WEEKI WACHEE NATURAL SYSTEM CARRYING CAPACITY STUDY-ANALYSIS AND REPORTING (WW06)

TASK #4

FINAL REPORT

Prepared for

Southwest Florida Water Management District
Brooksville, Florida

and

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EXECUTIVE SUMMARY

Introduction

Wood Environment & Infrastructure Solutions, Inc. (Wood) was contracted by Southwest Florida Water Management District (SWFWMD) to conduct an ecologically-based carrying capacity study to evaluate the effects of recreational use on the natural systems of the Weeki Wachee River in western Hernando County, Florida. The Weeki Wachee River is a first magnitude spring run fed primarily by the main headspring and a few other smaller spring vents. From the headspring, the river flows approximately 7.5 miles to the Gulf of Mexico, which provides tidal influence on the lower part of the river. The headspring is located within the Weeki Wachee Springs State Park (State Park), which features a water park and the famous underwater mermaid show. The State of Florida designated the spring and the river segment within the State Park as an Outstanding Florida Spring (OFS) and an Outstanding Florida Water (OFW), respectively. Weeki Wachee Springs and River have exceptionally clear water and abundant natural vegetation and wildlife, making the river a destination for visitors from around the world. SWFWMD designated the springs and river as a Surface Water Improvement and Management (SWIM) priority water body and developed a SWIM Plan in 2017 to provide a strategy to effectively conserve, manage, and restore this very important natural resource.

Study Purpose

The Weeki Wachee River is a popular recreation destination. Its growing popularity and increased visitor traffic have led to concerns about potential degradation of the river and its ecosystems. Preliminary site investigation suggested that exposed sandy beaches on river bends (point bars) have resulted, in part, from vegetation and soil losses due to recreational use. The carrying capacity study was designed to collect scientifically-based data associated with recreational activities along with better understanding the relationships between recreation, water quality, ecological, hydrological, and geomorphological characteristics. The collected data were used to assess potential impacts of recreation on the river and to help guide future studies and management decisions relating to recreation along the Weeki Wachee River.

Study Components

This study was designed to include multiple weights of evidence in regard to recreational impact, such as the following components, which are explained in detail in later sections.

- Collection of water quality data using grab samples and continuous sonde deployments that were coupled with recreational counts in the field and from video camera footage.
- Characterization of recreation by analyzing and summarizing recreational data collected by this study and State Park vessel launch data.
- A fluvial geomorphology assessment, including interpretation of aerials for changes in point bar vegetation, experimental assessment of vegetation trampling, comparative assessment within a similar, less-impacted spring run, and a cumulative assessment of point bars throughout the Weeki Wachee River.

- Multivariate statistical analyses with water quality, recreational and hydrologic data to assess relationships between recreational use and environmental responses.

Water Quality and Recreational Use Data Collection

Water quality and human use (recreational activity) data were collected over the course of one year, from July 2018 to June 2019 at four stations along the river that were selected to represent various intensities of recreational use.

Characterization of Recreation

The long-term dataset of vessels launched from the State Park (July 2012-June 2019) showed significantly increasing trends in average daily launches, with a long-term average of approximately 185 vessels per day and a maximum of 687 vessels per day. The highest number of vessels launched daily from the State Park were recorded in May 2016.

The field and camera user count data collected during the study showed that higher numbers of vessels and users occurred on holidays and weekends as compared to weekdays. At downstream stations closer to Rogers Park, higher user counts were also recorded as compared to upstream stations closer to the State Park. Approximately 50% of vessels counted at downstream stations were found to be traveling upstream. This is compared to only 3 to 10% of vessels travelling upstream at the upstream stations that were closer to the State Park. Throughout the river, approximately 90% of all vessel traffic was composed of kayaks, while paddleboards, motorboats, and canoes made up the remaining 10%. The station closest to Rogers Park received the most motorboat traffic, docked vessels, and people wading/swimming, although the station located at the original park exit sign had the highest percentage of passing vessels that stopped to dock at the point bar. Results from the social surveys found that the majority of visitors claimed to enjoy the river and recommended it as a place to view wildlife and crystal-clear water and about 80% of them docked and recreated on point bars. However, many visitors found the river to be over-crowded, and several long-time visitors noticed changes in submerged aquatic vegetation and an increase in the number of visitors over the years.

Fluvial Geomorphology Assessment

Fluvial geomorphology, or the interaction of flowing water with its environment, is influenced by climate, topography, soils, land use, and activities within the river and its watershed. A series of assessments were performed to gain an understanding of the geomorphology of the Weeki Wachee River and how it has been potentially impacted from recreation.

To observe and document apparent changes in vegetation and morphology of point bars through time, a series of aerials were assessed for vegetated cover. The 2008 imagery showed intact (fully vegetated) point bars, while subsequent aerials up to 2017 (most recent available) showed cumulative reductions in vegetation starting as early as 2011, which predated when count data were recorded by the State Park. The pattern of vegetation loss since 2008 suggests that a threshold of impactful use occurred before the peak in recreational use, which occurred in May 2016. Since the initial impacts predated the available launch count data, caution should be used when trying to use vessel launch numbers and apparent recreational damage to the point bars based on aerial imagery as a means for assigning a number of users when developing a management plan for recreational use. The in-water and on-bar activities likely had a great impact on the bar morphology and vegetative coverage and need to be a major consideration in management decisions.

An experimental recreational trampling assessment was conducted to measure impacts to vegetation and soils on three vegetated point bars within the State Park boundary. The initial trampling event occurred in May 2019 with follow-up visits after 2 weeks and 6 months after the trampling event to observe initial impacts (after 2 weeks) and during the reestablishment period (after 6 months). Two weeks and six months after the trampling impact occurred, all trampled plots showed increases in exposed soil and dead vegetation, with observable reductions in relative vegetative cover and organic soils within the soil profiles. During the reestablishment/recovery stage (six months after the trampling impact), it was evident that the trampled plots were still highly altered, but that wetter conditions likely influenced the potential recovery of the soils and vegetation. Overall, the experimental trampling assessment showed that 1) even a small amount of trampling can greatly impact vegetation and organic soils, 2) trampling increases turbidity in the river, and 3) vegetation on the submerged edges of the point bars are most likely to be extensively impacted. In addition, a follow up visit at the one-year mark (May 2020) that represents hydrologic conditions similar to the trampling event is needed to better assess recovery status of the impacted plots.

To view the apparent recreational impacts at the Weeki Wachee River in a larger context of first magnitude spring runs, a comparative site assessment was conducted between four randomly selected point bars each on the Weeki Wachee River and at Alexander Springs Run, which is less impacted and has similar fluvial geomorphic characteristics. Overall, the point bars at Alexander Springs were more ecologically intact than those at Weeki Wachee, with full vegetation coverage and ample organic soils. The point bars that were evaluated at Weeki Wachee often exhibited bare, sandy “denuded” zones, where vegetation and organic soils have been lost to damage and erosion. Another important recreationally-induced geomorphic feature common at Weeki Wachee point bars, but not observed at Alexander Springs, was a scarp, or ledge on impacted bars where vegetation and organic soils appear to have been carved out by vessel docking and/or trampling. The scarps were generally around 1 to2 ft tall, which was interpreted as the approximate depth of organic soil loss on the impacted point bars.

To evaluate the overall condition of point bars along the Weeki Wachee River, a cumulative assessment of point bars was conducted at 10 randomly selected point bars between the State Park and Rogers Park. Similar to the comparative study methodology, topographic, vegetation, and soil data were collected in each ecological zone. Denuded zones and scarps were observed at most of the bars averaging 74 ft in length, 13 ft in width, with 1 to 2 ft scarp depths. Along the river, 24 additional scarps were observed and measured. Using the approximated areas of denuded bar zones and depth of scarps at the 34 point bars assessed, it appears that an estimated 1,000 CY of organic soils and 20,000 square ft of vegetated bar area may have been lost.

Statistical Analysis to Assess Recreational Impacts

Turbidity was selected as a representative response variable to assess relationships between recreation and impacts to water clarity and quality of the river. Recreational use and turbidity data from the study period were used in multivariate statistical analyses to test if recreational variables and turbidity are related, while controlling for spatial and temporal variability. The statistical analyses provided empirical evidence that cumulative number of vessels/users and in-water activities such as docking, wading, and swimming contributed significantly to turbidity along the river, which suggests that recreation has negative effects on water quality. Although turbidity concentrations were found to be relatively low in comparison to state water quality standards and other rivers, small changes in turbidity could have ecological implications on submerged aquatic vegetation by increasing sedimentation and reducing light availability.

Management Options

The data and observations from this study were used to develop a preliminary list of possible management options that could potentially reduce further recreational impacts. The options provided for consideration include additional river stewardship education through recreational guidance signage and outreach programs, reestablishment of key vegetation communities and organic soils on impacted point bars, continued removal of rope swings, changes in boat docking practices to reduce direct impacts to vegetation, or reinforcement of banks or trees susceptible to erosion. Possible regulatory management options include extension of State Park regulations and restrictions down to Rogers Park, partial or complete restrictions on exiting vessels, evaluation of restricting vessel types, sizes, or engine sizes, and evaluation of possible further restrictions on the number of users or vessels allowed to access the river per day. Potential additional studies or plans to provide more information and additional management options include revisiting the trampling plots after one full year of recovery, studies of tree falls, bank undercutting, and sufficiency of tree snags as habitat, studies on sufficiency of clearing ordinances and wetland buffer distances along the riverfront, development of a river-wide management plan, and a study tracking effectiveness of implemented management options. Finally, to effectively review results from this study and proposed management options, a multi-agency working group should be convened to work together to pursue a path to implement the most appropriate options that would align with jurisdictions. Effective methods to enforce the selected management options could also be evaluated by the working group.

1.0 INTRODUCTION

Wood Environment & Infrastructure Solutions, Inc. (Wood) was contracted by Southwest Florida Water Management District (SWFWMD) to conduct an ecologically-based carrying capacity study to evaluate the effects of recreational use on the natural systems of the Weeki Wachee River in Hernando County, Florida (**Map 1**). The study is intended to provide information that will assist resource management decision making to reduce, mitigate, and manage ecological impacts on natural systems from recreational usage. This report provides a description of the resource and study purpose (Section 1), water quality and recreational use data collection (Section 2), a characterization of recreation (Section 3), a fluvial geomorphic assessment (Section 4), a statistical analysis to assess recreational impacts (Section 5), and management options to balance recreation and environmental factors (Section 6).

1.1. Location and Hydrology

The Weeki Wachee River in western Hernando County is fed primarily by the first magnitude (spring that discharges greater than 100 cubic feet per second, cfs) main headspring. The headspring and upper part of the river is located within Weeki Wachee Springs State Park (State Park) and discharges an average of approximately 170 cfs[1] (**Map 1**). Smaller spring vents such as Twin Dees (near the headspring), Salt Spring, Mud River Spring, and Hospital Hole also discharge along the length of the river (DRP 2011). The river extends approximately 7.5 miles from the headspring to the Gulf of Mexico and the lower river is tidally influenced. Weeki Wachee Springs is designated as an Outstanding Florida Spring (OFS), and all waters within the State Park are designated as Outstanding Florida Waters (OFW). The State Park also features a water park and the famous underwater mermaid show and is open to visitors year-round. Weeki Wachee Springs and River have exceptionally clear water and abundant natural vegetation and wildlife, making the river a destination for visitors from around the world. SWFWMD designated the springs and river as a Surface Water Improvement and Management (SWIM) priority water body and developed a SWIM Plan in 2017 to provide a strategy to effectively conserve, manage, and restore this very important natural resource.

For purposes of this study, the river was divided into 4 functional process zones (FPZs[2]) from the headspring at Weeki Wachee Springs State Park to Rogers Park, the downstream end of the study area (**Map 2**). FPZ-1 extends from the headspring to just below the previous State Park boundary[3] and is characterized as more karst with limestone rock outcroppings and high banks with upland bluffs. FPZ-2 extends from the previous State Park boundary to just below the new State Park boundary and is more alluvial in nature. Here, the channel is deep and narrow with numerous tight bends exhibiting well-developed point bars. It courses through a meander belt consisting of a mix of high and low banks with both wetland and upland floodplain communities. FPZ-3 extends

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[1] Average calculated from stream flow data at USGS station 02310500 (February 1917-February 2010).

[2] An FPZ is a portion of a stream valley with an internally consistent set of existing or projected controlling biophysical conditions that are based on geomorphic characteristics. Moreover, FPZs are segments of the stream that share common flow, channel, and habitat characteristics.

[3] The State Park boundary was extended approximately 1-mile downstream of the original boundary in October 2018.

from just below the new State Park boundary (**Map 2**) to approximately 1 mile upstream of Rogers Park and is characterized by more uniformly low banks with wetland communities that experience overbank flooding during the wet season. Part of this segment is tidally-influenced. FPZ-4 begins 1 mile upstream of Rogers Park and exhibits a wider and shallower channel than the other FPZ segments. This suggests it is an area subject to greater sediment accumulation as the river increasingly approaches the tide, which was also noted by a sediment transport study that was conducted to support the restoration and design of a section of the lower Weeki Wachee River (VHB 2019). It is also the most developed segment with private homes, associated sea walls, and various canal inputs.

1.2. History of Cultural Resources

A group of developers and investors entered a 30-year lease with the City of St. Petersburg in 1946 for the land surrounding the headspring, and the first underwater theater for mermaid shows was opened in 1947. Weeki Wachee Springs gained popularity and was operated as one of Florida's premier roadside tourist attractions. The 12 historic structures associated with the mermaid show attractions are included in the park's cultural resources along with 6 archaeological sites (DRP 2011).

The Buccaneer Bay waterpark was opened in 1982, featuring a sand beach, waterslides, and a swimming area. Sand of an unknown origin was brought to the headspring to create the Buccaneer Bay beach in 1982, and when the sand was periodically transported downstream from rain events, it was dredged and reapplied to the beach, until construction of a retaining wall in 2006 to hold the sand in place (DRP 2011).

Approximately two miles downstream of the State Park, the Florida Fish and Wildlife Commission (FWC) opened "The Bluffs", which are the Weeki Wachee Tract of the Chassahowitzka Wildlife Management Area (shown in Map 2) for public recreation after acquiring the land in 1995 (FWC 2007). Between 1997 and 2003, large sections of the natural sandhill bluff eroded, contributing sand into the river that has been transported downstream over time (FWC 2007)

1.3 History of State Park

The Florida Department of Environmental Protection (FDEP) Division of Recreation and Parks (DRP) manages the Weeki Wachee Springs State Park (previously Weeki Wachee Park attraction), which includes the underwater theater, Buccaneer Bay waterpark, and the river cruise near the headspring (DRP 2011). On November 1, 2008, DRP leased 538 acres of property surrounding the spring and river from SWFWMD under a 50-year lease, and the lease states that the DRP manages the State Park only for the conservation and protection of natural and historical resources and for public recreation that is compatible with the conservation and protection of the property (DRP 2011). In February 2010, the DRP became authorized to operate underwater structures related to the amphitheater and waterpark, operate a boat tour, and to launch kayaks/canoes through a 25-year sovereign submerged lands lease agreement with the Board of Trustees of the Internal Improvement Trust Fund of the State of Florida (DRP 2011).

1.4 Purpose of Study

The growing popularity of the Weeki Wachee River as a recreational amenity has led to concerns from riverfront property owners, residents, river advocates, and state and local government officials about the state of the river and the ecosystems it sustains. The purpose of the carrying capacity study was to record and document spatial and temporal data associated with recreation occurring in the river along with water quality, ecological, hydrological, and geomorphological data to assess the effects of recreational activities on the river system. The intention of the study was not to set a specific value of vessels or users allowed on the river, but to collect and analyze data that relates human use to water quality, hydrologic, geomorphic, or ecological degradation of the river. The data and findings of this study can be used to inform management actions relating to recreation on the Weeki Wachee River.

This approach recognizes that entities with jurisdiction to manage the river and associated ecosystems may elect to protect the river through a variety of means in addition to, or in lieu of, limiting the types and numbers of vessels. This is apparent given that some of the most severe alterations to the river are associated with people leaving their vessels and trampling habitat. Some examples of potential protective approaches include banning harmful activities, installing ecological restoration treatments, increasing public education and enforcement of existing restrictions, and providing designated sites engineered for vessel docking and other recreational activities away from ecologically sensitive areas, among others. Successful management of the river will likely require a multi-faceted strategy combining vessel limits with other approaches, especially activity restrictions. The first step to recovering areas of the river that have already been impacted and to protect areas that have not yet been impacted, is to scientifically describe the harm in association with recreational use and quantify it using the best available information, which is the intent of this report.

The study approach includes interpretation of existing data, new data collection, and an onsite field experiment. Given that harm has already occurred in some areas on the river, this study is at least partially forensic in its design relying on weight-of-evidence from multiple lines of investigation and a body of existing data to draw conclusions. Existing available data include high-resolution aerial photographs from multiple years, river flow, sediment transport, water quality, and the number of vessels originating from the State Park over various time frames. The study also includes a variety of original data development aimed at concurrently documenting visitor usage and recreational activity with water quality changes, habitat loss, channel morphology changes, and user perspectives. Those aspects of the study enabled Wood's scientists to make direct observations regarding how the river is being used and what impacts occur during such use. The study also includes a field experiment regarding the sensitivity of point bar vegetation to trampling, and a biophysical comparison of relatively untrampled point bars from another intact and less impacted spring-fed river. That combination of experimentation and comparison aims to describe what a healthy point bar should look like and enhances understanding of how and why the Weeki Wachee's point bars depart from a more natural condition. As will be discussed in more detail, much emphasis was placed on evaluating point bar ecological condition as these are highly altered and heavily recreated on the river. Healthy point bars can be sensitive indicators of a healthy river and disturbance of point bars can contribute to disbursement of an abnormal magnitude and distribution of sediment transport into downstream areas of the river.

In summary, this study examines and describes past and present recreational impacts along the river, plus an experimental test of point bar sensitivity to human trampling that can be used to better inform decisions regarding caps on users and restrictions on harmful activities in ecologically sensitive areas.

2.0 WATER QUALITY AND RECREATIONAL USE DATA COLLECTION

In the data collection phase of the study (TWA 18TW0001601), Wood, in collaboration with SWFWMD and FDEP via in-kind services agreements, performed water quality sampling and lab analysis and human use sampling through visitor counts and surveys, as described in the following sections.

2.1. Instantaneous Sampling: Field Counts/Grab Samples

2.1.1 Sampling Events and Locations

Wood collected water quality and human use data during 9 sampling events from July 2018 to June 2019 at four stations: WW1, WW2, WW3, and WW4 (**Map 3**) During 5 of the 9 events, an additional site, WW5, was monitored by a SWFWMD staff member. Sampling stations were selected based on data collected during a field reconnaissance conducted by Wood staff on 6/19/2018. This reconnaissance and previous investigations strongly suggested impacts to formerly vegetated point bars at river bends, which subsequently became exposed sandy beaches. Thus, the goal of the site selection was to select point bars which covered varying degrees of recreational use and which spanned the various FPZs. Point bars are geomorphic features occurring along the inner bend where sand is deposited forming a gently sloped bar. The outer portions of these bends are characterized by deeper pools. The relatively shallow depths and gentle slopes of point bars are welcoming locations to dock a vessel for a break from paddling or disembark to wade, swim, or snorkel into the deeper waters of the outer bend.

The first sampling station selected, WW1, was chosen as a control site, as it is within the State Park boundary where visitors have always been informed not to exit their vessels. Sampling location WW2 was selected because it was the point bar located immediately beyond (i.e. downstream) the original State Park boundary exit sign[4], where visitors were first allowed to dock and exit their vessels and recreate. During the field reconnaissance, it was observed to be one of the most popular recreation point bars along the river. Sampling location WW3 was chosen because it is a point bar toward the middle of the river run that experiences a moderate amount of recreation. It is located just upstream of "the Bluffs," which is currently being constructed as an early take-out location (midpoint) within the new State Park boundary. Sampling location WW4 was chosen because it is a point bar toward the downstream end of the run (near Rogers Park) that experiences high recreation from visitors traveling both upstream and downstream and because it had a rope swing at the time of site selection.[5] WW5 is a high recreation site with a tree jump and a rope swing (one on each bank), located upstream of WW4 but within the same FPZ.

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[4] In October 2018, the State Park boundary was extended to the "new Park exit sign" location shown in **Map 3**. However, the "original Park exit sign" was never removed during the study. Because the original Park exit sign was never removed, users continued to dock and exit their vessels at WW2 at the same rate as was observed prior to the extension of the park boundary. Therefore, the new State Park boundary sign appeared to have no effect on the study.

[5] The rope swing tree at WW4 was struck by lightning and fell between the August and September 2018 events; therefore, the rope swing was only present for the first two sampling events.

Sampling events occurred once per month during the high recreation season (May-September), and every other month during the low recreation season (October-April). The sampling events also included holidays such as 4th of July long weekend, Labor Day, and Memorial Day. The dates of sampling events are provided below. Note that events with an asterisk indicate sampling events that included WW5.

- July 5, 2018 (4th of July long weekend)
- August 7, 2018
- September 3, 2018 (Labor Day)
- October 2, 2018*
- December 19, 2018*
- February 19, 2019*
- April 24, 2019
- May 27, 2019 (Memorial Day)*
- June 24, 2019*

2.1.2 Data Gathered

Human use data were gathered in the form of hourly total counts of both vessels and users. A “vessel” was defined as one boat of any type (kayak, canoe, motorboat, paddleboard, or other), and a “user” was defined as a human individual in a vessel (kayaker, canoer, motorboat driver or passenger, etc., not including infants, dogs, or other pets on board). Vessel counts were tracked in both the upstream and downstream directions, which is termed a “pass” in either direction and each directional pass was counted individually. Additionally, staff recorded hourly totals of vessels docked on the point bar and hourly totals of people that exited their boats to wade, swim, or recreate on the point bar. Staff also noted types of recreational activities at the point bars, size of boat motors (when possible), and any obvious changes in water level, vegetation, or soils. Photographs were taken at each point bar at the beginning of each sampling event and are provided in **Appendix A**. At the downstream stations (WW4 and WW5), social surveys were conducted with randomly selected groups of users to get information on vessel launch locations, recreation times and activities, and any concerns related to recreational use of the river. The standard questionnaire used in the social surveys is provided in **Appendix B**.

Additionally, tree jump/rope swing data were collected at sites WW4 and WW5. The hourly total number of rope swing jumps was recorded at WW4 for the July and August events, but the tree was struck by lightning and fell before the September event. The hourly totals of rope swing/tree jumps were collected at site WW5 for the October, December, February, May, and June events.

For the first two sampling events, the hourly counts began at 8:30, and were taken on the half hour until 16:30. Because users were observed on the river before 8:30 and were mostly off the river by 16:00, the sampling schedule was shifted to span from 8:00 to 16:00 for subsequent events to capture the earlier recreational usage.

Water quality sampling was also conducted during the 9 sampling events. Water quality parameters related to recreationally-induced sediment transport and subsequent water clarity declines were selected to assess potential effects of recreation on water quality conditions. The sediment/clarity surrogate parameters that were evaluated as part of this study were total suspended solids (TSS), volatile suspended solids (VSS), and turbidity, which have been found to be good proxies for modeling optical water clarity in clear spring-fed systems such as Weeki Wachee River in other studies (Szafraniec 2014). The evaluation was based on answering the question that asked if recreation at certain levels may be impacting water clarity and quality conditions in the river.

At each station, two grab sample bottles were filled 0.3 m below the water surface once every two hours, with the first sample at 8:00 and the last sample at 16:00 (8:30-16:30 for the first two events), for a total of 5 samples (10 bottles) per site, per event. Quality control samples (i.e. field blank and a duplicate) were also collected during each sampling event. The samples were preserved on ice and transported to the FDEP Analytical Chemistry Laboratory in Tallahassee, where they were analyzed as part of an in-kind services agreement for this project. The FDEP lab analyzed the grab samples for TSS, VSS, and turbidity. It should be noted that if severe weather was forecast, grab sample collection times were adjusted to an hourly basis. Weather related time adjustments occurred during the September and December sampling events.

2.2. Continuous Sampling: Video Camera/Sonde Deployments

2.2.1 <u>Video Camera Deployment and Counts</u>

Video cameras were installed across from and facing the point bars at sampling sites WW1, WW2, WW3, and WW4 to make observations on vessels, users, vessel docking, users wading/swimming, and presence of wildlife over two-week intervals. The digital video data were collected by Wood, delivered to SWFWMD. Counts and observations were recorded as part of in-kind services by SWFWMD staff. To correspond to field count data, the video-recorded users (total), vessel passes (upstream and downstream), docked vessels, and people wading/swimming were recorded as hourly totals, with time intervals matching the field sampling events (8:30-16:30 for the first two deployments and 8:00-16:00 for the remaining deployments).

The video cameras were deployed for 6 two-week periods overlapping the field sampling events. The camera deployment schedule was as follows:

- 6/29/2018 – 7/16/2018
- 8/28/2018 – 9/17/2018
- 12/5/2018 – 12/19/2018
- 2/6/2019 – 2/19/2019
- 4/10/2019 – 4/24/2019
- 5/22/2019 – 6/5/2019

2.2.2 Water Quality Sensor Deployment/Retrieval

This monitoring component was accomplished as part of a collaborative effort that included in-kind services from both the SWFWMD Data Collection Bureau (DCB) and the FDEP's Southwest Regional Operation Center. The SWFWMD DCB staff provided 4 calibrated multiparameter water quality data collection sondes to the FDEP ROCS staff to deploy at the 4 sampling locations (WW1, WW2, WW3, WW4). Each sonde collected continuous dissolved oxygen, temperature, specific conductance, pH, and turbidity, recorded at 30-minute intervals (on the hour and half-hour). The FDEP ROCS and SWFWMD DCB staff coordinated on data retrieval, proper QA/QC, and sonde maintenance at the end of each deployment period. The water quality sonde data were processed and compiled by Wood and used for statistical analysis. The sondes were deployed for 6 two-week periods during the same time periods that the cameras were deployed.

2.3. Changes Observed During the Study

Over the course of the study (June 2018-July 2019), several changes occurred on the river that may pertain to the study and should be noted but were not found to influence the results of the study. The changes observed during the study are provided below:

- The State Park boundary was extended approximately 1-mile downstream of the previous location. New exit signs were erected at the new boundary; however, the previous upstream boundary exit signs remained in place throughout and after the study was complete. It was observed that users still docked and exited their vessels upon reaching the previous boundary sign at similar rates as before the boundary was moved further downstream. Therefore, the Park boundary change did not influence data collection results.
- In October 2018, the State Park began limiting launches by the number of users on the river per day rather than by the number of vessels per day. In addition to the existing 4-hour time limit, launches from the State Park ended by noon. Additionally, a disposables ban was enacted in January 2019, whereby no disposable items (including any alcohol) can be brought into the State Park through a thorough cooler and bag check at the State Park's concession. Although these changes did not affect the results of the study based on the number and temporal distribution of the samples collected, accounting for these changes is highly useful information because it shows that activity restrictions such as the disposable ban can be a productive management tool and it also shows that user limits can be effectively enforced at controlled access points.
- Garbage cans were observed at stations WW4 and WW5 during the September sampling event. They were placed there temporarily to curb litter. Based on Wood and FDEP's staff observations during the sampling events, it did not appear that the garbage cans drew more people to stop at those point bars. However, during one event the garbage can at WW5 appeared to have been knocked over by wildlife. The garbage cans were removed and do not appear to have influenced data collection results.

- The tree used for jumping/swinging at WW4 was struck by lightning and fell after the 8/17/2018 sampling event. The numbers of people that stopped at WW4 were still relatively high even after the tree fell, but it appeared that fewer people may have stopped once that tree was gone. As might be expected, this shows that rope swings may draw people to stop and recreate at areas focused near them.
- In May 2019, Hernando County Sheriffs increased controls on the river by providing a marine patrol deputy. The patrol staff noted that patrol presence noticeably changed types of recreational behaviors on the river.
- Lastly, photographs were taken at each sampling site at the start of each sampling event. A series of photographs by site is provided in **Appendix A**. Samplers at WW2 and WW4, the high recreation bars, observed increased erosion over time at particular spots on their respective point bars as users docked their vessels onto the banks.

3.0 CHARACTERIZATION OF RECREATION

Several datasets were used to characterize the counts and types of vessels and recreational activities along the Weeki Wachee River. Field and camera count data provided spatial and temporal recreational vessel/user data during the study period (July 2018-June 2019), while counts of vessel launches from the State Park provided a long-term dataset to assess historical patterns and trends.

3.1. State Park Count Data

The State Park provided daily total counts of vessels launched from their facilities from 7/1/2012 to 6/1/2019 (State Park fiscal year, FY, starts July 1st and ends June 30th). **Figure 3.1** shows the total vessel launches (left panel) and the daily average launches (right panel) for each FY by type (park concession, private, outfitter, and total). The total and daily average launches from the State Park increased each FY by approximately 20,000 vessel launches per year and 50 vessel launches per day between FY 2012/2013 and FY 2015/2016, when vessel launches peaked at approximately 90,000 per year and an average of 250 per day. While no data for launches from the State Park area were available prior to 2012, staff have stated that the vendor owned 60 kayaks in years prior.

Figure 3.1 – Long-Term State Park Vessel Launch Data (by Fiscal Year)

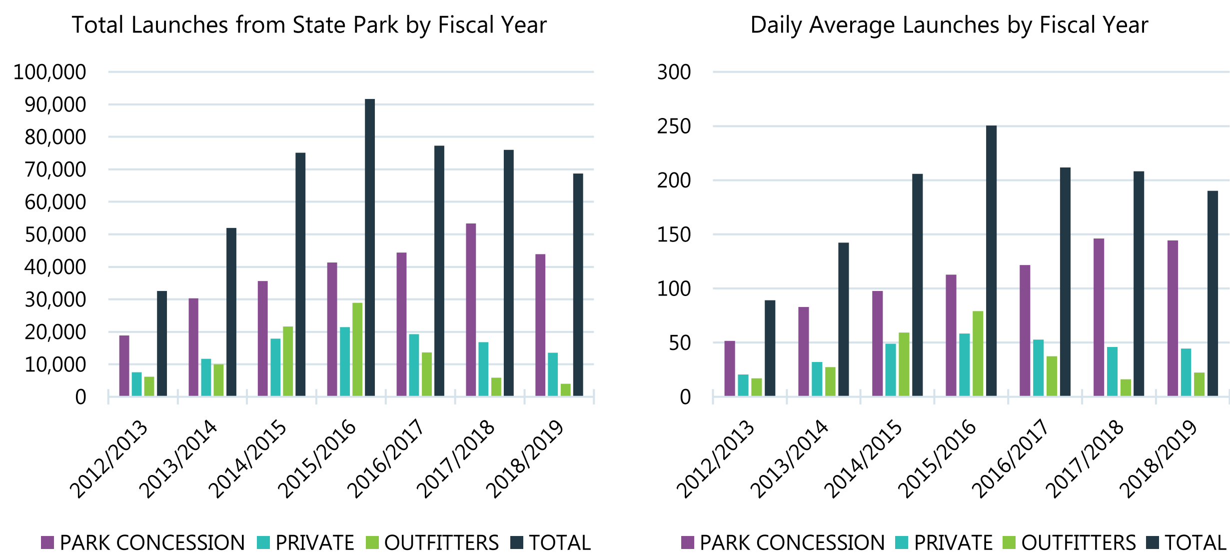
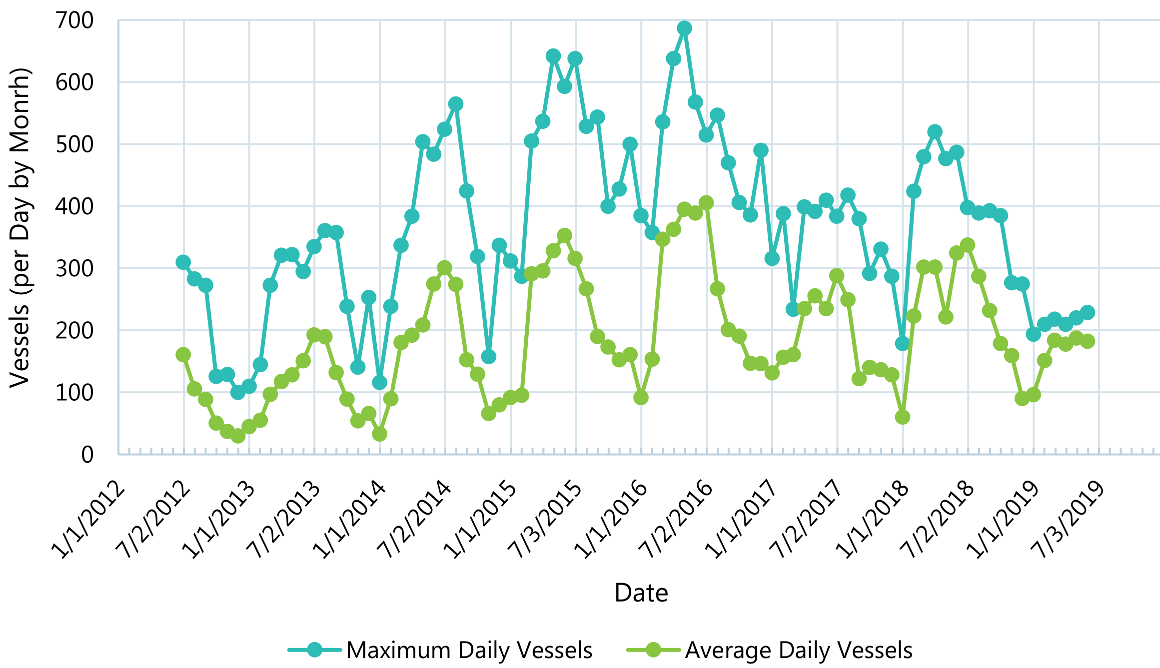


Figure 3.2 shows maximum and average daily total vessel launches from the State Park by month. The plot shows a seasonal pattern in recreation, with peak use in summer months and lower use in winter months. Total vessel launches peaked in May 2016, with an average of approximately 400 vessels per day and a maximum of nearly 700 vessels per day. It should be noted that the Weeki Wachee Springs State Park Unit Management Plan (UMP) (approved June 28, 2011) estimated the optimum carrying capacity of the canoe/kayak use on the river to be 280 users per

day[6], which is approximately equivalent to 192 vessels per day (calculated from a regression equation using Wood study data of kayaks and canoes vs. users: Users = 1.46*Vessels). A change to the way the UMP was being enforced occurred in October 2018. Additionally, the disposables ban went into effect in January 2019. The new enforcements occurred later during the study and may have reduced the number of vessels that launched from the State Park. But it is unknown what other factors may have also led to the reduction from previous years.

Figure 3.2 – State Park Daily Total Vessels (Max and Average Monthly Values)



3.2. Field Count Data

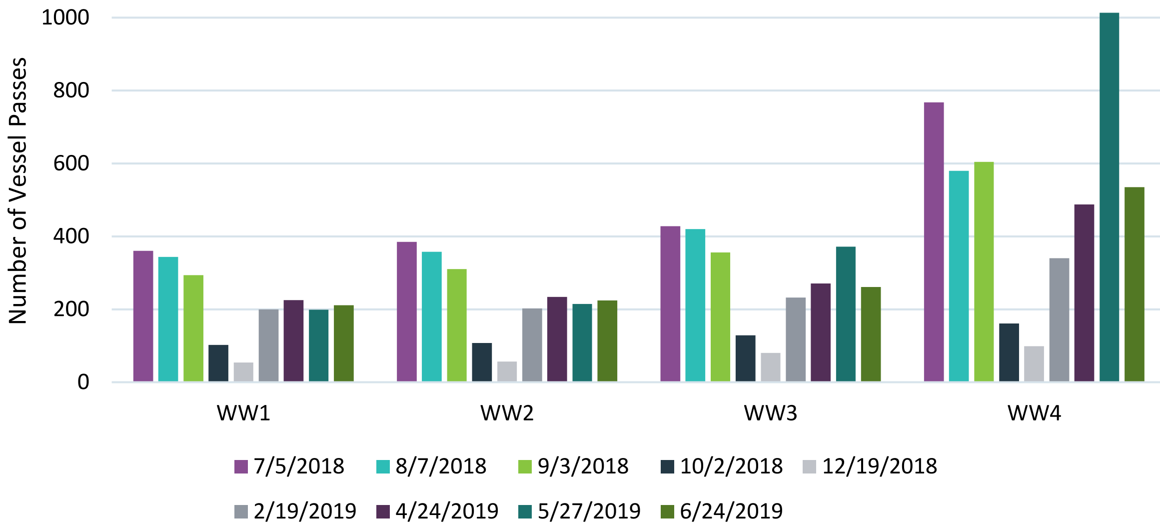
3.2.1 <u>Total Counts</u>

During 9 sampling events, Wood field staff tracked the number of users and vessels that passed each sampling location, as well as the direction they were headed (upstream or downstream). The total daily vessel passes observed on each sampling day are shown in **Figure 3.3**. Note that the total daily counts include vessels passing the sampling station in both directions, as this provides quantification of the total activity near the point bar. Therefore, vessels/users who travel in both the upstream and downstream direction are counted twice in the total counts. During the high recreation season (May-September), approximately 200-400 vessels per day passed by the upper sampling sites, WW1, WW2, and WW3, while approximately 700-1000 vessels passed by the furthest downstream sampling site, WW4. In the lower recreation season (October-April), approximately 50-200 vessels per day passed the upper stations, while 100-400 vessels per day passed the downstream station. The daily total number of vessel passes was tightly correlated

[6] The basis for this recommendation was not provided in the 2011 State Park Unit Management Plan.

with the daily total number of users (Users = 1.46*Vessels, R^2=0.99) and therefore follows a similar distribution. **Appendix B** shows the total daily users observed on each sampling day.

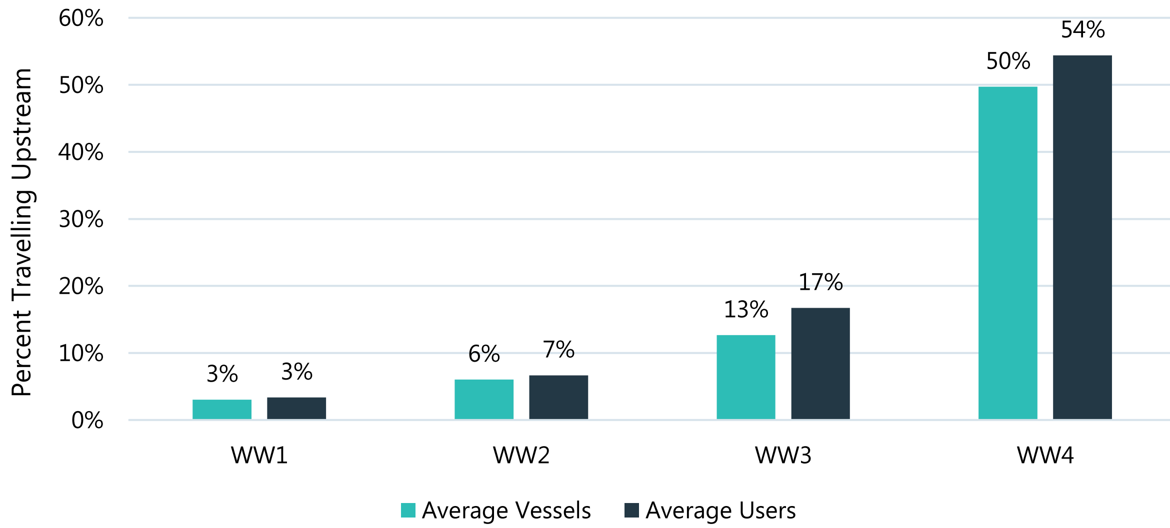
Figure 3.3 – Daily Total Number of Vessel Passes by Sample Site



3.2.2 Travel Direction

While the total count of vessels or users traveling upstream and downstream provides quantification of the total activity near the point bar, the truest count of individual vessels on the river is the number of vessels traveling downstream since almost all users/vessels traveling upstream must come back downstream. As shown in **Figure 3.4**, station WW4, the furthest downstream site, had the most vessels that traveled upstream (mostly from Rogers Park, other commercial vendor locations or private launch areas). On average, 50% of vessels and 54% of users were travelling upstream at WW4, while WW1 had the least vessels/users travelling upstream (3%). This finding highlights that any limits set to curb recreational use on the river should also consider enforcement downstream at Rogers Park and other vendor locations in addition to the State Park launch restrictions. Additional figures in **Appendix B** show the distribution of downstream versus upstream vessels by site and by sampling event.

Figure 3.4 – Percent of Vessels and Users Traveling Upstream at Each Station

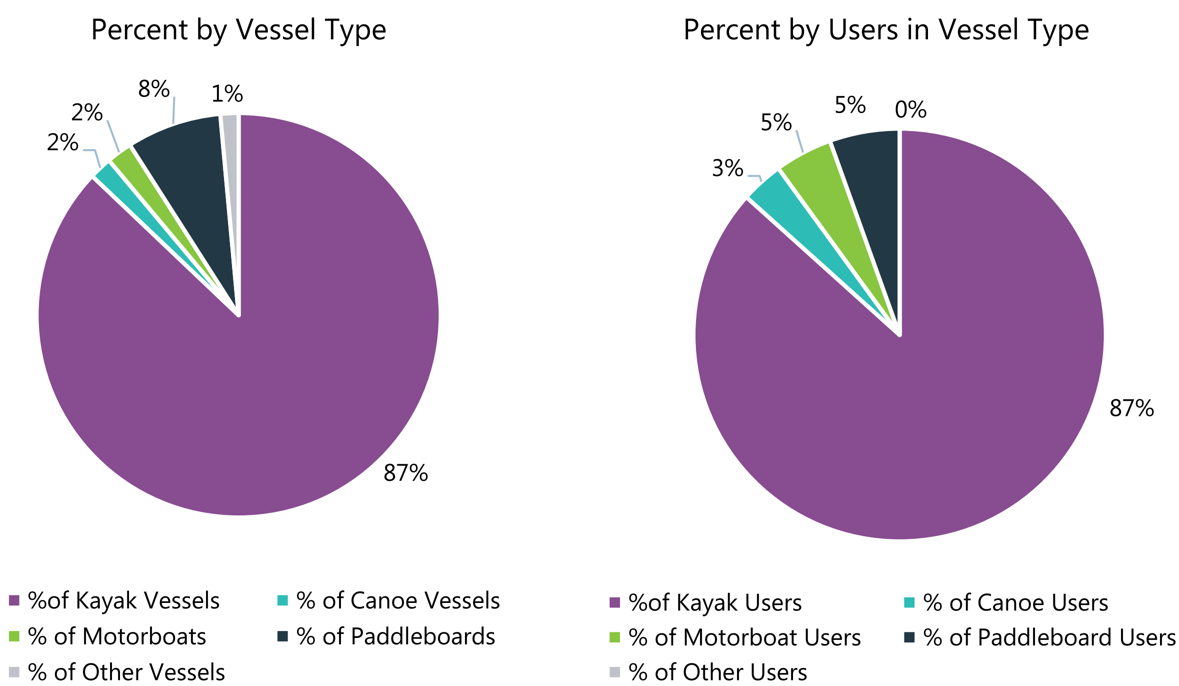


3.2.3 <u>Vessel Type</u>

The type of vessel (kayak, canoe, paddleboard, motorboat, or other) was also noted during field counts, and the overall percent of each vessel type (left panel) and percent of users in each vessel type (right panel) over all stations and for all events are shown in **Figure 3.5**. It should be noted that these values include the number of users/vessels observed at each sampling location traveling in the downstream direction only (which is a truer representation of total people on the river on a given day). Additional figures in **Appendix B** show the detailed distribution of vessel types by site and sampling event and the average percent of vessel types per site. The number of motorboats traveling only downstream is also shown in **Appendix B**. Additionally, **Table 3.1** shows the average number of users per vessel type, calculated with user and vessel data collected at all sample locations during the sampling events. Motorboats had the highest number of users per vessel while paddleboards had the fewest.

The data show that kayaks are the dominant vessel type used on the Weeki Wachee River. At the upstream sampling locations (WW1 and WW2), 90% of all vessels were kayaks, followed by 8% paddle boards and 1-2% canoes and motorboats (**Figure 3.5**). The downstream stations (WW3 and WW4) are closer to areas with access to boat ramps such as Rogers Park, Weeki Wachee Marina, and privately-owned docks along the river and canals where visitors can launch motorboats. For the most part, there is not much restriction other than boat rental availability or the number of available trailer parking spots for privately owned boats that are non-river residents. Even at these downstream stations, kayaks made up approximately 85% of all vessels, with paddleboards at 7%, motorboats at 3%, and canoes at 2%. Averaging across all stations and events, motorboats made up approximately 2% of all vessels on the river, but they do transport over twice as many users as kayaks on a per vessel basis. Overall, users traveling by motorboat made up approximately 5% of all users on the river.

Figure 3.5 – Overall Percentage of Vessel and User Types from Field Count Data



Note: Values are overall averages for all stations using only downstream travel direction data.

Table 3.1 – Average Number of Users per Vessel Type

Vessel Type	Average Number of Users/Vessel
Kayak	1.5
Canoe	2.5
Motorboat	3.4
Paddleboard	1.1

3.2.4 Motorboat Engine Size

Another metric counted during field sampling events was the size of motors on motorboats. **Table 3.2** summarizes the average daily count of each motorboat engine type observed at each site. The motor sizes most commonly observed were less than 10 horsepower (hp), followed closely by 10-50 hp. Note that the Weeki Wachee Marina rents out boats with a 9.9 hp engine, and these were commonly observed at WW4 (the downstream-most sampling site). Larger motors, some with more than 100 hp were observed, but only at the downstream stations. It should be noted that the data used in this assessment were adjusted for vessels returning downstream, to avoid double-counting motorboats. **Appendix B** provides a further breakdown of observed motorboat engines by site by sampling event. Although the number of motorboats did not make up a large percentage of the total number of boats on the river, it should be noted that prop scars from motorboats were observed in some shallower downstream areas that contained submerged aquatic vegetation. The prop scars appeared to occur when motorboats were in shallow and narrow areas when attempting to pass groups of kayakers.

Table 3.2 – Average and Range of Daily Count of Motorboat Engine Types (Field Counts)

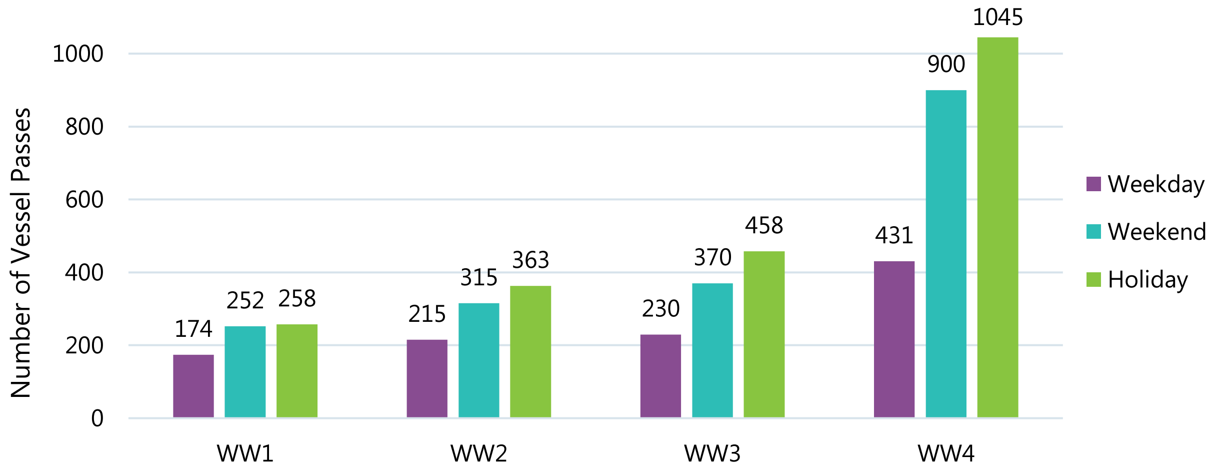
Site	PWC*	Trolling	<10HP	10-50 HP	60-100 HP	>100HP	Unknown	Total
WW1	0 (0-1)	0 (0-0)	1 (0-4)	1 (0-6)	0 (0-0)	0 (0-0)	1 (0-5)	3 (0-8)
WW2	0 (0-3)	0 (0-0)	0 (0-1)	0 (0-0)	0 (0-0)	0 (0-0)	3 (0-8)	3 (0-9)
WW3	1 (0-2)	1 (0-4)	5 (0-17)	1 (0-4)	0 (0-3)	0 (0-1)	1 (0-2)	8 (0-24)
WW4	1 (0-4)	2 (0-7)	6 (0-19)	5 (0-17)	2 (0-5)	1 (0-3)	0 (0-1)	17 (1-48)

Note: Top number is the average, parentheses include the range (minimum-maximum). *PWC: Personal watercraft.

3.2.5 Vessel Counts by Day Type

Camera count data were used to estimate the average number of vessel passes by site among the various deployment events by day type (weekday, weekend, holiday) since they cover a longer period of record than the field counts (**Figure 3.6**). As expected, holidays had the highest vessel counts, followed by weekends, and weekdays. It should be noted that these values are totals (upstream and downstream), which explains why site WW4, the downstream-most site that receives approximately half of its vessels/users coming in the upstream direction, shows higher vessel values than the other sites. **Appendix B** provides additional vessel count data segregated by site and by camera deployment to show daily vessel distributions across sites and across seasons.

Figure 3.6 – Average Number of Vessel Passes by Day Type



Note: Data source is camera count data

3.3. Recreational Use of Point Bars

3.3.1 Docking/Wading

The number of vessels docking and the number of people exiting vessels to recreate (i.e. wading/swimming) on the point bars were also recorded during sampling events (field and camera observations). Field observations showed that docking of vessels flattened and/or damaged vegetation on the bars, exposing roots and the underlying soil matrix, which was subsequently washed away 1) during rain events, 2) when water levels increased, or 3) from boat wake. The average number of vessels docking on point bars per hour was calculated and is shown in **Figure 3.7**. Station WW1 is within the original State Park boundary, where visitors are not allowed to dock or leave their vessels, so it is not included in the plots (all values were zero). The 4th of July holiday saw the highest average number of vessels docked per hour, with an average of 22 docked per hour at WW4, which was when the rope swing was still active. All three sites follow a similar pattern with higher numbers per hour docking during the high recreation months (May-September) and fewer numbers per hour docking in the low recreation months (October-April). It should be noted that the average number of vessels per hour decreased over the course of the study at both WW2 and WW4. The decrease at WW2 may be due to fewer vessels launching from the State Park during the higher recreation months, which may be related to the enforcement of user versus vessel limits and also perhaps due to the disposables ban (less partying was observed occurring at this bar post ban). **Figure 3.8** shows a photo of users docked and recreating at the point bar at station WW5, including people wading, swimming and using the rope swing. The decrease in number of people docked at WW4 may have been due to the rope swing tree falling down. The average number of people on the point bar wading and swimming per hour was also calculated and is shown in **Appendix B**; it follows a similar distribution as the vessels but with higher numbers per hour since there are typically 1.46 users per vessel.

Figure 3.7 – Average Number of Vessels Docked Per Hour by Site

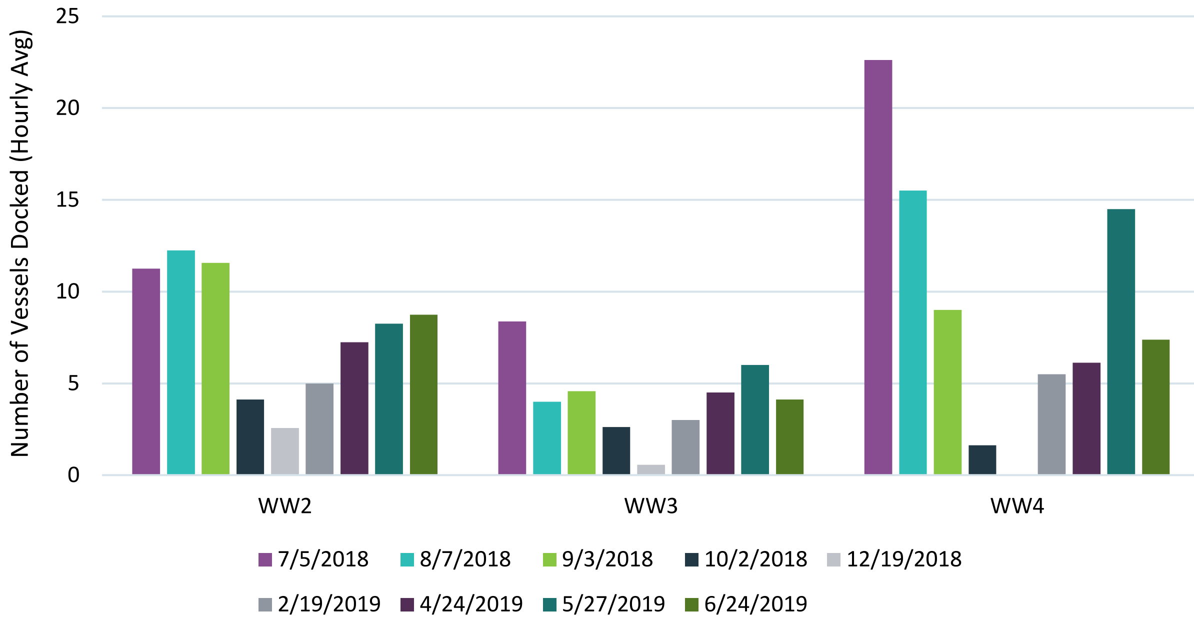
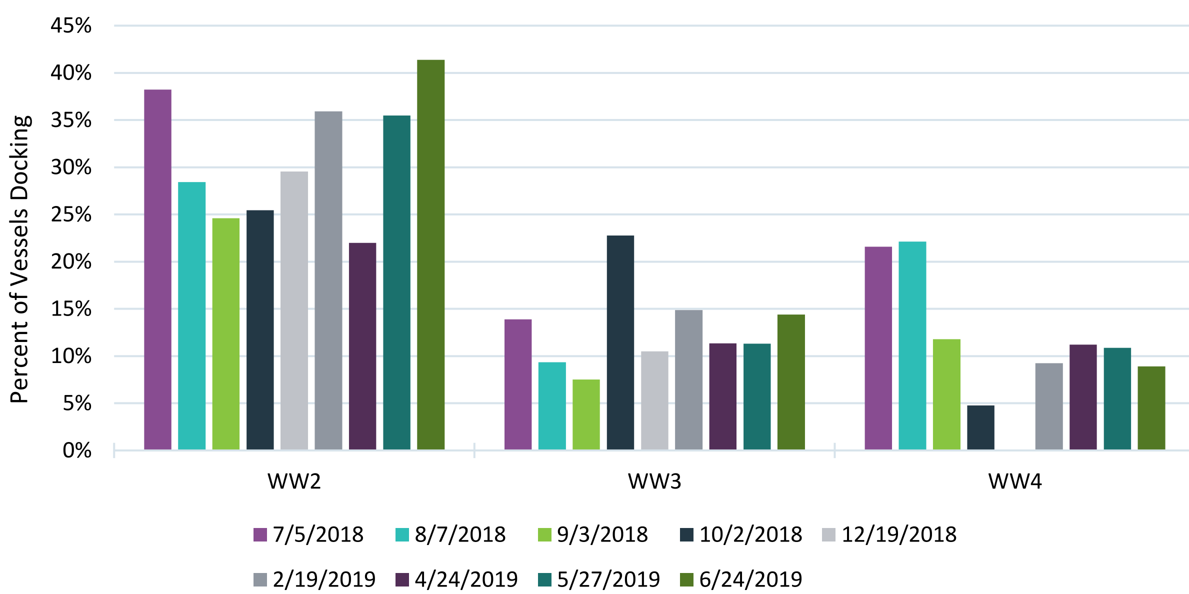


Figure 3.8 – Rope Swing, Docked Vessels, and People Wading and Swimming at WW5

Figure 3.9 shows the percentage of passing vessels that docked at each point bar. The number of vessels docked per people wading and swimming are notably higher during the higher recreation season, but the percentage of vessels docking remains relatively stable throughout the year at WW2 and WW3. Station WW2 had the highest percentage of passing vessels that docked on the point bar (between 20% and 40%), likely because it was directly downstream of the original

State Park boundary exit sign and was historically the first place that State Park visitors were allowed to exit their boats. It should be noted that although the State Park boundary was extended about a mile downstream in October 2018, the percentage of vessels docking at WW2 did not decrease through the end of the study. Field staff stationed at WW2 also noted that most visitors either did not know or did not acknowledge that the State Park boundary had moved further downstream since the original exit sign was still in place. WW3 was the least recreated of the sampling stations, likely because it is a smaller point bar located just downstream of a large, heavily recreated bar so many people have recently stopped at a point bar by the time they pass WW3. While station WW4 generally has more overall traffic than WW2, a smaller percentage of passing vessels stopped at WW4 than at WW2. Based on observations of field staff stationed at WW4, this is likely due to the following reasons: 1) users travelling downstream are often in a hurry to make their pick-up time at Rogers Park; 2) this portion of the river is tidally-influenced and users tend to pass the bar when water levels are higher; 3) the water is more tannic/less clear in this segment; and 4) the tree used for jumping/swinging was struck by lightning and fell after the 8/17/2018 sampling event and fewer people stopped at WW4 once that tree was gone and those that did seemed to stay for less time. Despite these factors, WW4 was still a heavily recreated point bar with obvious impacts from recreational use.

Figure 3.9 - Percent of Vessels Docking (per hour) by Site



3.3.2 Rope Swing/Tree Jumps

The number of jumps from trees and rope swings were also counted during sampling events at sampling location WW4, and at an added location, WW5, after the tree at WW4 fell. Additional figures in **Appendix B** show the number of jumps from trees or rope swings per hour by event and site. It should also be noted that station WW5 had jumping trees on both the left and right banks. At both WW4 and WW5, holidays tended to have the highest amount of tree jumps, reaching up to 47 jumps in one hour. During the remaining events, the frequency of tree jumps tended to peak between noon and 13:00 with 10-30 jumps per hour. As previously mentioned, the absence of the rope swing tree at WW4 appears to have had a direct effect on the number of users docking at the bar. While many users still utilized the bar for recreation, they did not tend to stay as long or stop as frequently. It can also be seen from **Figure 3.10** that the tree roots are uncovered in both photos, which is likely due to trampling along the bar to access the rope swing on the tree.

Figure 3.10 – Rope Swing at Site WW4 Before and After Tree Fall

3.4. Social Surveys

Field staff at the downstream-most sampling sites (WW4 and WW5) conducted exit interviews with randomly selected groups of visitors using a standard set of questions (provided in **Appendix B**). Over the course of the study, 82 groups (327 individuals) were interviewed. Up to 10 interviews were conducted per field sampling day, which were spread throughout the day. Of the surveyed groups, visitors noted similar recreational reasons for stopping on point bars, such as picnicking, swimming, and taking a break from travelling in their respective vessels. Visitors reported to enjoy the river, suggesting that they would recommend the Weeki Wachee River as a place to view wildlife and the crystal-clear water. Those with negative comments about their experience noted that there were too many people on the river. In general, visitors in motorboats complained there were too many inexperienced kayakers on the river, while kayakers complained there were too many inexperienced motorboat drivers on the river. When asked about the rope swings, not many of the people interviewed had used them due to safety concerns. Several long-time visitors noticed changes in submerged aquatic vegetation and an increase in the number of visitors over the years. Summarized survey results are provided in **Table 3.3**.

Table 3.3 – Summary of Social Survey Responses

Survey Metric	Percent of Total Surveyed
First time groups	38%
Returning groups	70%
Groups sharing returning and first-time users	7%
Users launching before noon	99%
Users renting watercrafts	59%
Users owning watercrafts	41%
Users docking under 30 minutes	62%
Users docking over 30 minutes	17%
Users that did not dock	12%
Users launching from Weeki Wachee State Park	39%
Users launching from Rogers Park or Kayak Shack	30%
Users launching from Weeki Wachee Marina	4%
Users launching from SUP Weeki	1%
Users launching from private residences	9%
Users reporting human & boat congestion	25%
Hernando County residents reporting congestion	8%

3.5. Summary of Recreational Activities

Data collected by Wood during 9 sampling events between July 2018 and June 2019 found that during the higher recreation season (May-September), the number of vessels observed per day along the Weeki Wachee River ranged between approximately 200 and 600, with higher numbers of vessels being observed at the downstream end, nearer to Rogers Park. During the lower-recreation season, (October-April), fewer total vessels were observed per day, ranging from approximately 50 to 200. The highest counts were observed on holidays, followed by weekends and weekdays. While total vessel and user numbers are important for quantifying impacts to the river system, it is also important to note that these totals include travelers going in both directions. Looking at the downstream only direction provides the most accurate count of the number of vessels/users on the river in a given day because those travelling upstream must come back downstream. Near the State Park, only between 3 to10% of the vessels observed were travelling upstream, while in the lower reaches of the river, near Rogers Park, approximately half of the vessel traffic was travelling upstream indicating that approximately half the users observed at WW4 came from the State Park and half came from Rogers Park, private river-access residences or from downstream vendors. At all stations, the majority of vessel traffic was composed of kayaks (85-90%), while paddleboards, motorboats, and canoes make up 7-8%, 1-4%, and 1-3%, respectively. The highest number of motorboats were observed at the downstream-most station (WW4), with the most common motor sizes observed being less than 10 horsepower (hp), followed closely by 10-50 hp. The highest number of vessels docking and users wading/swimming per hour was observed at the downstream-most station (WW4), but the highest percent of passing vessels that docked occurred at the historic State Park exit (WW2). Data and observations also showed that visitors jumped from trees up to 40 times per hour and that jumping trees/rope swings contribute to the popularity of a bar as a docking location and damage to the point bar from trampling. From the social surveys, it appears that approximately 40% of users launch from upstream at the State Park, while 30% launch from downstream at Rogers Park or Kayak Shack, and the remainder launch from various marinas and private residences on the downstream end of the river. While it appears that many visitors believe the river is crowded, they also do enjoy the clear waters and natural systems of Weeki Wachee.

4.0 FLUVIAL GEOMORPHOLOGY ASSESSMENT

Fluvial geomorphology can be described as the interaction of flowing water with its environment; which affects channel shape and size, bed substrate, flow, velocity, vegetation, and river corridor ecology and biodiversity. Many factors influence the geomorphology of a stream, including climate, soil types, groundwater influence, topography, vegetation, land use in the contributing watershed, and activities within the stream or along the streambanks. The discipline of fluvial geomorphology can help to understand the processes occurring within a stream system. Various fluvial geomorphic assessments were performed as part of this study to assess whether the Weeki Wachee River diverges from expected self-sustaining characteristics, and to assess whether divergence can be linked to recreation. These included an aerial point bar interpretation (**Task 2.1**), recreational trampling assessment (**Task 2.3**), comparative site assessment (**Task 2.1**), cumulative assessment (**Task 2.2**), and assessment of leaning trees as described in the subsequent sections. **Map 4** shows the locations of the point bars used in each analysis.

4.1. Aerial Point Bar Interpretation

Point bars with clear expanses of beach-like sand are a recreational draw for visitors to the Weeki Wachee River; however, these are not normally observed in Florida spring runs. While the natural bed material of the Weeki Wachee River is comprised predominantly of sand, point bars in Florida spring runs generally support herbaceous vegetation and subsequently accumulate organic soils on the bar. An assessment of vegetative cover over the past decade at selected point bars within the Weeki Wachee River was conducted to observe whether a pattern of progressive vegetation and organic soil loss has occurred.

4.1.1 Methodology

Using aerial imagery from Google Earth Pro software (image source Landsat/Copernicus), apparent changes in vegetation and morphology on selected point bars were observed through time. The 6 point bars used in aerial interpretation were selected because they had the clearest views of bar vegetation in the available aerials over the last decade. The vegetated area of each bar was calculated by setting reference points at the forested edge and tracing the vegetated limits of the exposed sand of the bar. Vegetated area did not include submerged aquatic vegetation or algae, and approximations aimed to account for overhanging trees. The vegetated areas for each year with a clear aerial image were compared to calculate a change in vegetative cover.

4.1.2 Results

Figure 4.1 shows the point bar at Wood Station WW2 (the historic exit of the State Park) in 2008 compared to 2017, and the vegetation loss of approximately 1600 ft^2. This side by side comparison clearly shows the magnitude of vegetation and subsequent organic soil loss at this point bar, and kayaks can even be seen docked in the 2017 image on the right. **Figure 4.2** shows the cumulative percent reduction in vegetation among all 6 point bars assessed compared to the average daily vessels launched from the State Park in each fiscal year (FY 2012/2013 plotted as 2013, etc.). State

Park launch data were used in the assessment because no other long-term user data from downstream of the State Park (i.e. private residents, Rogers Park or other vendors) were available. Based on previously discussed results, up to 50% of the total users in the downstream areas came from downstream of the State Park. Using the available information from the State Park, **Figure 4.2** clearly shows that as the average daily vessels launched from the State Park increased, so too did the cumulative reduction in point bar vegetation. However, it should be noted that the State Park launch data only dates back to July 2012, while reductions in vegetative cover occurred between the available aerials from 2008 and 2011.

Appendix C provides a full suite of imagery comparisons and vegetated areas for all 6 point bars assessed. Among the sites, impacts can already be seen occurring sometime prior to 2011, while cumulative reductions in vegetation and changes in point bar morphology can be observed through the most recent assessed aerial in 2017. While 2016 is notably when the number of vessels launched from the State Park reached their peak and it coincides with a large trend in vegetation loss, the trend of vegetation loss commenced well before such levels of use.

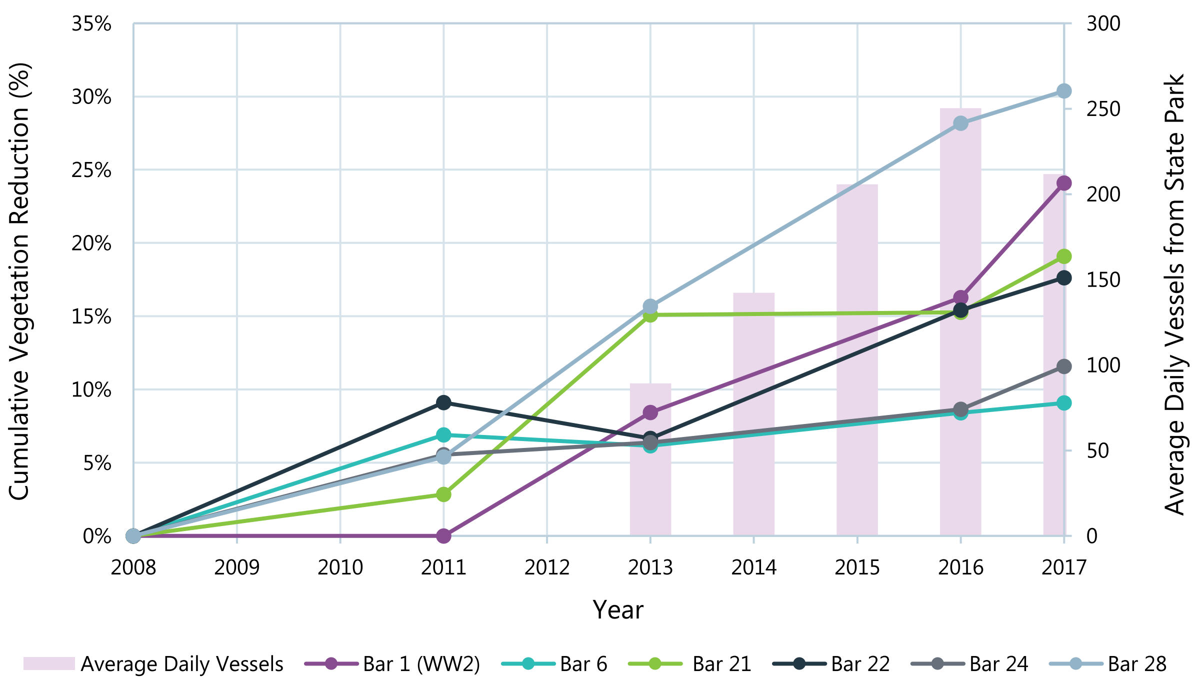
The vegetation loss pattern since 2008 suggests that a threshold of impactful use occurred at least several years before vessels peaked in 2016. In river morphology and stream ecology, there is a concept of lag time. Impacts may be occurring for several years but have not yet reached a threshold at which rapid changes occur, such as the large-scale reduction in vegetation and organic soils observed in the 2016 aerials. There may be secondary effects, which would not occur had it not been for the first impact. For example, once a space is opened in the point bar vegetation, more docking occurs because of that opening and it in turn creates a larger opening. Once the organic soil is lost to physical disturbance and further erosion, the sand below is exposed which makes the point bar even more inviting for stopping. Another secondary effect is that vegetation loss exposes easily transportable sand, releasing it downstream and enabling some point bars to enlarge (aggrade). This truncates the open channel width and increases the fluvial forces on the opposite streambank, which can greatly accelerate erosion at the outer bends.

Because the initial impacts pre-date the State Park count data, and no information is available from downstream users, caution should be used when trying to assign a carrying capacity number based solely on the State Park vessel launch numbers. The initial impacts occurred prior to the available user counts. It is clear, however, that more vessels and users correspond with more impacts to point bars. In addition to limiting the number of users launching at a given entry point, albeit from the State Park and/or from downstream of the State Park, to reduce or prevent impacts to point bars, the activities that occur on the river, such as docking/exiting the vessels would need to be limited or restricted.

Figure 4.1 – Reduction in Vegetation from 2008 to 2017 at Weeki Wachee Point Bar 1

Note: Historic aerial imagery sourced from ESRI ArcGIS Online Imagery Services and/or freely available downloadable imagery from SWFWMD and FDOT. Left Image: Aerial 10/2008; Bar vegetated area = 7,031 sq. ft. Right Image: Aerial 6/2017; Bar vegetated area = 5,337 sq. ft.

Figure 4.2 – Cumulative Percent Reduction of Vegetation on Point Bars Compared to Average Daily State Park Vessel Launches



Note: Cumulative vegetation reduction is calculated as (vegetated area in year X – vegetated area in 2008)/vegetated area in 2008. The earliest State Park vessel launch data begins in June 2012. Point bar locations shown in **Map 4.**

4.2. Experimental Recreational Trampling Assessment

An experimental trampling assessment was conducted to measure the impact, intensity of recreational disturbance, and potential recovery of plant communities and soils within the Weeki Wachee River. Disturbances caused by trampling events often have extensive implications for the health and function of natural ecosystems. Studies involving even low levels of visitor traffic on natural systems have shown that recreational trampling can have negative effects on vegetation and soils (Jägerbrand and Alatalo 2015; Pertierra et al. 2013). Commonly documented effects on vegetation include changes in species diversity, composition, growth patterns, percent cover and an increased abundance of opportunistic and rapidly colonizing invasive species (Cole 2004; Kuss and Hall 1991; Pickering and Growcock 2009). Concurrent changes to soil compaction and water-holding capacity can also lead to erosional sources of sediment transport and sedimentation, decreased water clarity, and loss of submerged aquatic vegetation within the river. Vegetative controls on spring run morphology are significant in preserving the key functions and health of riverine ecosystems such as the Weeki Wachee River (Kiefer et al. 2015).

4.2.1 Methodology

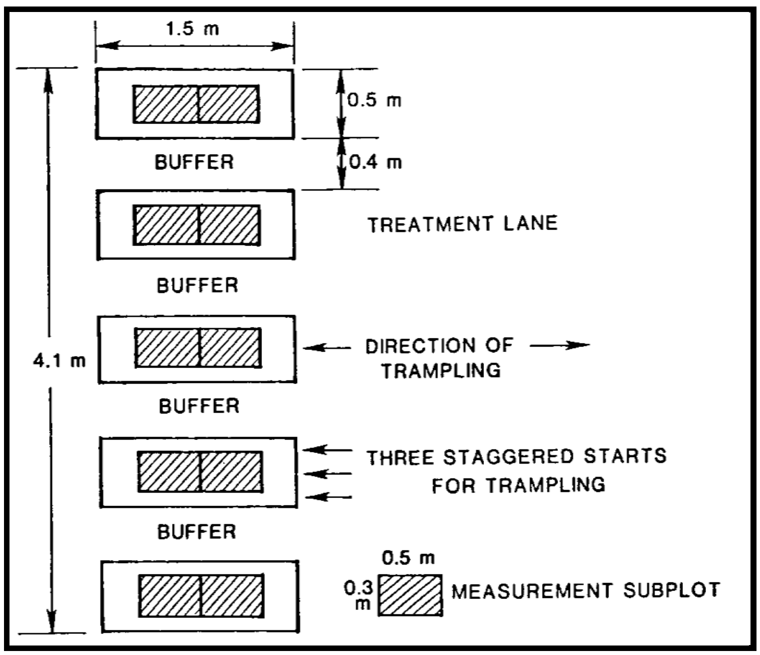
A total of 3 point bars with intact herbaceous vegetation were selected at random for the experimental trampling assessment (**Map 4**). These sites were located within the previous State Park boundary where vessels are not supposed not dock and clear impacts to point bar vegetation were not observed. The initial trampling event was conducted on 5/28/2019, with a two-week follow-up site visit to assess immediate impacts on 6/12/2019, and a 6-month interim follow-up site visit to assess potential reestablishment within the recovery period on 11/24/2019. Additional follow-up site visits at the 1-year mark (May 2020) and 2-year marks (May 2021) since trampling should also be conducted to assess potential recovery from trampling. It is important to note that the trampling event occurred during low water levels, and the bar substrates were merely saturated and not under standing water. Therefore, the recovery assessments should also occur during similar hydrologic conditions. The interim reestablishment assessment in November 2019 occurred during high water levels and the bars were all under almost a foot of water. The information gleaned from the interim assessment provided good information on how the bars were beginning to recover under varying hydrologic conditions, which are important for management considerations.

Adapting methodology from Cole and Bayfield (1993), 5 equally-dimensioned lanes (**Figure 4.3**) of different trampling intensities, each with two subplots, were identified on each of the 3 experimental point bars. Upon site selection, pin flags were placed at each subplot corner and photographs documenting vegetation cover and height were taken. Photographs of trampling sites with applied treatments, and their respective soil profiles can be found in **Appendix D**.

Percent vegetation cover and species type along with soil matrix profiles were identified for each subplot (10 subplots per bar) prior to trampling. Percent cover was recorded as 0, 0.2 (if between 0 and 0.5%), 1, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90 or 100% for vegetation, with the same percentage categories used for dead vegetation and bare soils. One soil matrix profile was taken within each subplot using a tubular soil sampler to document the thickness and type of overlaying soil layers. Soil types were documented as detritus, peat, muck, sand, silt, clay, combinations or other when present in the upper 30 cm of the soil core.

Each of the 5 lanes was randomly assigned a trampling intensity (0, 25, 50, 100, or 200 passes), with one pass defined as walking at a natural gait in one direction. Trampling was performed by the same individual to provide consistency across sites. After receiving the designated intensity of trampling, the immediate effects to soil and vegetation were recorded and photographed. Signage informing that the site was restricted was placed onto construction fencing that was held up by steel rebar was installed as a barrier at each trampling site to restrict site access to the research plots (**Figure 4.4**).

Figure 4.3 – Layout of Recreational Trampling Assessment Lanes



Cole and Bayfield (1993)

Figure 4.4 – Construction Fence Barrier

The soils and vegetation cover were recorded again, repeating all measurements for each subplot two weeks and six months after the initial trampling event to document both the short-term and long-term impacts caused by recreational trampling. Relative cover (RC) was calculated as the primary measure of vegetation change for the periods occurring two weeks after trampling (impact assessment) and six months (interim reestablishment assessment during recovery period) after trampling. Impact refers to the amount of damage resulting from the initial trampling event while recovery refers to the rate at which vegetation reestablished after the trampling event. Using Cole and Bayfield's equation to calculate RC, the percent coverages of all plant species within each subplot were summed, and then a mean sum of cover was derived for each plot.

RC= 100% * cf * (surviving cover on trampled subplots) / (initial cover on trampled subplots)
Where cf= (initial cover on control subplots) / (surviving cover on control subplots)

Additional statistical interpretations were performed to examine the effects of trampling intensity on the vegetation and soils of the study sites through periods of impact, reestablishment and recovery.

Figure 4.5 – Pre and Post Trampled Vegetation and Organic Soils

4.2.2 <u>Results</u>

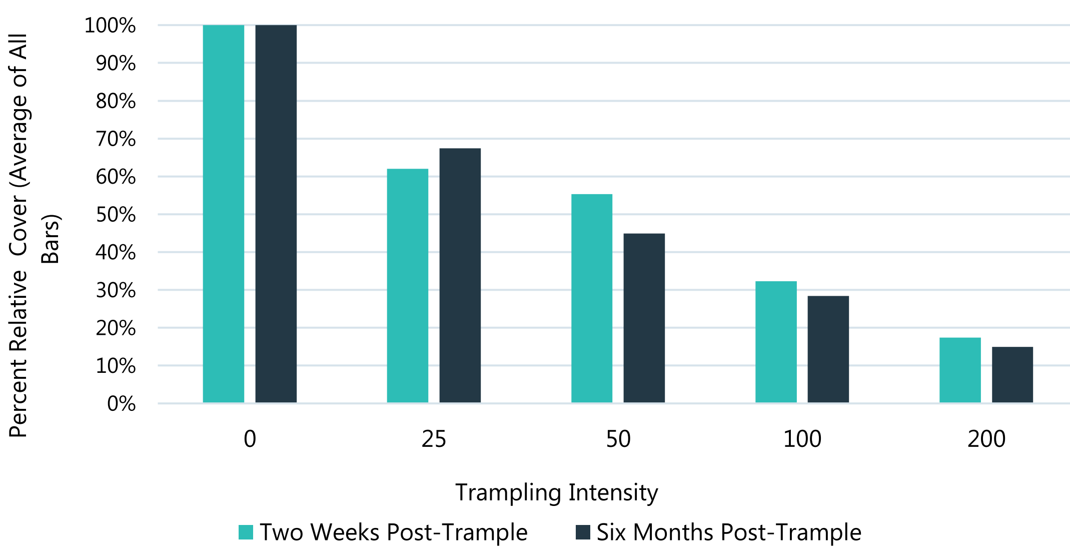
One-way ANOVA with Tukey and Fisher pairwise tests for comparison of means was performed on just the pre-trampled vegetation percent coverage values for each trampling lane (average of both subplots in each lane) to establish that none of the lanes had statistically different pre-trampled percent vegetation cover. The results showed no statistical difference in vegetation cover of pre-trampled plots.

Overall, it appeared that vegetated cover was lower 2 weeks after trampling for all intensities, while some reestablishment at different stages of recovery were observed for each intensity at 6 months post-trampling. Relative cover values were used for analysis because they account for seasonal or water-level-dependent changes in vegetated cover by normalizing values with the results of the untrampled plots (percent cover values are shown for each plot in **Appendix D**). **Figure 4.6** shows the average percent relative cover of vegetation for the 2-week and 6-month periods after trampling. These results suggest that relative vegetation cover decreases with increasing trampling intensity.

The vegetation relative cover data from the 3 experimental bars and trampling intensities (except for 0 passes, which was the control), were pooled and used to conduct a nonparametric Wilcoxon Signed Rank test, which compared the medians of the pre-trample and 2-week post-trample data for similarity. The test was significant at a p-value less than 0.05, showing that the percent vegetation cover was significantly lower after trampling, for all trampling intensities. The same test was conducted to compare the pre-trample and 6-month post-trample data. The test was significant at a p-value less than 0.05, suggesting that vegetation had not yet begun to significantly reestablish 6 months after the original trample date.

Linear regression plots (in **Appendix D**) for each trample site show a positive relationship between trampling intensity and reduction in percent of vegetation cover. To assess differences in effects of trampling intensities, one-way ANOVA with Tukey and Fisher pairwise tests along with a Dunnett Multiple Comparisons test (with trampling intensity 0 as the control) were performed on the relative cover of vegetation dataset (2-weeks and 6-months after trampling). For the 2-week post-trampled dataset, the Fisher test for difference in means showed that relative cover was significantly less (at alpha=0.05) than the control at a trampling intensity of 200, but not at intensities of 25, 50, or 100. For the 6-month post-trampled dataset, the Tukey and Dunnett comparisons tests showed that relative cover was significantly less (at alpha=0.05) than the control at trampling intensities of 100 and 200, and the Fisher comparison test showed that relative cover was significantly less than the control at trampling intensities of 50, 100, and 200. Overall, based on the various statistical analyses, the higher trampling intensities showed greater reductions in relative vegetation coverage.

Figure 4.6 – Percent Relative Cover Two Weeks and Six Months After Trampling (Average of All Trample Bars)



Figures 4.7 - 4.9 show the relationship between relative cover and the intensity of trampling received to the study site after the initial 2-week period (impact) and 6-month period (interim reestablishment). Impact is defined as 2 weeks after trampling because it leaves sufficient time to observe plant deaths due to trampling (as opposed to immediately after trampling when vegetation still appear alive but flattened). After the 2-week impact period, the recovery period begins with some reestablishment of mostly opportunistic invasive vegetation, and the first interim recovery observations were taken at 6 months. It should be noted that recovery may take much longer than 6 months (depending on environmental and seasonal factors), and that 12-month recovery data will be collected, although it will occur outside of the carrying capacity study contract period. Overall, after the initial 2-week trampling event, percent relative cover decreased in response to the increasing trampling intensity across all 3 bars.

At the interim 6-month point in the recovery period, it appeared that the trampled plots were in different stages of recovery, depending on their environments. Overall, it appeared that higher water levels and onset of winter may have been limiting factors in vegetation recovery, as dead and bare coverage, even in the un-trampled control lanes were observed at all bars. In addition to these overall observations, each of the three bars appeared to have different recovery responses. At Bar 1, where there is lower flow than at Bars 2 and 3, organic sediments had begun collecting in the submerged trampled plots, but presumably high water levels prevented reestablishment of many species that were present before trampling. On the bar that remained above the waterline (Bar 2), the dead, trampled *Cladium jamaicense* (sawgrass) appeared to have created a physical barrier (similar to mulch) on the top of many of the plots, potentially limiting reestablishment of vegetation. Bar 3 was also submerged but located on an outer bend that appears to receive higher flows/velocities than at Bar 1. At Bar 3, it appears that organic sediments were not accumulating (presumably due to higher flows), however, floating vegetation such as *Pistia stratiotes* had been transported by flow into the plots. Additionally, dense submerged vegetation and vines (such as *Najas guadalupensis*, *Diodia virginiana*, and *Mikania scandens*) had grown into the trampled plots that were originally dominated by larger emergent herbaceous species (such as *Typha sp*. and *Sagittaria lancifolia*), which creates the appearance of a high recovery (>100%) of total vegetation cover, but with different, ephemeral species. Therefore, at the one-year mark, it will be important to assess the vegetation in terms of a more qualitative metric such as types of communities that colonized, reestablished or recovered, rather than a total percent coverage as a quantitative metric to assess recovery.

Figure 4.7 – Relative Cover After Impact and Reestablishment at Trample Bar 1

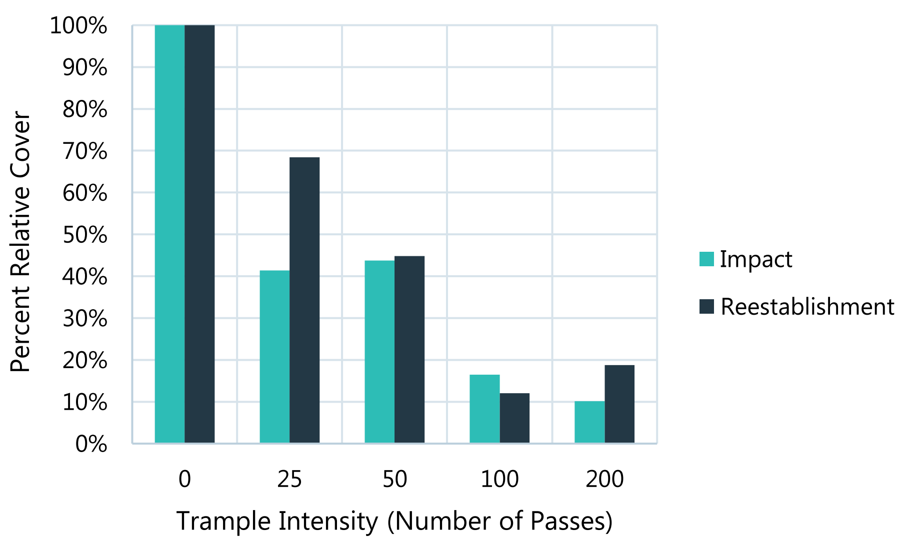


Figure 4.8 – Relative Cover After Impact and Reestablishment at Trample Bar 2

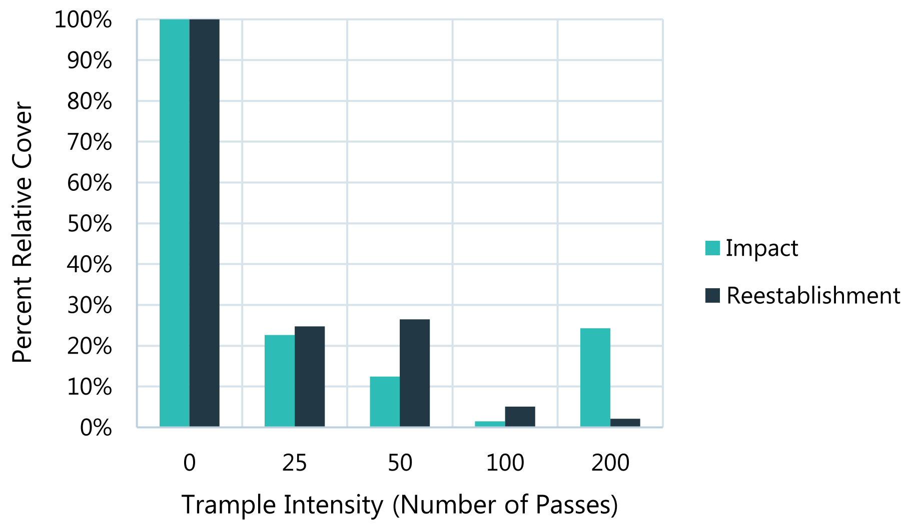
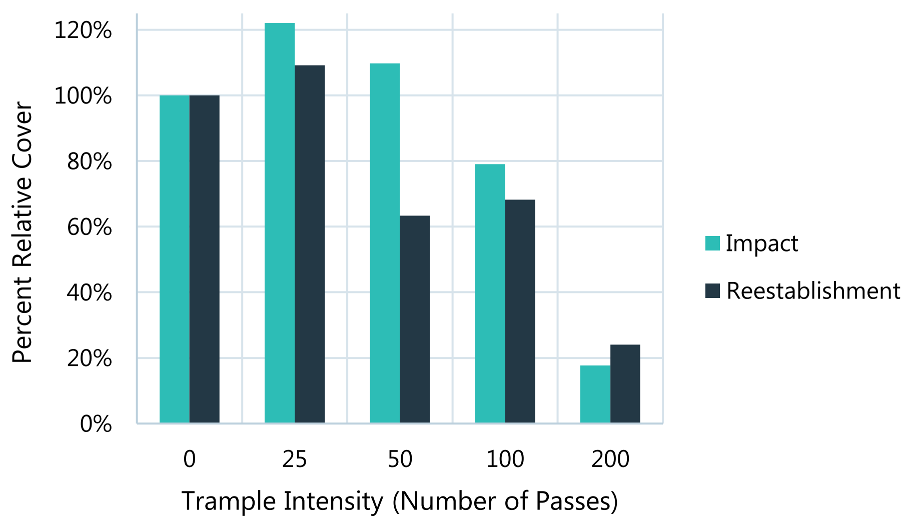


Figure 4.9 – Relative Cover After Impact and Reestablishment at Trample Bar 3



Common vegetation described at trampling sites prior to trampling were primarily composed of herbaceous vascular plants. **Table 4.1** provides a list of dominant species at each trampling location. Floating-leaf aquatic plants were noted as part of the vegetative survey but were not used in the calculation of total percent cover.

Table 4.1 – Dominant Vegetation at Trampling Sites

Trample Bar 1	Trample Bar 2	Trample Bar 3
Cyperus haspan *Boehmeria cylindrica* *Cicuta maculata* *Hydrocotyle umbellata* *Cladium jamaicense* *Sagittaria lancifolia* *Mikania scandens* *Alternanthera philoxeroides* *Bacopa monnieri* *Colocasia esculenta* *Cynodon dactylon* *Micranthemum umbros* *Pistia stratiotes**	*Cladium jamaicense* *Cicuta maculata* *Vitis rotundifolia* *Cyperus haspan* *Colocasia esculenta* *Ludwigia sp.* *Boehmeria cylindrica* *Toxicodendron radicans* *Polygonum sp.* *Micranthemum umbros* *Mikania scandens*	*Typha sp.* *Sagittaria lancifolia* *Ludwigia sp.* *Polygonum sp.* *Boehmeria cylindrica* *Cicuta maculata* *Micranthemum umbros* *Diodia sp.* *Hydrocotyle umbellata* *Mikania scandens* *Pistia stratiotes**

**Pistia stratiotes* is a floating leaf aquatic plant and was not included in percent cover values

The soil profile data collected before and two weeks after trampling were used to identify loss of organic matter from recreational trampling. If there was substantial organic content in the top 6-10 cm of the profile, the subplot was marked as "organics present". If the core was primarily sand, it was assigned "organics not present". The binary dataset was used to perform McNemar's test (non-parametric statistical test), which tests whether paired proportions are significantly different (i.e. if soils before trampling and 2 weeks after trampling were significantly different). When comparing the soils before and 2 weeks after trampling, the test was significant with a p-value less than 0.05 suggesting that organic soils decreased significantly after the initial trampling event. The test was also significant (p-value <0.05) when comparing the soils before and 6 months after trampling, suggesting that the organic soils were still significantly reduced 6 months after trampling. When comparing the soils data 2 weeks after and 6 months after trampling, the test was not significant, indicating that there was no significant loss or recovery of organic soils during the 2-week and 6-month period. Overall, these results suggest that soils can be significantly impacted within 2 weeks of trampling, and that those impacts may persist until at least 6 months after trampling.

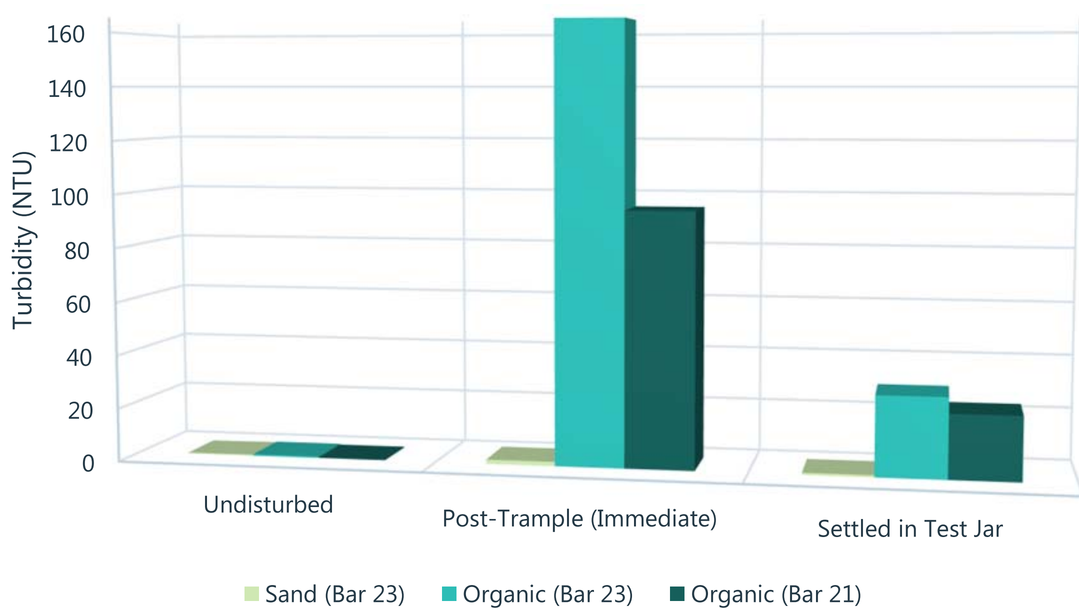
Trampling events at submerged bars were often subject to higher cases of soil disturbance than events on non-submerged bars. It is worth noting that saturation of soils and/or depth of water in trampling lane appears to intensify effects of trampling and potential for recovery. Wet soils displace under foot and adhere to footwear, so vegetation is not only trampled, but can also be uprooted and buried. Areas originally containing lower amounts of water, expressed increased water pooling after the initial trampling, which is consistent with changes in soil compaction. In the submerged point bars, disturbed soils from trampling also appeared to be more susceptible to washout during rain events. It should also be noted that the submerged vegetation at the edge of the bars appears to be especially susceptible to trampling because these water depths are conducive to safely exiting a kayak (or other vessels).

Turbidity was measured in triplicates and averaged at select bars to describe water clarity before and after recreational trampling. As an undisturbed control, turbidity measurements were taken from the boat above areas with clean sand and areas composed of mostly organics. Turbidity was then measured at the same sites immediately after soils were disturbed by trampling activity, and again after the sample had been allowed to settle for 5-10 minutes in a test jar. **Table 4.2** and **Figure 4.10** show the measured values of turbidity at select bars.

Table 4.2 – Turbidity (NTU) Values at Trample Sites Before and After Trampling

Substrate Material (Location)	Average Turbidity (NTU)		
	Undisturbed	Post-Trample (Immediate)	Settled in Test Jar
Sand (Bar 23)	0.36	1.6	0.8
Organic (Bar 23)	0.57	164.9	30.0
Organic (Bar 21)	0.27	95.0	24.0

Figure 4.10 – Comparison of Turbidity (NTU) at Bar 21 and Bar 23



4.2.3 <u>Summary of Recreational Trampling Assessment</u>

The experimental trampling assessment provided documentation of vegetation and soil sensitivity in select shoreline sites of the Weeki Wachee River. After the initial trampling event, each of the 3 subplots showed increases in exposed soil and dead vegetation. As expected, areas trampled at variable intensities were subject to fluctuating amounts of vegetation and soil disturbance. Percent relative cover of vegetation declined substantially as trampling intensity increased after the initial 1-week and 6-month trampling events. Percent relative cover was somewhat variable at the six-month interim reestablishment event suggesting each subplot is at a different stage of recovery influenced not only by trampling intensity, but multiple other environmental variables. The reestablishment of vegetation after six months of recovery appeared to be influenced by water level, flows, seasonal climate, and surrounding vegetation. Submerged bars were often newly colonized by floating-leaf aquatic plants such as *Pistia stratiotes* and traveling vines such as *Mikania scandens,* thus changing the community composition. Soil profiles taken after initial impact showed decreases in surface organic matter, signifying disruptions from soil compaction and disturbance. The loss of organic soils was significant two weeks after trampling, and continued to be significant 6 months after trampling, with no significant change in presence of organic soils between two weeks and 6 months.

Recreation-induced vegetation trampling has been shown to adversely impact the herbaceous shoreline of the Weeki Wachee River. Limiting or fully restricting vessel docking along the shorelines in general or setting up specific areas for docking and recreation at designated areas that have been engineered for that purpose could decrease the amount of vegetation loss and erosion along the river.

4.3. Comparative Site Assessment

4.3.1 <u>Site Selection</u>

Wood selected a spring-fed river containing point bars with intact vegetative cover to provide a comparative reference site from which to assess ecological impacts observed at point bars on the Weeki Wachee River (such as vegetation and organic soil loss). Candidate spring runs included Alexander Springs Run and Juniper Spring Run in the Ocala National Forest and Rock Springs Run in Orange County. These rivers were reviewed via aerial imagery and site visits to find a site with similar fluvial geomorphic characteristics such as meander pattern, bend geometry, and hydrologic regime to the Weeki Wachee River. Alexander Springs Run was selected as the comparative site for the Weeki Wachee River because it had similar geomorphic patterns, dimensions, and flow regime. It also displays fewer impacts from recreation versus Rock Springs Run, which is heavily eroding in some areas. While the Alexander Springs Run in the studied section is not entirely pristine (it has some rope swings, docks, short segments of cleared shoreline, an eroded kayak/small boat launch, and an actively eroded bluff), it has numerous vegetated and intact point bars available to study lacking erosional scarps or other evidence of impacts from recreational use of the bars.

Juniper Spring Run has intact point bars and low impacts but was rejected as a candidate for the comparative study because it is much narrower than the Weeki Wachee River and has a different flow regime. Of note, Juniper Spring Run is heavily recreated by kayakers, but user impacts are managed by 1) prohibitions on disposables, 2) enforcing a late-morning curfew on livery launches, and 3) the fact that the river is quite swift and narrow which is a major disincentive to swimming and wading. Therefore, very few, if any, users exit their vessels in Juniper Spring Run. It would make an interesting case study for these reasons, but it is geomorphically dissimilar, demonstratively smaller river with reduced point bar development versus the Weeki Wachee River, and therefore did not meet the criteria to be included as a comparison site for the purpose of this study.

4.3.2 Methodology

Four point bars from both Alexander Springs Run and Weeki Wachee River were randomly selected to be included in the comparative assessment (**Maps 4** and **5**). Each of the 8 selected point bars was mapped using survey equipment to collect relative horizontal and vertical information at and within various ecological breaks and zones. A series of up to 5 cross-sections covering the point bar and spanning the various zones were mapped, and soil and vegetation data were recorded within each zone. Detailed information including comparative flow duration curves, photographs, point bar maps, representative cross-sections, and soil and vegetation data for each comparative point bar are provided in **Appendix E**.

4.3.3 Results

Table 4.3 provides a general list and definitions of the various ecological zones encountered during the comparative assessment, as well as the general plant species and soils observed within those zones. In general, the Alexander Springs Run reference point bars were more intact than those in the Weeki Wachee River and included an open water zone, emergent vegetation zone, shrubby flow-way, and forested zone (**Figure 4.11**). One point bar also included a deeper aquatic zone. Point bars at the Weeki Wachee River typically included an open water zone, a denunded bar zone (that should contain aquatic vegetation), and a forested zone (**Figure 4.12**). Two of the Weeki Wachee sites had a truncated emergent vegetation zone that was only present at the upstream end/head of the point bar, while the downstream portion of the point bar was denuded. Where the denuded bar zones in the Weeki Wachee River encountered an intact vegetated zone (whether it be emergent or forested), an approximate 1-foot high scarp or vertical wall was typically observed (BRK-2, **Figure 4.13**). This scarp can be defined as a ledge feature on the impacted point bars where soils and vegetation appear to have been directly carved out by vessel docking and trampling activities, and it can be interpreted as the approximate depth of organic soil loss occurring at the point bar. By comparison, no scarps or denuded bars were observed at Alexander Springs Run. Many exposed roots were also often observed at the Weeki Wachee River sites within the forested zone, which would otherwise be covered and protected by several feet of organic soil material if the material was not removed by disturbance and erosion (**Figure 4.14**).

Table 4.3 – Ecological Zones Observed at Comparative Point Bars

Zone	Description	Representative Vegetation	Representative Soil Type
Open Water	Mainstream channel	--	Sand
Aquatic	Deeper zone with aquatic floating and/or submerged plant species	*Nuphar advena*	Organic
Emergent	Shallow bar area with herbaceous and early successional plant species	*Baccharis halimifolia, Cephalanthus occidentalis, Cladium jamaicense, Cyperus spp., Mikania scandens, Pontederia cordata, Sagittaria lancifolia, Sagittaria latifolia, Salix caroliniana, Woodwardia virginica*	Organic
Flow-way	Backwater area landward of the emergent zone, slightly deeper and lacking groundcover	*Cephalanthus occidentalis, Cornus foemina, Cyperus spp., Myrica cerifera, Salix caroliniana*	Organic
Denuded Bar	Shallow ledge devoid of expected vegetation (was historically vegetated and may now have a larger footprint due to sedimentation)	None*	Sand
Forested	Wetland forest structure with trees, shrubs, and groundcover canopies	*Cyperus spp., Acer rubrum, Baccharis halimifolia, Cephalanthus occidentalis, Cladium jamaicense, Cornus foemina, Gordonia lasianthus, Ilex cassine, Magnolia virginiana, Myrica cerifera, Nyssa sylvatica, Sabal palmetto, Serenoa repens, Taxodium distichum, Woodwardia virginica*	Organic

Note: *Benthic filamentous macroalgae may be present on top of the sand substrate.

Figure 4.11 – Alexander Springs Comparative Point Bar

Figure 4.12 – Weeki Wachee Comparative Point Bar

Figure 4.13 – Weeki Wachee Scarp Example (Point Bar 1)

Note: Example of a scarp (unnatural vertical wall), representing BRK-2 as a breakpoint in the point bar mapping exercise.

Figure 4.14 – Weeki Wachee Exposed Roots Example (Point Bar 33)

Of the 8 point bars mapped, 3 at Alexander Springs Run and 2 at Weeki Wachee River had an emergent vegetation zone. The emergent zone at Alexander point bars averaged 61 feet long by 19 feet wide with an average area of 910 square feet, while the emergent zone at Weeki Wachee point bars averaged 106 feet long by 23 feet wide with an average area of 2043 square feet (**Table 4.4**). Note that the emergent zone for the Weeki Wachee River appears to be substantially larger because one of the point bars (#1/WW2) has a very large (although much impacted) emergent zone. By comparison, the denuded point bars observed in the Weeki Wachee River averaged 72 feet long by 12 feet wide with an average area of 779 square feet. What is now denuded at the Weeki Wachee River was likely once intact with vegetation and organic soils based on both the comparable site point bar mapping results and the vegetation losses observable over time on aerial photographs of the Weeki Wachee River.

At both Alexander Springs Run and Weeki Wachee River, the emergent zone contained organic soils ranging from 0.2 to 3 feet thick, while the denuded zones at Weeki Wachee were just sand. The average depth of the emergent zone relative to the bankfull stage was 1.7 feet at Alexander Springs Run. The average depth of the waterward edge of the denuded bar at Weeki Wachee (BRK1, which presented itself as a sand ledge) was 1.9 feet, while the average depth of the landward edge of the denuded bar where the scarp occurred (BRK2) was 1.1 feet, indicating that the current edge of the point bar at Weeki Wachee has a similar bankfull depth to the intact point bars at Alexander Springs Run (**Table 4.4**).

Table 4.4 – Summary of Comparative Site Assessment Point Bar Dimensions

Site	Zone	Length (ft)	Average Width (ft)	Area (sq. ft)	*Average Depth Relative to Bankfull (ft)	Organic Soil Thickness (ft)	Average Estimated Organic Soil (cy)
Alexander Spring Run	Emergents (n=3)	61 (48-71)	19 (16-22)	910 (726-1213)	1.7 (1.5-1.8)	0.5 - 3	57
Weeki Wachee River	Emergents (n=2)	106 (20-191)	23 (8-38)	2043 (156-3930)	0.1 (0.1-0.2)	0.2 - 3	34
	Denuded (n=4)	72 (49-99)	12 (9-16)	779 (325-1204)	BRK1 Sand Ledge: 1.9 (1.3-2.4) BRK2 Scarp Toe: 1.1 (0.9-1.3)	Sand only	-31

Note: Top number is the average, parentheses include the range (minimum-maximum).
*Average depth relative to bankfull indicates the relative elevation of the soil surface.

Using the mapped areas of point bar zones and the depth of organic soils in each zone, an estimated volume of organic soils at each bar was calculated for Alexander Springs Run and Weeki Wachee River. The emergent vegetation zones of Alexander Springs point bars were compared to the emergent vegetation and denuded point bar zones of Weeki Wachee (inferring from historic aerial interpretation that denuded point bars historically contained vegetation). Averaging organic volumes at each site, Alexander Springs emergent zones characteristically contained 57 cubic yards of organic soils per bar, Weeki Wachee emergent zones contained an average of 34 cubic yards of organic soils per bar, and Weeki Wachee denuded zones are estimated to have lost an average of 31 cubic yards per bar, when multiplying the area by the depth of soil loss (**Table 4.4**). Denuded zone organic soil loss was estimated by multiplying the average zone area by the average scarp depth.

4.4. Cumulative Assessment

4.4.1 Methodology

A cumulative assessment was conducted to document organic soil and vegetation losses at Weeki Wachee River point bars by measuring apparent denudation surface areas and soil loss thicknesses at 10 randomly selected point bars from the State Park to Rogers Park. The random selection included at least 2 point bars in each functional process zone, at least 1 of which was forested and 1 of which was herbaceous (locations in **Map 4**). General dimensions (length, width, depth), soil, and vegetation data were recorded within each ecological zone at the 10 selected point bars. The data gathered in this assessment, as well data collected at reference point bars in the comparative study, were then used to estimate soil and vegetation losses at denuded point bars, and to gain an understanding of the average conditions of the point bars along the Weeki Wachee River. Detailed information including photographs, measurements, and soil and vegetation data for each cumulative assessment point bar are provided in **Appendix F**.

Of the 10 point bars assessed on the Weeki Wachee River, 9 exhibited a denuded zone with scarps and soil loss that appear to be from recreational use, while 1 remained largely intact. It should be noted that at point bars classified as forested, it was unclear whether emergent herbaceous vegetation zones had been lost or if the dense canopy had never provided conditions to support emergent vegetation. It is also worth noting that similarly dense forested areas of Alexander Springs Run did support emergent, herbaceous vegetation zones. Therefore, the assumption would be that the forested bars on Weeki Wachee River should also have an herbaceous emergent zone to be considered intact and unimpacted. The denuded zones measured at the cumulative assessment point bars averaged 74 feet long and 13 feet wide, with an average area of 1,038 square feet and an average scarp thickness of 1.4 feet (**Table 4.5**).

To estimate the amount of organic soil lost at each denuded cumulative assessment site, each site's average scarp thickness was multiplied by the area of the denuded zone. Using this approach, it can be estimated that nearly 500 cubic yards of organic soil has been lost from the measured cumulative assessment point bars across over 9,300 square feet of measured denuded zone (**Table 4.5**). Reference bar soil thicknesses were also considered for use to estimate soil thickness loss at denuded bars. However, organic soil depths within intact emergent zones at both Alexander Springs Run and Weeki Wachee River ranged from less than 1 foot to over 3 feet (**Appendix E**). Due to the wide range of organic soil depths encountered at these reference point bars, the scarp thickness was assumed to be the most accurate depth for estimating organic soil losses at each particular point bar; however, using scarp thickness is a forensic estimate of actual organic soil loss with degree of uncertainty regarding if it is an over- or under-estimation.

Table 4.5 – Summary of Cumulative Assessment Denuded Point Bar Dimensions (n=9)

Summary Statistic	Length (ft)	Average Width (ft)	Area (sq. ft)	Average Scarp Thickness (ft)	Estimated Organic Soil Volume Loss (cy)
Minimum	49	3	134	0.9	9
Maximum	116	26	2575	1.8	149
Average	74	13	1038	1.4	55
Total	**670**	**--**	**9338**	**--**	**498**

Note: Area displayed in table is not equal to length*width in table. Area of each point bar was calculated with bar's individual length and average width, but table shows minimum, maximum, and average dimensions across all bars.

In addition to the detailed assessment of the 10 selected point bars described above, locations and estimated dimensions of an additional 24 point bars with scarps that appeared to be from recreational use were documented along the river (**Map 4**). The goal of this additional data collection was to obtain more comprehensive information to help estimate total organic soil losses along the river. It should be noted that this additional assessment was conducted with rough measurements, not measured with the more detailed methods described above in earlier sections. The measurements and calculations were intended to provide a general estimate of total soil volume loss along the length of the river.

The length of each scarp was estimated, and the thickness of each scarp was measured at 1 representative location along the scarp. The 24 additional bars with scarped areas averaged 37 feet long and 1.1 feet thick (**Table 4.6**). To estimate the amount of organic soil lost at each additional scarp, each site's average scarp thickness was multiplied by the estimated length and by the average width of the cumulative assessment sites' denuded zone (13 feet). Using this approach, it was estimated that nearly 500 cubic yards of organic soil has been lost from these additional scarps (**Table 4.6**). Using the estimated lengths and the average 13-foot width, the additional scarps have an associated denuded zone area of approximately 12,000 square feet.

Table 4.6 – Summary of Additional Observed Scarp Dimensions (n=24)

Parameter	Length (ft)	Scarp Thickness (ft)	Estimated Organic Soil Loss (cy)
Minimum	15	0.8	7
Maximum	110	2.0	51
Average	37	1.1	20
Total	**880**	**--**	**485**

Totaling the estimated organic soil losses from the cumulative assessment sites and the additional scarp sites, approximately 1,000 cubic yards of organic soil has been lost from point bars within the Weeki Wachee River study area. Denuded zone surface area totals over 20,000 square feet, which may be an indication of how much vegetation has been lost. As demonstrated in the trample study, once vegetation has been trampled and lost, the denuded point bar no longer holds organic soils. These soils wash away, exposing the sand below, which then becomes easily transportable and is redistributed, causing downstream point bar dimensions to shift over time. Due to these shifts, the apparent denuded zones measured in this study may be smaller or larger in size than the actual footprint of vegetation and soil losses that have occurred over time. Irrespective of the quantitative accuracy of the amount of soil involved, it is clear that the Weeki Wachee River's point bar equilibrium and ecological integrity have been severely compromised.

4.5. Inventory of Leaning Trees

While conducting cumulative assessments on Weeki Wachee River, it was noted that many trees were leaning over or into the water at an angle that would make the trees susceptible to an impending tree fall, particularly within FPZ-3. Many of the leaning trees had roots that appear to have been exposed from soil washout/erosion and moderate to severe bank undercutting. Along the spring run from the State Park to Rogers Park, 76 leaning trees were observed (56 in FPZ-3, 26 in FPZ-2). Overall, the leaning trees appeared to be on outer bends of the river. At one outer bend, at the Weeki Wachee Christian Camp, 1 large bay tree had fallen during the end of the study, exposing the root system and disturbing the soils of the bank. Along the same outer bend at the Christian Camp, several more leaning trees were noted along with approximately 6 feet of bank undercutting (**Figure 4.15**). Bank undercutting increases potential for tree fall when trees are rooted into the undercut bank, which can create a hazard and obstruction for navigation when the tree falls into the river. Outer bends with severe undercutting can also be associated with point bar enlargement, which appears to be occurring on several bars.

The Hernando County staff that maintain and remove fallen trees noted that many of the fallen trees they remove used to be rope swing or jumping trees. Jumping trees and rope swings appear to have multiple effects on point bar and bank morphology. The tree is a recreational draw, attracting vessels to dock and users to wade and swim, which may expose shoreline to enhanced vulnerability to scour and accelerated erosion of the banks. The energy transferred to the water from the impact of individuals jumping from heights can produce additional erosive forces not normal for the river in the form of waves. If enough soil is lost that the roots can no longer hold the tree in place, it may fall, tearing soil up with the roots, and leaving exposed soils that can then be washed downstream.

Figure 4.15 – Leaning Trees on Right Bank at Weeki Wachee Christian Camp

4.6. Desktop GIS Inventory

GIS software in conjunction with ground-truthing in the field were used to create an inventory of features that provide recreational access to the river such as docks, boat ramps, seawalls, and other (including earthen ramps, stairs, and cleared grass slopes (**Table 4.7**). Additionally, GIS was used to assess the available parking spaces at the State Park and Rogers Park, along with any other identifiable vendor parking areas (**Table 4.8**). All discernable vessel vendors (**Table 4.9**) were contacted for rental data; however, no data were provided. It should also be noted that from desktop inventory, it appears that other businesses (such as bait shops or restaurants/bars) may rent kayaks to launch at the State Park or Rogers Park. It also appears that vacation property rentals on canals provide kayaks to patrons.

Table 4.7– Inventory of Docks and Seawalls

Feature	Count
Docks	75
Boat ramps	3
Seawalls	33
Access/Other*	23

Note: *Access/Other category includes any feature that provides access to the water, such as ramps, staircases, and cleared grass slopes

Table 4.8 – Available Parking at Launch Locations

Location	Type of Vehicle	Type of Parking Space	Number of Parking Spots
Rogers Park	Regular vehicles, Trailers	Paved Paved	56 16
State Park main parking lot State Park kayak launching site parking lot State Park kayak launching RV parking	Regular vehicles Regular vehicles RV's	Paved Grass/Gravel Asphalt/Gravel	351 150 4

Note: Weeki Wachee Kayak Shack (across from Rogers Park) has 40 grassed parking spaces. Parking at Weeki Wachee Marina does not appear to be in designated spaces, but the surrounding paved area can reasonably accommodate 20-30 vehicles.

Table 4.9 – Summary of Vendors Contacted for Rental Data

Vendor Name	Contact Information
Weeki Wachee Kayaking	8103 Cortez Blvd, Weeki Wachee, FL 34607 (352)-684-7180 weekiwacheekayakinginfo@gmail.com
SUP Weeki	6895 East Richard Drive, Weeki Wachee, Florida 34607 (727) 480 4294 info@supweeki.com
Kayaks & Attractions	7383 Shoal Line Blvd, Weeki Wachee, FL 34607 (352) 796-2289
Weeki Wachee Marina	7154 Shoal Line Blvd, Weeki Wachee, Florida 34607 352-596-2852 weekiwacheemarina.com
Weeki Wachee The Kayak Shack	5414 Darlene St, Spring Hill, FL 34607 (352) 610-4169

4.7. Summary of Fluvial Geomorphology Assessment

From interpretation of aerial imagery, it is apparent that point bars along the Weeki Wachee River have lost vegetation and organic soils since 2008 (the oldest available clear aerial imagery). An experimental study of recreational trampling showed that even a small amount of trampling can impact vegetation and cause organic soil losses, and that trampling increases turbidity, especially when it occurs in organic soils. The trampling study also showed that vegetation on the submerged edges of point bars are the most likely to be extensively impacted.

The less-impacted comparison sites at Alexander Springs Run showed that point bars, even in densely forested reaches, support emergent herbaceous vegetation and contain organic substrates, while point bars surveyed at the Weeki Wachee River had a denuded zone devoid of emergent vegetation or the emergent zone was truncated. The comparative study results provided another layer of evidence and documented that point bars in Weeki Wachee River have been impacted in comparison to Alexander Spring Run and approximately 30 cy/bar has been lost from Weeki Wachee River point bars.

The cumulative assessment showed that 9 out of 10 point bars on the Weeki Wachee River were impacted and had denuded herbaceous zones, with only 1 out of 10 assessed bars remaining intact. In addition, 33 point bars showed that approximately 1-2 ft of organic soil depth has been lost at many point bars on the river along with up to 20,000 square feet of estimated vegetation loss based on the sizes of the denuded zones observed. The denudation on this set of bars likely resulted in something on the order of 1,000 cubic yards of organic soil alone (approximately 60 dump truck loads).

5.0 STATISTICAL ANALYSIS TO ASSESS RECREATIONAL IMPACTS

The historic aerials, physical assessments, and experiments detailed in previous sections consistently suggest that recreation has impacted the vegetation, soils, and morphology of the river. Experimental turbidity recordings before and after trampling showed that trampling leads to increases in turbidity. The data collected as part of this project were analyzed, along with other environmental data to determine if statistically significant relationships exist between recreation and water quality parameters, specifically turbidity. Turbidity is caused by light scatter from fine particles floating in the water and a variety of activities can increase the load of such particles, including trampling, docking, wave induction, and prop wash from motorboats. Increased turbidity reduces water clarity and light penetration through the water column, which can affect the photosynthesis of submerged aquatic plant communities. Increased turbidity may also indicate suspension of sediments that may redeposit and smother aquatic plants and other benthic habitats. Florida spring runs characteristically have very low turbidity, so elevated turbidity indicates potential water quality issues related to recreational activity if it can be measured to increase during such activities.

Wood concurrently sampled turbidity, total suspended solids (TSS), and volatile suspended solids (VSS) at varying levels of recreational use to statistically assess associations between these variables. All three variables essentially measure the number of suspended particles in the water column and are typically co-variates when the variables are used as proxies for water clarity, quality, and to assess potential sediment transport. However, during quality control processing and screening (i.e. review of laboratory qualifier codes and other reported quality controls), the TSS and VSS data were found to be below detection and were not used for statistical analyses. The processed and screened turbidity dataset was found to be adequate for statistical analyses and were used for several different statistical tests as described below. It should be noted that because turbidity can increase absent recreational influence in response to rainfall, and due to algal production as the day unfolds, Wood accounted for such responses in the statistical assessments.

5.1. Exploratory Analysis with Long-Term Data

5.1.1 Turbidity Trend Analysis

Trend analysis was performed on the quarterly average time series of SWFWMD ambient turbidity data from stations 20923 (SWFWMD WW1, Wood WW2), 20600 (SWFWMD WW3, near Wood WW3), and 20650 (SWFWMD WW5, between Wood WW4 and Rogers Park) using the USGS Fortran code for the nonparametric Seasonal Kendall Test, which acknowledges and adjusts for potential autocorrelation (Helsel et al. 2006). The trend analysis was performed on time series with and without outliers (defined as greater than 2*standard deviation). Overall, the results showed significant increasing trends at all stations from 2006 to 2019 (except for station 20600 with outliers.) The complete trend analysis results are shown in **Table 5.1.**

Table 5.1 – Long-term Turbidity Seasonal Kendall Trend Analysis Results

Station	Parameter (NTU)	Tau	Selected p-value	Slope (NTU/quarter)	Trend
20923	Turbidity	0.246	**0.032**	0.006	**Significant increasing**
20923	Turbidity (no outliers)	0.368	**<0.001**	0.010	**Significant increasing**
20600	Turbidity	0.103	0.279	0.013	No significant trend
20600	Turbidity (no outliers)	0.331	**0.001**	0.024	**Significant increasing**
20650	Turbidity	0.387	**<0.001**	0.032	**Significant increasing**
20650	Turbidity (no outliers)	0.225	**0.027**	0.026	**Significant increasing**

Note: Period of record for stations –20923 (2/27/2006 – 4/22/2019), station 20600 (10/13/2005 – 4/22/2019), station 20650 (10/13/2005 – 4/22/2019).

5.1.2 Correlation Analysis

The long-term State Park vessel data (daily vessel launch totals from 7/1/2012 – 6/1/2019) were compared to the long-term SWFWMD turbidity data using nonparametric Spearman's Rho correlation analysis. The same three SWFWMD turbidity stations used in trend analysis were used for correlation analysis, but the data were not converted to quarterly average series. The State Park daily vessel launch counts were summarized at a monthly time step as several metrics (total vessels per month, average daily vessels by month, and maximum daily vessels by month). Daily discharge data from USGS station 2310525 and daily rainfall data from SWFWMD station 20912 were converted to monthly average (discharge) and monthly total (rainfall) series and included in the correlation matrix.

The complete results of the Spearman Rho correlation are shown in **Table 5.2**. Turbidity at all stations was positively, significantly correlated to State Park vessels counts, meaning that with higher vessel counts, turbidity is also higher. The strongest correlation between vessel counts and turbidity was found at the station near the State Park boundary (20923). The lower strength of correlation between turbidity and number of vessels at the more downstream stations may be due to half of the vessels entering the river from downstream and not the State Park. Therefore, the State Park vessel count data only account for a portion of the total recreational activity that may be affecting turbidity at the downstream sites. The correlation would likely be stronger at the downstream stations if long-term data were available for vessels traveling from downstream to the lower stations to achieve a truer total number of vessels that may be influencing turbidity values. Vessel counts were also negatively, significantly correlated to rainfall and positively, significantly correlated to discharge. These values may be explained by lower recreation during rain events and the possible overlap of the summer high-recreation season with the wet season. At this time step, rainfall was not significantly correlated to turbidity.

Table 5.2 – Results of Spearman Rho Correlation Analysis

	Turbidity at 20923	Turbidity at 20600	Turbidity at 20650	Monthly Total Vessels	Avg Daily Vessels (by month)
Turbidity at 20923		0.581 **0.001**			
Turbidity at 20650	0.322 ***0.094***	0.348 ***0.069***			
Monthly Total Vessels	0.588 **0.001**	0.374 **0.05**	0.365 ***0.056***		
Avg Daily Vessels (by month)	0.559 **0.002**	0.356 ***0.063***	0.374 **0.05**	0.998 **0**	
Max Daily Vessels (by month)	0.518 **0.005**	0.294 0.129	0.163 0.408	0.881 **0**	0.872 **0**
Discharge	0.205 0.295	0.203 0.3	0.312 0.106	0.426 **0.024**	0.436 **0.02**
Rainfall	-0.047 0.81	-0.251 0.197	-0.257 0.186	-0.479 **0.01**	-0.497 **0.007**

Note: The top value in cell is Spearman's Rho, bottom is p-value. Bold p-values indicate statistical significance at alpha=0.05. Bold italic p-values indicate statistical significance at alpha=0.1. Green shading indicates positive, significant correlation. Red shading indicates negative, significant correlation.

5.2. Statistical Analyses with Field, Camera, and Sonde Data

The exploratory analysis with long-term data showed a correlation between number of vessels launched from the State Park and turbidity, so the relationship was further explored in more detail and with a tighter sampling frequency using data collected as part of this study (details regarding data collection intervals and protocols are provided in **Section 2**). Two independently collected datasets were used to identify if relationships exist between turbidity and recreational use in the river at Wood's monitoring stations:

- Continuous turbidity (FNU) data were collected *in situ* via a sonde instrument (deployed and retrieved by FDEP). Concurrent continuous recreational use data recorded by video cameras (deployed and retrieved by Wood) was transcribed by SWFWMD from recorded video footage. This coupled dataset is referred to as the 'continuous dataset.'
- On the 9 sampling events conducted by Wood, grab samples were collected in the field and analyzed in the FDEP laboratory for turbidity (NTU). Concurrent recreational use data (user and vessel counts) were collected in the field by Wood. This dataset is referred to as the 'grab-sample dataset.

Each of the datasets listed above also included daily rainfall and spring discharge (flow) data recorded at SWFWMD station 20912 and USGS station 2310525, respectively (same data as used in correlation analysis).

The statistical analyses treated turbidity as the response variable. As is common for water quality data, the turbidity data were log-normally distributed. Therefore, to meet assumptions for the applicable parametric and linear analyses, the turbidity data were $\log_{10}$ transformed prior to analysis. The results should be interpreted in terms of explanatory variables' influence on the *order of magnitude* of turbidity, and not simply on the absolute value.[7]

Explanatory variables in each analysis included the sampling site (spatial variation), seasonal and daily effects (temporal variation), user counts, vessel counts, rainfall (in.), and spring discharge (cfs). User counts, vessel counts, and rainfall were broken out into several variables ('predictors') used in the statistical models (**Table 5.3**). Based on the raw count data, various hourly and cumulative user and vessel counts were developed: the number of users present during the one hour prior to sampling (e.g., hourly users, *user.hour*) and the running count of users up until the sampling time each day (e.g., hourly cumulative users, *user.cumu*).

Table 5.3 – Summary of Variables used in Analyses

Variable Name	Description	Unit	Type
turb.ntu	turbidity analyzed in lab (grab sample)	NTU	continuous
turb.fnu	turbidity recorded by sonde	FNU	continuous
site	turbidity sampling site (WW1, WW2, WW3, or WW4)		categorical
date	turbidity sampling date		categorical
time	turbidity sampling time		categorical
rain.in.d0	rainfall on sampling date	in	continuous
rain.in.d1	rainfall one day prior to sampling date	in	continuous
rain.in.d2	rainfall two days prior to sampling date	in	continuous
rain.in.d3	rainfall three days prior to sampling date	in	continuous
rain.in.tot	total rainfall during sampling date and the three days prior	in	continuous
flow.cfs	spring discharge	cfs	continuous
user.hour	count of users during the one hour prior to sampling time		discrete
user.cumu	cumulative count of users on the sampling date, up until the sampling time		discrete
swim.hour	count of people wading/swimming during the one hour prior to sampling time		discrete
swim.cumu	cumulative count of people wading/swimming on the sampling date, up until the sampling time		discrete
vessTOT.hour	count of vessels (all types) during the one hour prior to sampling time		discrete
vessTOT.cumu	cumulative count of vessels (all types) on the sampling date, up until the sampling time		discrete
dockTOT.hour	count of docked vessels (all types) during the one hour prior to sampling time		discrete

[7] The log transformation replaces each observed turbidity value with the base-10 logarithm of that value: The logarithm function returns the exponent to which 10 must be raised to produce the original value. For instance, the logarithm of 10 is 1, and the logarithm of 100 is 2, because 10^1=10 and 10^2=100. Therefore, an increase of one on the logarithmic scale represents a tenfold increase in turbidity.

Variable Name	Description	Unit	Type
dockTOT.cumu	cumulative count of docked vessels (all types) on the sampling date, up until the sampling time		discrete
dockHP.hour	count of docked human-powered vessels during the one hour prior to sampling time		discrete
dockHP.cumu	cumulative count of docked human-powered vessels on the sampling date, up until the sampling time		discrete
dockMP.hour	count of docked motorized vessels during the one hour prior to sampling time		discrete
dockMP.cumu	cumulative count of docked motorized vessels on the sampling date, up until the sampling time		discrete

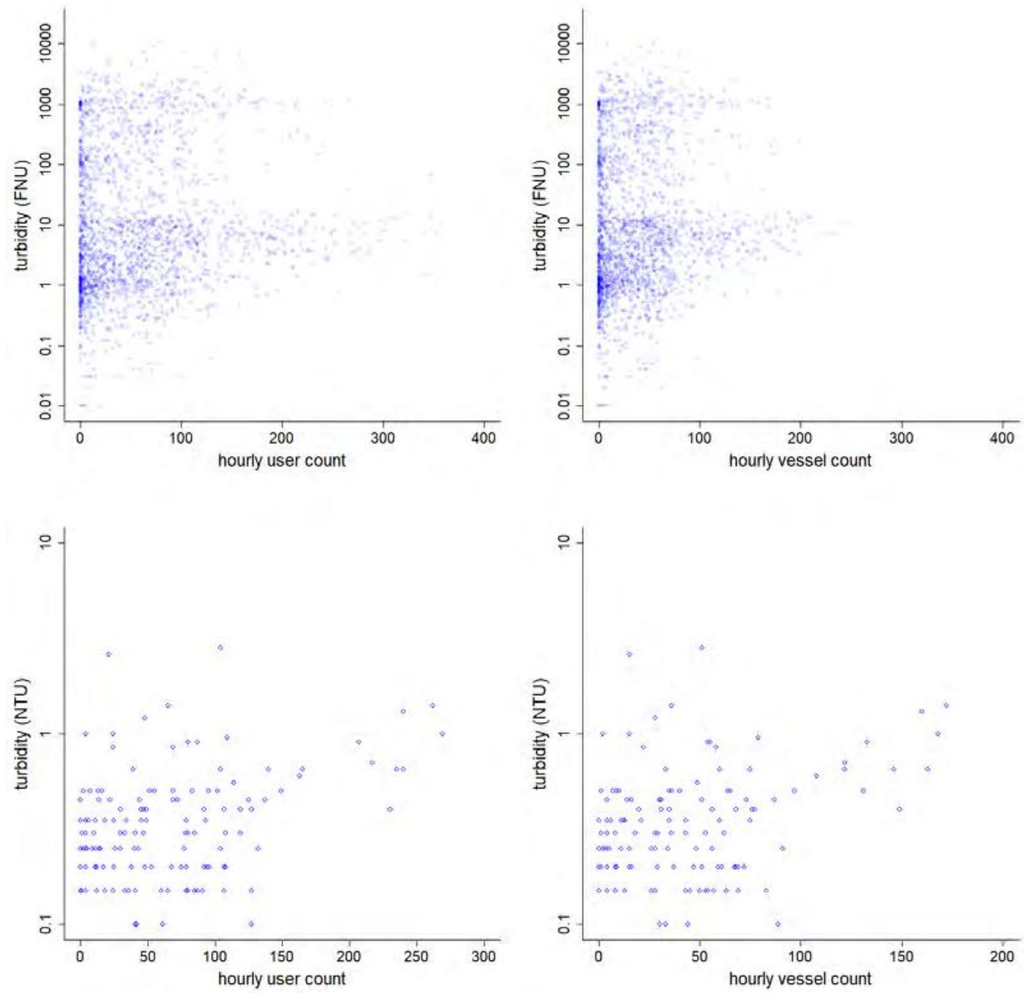
5.2.1 Data Exploration

Based on results shown in **Figure 5.1**, turbidity values are low relative to most water bodies. However, it's important to note that even small changes in turbidity in spring systems can have substantial effects on water clarity since the submerged aquatic vegetation communities that are commonly found in spring systems such as Weeki Wachee River require greater light availability (Szafraniec 2014). Therefore, maintaining low turbidity concentrations (between 0.2 to around 1 NTU, which varies based on distance from the headspring and associated inflows) in Weeki Wachee River is relevant for both aesthetic and ecological reasons.

Upon examining linear relationships between turbidity and recreational parameters, recreational use did not exhibit a straightforward linear relationship to turbidity, as illustrated in **Figure 5.1**. Therefore, more advanced statistical techniques were required to isolate recreational effects from other, potentially confounding effects (e.g., spatial variability, seasonality, hydrological effects). Further, results from the scatterplots did not show clear evidence of a user/vessel count vs. turbidity breakpoint that would be considered statistically significant, which might justify estimation of a recreational carrying capacity—the recreational intensity below which the effects on turbidity were minimal. This is likely due to the additional effect of user activities on the river that included docking, exiting vessels, wading, swimming, etc. that influences turbidity and potential impact as much if not more than if users did not exit their vessels. It appears that the grab-sample dataset showed patterns of higher turbidity values with higher vessel/user counts. Therefore, a potential threshold may be drawn from the results for management purposes if other recreational activities (e.g.) are taken into consideration since these activities are influencing turbidity values as well.

Two statistical methods were used to assess the impact of recreational use on turbidity in the Weeki Wachee River: random forests and linear mixed effects models. These methods were applied to each of the datasets in separate analyses. The large number of observations in the sonde dataset provided sufficient statistical power and enabled analysis across sites and by individual site; the smaller grab-sample dataset was analyzed without disaggregating by site.

Figure 5.1 – Scatterplots of Turbidity vs. Hourly User and Vessel Counts



Note: The top two figures depict the continuous dataset, and the bottom two depict the grab-sample dataset. The y-axes are hourly turbidity on a logarithmic scale.

5.2.2 Random Forest Methodology

Using R package ‘gbm’ (Greenwell et al. 2019; R Core Team 2018), random forests with gradient boosting were applied to rank predictors according to their ‘relative influence’ on turbidity. A *random forest* model develops an ensemble of ‘decision trees’ that each partition the predictor space using random subsets of predictors; while each tree is a weak predictor, the collective prediction skill of the ensemble is generally much greater (James et al. 2013). *Gradient boosting* improves prediction skill by sequentially fitting trees to the residuals from previous trees. *Cross-validation*, which is training the model on random subsets of data (‘training data’) and testing the model on each out-of-sample data set (‘test data’), was applied to optimize tuning parameters that control the algorithm (the loss function and the number of sequential trees in each model).

The boosted random forest model provides a *relative influence* metric that reflects each predictor's contribution to improved prediction skill across the ensemble (Ridgeway 2019).

Modeling with random forests offers increased ability to detect complex, nonlinear relationships between predictors and the response, and typically increases out-of-sample prediction skill as compared to classical regression. However, these advantages come with a trade-off: The random forests' results are less interpretable, and inferences about predictor-response relationships are limited to the relative-influence ranking. This is in contrast to least-squares regression, which quantifies the relationships with a coefficient estimate for each predictor. Consequently, results from the random forest models are presented only as a preliminary indicator of the variables with the greatest influence on turbidity. The results gain credibility to the extent that cross-validation demonstrates skillful prediction on out-of-sample data.

The out-of-sample prediction skill of each model was measured using Nash-Sutcliffe efficiency (NSE):

$$NSE = 1 - \frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} = 1 - \left(\frac{RMSE}{\sigma}\right)^2$$

where y_i and $\hat{y}_i$ are the i^{th} observed and predicted values of the response variable, respectively; $\bar{y}$ was the mean of the observed response values. Equivalently, the NSE can be expressed in terms of the ratio between the root-mean-squared error (RMSE) of the model and the standard deviation (σ) of the response data, as above. A value of NSE=0 indicates that the model predicts the mean response value; values below zero indicate that the mean is a better predictor than the model; values above zero indicate that the model is a better predictor than the mean; and a value of NSE=1 indicates a perfect fit between the predicted and observed response values. A minimum threshold of NSE≥0.50 was adopted as an acceptance criterion for the prediction skill of each model (Moriasi et al. 2007). Next, the random forest results were used to inform specification of linear mixed effects models that tested the identified predictor-turbidity relationships for statistical significance.

5.2.3 Linear Mixed Effects Model Methodology

A *linear mixed effect model* (LMEM) is a generalized form of least-squares regression that estimates coefficients for *fixed effects* (measured variability in the explanatory variables) and their statistical significance, while controlling for *random effects*—unmeasured variability attributed to spatial or temporal replication (Galecki and Burzykowski 2013).

Ordinary least-squares regression estimates response values according to the equation

$$\hat{\mathbf{y}} = \mathbf{X}\boldsymbol{\beta}$$

where $\hat{\mathbf{y}}$ is the n×1 vector containing predicted values of the response variable (e.g., turbidity); $\mathbf{X}$ is the $n\times(p+1)$ design matrix, whose first column is a vector of 1's and whose subsequent p columns each contain n observed values of a predictor; and $\boldsymbol{\beta}$ is the $(p+1)\times1$ coefficient vector $[\beta_0, \beta_1, \beta_2, \ldots, \beta_p]^T$, whose first element is the estimated intercept and whose subsequent elements are the slopes estimated for p predictors. The intercept represents the baseline value of the response (given no influence from the predictors), and each slope represents the estimated adjustment to the mean response value given a unit change in a predictor.

A linear mixed effects model adds a term to the above regression equation to estimate intercepts (and optionally, slopes) for random effects:

$$\hat{\mathbf{y}} = \mathbf{X\beta} + \mathbf{Z\alpha}$$

where $\mathbf{X}$ is the design matrix for fixed effects; $\boldsymbol{\beta}$ is the fixed-effects coefficient vector; $\mathbf{Z}$ is the design matrix for random effects; and $\boldsymbol{\alpha}$ is the random-effects coefficient vector (Galecki and Burzykowski 2013). The $\boldsymbol{\alpha}$ vector may include random intercepts and slopes, or random intercepts only. Each random intercept represents an adjustment to the baseline intercept β_0, based on membership of an observation in a random-effects group. For instance, a random intercept for each sampling site would adjust the baseline turbidity values for each site (assuming no influence from the fixed-effects predictors).

The R package 'nlme' was used to develop the mixed effects models (Pinheiro et al. 2018; R Core Team, 2018). Specification of each LMEM was informed by the results from the corresponding random forest model. The LMEMs tested whether the five top-ranked predictors identified by each random forest model were statistically significant (alpha=0.05) predictors of turbidity (log-transformed), while controlling for spatial and temporal variability as random effects. Akaike's Information Criterion (AIC) was applied to select the variables for inclusion as random effects (from among sampling site, date, and time, as applicable, Akaike 1973). The AIC balances goodness of fit with model complexity (the number of parameters in the model) to select the most efficient model from a set of candidate models.

For each mixed-effects model, the Pearson residuals were examined to ensure that the residuals were unstructured with respect to fitted values, fixed effects values, and random effects values. Further, the prediction skill of each model using the NSE metric was computed (see the previous section). Here, NSE is equivalent to the familiar coefficient of determination R^2, in that it reflects the amount of variance from the mean explained by the model. The NSE values reported for mixed-effects models were computed using the full set of turbidity data and predictions. The p-values are reported for fixed effects as provided by the *lme()* function in the 'nlme' package: the function computes p-values after estimating the degrees of freedom as $n–p$, where n is the sample size and p is the number of parameters in the model.

5.2.4 Results of Random Forest Models

Random forest models were run to identify the variables exerting the greatest 'relative influence' on turbidity across all four sites and at each site individually. In addition, the random forest results informed the selection of variables for hypothesis testing with mixed effects models (discussed in following section). The predictors considered by each model included user counts, vessel counts, rainfall, and spring discharge, as well as the sampling site, date, and time (full list of variables in **Table 5.3**). Each model yielded an acceptable fit to out-of-sample data during cross-validation (NSE>0.50), suggesting reliability for drawing inferences (**Table 5.4**).

Overall, the analysis sought to identify recreational factors influencing turbidity while controlling for the spatial and temporal variability associated with the sampling sites, dates, and times. These categorical variables were therefore included in the random forest models although they were not of primary interest as predictors of turbidity. Because sampling site, date, and time ranked highly in each model, they were specified as candidate 'random effects' in the mixed effects models (following section).

The top-five numerical predictors in each random forest model are marked in **Table 5.4**. Among the five models, the hourly cumulative vessel count (*vessTOT.cumu*) most often ranked highest. The hourly cumulative counts of users (*user.cumu*) and people wading/swimming (*swim.cumu*) were also highly ranked across models. These results provide a preliminary indication that both the cumulative number of vessels per hour and the cumulative number of users in the water per hour each day exerted a relatively strong influence on turbidity concentrations.

Spring discharge (*flow.cfs*) was ranked as the most influential predictor of turbidity by the WW3 model (continuous sonde data). Otherwise, the random forest models detected zero influence on turbidity from rainfall and spring discharge. These results should not be interpreted as evidence that rainfall and spring discharge did not physically influence turbidity. Instead, the results may be an artifact of the temporal resolution of these data. The daily resolution of the rainfall and discharge data means that their (numerical) variability would easily be captured by the categorical sampling date variable (*date*).

The motorized vessel counts (*dockMP.hour* and *dockMP.cumu*) did not rank in the top-five most influential predictors across models. This result should not be interpreted as evidence that motorized vessels did not influence turbidity. Instead, the result likely reflects the low variance in the motorized vessel data, relative to the variance present in other predictors.

Table 5.4 – Summary of Random Forest Model Results

Dataset		**Continuous Sonde and Camera Count Data**					**Grab-Sample and Field Count Data**
Response variable		**Turbidity ($\log_{10}$, FNU)**					**Turbidity ($\log_{10}$, NTU)**
Site		**WW1**	**WW2**	**WW3**	**WW4**	**All sites**	**All sites**
Observations	***n***	384	480	433	362	1659	144
Error Statistics	***test NSE***	0.801	0.933	0.966	0.539	0.562	0.609
	test RMSE	0.435	0.297	0.273	0.295	0.746	
Predictor	rain.in.d0						
	rain.in.d1						
	rain.in.d2						
	rain.in.d3						
	rain.in.tot						
	flow.cfs			**X**			
	vessTOT.hour			x			
	vessTOT.cumu	**X**	**X**		**X**		**X**
	user.hour	x			x		
	user.cumu	x	x	x	x		x
	dockHP.hour				x		
	dockHP.cumu		x	x		x	
	dockMP.hour						
	dockMP.cumu						
	dockTOT.hour						
	dockTOT.cumu		x				x
	swim.hour				x	**X**	x
	swim.cumu		x	x		x	x

Note: The top-five predictors from each model are marked; a bold **X** indicates the top-ranked predictor. (The models for WW1 and all sites based on the continuous sonde data identified only three numerical variables with non-zero influence.) Error statistics on out-of-sample ('test') data indicate that the models provide a reliable basis for inference.

5.2.5 Results of Linear Mixed Effects Models

Based on the random forest model results, linear mixed effects models were specified to test whether various user and vessel counts had statistically significant effects on turbidity, after controlling for spatial and temporal variability arising from replicate sampling.

Each selected predictor was correlated with each other predictor (shown in **Appendix G**). Including correlated predictors (i.e. co-variates) in the same model would make coefficient estimation and hypothesis testing unreliable, because the regression procedure would be unable to accurately isolate the effect of each correlated variable on the response variable (turbidity). To avoid this problem, a separate mixed-effects model (and hypothesis test) was developed for each selected predictor.

AIC was applied to select the variables for inclusion as random intercepts for each LMEM; random slopes were not included. For the LMEM of the grab-sample dataset (all sites), random intercepts were specified by *site*, *date*, and *time*. For the continuous sonde dataset (all sites), random intercepts were specified by *site* and *date* (inclusion of random intercepts for *time* did not improve the AIC score). Likewise, for each of the 4 site-specific models (continuous sonde dataset), random intercepts were specified by *date*.

Each mixed-effects model achieved a high NSE value (NSE≥0.85), and visual checks of each model's Pearson residuals did not show evidence of residual structure or autocorrelation. Results of the hypothesis tests are summarized in **Table 5.5**. Each of the statistically significant coefficient estimates associated with user and vessel counts were positive, indicating a significantly positive relationship with turbidity.

The following results are from analysis of the continuous sonde dataset. The mixed effects model for all sites identified the hourly cumulative counts of docked human-powered vessels and people wading/swimming as highly significant predictors of turbidity ($p < 0.0001$). Results from the site-specific mixed effects models generally agreed with these results:

- At WW1, the hourly cumulative counts of vessels (all types) and users were identified as significant predictors of turbidity (p=0.0002 and p=0.0003, respectively).
- At WW2, the hourly cumulative counts of vessels (all types), docked vessels (all types), users, docked human-powered vessels, and people wading/swimming were identified as significant predictors of turbidity ($p < 0.0001$).
- At WW3, spring discharge and the hourly cumulative counts of users, docked human-powered vessels, and people wading/swimming were identified as significant predictors of turbidity ($p < 0.0001$). The coefficient estimated for spring discharge (*flow.cfs*) was negative, indicating a negative relationship between discharge and turbidity.
- At WW4, the cumulative hourly counts of vessels (all types), users, and docked human-powered vessels were identified as significant predictors of turbidity ($p < 0.0001$). Also, the hourly counts of people wading/swimming (p=0.0025) and users ($p < 0.0001$) were identified as significant predictors of turbidity.

Several predictors identified as highly influential by a random forest model were not identified as statistically significant by the LMEMs, which included the number of people wading/swimming in the all-sites model (p=0.582), the hourly user count at WW1 (p=0.058), and the hourly count of vessels at WW3 (p=0.31).

The mixed effects model for the grab-sample dataset identified the hourly cumulative counts for vessels (all types), users, docked vessels (all types), and people wading/swimming as significant predictors of turbidity ($p < 0.0001$), which essentially corroborated the results from the continuous sonde dataset analysis. The hourly count of people wading/swimming was not identified as a significant predictor (p=0.31).

Table 5.5 – Summary of Hypothesis Test Results from Linear Mixed Effects Models

Dataset		Continuous Sonde and Camera Count Data					Grab-Sample and Field Count Data
Response variable		**Turbidity (log_{10}, FNU)**					**Turbidity (log_{10}, NTU)**
Site		**WW1**	**WW2**	**WW3**	**WW4**	**All sites**	**All sites**
Predictor	flow.cfs			***<0.01***			
	vessTOT.hour			0.31			
	vessTOT.cumu	**<0.01**	**<0.01**		**<0.01**		**<0.01**
	user.hour	0.06			**<0.01**		
	user.cumu	**<0.01**	**<0.01**	**<0.01**	**<0.01**		**<0.01**
	dockHP.hour				**<0.01**		
	dockHP.cumu		**<0.01**	**<0.01**		**<0.0001**	
	dockMP.hour						
	dockMP.cumu						
	dockTOT.hour						
	dockTOT.cumu		**<0.01**				**<0.01**
	swim.hour				**0.0025**	0.58	0.31
	swim.cumu		**<0.01**	**<0.01**		**<0.01**	**<0.01**

Note: Each p-value represents the result from a model testing the significance of a single predictor (fixed effect) on the turbidity response, after controlling for spatial and temporal variability (random effects). Values in bold indicate statistical significance (α=0.05). All significant coefficient estimates are positive, except for *flow.cfs* (indicated by italics).

5.3. Summary of Statistical Analysis to Assess Recreational Impacts on Water Quality

The statistical analysis results provided empirical evidence that both the cumulative number of vessels and users per hour contributed to turbidity along the spring run during the study period (July 2018 through June 2019). Hypothesis tests using linear mixed effects models corroborated the initial results from the random forest models. The fact that the models largely favored cumulative user and vessel counts over hourly counts suggests that recreation has an additive and cumulative effect on turbidity, and thus water clarity and quality. In summation, the results suggest that there are statistically significant relationships between the number of users/vessels and turbidity, and also between in-water recreational activities, such as docking, wading, and swimming and turbidity in the Weeki Wachee River. These results also suggest that a simple reduction in the number of users/vessels alone may not reduce the effects on turbidity and water clarity/quality and the in-water activities will need to be considered before making important management decisions on recreational use.

6.0 MANAGEMENT OPTIONS

This study found links between recreational activities and ecological degradation and collected a large, varied dataset which will be useful for guiding management decisions or directing future focused studies. The data, analyses, and observations from this study have informed a preliminary list of possible management options that have potential to reduce the observed impacts from recreation.

Key observations include:

- Point bars started to be denuded of herbaceous vegetation between 2008 and 2011, indicating user impacts commenced before censusing data was collected starting in 2012.
- By 2016, many points bars had become severely denuded of vegetation, and some were accreting sandy sediments presumably from upstream erosion of the denuded bars. Stress and erosion of the opposite streambanks from the accreting point bars became substantial at some locations during our study in 2019.
- The period from 2012 to 2016 saw a linear increase in users, with a moderate decline to current levels thereafter. There has been no apparent trend in point bar recovery during the reduced use. In fact, point bars have continued to denude. A total of 20,000 square feet of shoreline vegetation habitat has been lost.
- Denudation appears to be initiated by vessel docking dislodging organic soils and vegetation on the point bars. This sets up a cascading series of events by facilitating more foot traffic at the impacted areas, expanding the denudation. Once a sandy beach is exposed, it contributes sand to the run that would otherwise not leave the bar. Organic soil releases are estimated at about 30 cy/bar based on the comparative and cumulative assessments, which sums up to approximately 1,000 cubic yards (approximately 60 dump trucks) from 33 impacted point bars.
- Rope swings appear to generate additional vessel docking and wading, which may accelerate impacts. Further, trees with rope swings and those used for climbing and jumping have been observed to fall more rapidly than if not used for these purposes.
- Effects of trampling of vegetation and the underlying soil matrix were documented and were shown to cause immediate and mid-term effects on recovery.
- Points bars release substantial turbidity from organic soil releases into the run when they are initially being denuded, but less once the vegetation and organic soils have been rather fully depleted of organic soils. If this study was conducted during a time prior to the point bars being denuded, then the effects on turbidity from recreational use would have likely been more pronounced. Thus, the turbidity increases that occurred during this study in direct association with increased vessels and users would likely be much more substantial if the river's point bars were in better ecological condition.
- A clear breakpoint between the number of users/vessels was not found that would be useful for setting a carrying capacity simply on the number of users/vessels. However,

statistical analyses provided empirical evidence that cumulative number of vessels/users and in-water activities such as docking, wading, and swimming contributed significantly to turbidity along the river, which suggests that recreation has negative effects on water quality. A potential threshold may be drawn from the results for management purposes if in-water and on-bar recreational activities are taken into consideration since these activities are influencing turbidity values.

- The sandy point bars at the Weeki Wachee River are a human activity artifact and are unnatural perturbations for Florida spring runs in general and represent a state change for the river that commenced sometime between 2008 and 2011.
- It appears that limits on the number of users launching from the State Park may have reduced the number of vessels on the river. Partying on upstream point bars appeared to decline once the disposables ban was enforced. However, even though partying may have declined, the in-water and on-bar activities may still be causing impacts.
- Downstream access points from Rogers Park and other sites contribute up to 50% of users for the lower point bars, but less for upstream point bars. This suggests that impacts are due to users from these areas as well as from launches at the State Park.
- About 80% of users dock and recreate on the point bars. These users are more likely to trample vegetation and compact organic soils on point bars and therefore have a greater ecological impact than non-disembarking users in terms of greater reductions in vegetation and changes in bar morphology.

The primary reasons a single carrying capacity value based on vessels (or users) alone could not be recommended is because 1) the number of users/vessels alone did not cause the ecological and water quality impacts and in-water and on-bar activities appear to have substantial acute and cumulative impacts; 2) long-term user/vessel count data were not available from downstream access points such as Rogers Park, vendors, and private residences to assess a "total" user/vessel count to assess potential breakpoints; and 3) the threshold for unacceptable impacts occurred prior to the period of available vessel/user data. In addition to these reasons, the stressors were sustained at impactful levels during the duration of the field study without adequate recovery times between high use periods (so even if low impact variability did occur during this study it wasn't sufficiently recovered before the next impactful episode occurred). The water quality data did not indicate a significant threshold break (just that increased users increase impacts), and the most transformative impacts are generated by a subset of users engaged in particular activities (docking, swimming/wading, rope swinging). Therefore, a simple reduction in the number of users/vessels alone may not reduce the effects on water clarity/quality and ecological condition. To reduce impacts to water quality and ecological condition, a multi-tiered management decision matrix may be needed to define the number of users/vessels launching from both the State Park and from downstream areas (i.e. Rogers Park, vendors, and private residences) along with a decision on whether and at what level in-water and on-bar activities will need to be restricted.

It is evident from the results of this study that managing the kinds of activities that can occur on the river and limiting where certain activities can occur may be at least if not more important as capping the total number of daily users. This approach has been implemented on other spring runs in Florida and elsewhere. Successful approaches range from 'soft' or indirect controls to explicit regulation with strong enforcement activity.

An example of indirect control occurs at the Juniper Run in the Ocala National Forest. The run is swift and narrow, which may limit swimming and bank excursions, and docking/exiting vessels is discouraged. The number of users is not explicitly capped, but similar to the Weeki Wachee State park, the sole kayak vendor restricts rentals to occur from 8:00 AM to 11:45 AM. They often sell out, so the number of vessels they have available is another informal cap on daily use. No one is allowed to self-launch a kayak 4 hours before sunset. The timeframe restrictions induce informal limits on daily use. Activities are also indirectly controlled by a total ban on disposables, which is enforced by cooler inspections at the launch. The intrinsic characteristics of the run prevent beaching and the ban on disposables dampens a desire to disembark and party in the run. The kayak vendor encourages boaters to stay in their vessels for safety. Despite high use during the day, the run has very good biophysical integrity because users have multiple incentives to remain in their boats. It is one of the most pristine spring runs in Florida.

To alleviate impacts from recreation, some types of management could be implemented sooner than others. The first category of management options are tasks that can be conducted without regulatory actions or changing permitted recreational activities.

- Additional recreation guidance signage can be added throughout the river.
- Educational outreach can be enhanced, and videos and posters can be produced to inform the public about ecological impacts of recreational activities.
- The existing impacted point bars can be revegetated with sawgrass and other native plantings to stabilize soils and restore lost structure and function. This would involve restrictions of recreation to allow establishment of vegetation and soils.
- Rope swings can continue to be removed when observed.
- Vendors can provide ropes, bungies, or ties with rented boats so that visitors can tie off in shallow open water areas away from the bar to reduce direct impacts to soils and vegetation when docking boats.
- Reinforcement of susceptible banks or trees can be considered to reduce erosion, sedimentation and tree falls.

The next category of management options involves considering changes to operations, regulations, and enforcement of recreational guidelines.

- The regulations and enforcement of State Park Rules could be extended down to Rogers Park and other downstream access locations to avoid moving issues downstream (especially the 'no disposables' rule, as this appears to have been effective at the State Park).

- Access to landing points on point bars could be completely restricted (except for private property), as it is in some other spring runs throughout the state (i.e. disallow docking or exiting vessels).
- Access to landing points for docking and exiting vessels could be limited to designated areas. Some such areas could be enhanced to increase their resiliency to such activities.
- Beach re-nourishment practices that contribute sediment yield in the river could be limited.
- Evaluation of regulations for type of boats allowed on the river (size of boat, size of motor) can be considered.
- After recreational activities such as docking and exiting vessels have been addressed, then additional restrictions on the number of vessels can be further evaluated.

The final category of management options includes collaboration by multiple agencies to work together to accomplish the recommendations, potential additional studies, or plans that could provide more information and additional management options. These can provide a feedback system to inform an adaptive management strategy.

- The experimental trampling plots should be left in place and a follow up assessment should be planned for one year after trampling (May 2020) to assess recovery of vegetation and organic soil accretion.
- Additional studies on tree falls, snag sufficiency, and streambank undercutting can be considered.
- Additional studies on sufficiency of wetland buffer clearing ordinances can be considered to evaluate if existing ordinances provide enough buffered areas to prevent erosion and tree falls.
- Hernando County and other agencies with jurisdiction could consider developing a management plan for the river, with enforcement.
- Restoration efforts can be tracked for ecological sustainability and improvement over time.
- Creation of a multi-agency working group to convene and work together to review the results from the study and proposed management options. The working group could pursue a path to implement the most appropriate recommendations that would align along jurisdictions. The working group could also evaluate and recommend the most effective methods for enforcing the selected management options.

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MAPS

MAPS

Map 1 – Location Map

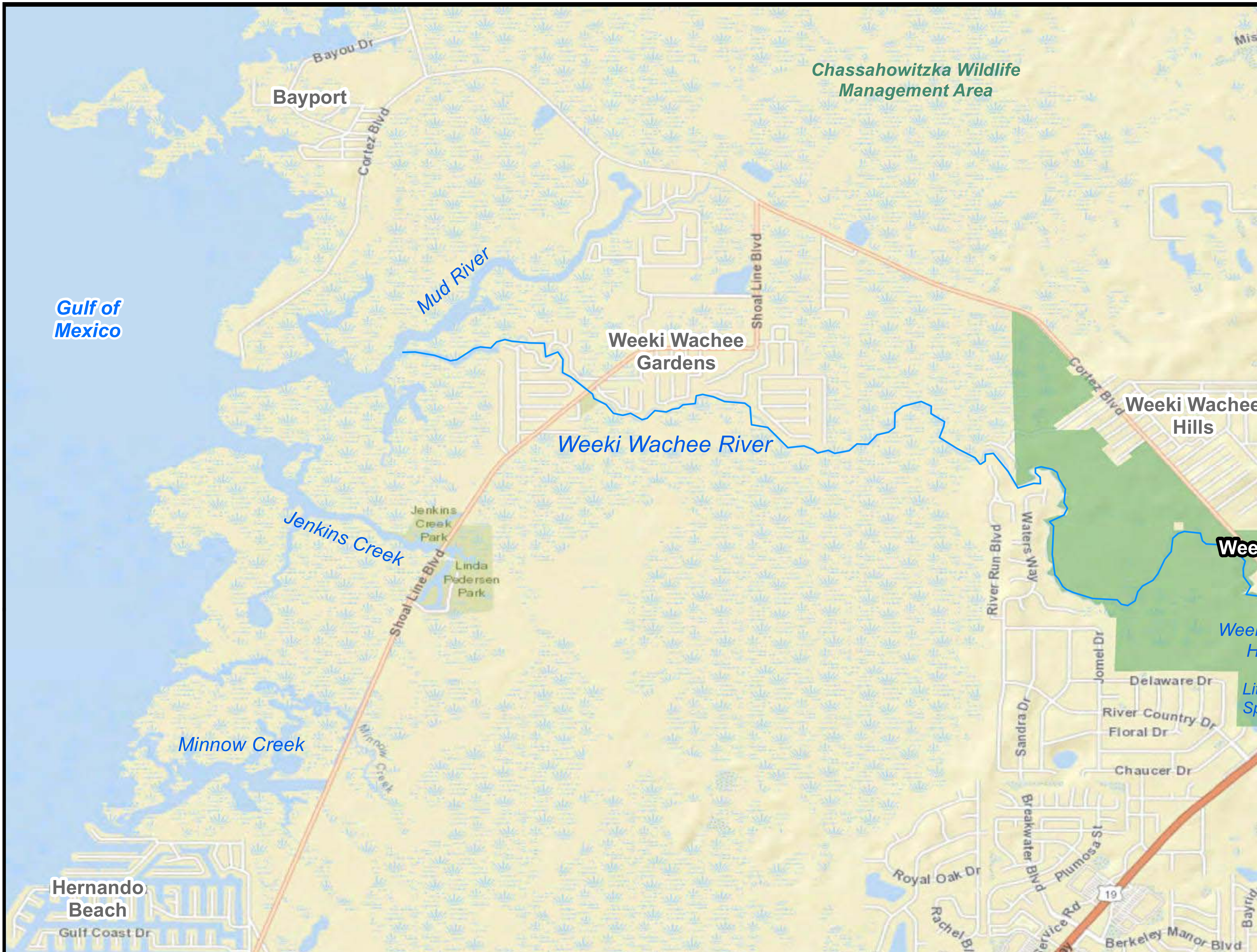
Map 2 – Site Map

Map 3 – Sample Locations

Map 4 – Weeki Wachee Point Bar Locations

Map 5 – Alexander Springs Run Point Bar Locations

Map 6 – Water Quality Stations



Bayou Dr
Bayport
Cortez Blvd
Chassahowitzka Wildlife Management Area
Gulf of Mexico
Mud River
Shoal Line Blvd
Weeki Wachee Gardens
Cortez Blvd
Weeki Wachee Hills
Weeki Wachee River
Jenkins Creek Park
Jenkins Creek
Linda Pedersen Park
Shoal Line Blvd
River Run Blvd
Waters Way
Jomel Dr
Delaware Dr
River Country Dr
Floral Dr
Sandra Dr
Chaucer Dr
Minnow Creek
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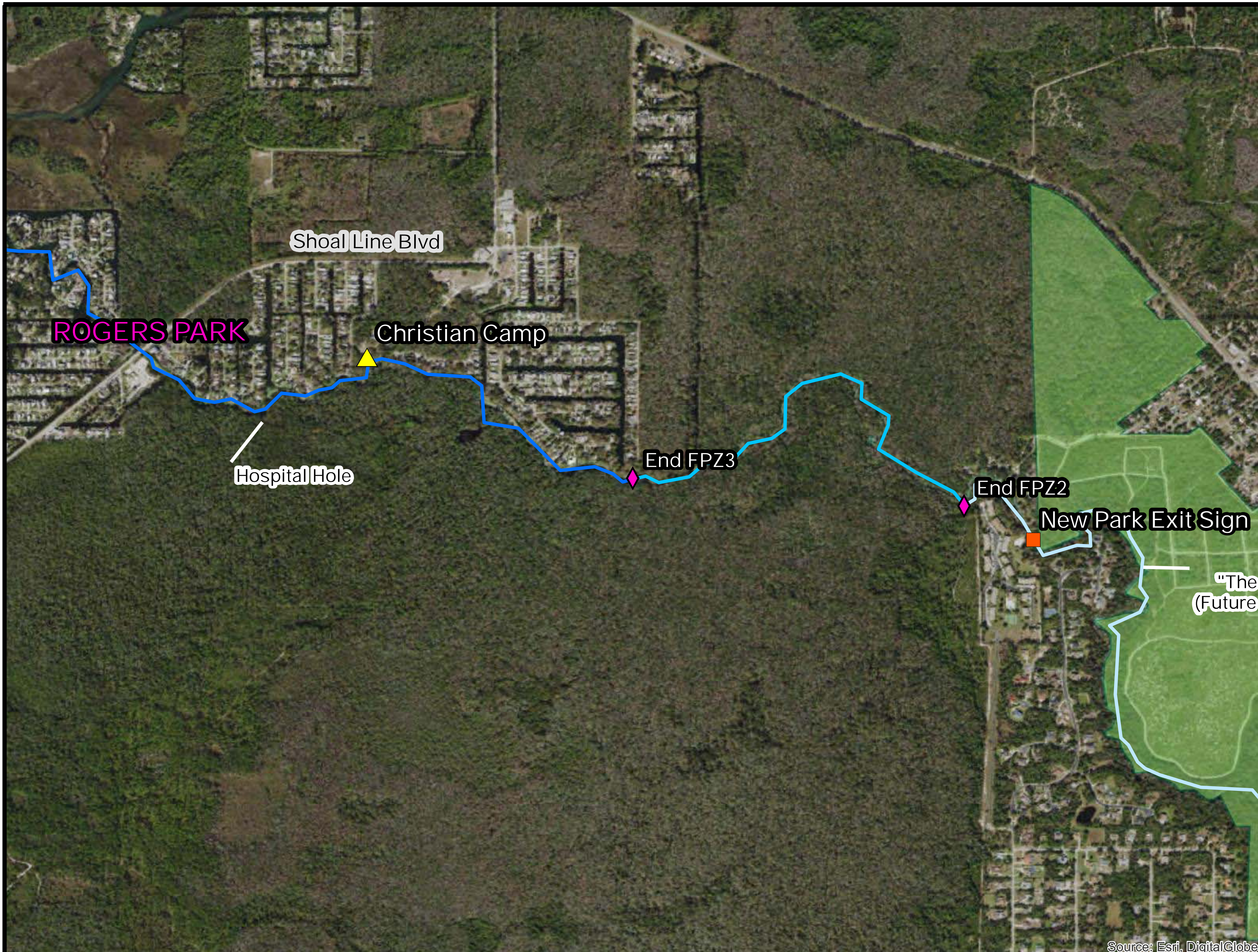
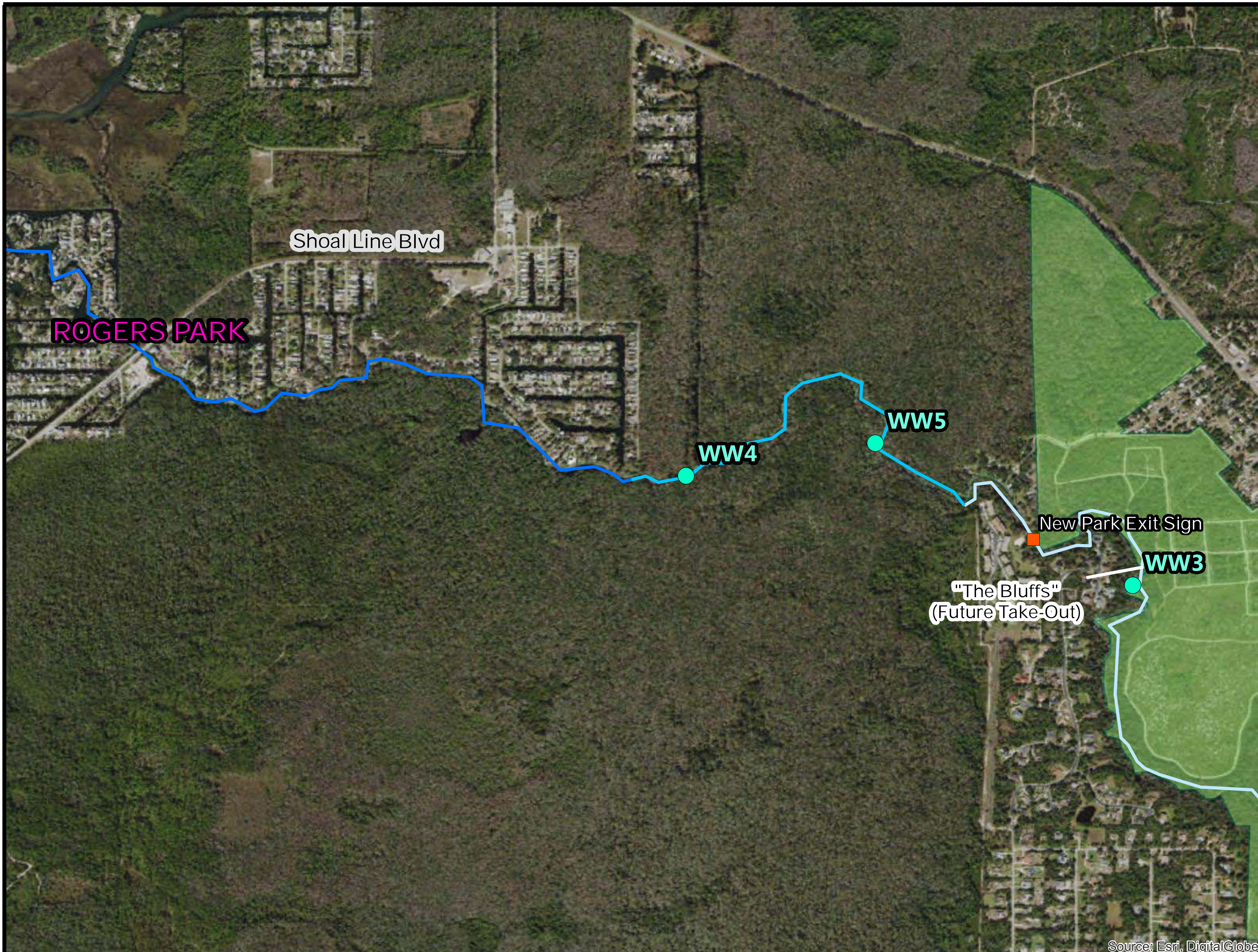
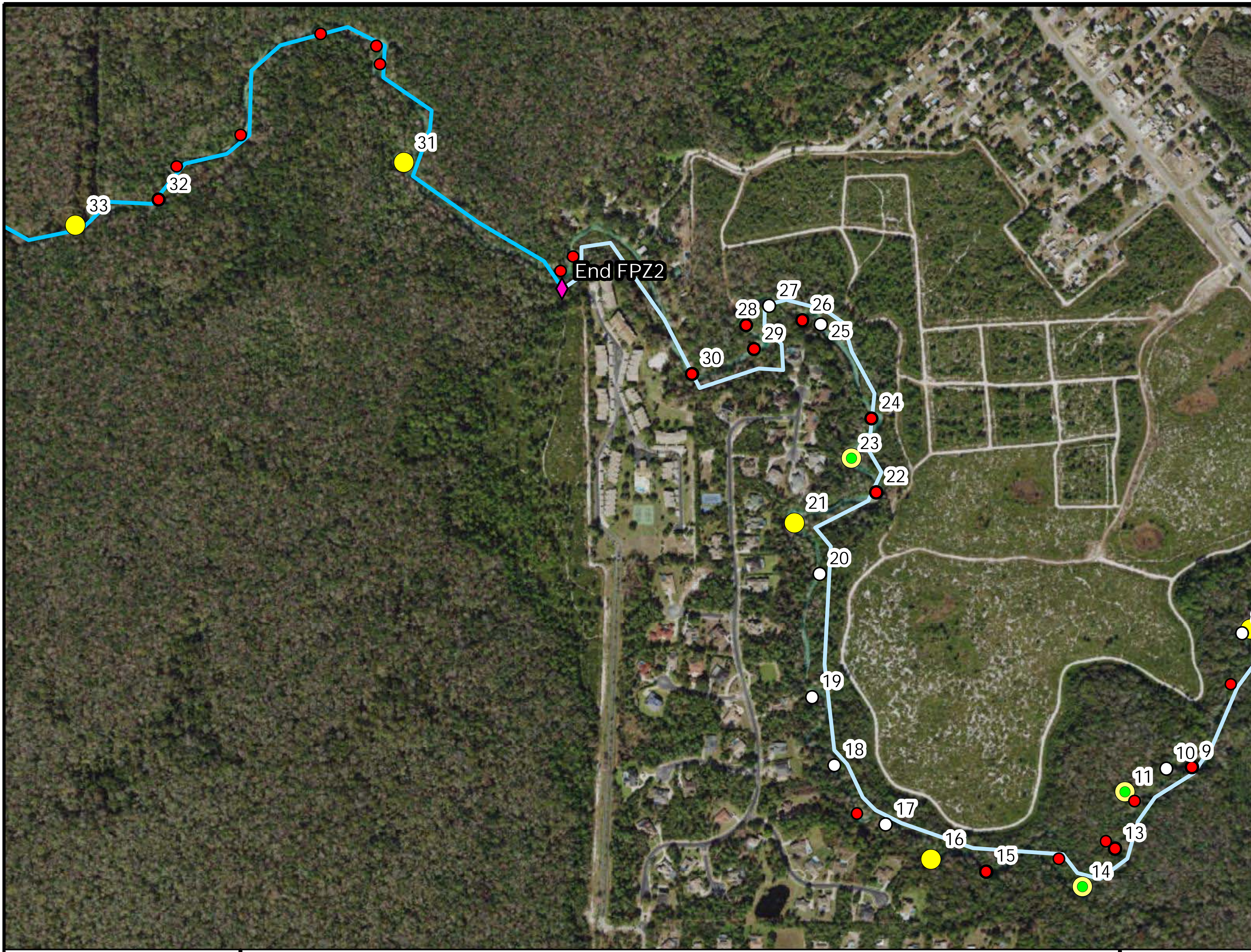
Hernando Beach
Gulf Coast Dr
Royal Oak Dr
Breakwater Blvd
Plumosa St
Rachel Blvd
Service Rd
19
Berkeley Manor Blvd


Shoal Line Blvd
ROGERS PARK
Christian Camp
Hospital Hole
End FPZ3
End FPZ2
New Park Exit Sign
"The
(Future
Source: Esri, DigitalGlobe



Shoal Line Blvd
ROGERS PARK
WW4
WW5
New Park Exit Sign
WW3
"The Bluffs"
(Future Take-Out)
Source: Esri, DigitalGlobe


End FPZ2
9
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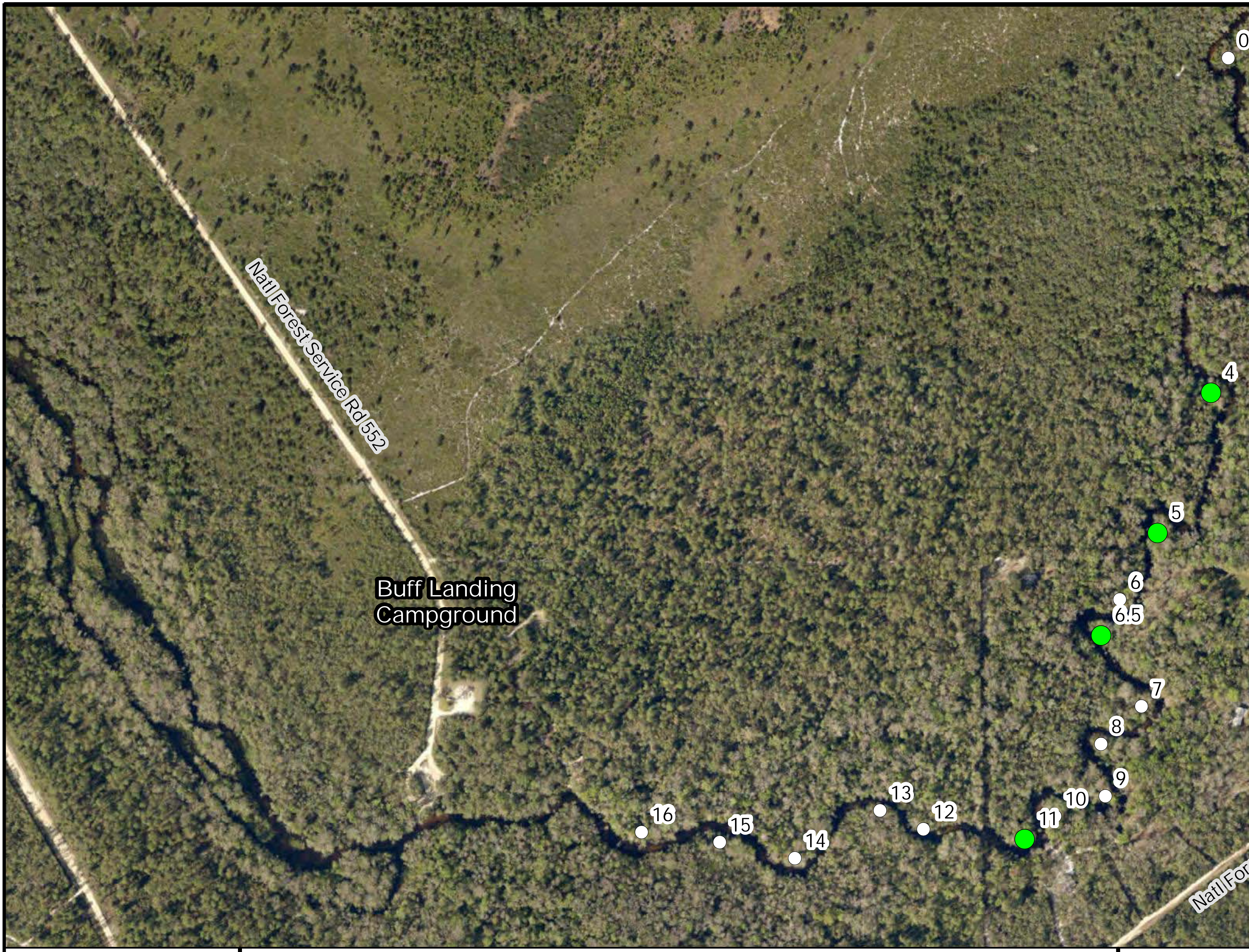

0
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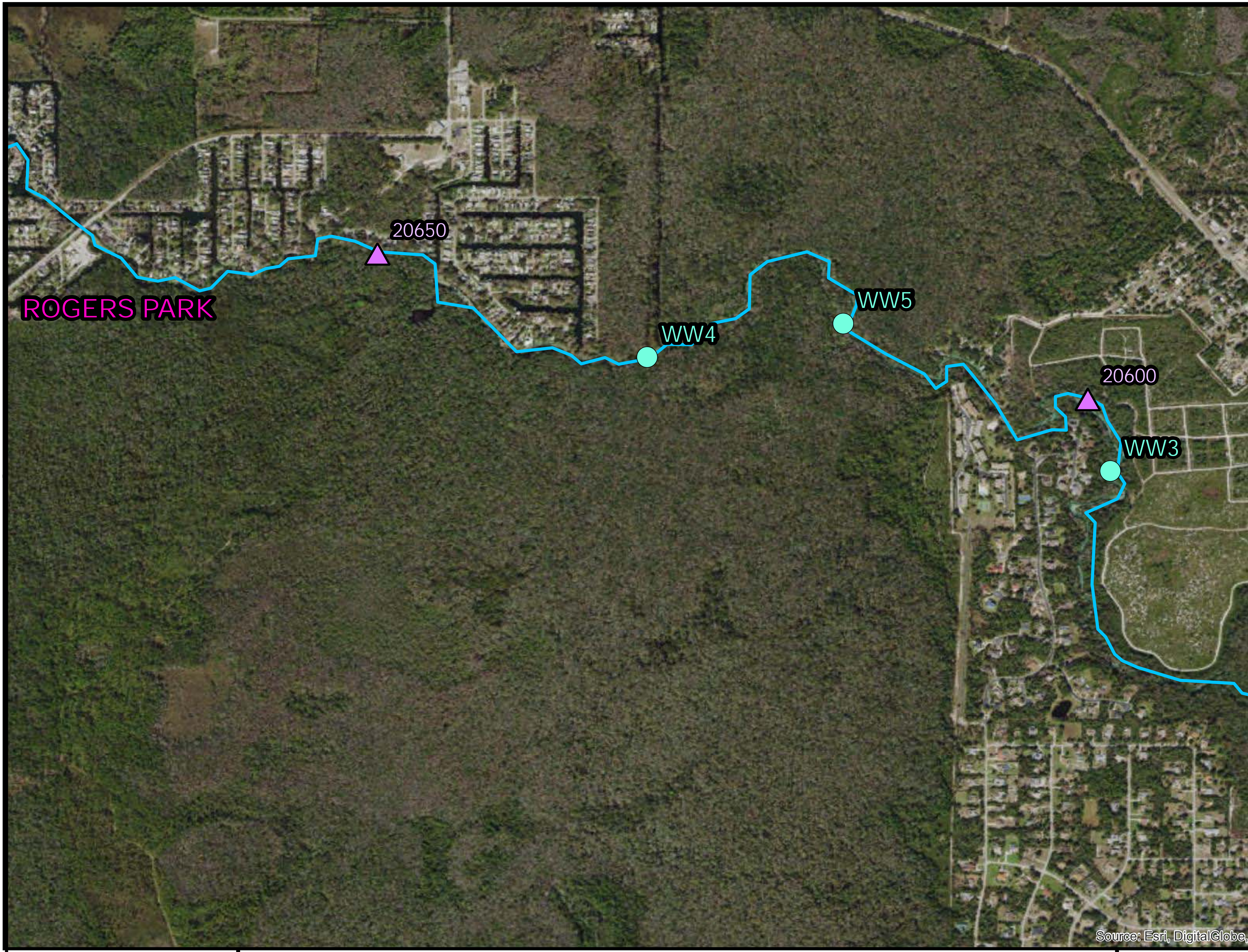
Buff Landing
Campground
Natl Forest Service Rd 552


ROGERS PARK
20650
WW4
WW5
20600
WW3
Source: Esri, DigitalGlobe,

APPENDICES

APPENDIX A

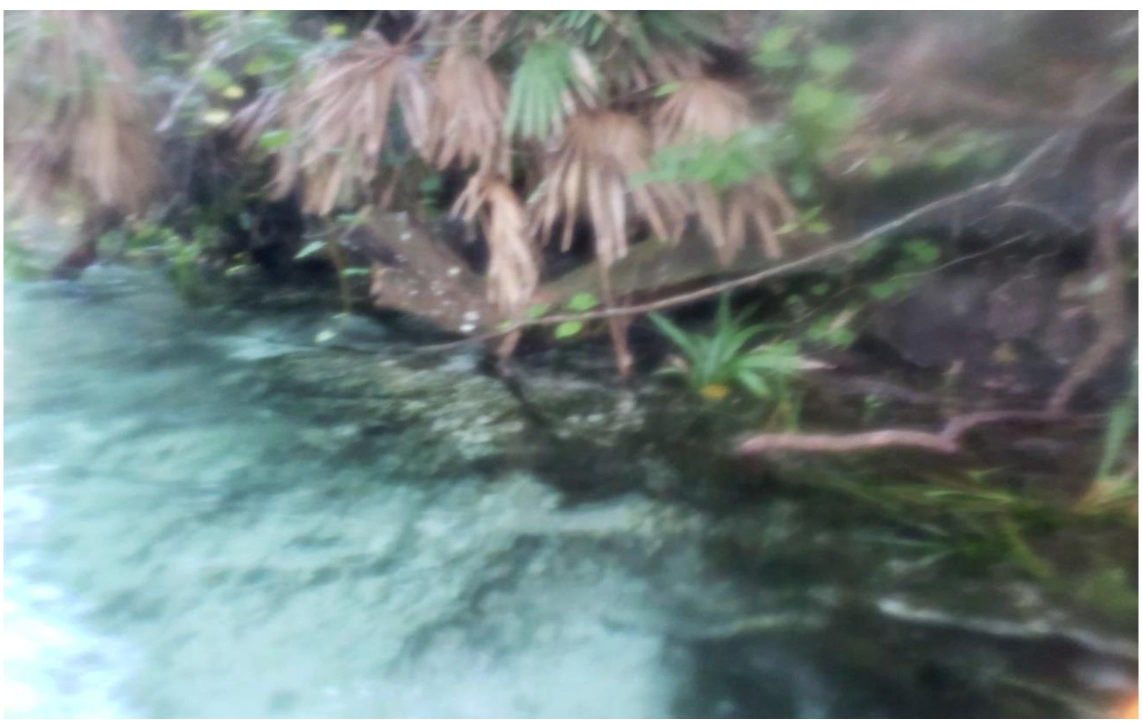
Photographs of Sampling Sites

WW1 – 2018-07-05

WW1 – 2018-08-07

WW1 – 2018-09-03

WW1 – 2018-10-02



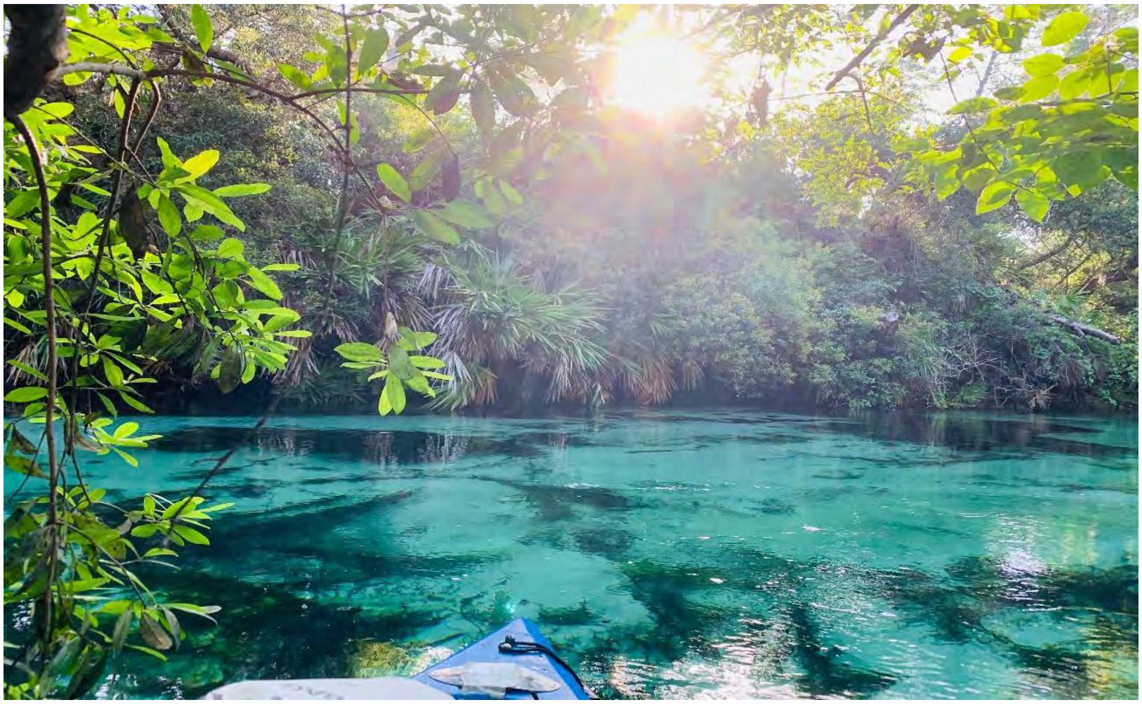
WW1 - 2018-12-19

WW1 - 2019-02-19

WW1 - 2019-04-24

WW 1 - 2019-05-27

WW 1 - 2019-06-24



WW2 – 2018-07-05

WW2 – 2018-08-07

WW2 – 2018-09-03

WW2 – 2018-10-02

WW2 – 2018-12-19

WW2 – 2019-02-19

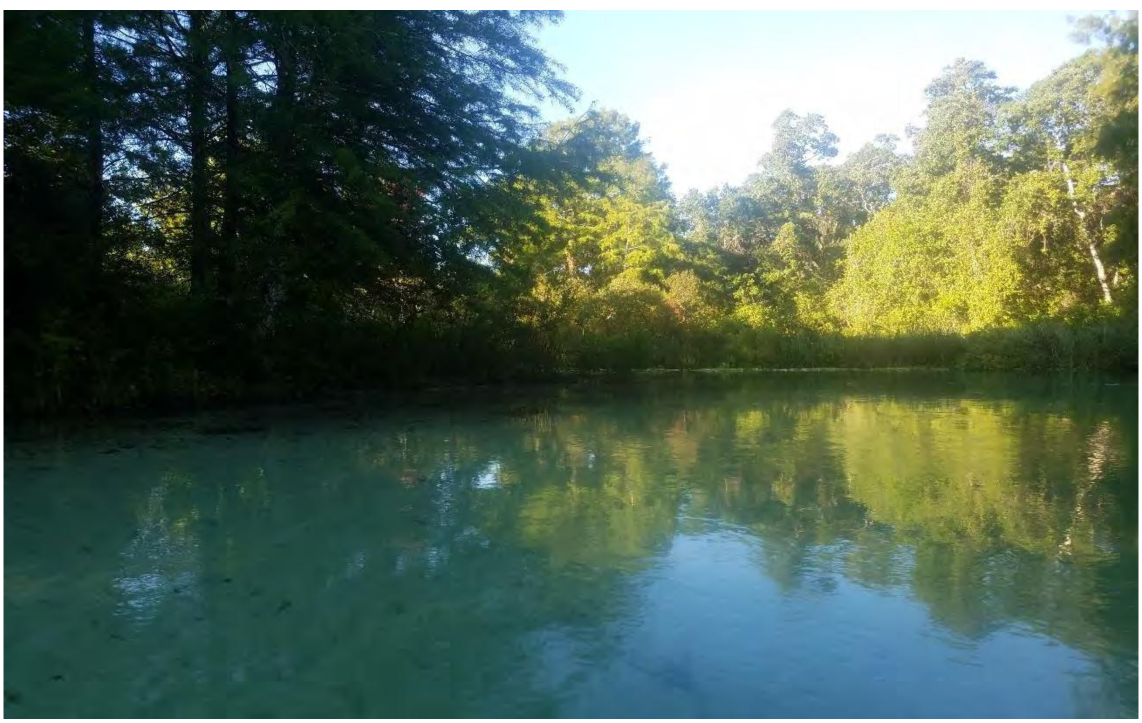
WW2 – 2019-04-24

WW2 – 2019-05-27

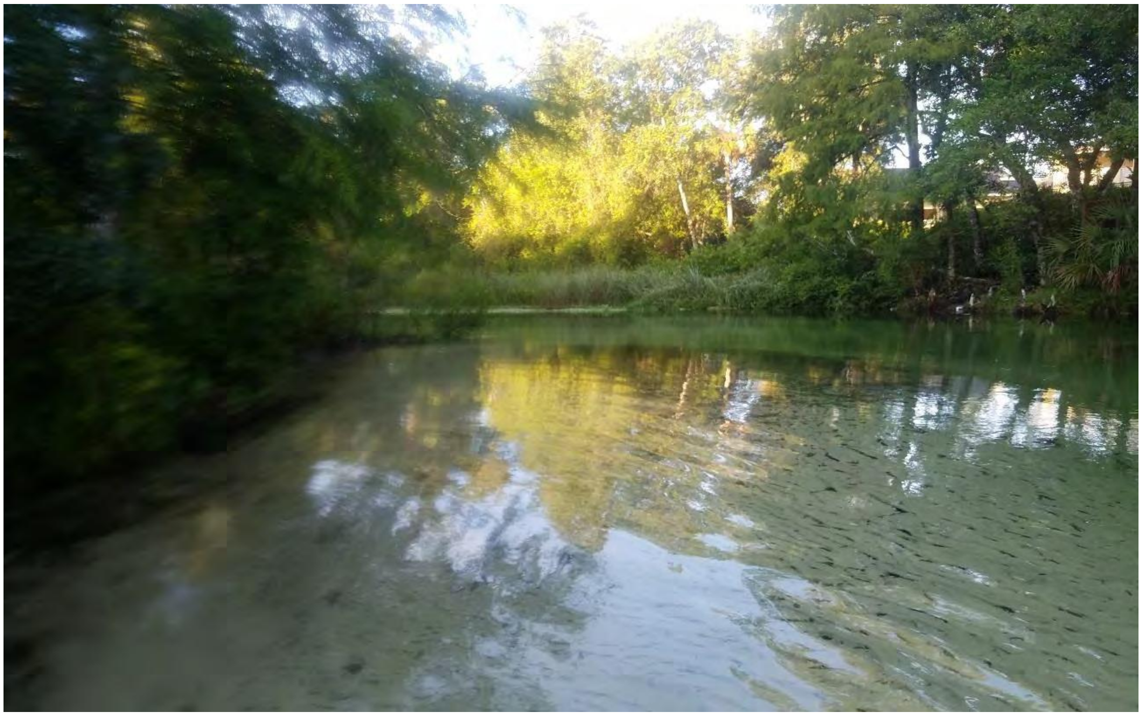
WW2 – 2019-06-24

WW3 – 2018-07-05

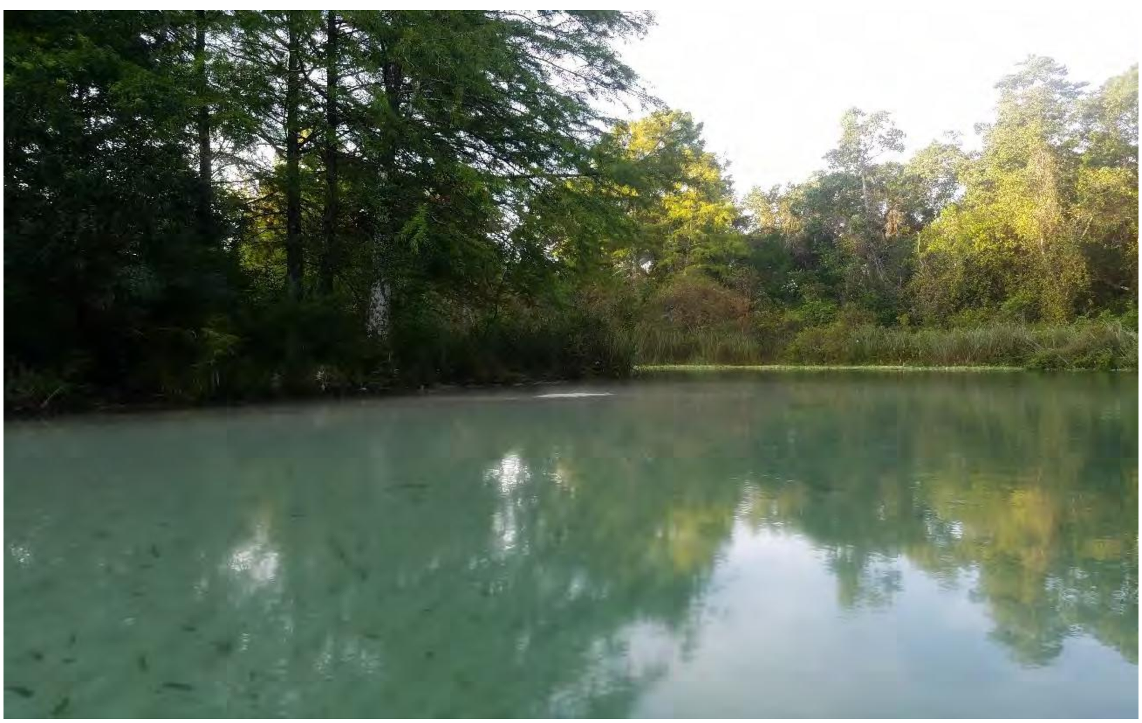
WW3 – 2018-08-07



WW3 – 2018-09-03

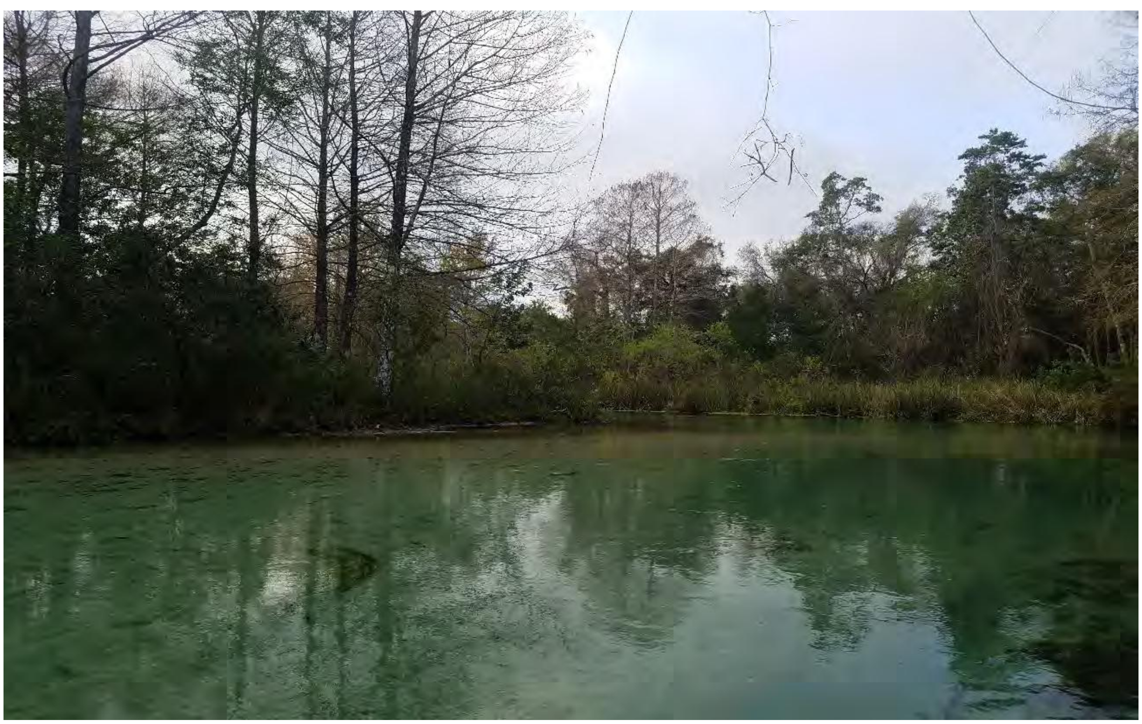


WW3 – 2018-10-02



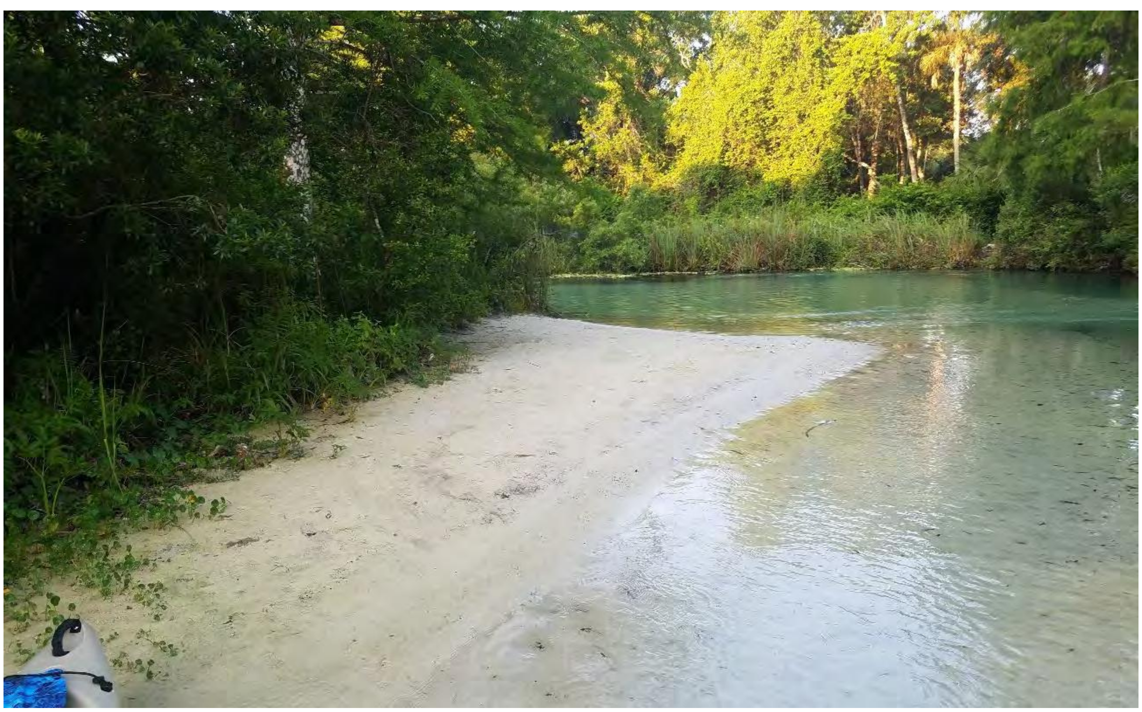
WW3 – 2018-12-19

WW3 – 2019-02-19



WW3 – 2019-04-24

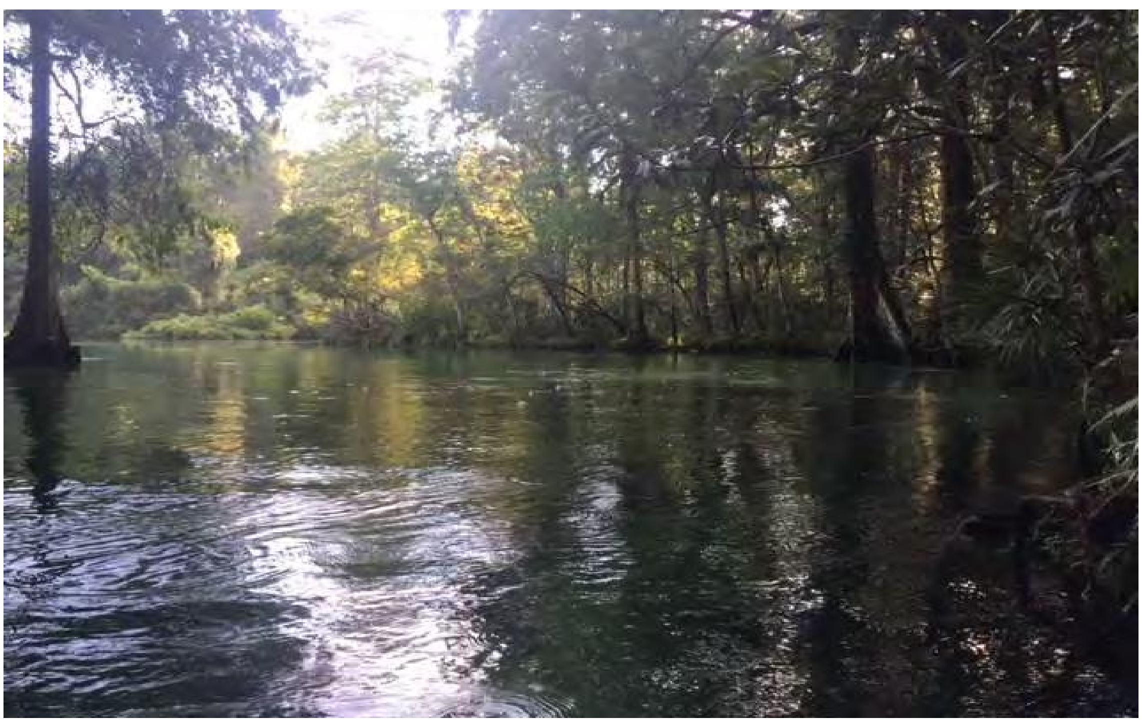
WW3 – 2019-05-27



WW3 – 2019-06-24

WW4 (Right Bank) – 2018-07-05

WW4 (Left Bank) – 2018-07-05

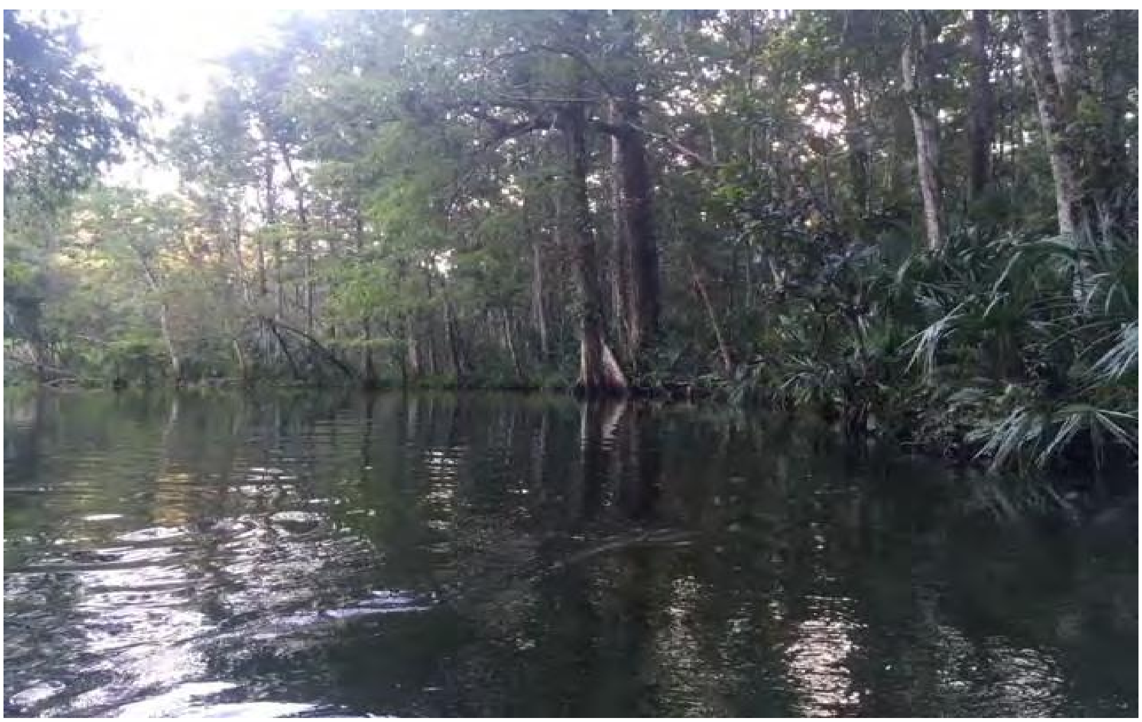


WW4 (Right Bank) – 2018-08-07

WW4 (Left Bank) – 2018-08-07

WW4 (Right Bank) – 2018-09-03

WW4 (Left Bank) – 2018-09-03



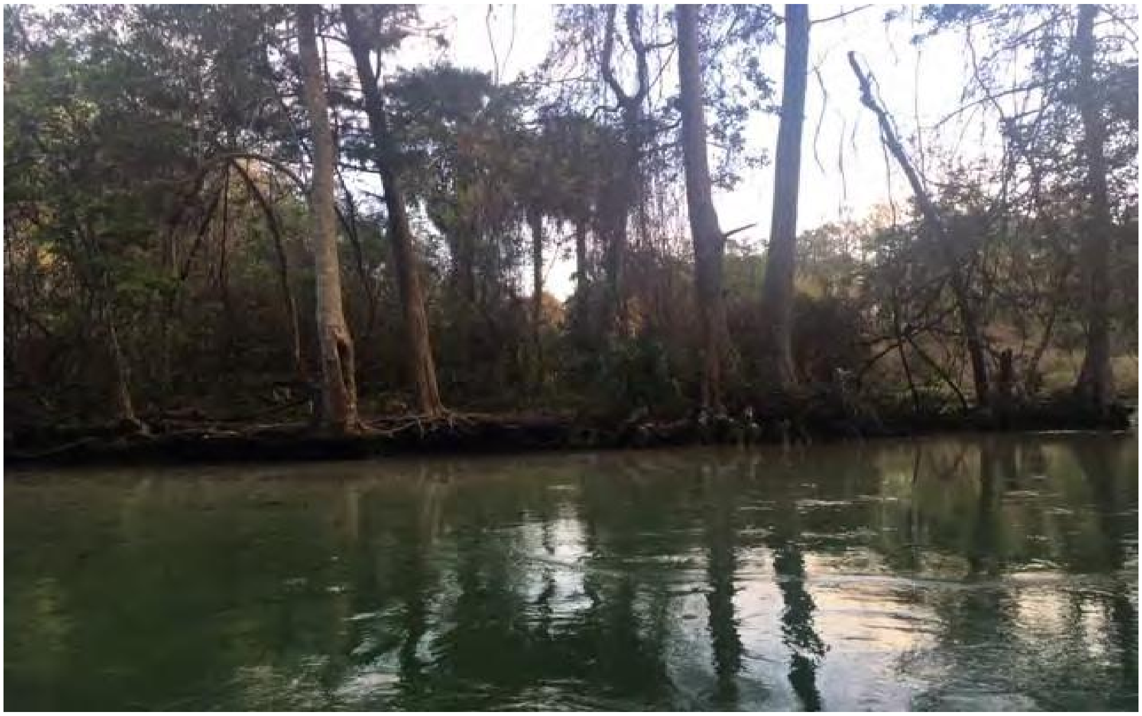
WW4 (Right Bank) – 2018-10-02

WW4 (Left Bank) – 2018-10-02

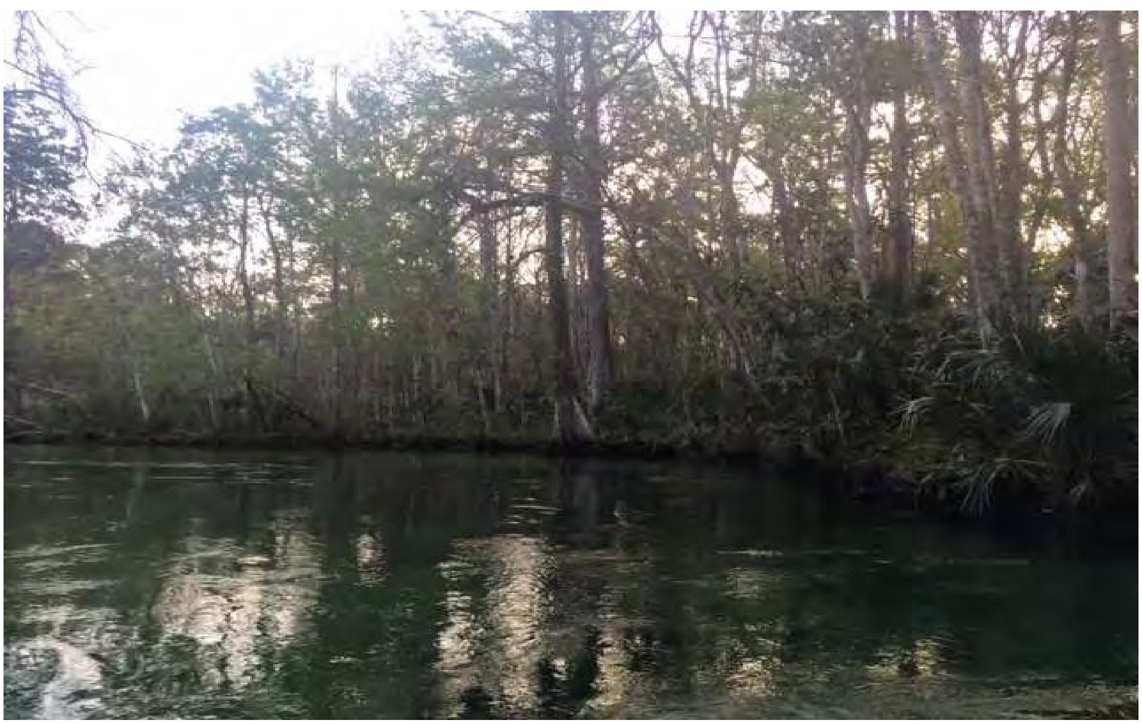
WW4 (Right Bank) – 2018-12-19

WW4 (Left Bank) – 2018-12-19

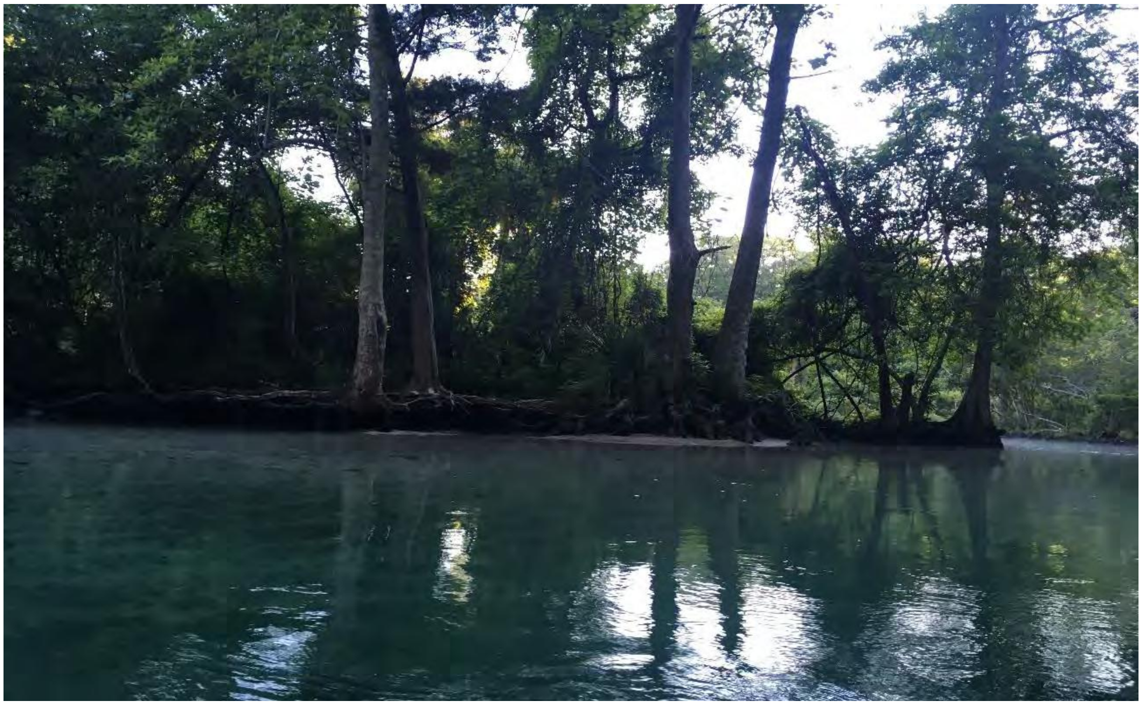
WW4 (Right Bank) – 2019-02-19



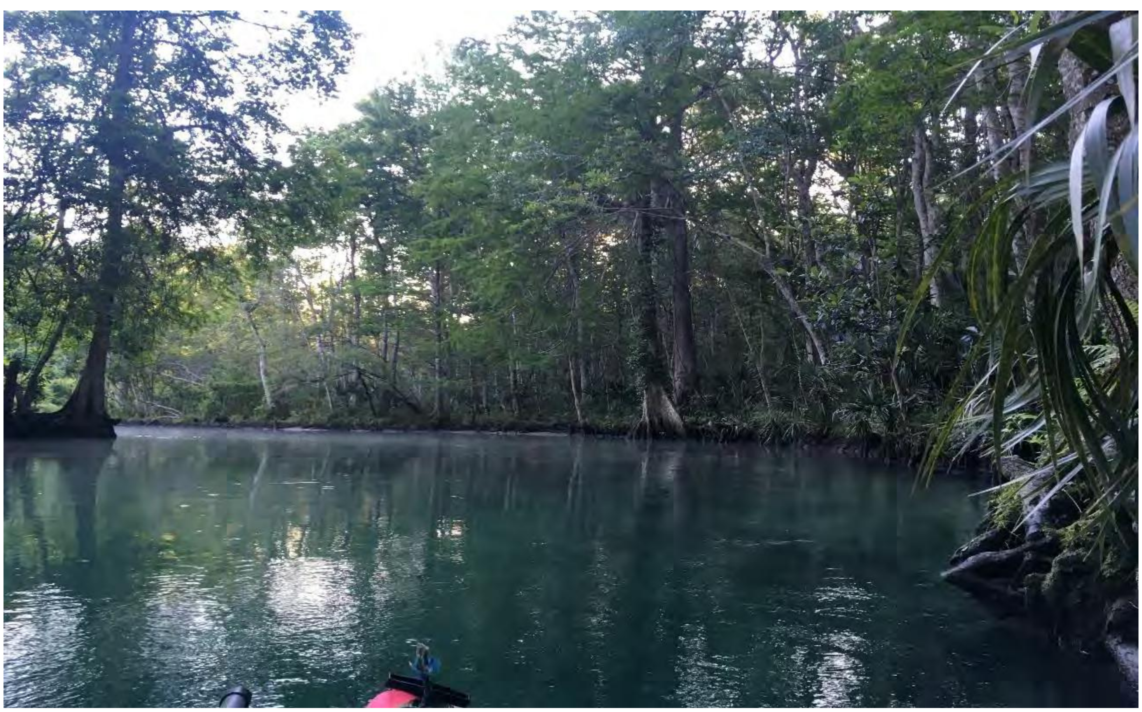
WW4 (Left Bank) – 2019-02-19



WW4 (Right Bank) – 2019-04-24

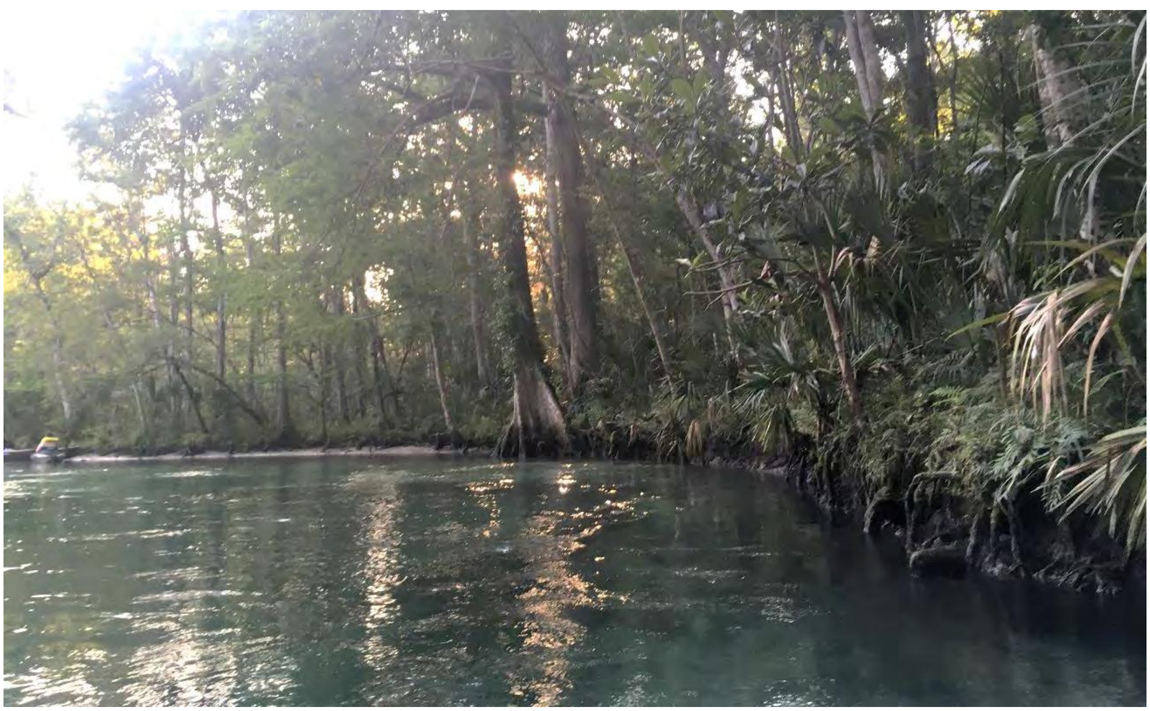


WW4 (Left Bank) – 2019-04-24



WW4 (Right Bank) – 2019-05-27

WW4 (Left Bank) – 2019-05-27



WW4 (Right Bank) – 2019-06-24

WW4 (Left Bank) – 2019-06-24

ADDITIONAL PHOTOS OF IMPACTED POINT BARS (WW2 AND WW4)

WW 2 – 2018-07-05

WW 2 – 2018-07-05

WW 2 – 2018-10-02

WW 2 – 2018-10-02

WW 2 – 2018-10-02

WW 2 – 2018-12-19

WW 2 – 2019-02-19

WW 2 – 2019-04-24

WW 2 – 2019-04-24

WW 2 – 2019-04-24

WW 2 – 2019-04-24

WW 2 – 2019-05-27

WW 2 – 2019-05-27

WW 2 – 2019-05-27

WW 2 – 2019-05-27

WW 2 – 2019-05-27

WW 2 – 2019-06-24

WW4 – 2018-06-19

WW4 – 2018-10-02

WW 4 – 2018-10-02

WW 4 – 2018-12-19

WW 4 – 2019-02-19

WW 4 – 2019-02-19

WW4 – 2019-02-19

WW 4 – 2019-04-24

WW 4 – 2019-04-24

WW 4 – 2019-05-27

WW 4 – 2019-05-27

WW 4 – 2019-05-27

WW 4 – 2019-06-24

PROGRESSION OF BOAT SCAR THROUGHOUT STUDY (WW2)

Boat Scar at WW2 – 9-3-2018

Note: Motorboat (5 hp) ran aground in this location on 8-7-2018 during sampling event. Silt and algae collected in scar.

Boat Scar at WW2 – 10-2-2018

Boat Scar at WW2 – 4-24-2019

Note: Lower water levels revealed lack of organic soils and vegetation in the scar

Boat Scar at WW2 – 5-27-2019

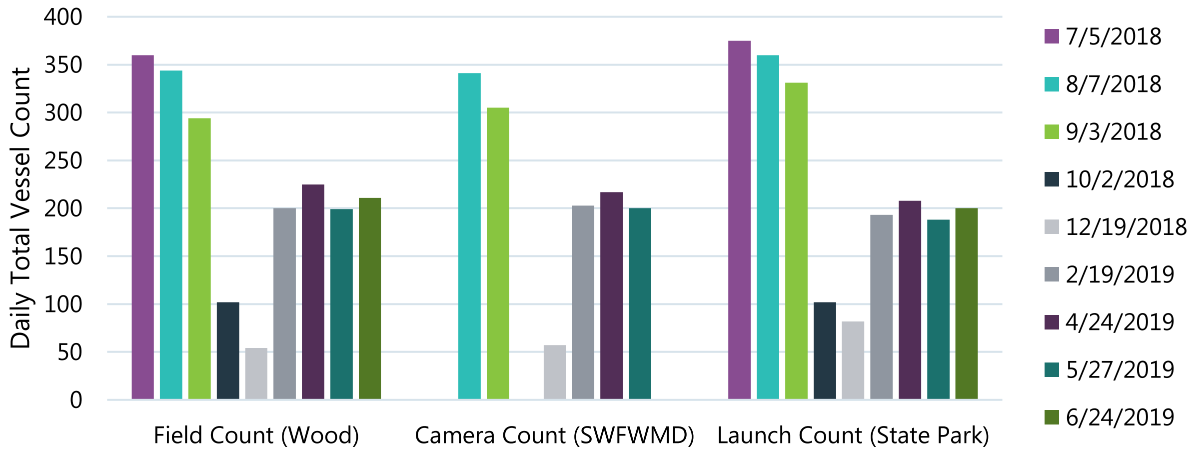
Boat Scar at WW2 – 6-24-2019

Note: Nearly 11 months after boat struck location, organic soils and vegetation not present.

APPENDIX B

Human Use Data and Social Survey

Figure B.1 – Comparison of Vessel Count Datasets at WW1



Note: WW1 was chosen for comparison because it is the closest station to the State Park vessel launch. Cameras were not deployed at WW1 for the July, December, or June Events. For the July, August, and September events, the State Park vessel launches began 30 minutes before field and camera counts.

Figure B.2 – Daily Total Number of User Passes by Sample Site (Field Counts)

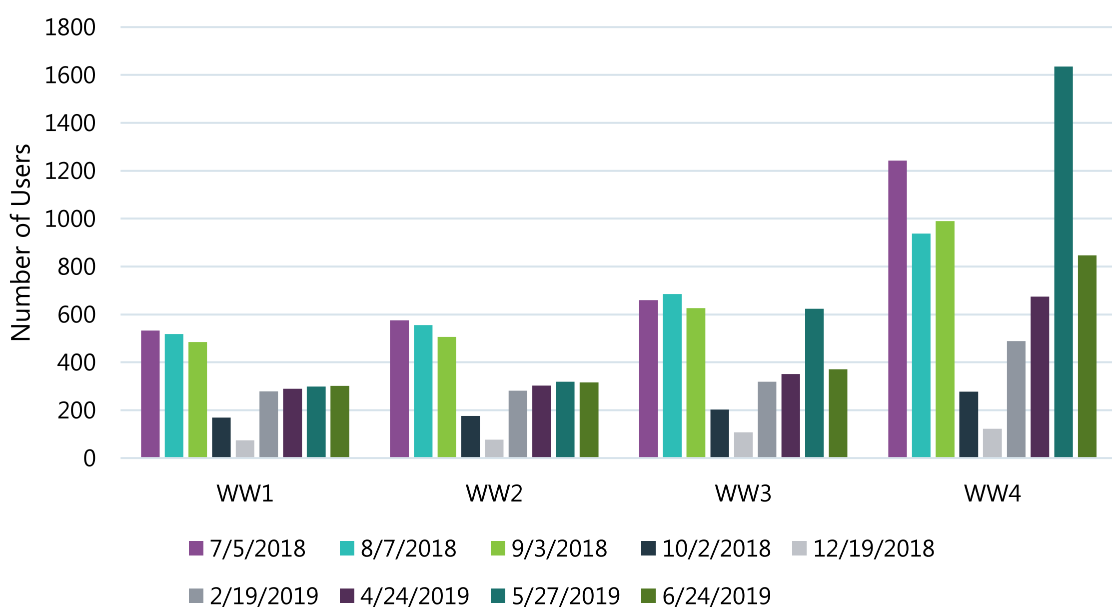


Figure B.3 - Daily Number of Vessels Traveling Downstream by Sample Site (Field Counts)

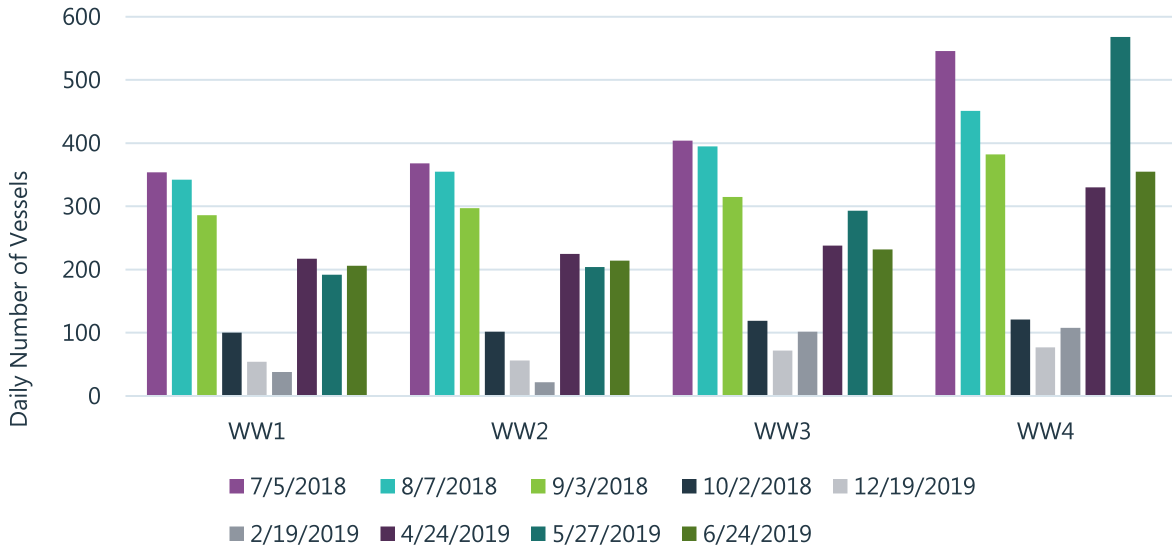


Figure B.4 - Daily Number of Vessels Traveling Upstream by Sample Site (Field Counts)

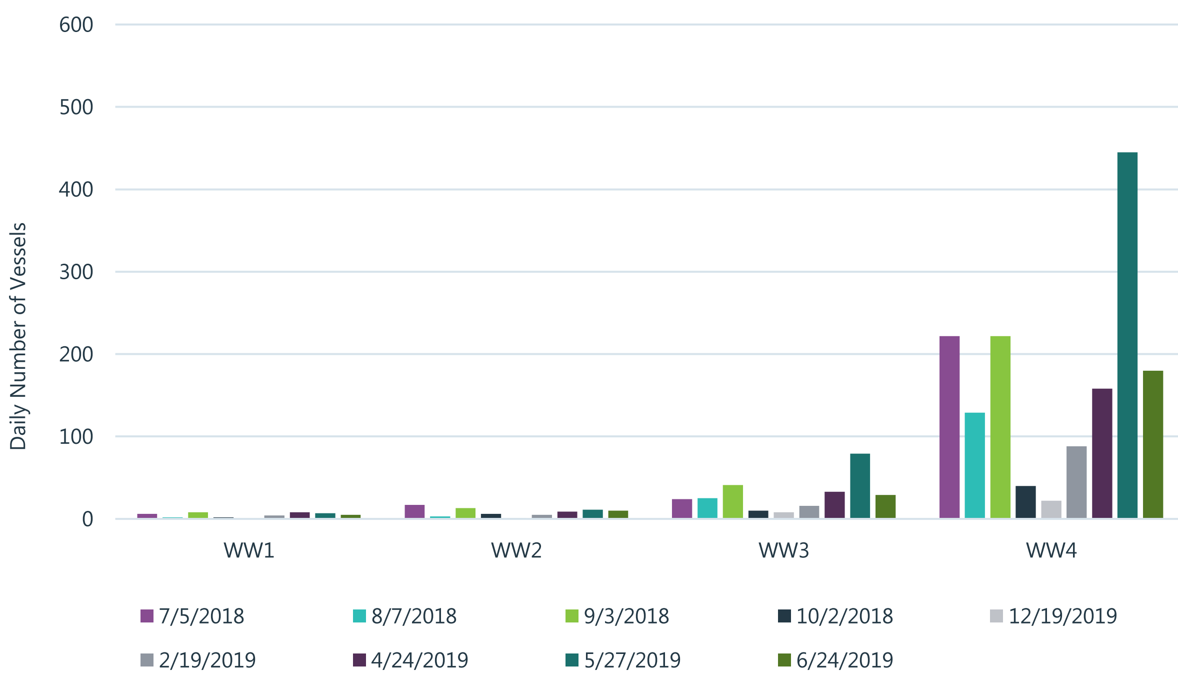


Figure B.5 - Percentage of Vessels Travelling Downstream by Vessel Type at location WW1 (Field Counts)

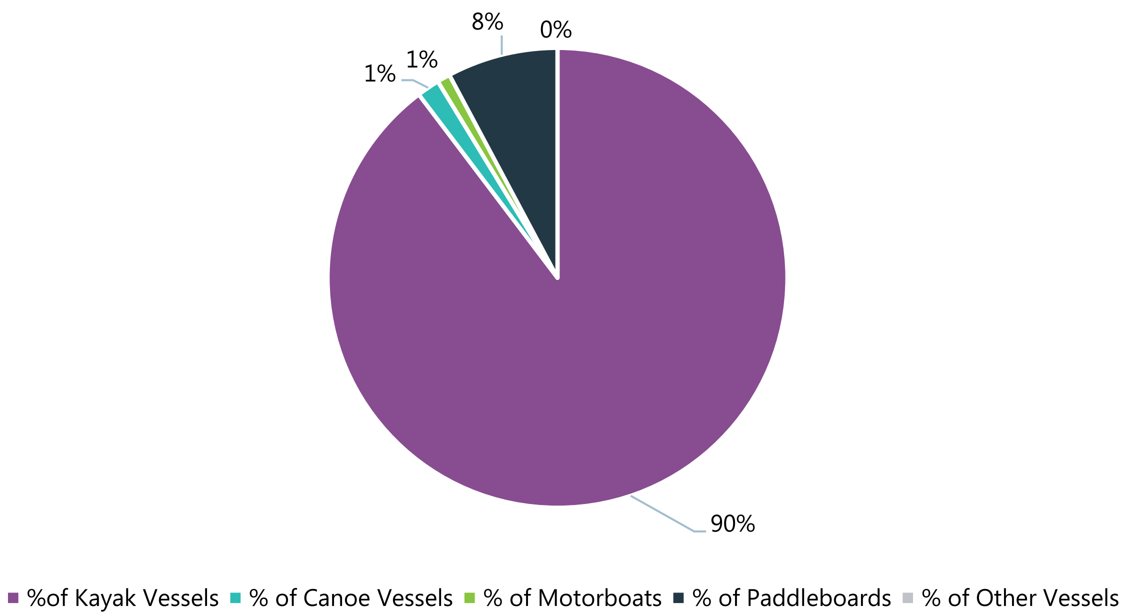


Figure B.6 - Percentage of Vessels Travelling Downstream by Vessel Type at location WW2 (Field Counts)

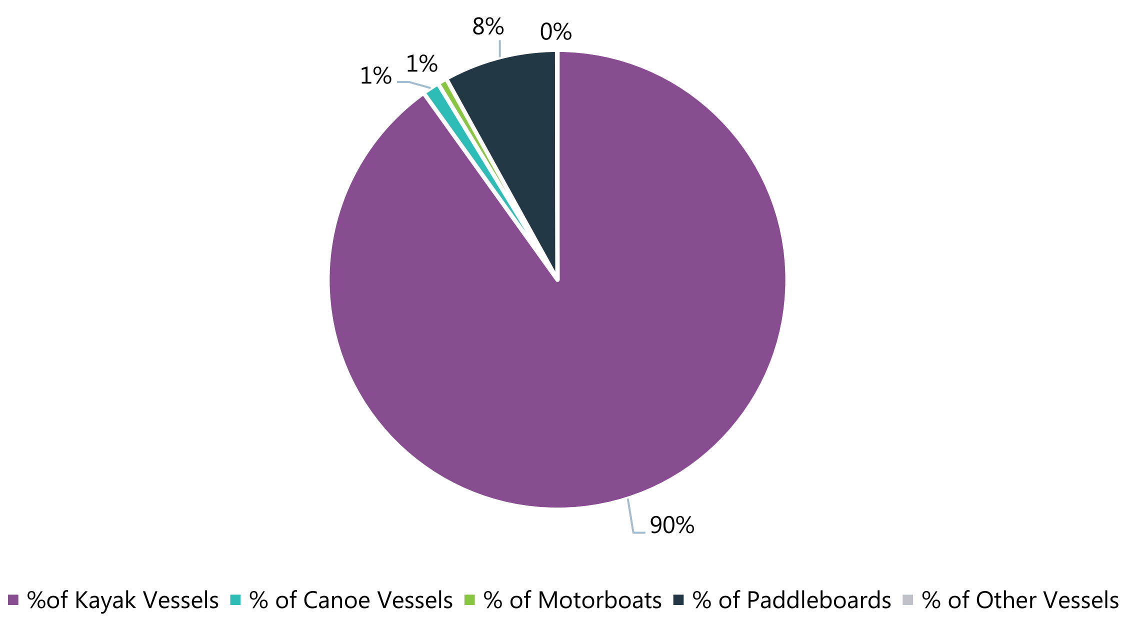


Figure B.7 - Percentage of Vessels Travelling Downstream by Vessel Type at location WW3 (Field Counts)

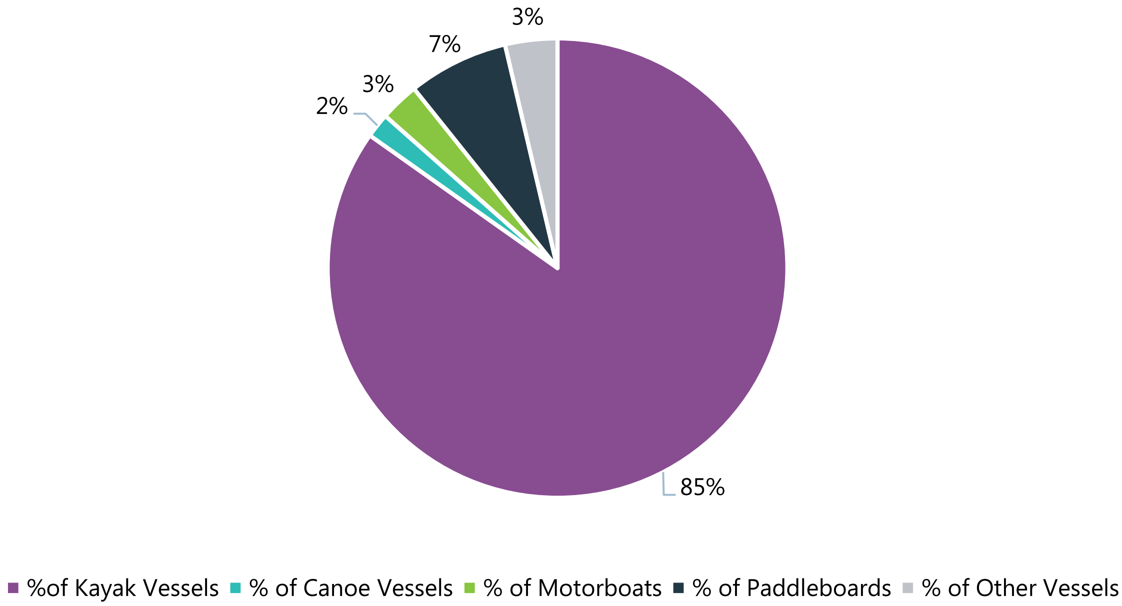


Figure B.8 - Percentage of Vessels Travelling Downstream by Vessel Type at location WW4 (Field Counts)

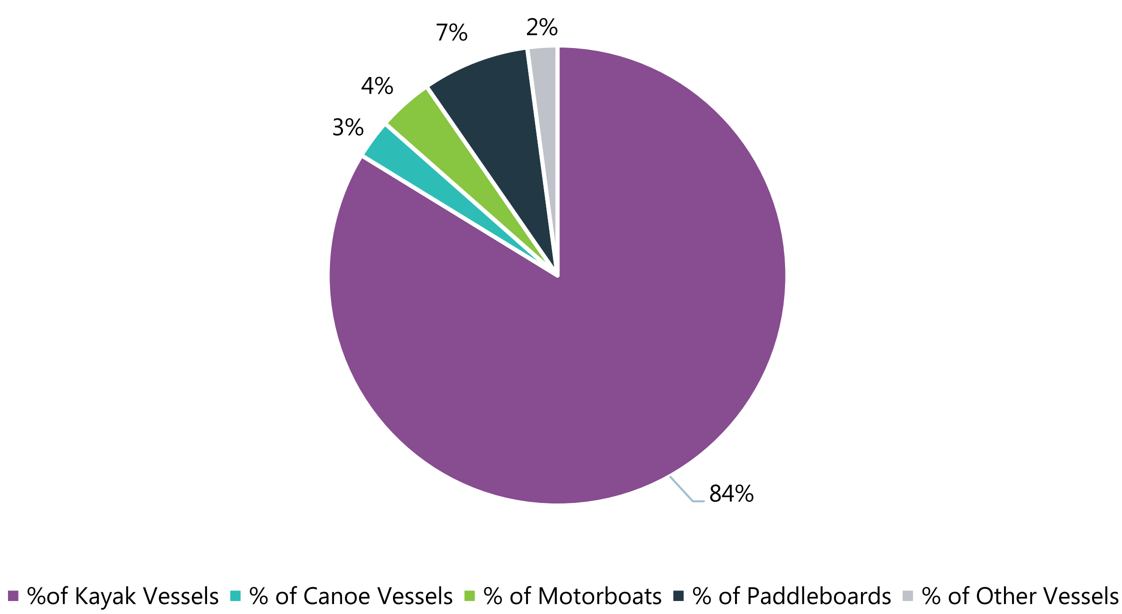


Figure B.9- Daily Total Number of Kayak Passes by Station (Field Counts)

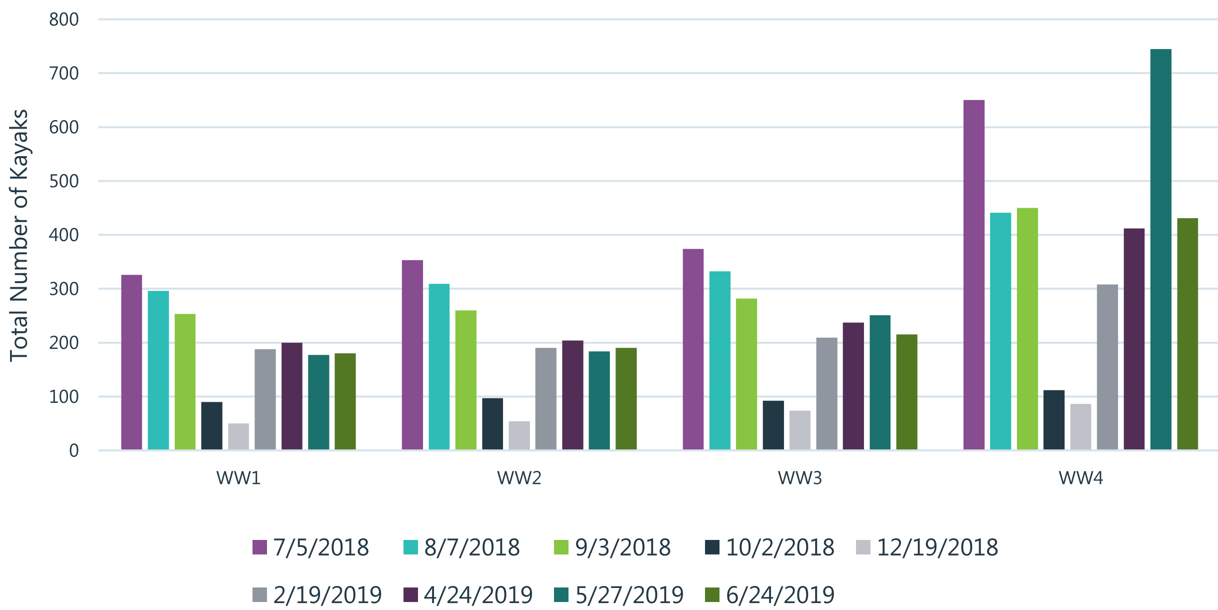


Figure B.10 - Daily Total Number of Canoe Passes by Station (Field Counts)

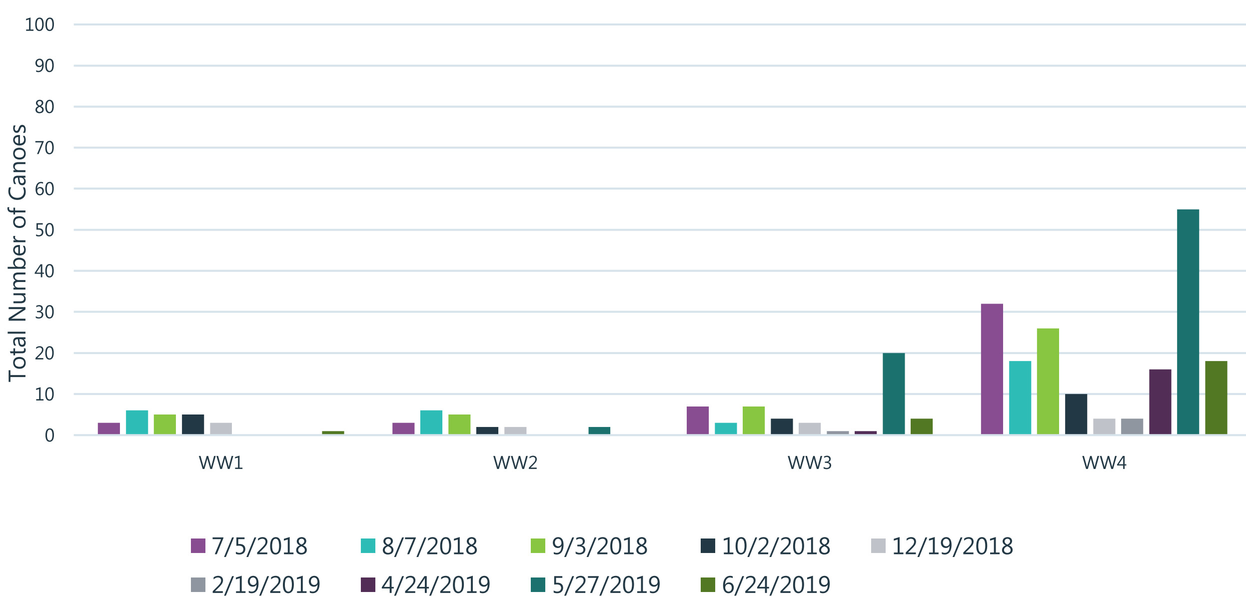


Figure B.11 - Daily Total Number of Motor Boat Passes by Station (Field Counts)

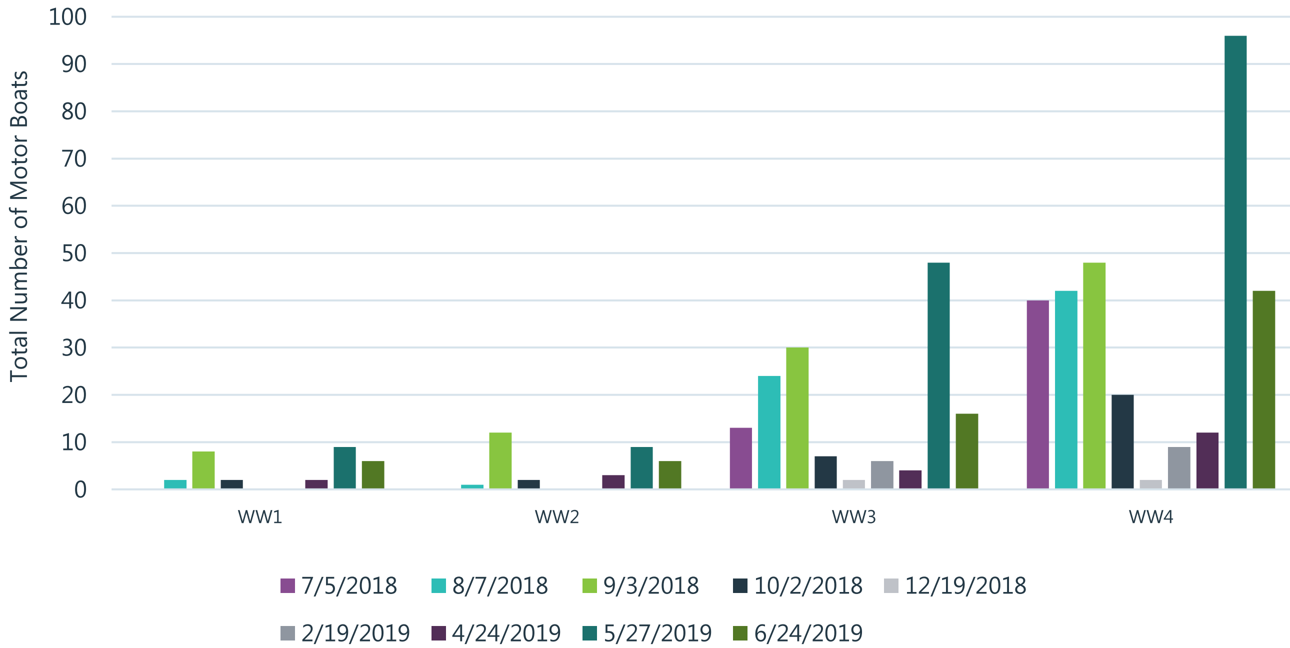


Figure B.12 - Daily Total Number of Paddleboard Passes by Station (Field Counts)

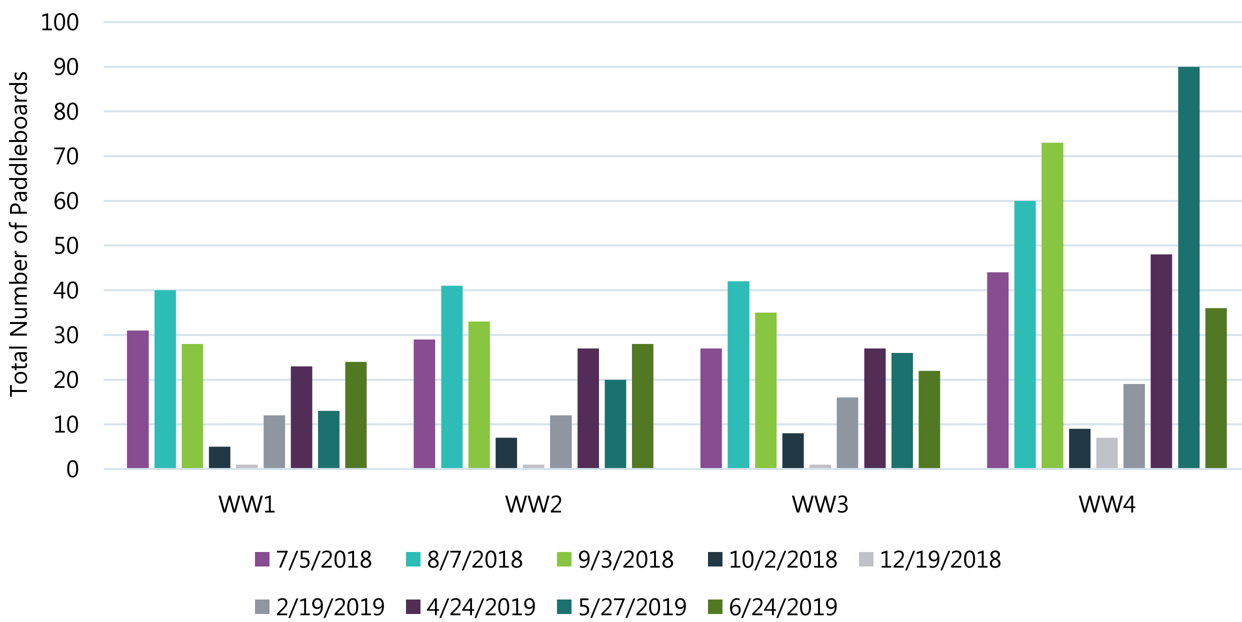


Figure B.13 - Summary of Total Number of Motorboat Passes on River by Station (Field Counts)

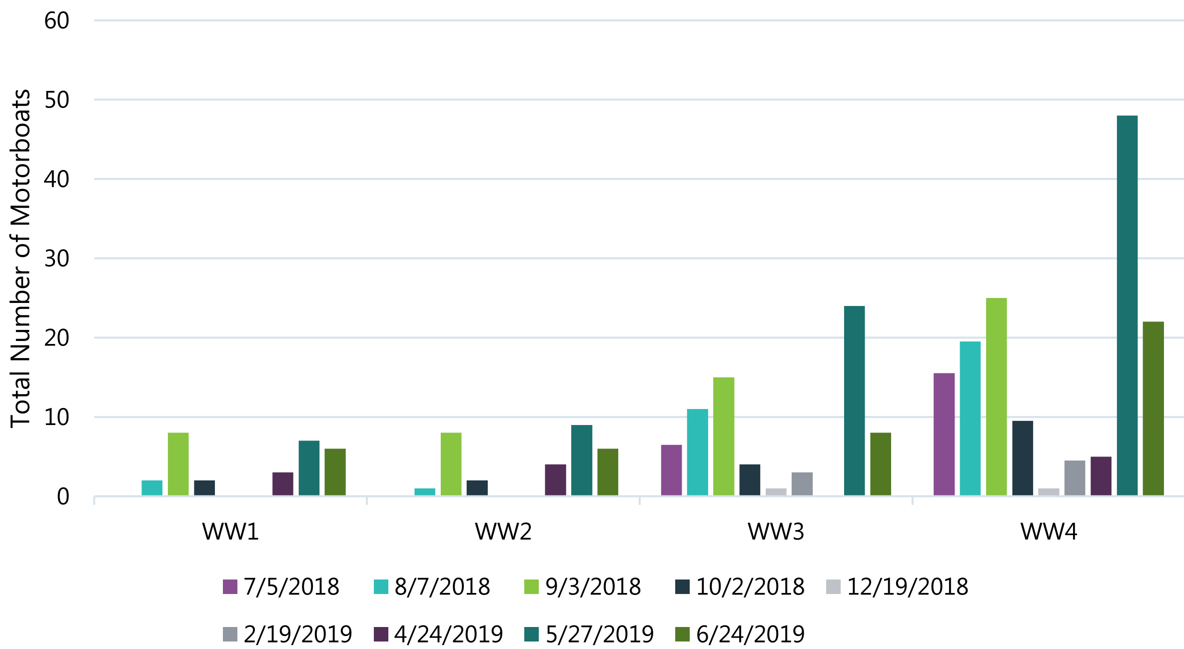


Figure B.14 – Daily Total Number of Vessel Passes at Station WW1 (Camera Counts)

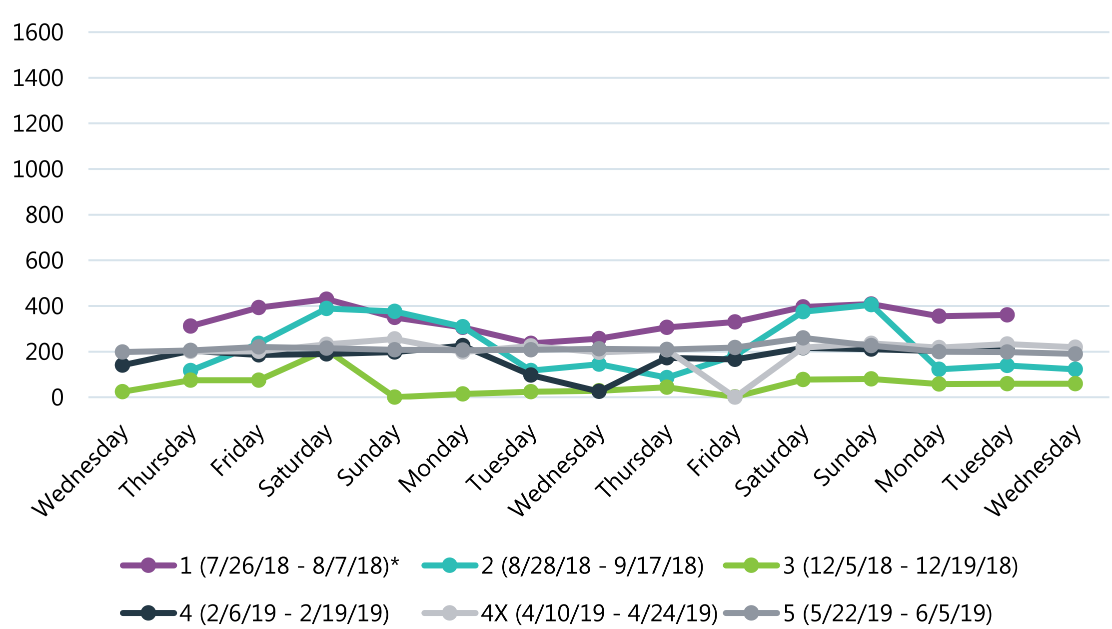


Figure B.15 – Daily Total Number of Vessel Passes at Station WW2 (Camera Counts)

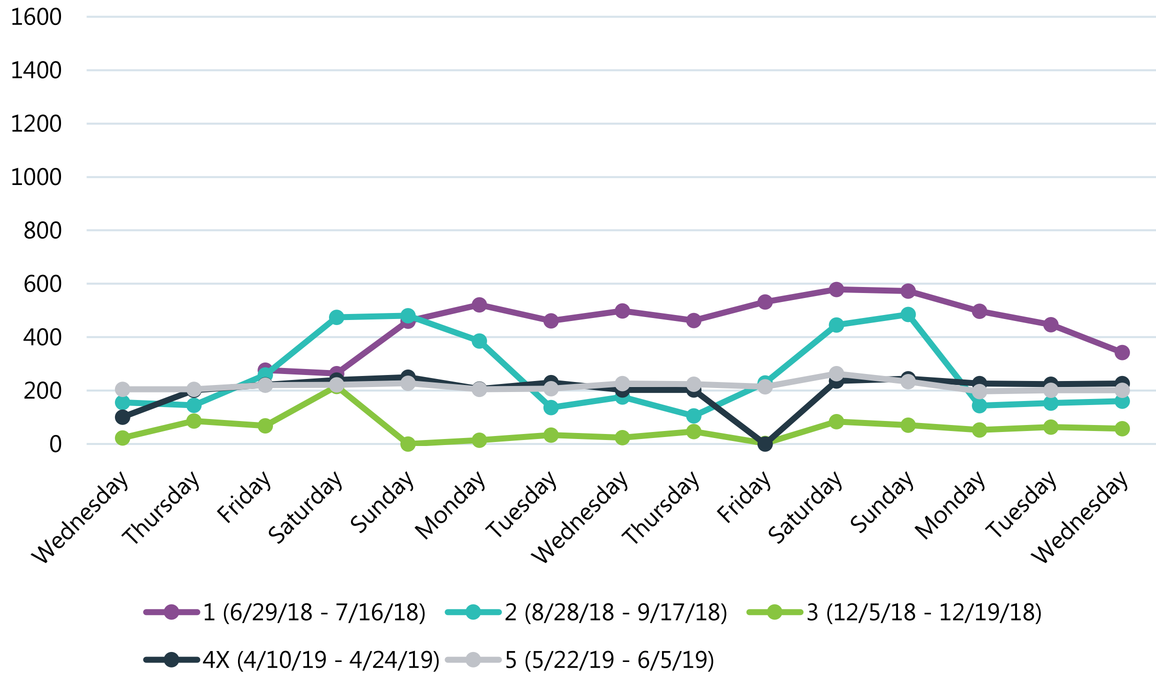


Figure B.16 – Daily Total Number of Vessel Passes at Station WW3 (Camera Counts)

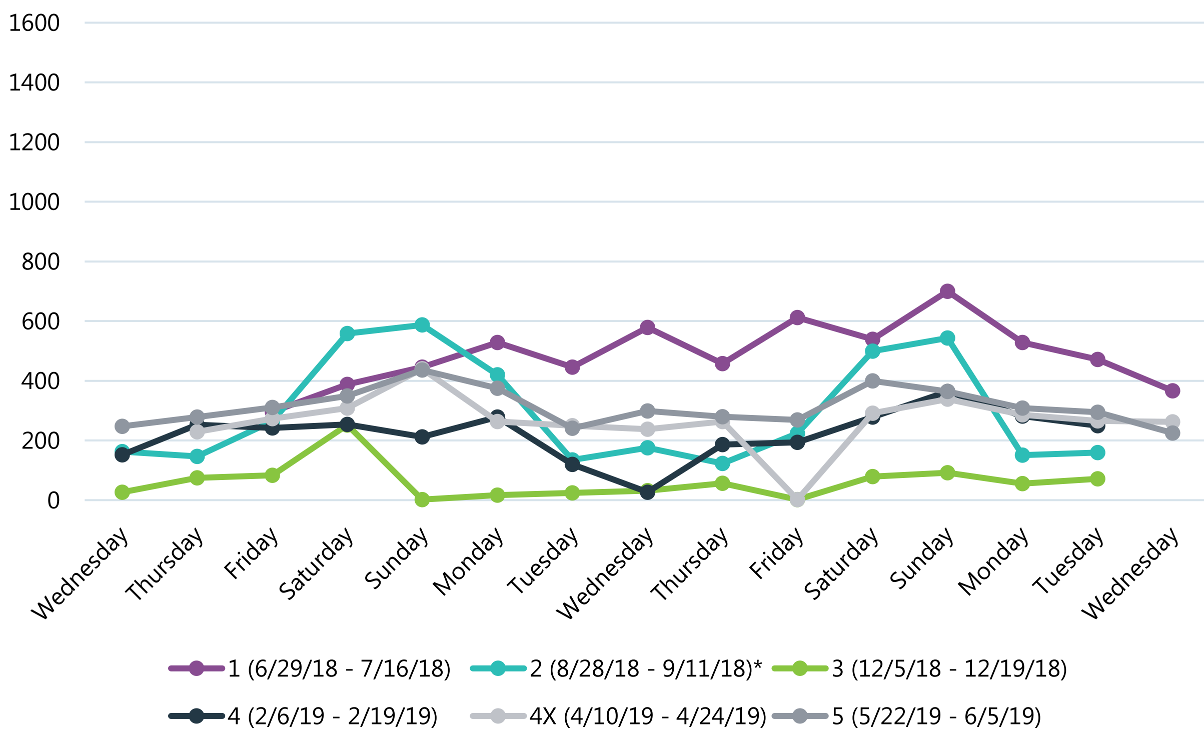


Figure B.17 – Daily Total Number of Vessel Passes at Station WW4 (Camera Counts)

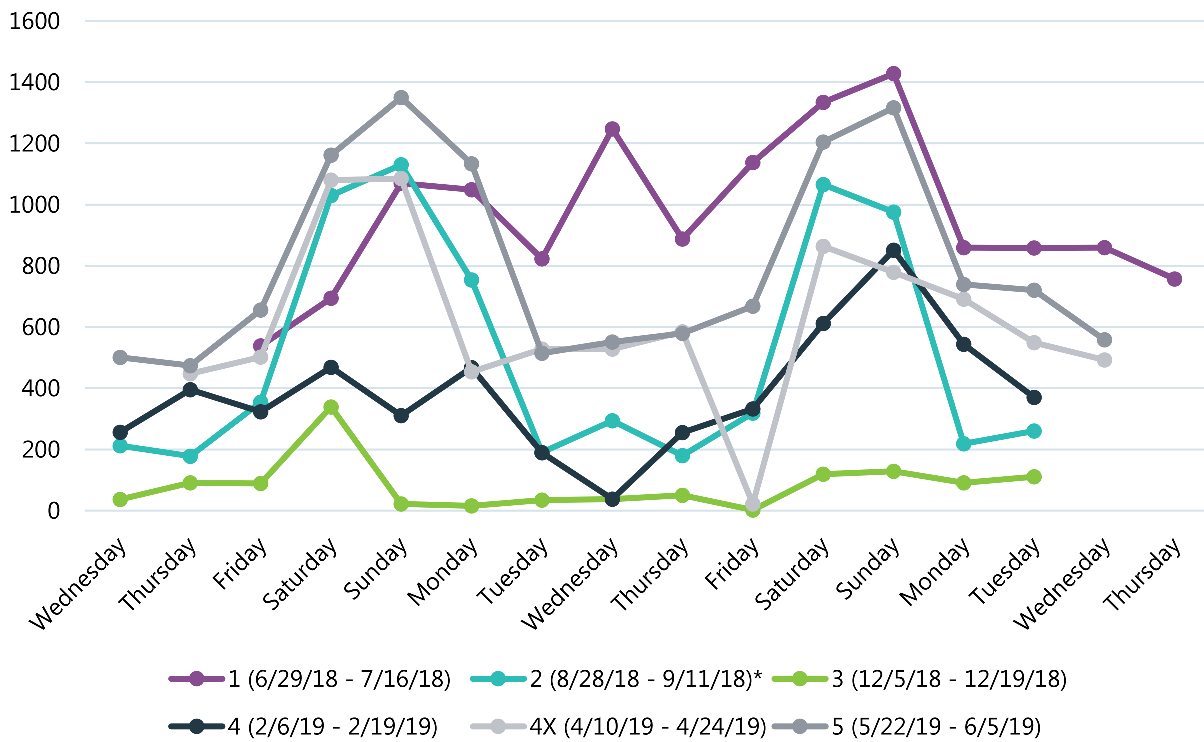


Figure B.18 – Hourly Average Number of Users Wading/Swimming by Station (Field Counts)

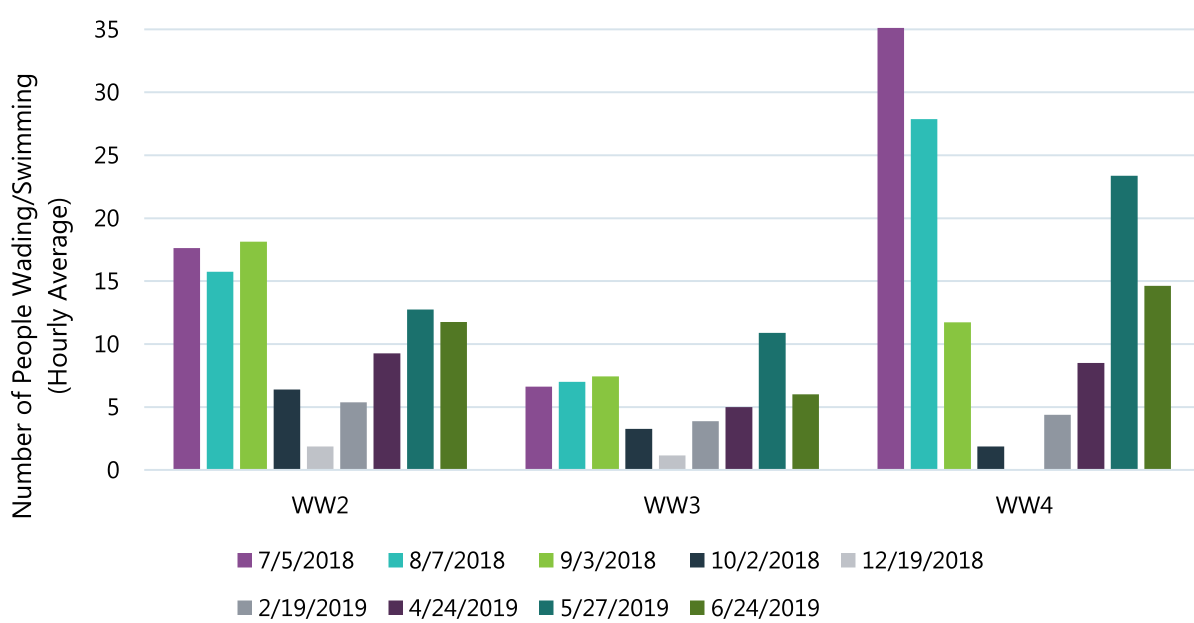


Figure B.19 - Hourly Total Number of Vessels Docking at Station WW2 (Field Counts)

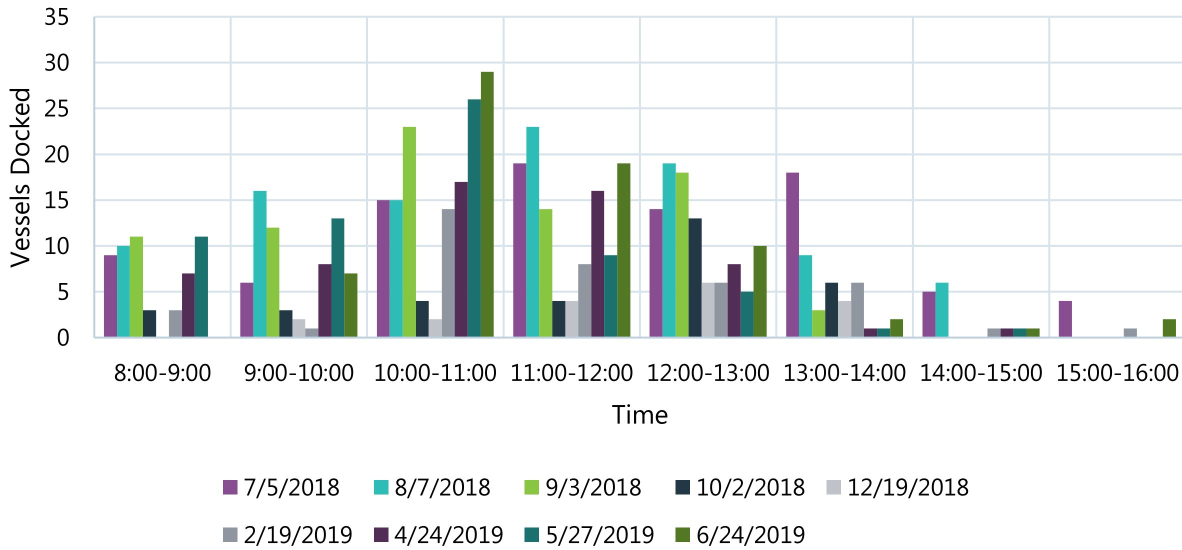


Figure B.20 - Hourly Total Number of Vessels Docking at Station WW3 (Field Counts)

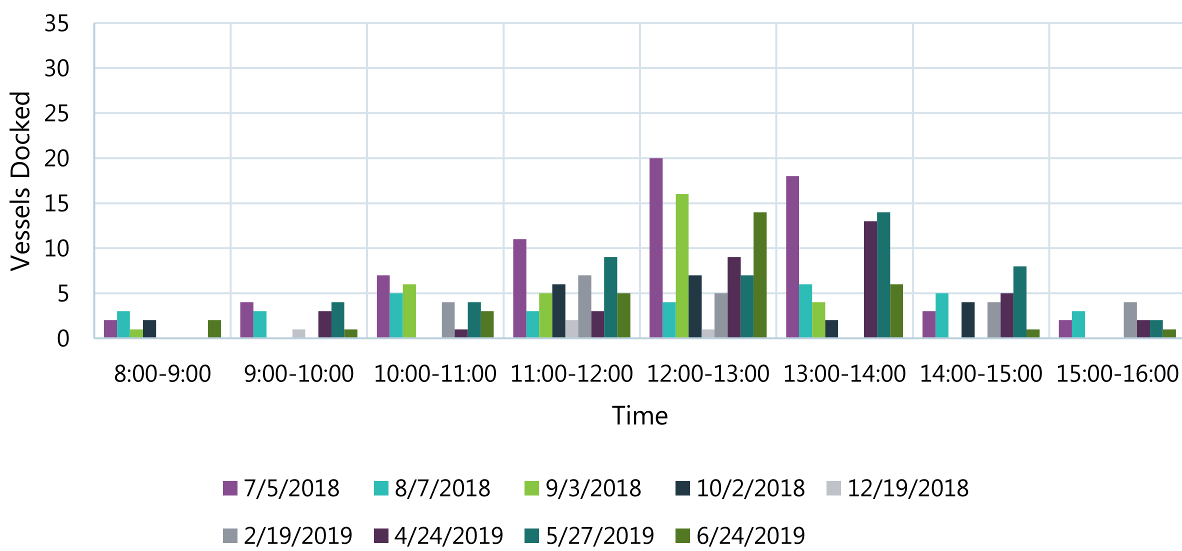


Figure B.21 - Hourly Total Number of Vessels Docking at Station WW4 (Field Counts)

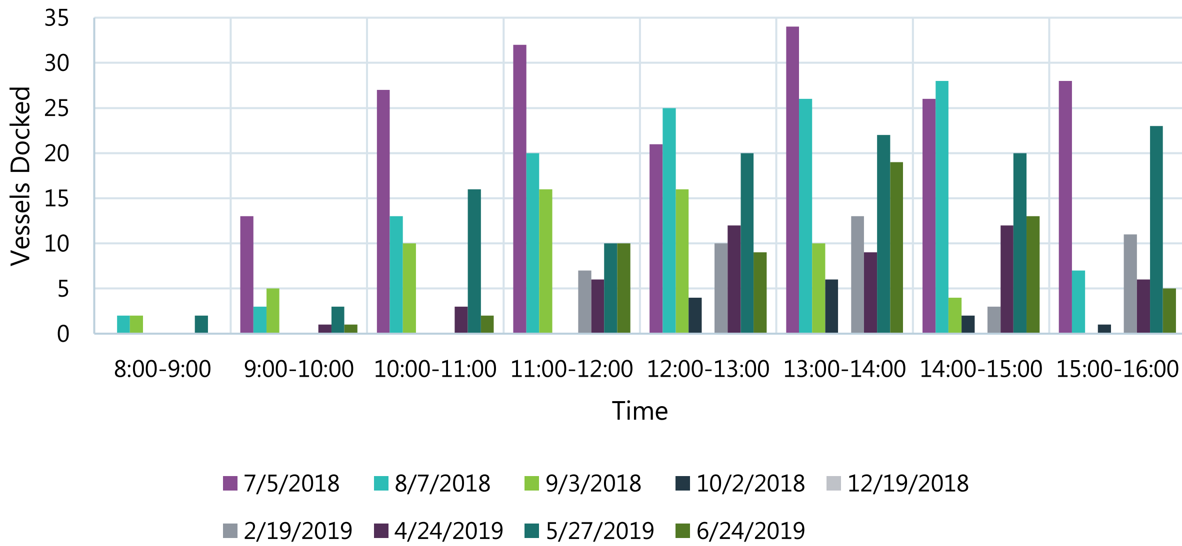


Figure B.22 - Hourly Total Number of Users Wading/Swimming at Station WW2 (Field Counts)

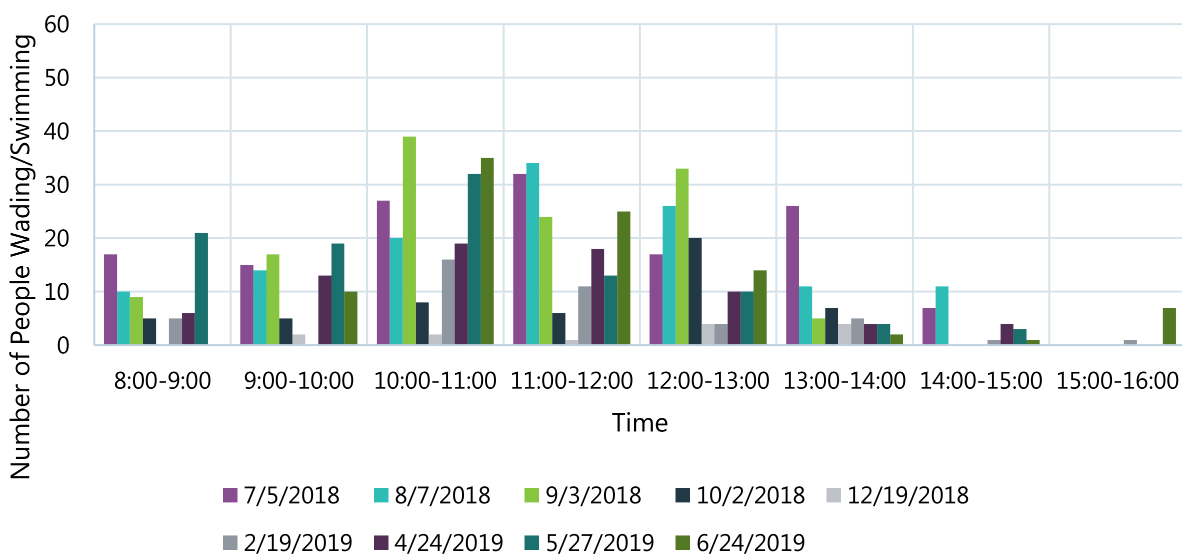


Figure B.23 - Hourly Total Number of Users Wading/Swimming at Station WW3 (Field Counts)

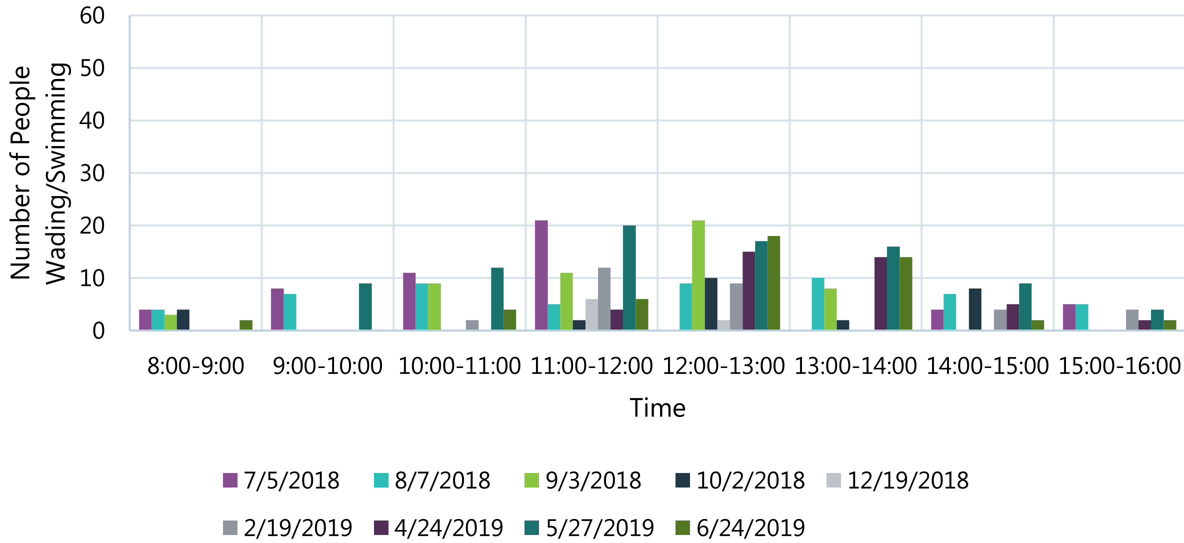


Figure B.24 - Hourly Total Number of Users Wading/Swimming at Station WW4 (Field Counts)

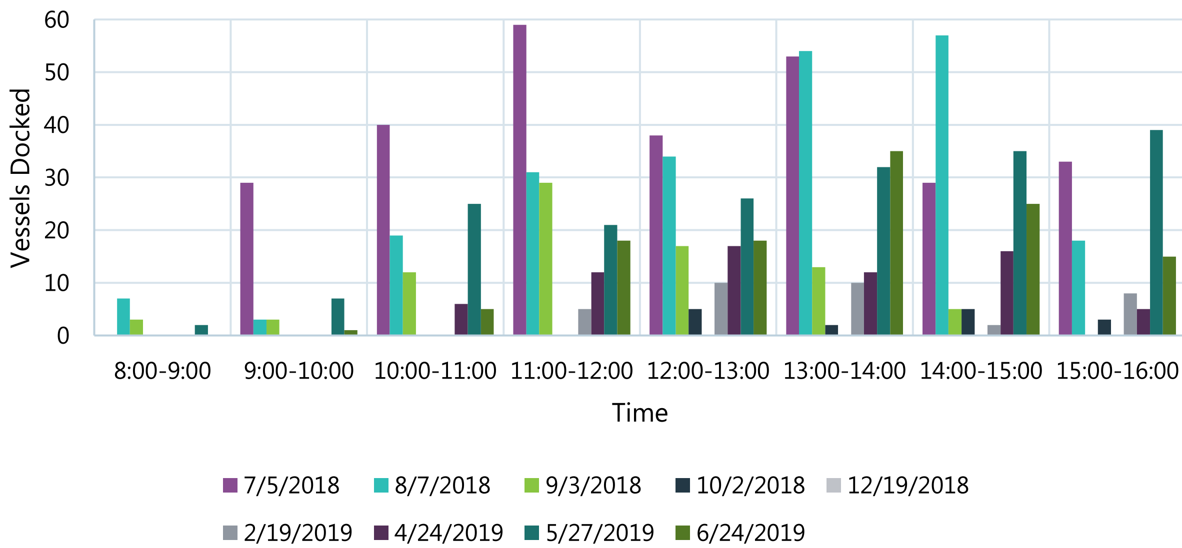


Figure B.25 – Hourly Number of Rope Swing Jumps at WW4

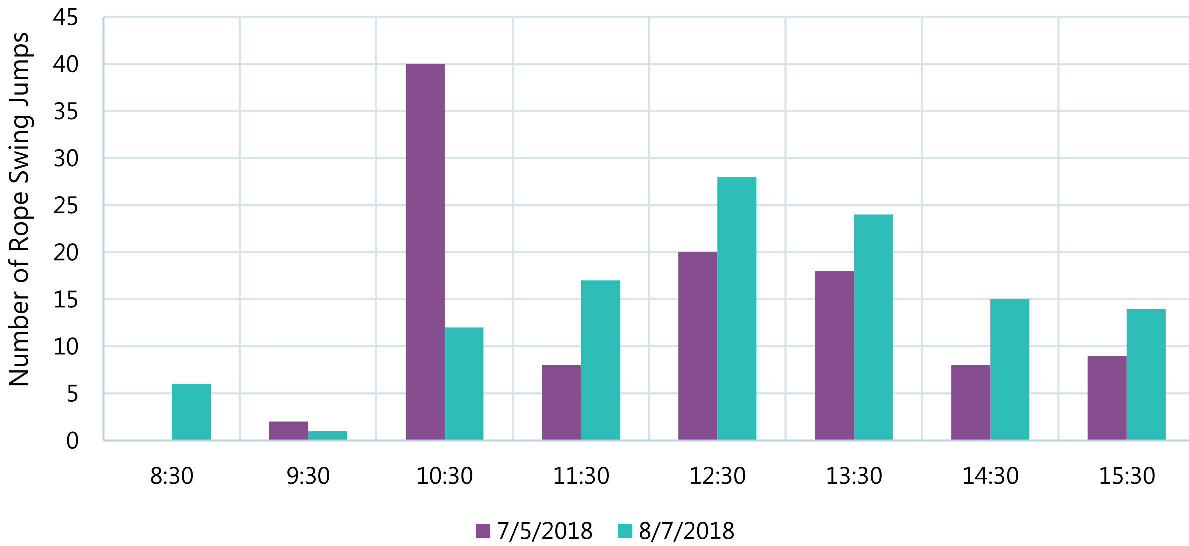


Figure B.26 – Hourly Number of Rope Swing Jumps at WW5

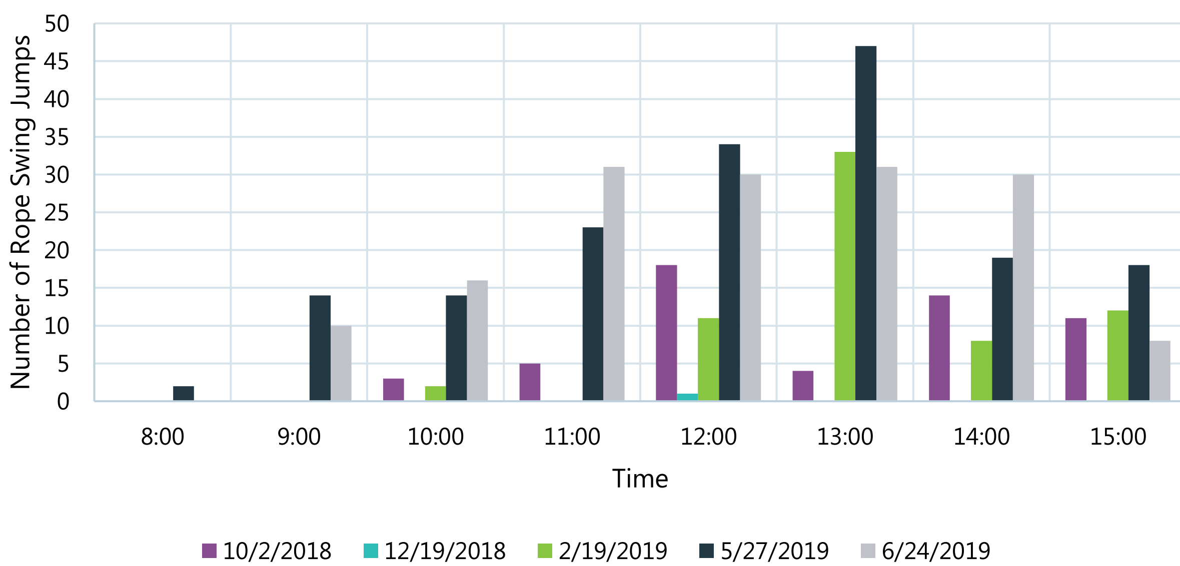


Table B.1 - Daily Total of Motorboat Engine Types at Station WW1 (Field Counts)

Date	PWC	Trolling	<10 HP	10-50 HP	60-100 HP	>100HP	Unknown	Total
7/5/2018	0	0	0	0	0	0	0	**0**
8/7/2018	0	0	0	0	0	0	2	**2**
9/3/2018	0	0	4	4	0	0	0	**8**
10/2/2018	0	0	2	0	0	0	0	**2**
12/19/2018	0	0	0	0	0	0	0	**0**
2/19/2019	0	0	0	0	0	0	0	**0**
4/24/2019	0	0	0	0	0	0	3	**3**
5/27/2019	0	0	0	6	0	0	1	**7**
6/24/2019	1	0	0	0	0	0	5	**6**
Total	**1**	**0**	**6**	**10**	**0**	**0**	**11**	**28**

Table B.2 - Daily Total of Motorboat Engine Types at Station WW2 (Field Counts)

Date	PWC	Trolling	<10HP	10-50 HP	60-100 HP	>100HP	Unknown	Total
7/5/2018	0	0	0	0	0	0	0	**0**
8/7/2018	0	0	1	0	0	0	0	**1**
9/3/2018	0	0	0	0	0	0	8	**8**
10/2/2018	0	0	0	0	0	0	2	**2**
12/19/2018	0	0	0	0	0	0	0	**0**
2/19/2019	0	0	0	0	0	0	0	**0**
4/24/2019	0	0	0	0	0	0	4	**4**
5/27/2019	1	0	0	0	0	0	8	**9**
6/24/2019	3	0	0	0	0	0	3	**6**
Total	**4**	**0**	**1**	**0**	**0**	**0**	**25**	**30**

Table B.3 – Daily Total of Motorboat Engine Types at Station WW3 (Field Counts)

Date	PWC	Trolling	<10HP	10-50 HP	60-100 HP	>100HP	Unknown	Total
7/5/2018	1	1	1	3	1	0	0	**7**
8/7/2018	0	1	7	0	3	0	1	**11**
9/3/2018	2	0	8	4	0	0	2	**15**
10/2/2018	0	0	4	0	0	1	0	**4**
12/19/2018	0	0	1	0	0	0	0	**1**
2/19/2019	0	0	2	1	0	0	1	**3**
4/24/2019	0	0	0	0	0	0	0	**0**
5/27/2019	2	1	17	3	0	0	2	**24**
6/24/2019	1	4	1	1	1	0	1	**8**
Total	**5**	**7**	**41**	**10**	**4**	**1**	**6**	**73**

Table B.4 – Daily Total of Motorboat Engine Types at Station WW4 (Field Counts)

Date	PWC	Trolling	<10HP	10-50 HP	60-100 HP	>100HP	Unknown	Total
7/5/2018	1	1	8	6	1	0	0	**16**
8/7/2018	0	1	8	4	5	3	0	**20**
9/3/2018	0	2	9	11	2	2	0	**25**
10/2/2018	0	1	4	0	3	2	0	**10**
12/19/2018	0	0	1	0	0	0	0	**1**
2/19/2019	0	0	2	3	0	0	0	**5**
4/24/2019	1	1	0	3	0	1	0	**5**
5/27/2019	4	6	19	17	3	0	0	**48**
6/24/2019	3	7	6	4	2	2	1	**22**
Total	**8**	**19**	**56**	**45**	**14**	**9**	**1**	**150**

WEEKI WACHEE EXIT SURVEY

Date:
Time
Interviewer:

1) Are you a FL resident?

2) Are you a resident of Hernando County?

3) Is this your 1st time on Weeki Wachee?

4) How many times have you been on the Weeki Wachee?

5) Where did you launch your boat from, upstream State Park launch site or a different vendor from downstream?

6) What time did you launch your boat?

7) Did you rent or bring your own boat?

8) How many people are in your group?

9) How many stops did you make along the river?

10) How long do you typically hang out on sand bars?

11) What were the reasons for your stops?

12) Did you use the rope swings? Do you think they are safe?

13) Was your experience positive?

14) If not, what was the reason for a negative experience?

15) What is your favorite thing about the Weeki Wachee?

16) Would you recommend the Weeki Wachee to others?

APPENDIX C

Aerial Point Bar Assessment

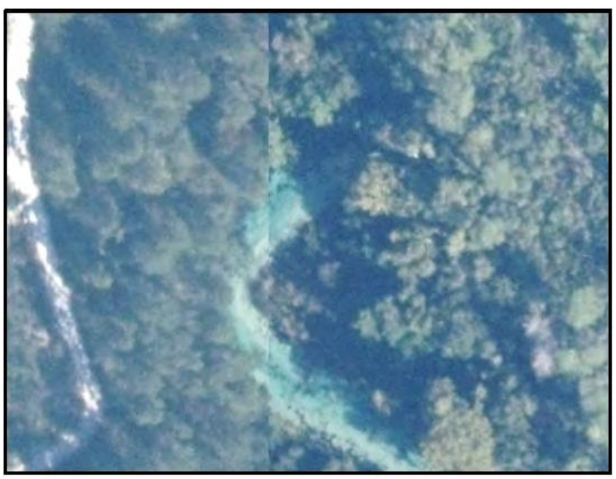
Figure C.1 – Changes in Vegetation from 2008 to 2017 at Weeki Wachee Point Bar 1 (WW2)

Aerial 10/2008

Bar vegetated area = 7,031 sq ft

Aerial 1/2011

Bar vegetated area = 7,113 sq ft



Aerial 3/2014

Bar vegetated area = 6,439 sq ft

Aerial 6/2017

Bar vegetated area = 5,337 sq ft

Note: Historic aerial imagery sourced from ESRI ArcGIS Online Imagery Services and/or freely available downloadable imagery from SWFWMD and FDOT.

Figure C.2 – Changes in Vegetation from 2008 to 2017 at Weeki Wachee Point Bar 6

Aerial 10/2008
Bar vegetated area = 11,661 sq ft

Aerial 1/2011
Bar vegetated area = 10,856 sq ft

Aerial 3/2014
Bar vegetated area = 10,682 sq ft

Aerial 6/2017
Bar vegetated area = 10,603 sq ft

Note: Historic aerial imagery sourced from ESRI ArcGIS Online Imagery Services and/or freely available downloadable imagery from SWFWMD and FDOT.

Figure C.3 – Changes in Vegetation from 2008 to 2017 at Weeki Wachee Point Bar 21

Aerial 10/2008
Bar vegetated area = 7,493 sq ft

Aerial 1/2011
Bar vegetated area = 7,281 sq ft

Aerial 3/2014
Bar vegetated area = 6,636 sq ft

Aerial 6/2017
Bar vegetated area = 6,063 sq ft

Note: Historic aerial imagery sourced from ESRI ArcGIS Online Imagery Services and/or freely available downloadable imagery from SWFWMD and FDOT.

Figure C.4 – Changes in Vegetation from 2008 to 2017 at Weeki Wachee Point Bar 22

Aerial 10/2008
Bar vegetated area = 8,508 sq ft

Aerial 1/2011
Bar vegetated area = 7,734 sq ft

Aerial 3/2014
Bar vegetated area = 7,941 sq ft

Aerial 6/2017
Bar vegetated area = 7,008 sq ft

Note: Historic aerial imagery sourced from ESRI ArcGIS Online Imagery Services and/or freely available downloadable imagery from SWFWMD and FDOT.

Figure C.5 – Changes in Vegetation from 2008 to 2017 at Weeki Wachee Point Bar 24 (The Bluffs)

Aerial 10/2008
Bar vegetated area = 7,012 sq ft

Aerial 1/2011
Bar vegetated area = 6,624 sq ft

Aerial 3/2014
Bar vegetated area = 6,565 sq ft

Aerial 6/2017
Bar vegetated area = 6,201 sq ft

Note: Historic aerial imagery sourced from ESRI ArcGIS Online Imagery Services and/or freely available downloadable imagery from SWFWMD and FDOT.

Figure C.6 – Changes in Vegetation from 2008 to 2017 at Weeki Wachee Point Bar 28

Aerial 10/2008
Bar vegetated area = 3,213 sq ft

Aerial 1/2011
Bar vegetated area = 3,040 sq ft

Aerial 3/2014
Bar vegetated area = 2,709 sq ft

Aerial 6/2017
Bar vegetated area = 2,237 sq ft

Note: Historic aerial imagery sourced from ESRI ArcGIS Online Imagery Services and/or freely available downloadable imagery from SWFWMD and FDOT.

APPENDIX D

Recreational Trampling Assessment Additional Figures

Figure D.1 – Percent Reduction of Vegetation Cover vs. Trampling Intensity after Two Weeks (Trample Bar 1)

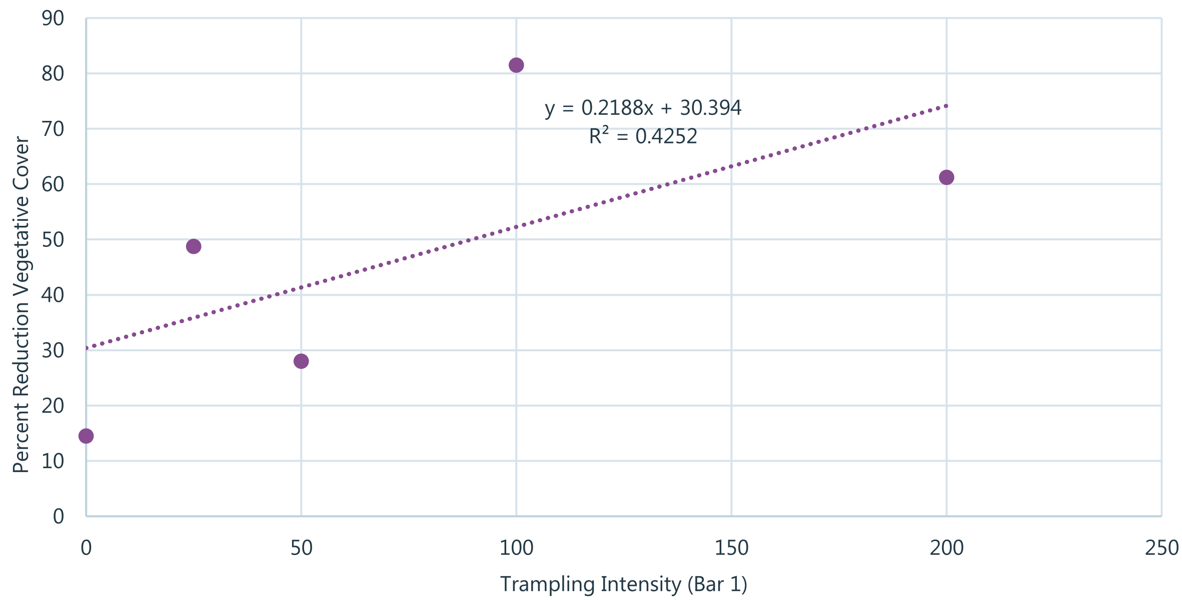


Figure D.2 – Percent Reduction of Vegetation Cover vs. Trampling Intensity after Two Weeks (Trample Bar 2)

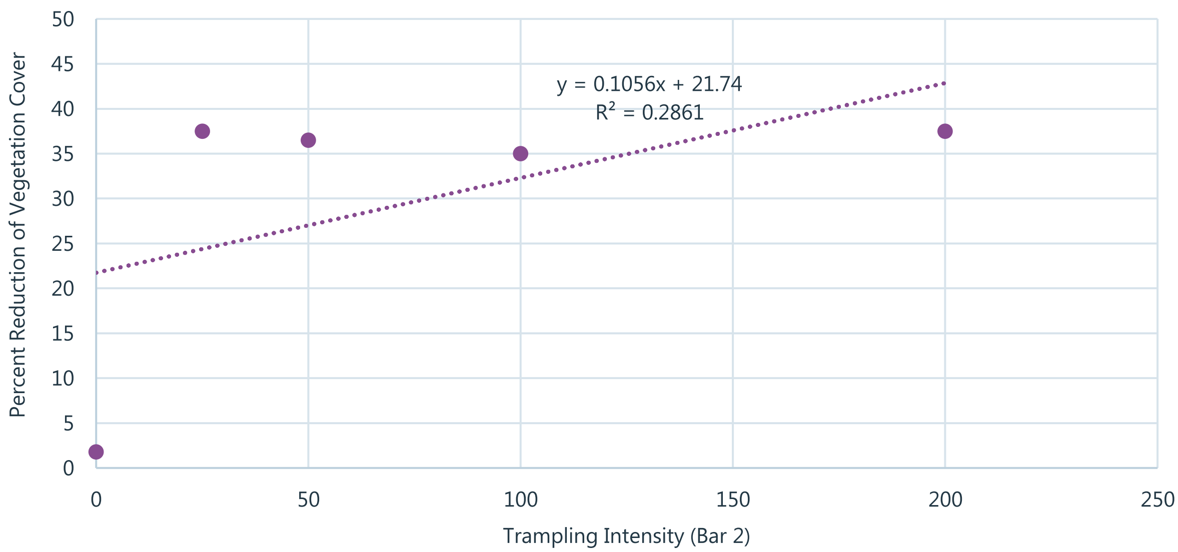


Figure D.3 – Percent Reduction of Vegetation Cover vs. Trampling Intensity after Two-Weeks (Trample Bar 3)

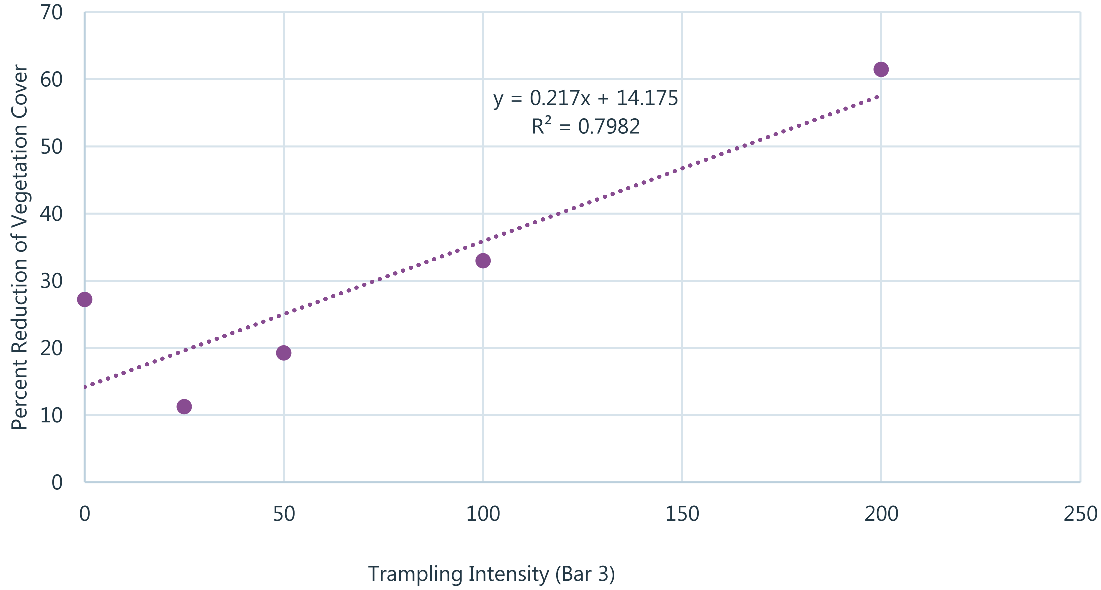


Figure D.4 – Percent Reduction of Vegetation Cover vs. Trampling Intensity after Six Months (Trample Bar 1)

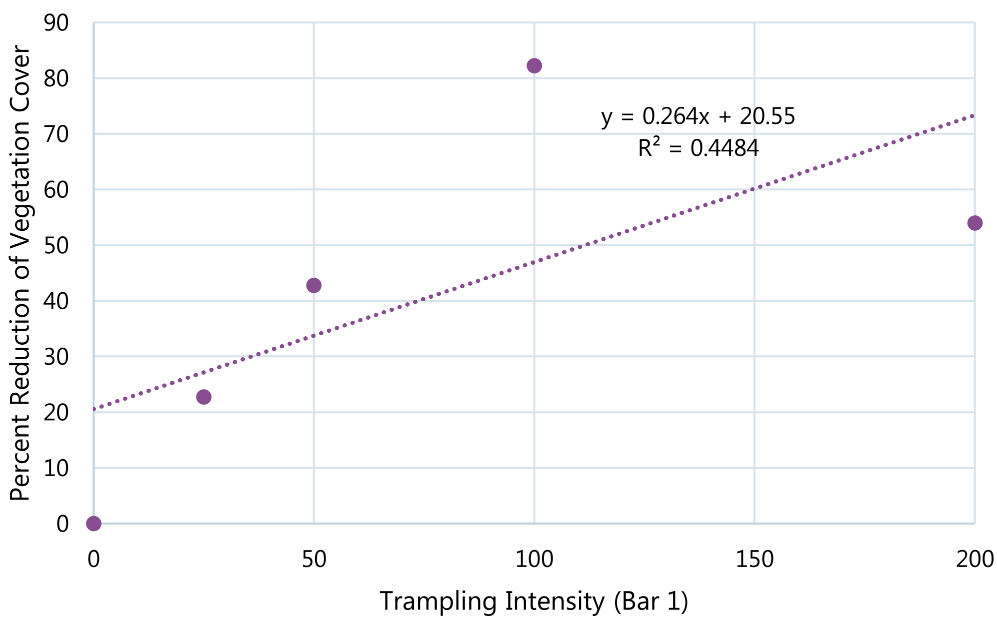


Figure D.5 – Percent Reduction of Vegetation Cover vs. Trampling Intensity after Six Months (Trample Bar 2)

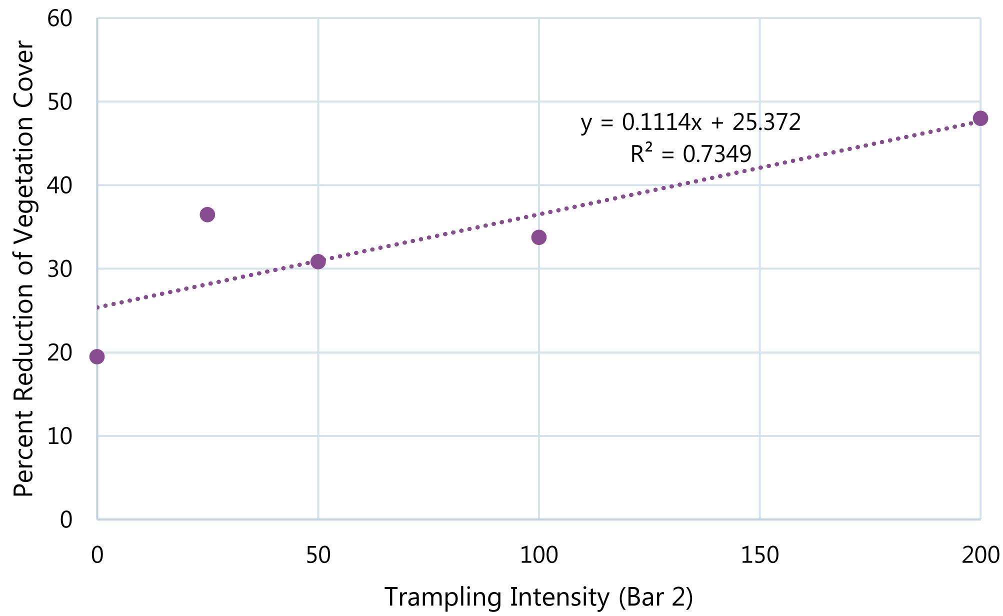


Figure D.6 – Percent Reduction of Vegetation Cover vs. Trampling Intensity after Six Months (Trample Bar 3)

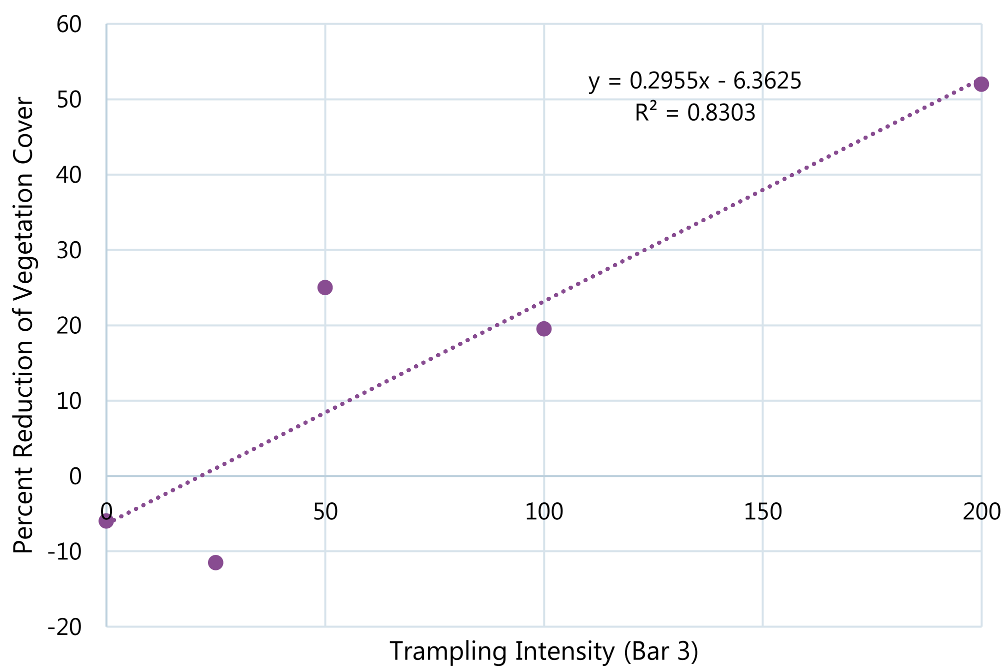


Figure D.7 – Mean Percent Vegetation Cover Before, Two Weeks, and Six Months after Trampling Bar 1

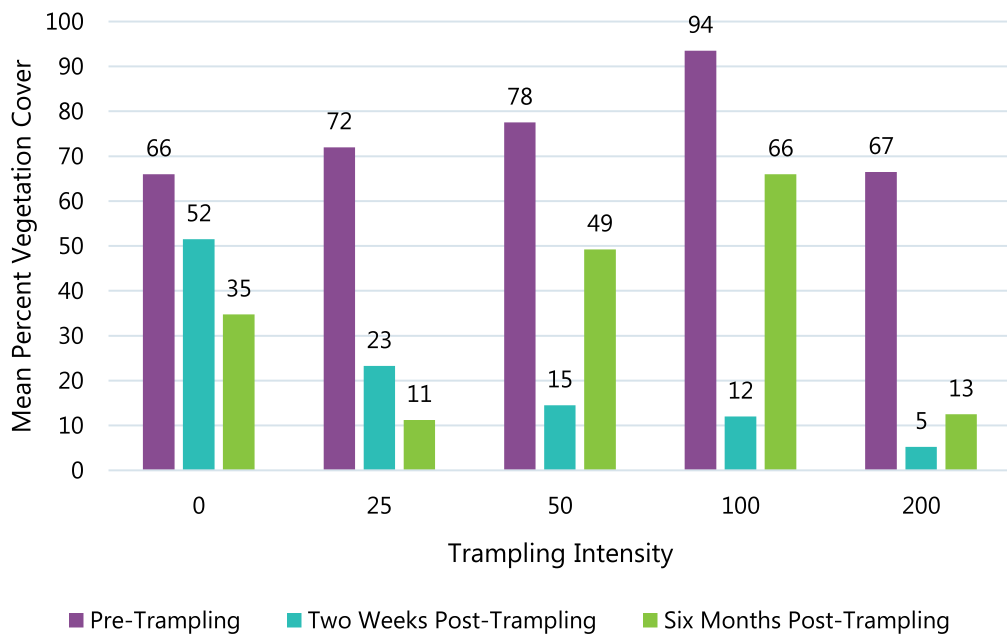


Figure D.8– Mean Percent Vegetation Cover Before and Two Weeks after Trampling Bar 2

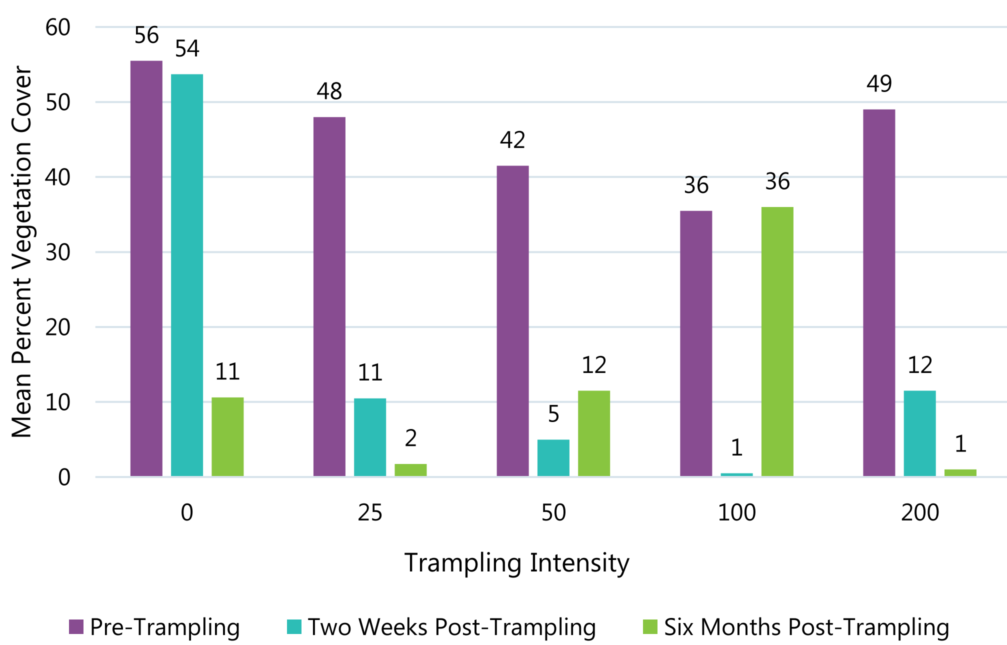
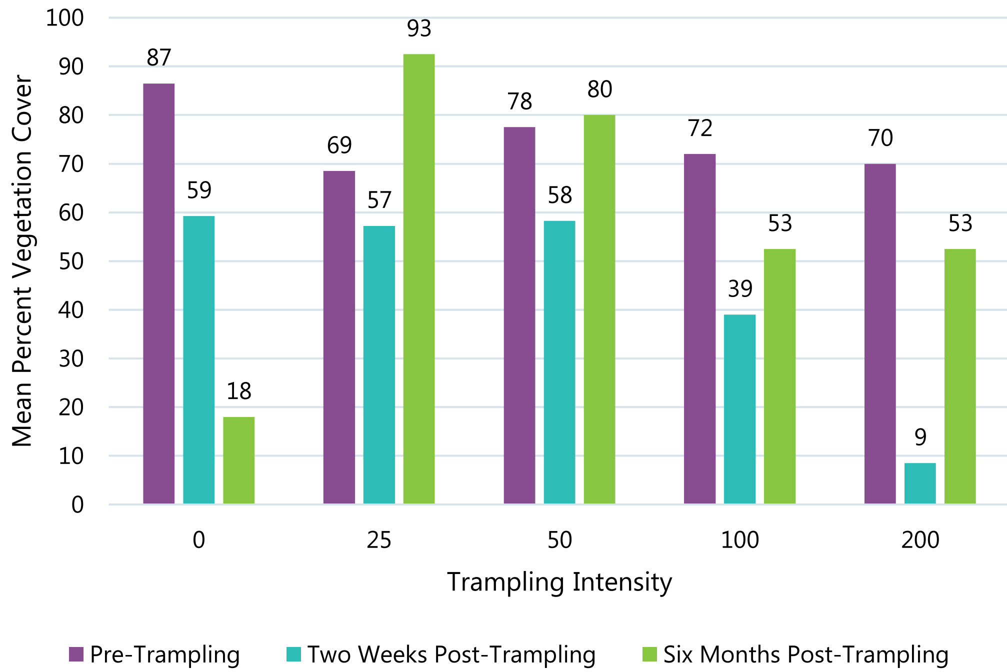


Figure D.9 – Mean Percent Vegetation Cover Before and Two Weeks after Trampling Bar 3



Trample Bar 1

Location: 28.518323, -82.580058
(SE of SWFWMD Education Center

Image: ESRI ArcGIS Online Imagery Services

Pre Trample Condition (5/28/2019)

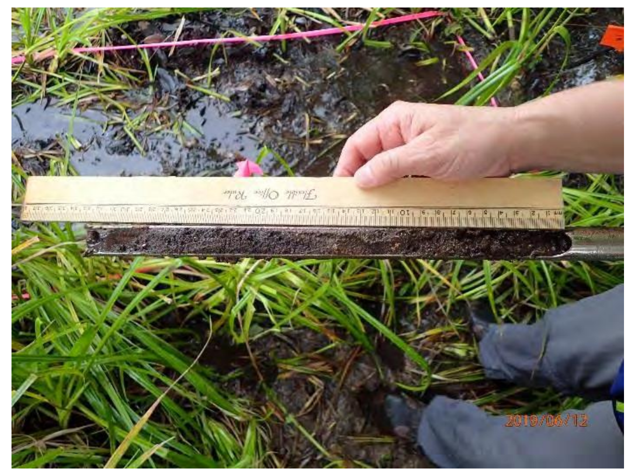
Trample Bar 1 – Subplot 1a (50 trample pass

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos



Subr
core

Trample Bar 1 – Subplot 1b (50 trample pass

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

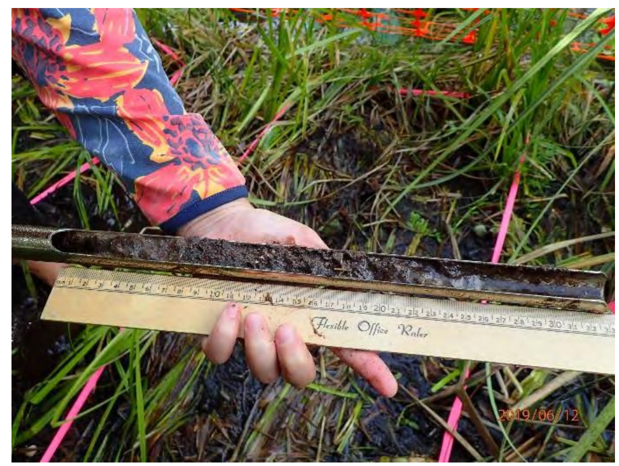
Subr
core

Trample Bar 1 – Subplot 2a (100 trample pas

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019



Pos

Trample Bar 1 – Subplot 2b (100 trample pas

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

Trample Bar 1 – Subplot 3a (25 trample pass

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

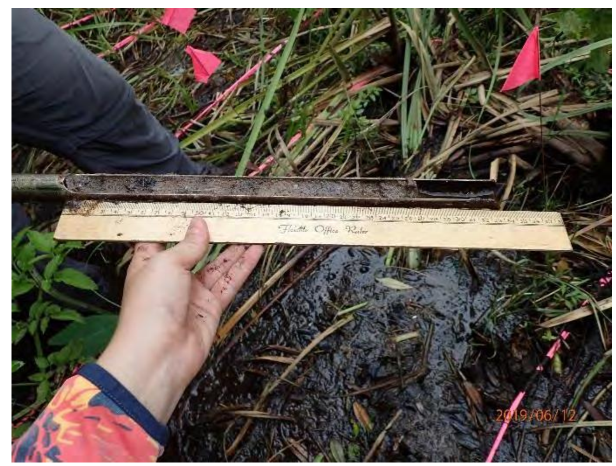
Pos

Trample Bar 1 – Subplot 3b (25 trample pass

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019



Pos

Trample Bar 1 – Subplot 4a (Control- 0 trample p

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

Trample Bar 1 – Subplot 4b (Control- 0 trample p

Pre Trample
5/28/2019

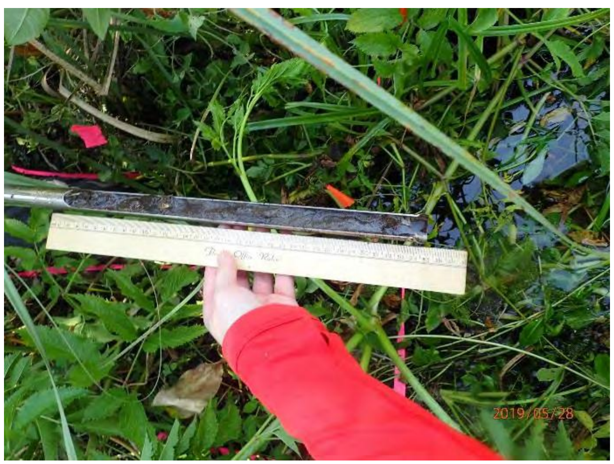
Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

Trample Bar 1 – Subplot 5a (200 trample pas

Pre Trample
5/28/2019



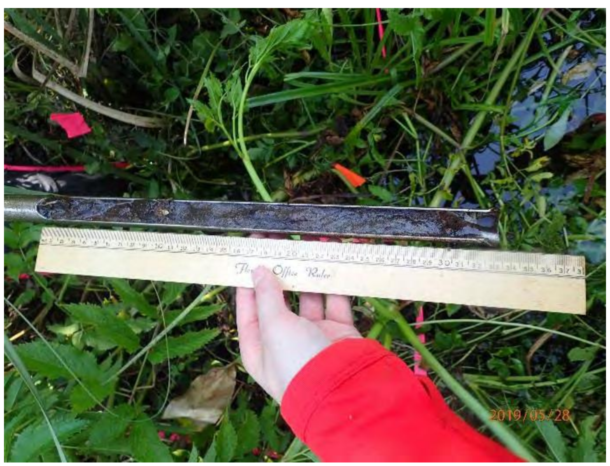
Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

Trample Bar 1 – Subplot 5b (200 trample pas

Pre Trample
5/28/2019



Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

Trample Bar 2

Location: 28.519323, -82.583412 (NW of WW1)

Image: ESRI ArcGIS Online Imagery Services

Pre Trample Condition (5/28/2019)

Trample Bar 2 – Subplot 1a (50 trample pass

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

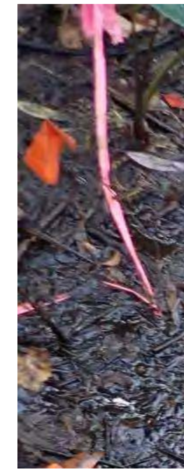
Trample Bar 2 – Subplot 1b (50 trample pass

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Post T



Trample Bar 2 – Subplot 2a (100 trample pas

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Post T

Trample Bar 2 – Subplot 2b (100 trample pas

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Post T

Trample Bar 2 – Subplot 3a (25 trample pass

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Post T

Appendix D

Trample Bar 2 – Subplot 3b (25 trample pass

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Post T

Trample Bar 2 – Subplot 4a (Control – 0 trampl

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Post T

Trample Bar 2 – Subplot 4b (Control – 0 trampl

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Post T

Trample Bar 2 – Subplot 5a (200 trample pa

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Post T

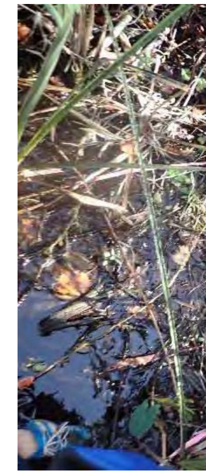
Trample Bar 2 – Subplot 5b (200 trample pa

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Post T



Trample Bar 3

Location: 28.520092, -82.583560
(SE of WW2)

Image: ESRI ArcGIS Online Imagery Services

Pre Trample Condition (5/28/2019)

Trample Bar 3 – Subplot 1a (200 trample pas

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

Trample Bar 3 – Subplot 1b (200 trample pas

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

Trample Bar 3 – Subplot 2a (Control- 0 trample p

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

Trample Bar 3 – Subplot 2b (Control- 0 trample p

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

Trample Bar 3 – Subplot 3a (25 trample pass

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

Trample Bar 3 – Subplot 3b (25 trample pass

Pre Trample
5/28/2019


Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019


Pos


Trample Bar 3 – Subplot 4a (100 trample pas

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

Trample Bar 3 – Subplot 4b (100 trample pas

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

Trample Bar 3 – Subplot 5a (50 trample pass

Pre Trample
5/28/2019

Post Trample
5/28/2019

Two Week
Post Trample Follow Up
6/12/2019

Pos

Trample Bar 3 – Subplot 5b (50 trample pass

Pre Trample
5/28/2019

Post Trample
5/28/2019

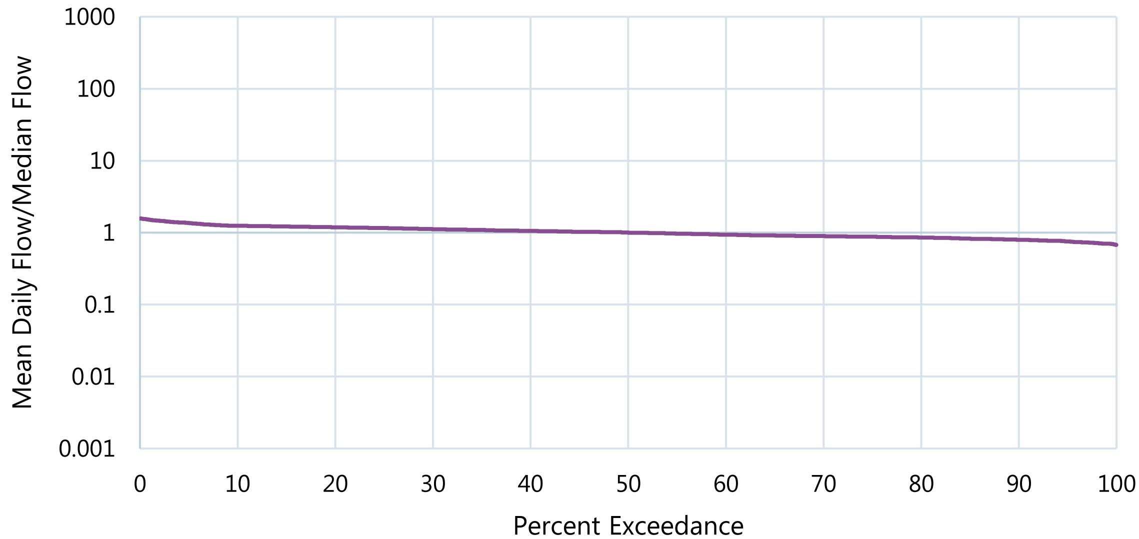
Two Week
Post Trample Follow Up
6/12/2019

Pos

APPENDIX E

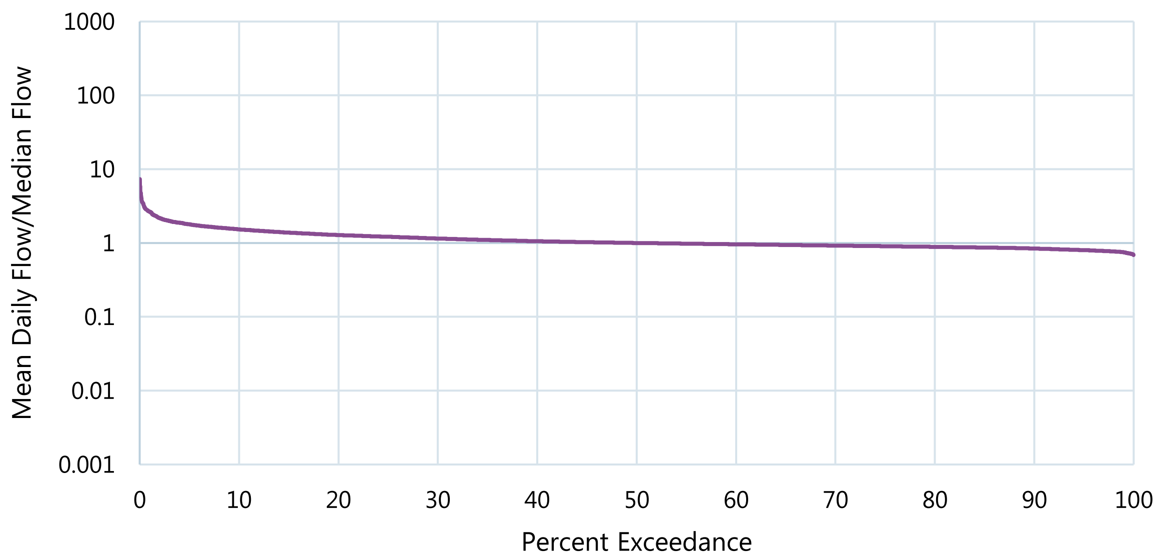
Comparative Assessment Additional Figures and Tables

Figure E.1 – Weeki Wachee River Exceedance Curve



Note: Normalized by median flow. Y axis is shown on $\log_{10}$ scale.

Figure E.2 – Alexander Springs Run Exceedance Curve



Note: Normalized by median flow. Y axis is shown on $\log_{10}$ scale.

Figure E.3 – Alexander Point Bar 4 – Left Bank, Herbaceous

Figure E.4 – Alexander Point Bar 5 – Right Bank, Herbaceous

Figure E.5 – Alexander Point Bar 6.5 – Right Bank, Forested

Figure E.6 – Alexander Point Bar 11 – Left Bank, Herbaceous

Figure E.7 – Weeki Wachee Point Bar 1 – Right Bank, Herbaceous

Figure E.8 – Weeki Wachee Point Bar 11 – Left Bank, Forested

Figure E.9 – Weeki Wachee Point Bar 14 – Right Bank, Forested

Figure E.10 – Weeki Wachee Point Bar 23 – Right Bank, Herbaceous

Figure E.11 – Alexander Springs Run Point Bar 4 Cross-Section

Figure E.12 – Alexander Springs Run Point Bar 5 Cross-Section

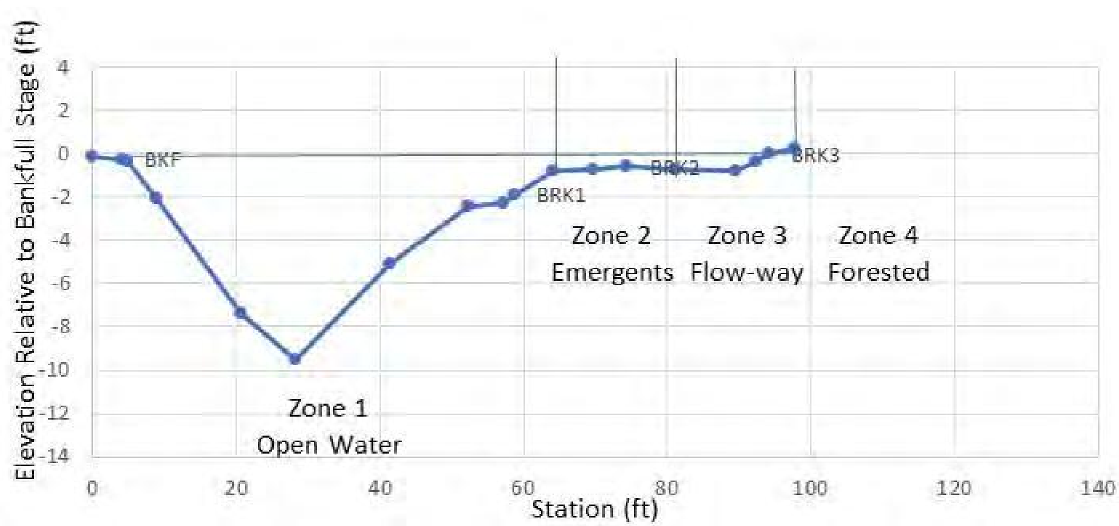


Figure E.13 – Alexander Springs Run Point Bar 6.5 Cross-Section

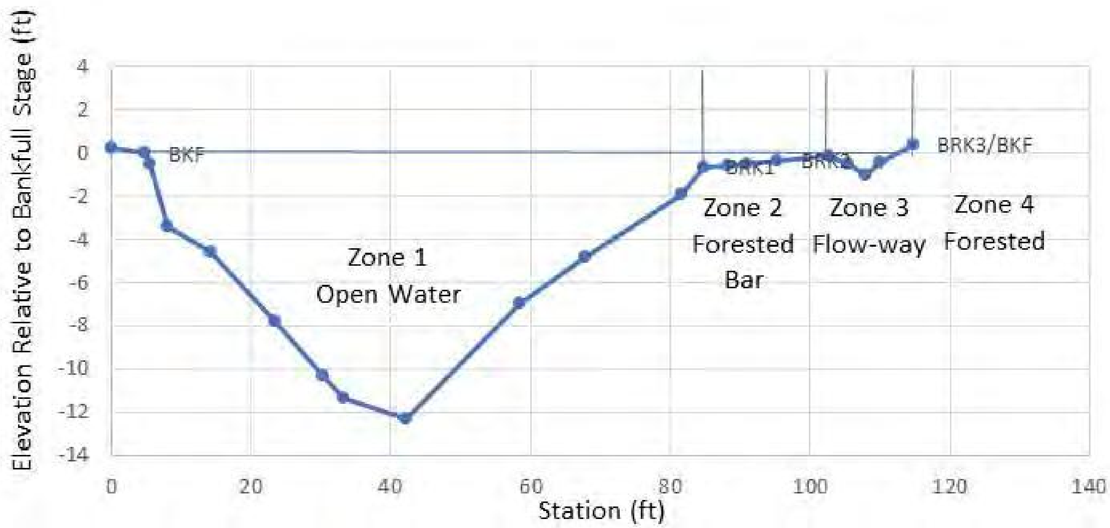


Figure E.14 – Alexander Springs Run Point Bar 11 Cross-Section

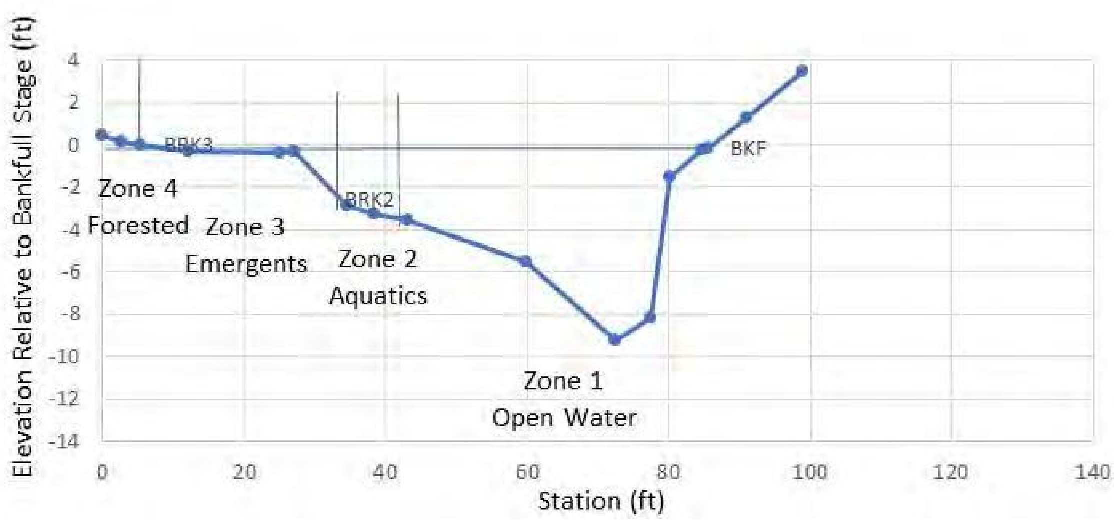


Figure E.15 – Weeki Wachee Point Bar 1 Cross-Section

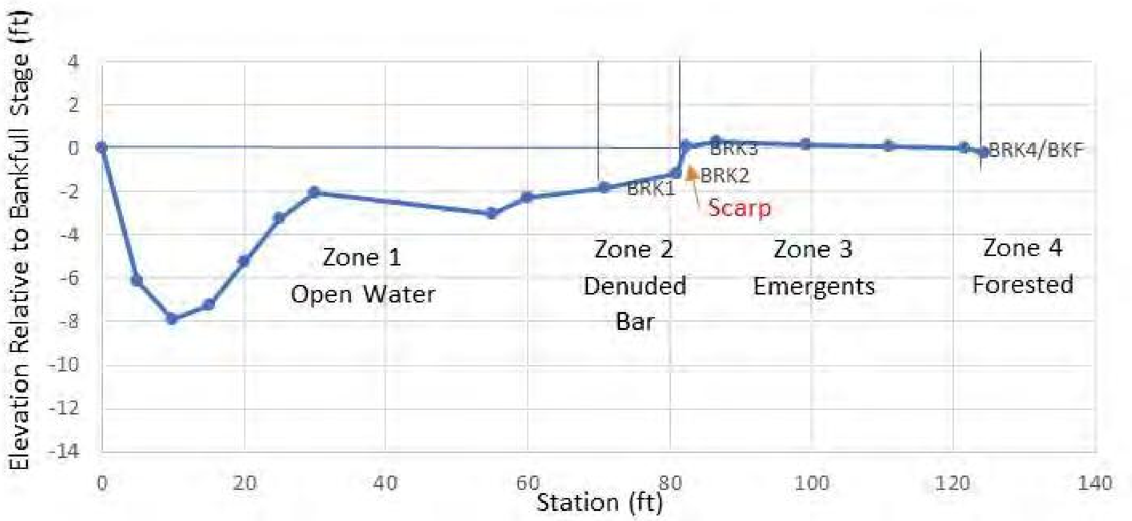


Figure E.16 – Weeki Wachee Point Bar 11 Cross-Section

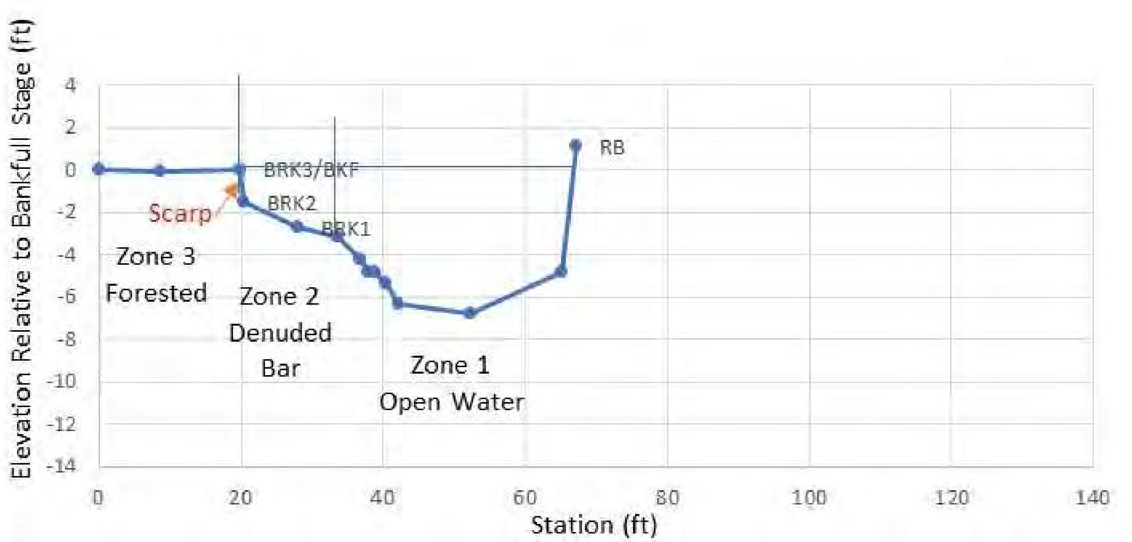


Figure E.17 – Weeki Wachee Point Bar 14 Cross-Section

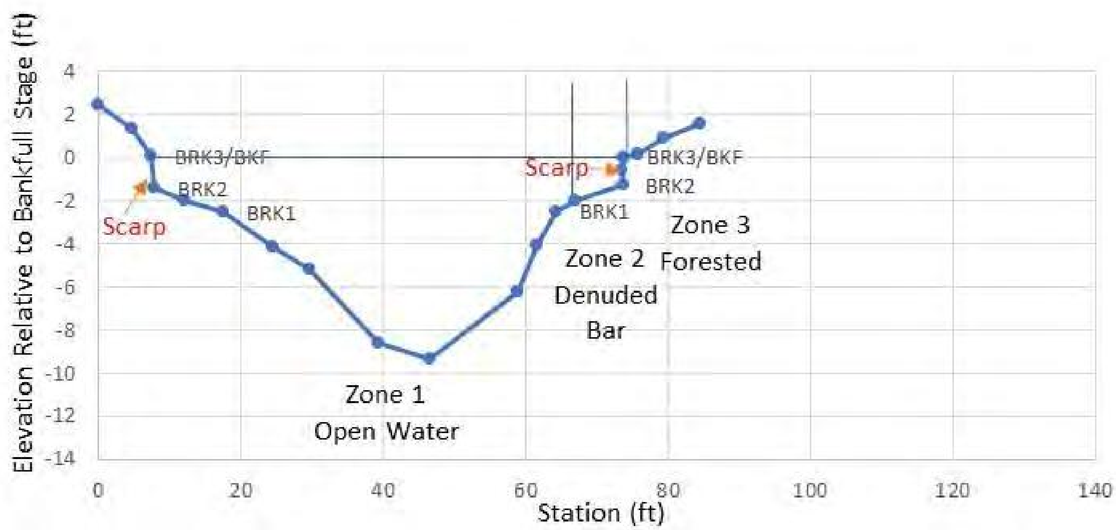


Figure E.18 – Weeki Wachee Point Bar 23 Cross-Section

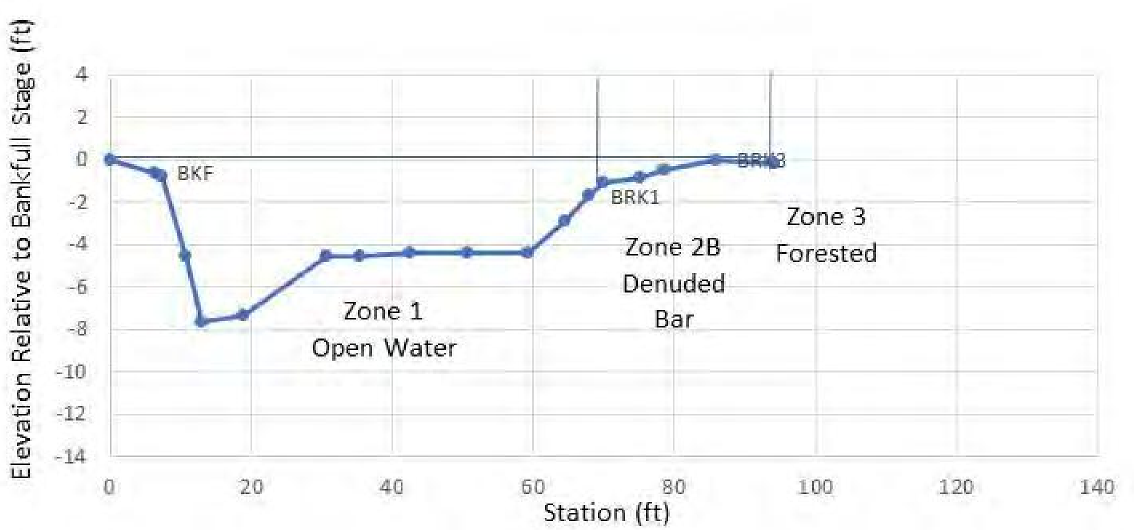
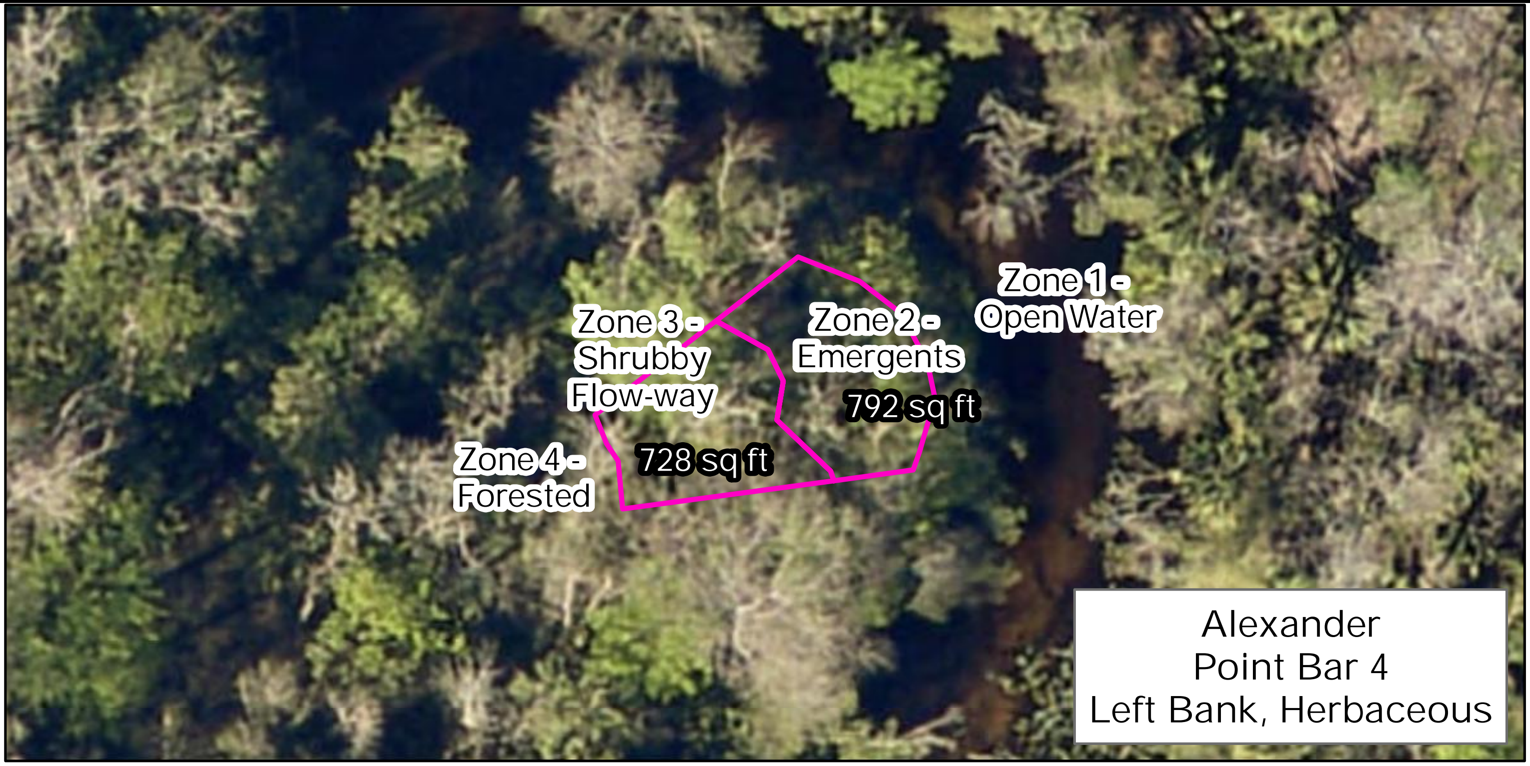


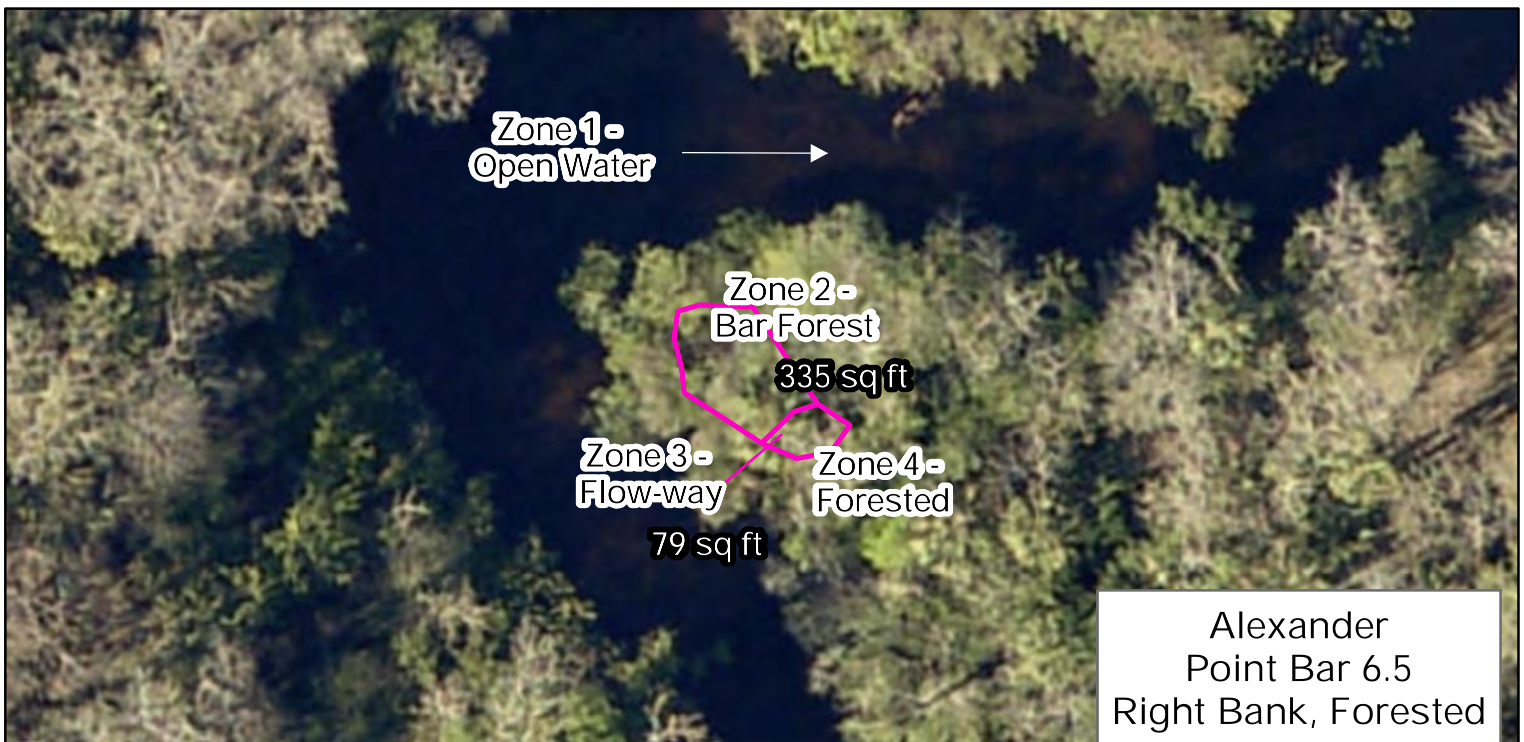
Table E.1 Alexander Springs Run Comparative Assessment Point Bar Data Su

Point Bar	Point Bar Type	Point Bar Bank Location	Zone Number	Zone Type	Associated Break	Length (ft)	Average Width (ft)	Depth Relative to Bankfull (ft)	Area
Bar 4	Herbaceous	Left Bank	1	Open Water	--	--	--	--	-
			2	Emergents	BRK1 - Emergents	48	19	-1.8	7
			3	Shrubby Flow-way	BRK2 - Flowway	35	30	-0.8	7
			4	Forest	BRK3 - Forest/Bankfull	18	--	0.0	-
Bar 5	Herbaceous	Right Bank	1	Open Water	--	--	--	--	-
			2	Emergents	BRK1 - Emergents	64	16	-1.7	7
			3	Shrubby Flow-way	BRK2 - Flowway	30	16	-0.4	3
			4	Forest	BRK3 - Forest/Bankfull	14	--	0.0	-
Bar 6.5	Forested	Right Bank	1	Open Water	--	--	--	--	-
			2	Forested Bar	BRK1 - Bar Ledge (Forested)	26	21	-1.3	3
			3	Flow way	BRK2 - Flowway	12	7	-0.3	7
			4	Forest	BRK3 - Bankfull	11	--	0.0	-
Bar 11	Herbaceous	Left Bank	1	Open Water	--	--	--	--	-
			2	Aquatic Vegetation	BRK1 - Aquatics	37	11	-2.8	5
			3	Emergents	BRK2 - Emergents	71	22	-1.5	12
			4	Forest	BRK3 - Forest/Bankfull	38	--	0.0	-

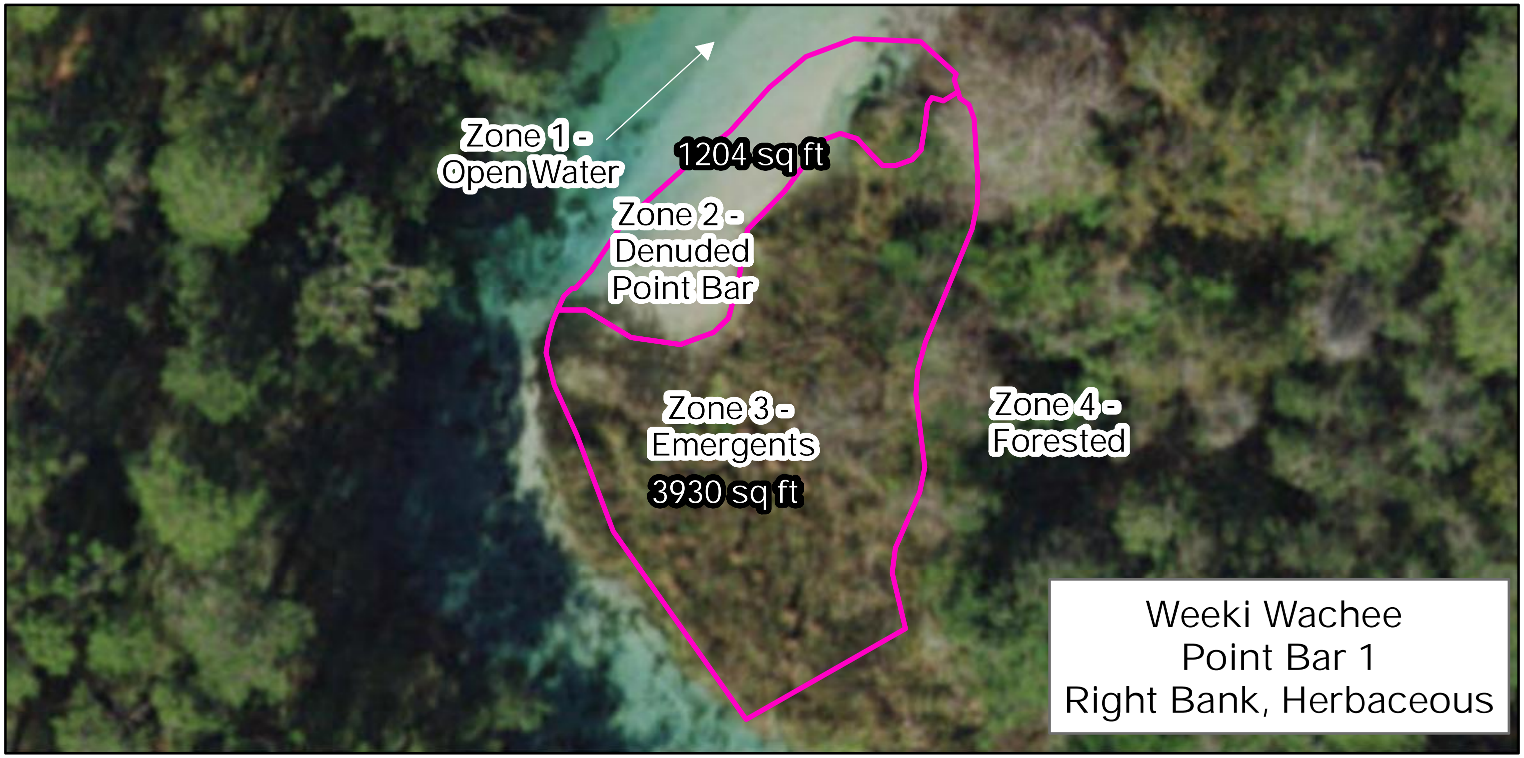
Table E.2 – Weeki Wachee River Comparative Assessment Point Bar Data Sur

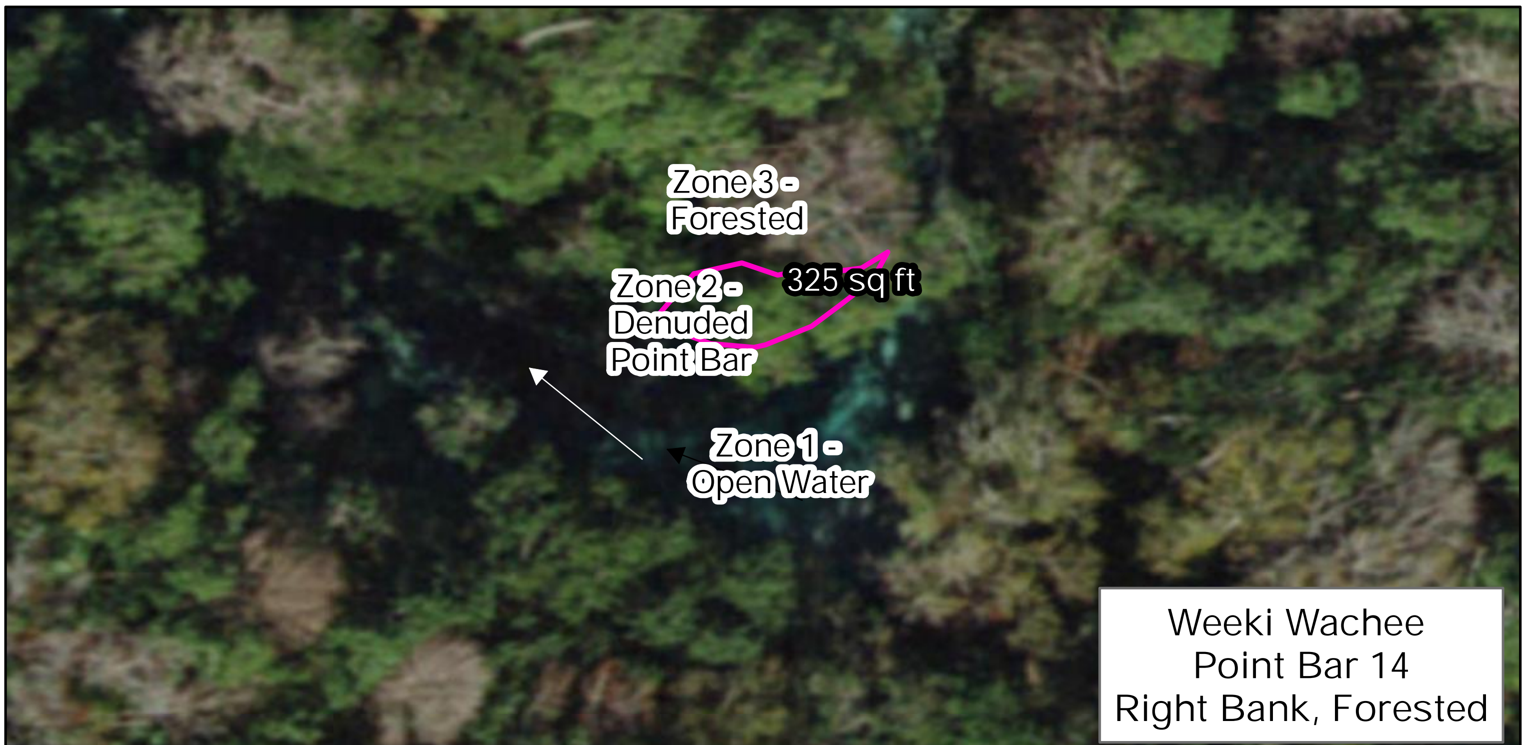
Point Bar	Point Bar Type	Point Bar Bank Location	Zone Number	Zone Type	Associated Break	Length (ft)	Average Width (ft)	Depth Relative to Bankfull (ft)	Area (sq ft)	Depth of Soils (i
Bar 1	Herbaceous	Right Bank	1	Open Water	BRK1 - Sand Ledge	87	--	-1.3	--	Sand
			2	Denuded Bar	BRK2 - Toe of Scarp	99	16	-0.9	1204	Sand
			3	Emergents	BRK3 - Emergents/Top of Scarp	191	38	-0.1	3930	18" of o
			4	Forest	BRK4 - Forest/BKF	80	--	0.0	--	> 36" of
Bar 11	Forested	Left Bank	1	Open Water	BRK1 - Sand Ledge	65	--	-2.4	--	Sand
			2	Denuded Bar	BRK2 - Toe of Scarp	49	9	-1.1	518	Sand
			3	Forest	BRK3 - Forest/Top of Scarp	49	--	0.0	--	6" of o
Bar 14	Forested	Right Bank	1	Open Water	BRK1 - Sand Ledge	40	--	-2.1	--	Sand
			2	Denuded Bar	BRK2 - Toe of Scarp	50	10	-1.3	325	2" of o
			3	Forest	BRK3 - Forest/BKF	49	--	0.1	--	42" of o
Bar 23	Herbaceous	Right Bank	1	Open Water	--	--	--	--	--	Sand
			2B	Denuded Bar	BRK1 - Bar/Sand Ledge	88	15	-1.8	1069	Sand
			2A	Emergents	BRK2 - Emergents	20	8	-0.2	156	8" of o
			4	Forest	BRK3 - Forest/BKF	52	--	0.1	--	4" of o

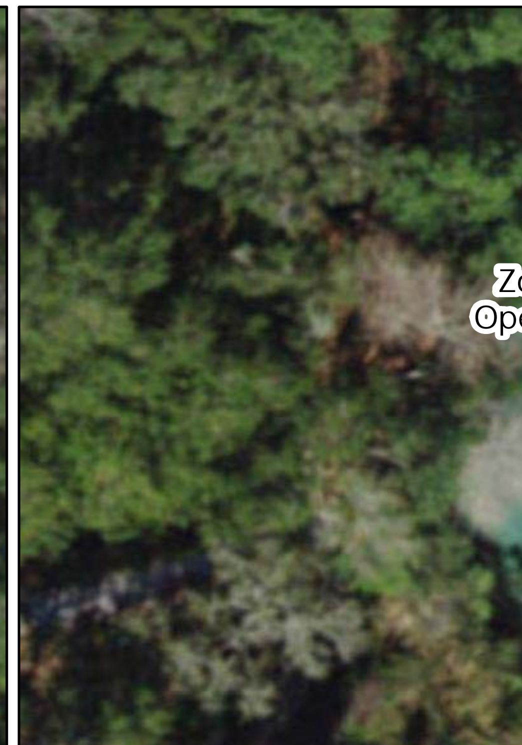

Zone 1 -
Open Water
Zone 2 -
Emergents
792 sq ft
Zone 3 -
Shrubby
Flow-way
728 sq ft
Zone 4 -
Forested
Alexander
Point Bar 4
Left Bank, Herbaceous


Zone 1 -
Open Water
Zone 2 -
Bar Forest
335 sq ft
Zone 3 -
Flow-way
79 sq ft
Zone 4 -
Forested
Alexander
Point Bar 6.5
Right Bank, Forested

Notes:


Zone 1 -
Open Water
1204 sq ft
Zone 2 -
Denuded
Point Bar
Zone 3 -
Emergents
3930 sq ft
Zone 4 -
Forested
Weeki Wachee
Point Bar 1
Right Bank, Herbaceous


Zone 3 -
Forested
Zone 2 -
Denuded
Point Bar
325 sq ft
Zone 1 -
Open Water
Weeki Wachee
Point Bar 14
Right Bank, Forested



APPENDIX F

Cumulative Assessment Additional Figures and Tables

Figure F.1 – Weeki Wachee Point Bar 1 – Right Bank, Herbaceous

Figure F.2 – Weeki Wachee Point Bar 2 – Right Bank, Forested

Figure F.3 – Weeki Wachee Point Bar 7 – Right Bank, Herbaceous

Figure F.4 – Weeki Wachee Point Bar 11 – Left Bank, Forested

Figure F.5 – Weeki Wachee Point Bar 14 – Right Bank, Forested

Figure F.6 – Weeki Wachee Point Bar 16 – Right Bank, Mixed

Figure F.7 – Weeki Wachee Point Bar 21 – Right Bank, Herbaceous

Figure F.8 – Weeki Wachee Point Bar 23 – Right Bank, Herbaceous

Figure F.9 – Weeki Wachee Point Bar 31 – Right Bank, Forested

Figure F.10 – Weeki Wachee Point Bar 33 – Right Bank, Forested

Table F.1 - Weeki Wachee Cumulative Assessment Point Bar Summary Data

Point Bar	Point Bar Type	Point Bar Bank Location	Zone Number	Zone Type	Assocaited Break	Length (ft)	Average Width (ft)	Depth Relative to Bankfull (ft)	Calculated Area (sq ft)	Depth of Organi Soils (inches)
Bar 1*	Herbaceous	Right Bank	1	Open Water	BRK1 - Sand Ledge	87	--	-1.3	--	Sand Only
			2	Denuded Bar	BRK2 - Toe of Scarp	99	16	-0.9	1204	Sand only
			3	Emergents	BRK3 - Emergents/Top of Scarp	191	38	-0.1	3930	18" of organics
			4	Forest	BRK4 - Forest/BKF	80	--	0.0	--	> 36" of organics
Bar 2	Forested	Right Bank	1	Open Water	BRK1 - Sand Ledge	50		-2.8		12" of organics
			2	Denuded Bar	BRK2 - Toe of Scarp	50	2.7	-1.8	134	Sand with 1" organics
			3	Forest	BRK3 - Forest/BKF	74		0.0		5" of organics
Bar 7	Herbaceous	Right Bank	1	Open Water	BRK1 - Sand Ledge	60	2.5	-3.0	150	Sand only
			2	Herbaceous	BRK2 - Emergents	60	11.0	-1.7	660	12" of organics
			3	Forest	BRK3 - Forest/BKF			0.0		12" of organics
Bar 11*	Forested	Left Bank	1	Open Water	BRK1 - Sand Ledge	65	--	-2.4	--	Sand only
			2	Denuded Bar	BRK2 - Toe of Scarp	49	9	-1.1	518	Sand only
			3	Forest	BRK3 - Forest/Top of Scarp	49	--	0.0	--	6" of organics
Bar 14*	Forested	Right Bank	1	Open Water	BRK1 - Sand Ledge	40	--	-2.1	--	Sand only
			2	Denuded Bar	BRK2 - Toe of Scarp	50	10	-1.3	325	2" of organics
			3	Forest	BRK3 - Forest/BKF	49	--	0.1	--	42" of organics

Used survey equipment to measure point bar

Note: Open Water and Forested zones extend beyond point bar; therefore, widths and areas were not measured.

Table F.2 - Weeki Wachee Cumulative Assessment Point Bar Summary Data (contin

Point Bar	Point Bar Type	Point Bar Bank Location	Zone Number	Zone Type	Assocaited Break	Length (ft)	Average Width (ft)	Depth Relative to Bankfull (ft)	Calculated Area (sq ft)	Depth of Organic Soils (inches)
			1	Open Water	BRK1 - Sand Ledge	87		-2.3		Sand only
			2B	Denuded Bar	BRK2 - Toe of Scarp	87	9.4	-1.4	818	Sand only
			2A	Emergents	BRK1 - Bar Edge	18	12.0	-1.3	216	36" of organics
Bar 16	Mixed	Right Bank	3	Forest	BRK3 - Forest/BKF	74		0.0		5" of organics
			1	Open Water	BRK1 - Sand Ledge	118		-1.7		Sand only
			2	Denuded Bar	BRK2 - Toe of Scarp	57	25.8	-1.5	1471	Sand only
			3	Emergents	BRK3 - Emergents	129	13.6		1754	2" of organics
Bar 21	Herbaceous	Right Bank	4	Forest	BRK4 - Forest/BKF	79		0.0		> 36" of organics
			1	Open Water	--	--	--	--	--	Sand only
			2B	Denuded Bar	BRK1 - Bar/Sand Ledge	88	15	-1.8	1069	Sand only
			2A	Emergents	BRK2 - Emergents	20	8	-0.2	156	8" of organics
Bar 23*	Herbaceous	Right Bank	4	Forest	BRK3 - Forest/BKF	52	--	0.1	--	4" of organics
			1	Open Water	BRK1 - Sand Ledge	121		-2.6		Sand only
			2	Denuded Bar	BRK2 - Toe of Scarp	116	22.2	-1.6	2575	Sand with some silt on top
Bar 31	Forested	Right Bank	3	Forest	BRK3 - Forest/BKF	192		0.0		10" of organics
			1	Open Water	BRK1 - Sand Ledge	53		-2.2		Sand only
			2	Denuded Bar	BRK2 - Toe of Scarp	74	11.8	-1.1	873	Sand only
Bar 33	Forested	Right Bank	3	Forest	BRK3 - Forest/BKF	74		0.0		7" of organics

Used survey equipment to measure point bar

Table F.3 – Additional Scarp Measurement Dimensions

Point Bar Number	Estimated Scarp Length (ft)	Scarp Thickness (ft)	Estimated Organic Soil Loss* (cy)
2	30	0.9	13
3	110	0.9	49
8	20	1.5	14
9	45	1.0	22
11	25	1.0	12
12	35	2.0	34
13	25	1.0	12
14	25	1.0	12
15	15	1.0	7
17	15	1.0	7
22	80	1.2	45
24	40	1.8	35
25	50	0.8	20
27	25	1.2	14
28	50	0.9	22
29	20	0.8	8
30	20	0.8	7
31a	35	0.9	15
31b	15	0.9	7
31c	30	0.9	13
31d	45	1.0	22
31e	50	1.0	24
32a	20	1.3	12
32b	55	1.3	33
Minimum	15	0.8	7
Maximum	110	2.0	49
Average	37	1.1	19
Total	880	--	460

*Calculated by multiplying the estimated scarp length x scarp thickness x 13 feet (average width of denuded zone from comparative study)

APPENDIX G

Statistical Analysis Additional Figures

Figure G.1 – Scatterplot of Correlations Among Selected Predictors in Continuous Sonde Dataset

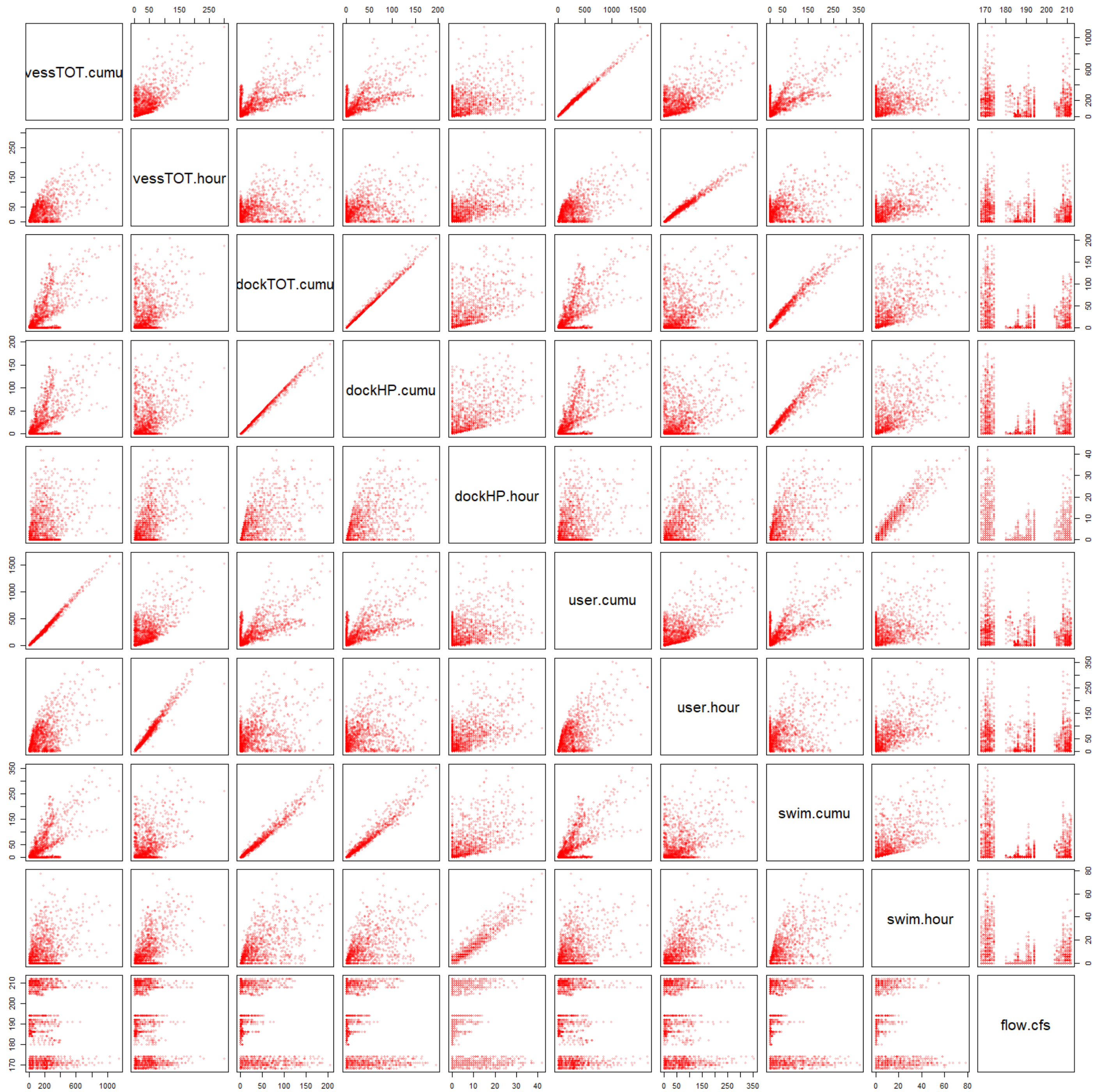


Figure G.2 – Correlation Matrix of Selected Predictors in Continuous Sonde Dataset

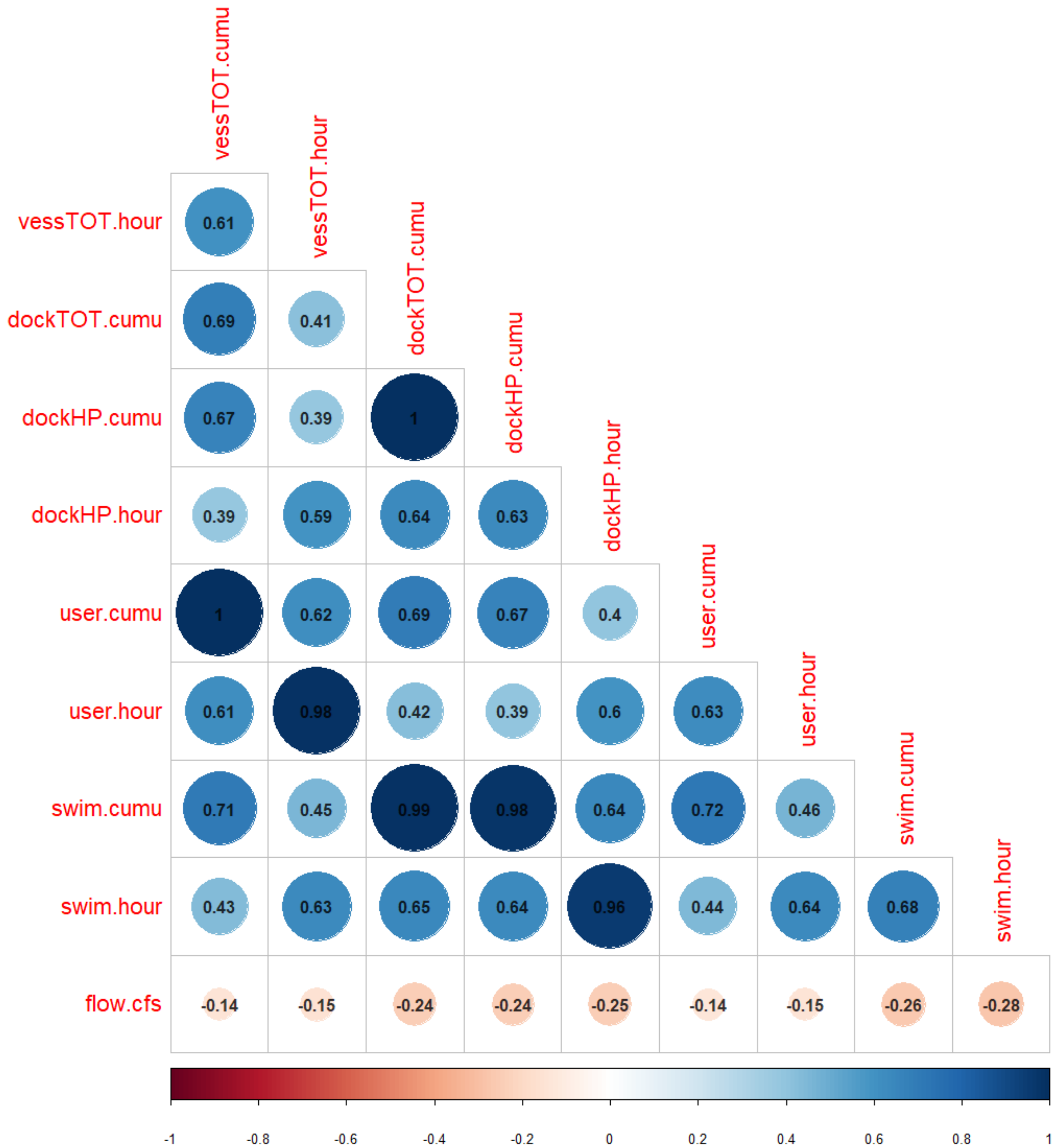


Figure G.3 –Scatterplot of Correlations Among Selected Predictors in Grab-Sample Dataset

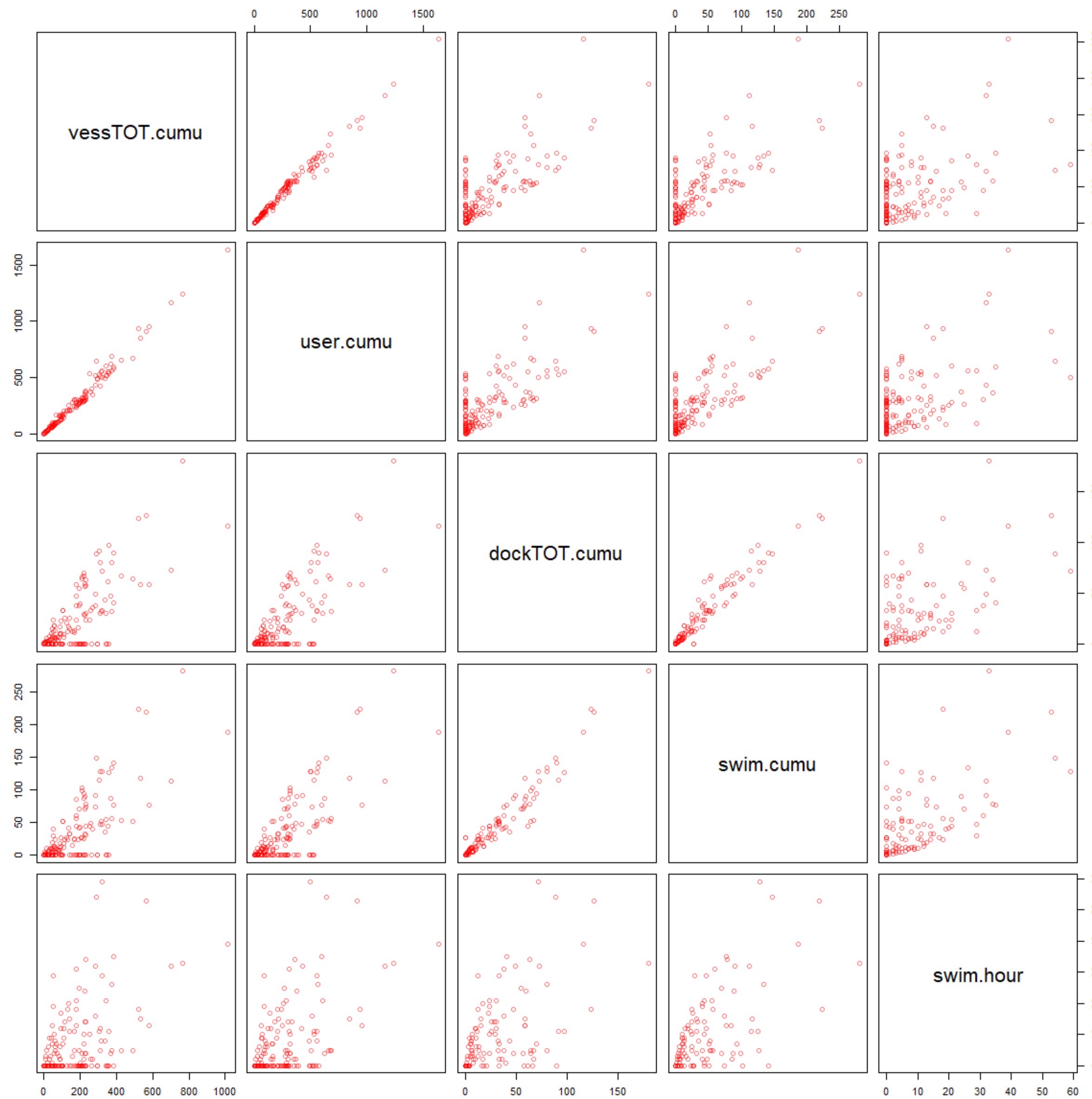


Figure G.4 – Correlation Matrix of Selected Predictors in Grab-Sample Dataset