	Fluvaquentic Haplosaprist	mollic	Fluvaquentic Haplosaprist	Insufficient depth to determine series
9-856 (2009)	Fluvaquentic Haplosaprist	mollic	Fluvaquentic Haplosaprist	Insufficient depth to determine series
9-858 (2009)	**Terra Ceia** (Typic Haplosaprist)	histic	Typic Haplosaprist	Taxonomy fits **Terra Ceia** series
9-884 (2009)	**Terra Ceia** (Typic Haplosaprist)	histic	Typic Haplosaprist	Taxonomy fits **Terra Ceia** series
9-1110 (2006)	**Terra Ceia** (Typic Haplosaprist)	histic	loamy Terric Haplosaprist	Taxonomy fits **Gator** series (silt layer atypical)
9-1210 (2006)	**Okeelanta** (sandy, Terric Haplosaprist)	histic	sandy, Terric Haplosaprist	Taxonomy fits **Okeelanta** series
9-1235 (2009)	**Okeelanta** (sandy, Terric Haplosaprist)	histic	sandy Terric Haplosaprist	Taxonomy fits **Okeelanta** series
9-1245 (2006)	**Anclote** (Sandy, Typic Endoaquoll)	mollic	sandy Fluvaquentic Endoaquoll	**Anclote** taxajunct – Fluvaquentic, not Typic
9-1275 (2006)	**Anclote** (Sandy, Typic Endoaquoll)	ochric	Typic Psammaquent	Taxonomy fits **Pompano** series
9-1365 (2006)	**Tavares** (Typic Quartzi-psamment)	ochric	Typic Quartzi-psamment	Taxonomy fits **Tavares** series

Figure 1. Silver River MFLs Transect Locations

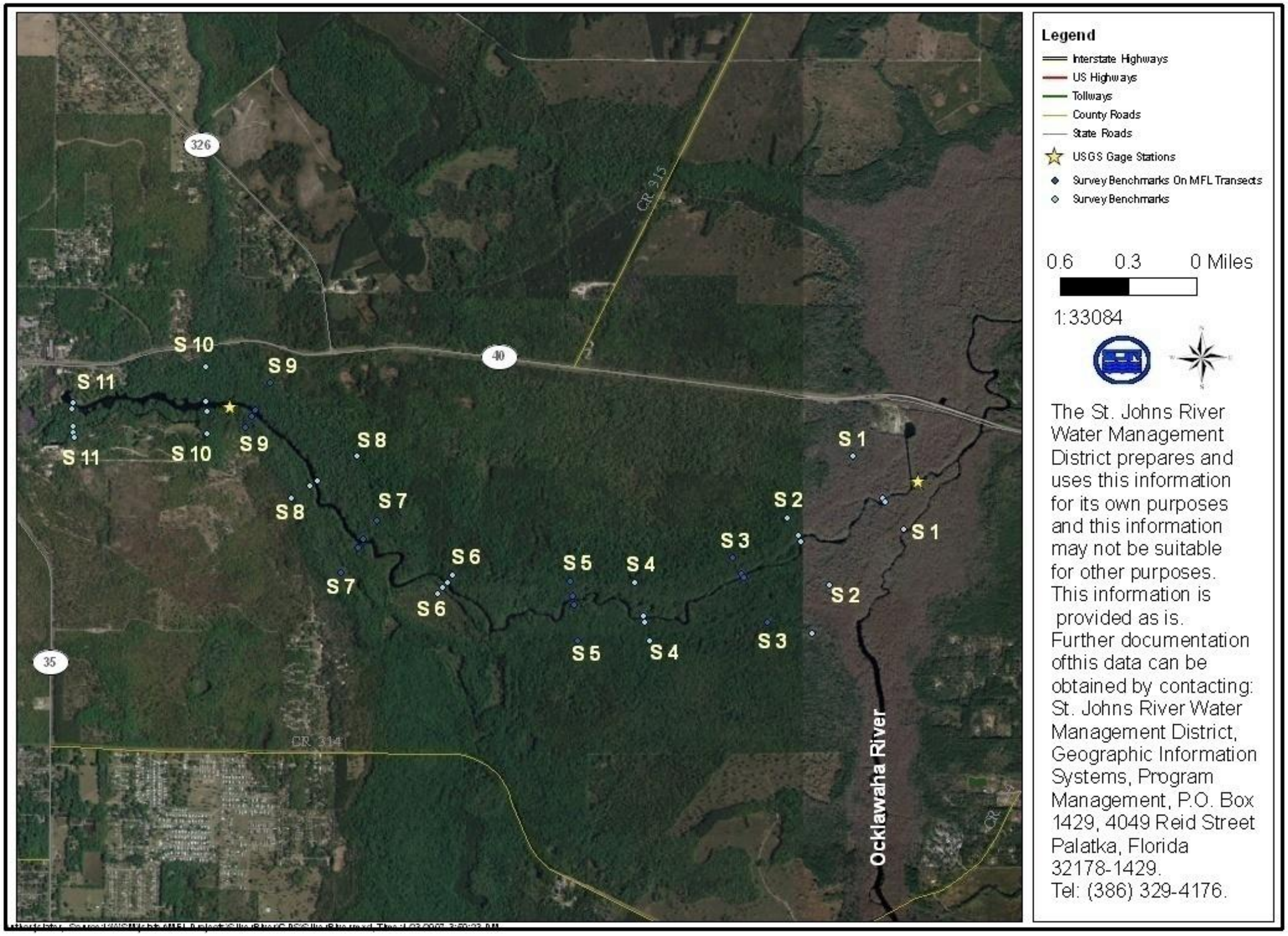


Figure 2. Transect 3: Estimated Distribution of Primary Hydric Soil Indicators.

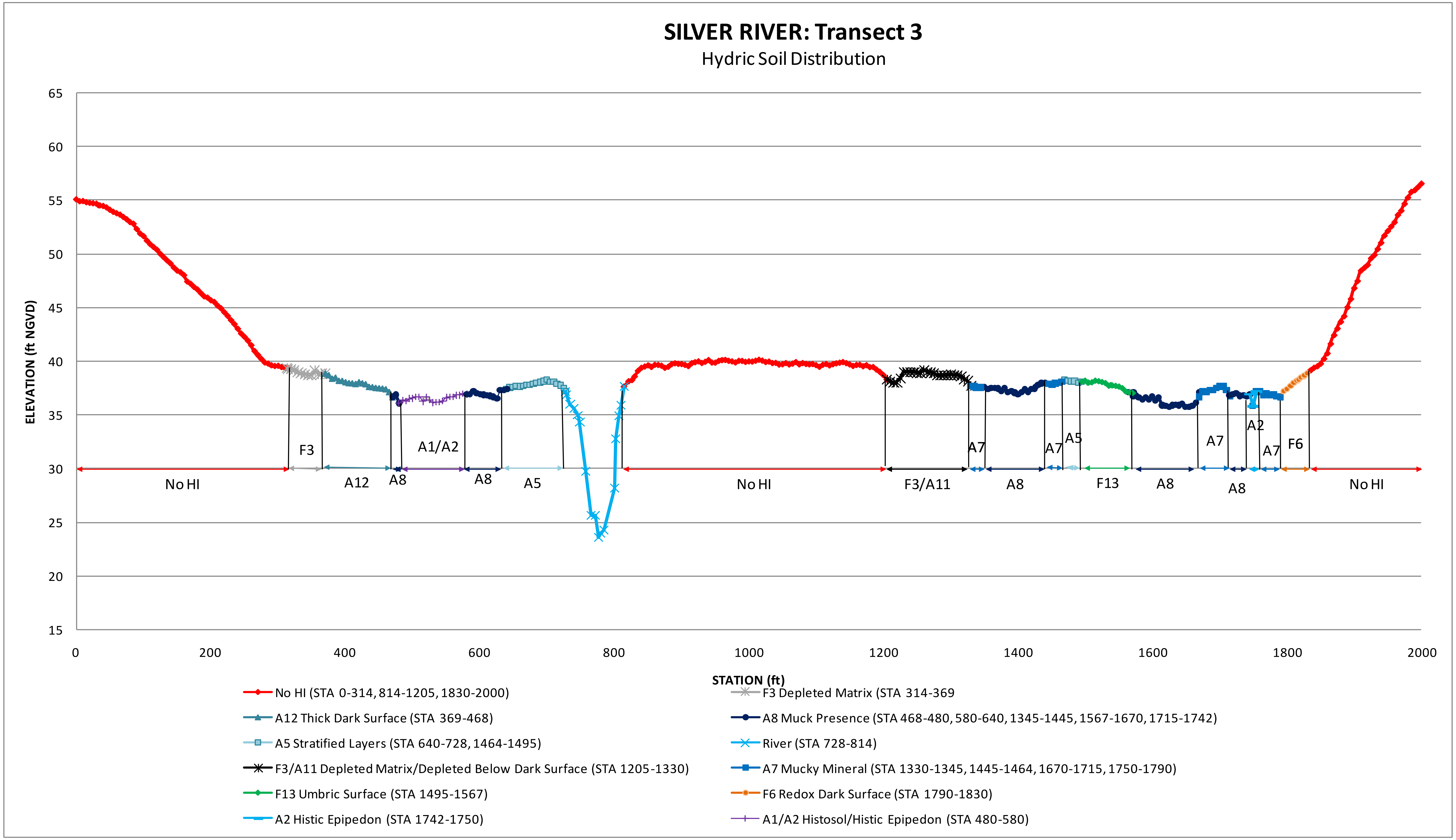


Figure 3. Transect 5: Estimated Distribution of Primary Hydric Soil Indicators.

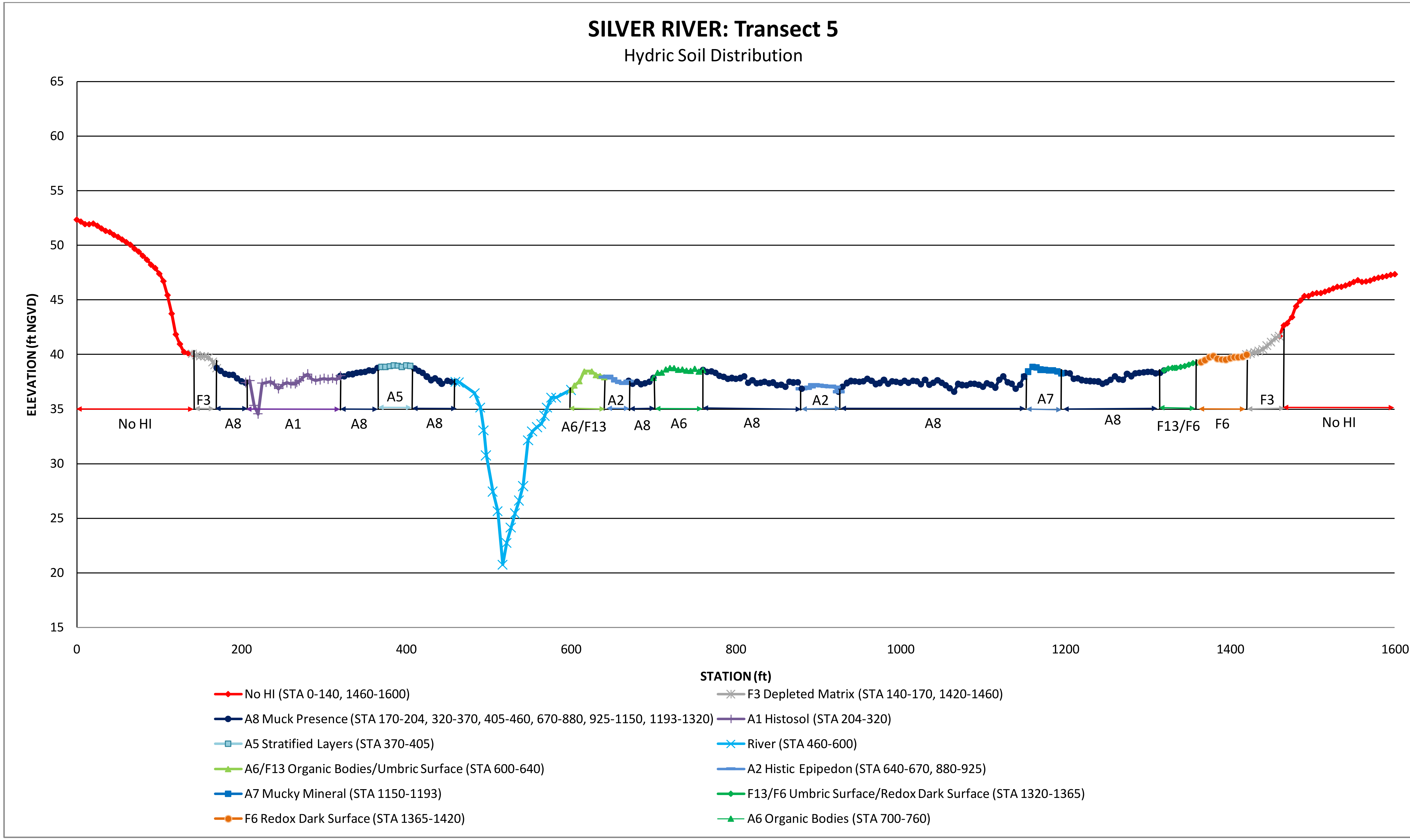


Figure 4. Transect 7: Estimated Distribution of Primary Hydric Soil Indicators.

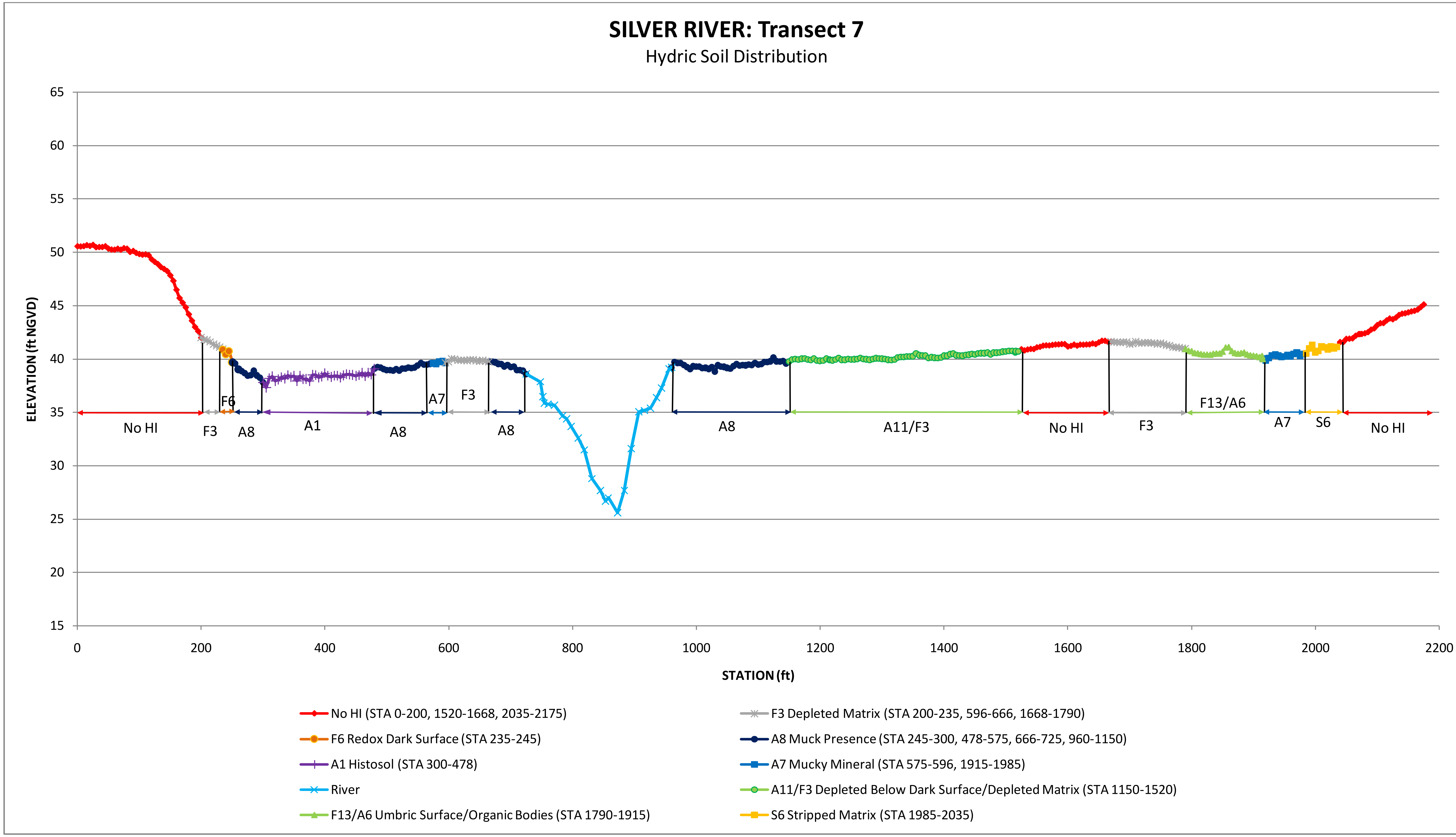
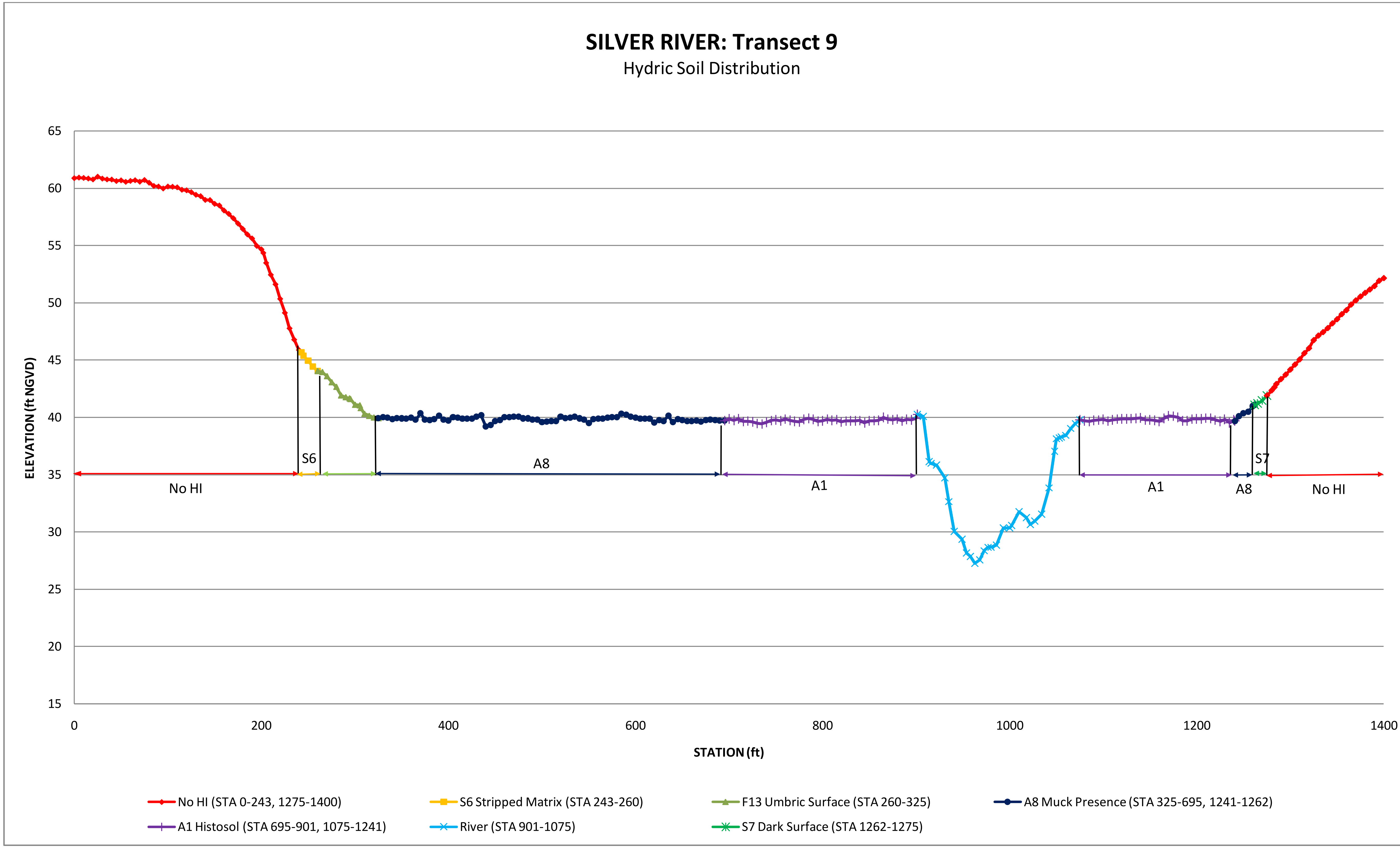


Figure 5. Transect 9: Estimated Distribution of Primary Hydric Soil Indicators.



Appendix 1. Soil Profile Descriptions from Silver River (2006)

Silver River 1446 Transect 3

0 Bluff

11/14/06; Series descr.; shoulder - S.aspect; Fine-loamy, Typic Endoaquoll

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A1	0	2	Sandy clay loam	10YR	3/1	
A2	2	7	Sandy clay	10YR	3/2	
A3	7	15	Sandy clay	10YR	3/2	Very strong, course angular blocky structure
Bk1	15	22	Sandy clay	10YR	4/3	
Bk2	22	30	Sandy clay	10YR	5/6	Few fine 5YR5/8 redox concentations
Bkg	30	36	Clay	10YR	6/2	Many N8/0 very course marl streaks and pockets
2Cg	36	56	Silty clay	N	8/	Predominently marl w/ limestone nodules and common, med to coarse, pockets of 10YR 5/2 mottles
2Cg	56	72	Clay	10YR	2/2	Few to common Fe/Mn concentrations (nodules), 10YR5/1 & N8/0 interlayers

33

11/14/06: HI Test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A	0	6	Sandy loam	10YR	2/1	
Bt1	6	12	Sandy clay	10YR	3/1	
Bt2	12	20	Sandy clay	10YR	3/2	Common fine redox concentrations 2.5YR5/8. 14" many redox concentrations 2.5YR5/8 with common solid black course FE/MN concentrations (10YR2/1)

130 Bluff

11/14/06; Series descr.; Fine-loamy Typic Endoaquoll w/buried horizons and marl features

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A	0	3	Sandy clay loam	10YR	2/1	
A2	3	12	Sandy clay	10YR	2/2	
B	12	26	Sandy clay	10YR	2/2	Many fine 5YR 4/6 RCs; few fine 10 YR 4/4 mottles; and few coarse 10YR 2/1 nodules
Bkg	26	38	Clay	10YR	6/2	Common coarse N 8/ marl steaks
Ab	38	46	Clay	10YR	3/2	Many, medium, N 8/ marl streaks, 2-10 mm thick
Bk	46	64	Clay	10YR	5/4	Many fine N 8/ marl streaks, 1-3 mm thick
Ckg	64	80	Clay	10YR	6/1	Many, very coarse, N 8/ marl masses, soft, plastic grading to many fine marl streaks

245 Bluff

11/14/06; Series descr.; Typic Endoaquoll (if mixed to 7") - carbonate and marl masks organics; backslope / toeslope - S. aspect

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A	0	3	Sandy clay	10YR	2/1	
A2	3	6	Sandy clay	10YR	4/1	
Bkg1	6	23	Sandy clay	10YR	4/2	Common, fine, marl masses and few fine to medium limestone nodules
Bkg2	23	44	Sandy clay	10YR	5/2	Many, fine parting to coarse N 8/ marl masses; Common, medium 10YR 4/4 RCs
Cg	44	72	Clay	N	8/0	Many, coarse, 10YR 5/1; 10 YR 5/6 clay streaks (interlayers); few fine 10YR 5/4 RCs grading to 5YR 5/6 RCs @ 60"; common, coarse 5YR 5/8 RC below 68"
Ckg	72	84	Clay	10YR	5/1	Varigated clay w/ 10YR 8/1 carbonatic nodules; common, fine 5YR 5/8 RCs (abrupt bound.); Cmn coarse 10YR 2/1 Mn/Fe conc.; few med 5BG6/1 mottles

Silver River 1446 Transect 3

Station / Horizon	From	To	Soil Series / Texture	Hue	Value-Chroma	Soil_Description - Truncated
310			**Bluff**			11/14/06; Series descr.; Typic Endoaquoll (if mixed to 7") - marl & carbonate masks organics; Toeslope location with south aspect;; Hydric starts 3' downstation
A	0	4	Sandy clay	10YR	2/1	
Bkg1	4	32	Sandy clay	10YR	4/1	Many, medium 10 YR 5/2 layer mottles; common 10YR 8/1 marl masses; few, fine 10YR 5/6 RCs in 4" - 5"; many coarse to very coarse 10YR 7/2 sand streaks
Bkg2	32	46	Clay	10YR	4/1	Many, coarse 10 YR 8/1 layered carb. / chalk masses; common, medium 10YR 5/8 RCs
Ckg	46	68	Clay	5GY	7/1	Variegated clay (no color predominates - as layers) 10YR 8/1 chalk; 10YR 3/2 FE/Mn conc,; 10 YR 5/6 RCs and 5GY 5.5/1 gleyed clay
314			**HI Description**			11/15/06; Hydric description to 20"; Landward extent of HSIs
HI	4	17				Redox dark surface (F6); **Landward extent of all HSIs
	0	4	Sandy clay loam	10YR	3/1	Many fine 10YR 8/1 carbonatic nodules and shell fragments
	4	17	Sandy clay	10YR	3/1	Many fine distinct 10YR4/4 RCs w/diffuse boundaries as ped coatings and in root channels
	17	20	Clay	N	4/0	Many fine faint N5/ mottles as streaks or layers; common carbonatic nodules
320			**HI Description**			11/15/06; Hydric descr. to 20"
HI	0	20	Sandy clay	N	3/	Redox dark surface (F6); same as #328 w/sand pocket 12-14"
	0	4	Sandy clay loam	10YR	3/1	Common, fine, carbonatic nodules and shell fragments
	4	12	Sandy clay	N	3/	Common, fine, faint 10YR 4/4 to 4/6 RCs as mottles and oxidized rhizospheres
	12	14	Sand (medium)	10YR	4/2	Sand layer
	14	20	Clay	N	4/	
328			**HI Description**			11/15/06; Hydric description to 20"
HI	2	14	Sandy clay	N	3/0	Redox dark surface (F6)
	0	2	Sandy clay loam	10YR	2/1	
	2	14	Sandy clay	N	3/0	Common fine distinct 10YR 4/4 RCs
	14	20	Clay	N	3.5/0	SAA w/ massive str.
346			**HI Description**			11/15/06; Hydric description to 20"
HI	3	20				Redox dark surface (F6)
	0	3	Sandy clay	N	2.5/0	Common, medium, distinct 10YR 4/4 to 4/6 and 5YR 3/4 RCs
	3	14	Sandy clay	N	3/0	Common, fine, distinct 10YR 4/4; many oxidized rhizospheres
	14	20	Sandy clay	N	3/0	SAA w/ few fine to medium prominent 5GY4/1 Redox depletions (RDs)
390			**Bluff**			11/15/06; Series descr.; Fine loamy, Typic Endoaquoll; Concave land form
HI	0	8				Redox dark surface (F6) - waterward extent; Thick dark surface (A12)
A1	0	5	Sandy clay loam	10YR	2/1	Common to many, fine to medium 10YR 4/4 RCs

Silver River 1446 Transect 3

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A2	5	20	Clay	10YR	2/1	Common to many, fine to medium 10YR 4/4 RCs to 8" depth
A3	20	30	Clay	10YR	3/1	massive structure; no RCs or mottling
Bg2	30	43	Clay	N	4/1	Many, medium, faint 10YR 4/2 mottles
Cg1	43	50	Clay	N	4/1	Common, med., distinct 10YR 5/4; common, med., distinct 5BG 4/1; Few, fine, sharp N 8/1
Cg2	50	80	Clay	N	4/1	Variegated clay (no color predominates): 10YR 5/6; 10YR 2/1 (Fe/Mn conc.); N 8/1 calcite crystals

415 **HI Description** 11/15/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						Thick Dark Surface (A12)

432 **HI Point Obs.** 11/15/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI			Muck (Sapric)			Muck presence (A8) - Landward extent

468 **HI Point Obs.** 11/15/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	5	Muck (Sapric)			Muck presence (A8) and Hydrogen sulfide (A4)

515 **HI Point Obs.** 11/15/06: HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	5	Muck (Sapric)			Muck presence (A8) and Hydrogen sulfide (A4) - Strong H2S

555 **HI Point Obs.** 11/15/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	6	Muck (Sapric)			Muck presence (A8)

586 **HI Point Obs.** 11/15/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	4	Muck (Sapric)			Muck presence (A8)

640 **Aquent** 11/15/06; Series description; Unknown Aquent

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	4				Muck presence (A8)
Oa	0	4	Muck (Sapric)	10YR	3/1.5	
A	4	7	Silty clay loam	10YR	2/1	
Cg	7	10	Silt loam	10YR	6/2	Many, medium carbonatic nodules and shell fragments; common 10YR 3/1 Mn/Fe conc. (pore linings and rhizospheres)
C1	10	40	Sandy loam	10YR	4/6	Sandy loam texture, shell fragments compose sand fraction (little or no silica)
C2	40	78	Loamy sand	10YR	6/3	same as above - 75%+ shell fragments in sand-size fraction
	78		Silt	10YR	5/2	Structureless, few sand grains

Silver River 1446 Transect 3

Station / Horizon	From	To	Soil Series / Texture	Hue	Value-Chroma	Soil_Description - Truncated
705			**HI Description**			11/15/06; Hydric descr. To 20"; Top of natural levee on N. side Silver River
						Hydrix - alluvial soil material
Oe	0	1	Mucky peat (He	10YR	3/2	
	1	3	Sandy clay loam	10YR	3/2	Many shell fragments
	3	14	Sandy clay loam	10YR	5/2	Interlayered beds of shell fragments; stratification consitent with levee landform
875			**Fluvaquent**			11/15/06; Series description; Unknown Fluvaquent - no HSIs - does not meet gleyed (F2) or depleted (F3) matrix - natural levee; silt / shell sediment layers - in Bluff mapping unit
A	0	6	Silt loam	10YR	3/2	FEW FINE SHELL FRAGMENTS
C	6	11	Silt loam	10YR	7/3	COMMON SHELL FRAGMENTS
Cg	11	14	Silt loam	10YR	4/2	MANY FINE SHELL FRAGMENTS
A'	14	19	Silt loam	10YR	3/2	MANY FINE SHELL FRAGMENTS
C'g	19	32	Sandy loam	10YR	4.5/2	Many, fine to medium, shell fragments
C'	32	80	Sandy loam	10YR	6/4	Many, fine, shell fragments
1270			**Fluvaquent**			11/15/06; Series description; Unknown Fluvaquent
HI	0	44				F3 (depleted matrix), A11 (depleted below dark surface), Stratified layers (A5)
A	0	3	Loam	10YR	3/1	
Cg	3	9	Sandy loam	10YR	6/2	Many fine to medium shell fragments
C	9	22	Loam	10YR	4/2	
C'g	22	42	Sandy loam	10YR	5/2	Many fine to very-fine shell fragments w/ beds or layers ~2" thick
Oa	42	44	Muck (Sapric)	10YR	2/1	Buried muck layer
2Cg	44	78	Sandy loam	10YR	6/2	silt depositions layers: 10YR 4/2, 5/2,. 6/2 grading to silt loam @ 80"
1330			**HI Description**			11/21/06; Hydric descr. to 20"
HI	0	5				Mucky mineral (A7)
	0	5	Mucky silty loam	10YR	2/2	Common fine shell fragments (10%)
	5	20	Silt loam	10YR	5/3	Many very coarse shell fragments (~70%)
1338			**HI Description**			11/21/06; Hydric descr. to 15"
HI	0	4				Mucky mineral (A7)
	0	4	Mucky silty loam	10YR	2/2	
	4	6	Silt loam	10YR	5/2	
	6	15	Silt loam	10YR	3/2	Many fine to medium shell fragments (50%)

Silver River 1446 Transect 3

Station / Horizon	From	To	Soil Series / Texture	Hue	Value-Chroma	Soil_Description - Truncated
1345			**HI Point Obs.**			11/21/06; HI test
HI						Muck presence (A8) over loamy mucky mineral (F1)
1350			**HI Point Obs**			11/21/06: HI test
HI			Muck (Sapric)			Muck presence (A8)
Oa	0	2	Muck (Sapric)	10YR	2/1	
	2	6	Mucky silty loam	10YR	3/1	
1374			**HI Point Obs.**			11/21/06; HI test
HI						Muck presence (A8) over Loamy mucky mineral (F1)
1385			**HI Description**			11/21/06; Hydric descr. to 20"
HI						Stratified layers (A5); Muck presence (A8)
Oa	0	4	Muck (Sapric)	10YR	2/1	Oa (~2") over Oe (~2") - also meets F1
A1	4	8	Silt	10YR	4/2	
A3	8	12	Clay	10YR	2/1	
C1	12	20	Silt loam	10YR	3/2	
1395			**HI Point Obs.**			11/21/06; HI test
HI						Muck presence (A8) over Loamy mucky mineral (F1); Stratified layers (A5);
1420			**HI Point Obs.**			11/21/06; HI test
HI	0	3				Muck presence (A8)
Oa	0	3	Muck (Sapric)	10YR	2/1	
	3	6	Mucky silty loam	10YR	3/1	
	4		Silt loam	10YR	4/2	
1445			**HI Point Obs.**			11/21/06; HI test *Landward extent muck (A8)
HI						Muck presence (A8) and Loamy mucky mineral (F1) **Landward extent (A8)
Oa	0	1	Muck (Sapric)	10YR	3/1	
	1	4	Mucky silty loam	10YR	3/1	
1464			**HI Description**			11/21/06; Hydric descr. to 15"
HI						Mucky mineral (A7), Stratified layers (A5)

Silver River 1446 Transect 3

Station / Horizon	From	To	Soil Series / Texture	Hue	Value-Chroma	Soil_Description - Truncated
	0	3	Silt loam	10YR	3/1	
	3	5	Mucky silty loam	10YR	2/1	
	5	8	Silt loam	10YR	5/2	Many fine to medium shell fragments (~80%)
	8	11	Silty clay loam	10YR	3/2	
	11	15	Silt loam	10YR	5/2	
1495			**Fluvaquent**			11/21/06; Series descr.; Unknown Fluvaquent
HI						Stratified layers (A5)
A1	0	4	Silt loam	10YR	3/2	Many fine shell fragments (~40%)
A2	4	6	Silty clay loam	10YR	2/1	Common fine-coarse shell fragments (~10%)
Cg1	6	12	Silt loam	10YR	3/2	Many fine to medium shell fragments (~25%)
Cg2	12	28	Silt	10YR	4/2	Many medium to coarse shell fragments (~40%)
Cg3	28	34	Silt loam	10YR	3/1	Common fine shell fragments (~20%)
Cg4	34	42	Loam	10YR	5/2	Many medium to fine shell fragments
Ab	42	48	Silt loam	10YR	2/2	
C'g1	48	70	Silt loam	10YR	5/2	Common medium to coarse shell fragments (~50%)
C'g2	70	80	Loam	10YR	4/2	Many fine shell fragments (~40%) as sand sized particles
1504			**HI Point Obs.**			11/21/06; HI test
HI						Muck presence (A8)
1510			**HI Point Obs.**			11/21/06; HI test
HI						Muck presence (A8) - muck 1.5" thick
1540			**HI Description**			11/21/06; Sampled 11/21/06; Hydric description to 6"
HI						Muck presence (A8)
Oa	0	1	Muck (Sapric)	10YR	2/1	Common fine to medium shell fragments
	1	3	Silt loam	10YR	3/2	Many fine to coarse shell fragments
	3	6	Silt loam	10YR	6/2	Many fine to coarse shell fragments
1550			**HI Point Obs.**			11/21/06; HI test
HI						Muck presence (A8)
1555			**HI Point Obs.**			11/21/06; HI test
HI	0	2	Muck (Sapric)	10YR	2/1	Muck presence (A8)

Silver River 1446 Transect 3

Station			Soil Series			
Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
1695			**HI Point Obs.**			11/21/06; HI test
HI						Muck presence (A8)
	0	4	Muck (Sapric)	10YR	3/1	
1715			**HI Point Obs.**			11/21/06; HI test
HI						Muck presence (A8)
1722			**HI Description**			11/21/06;Hydric descr. to 9"
HI						Muck presence (A8
	0	3	Muck (Sapric)	10YR	3/1	
	3	5	Silty clay loam	10YR	2/1	
	5	9	Silt loam	10YR	5/2	
1742			**HI Point Obs.**			11/21/06; HI test
HI						Histic epipedon (A2)
1750			**HI Point Obs.**			11/21/06 - HI test
HI						Histic epipedon (A2)
	0	10	Muck (Sapric)	10YR	2/1	
	10	13	Silty clay loam	10YR	2/1	
	13		Silt loam	10YR	6/4	
1770			**HI Description**			11/21/06; Hydric description to 10"
HI						Muck presence (A8)
	0	6	Muck (Sapric)	10YR	2/1	
	6	10	Silty clay	10YR	2/1	
1790			**HI Description**			11/21/06; Hydric indicator description to 11"
HI						Muck presence (A8)
	0	4	Muck (Sapric)	10YR	2/1	
	4	11	Silty clay	10YR	2/1	
1805			**HI Point Obs.**			11/21/06 - HI Test
HI						Muck presence (A8) **landward extent

Silver River 1446 Transect 3

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
1817			**Bluff**			11/21/06; Series descr; Fine-loamy, Typic Endoaquoll; Toe slope - N. aspect;
HI	0	20	Silty clay	10YR	2/1	Redox dark surface (F6)
A1	0	6	Silty clay	10YR	2/1	
A2	6	9	Silty clay	10YR	2/1	Few, fine, distinct 10YR 4/4 RCs
A3	9	12	Silty clay loam	10YR	2/1	Common, medium, distinct 10YR 4/4 RCs
A4	12	20	Silty clay	10YR	2/1	Common medium layers fine sandy loam 1-2 cm thick
A5	20	30	Silty clay	N	3/0	
Bk1	30	50	Silty clay	N	3/0	Many coarse distinct to prominent N 4/, 5/, and 8/ marl steaks/mottles; Common, coarse, charcoal bodies
Bkg1	50	64	Silty clay	N	6/0	Many medium prominent N 4/0, 3/0 mottles
Bkg2	64	80	Clay	N	7/0	Variegated clay (no predominant color): N 5/; 10YR 8/2; 10YR 3/1; and many medium to coarse carbonatic masses as interlayers
1830			**HI Point Obs.**			11/21/06; HI test
HI						Redox dark surface (F6) * Landward extent
	0	6		10YR	3/1	Many fine to medium 2.5YR4/6 RCs
1885			**Bluff**			11/21/06; Series description; Fine-loamy, Typic Endoaquoll; backslope location, N aspect
A1	0	12	Sandy clay loam	10YR	2/1	Common fine to medium shell fragments
A2	12	24	Silty clay	10YR	4/4	Many fine to coarse shell fragments (~30%); 10YR 2/1 mottles
Bkg1	24	40	Sandy clay loam	10YR	6/2	Few coarse prominent 10YR 2/1 and 4/4 mottles and many fine to medium shell fragments (~50%)
Bkg2	40	58	Sandy clay loam	10YR	7/2	Many fine to coarse N 8/ marl nodules and common fine to coarse 10YR 6/2 mottles and 5/6 RCs; ~50% shell fragments
Ckg	58	80	Sandy clay	10YR	5/2	Variegated clay: N8/ 10YR 5/2, 4/2, and 5/6 w/ few coarse marl/carbonatic nodules
1950			**Bluff**			11/21/06; Epipedon description; Top of primary terrace; likely Typic Endoaquoll; Limnic layer
A1	0	4	Sandy clay loam	10YR	2/1	
A2	4	12	Sandy clay loam	10YR	3/1	Many common faint 10YR 3/2 mottles as ped coatings
Bkg	12	20	Silty clay loam	10YR	5/2	Many coarse 10YR 3/2 mottles
Cg	20		Silty clay	N	8/	Predominantly marl

Silver River 1446 Transect 5

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
40			**Bluff**			11/22/06; Series descr.; Typic Endoaquoll with limnic feature; shoulder position; S. aspect
A1	0	1	Sandy clay	10YR	2/1	
A2	1	7	Sandy clay	10YR	2/2	no mottles
B	7	32	Clay	10YR	4/4	Many, fine, distinct 5YR 4/6 mottles; Common, coarse, prominent Fe/Mn concentrations on ped faces
Lma	32	72	Silty clay	N	8/0	Marl layer w/ many fine 10YR 6/2. 10YR 5/3 layers and few, fine 10YR 4/6 layers; soft, plastic, chalky

Silver River 1446 Transect 5

Station / Horizon	From	To	Soil Series / Texture	Hue	Value-Chroma	Soil_Description - Truncated
C1	72	74	Fine sand	10YR	5/3	single grain, loose
C2	74	80	Silty clay	2.5YR	4/6	Variegated clay - no color predominates:2.5YR 4/6; N 8/; 10YR 5/2; 10YR 4/2
140			**Bluff**			11/22/06; Series descr.; Typic Endoaquoll; Backslope location, S. aspect; significant drop in elevation from last station
HI						F6 (redox dark surface)
A1	0	2	Sandy clay loam	10YR	2/1	
A2	2	7	Sandy clay loam	10YR	3/2	no redox, friable
AB	7	12	Sandy clay loam	10YR	3/1	Common, fine 10YR 4/6 and 5/6 RCs; and 10YR 6/3 mottles
Bkg1	12	20	Clay	10YR	4/1	Many, coarse 1YR 8/1 marl masses and layers; many, fine 10YR 5/6 RCs as pore linings; common, coarse 5B7/1 gley mottles
C1	20	40	Clay	N	6/0	Variegated clay, no color predominates N 6/, N8/, 5B7/1; few, fine 10YR 5/6 RCs - massive str.
C2	40	80	Clay	N	6/0	Many coarse N8/ marl masses/streaks common, coarse 5B6/1 gley mottles; firm, very sticky
150			**HI Point Obs.**			11/22/06; HI test
HI						Redox dark surface (F6)
	0	15	Sandy clay	10YR	3/1	Many, fine to medium, 10YR 4/6 RCs as pore linings; few fine shell fragments
160			**HI Point Obs.**			11/22/06: HI Test
HI						Redox Dark Surface (F6); same as Station 150
170			**HI Description**			11/22/06; HI descr.to 12"
HI	0	12				Muck presence (A8), Redox dark surface (F6)
A1	0	2	Silty clay	10YR	2/1	Muck layer at surface
A2	2	12	Silty clay	N	2.5/0	Common, distinct 5YR 4/4 RCs; layer of washed sand at 2" depth
175			**HI Point Obs.**			11/22/06; HI test
HI						Muck presence (A8); few faint RCs as rhizopheres
180			**HI Point Obs.**			11/22/06; HI test
HI	0	4	Muck (Sapric)	10YR	2/1	Muck presence (A8); no redox
345			**HI Description**			11/22/06; HI descr to 20"
HI	0	4	Muck (Sapric)	10YR	3/1	Muck presence (A8)
Oa	0	4	Muck (Sapric)	10YR	3/1	Few fine shell fragments
A1	4	7	Silty clay	N	2.5/	Many fine to coarse shell fragments
C1	7	9	Silt loam	10YR	6/1	

Silver River 1446 Transect 5

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
Station			**Soil Series**			
C2	9	12	Silt	10YR	4/1	Many fine to medium shell fragments
C3	12	18	Silt loam	10YR	7/3	Many fine to coarse shell fragments; layer comprised mainly of finely crushed shell
C4	18	20	Silt loam	10YR	6/2	Inner layers of coarse shell deposits
360			**HI Description**			11/22/06; HI descr. To 15"
HI						Stratified layers (A5); muck presence (A8)
Oa	0	1	Muck (Sapric)	10YR	2/1	
A1	1	4	Silt loam	10YR	3/1	
A2	4	6	Silty clay loam	N	2.5/0	
C1	6	12	Silt	10YR	4/2	Many fine to medium shell fragments (throughout profile)
C2	12	15	Silt loam	10YR	3/2	
370			**HI Point Obs.**			11/22/06; HI test
HI						Muck presence (A8) - end
405			**HI Point Obs.**			11/22/06; HI test
HI						Restart muck presence (A8)
410			**HI Point Obs.**			11/22/06; HI test
HI						Muck presence (A8); Areas of recurring histic epipedon (A2) along transect area (Stations 400-420)
640			**HI Description**			11/22/06; HI descrip. To 20"
HI						Histic epipedon (A2)
Oa	0	12	Muck (Sapric)	N	2.5/	
A1	12	20	Loam	10YR	3/3	Many fine shell fragments; sand component predominately shell fragments
670			**HI Point Obs.**			11/22/06; HI test
HI	0	8	Muck (Sapric)	10YR	2/1	Histic epipedon (A2)
680			**HI Point Obs.**			11/22/06; HI test
HI	0	5	Muck (Sapric)			Muck presence (A8); 20% shell fragment
695			**HI Description**			11/22/06; HI descr. To 20"
HI						Muck presence (A8)
Oa	0	3	Muck (Sapric)	10YR	2/1	

Silver River 1446 Transect 5

Station / Horizon	From	To	Soil Series / Texture	Hue	Value-Chroma	Soil_Description - Truncated
A1	3	6	Silty clay	N	2.5/	
C1	6	13	Silt	10YR	4/2	Many fine to coarse shell fragments as sand component
C2	13	20	Silt loam	10YR	7/3	
765			**Fluvaquent**			11/22/06; Series descr.; - alluvial sediment layers with buried O horizon
HI	0	1	Muck (Sapric)	10YR	2/1	Muck presence (A8)
Oa	0	1	Muck (Sapric)	10YR	2/1	
Cg1	1	3	Fine sandy loam	10YR	2/1	Many, fine to medium shell fragments
Cg2	3	6	Silt loam	10YR	4/2	~ 30% shell fragments
Cg3	6	13	Silt loam	10YR	3/2	SAA
C	13	32	Fine sandy loam	10YR	4/3	50% fine to medium shell fragments
O'e	32	46	Mucky peat (He	N	2.5/0	Hemic materials present
Cg'1	46	66	Silt loam	10YR	4/2	Many fine to medium shell fragments
Cg'2	66	80	Fine sandy loam	10YR	8/1	Sand component - composed wholly of shell fragments; little/no silica
800			**HI Point Obs.**			11/55/06; HI test
HI						Hydrogen sulfide (A4) odor; Stations 800-1145
960			**HI Description**			11/22/06; HI descrip 16"
HI						Muck presence (A8), Hydrogen sulfide odor (A4)
	0	3	Muck (Sapric)	10YR	2/1	
	3	8	Silty clay	N	2.5/	
	8	16	Silt loam	10YR	4/3	Fine to medium shell fragments (~50%)
1120			**HI Description**			11/22/06; HI description to 20"
HI						Muck presence (A8), Hydrogen sulfide odor (A4), 5 cm Mucky Mineral (A7)
Oa	0	6	Muck (Sapric)	10YR	2/1	Muck w/ shell fragments grading from 20% (top) to 50% (bottom)
	6	20	Sand (medium)	10YR	4/2	90 % fine to medium shell fragments as sand component
1145			**HI Point Obs.**			11/22/06; HI test
HI						Hydrogen sulfide odor (A4) - end
1170			**HI Description**			11/22/06; HI description to 20"
HI						Muck presence (A8)
	0	1	Muck (Sapric)	10YR	2/1	Many fine to medium shell fragments
	1	7	Sandy loam	10YR	4/1	80% fine to coarse shell fragments as sand component

Silver River 1446 Transect 5

Station / Horizon	From	To	Soil Series / Texture	Hue	Value-Chroma	Soil_Description - Truncated
	7	20	Sand (medium)	10YR	7/4	90% pulverized shell fragmetns as sand component, loose granular structure
1295			**HI Description**			11/22/06; HI description to 12"; Clear obs. Silica (vs. SFs)
HI						Muck presence (A8)
	0	2	Muck (Sapric)	10YR	2/1	
	2	4	Sandy clay loam	10YR	2/1	Common, uncoated grains (skeletans)
	4	7	Clay	N	2.5/	
	7	12	Fine sandy loam	10YR	4/1	Few medium 10YR 6/1 RDs; few uncoated grains (sk) - silica presnt
1310			**Bluff**			11/28/06: Series descr.; Fine-loamy, Typic Endoaquoll
HI			Muck (Sapric)			Muck presence (A8), Thick Dark Surface (A12)
Oa	0	1	Muck (Sapric)	10YR	2/1	
A	1	16	Clay loam	10YR	2/1	
Bg	16	42	Sandy clay	N	2.5/0	Common fine to medium 2.5YR 4/3 ox. rhizospheres; few interlayers 5-10 mm thick of uncoated sand grains
Cg	42	80	Clay	10YR	5B 5/1	Variegated clay - no color predominates; 5B 5/1; N8/0; 10YR6/3; 5GY7/1; 10YR2/1 (top of Hawthorn fomration)
1315			**HI Point Obs.**			11/22/06; HI test
HI						Muck presence (A8); few RCs
1330			**HI Description**			11/22/06; HI description to 15"
HI						Umbric surface (F13) and Redox dark surface (F6)
	0	2	Sandy clay loam	10YR	2/1	Common medium pockets of uncoated grains
	2	6	Sandy clay loam	10YR	3/1	Many fine distinct 10YR 4/6 RCs as pore linings and grain coatings
	6	15	Sandy clay	N	3/	
1345			**HI Point Obs.**			11/22/06; HI test
HI						Umbric surface (F13), Redox dark surface (F6)
	3	10				Common, medium, distinct 10YR 4/6 RCs as pore linings and grain coatings
1355			**HI Description**			11/28/06; Hydric description to 15"
HI						Umbric surface (F13), Redox dark surface (F6)
	0	2	Sandy loam	10YR	2/1	
	2	6	Sandy clay loam	10YR	3/1	Common distinct 10YR 4/4 RCs w/ diffuse margins and few medium distinct 10YR 5/1 RDs
	6	15	Sandy clay loam	10YR	3/1	many distinct, prominent, 10YR 4/6 RCs; few, medium 10YR 6/1 RDs

Silver River 1446 Transect 5

Station / Horizon	From	To	Soil Series / Texture	Hue	Value-Chroma	Soil_Description - Truncated
1390			**HI Description**			11/28/06; hydric description to 14"
HI						Redox dark surface (F6)
	0	2	Sandy clay loam	10YR	2/1	
	2	4	Sandy clay loam	10YR	2/2	Common fine to medium faint 10YR 4/3 RCs
	4	14	Sandy clay loam	10YR	3/2	Common fine distinct 10YR 4/4 RCs w/ clear to diffuse boundaries
1415			**HI Point Obs.**			11/28/06; HI test
HI						Redox dark surface (F6)
	0	12				Many fine to coarse distinct 10YR 5/3 to 5/6 RCs as pore linings and oxid. Rhizospheres
1420			**HI Point Obs.**			11/28/06; HI test
HI						Redox dark surface (F6), Depleted matrix (F3) start
1430			**Bluff**			11/28/06; Toeslope position, north aspect; 19"; Bluff variant - eroded
HI						Depleted matrix (F3)
A1	0	1	Sandy loam	10YR	2/1	
A2	1	5	Sandy clay loam	10YR	2/1	Common, fine to medium marl pockets/masses
Bkg1	5	17	Sandy clay loam	10YR	4/2	Many, medium, clear 10YR 4/4 RCs w/ clear boundaries; few, fine to coarse marl masses
Bkg2	17	19	Clay	10YR	4/1	Many medium 10YR 4/3 mottles; many, fine to medium marl masses; few, medium charcoal masses
Ckg	19	80	Clay	5B	5/1	Variegated clay, no color really predominates - SAA w/ many marl layers
1450			**HI Description**			11/28/06; HI test
HI						Depleted matrix (F3)
	0	1	Mucky peat (He			Duff layer
	1	4	Sandy clay loam	10YR	3/1	Common, medium prominent 2.5YR 2.5/3 mottles and rhizospheres
	4	12	Clay	10YR	4/1	Many medium to coarse prominent 2.5 YR 4/6 RCs as oxidized rhizospheres
1460			**HI Point Obs.**			11/28/06: HI test
HI						Depleted matrix (F3) end - Landward extent of HSIs
1555			**Bluff**			11/28/06; Series descr.;Fine-loamy, Typic Endoaquoll; Shoulder position, north aspect
A1	0	2	Sandy clay loam	10YR	3/1	Many uncoated grains
A2	2	10	Clay	10YR	3/1	Plastic, very sticky clay
Bkg1	10	52	Clay	10YR	4/1	Many fine, distinct 7.5YR 4/4 RCs w/ clear boundaries; Many, fine to medium marl masses and carbonate nodules; Common fine 10YR 2/1 Fe/Mn masses

Silver River 1446 Transect 5

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
C1	52	64	Clay	N	5/0	Variegated clay - no color predominates (N5/0; 10YR4/6; 10YR8/1; N8/0) ; platy interlayers of soft marl
C2	64	80	Clay	N	5/0	same as above + Fe/Mn masses and ped faces

Silver River 1446 Transect 7

20 **Bluff** 11/28/06; Series descr.;Typic Endoaquoll; Summit/shoulder location

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A1	0	4	Sandy loam	10YR	2/1	
A2	4	14	Sandy clay	N	3/	N4/0 to 10YR3/1
Bg	14	24	Clay	10YR	4/1	Many, medium, prominent 5YR 5/6 Fe accumulations (RCs)
C	24	44	Clay	10YR	4/2	Variegated clay - no color predominates: 10YR 4/2; N2.5/; 10YR5/1, 4/1, 3/1; 7.5YR 5/6
C1kg	44	70	Clay	10YR	5/1	SAA: except more gleying, less Fe accum., N8/ marl pockets and streaks
C2k	70	80	Clay	10YR	5/3	>50% N8/ by volume marl pockets/layers

135 **Bluff** 11/29/06; Series descr.; Fine-loamy, Typic Endoaquoll; Shoulder location - south aspect

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A1	0	3	Fine sandy loam	N	2.5/1	Loose granular structure; many uncoated grains
A2	3	5	Sandy clay	10YR	2.5/1	common uncoated grains
A3	5	9	Sandy clay	10YR	2/1	
Bg	9	24	Clay	10YR	4/1	Many coarse 2.5Y 5/4 mottles (Fe accum.); Many 10YR 3/1, 2/1 Fe/Mn accum in ped faces (prominent ped coats ~90%)
Bkg	24	68	Silty clay	10YR	7/1	Many (~50%) N8/ marl streaks (5-10mm); common 2.5Y5/4 streak mottles

195 **HI Point Obs.** 11/29/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
	0	6		10YR	2/1	dark layer with much characteristics (does not meet A8)

200 **HI Point Obs.** 11/29/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						Depleted matrix (F3) - landward extent
	7	14		10YR	6/1	Depleted matrix (F3) w/common distinct 10YR 4/4 RCs

215 **HI Point Obs.** 11/26/06; HI test, landward extent of depleted matrix

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						Depleted matrix (F3)

230 **HI Description** 11/26/06; hydric descrip to 14"

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						Depleted matrix (F3)
	0	5	Silty clay	10YR	5/1	Common, faint, fine RCs
	5	8	Silty clay	10YR	3/1	Common, medium, distinct 10YR 4/4 RC's
	8	14	Silty clay	10YR	5/1	Many fine 10YR 4/4 RC's, grading to few

Silver River 1446 Transect 7

Station / Horizon	From	To	Soil Series / Texture	Hue	Value-Chroma	Soil_Description - Truncated
235			**Bluff**			11/29/06; Series descr.; Toe slope location - south aspect; Bluff variant - eroded
HI						Depleted matrix (F3) and Redox dark surface (F6)
A1	0	4	Clay loam	10YR	4/1	Many medium distinct 10YR4/6 RCs
A2	4	9	Silty clay	10YR	3/1	Many coarse 10YR4/1 mottles; Common medium distinct 10YR 4/4 RCs diffuse boundaries
Bk1	9	15	Silty clay	10YR	6/1	Many 10YR 4/4 RCs as pore surfaces and rhizospheres; Many coarse 10YR 3.5/1 mottles; many coarse 10YR 8/1 marl masses and streaks
Bk2	15	32	Silty clay	10YR	4/1	Many medium to coarse marl/carbonate masses and shell fragments (interlayed); few medium 5BG7/1 mottles
Lma	32	54	Silty clay	N	8/0	Variegated clay, dominated by marl - 10YR 5/4; 5G7/1; N5/ few, fine 10YR5/6 mottles
C	54	66	Clay	10YR	6/2	Variegated clay - no color predominates: 10YR6/2; N8/ ; 5G6/1; 5BG6/1
240			**HI Description**			11/26/06; hydric descr. to12"
HI				10YR		Redox dark surface (F6)
	0	6	Clay loam	10YR	3/2	Many medium prominent 2.5 YR 4/6 RCs, 20% fine to medium shell fragments
	6	10	Clay	10YR	2/1	
	10	12	Clay loam	10YR	3/2	
245			**HI Description**			11/28/06; Hydric descr.
HI						Muck presence (A8) - end; Redox dark surface (F6)
Oa	0	0.5	Muck (Sapric)	10YR	2/1	
	0.5	12	Silt loam	10YR	2/1	Many medium to coarse distinct 2.5 YR 4/6 RCs as pore linings in rhizospheres, 10% shell fragments
1100			**HI Description**			11/29/06; HI descr 20"
HI						Muck presence (A8)
Oa	0	6	Muck (Sapric)	10YR	3/1	30% medium shell fragments
	6	20	Silt loam	10YR	5/3	50% fine to coarse shell fragments
1200			**HI Description**			11/29/06; HI descrip to 20"
HI						Muck presence (A8)
Oa	0	1	Muck (Sapric)	10YR	3/1	
	1	3	Silty clay loam	10YR	2/1	
	3	5	Silty clay loam	N	2.5/	
	5	8	Loamy fine sand	10YR	6/2	
	8	11	Loamy fine sand	10YR	5/1	
	11	20	Loamy sand	10YR	6/1	Sand component predominantly shell fragments for all layers

Silver River 1446 Transect 7

Station / Horizon	From	To	Soil Series / Texture	Hue	Value-Chroma	Soil_Description - Truncated
1217			**HI Point Obs.**			11/29/06; HI test
HI						Muck presence (A8) - end of muck (discontinuous on transect)
1248			**HI Point Obs.**			11/29/06; HI test
HI						Muck presence (A8); same as Station 1200 except stratified layers as depths 0-1, 1-4, 4-7, 7-15+)
1255			**Hi Point Obs.**			11/29/06: HI test
						no muck
1315			**Bluff**			11/29/06; Series descr.; Fine-loamy, Typic Endoaquoll; over alluvium
HI			Muck (Sapric)			Muck presence (A8)
Oa	0	2	Muck (Sapric)	10YR	3/1	with common fine shell fragments
A1	2	5	Silt loam	10YR	3/1	Many fine to medium shell fragments (~35%)
A2	5	8	Clay	N	2.5/0	Soft moderately plastic few fine shell fragments
C1	8	10	Fine sandy loam	10YR	6/1	Many fine to coarse shell fragments (~50%); sand size particles all shell fragments
C2	10	13	Fine sandy loam	10YR	4/1	Same as above
C3	13	29	Sandy loam	10YR	6/2	Many fine to coarse shell fragments; grading to 10YR 4/2
C4	29	33	Fine sand	10YR	6/2	Fine granular structure (silica)
Oa	33	35	Muck (Sapric)	N	2.5/1	
2Cg	35	39	Silt	N	4/	Many medium shell fragments
O'a	39	44	Muck (Sapric)	N	2.5/0	Few very fine shell fragments
3C	44	45	Sand (medium)	10YR	4/1	Loose platy; sand particles consist of all crushed shell
Cg	45	80	Sandy loam	N	8/	Marl, massive structure
1435			**HI Point Obs.**			12/08/06; HI test
HI						Muck presence (A8) - recorded as mucky mineral but fragmental
1490			**HI Point Obs.**			12/08/06; HI test
HI						Mucky mineral (A7) and stratified layers (A5) - silica presence
1500			**Fluvaquent**			11/29/06; Series description; at back swamp/wet (Andropogon) prairie interface
HI	0	4	Muck (Sapric)	10YR	3/1	Muck presence (A8)
Oa	0	4	Muck (Sapric)	10YR	3/1	Few, fine shell fagments
C1	4	10	Sandy loam	10YR	4/1	Many fine to coarse shell fragments (~60%)

Silver River 1446 Transect 7

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
C2	10	34	Silt loam	10YR	5/2	Grading to 10YR 6/2; Many coarse shell fragments - grading to common, fine shell fragments (top to bottom)
O'a	34	38	Muck (Sapric)	N	2.5/	
2Ck	38	41	Silt	10YR	3/1	Predominantly crushed, medium shell fragments
2Cr	41	43	Coarse Sand	10YR	8/1	Lithified shell fragments (limerock), very rigid consitence, massive structure
3C	43	50	Fine sand	10YR	6/3	Saturated, granular structure (silica)
3C2	50	80	Fine sandy loam	10YR	7/4	Grading to N8/ at 80", saturated massive
Cg	80	84		10YR	8/	

1515 — HI Point Obs.

12/08/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	7				Mucky mineral (A7) to 7"

1530 — HI Point Obs.

12/08/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						Mucky mineral (A7) - end

1555 — HI Point Obs.

12/08/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
	0	3	Fine sand	10YR	2/1	Does not meet mucky mineral (A7); many fine shell fragments
	3	6	Silt loam	10YR	4/1	Many fine to medium shell fragments, thin organic coatings
	6	12	Silt loam	10YR	4/2	Approximately 50% shell fragments; thin coatings on all grains

1600 — HI Point Obs.

12/08/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						Organic bodies (A6) - in root mat (1 to 5" deep); Andropogon spp.

1670 — HI Point Obs.

12/08/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						Organic bodies (A6)

1700 — Fluvaquent

12/8/06; Series descr.:alluvial sediment layers with shells

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	4	Mucky loam	10YR	2/1	Mucky mineral (A7) and Organic bodies (A6)
A1	0	4	Mucky loam	10YR	2/1	Many fine shell fragments
A2	4	9	Sandy loam	10YR	4/1	Many fine to medium shell fragments
A3	9	36	Fine sandy loam	10YR	6/2	Many fine to coarse shell fragments, grading finer w/ depth
Cg	36	50	Clay loam	10YR	3/2	Massive; many fine shell fragments; common, coarse charcoal nodules
R	50	55		10YR	7/4	Resistance - limerock

1740 — HI Point Obs.

12/08/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						Organic bodies (A6)

Silver River 1446 Transect 7

Station / Horizon	From	To	Soil Series / Texture	Hue	Value-Chroma	Soil_Description - Truncated
1800			**HI Description**			12/08/06; HI descr to 18"
HI						Organic bodies (A6); stratified layers (A5); Umbric surface (F13)
	0	6	Sandy loam	10YR	2/1	Many fine shell fragments (20%); few uncoated sand grains; silica present
	6	9	Loam	10YR	4/1	Many fine to very coarse shell fragments
	9	10	Mucky loam	10YR	3/2	Common fine to medium shell fragments
	10	18	Clay loam	10YR	4/1	Many fine to coarse shell fragments (>50%); few fine to medium 10YR 4/4 RCs; marl streaks
1830			**HI Description**			12/08/06; HI descr to 12"; silica predominates over shell fragments; now using sandy indicators
HI						Umbric surface (F13), organic bodies (A6)
	0	6	Sandy loam	10YR	2/1	Common fine shell fragments
	6	9	Sandy loam	10YR	4/1	
	9	10	Sandy clay loam	10YR	2/1	
	10	12	Sandy loam	10YR	4/1	
1875			**HI Point Obs.**			12/08/06; HI test
HI	0	6	Fine sandy loam	10YR	2/1	Umbric surface (F13)
	6	20	Limestone	10YR		Resistance - probable sink area
1900			**HI Point Obs.**			12/08/06; HI test
HI						Umbric surface (F13)
1920			**Anclote**			12/8/06; Series description; Sandy Typic Endoaquoll; w/thicklayer of crushed shell.
A1	0	2	Sandy loam	10YR	2/1	Many uncoated grains (20%)
A2	2	12	Fine sandy loam	5YR	2.5/1	Many uncoated grains (~40%)
C1	12	45	Sandy loam	10YR	7/3	90% crushed shells (very fine); few, medium carbonatic concretions
C2	45	48	Sandy loam	2.5YR	7/4	Variegated sand; no color predominates: 2.5Y7/4; N5/; 10YR7/3; 5G6/1; saturated structureless
Cg1	48	69	Loamy sand	5G	5/1	Grading to 5BG7/1; grading to finer texture
Cg2	69	80	Loamy fine sand	5BG	7/1	Saturated, flowable
1940			**HI Description**			12/08/06; HI descr to 18"
	0	2	Sandy loam	10YR	2/1	Common uncoated grains
	2	5	Loamy sand	10YR	3/1	Common uncoated grains
	5	9	Sandy clay loam	10YR	2/1	Few uncoated grains
	9	10	Sandy clay loam	10YR	7/2	Very firm - brittle, consistent; common medium 10YR 5/6 RCs
	10	18	Sandy clay loam	10YR	7/3	Many faint 10YR 6/4 RCs and many coarse 10YR 5/1 models; many fine shell fragments (30%)

Silver River 1446 Transect 7

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated

2000 HI Description

12/08/06; HI descr to 15"

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
Oe	0	2	Mucky peat (He	10YR	3/1	
	2	7	Sandy loam	10YR	2/1	Many uncoated grains ~25%
	7	12	Fine sand	10YR	6/3	Many fine 10YR 5/3 models; many fine, faint 10YR 4/4 RCs
	12	15	Loamy fine sand	10YR	4/2	Common distinct coarse 5YR 4/4 RCs

2145 Pomona

12/08/06; Series description; Ultic Alaquod; Backslope w/ N aspect; SHS (S6- stripping) at 8"

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A	0	6	Fine sand	10YR	2/1	Many uncoated grains (50%)
A2	6	11	Fine sand	10YR	4/1	SHS (stripping at 8"); Common, medium 10YR4/1 and 5/1 mottles w/ diffuse boundaries
E1	11	30	Fine sand	10YR	6/1	Single grained
E2	30	46	Fine sand	7.5YR	7/2	Single grained; Common, medium, faint 7.5 YR 6/2 mottles
Bw	46	52	Fine sand	5YR	4/3	Very thin organic coatings
Bh	52	58	Fine sand	5YR	4/4	Many stained grain coatings (~60%)
EB	58	62	Fine sand	10YR	7/4	
E'	62	66	Fine sand	10YR	7/1	Many coarse 10YR 4/4 iron accumulations in root channels
B'h	66	69	Fine sand	10YR	3/2	Common, medium 10YR 4/4 RCs with diffuse boundaries
Btg	69	82	Loamy sand	10YR	5/1	Loamy sand grading to sandy loam w/ few fine faint 10YR 4/4 RCs
Cg	82	90	Sandy clay	N	6/0	Common grading to many very coarse iron accumulations and mottles

Silver River 1446 Transect 9

10 Sparr

12/12/06; Series description; Grossarenic paleudult; somewhat poorly drained, lower landscape position.

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A1	0	4	Fine sand	10YR	4/2	
E1	4	14	Fine sand	10YR	5/8	Many coarse pockets of 10YR4/2
E2	14	28	Fine sand	10YR	5/8	
E3	28	38	Fine sand	10YR	6/6	10YR 8/3 when dry Albic horizon
EB	38	46	Fine sand	10YR	5/6	
Bt1	46	64	Loamy sand	7.5YR	6/8	Common coarse 10YR 7/4 masses, few 5YR 5/8 RCs as sand coatings; many thin grain coatings
Btv1	64	73	Loamy sand	5YR	5/8	Common, fine layers of 10YR 8/1 washed grains; many medium 10YR 3/3 Fe/ Mg concretions and sandy masses (plinthite?)
Btv2	73	80	Loamy sand	10YR	6/6	Many coarse 10YR 7/3 mottles; few coarse plinthite nodules
Btv3	80	86	Sandy loam	7.5YR	5/6	Common, medium coarse plinthite nodules

180 Jumper

12/12/06; Series description; Arenic plinthaquic paleudult

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A	0	4	Fine sand	10YR	5/1	
E1	4	10	Fine sand	10YR	6/2	
E2	10	18	Fine sand	10YR	6/2	Few fine 7.5 YR 4/4 RCs as root channels

Silver River 1446 Transect 9

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
E3	18	28	Fine sand	10YR	8/2	grading to 10YR 8/1 (Albic)
Bwv	28	32	Fine sand	10YR	6/6	many fine to medium 7.5 YR 5/8 RCs as grain coatings; many medium plinthite nodules
E'	32	38	Fine sand	10YR	7/1	Many (90%) uncoated grains (Albic #2)
Bt1v	38	46	Sandy loam	5YR	5/8	Many medium to coarse 5YR3/2 Fe/Mg and plinthite nodules; grading to 10YR 4/2 RDs as ped coatings
Bt2	46	52	Sandy loam	5YR	5/1	Many med. to coarse 5YR 4/6 RCs as ped coatings
BtC	52	62	Sandy clay	7.5YR	6/1	Many medium to coarse 7.5YR 5/8 RCs and 5YR 4/6 RCs as root channels and ped coatings
C	62	84	Sandy loam	7.5YR	6/1	Variegated sand 7.5 YR 6/1; 7.5YR 4/6; 7.5YR 5/8 - as coarse mottling and interlayering (5-10 mm)

242 HI Point Obs.

12/12/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
	0	8		10YR	5/1	stripping at 8" and below - 20% 10YR 6/1 stripping, 10YR5/1 matrix

243 HI Point Obs

12/12/06: Hi test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						Stripped Matrix (S6) stripping at 6" and below. 20% 10YR6/1 stripping, 10YR5/1 matrix
	0	6		10YR	5/1	20% 10YR6/1 stripping

255 HI Point Obs.

12/12/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						Stripped matrix (S6) - stripping at surface

294 HI Point Obs.

12/12/06; HI descr to 15"

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						Redox dark surface (F6); Umbric dark surface (F13)
	0	2	Mucky silty clay	10YR	2/1	
	2	5	Sandy clay	10YR	3/1	Common fine to medium distinct 10YR 4/4 RCs; common uncoated grains
	5	15	Sandy clay	10YR	3/1	Many fine to medium distinct 10YR 4/4 and 5YR 4/6 RCs as ped coatings and rhizospheres

306 HI Point Obs.

12/12/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						Muck presence (A8) - begin

325 Bluff

12/12/06; Series description; Classic Bluff soil

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	4	Muck (Sapric)	10YR	2/2	Muck presence (A8); Umbric dark surface (F13)
Oa	0	4	Muck (Sapric)	10YR	2/2	
A1	4	6	Mucky clay	10YR	3/1	Thick ped coatings N3/
A2	6	24	Clay	10YR	3/1	Thick ped coatings N3/
Oab	24	42	Muck (Sapric)	N	2.5/0	Many fine 10YR 3/3 mottles; soft, plastic
Ab1	42	66	Mucky fine sand	N	2.5/0	
Ab2	66	70	Clay	N	2.5/0	
C1	70	74	Mucky fine sand	N	2.5/0	

Silver River 1446 Transect 9

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
C2	74	80	Sandy loam	10YR	6/2	
1110			**Terra Ceia**			12/14/06; Series description; Typic haplosaprist
HI	0	50	Muck (Sapric)	10YR	3/1	Histosol (A1)
Oa1	0	3	Muck (Sapric)	N	2.5/0	No stickiness no sand grains
Oa2	3	20	Muck (Sapric)	10YR	2/1	
Oa3	20	50	Muck (Sapric)	10YR	3/1	Grades to 10YR 3/2 w/depth
Cg	50	84	Silt	10YR	4/2	Many very fine shell fragments and few fine to medium SF, no sand grains
1210			**Okeelanta**			12/14/06; Series description; Terric haplosaprist
HI	0	38	Muck (Sapric)	10YR	2/1	Histosol (A1)
Oa1	0	6	Muck (Sapric)	N	2.5/0	No shells, no sand, no stickiness
Oa2	6	21	Muck (Sapric)	10YR	2/1	SAA
Oa3	21	38	Muck (Sapric)	10YR	3/1	SAA
A1	38	40	Mucky fine sand	10YR	2/1	~15% 10YR 7/1 uncoated sand grains
Cg1	40	53	Sand (medium)	10YR	4/2	20% 10YR 3/1 mottles and 10% 10YR 2/1 mottles
Cg2	53	66	Sand (medium)	10YR	6/2	no roots no mottles
1241			**HI Description**			12/14/06; HI descr to 18"; end histosol, begin histic epipedon
HI						Histosol (A1) - end/landward extent
Oa1	0	6	Muck (Sapric)	10YR	2/1	
Oa2	6	16	Muck (Sapric)	10YR	3/1	No sand grains, no stickiness
	16	18	Mucky fine sand	10YR	3/1	5% uncoated sand grains
1245			**Anclote**			12/14/06; Series description; Anclote variant - Histic endoaquoll; Landward extent - Histic epipedon;
HI			Muck (Sapric)	10YR	3/1	Histic Epipedon (A2) landward extent
Oa	0	1	Muck (Sapric)	10YR	2/1	No stickiness, very few uncoated grains
A1	1	6	Sand (medium)	10YR	3/1	40% uncoated sand grains (10YR 7/1)
A2	6	8	Mucky fine sand	10YR	2/1	5% uncoated sand grains
O'a	8	15	Muck (Sapric)	10YR	3/1	No stickiness, no sand grains
A'1	15	17	Mucky fine sand	10YR	3/1	2% uncoated sand grains
A'2	17	30	Sand (medium)	10YR	4/1	20% mottles 10YR 3/1; 20% mottles 10YR 5/2; 10% uncoated sand grains
Cg1	30	37	Sand (medium)	10YR	5/2	10% uncoated sand grains
Cg2	37	60	Sand (medium)	10YR	7/2	
1255			**HI Description**			12/14/06; HI descr to 20"
HI						Muck presence (A8); organic bodies (A6) and dark surface (S7)

Silver River 1446 Transect 9

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
Oa	0	1	Muck (Sapric)	10YR	2/1	5% uncoated grains
	1	5	Fine sand	10YR	3/1	20% 10YR 4/1 mottles; 20% uncoated sand grains; organic bodies of muck
	5	10	Mucky fine sand	10YR	2/1	2% uncoated sand grain; organic bodies of muck
Oab	10	11	Muck (Sapric)	10YR	2/1	
	11	13	Fine sand	10YR	3/1	Many 10YR 3/1 mottles (20%); uncoated sand grains; organic bodies of muck
Oab	13	14	Muck (Sapric)	10YR	3/1	2% uncoated sand grains
	14	17	Fine sand	10YR	5/2	Common 10YR 2/1 mottles (10%) and many 10YR 3/1 models (25%) - 5% uncoated sand grains

1262 HI Point Obs.

12/14/06; HI test; vegetation break from hydric swamp to mesic slope forest

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						Muck presence (A8) - landward extent

1275 Anclote

12/14/06; Series description; Sandy, siliceous, hyperthermic, typic endoaquoll

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	7	Fine sand	10YR	2/1	Dark surface (S7) - Landward extent
A1	0	3	Fine sand	10YR	2/1	40% uncoated sand grains
A2	3	7	Fine sand	10YR	2/1	<20% uncoated sand grains
Cg1	7	10	Fine sand	10YR	5/1	w/20% 10YR 2/1 mottles; 20% uncoated sand grains; few, medium faint RCs (10YR 5/3)
Cg2	10	24	Sand (medium)	10YR	5/1	50% uncoated sand grains; 10% 10YR 5/2; 10% 10YR 2/1 w/ few fine faint 10YR 5/3 RCs
Cg3	24	49	Sand (medium)	10YR	4/1	10% uncoated grain; no mottles; no RCs
Cg4	49	64	Sand (medium)	10YR	7/1	Few mottles 10YR 5/1; Resistance at 64"

1280 HI Point Obs.

12/14/06; HI test

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
						No HSIs

1365 Tavares

12/14/06; Series description; Typic Quartzipsamment - backslope/toeslope positions

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A	0	7	Fine sand	10YR	7/1	Many uncoated grains (10YR 4/1) near surface
C1	7	16	Sand (medium)	10YR	7/1	Loose, single grained
C2	16	47	Sand (medium)	10YR	7/1	Grading to 10YR 7/2 at bottom; 10% 10YR 6/2 and 10% 10YR 8/1 mottles
C3	47	63	Sand (medium)	10YR	7/3	Grading from 7/3 to 6/3 w/depth; 10% 10YR 6/2 mottles
C4	63	75	Sand (medium)	10YR	6/4	Few, medium faint 10YR 6/5 RCs @ 66"
C5	75	83	Sand (medium)	10YR	6/4	Grading to 10YR 7/3; common, medium, prominent 10YR 5/6 RCs and common, medium to coarse 10YR 7/2 mottles
C6	83	89	Sand (medium)	10YR	5/4	W/ common coarse 10YR 7/1 depletions and common, coarse faint 10YR 5/3 mottles ; few fine faint 10YR 5/6 RCs

Appendix 2. Soil Profile Descriptions from Silver River (2009)

Silver River 1446 Transect 3

0 Paisley

Does not meet F13 HI due to upland landform. Profile pictures taken (labelled "T3 stn0"), to be loaded to Oracle..

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description
A	0	8	Sandy clay loam	10YR	3/1	2mGR
Bt1	8	25	Sandy clay	10YR	3/2	f1p 7.5YR 4/6 RC; 2mSBK
Bt2	25	40	Sandy clay	10YR	4/3	c2f 10YR 4/4 RC and c2f 10YR 5/2 RD; 3cSBK
Btg	40	51	Clay	10YR	5/2	c1d 10YR 5/4; 3cSBK
Btk	51	65	Clay	10YR	5/2	c1d 10YR 5/6 RC; c3 nodules of carbonates

290

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description
A	0	9	Sandy clay loam	10YR	4/2	

310

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description
A	0	3	Silty clay loam	10YR	3/1	
Bt	3	10	Clay	10YR	4/1	

320

extensive hog rooting

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description
HI						F3 (depleted matrix)
A	0	4	Loam	10YR	3/1	
Btg	4	8	Clay loam	10YR	4/1	c1d 10YR 4/4 RC

388

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description
HI						F6 (redox dark surface), A12 (thick dark surface)
A	0	8	Clay loam	10YR	3/1	c1d 10YR 4/4 RC

465

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description
HI						A12 (thick dark surface), F13 (umbric surface)
A	0	9	Silt loam	10Y	2.5/1	
Bt1	9	17	Silty clay loam	10Y	2.5/1	sticky, plastic
Bt2	17	30	Silty clay	5GY	2.5/1	very sticky, very plastic

482

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description
HI	0	2				A8 (muck presence)

Silver River 1446 Transect 3

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
Oa	0	2	Muck (Sapric)	10Y	2.5/1	m1 roots
A	2	12	Loam	5GY	2.5/1	m1 roots

500

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A1 (Histosol)
Oa	0	5	Muck (Sapric)	N	2.5/	
A	5	12	Mucky loam	N	2.5/	ss/sp
O'a	12	40	Muck (Sapric)	N	2.5/	

550

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	12				A2 (histic epipedon)
Oa	0	12	Muck (Sapric)	N	2.5/	
A	12	23	Mucky loam	N	2.5/	ss/sp
C	23	30	Sand (medium)	10YR	5/2	

600

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A8 (muck presence)
Oa	0	6	Muck (Sapric)	N	2.5/	C1 roots
A	6	10	Mucky loam	N	2.5/	C1 roots; ss/sp
C	10	28	Fine sandy loam	10YR	4/2	F1 roots

622

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	4				A8 (muck presence)
Oa	0	4	Muck (Sapric)	10Y	2.5/1	
A	4	25	Loam	5GY	2.5/1	very sticky, v. plastic

689

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A5 (stratified layers)
A	0	4	Sandy loam	10YR	3/1	
C	4	6	Loamy fine sand	10YR	4/2	
Ab	6	8	Loam	10YR	2/1	
C'	8	10	Loamy fine sand	10YR	4/2	

825

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A	0	4	Fine sandy loam	10YR	4/1	
C	4	7	Fine sandy loam	10YR	5/2	

Silver River 1446 Transect 3

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated

900 Fluvaquent

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A	0	4	Silt loam	10YR	3/2	c1 roots
C1	4	22	Silt loam	10YR	5/2	f1 roots; c1 shell fragments
C2	22	26	Silt loam	10YR	5/2	f1 roots; c2 10YR 4/1 streaks
C3	26	37	Silt loam	10YR	6/2	f1 roots
C4	37	52	Sandy loam	10YR	5/2	c1 roots
C5	52	60	Sandy loam	10YR	4/2	

1006

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A	0	6	Silt loam	10YR	3/1	
C	6	10	Silt loam	10YR	5/2	

1215

A11/ F3 estimated to start at sta 1205

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						F3 (depleted matrix), A11 (depleted below dark surface)
A	0	5	Silt loam	10YR	2/1	
C	5	11	Silt loam	10YR	6/1	c1f 10YR 5/2 mottles

1256

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						F3 (depleted matrix), A11(depleted below dark surface)
A	0	3	Silt loam	10YR	2/1	
C	3	8	Silt loam	10YR	6/2	

1270

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						F3 (depleted matrix), A11(depleted below dark surface)
A	0	3	Silt loam	10YR	3/1	
C	3	8	Silt loam	10YR	6/2	c1 shell fragments

1330

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	2				A7 (mucky mineral)

1400

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A8 (muck presence)

Silver River 1446 Transect 3

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
Oa	0	3	Muck (Sapric)	10YR	2/1	m1 roots; c1-2 shell; 27.5% organic carbon (LOI)
A	3	11	Mucky sandy loa	10YR	2/1	c2 roots; 11-2 shell; 9.9% organic carbon (LOI)
C1	11	14	Sandy loam	10YR	4/2	m1-2 shell
C2	14	22	Sandy loam	10YR	5/2	c1-2 shell

1502

extensive hog rooting

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A11 (depleted below dark surface), F3 (depleted matrix), F13 (umbric surface)
A	0	9	Sandy loam	10YR	3/1	m1 shell fragments
C	9	15	Sandy loam	10YR	6/2	m3f 10YR 5/2 streaks

1577

A8 estimated to start at sta 1567, end at 1662

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A4 (hydrogen sulfide), A8 (muck presence)
Oa	0	4	Muck (Sapric)	10Y	2.5/1	
Cg1	4	13	Sandy loam	10Y	4/1	
Cg2	13	28	Loamy sand	10YR	6/2	
Cg3	28	40	Sandy loam	10YR	4/2	

1640

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	4				A8 (muck presence)
Oa	0	4	Muck (Sapric)	10Y	2.5/1	
Cg	4	32	Silt loam	10YR	4/2	

1680

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	3				A7 (mucky mineral)
A	0	3	Mucky sandy loa	10YR	2/1	
C	3	6	Sandy loam	10YR	3/1	

1755

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	2				A7 (mucky mineral)
A1	0	2	Mucky silty loam	10Y	2.5/1	
A2	2	9	Silt loam	10Y	2.5/1	slightly sticky, slightly plastic
Cg1	9	16	Silt loam	10Y	3/1	m1 shell fragment
Cg2	16	23	Loamy fine sand	10YR	6/2	

1805

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						F6 (redox dark surface)

Silver River 1446 Transect 3

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A1	0	4	Loam	10YR	2/2	8.0% O.C. (LOI)
A2	4	8	Clay loam	10YR	3/2	c1d 10 YR 4/6 RC

1810

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						F6 (redox dark surface)
A	0	9	Clay loam	10GY	2.5/1	c1d 10YR 3/3 RC

1840

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A	0	8	Sandy clay loam	10Y	3/1	f1d 10YR 3/4 RC

Silver River 1446 Transect 5

140

extensive hog rooting

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						F3 (depleted matrix)
A	0	7	Sandy clay loam	10YR	4/1	c1d 10YR 4/4 RC

201 Bluff

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	3				A8 (muck presence)
Oa	0	3	Muck (Sapric)	10Y	2.5/1	
C1	3	10	Clay loam	10Y	2.5/1	
C2	10	35	Loam	10GY	2.5/1	

206 Gator

A1 estimated in field to extend from sta 204 to sta 290

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A1 (histosol)
Oa	0	14	Muck (Sapric)	5GY	2.5/1	2mGR
C	14	17	Silty clay loam	10Y	2.5/1	MA
O'a	17	27	Muck (Sapric)	5GY	2.5/1	3mGR (strong granular structure may be the result of past episodes of oxidation)
C'	27	40	Loam	10GY	2.5/1	

240 Gator

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A1(histosol)
Oa	0	4	Muck (Sapric)	5GY	2.5/1	1mGR
C	4	20	Clay loam	5GY	2.5/1	
O'a1	20	24	Muck (Sapric)	N	2.5/	3mGR
O'a2	24	35	Muck (Sapric)	N	2.5/	1mGR

Silver River 1446 Transect 5

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated

285 Okeelanta

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A1 (histosol)
Oa	0	3	Muck (Sapric)	10Y	2.5/1	
C	3	12	Loam	5GY	2.5/1	
O'a	12	23	Muck (Sapric)	N	2.5/	3mGR
C'	23	27	Loamy sand	10YR	6/3	
O"a	27	30	Muck (Sapric)	10YR	2/1	
C"	30	32	Loamy sand	10YR	6/3	

300 Denaud

dense root mat - soil pit dug 4' west of transect line

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A2 (histic epipedon), appears to be an inclusion within an area of Histosols
Oa1	0	3	Muck (Sapric)	5GY	2.5/1	
Oa2	3	9	Muck (Sapric)	5GY	2.5/1	
Oa3	9	12	Muck (Sapric)	N	2.5/	
C	12	19	Loamy sand	10YR	6/3	
O'a	19	21	Muck (Sapric)	10Y	2.5/1	
C'	21	32	Sandy loam	10YR	6/2	

318 Okeelanta

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	20				A1 (Histosol)
Oa1	0	6	Muck (Sapric)	5GY	2.5/1	m1 roots
Oa2	6	20	Muck (Sapric)	5GY	2.5/1	f1 roots; 26.2% organic carbon (LOI)
C2	20	30	Loamy sand	10YR	6/3	
C3	30	32	Loamy sand	10YR	6/2	

377

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A5 (stratified layers)
A1	0	4	Sandy loam	10YR	5/2	
A2	4	5	Sandy loam	10YR	3/1	
A3	5	6	Sandy loam	10YR	5/2	

412

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI		0		10YR		A8 (muck presence),

Silver River 1446 Transect 5

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
446						
HI	0	6	Muck (Sapric)	10YR		A8 (muck presence)
Oa	0	6	Muck (Sapric)	10YR	2/1	
C	6	7	Sandy loam			
630						
HI						A6 (organic bodies), F13 (umbric surface)
A1	0	9	Silt loam	10YR	2/2	C1 roots; 20% 10YR 2/1 muck bodies; 10% 10YR 3/2 mottles
A2	9	12	Sandy loam	10YR	3/2	
C	12	28	Sandy loam	10YR	5/2	
641						
HI						A2 (histic epipedon)
Oa	0	12	Muck (Sapric)	10YR	2/1	
C	12	13	Sandy loam			
700						
HI						A6 (Organic bodies)
A	0	20	Loamy fine sand	10YR	5/2	5% muck bodies
816						
HI	0	5	Muck (Sapric)			A8 (muck presence)
Oa	0	5	Muck (Sapric)	10YR	2/1	
C	5	32	Sandy loam	10YR	5/2	
900						
HI	0	12				A2 (histic epipedon)
Oa1	0	6	Muck (Sapric)	10YR	2/1	m1 roots
Oa2	6	12	Muck (Sapric)	10YR	2/1	f1 roots: 19.3% organic carbon (LOI)
C1	12	16	Loamy fine sand	10YR	4/2	
C2	16	25	Loamy fine sand	10YR	5/3	
1109						
HI	0	8				A8 (muck presence)

Silver River 1446 Transect 5

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
Oa	0	8	Muck (Sapric)	10YR	2/1	
C1	8	12	Sandy loam	10YR	4/1	
C2	12	20	Sand (medium)	10YR	6/3	

1170

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	2				A7 (mucky mineral)
A1	0	2	Mucky sandy loa	10YR	2/2	
A2	2	8	Sandy loam	10YR	4/1	

1204

A8 estimated in field to extend from sta 1193 to sta 1320

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	5				A8 (muck presence)
A1	0	5	Muck (Sapric)	10YR	2/1	
A2	5	10	Loam	10YR	3/2	

1340

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						F13 (umbric surface), F6 (redox dark surface)
A	0	8	Sandy clay loam	10Y	2.5/1	
C	8	30	Sandy clay loam	10Y	3/1	c1d 10YR 3/4 RC

1458

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	7	13				F3 (depleted matrix)
A1	0	3	Sandy loam	10YR	3/1	
A2	3	7	Sandy clay loam	10YR	4/1	
C	7	13	Clay	10YR	5/2	c1d 10YR 5/6 RC

1500

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A1	0	4	Sandy clay loam	10YR	3/1	
Bt	4	8	Clay	10YR	4/2	

Silver River 1446 Transect 7

24 **Paisley**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A	0	6	Sandy loam	10YR	3/2	
Bt1	6	16	Sandy clay loam	10YR	3/2	c2d 10YR 3/6
Bt2	16	51	Sandy clay	10YR	3/2	m2d 10YR 4/6 RC; c2d 10YR 6/2 RD; v. sticky, v. plastic; v. firm
Btg	51	60	Clay	10YR	6/2	m2p 10YR5/6 RC; v. sticky, v. plastic, v. firm
BC	60	65	Clay loam	10YR	7/2	c1p10YR 6/6 RC; c2p N 8/ carbonate masses

Silver River 1446 Transect 7

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
202						
HI						F3 (depleted matrix)
A	0	4	Sandy loam	10YR	3/1	
Btg	4	10	Sandy clay loam	10YR	5/2	c1d 10YR 4/6 RC
220						
HI						F3 (depleted matrix)
A1	0	3	Sandy loam	10YR	3/1	
A2	3	10	Sandy loam	10YR	4/1	c1d 10YR 4/4 RC
240						
HI						F6 (redox dark surface)
	0	6	Clay loam	10YR	3/1	c1d 10YR 4/4 RC
250						
HI	0	0.5				A8 (muck presence)
279			**Bluff**			
HI	0	4				A8 (muck presence)
Oa	0	4	Muck (Sapric)	N	2.5/	1mGR structure
A	4	18	Mucky silty clay l	N	2.5/	10.7% organic carbon (LOI)
O'a	18	25	Muck (Sapric)	N	2.5/	3mGR structure
C'g	25	35	Loam	N	2.5/	
294			**Endoaquoll**			
HI	0	3				A8 (muck presence)
Oa	0	3	Muck (Sapric)	N	2.5/	
Cg	3	18	Mucky sandy loa	N	2.5/	3mGR structure
O'a	18	30	Muck (Sapric)	N	2.5/	
C'g	30	40	Loam	N	2.5/	
306			**Gator**			
HI						A1 (histosol)
Oa	0	1	Muck (Sapric)	10Y	2.5/1	

Silver River 1446 Transect 7

Station / Horizon	From	To	Soil Series / Texture	Hue	Value-Chroma	Soil_Description - Truncated
Cg	1	12	Mucky silty loam	10Y	2.5/1	
O'a	12	30	Muck (Sapric)	N	2.5/	
C'g	30	43	Silt loam	5GY	5/1	
400			**Gator**			
HI						A1 (histosol)
Oa1	0	8	Muck (Sapric)	N	2.5/	
Oa2	8	36	Muck (Sapric)	10Y	2.5/1	
Cg	36	40	Sandy loam	10Y	5/1	
470			**Okeelanta**			histosol estimated to extend to station 478
HI						A1 (histosol)
Oa	0	5	Muck (Sapric)	10Y	2.5/1	
Cg	5	15	Loam	5GY	2.5/1	
O'a	15	18	Muck (Sapric)	5GY	2.5/1	
C'g	18	20	Loamy sand	5GY	3/1	m3d pockets 10YR6/3
O"a	20	32	Muck (Sapric)	5GY	2.5/1	
C	32	35	Loamy sand	10YR	6/3	
C"g	35	38	Mucky loamy sa	5GY	2.5/1	
484			**Endoaquoll**			dense root mat on line - soil pit dug 8' west of transect line
HI	0	6	Muck (Sapric)			A8 (muck presence)
Oa	0	6	Muck (Sapric)	N	2.5/	
Cg1	6	18	Loam	5GY	2.5/1	5.1% organic carbon (LOI)
Cg2	18	29	Loamy fine sand	10Y	2.5/1	
O'a	29	34	Muck (Sapric)	5GY	2.5/1	
C	34	36	Loamy sand	10YR	5/2	
O"a	36	40	Muck (Sapric)	5GY	2.5/1	
500						
HI	0	4				A8 (muck presence)
Oa	0	4	Muck (Sapric)	N	2.5/	
Cg1	4	8	Sandy loam	N	3/	c1 shell fragments
Cg2	8	15	Loam	5GY	2.5/1	
Cg2	15	20	Sandy loam	5GY	3/1	c1 shell fragments

Silver River 1446 Transect 7

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
555						
HI	0	2	Muck (Sapric)			A8 (muck presence)
588						A7 estimated in lfield to begin at sta 575
HI	0	2	Mucky loamy sa			A7 (mucky mineral)
620						
HI						F3 (depleted matrix)
A1	0	3	Sandy loam	10YR	3/1	
A2	3	10	Sandy loam	10YR	4/2	m3f 10YR 5/2 pockets; c1d 10YR 4/6 RC
673						A8 estimated in field to extend from sta 666 to river
HI	0	2	Muck (Sapric)			A8 (muck presence)
1000			Endoaquoll			photo taken (labelled "Transect 7 sta 1000"). To be uploaded to Oracle
HI	0	7				A8 (muck presence)
Oa	0	7	Muck (Sapric)	10YR	2/1	
Cg1	7	11	Loam	10YR	3/1	4.2% organic carbon (LOI)
Cg2	11	26	Loam	10YR	5/2	
Cg3	26	31	Mucky sandy loa	10YR	3/1	
O'a	31	41	Muck (Sapric)	10YR	2/1	
1201						heavy crayfish activity may have disturbed a muck layer
HI						A11 (depleted below dark surface), F3 (depleted matrix)
A	0	6	Silt loam	10YR	3/1	
C1	6	12	Sandy loam	10YR	5/1	
C2	12	40	Sandy loam	10YR	5/2	
1315			Fluvaquent			extensive crayfish burrowing
HI						A11 (depleted below dark surface), F3 (depleted matrix)
A	0	5	Silty clay loam	N	2.5/	
C1	5	13	Sandy loam	10YR	5/1	c1 shell fragments
C2	13	33	Sandy loam	10YR	4/1	
Oa	33	34	Muck (Sapric)	10YR	2/1	

Silver River 1446 Transect 7

Station / Horizon	From	To	Soil Series / Texture	Hue	Value-Chroma	Soil_Description - Truncated
1500						soil pit dug 10' west of line
HI						A11 (depleted below dark surface), F3 (depleted matrix)
A	0	6	Sandy loam	10YR	3/1	c1 shell fragments; 20% 10 YR 5/1 pockets
C	6	12	Sandy loam	10YR	5/1	m1 shell fragments; 20% 10YR 3/1 pockets
1517						extensive hog rooting
HI						A11 (depleted below dark surface), F3 (depleted matrix)
A	0	4	Sandy loam	10YR	3/2	
C	4	12	Sandy loam	10YR	5/1	c1d 10YR5/6 RC
1542						
A1	0	5	Sandy loam	10YR	3/1	
A2	5	11	Sandy loam	10YR	4/1	f1d 10YR 5/4 RC
1628						
A	0	3	Sandy loam	10YR	4/1	
C	3	10	Sandy loam	10YR	5/2	
1668			**Fluvaquent**			
A1	0	2	Sandy loam	10YR	3/1	
A2	2	7	Sandy loam	10YR	4/1	
C1	7	12	Sandy loam	10YR	5/1	
C2	12	35	Sandy loam	10YR	5/1	
C3	35	37	Mucky loamy sa	N	2.5/	c2p 10 YR 6/2 nodules
1700						
HI						F3 (depleted matrix), similar soil characteristics to station 1668
1792						
HI						A6 (organic bodies), F13 (umbric surface), A11 (depleted below dark surface)
A	0	7	Fine sandy loam	10YR	2/1	>2% organic bodies observed in 0-3" zone
C	7	13	Fine sandy loam	10YR	6/1	c1d 10YR 5/4 RC

Silver River 1446 Transect 7

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated

1826

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A6 (organic bodies), A11 (depleted below dark surface), F13 (umbric surface)
A	0	9	Sandy loam	10YR	2/1	
C	9	12	Sandy loam	10YR	6/1	

1915

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						estimated start of A7 (mucky mineral)

1960

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A7 (mucky mineral)
		0		10YR		

1985

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	2				A7 (mucky mineral), F13 (umbric surface), landward extent of A7, F13
A1	0	2	Mucky sandy loa	10YR	2/1	
A2	2	8	Sandy loam	10YR	2/1	
C	7	13	Sandy loam	10YR	6/2	c2f 10YR 6/1 weakly cemented nodules; c1d 10YR 6/6 RC

2019

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						S6 (stripped matrix)
A	0	5	Loamy sand	10YR	2/1	
C	5	10	Sand (medium)	10YR	6/1	c2f 10YR 6/2 and 10YR 5/2 streaks (stripping)

2073

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A	0	2	Sand (medium)	10YR	3/1	50% coated sand grains
C	2	8	Sand (medium)	10YR	5/3	c1d 10YR 3/1 pockets

Silver River 1446 Transect 9

10

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
A	0	6	Sand (medium)	10YR	5/2	
E1	6	19	Sand (medium)	10YR	6/6	
E2	19	27	Sand (medium)	10YR	7/4	f1f 10YR 7/2 RD and f1d 7.5YR 6/6
E3	27	38	Sand (medium)	10YR	7/3	f1f 10YR 7/2 RD and f1d 7.5YR 6/6
E4	38	60	Sand (medium)	10YR	7/2	

Silver River 1446 Transect 9

Station **Soil Series**

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
E5	60	65	Sand (medium)	10YR	7/2	c2-3 spherical nodules of ironstone

243

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						S6 (stripped matrix), begin HI
A1	0	3	Sand (medium)	10YR	4/1	50% uncoated sg
A2	3	6	Sand (medium)	10YR	4/1	c2f 10YR 5/1 w/ df bnd; c2f 10YR 6/2 w/ df bnd (stripped matrix)

325

estimated start of A8

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	0.5	Muck (Sapric)			A8 (muck presence), F13 (umbric surface)
Oa	0	0.5	Muck (Sapric)	10YR	2/1	
A1	0.5	3	Silty clay loam	10YR	2/1	
A2	3	10	Silty clay	10YR	3/1	

350

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	2	Muck (Sapric)			A8 (muck presence)

460

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	2	Muck (Sapric)			A8 (muck presence)

575

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	2	Muck (Sapric)			A8 (muck presence)

600 Bluff

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	3	Muck (Sapric)			A8 (muck presence)
Oa	0	3	Muck (Sapric)	10YR	2/1	
Cg1	3	20	Silty clay	10YR	2/1	v. sticky, v. plastic, firm
Cg2	20	35	Silty clay loam	10YR	2/1	

670

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	3	Muck (Sapric)			A8 (muck presence)

700 Fluvaquentic Haplosaprist

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI	0	3				A1 (histosol)
Oa	0	3	Muck (Sapric)	10YR	2/1	

Silver River 1446 Transect 9

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
Station			**Soil Series**			
Cg	3	16	Silty clay	10YR	2/1	v. sticky, v. plastic
O'a	16	35	Muck (Sapric)	10YR	2/1	
775			**Terra Ceia**			at the "big hole", a soil profile photo was taken ("T9 stn775") to be uploaded to Oracle
HI						A1 (histosol)
Oa	0	5	Muck (Sapric)	10Y	2.5/1	non-sticky, non-plastic, m1 roots
Cg1	5	12	Silty clay loam	5GY	2.5/1	moderately sticky, moderately plastic
Cg2	12	15	Mucky silty clay l	5GY	2.5/1	slightly sticky, slightly plastic
O'a	15	55	Muck (Sapric)	N	2.5/	non-sticky, non-plastic; c1 undecomposed roots
800			**Fluvaquentic Haplosaprist**			
HI						A1 (histosol)
Oa	0	7	Muck (Sapric)	10YR	2/1	
Cg	7	13	Silty clay loam	10YR	2/1	
O'a	13	25	Muck (Sapric)	10YR	2/1	c3 partially decomposed wood fragments
825			**Fluvaquentic Haplosaprist**			
HI						A1 (histosol)
Oa	0	4	Muck (Sapric)	10YR	2/1	
Cg1	4	7	Silty clay	10YR	2/1	
Cg2	7	11	Silty clay loam	10YR	2/1	
O'a	11	25	Muck (Sapric)	10YR	2/1	m3 partially decomposed woody debris
856			**Fluvaquentic Haplosaprist**			
HI						A1 (histosol)
Oa	0	7	Muck (Sapric)	10Y	2.5/1	
Cg	7	10	Silty clay loam	N	2.5/	
O'a	10	25	Muck (Sapric)	N	2.5/	
858			**Terra Ceia**			
HI						A1 (histosol)
Oa1	0	7	Muck (Sapric)	10Y	2.5/1	
Oa2	7	52	Muck (Sapric)	N	2.5/	
884			**Terra Ceia**			photo taken
HI						A1 (histosol)

Silver River 1446 Transect 9

Station			Soil Series			
Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
Oa1	0	8	Muck (Sapric)	10Y	2.5/1	c1 roots
Oa2	8	40	Muck (Sapric)	10Y	2.5/1	f1 roots
Oa3	40	55	Muck (Sapric)	10Y	2.5/1	

1235 Okeelanta

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						A1 (histosol)
Oa1	0	7	Muck (Sapric)	10YR	2/1	m1 roots
Oa2	7	24	Muck (Sapric)	10YR	2/1	
Cg	24	27	Sand (medium)	10YR	4/2	

1275

Horizon	From	To	Texture	Hue	Value-Chroma	Soil_Description - Truncated
HI						S7 (dark surface)

Appendix 3. Measured Organic Carbon Levels from Selected Horizons.

Lab #	Site ID	Depth (in)	Wt_Boat (g)	Wt_110C (g)	Wt_400C (g)	Wt_Soil 110C	Wt_Soil 400C	% organic matter	%organic carbon	
1	T3-1400	0-3	1.048	11.687	6.639	10.639	5.591	47.45%	**27.52%**	**muck**
2	T3-1400	3-11	1.045	10.956	9.263	9.911	8.218	17.08%	**9.91%**	**muckmin**
3	T3-1540	0-1	1.013	11.184	10.1	10.171	9.087	10.66%	**6.18%**	**min**
4	T3-1695	0-4	0.987	11.681	9.713	10.694	8.726	18.40%	**10.67%**	**muckmin**
5	T3-1750	0-10	1.001	12.331	8.723	11.33	7.722	31.84%	**18.47%**	**muck**
6	T3-1790	0-4	0.985	11.314	9.168	10.329	8.183	20.78%	**12.05%**	**muckmin**
7	T3-1790	4-11	1.002	11.435	9.358	10.433	8.356	19.91%	**11.55%**	**muckmin**
8	T3-1805	0-4	0.996	12.235	10.69	11.239	9.694	13.75%	**7.97%**	**min**
9	T5-318	6-20	0.975	11.362	6.674	10.387	5.699	45.13%	**26.18%**	**muck**
10	T5-900	6-12	1.044	13.028	9.035	11.984	7.991	33.32%	**19.33%**	**muck**
11	T7-279	4-18	1.026	12.637	10.49	11.611	9.464	18.49%	**10.72%**	**muckmin**
12	T7-484	6-18	1.047	11.818	10.872	10.771	9.825	8.78%	**5.09%**	**min**
13	T7-1000	7-11	1.047	11.529	10.778	10.482	9.731	7.16%	**4.16%**	**min**
Repeat	T5-900	6-12	0.999	11.618	8.097	10.619	7.098	33.16%	**19.23%**	**muck**

APPENDIX H – IMPORTANCE OF FLOW AND STAGE FOR RIVERINE ECOSYSTEMS

Ecological Importance of Flow and Stage in Riverine Systems

The importance of naturally dynamic flow and stage regimes to the long-term maintenance of a river's physical structure, biogeochemistry and ecological integrity is widely recognized (Junk et al. 1989, Poff et al. 1997, Lytle and Poff 2004, Tockner et al. 2008, Arthington 2012). In lotic ecosystems, flow is considered a master variable that drives key physicochemical processes, shapes physical habitat, influences life history strategies and as a result affects the composition, distribution and interactions of biological communities. While water level (i.e., stage) is linked with flow, they are mechanistically distinct, and therefore often influence related but different aspects of riverine form and function. Therefore, the maintenance and long-term integrity of lotic ecosystems is largely determined by the range of both flows and levels that comprise their "natural flow regime" (Hill et al. 1991, Poff et al. 1997, Richter et al. 1997, Poff and Zimmerman 2010, Arthington 2012). The following summary describes the importance of and negative effects of alterations to flows and levels within riverine environments.

Research clearly demonstrates that alterations of high and low flows have profound effects on all aspects of lotic environments, from physical structure, habitat quality, and biogeochemistry to biological community structure and ecological functioning. As such, the long-term persistence and integrity of riverine ecosystems is fundamentally linked to their naturally dynamic flow regime (Poff et al. 1997, Richter et al. 1997, Ward et al. 1999, Poff et al. 2009, Arthington 2012).

The current environmental flows paradigm asserts that flooding and drying events are necessary to maintain an ecosystem's natural characteristics (King and others 2003) and that healthy aquatic and wetland populations and communities require variable flow regimes to protect habitat and life history processes (Poff and others 1997). Multiple MFLs are set in an effort to provide protection to multiple portions of a system's flow and stage regimes.

Hill et al (1991) suggest that the influence of a river's natural flow regime is manifest in four critical ways: 1) flood flows create and maintain floodplain and valley features; 2) overbank flows maintain riparian vegetation, water tables, soil saturation zones and adjacent upland boundaries; 3) in-channel flows determine the structure and function of stream banks and channels; and 4) in-channel flows meet critical life-history needs of aquatic biota. The following sections summarize the importance of maintaining the natural, dynamic flow and stage hydrologic regimes to a river's physical structure, biogeochemistry and ecological integrity.

Geomorphology and Physical Habitat

Channel and floodplain geomorphology are both dependant on flood and drought magnitude, duration, frequency, timing and rate of change. River channel sinuosity and cross section shape are determined by the interplay between flow regime, parent geology, local gradient and sediment character (Chorley et al. 1984, Newbury and Gaboury 1993, Leopold 1995). Natural channel migration and formation of undercut banks is mediated by the frequency and duration of channel forming flows (i.e., bankfull events; Leopold 1995). Flows and levels also influence channel geometry (e.g., width to depth ratio), and the diversity and stability of small patches of habitat within the channel and floodplain (Arthington 2012). Flow influences current velocity and the particle distribution and transport/deposition of fine sediment, thereby influencing streambed structure, topography and complexity (Newbury and Gaboury 1993, Ritter et al. 1995).

In addition to influencing the character of within-channel structure, natural flow and stage variability and magnitude also maintain the long-term geomorphology of floodplains. Floodplains are dynamic environments created and maintained by overbank flows through the processes of erosion, channel migration, point-bar extension, mid-channel bar formation and ultimately floodplain development due to the vertical and lateral accretion of alluvial sediments (Newbury and Gaboury 1993, Leopold 1995). Natural flow variability and within-channel processes control channel migration and, therefore, help maintain valley and floodplain geomorphology, long-term succession of riparian vegetative communities and overall floodplain ecosystem integrity (Wolman and Leopold 1957, Nanson and Beach 1977, Leopold 1995). High-energy flood flows increase the heterogeneity of floodplain habitats, which is linked to increased biodiversity (Salo et al. 1986, Junk et al. 1989). At a given stage, lower flow results in lower stream power and a reduced ability of lotic systems to erode, transport and deposit sediment. Therefore, even if stage is kept constant (e.g., by vegetative damming or some other natural or anthropogenic process) flow reductions can, via reductions in stream power, have a significant negative effect on the long-term maintenance of floodplain structure and function.

Flow regime influences channel migration, which in turn influences the abundance and distribution of two important riverine habitats: undercut banks and large woody debris. Undercut areas caused by channel migration and bank erosion serve as important cover habitat for predatory fish and refugia for both large and small species. Flood induced bank erosion causes riparian tree fall and this input of large woody debris (LWD) in turn provides numerous benefits to lotic systems. These benefits include but are not limited to: increased streambed stability; energy absorption and reduced channel erosion; increased habitat volume and habitat complexity; pool formation; increased carbon input (basal resource for heterotrophic foodweb); increased trapping of fine inorganic sediment; and increased transient storage of fine particulate organic matter (Bilby 1984, Harmon et al. 1986, Abbe and Montgomery 1996, Rosenfeld and Huato 2003, Arthington 2012).

Organic Matter and Nutrient Dynamics

Flow regime also affects the transport and distribution of energy (i.e., organic carbon) and nutrients. Overbank floods flush organic carbon from floodplain to channel, contributing material that ranges in size from large trees to particulate detritus to dissolved organic matter. For large floodplain rivers, lateral contributions of carbon from the floodplain are thought to be much more important to overall river productivity than upstream sources (Junk et al. 1989). Once in the channel, flowing water then moves woody debris downstream, changing the distribution of LWD habitat, fragmenting detritus from coarse to fine and dissolved fractions, and finally transporting and redistributing this basal food resource among different habitats. LWD influences the trapping and storage of fine and coarse particulate organic matter, which allows for increased retention and utilization by microbes, microinvertebrates and macroinvertebrates (see summary in Harmon et al. 1986).

During large floods, previously isolated areas become important food sources for the microbial foodwebs (primarily bacteria and fungi). High flood stages that increase lateral connectivity between the channel and floodplain also increase the transport of higher quality dissolved and fine particulate organic matter to adjacent and lower river reaches (Atkinson et al. 2009). During these two-way exchanges between channel and floodplain, energy and nutrients from highly productive microbial communities is transferred through higher trophic levels, resulting in increased production of microinvertebrates and macroinvertebrates, fish and other vertebrate species (Junk et al. 1989, Bunn et al. 2006, Poff et al. 2009, Arthington 2012).

In addition to being a key driver of carbon cycling, flow also mediates the biogeochemical processing of nutrients (Bernot and Dodds 2005). Flood flows transport nutrients from the channel to the floodplain facilitating nutrient filtration and removal, as well as remineralization and dissimilatory removal (e.g., denitrification). During high flow events nutrients and carbon are transported from the floodplain to the channel (Junk et al. 1989). These physical processes and biogeochemical reactions are key to both autotrophic and heterotrophic productivity within channel and floodplain environments. Biogeochemical processing of nitrogen depends on how water interacts with benthic sediments and organisms within the channel and between channel and floodplain (Cohen et al. 2011). Flow-mediated inputs of LWD increase instream habitat complexity and transient storage of nutrients, thereby shortening nutrient spiraling lengths and ultimately increasing uptake and dissimilation (e.g., denitrification; Webster and Patten 1979, Newbold et al. 1981, Ensign and Doyle 2005, Bukaveckas 2007). Nutrient flux within lotic systems is a function of transport mediated by flood stage and flow, physical storage, biotic retention and remineralization (Newbold et al. 1981). Therefore, nutrient uptake length is strongly influenced by flow. Flow alterations can affect nutrient availability and metabolic waste removal within microbial/biofilm communities, influencing nutrient uptake and transformation. Decreased local velocities can also reduce uptake by decreasing dispersion through biofilms, stimulating increased dependence on internal recycled nutrients (Mulholland et al. 1994). Increased connectivity with the floodplain can also increase system-wide retention of both dissolved and particulate nutrients (Meyer et al. 1988). Decreased flows can reduce denitrification rates in lotic systems by reducing necessary labile organic carbon (e.g., from floodplain, or organic matter fragmentation; Bernot and Dodds 2005). Flood flows and stages can also affect the retention of phosphorus, the uptake of which is related to transport of particulate organic matter and sedimentation rate (Meyer et al. 1988).

River floodplains act as both sources and sinks for sediment and nutrients. The frequency and duration of inundation directly affects nitrogen cycling in floodplains (Arthington 2012). Flood flows mobilize and deposit nutrient rich inorganic and organic sediment. Natural fluctuations between wet and dry phases in turn alternate the duration of aerobic and anaerobic phases within floodplain alluvial soils (Pinay et al. 2002). Aerobic phases are marked by increased nitrification of ammonia, and uptake of nitrate by microbes and plants. During anaerobic phases nitrate is reduced to ammonia, organic material is also reduced to ammonia (ammonification), and dissimilatory removal (i.e., denitrification) occurs. Despite periods of increased denitrification during anaerobic phases, evidence suggests that some floodplain wetlands are overall nitrogen sinks (Brinson et al. 1980). Phosphorus bound to oxidized sediments are deposited, and are taken up by vegetation and microbes. Redox conditions in the surface sediment determines phosphorus release. During long periods of high water level on the floodplain anoxic conditions lead to mobilization and availability of phosphorus. Release and storage of both phosphorus and nitrogen are mediated by hydrology, vegetative cover and growing season (Junk et al. 1989).

During both phases nutrients are incorporated into the microbial loop and vegetative communties. A naturally functioning floodplain is the site of nutrient storage, transformation, uptake and removal. Therefore, flood flow alterations that decrease natural water-table fluctuations and soil saturation, in turn reduce floodplain and whole system fertility and productivity (Arthington 2012). Alteration of the natural flow regime also reduces the ability of floodplains to remove excessive nutrients from the system.

Biological Communities

As a major determinant of geomorphology, physical habitat structure and water chemistry, flows and levels also influence the abundance, diversity and distribution of aquatic and wetland-dependant organisms within riverine channels and floodplains (Poff and Ward 1990, Poff et al. 1997, Bunn and Arthington 2002, Lytle and Poff 2004, Arthington et al. 2006). By redistributing sediment in the channel and floodplain, flow affects habitat suitability and distribution of macroinvertebrates, fishes and other aquatic species (Ward and Stanford 1983, Bain et al. 1988, Ligon et al. 1995, Poff et al. 1997, Marchetti and Moyle 2001). As well as increasing habitat suitability for native fauna and flora, high flows also scour and remove excessive algae and macrophytes, and purge exotic and/or invasive species (e.g. *Hydrilla*) from river and stream channels

(Arthington 2012, King 2014). Reduced variability of river levels can favor exotic fish species that prefer seasonal stability (Moyle and Light 1996, Gehrke et a. 1995).

One of the primary functions/benefits of flow-mediated maintenance of in-channel and floodplain structural heterogeneity and integrity, is the provision of forage, reproductive and refugial habitat for biological communities (Bunn and Arthington 2002). Natural flood flows and levelsincrease habitat heterogeneity and complexity through the scour of pools, increased inputs of LWD and increased undercut banks. Greater habitat complexity provides increased niche diversity, and foraging opportunities. Maintenance of complex habitat increases macroinvertebrate and fish species richness, relative abundance and distribution (Angermeier 1989, Gorman and Karr 1978, Resh et al. 1988, Poff and Allan 1995, Spence et al. 1999, Schneider and Winemiller 2008). Flood induced inputs of LWD provide numerous benefits for lotic communities, including, sediment (organic and inorganic) and nutrient storage; pool formation; provision of substrate for macroinvertebrates, microbial biofilm, periphyton and filamentous algae; basking sites for reptiles; resting sites for birds; and cover for fishes and other vertebrates (Harmon et al. 1986, Piégay et al. 1997, Collins and Montgomery 2002, Pusey and Arthington 2003, Wallerstein and Thorne 2004; Arthington 2012). Fallen trees that have been eroded by floods provide important basking habitat for turtles, snakes and alligators (DonnerWright et al. 1999, Lindeman 1999). In some riverine systems, turtle density, abundance and assemblage structure are positively and strongly related to abundance of downed trees, which serve as basking sites and control water velocity and depth (Gippel 1995, DonnerWright et al. 1999, Lindeman 1999). Exposed trees and logs also provide valuable resting habitat for many species of birds.

The maintenance of river levels sufficient to cover fallen submerged trees is critical for fishes, which rely on LWD in numerous ways (Bilby and Bisson 1998). Submerged LWD is used as spawning substrate (Van Den Avyle and Petering 1988), cover from avian and piscine predators (Angermeier and Karr 1984, Crook and Robertson 1999), protection from high flows (Todd and Rabeni 1989), visual isolation from other fish (Crook and Robertson 1999), thermal refuge (Bilby and Bisson 1998) and especially as foraging habitat (Benke et al. 1985, Van Den Avyle and Petering 1988, Lehtinen et al. 1997, Bilby and Bisson 1998, Schneider and Winemiller 2008). LWD is especially important as a source of invertebrate prey for many sunfishes (*Lepomis* spp.) and other fish species (Wallace and Benke 1984, Benke et al. 1985, Crook and Robertson 1999). LWD input is related to increased habitat complexity and concomitant increases in richness and abundance of fishes and macroinvertebrates (Frothingham et al. 2001, Brooks et al. 2004, Schneider and Winemiller 2008, Lyon et al. 2009, Howell et al. 2012).

In addition to structuring instream habitat through LWD inputs, pool formation and increasing substrate heterogeneity, flood flows also increase the area, diversity and complexity of aquatic habitat by connecting the main channel to temporarily isolated areas (floodplains, sloughs, backwater pools, etc). Flow and stage dynamics also create a diverse mosaic of habitat patches of varying depth, inundation and vegetation successional stage (Ward et al. 1999). This expansion of habitat provides important nursery areas for fish and abundant forage habitat for invertebrates, fish, amphibians, reptiles and birds. Regular flooding increases floodplain fertility, and the abundance of food resources for fishes and other aquatic and wetland-dependent species. Forage for invertebrates and vertebrates may increase to the point where it is not limiting to species abundance or individual growth (Junk et al. 1989).

The natural flow and stage regime of a river is thought to maintain maximum biodiversity at an intermediate level of connectivity between the channel and floodplain (Ward et al. 1999). Low connectivity with the floodplain fragments and reduces habitat, and excessive connectivity homogenizes habitat, thereby reducing biodiversity (Ward et al. 1999). Naturally receding floodplain stage creates ephemeral, heterogeneous and irregularly distributed areas of shallow water with concentrated prey for wading birds and other animals (Battley et al. 2003, Gimenes and Anjos 2011). Reduction of flood levels reduces foraging habitat causing concomitant reductions in diversity and abundance of wading birds (Kushlan 1993, Kingsford and Thomas 1995).

Floodplain inundation enhances dispersal and recruitment and may be important to the population dynamics of many fish species (Copp 1989, Leitman et al. 1991, Hill and Cichra 2005). Prolonged periods of high stage allow fish, invertebrates and other species to migrate from the channel to the floodplain, to foraging and spawning habitats. Seasonal floodplain inundation has also been associated with increased spawning activity and production of riverine fishes (Bayley 1991, Burgess et al. 2012). While some fish species spawn opportunistically within the channel, reproductive cues for some species are tied to timing of rising river stage and floodplain inundation (Bunn and Arthington 2002). Duration of floodplain inundation can influence growth potential and recruitment success for some fish species (see review in Poff et al. 1997, Sommer et al. 2001). Increased stage in the floodplain also provides increased forage opportunities for numerous species of mammals and birds (Postel and Richter 2003). High flood stages that increase lateral connectivity between the main channel and floodplain (and backwater sloughs, etc.) are critical to the many life-history process of aquatic and wetland-dependant species (e.g., invertebrates, fishes, turtles, alligators, wading birds, etc.; Bunn and Arthington 2002, King et al. 2003, Arthington 2012).

Natural instream flow variability and magnitude can also influence macroinvertebrate and fish communities through density-dependent interactions. By changing the relative area (or habitat volume) of different types of habitat within the channel and/or floodplain, as well as accessibility to floodplains, backwaters and off-channel structures, natural flood variability often shifts the competitive advantage of different species over time. Therefore, flow-mediated environmental variation can lead to long-term community stability and increased biodiversity within riverine systems (Grossman et al. 1998, Taylor et al. 2006). Loss of high flows has been shown to impact aquatic communities through reduced diversity, altered assemblages and dominant taxa, reduced abundance and increased exotic species (Poff and Zimmerman 2010). Some research suggests that flood flows may remove exotic fish species while also improving spawning habitat conditions for natives (Marchetti and Moyle 2001).

In addition to creating spatial and temporal habitat patchiness, flow variability also affects aquatic communities through natural selection (Facey and Grossman 1992, Bunn and Arthington 2002, Lytle and Poff 2004). Biota within a given riverine system have evolved life history strategies in response to the natural range of hydrological and hydraulic conditions in that system (Townsend and Hildrew 1994, Poff et al. 1997, Richter et al. 1997). Critical life-history events, for both animals and plants, are tied to short and long-term flow variability. Frequency and timing of high flood stages and flows provide for life-cycle transitions for fish (e.g., movement to floodplain, spawning cues, migration upstream; Poff et al. 1997). Some adaptations are manifest as behavioral responses, such as the flow-induced increase in downstream drift of many macroinvertebrate species. Other types of behavior (e.g., spawning) and emergence from diapause of macroinvertebrates, benthic microorganisms and zooplankton are also linked to rate and magnitude of rising flood waters (Bunn and Arthington 2002). Morphological and behavioral adaptations of some fish species confer a competitive advantage in heterogeneous flow environments (Facey and Grossman 1992, Bunn and Arthington 2002, Lytle and Poff 2004). Therefore, flow regime alterations may reduce the fitness and long-term persistence of some species (e.g., darters, benthic minnows) that are suited to high or variable flow (Carlisle et al. 2010). Reduced maximum and minimum flows has been shown to change fish and macroinvertebrate community composition, favoring those species that can leave unsuitable conditions (e.g., strong swimmers, fast crawlers) or that prefer fine versus coarse substrate (Carlisle et al. 2010). Flow also influences lotic assemblage structure and recruitment by distributing adults and early life stages of fish and invertebrates among different habitats and by aerating fish nests and eggs (see reviews in Poff et al. 1997 and Arthington 2012). For large, low-gradient floodplain rivers, continued connectivity between the channel and floodplain is critical to their diversity, production and long-term ecological integrity (Junk et al. 1989, Sparks 1995, Arthington 2012).

Aquatic macrophyte assemblage structure is, in part, determined by flow. Physical processes mediated by flow include direct scour, substrate stability, micro-scale variability in velocity and shear stress (Wetmore et al. 1990, French and Chambers 1996). Macrophyte location is often patchy within a river. A major driver of this patchy distribution is flow and shear stress variability. Spatial variability in disturbance (i.e., flood flow) frequency and magnitude results in variations in persistence and recolonization (Rea and Ganf 1994, Bunn and Arthington 2002). Reduced flow or flow variability can negatively influence recruitment of floodplain plants, transport of seeds, nutrient availability, and removal of metabolic waste products. Reduction of high flows can impact aquatic macrophyte communities by reducing scour and thereby reducing habitats suitable for recolonization.

Riparian vegetative communities are also structured by flood flows that scour floodplain soils, remove competitors, and saturate soils (Bunn and Arthington 2002). Location and structure of riparian and floodplain vegetative communities are determined, in part, by water table elevation and soil moisture. Frequency and duration of flooding influence distribution, abundance and diversity of plants within floodplains and wetlands adjacent to the river channel (Nilsson and Svedmark 2002). Alterations to flood stage magnitude, duration and frequency can affect plant community succession, boundary location and persistence (Arthington 2012). The natural variability of flooding events is necessary to maintain the native diversity of riparian plant communities, and plants species within a community (Postel and Richter 2003). Natural duration and frequency of de-watering events are also essential, as they allow for soil decomposition, nutrient transformation and recruitment of wetland plant species that need moist, non-inundated soils for natural regeneration (e.g., cypress). Elevated water tables in the floodplain and riparian margin also provide seedlings with prolonged soil moisture, necessary during establishment (Arthington 2012). Flood frequency and timing are also of importance because the life cycles (e.g. seed dispersal, germination etc) of many riparian plant species are adapted to a natural flow regime (Poff et al. 1997).
Note: Literature cited is listed in main MFLs report.