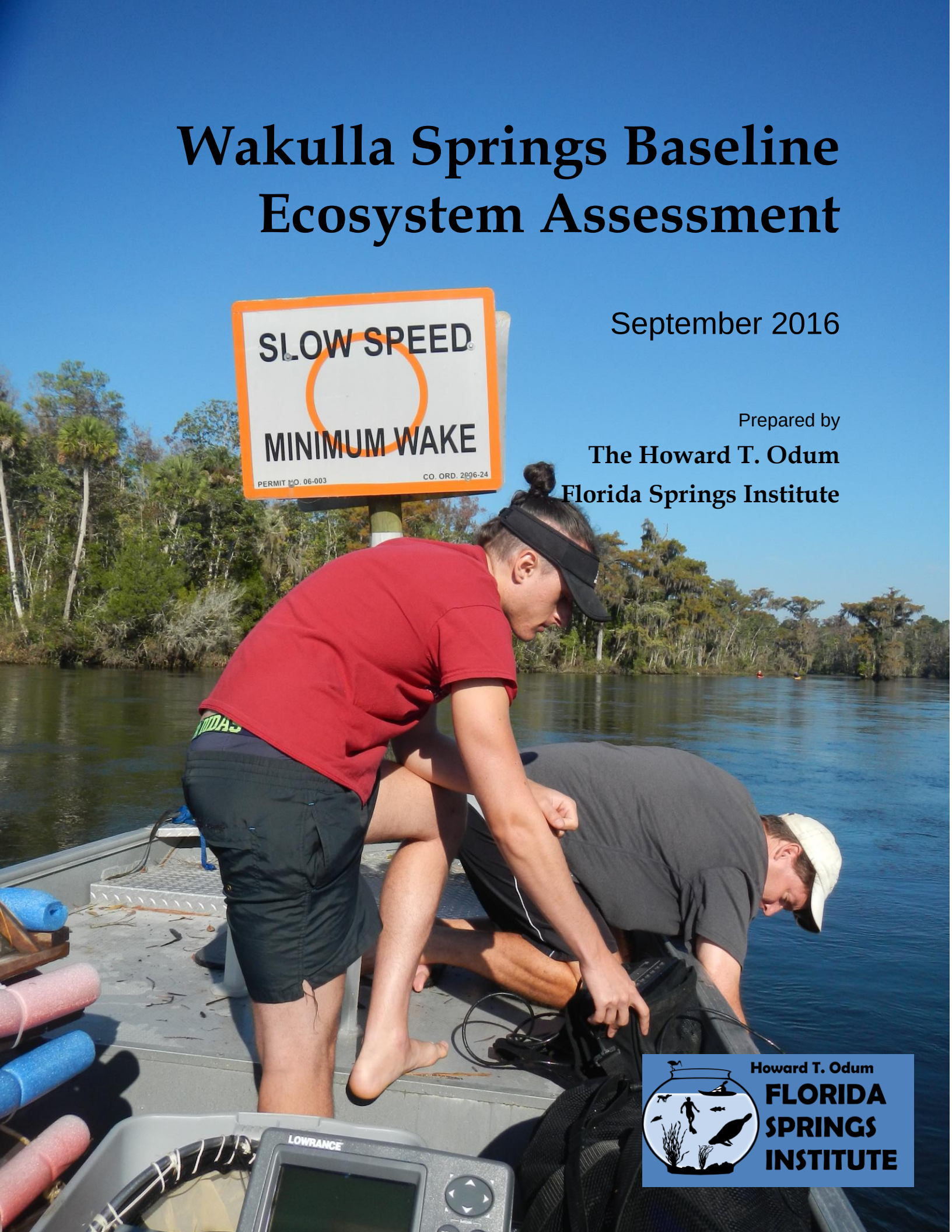
Wakulla Springs Baseline Ecosystem Assessment

September 2016

Prepared by

The Howard T. Odum Florida Springs Institute



Howard T. Odum FLORIDA SPRINGS INSTITUTE

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Acknowledgements

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The following individuals volunteered their time to assist FSI staff with baseline data collection: Knox Bagwell, Tanner Dafoe, Paul Donsky, Kathryn Gibson, James Hennessey, Lewis Holcombe, Ryan Kilbride, Debbie Segal, Mackenzie Vecchio, and Robert Williams.

As with collection and analysis of all environmental data, techniques and interpretations may change over time. The raw data collected for this study are available from the Florida Springs Institute upon written request. The Director and staff of the Florida Springs Institute take full responsibility for any errors or omissions in this report.

Section 1.0 Introduction

1.1 Background

Florida's 1,000+ artesian springs are undergoing rapid environmental changes due to a variety of stressors, including reduced discharge, increased nitrate-nitrogen levels, excessive recreation, side effects of aquatic plant management, and structural alterations. These changes result in a shifting ecological baseline for each spring. As the state embarks on comprehensive restoration activities at these springs, there is often little historic data available to assess recovery or continuing decline. The Howard T. Odum Florida Springs Institute (FSI) is embarking on a number of projects to document existing baseline ecological conditions in the springs of Florida. Data collected for these baseline assessments, in combination with ecological data from previous studies will be used to provide a continuing record of changes, both positive and negative, in Florida's endangered springs and spring runs.

Wakulla Spring is one of the largest first-magnitude artesian springs in Florida and in the United States. Wakulla Spring lies within the Edward Ball Wakulla Springs State Park. Wakulla Springs State Park and Lodge are listed on the Natural Register of Historic Places and are a designated National Natural Landmark. A section of the Wakulla Spring run ecosystem, approximately 5.5 miles downstream of Wakulla Spring (upstream of U.S. Highway 98), has received limited previous scientific study and was utilized for this springs baseline assessment project (Figure 1). Wakulla Spring forms the headwaters of the Wakulla River which is nearly 11 miles long to where it merges with the St. Marks River at St. Marks, Wakulla County.

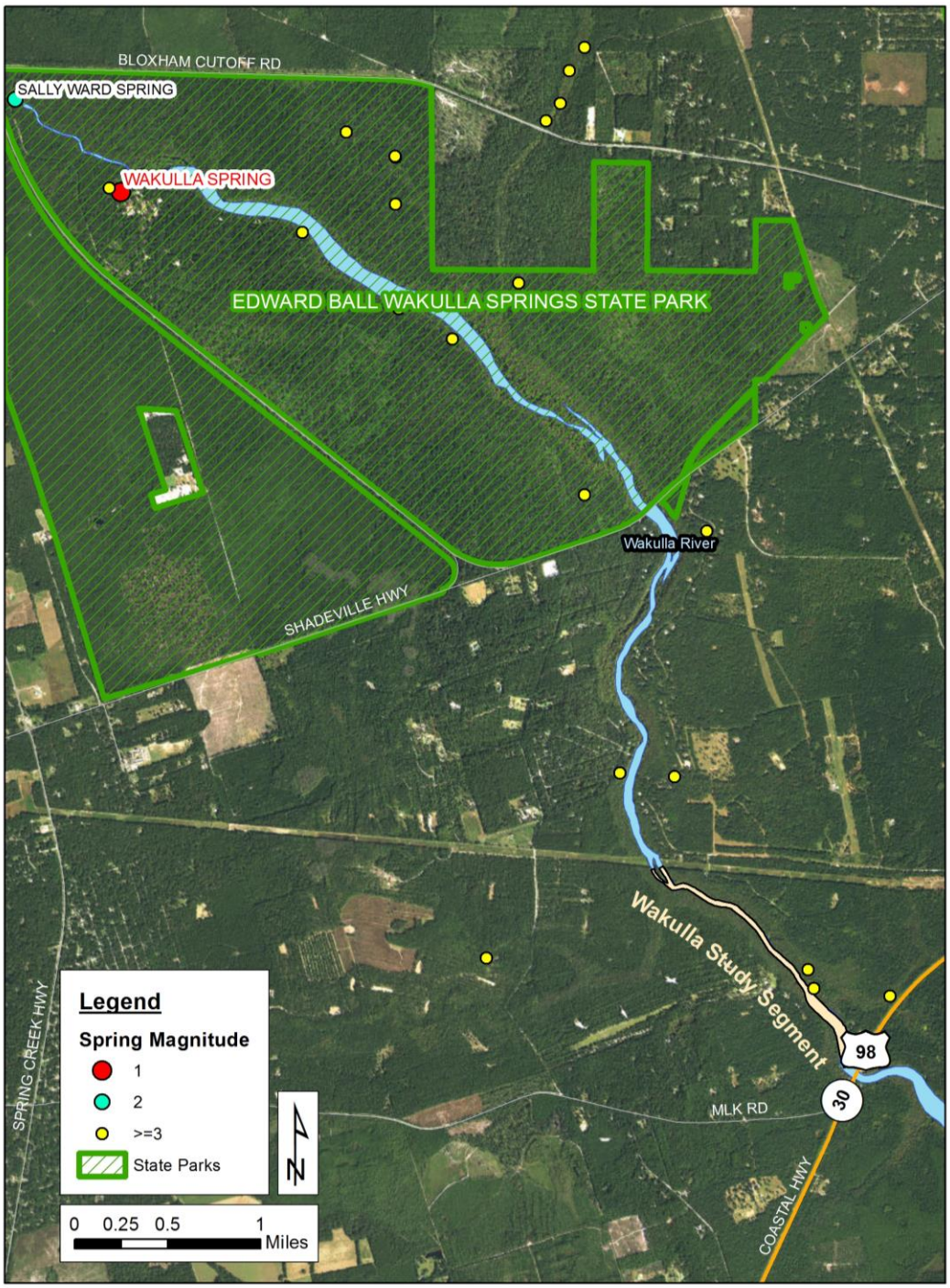


Figure 1. Wakulla River Ecosystem Baseline Project location

Section 2.0 Methods

2.1 Introduction

Florida's springs and spring runs are composed of a diverse and interconnected ecosystem of physical, chemical, and biological components. While most biological systems vary considerably due to seasonal changes in sunlight, temperature, and precipitation, this variation is greatly reduced in spring-fed aquatic ecosystems due to their groundwater supply. These natural groundwater discharges demonstrate relatively consistent water temperature, inflow volume, and water chemistry (Odum 1957; Knight 2015). The one major environmental factor that is seasonally variable in springs is the input of solar energy. This seasonal variability must be considered in springs data collection and analysis.

Spring ecosystem data collection occurred over two, 2-week periods (October 19-30, 2015; March 7-17, 2016) and included as many environmental variables as practical. The following ecological metrics were measured in the 1.4-mile long Wakulla River Segment that was the location of this ecosystem baseline assessment (Figure 2):

Physical Environment

- Insolation and photosynthetically active radiation (PAR) and underwater light transmission of PAR
- Stream discharge (water level and flow) and stream velocity
- Secchi disk visibility
- Segment morphometry (water surface area, water depth, and water volume)
- Water quality field parameters (temperature, pH, dissolved oxygen, conductance)

Water Chemistry

- Water chemistry (total Kjeldahl nitrogen [TKN], nitrate+nitrite nitrogen [NOx-N], and ammonia nitrogen [NH_4-N]. Total nitrogen [TN] and organic nitrogen [ON] were calculated.)

Biology

- Plant community characterization (species, coverage)
- Macrofauna observations (species and counts for emerging insects, snails, turtles, birds, and mammals)
- Human uses

Ecosystem Level

- Ecosystem metabolism metrics (gross primary productivity [GPP], net primary productivity [NPP], community respiration [CR], P/R ratio, and ecological efficiency)
- Nutrient assimilation
- Community export (fine particulate export)

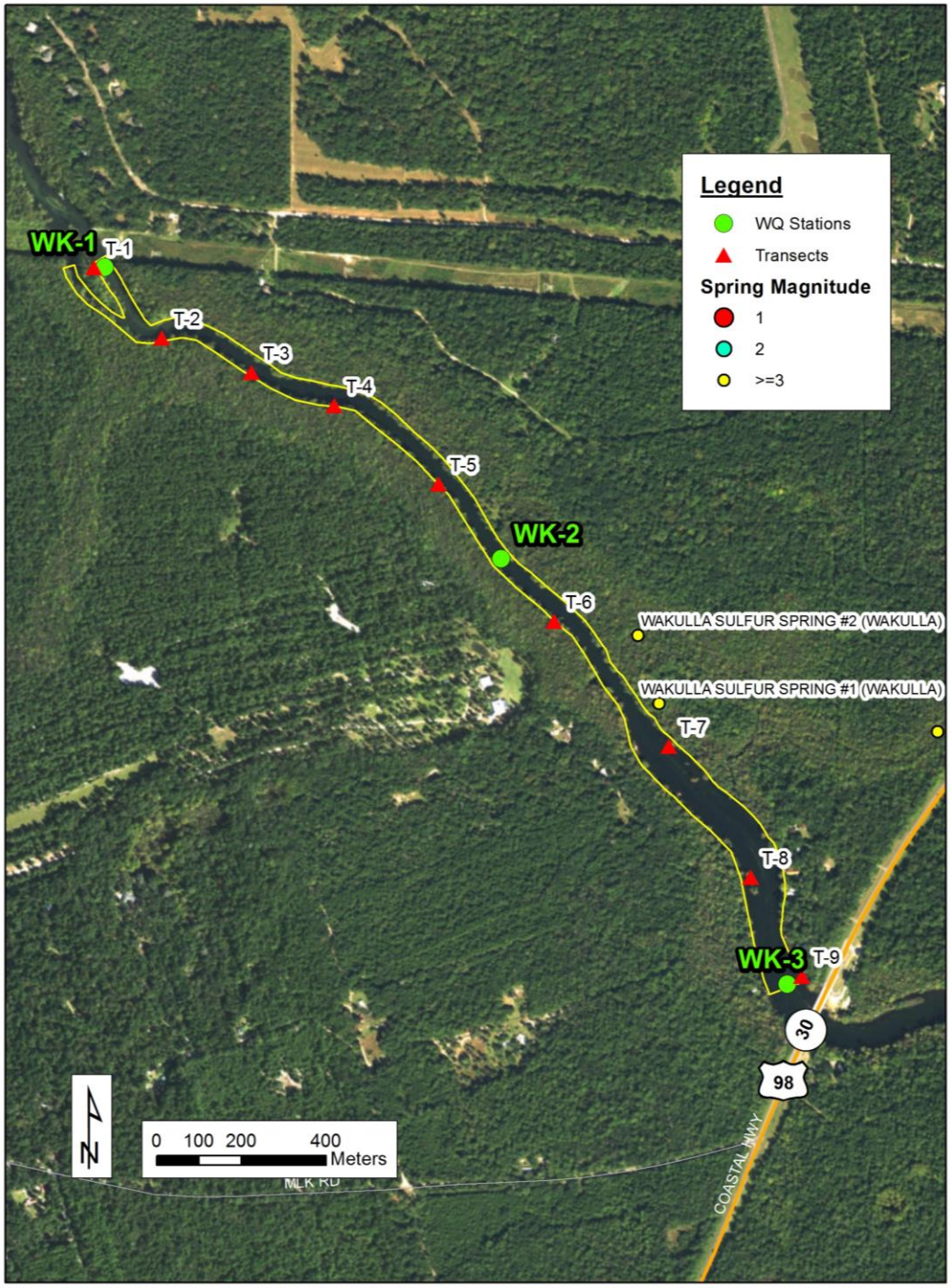


Figure 2. Wakulla River Ecosystem Baseline Assessment segment station locations

2.2 Physical Environment

2.2.1 Underwater Light Transmission

Photosynthetically Active Radiation (PAR) underwater light transmission and attenuation coefficients were measured within the study segment at WK-1, WK-2, and WK-3 in the Wakulla River (Figure 2) using LI-COR brand sensors; LI-200SA (surface quantum sensor), and LI-192 (underwater quantum sensor). Figure 3 provides a typical light senor installation. A LI-200SA sensor was used to measure PAR energy reaching the water surface, while an underwater LI-COR LI-192 sensor was used to measure PAR energy at multiple water depths. The underwater PAR sensor was attached to a weighted frame and readings were logged at 15 to 30 cm (0.5 to 1 ft) depth intervals from the surface to the bottom of the water column. Measurements at each depth were collected following at least a ten second stabilization period. Light extinction (attenuation) coefficients were calculated from these data using the Lambert-Beer equation (Wetzel 2001):

$$Iz = Io(e\text{-}kz)$$

Where:

Iz = PAR at depth z

Io = PAR at the water surface

k = diffuse attenuation coefficient, m^{-1}

z = water depth, m

Figure 3. Underwater LI COR sensor used to measure PAR

2.2.2 Stream Discharge and Current Velocity

Stream discharge and velocity were measured at downstream end of the study segment using the Marsh-McBirney Flo-Mate portable flow meter. A fiberglass tape was stretched across the stream channel at the U.S. Highway 98 bridge (Figure 4) perpendicular to the flow direction, allowing depth and velocity to be measured in approximately 25 evenly-spaced segments. At water depths less than 2.5 ft, velocity was measured at 0.6 of the water column. For water depths greater than 2.5 ft, velocity was measured at 0.2, 0.6, and 0.8 fractional depths of the water column. For each of the resulting cross-section sub-segments, velocity was multiplied by width and depth to calculate sub-segment discharge. The total discharge was calculated from the cumulative discharge of all cross-section sub-segments.

The USGS also maintains a discharge station upstream of the study segment at Shadeville Road (USGS 2327022, Figure **1**). This station was used to estimate daily discharge within the study segment.

Figure 4. Stream discharge measurement collected along a cross-section of the Wakulla River at U.S. Highway 98

2.2.3 Stream Segment Morphometry

Segment depths were measured by use of a boat-mounted recording depth finder linked to the Global Positioning System (GPS). These data were processed using ArcGIS software to extrapolate the wetted surface area and volume of the spring study segment. Nominal hydraulic residence times were calculated in a spreadsheet for the study segment based on these estimated water volumes and the upstream and downstream flow estimates. These data were used to estimate the wetted surface area, mean depth, and water volume of the study segment. Nominal hydraulic residence times were calculated in a spreadsheet for the study segment based on these estimated water volumes and the upstream and downstream flow estimates.

2.2.4 Secchi Disk Visibility

Water clarity was rapidly assessed using Secchi disk visibility, the distance where the disk disappears from sight. In spring systems, this distance is commonly greater than the depth of the water column and Secchi disk visibility must be measured horizontally. Secchi distance was measured with a 20-centimeter diameter black and white disk attached to the end of a tape measure and held below the surface of the water. A skin diver then extended the tape while moving away from the disk until it is no longer visible.

2.2.5 Weather Station

Local area weather (rainfall, air temperature, solar radiation, and evapotranspiration) was estimated using the University of Florida – Florida Automated Weather Network (FAWN, http://fawn.ifas.ufl.edu/). The FAWN network includes a total of 44 weather stations throughout Florida reporting weather data at 15-minute increments. The closest FAWN stations to the Wakulla River Study Segment were in Quincy (32 miles) and Monticello (31 miles).

2.2.6 Water Quality

During each 2-week sampling period, field variables (water temperature, dissolved oxygen concentration, oxygen percent saturation, pH, conductivity and specific conductance) were measured and logged at 30 minute intervals using YSI 6920 recording data sondes.

Oxygen data were collected using optical sensors with automated wipers, which improve calibration and reduce instrument drift during deployment. Data sondes were deployed near the middle of the water column at the upstream and downstream ends of the study segment for periods up to 2-weeks (Figure 5). Data sondes were calibrated prior to deployment and subsequent to their retrieval for each sampling period following the manufacturers protocol.

Water chemistry samples were collected at the beginning and end of each study period, at the upstream, midpoint, and downstream stations. Water chemistry samples were collected as sub-surface grabs. A rinsed water collection bottle was used to collect water samples from about 1 foot below the water surface and used to fill acid-preserved sample bottles. Following collection, samples were placed in an ice-filled cooler and delivered to the analytical laboratory for analysis within 24 hours. Water depth and field variables (temperature, dissolved oxygen, pH, and specific conductance) were also recorded during all water chemistry sampling events.

Water chemistry samples were analyzed for TKN, NOx-N, and NH_4-N by Advanced Environmental Labs, Gainesville FL, (FDOH certified laboratory # E82620).

Figure 5. Image of data sonde housing with holes that allow free movement of water, while the locking cap and cable provide security.

2.3 Biology

2.3.1 Plant Community Characterization

The distribution and percent cover of aquatic plant communities (macroalgae and submerged aquatic vegetation) in the study segment were visually estimated during the baseline sampling events. Aquatic vegetative cover was documented along transects at station T-1 through T-9 in

the Wakulla River (Figure 2) using a semi-quantitative visual method. At each station, all aquatic vegetation within a transect-belt extending from shore to shore (perpendicular to flow) was recorded and percent cover estimated. Linear distance by species was estimated by multiplying the percent cover by the transect-belt distance. These data were used to estimate percent cover, frequency, relative cover, and relative frequency. Frequency was based on dividing the transect into 8 equal sized sub-transects. Values by species were summed and averaged to yield an importance value as follows:

$$\text{Linear Cover Distance for Species A} = \sum \text{line intercept distances for Species A (m)}$$

$$\text{Percent Cover} = \frac{\text{Linear cover distance of Species A (m)}}{\text{Total transect distance (m)}} \times 100$$

$$\text{Relative Percent Cover} = \frac{\text{Linear cover distance of Species A (m)}}{\text{Total linear cover distance of all species (m)}} \times 100$$

$$\text{Absolute Frequency} = \frac{\text{Number of subtransects in which Species A occurred}}{\text{Total number of subtransects}}$$

$$\text{Relative Frequency} = \frac{\text{Absolute frequency of Species A}}{\sum \text{absolute frequencies of all species}} \times 100$$

$$\text{Importance Value} = \frac{(\text{Relative Vegetative Cover} + \text{Relative Frequency})}{2}$$

Observed plants were identified to species or lowest practicable taxonomic classification. No quantitative plant biomass samples are collected.

2.3.2 General Faunal Observations

Bird surveys were conducted during each study period on the Wakulla River from Shadeville Road to Highway 98 (Figure 2). Surveys started at the upstream location at sunrise and worked their way downstream with the current in canoe/kayak. All birds observed (visually or audibility) on the spring run and upland areas were counted and identified to species. These data were used to estimate bird population and diversity in the study area.

2.3.3 Adult Aquatic Insects

Aquatic insect species diversity and populations were characterized based on collections of adults as they emerge from the water. Insect emergence was measured through the use of floating pyramidal traps, each with a sampling area of 0.25 m^2 (Figure 6). The trap design was based on traps used for midge and mosquito sampling from wetland and aquatic environments (Walton et al. 1999). Each trap was constructed of wood and has four sides covered with fiberglass window screen. Flotation was provided by foam "noodles" attached along the bottom wooden supports. The traps work under the premise that insects emerging into the trap generally seek the highest spot and in the process travel through an inverted funnel into a 500 mL jar inverted over the end of the funnel. A total of up to ten traps were deployed at locations along the periphery of the spring run. At each location the substrate was noted. Traps were deployed and the jars containing the emergent insects collected at 24 to 48 hour intervals during

each study period. Insect identifications were made to the lowest practical taxonomic level. The number of insects captured in traps was used to calculate emergence rates and extrapolated across the wetted area of the study segment.

Figure 6. Trap used to collect adult aquatic insects as they emerge from the water

2.3.4 Snails

A visual survey for apple snail egg clutches was conducted within the Wakulla River (Figure 2). The number of egg masses and estimated clutch size (number of eggs per clutch) was documented along each shoreline within the study segment.

Figure 7. Apple snail egg clutch example

2.3.5 Fish

Visual surveys of the fish communities were made in the Wakulla River along two areas of the study segment (Figure 2), between T-1 to T-2 (0.9 ac) and T-8 to T-9 (1.1 ac). Surveys of fish communities were made in October 2015 by four to six people using mask and snorkel gear. The fish observers started at an upstream location and worked their way downstream with the current. The spring run segment was partitioned into approximately equal sections from bank-to-bank with one observer observing and counting in each section. Observers noted the fish species or groups of similar species (lowest practical taxonomic level) of all observed fish, and these observations were reported to a data recorder, who followed the observers in a boat. Following each survey, observers estimated the total length (average and range) by fish species. Fish density was calculated for each sub-section by dividing the average number of individuals counted, by the area sampled. Biomass of fish species was estimated using published length-weight relationships (Schneider et al. 2000) and average species total lengths and numbers. Fish assemblage diversity was calculated using the Shannon-Wiener diversity index based on the calculated densities of individual species (Zar 1984).

2.3.6 Turtles

Quantitative monitoring of the aquatic turtle community was conducted on the study segment during each monitoring period. Turtle censuses were conducted during general wildlife surveys by volunteers and incidental observations during other field collection efforts. The aquatic turtle population density was reported as the number of individuals divided by the surface area of the study segment.

2.3.7 Human Use

Detailed observations of human use were made throughout the time that the study segment was visited. These observations were made from the boat ramp located at Highway 98 (Figure 2) for the visible portions of the spring run and surrounding upland areas. The count area is referred to as the "observation area". Primary water contact activities were categorized as: wading (less than waist deep), bathing (greater than waist deep and less than neck deep), swimming, snorkeling, tubing, canoeing/kayaking, power boating, and fishing. Primary out-of-water activities included: sitting, walking, sunbathing, and nature study.

For each of these activity categories, the counts of all persons within the observation area were made at 15 minute intervals. Individual counts were multiplied by 0.25 hours (15 minutes) to estimate the average person-hours throughout the period of observation. The total human-use during a one-day period, reported in units of person-hours, was estimated as the sum of the 15-minute counts as follows:

$$\sum_{t1}^{t2} no.persons.dt = \text{person-hours}$$

Where:

T = time (hours)

t1 = time (start)

t2 = time (finish)

Person-hour estimates are in turn divided by the total observation interval in hours to estimate an average number of persons involved in in-water and out-of-water activities for each day of observation. Water and upland areas within the zone of observation were estimated from maps and aerial photographs to normalize data on a per-area basis:

Human-Use Density = no. persons/area counted

The resulting data were tabulated and reported as the average number of persons and human-use density (persons per area) basis by activity and location.

2.4 Ecosystem Level Monitoring

2.4.1 Ecosystem Metabolism

Ecosystem metabolism was calculated in the study segment using an Excel spreadsheet adaptation of the upstream/downstream dissolved oxygen (DO) change methods of H.T. Odum (1957a, 1957b). This method estimates and subtracts upstream from downstream DO mass fluxes corrected for atmospheric diffusion to determine the metabolic oxygen rate-of-change of the aquatic ecosystem. Dissolved oxygen mass inputs typically include spring discharges, atmospheric diffusion into the water column (when DO is less than 100% saturation), accretion from other undocumented stream or spring seep inflows, and the release of DO as a by-product of aquatic plant photosynthesis. Oxygen losses include diffusion from the water column to the atmosphere (under super-saturated conditions), the metabolic

respiration of the aquatic microbial, plant, and animal communities, and sediment biological oxygen demand.

The downstream DO concentration measured at any time is the net effect of these gains and losses as shown in the following conceptual equation:

$$\Delta DO = GPP - CR + Din + A$$

Where:

Δ DO = DO rate-of-change, g $O_2/m^2/d$

GPP = gross primary productivity, g $O_2/m^2/d$

CR = community respiration, g $O_2/m^2/d$

Din = diffusion into the water under unsaturated conditions, g $O_2/m^2/d$

A = accrual of DO from other spring boils, g $O_2/m^2/d$

The DO measurements used to estimate segment ecosystem metabolism were collected at the upstream and downstream end of each study segment at 30 minute intervals using recording YSI 6920 data sondes with optical DO sensors.

Upstream and downstream dissolved oxygen data were each shifted by one-half of the estimated travel time between the upstream and downstream study segment stations and an oxygen rate-of-change curve was prepared. Areas, volumes, current velocities and diffusion measurements were used to estimate ecosystem metabolism. Water surface area was estimated for the study segment using the survey methods described above and corrected hourly using an estimated stage: area relationship. Average velocities were estimated from the stage: volume relationship and spring discharge measurements. Nominal travel times for the water mass were estimated based on the length of the spring run and the estimated hourly current velocities.

This DO rate-of-change curve is corrected for atmospheric diffusion based on measured percent oxygen saturation in the water, and oxygen diffusion rates corrected for water velocity. The corrected oxygen rate-of-change curve for each 24-hour period was used to estimate gross primary productivity (GPP), community respiration (CR), net primary productivity (NPP), production/respiration (P/R) ratio, and ecological efficiency. Figure 8 illustrates these metabolism measurements based on development of a typical oxygen rate-of-change curve.

Descriptions of the ecosystem metabolism parameters follow below:

- Gross primary productivity (GPP) is estimated as the entire area under the oxygen rate-of-change curve, calculated by extending the nighttime corrected oxygen rate-of-change through the daylight hours and estimating the entire area under the daytime curve in g $O_2/m^2/d$. GPP is a measure of all aquatic plant productivity occurring below the water surface within the study segment. GPP includes primary productivity of both algae (including photosynthetic bacteria) and submerged vascular plants.
- Community respiration (CR) is the average of the corrected nighttime oxygen rate-of-change values in g $O_2/m^2/d$. CR is a measure of the total dark metabolism of the entire submerged ecosystem within each study segment. CR includes the respiration of all microbes in the sediments and water column, respiration of bacteria, algae, and

plants in the water column, and respiration of most aquatic animals, including protozoans, macroinvertebrates, crustaceans, and fish. Respiration of turtles, alligators, frogs, snakes, manatees, and other air-breathing aquatic fauna is not included in this calculation.

- Net primary productivity (NPP) is equal to the difference between these two estimates (GPP-CR). NPP provides an estimate of the net fixed carbon that remains each day after the respiratory needs of the aquatic ecosystem are met. CR may be higher than GPP in some streams and during some periods of time, indicating that there are unmeasured inputs of fixed carbon or losses of fixed carbon that were previously stored in the ecosystem.
- The P/R ratio or ecological quotient is equal to GPP/CR. A P/R ratio of one indicates that production and consumption are equally balanced. A ratio greater than one indicates an autotrophic aquatic ecosystem while a value less than one indicates a heterotrophic ecosystem.
- Photosynthetic efficiency (PE) is equal to the rate of gross primary productivity divided by the incident PAR during a specified time interval. It estimates the overall efficiency of an aquatic ecosystem to utilize the visible fraction of incident solar radiation, the principal forcing function for autotrophic stream ecosystems. PAR reaching the plant level is estimated based on river stage, the plant community characterization data for segment depth, and the light attenuation coefficient estimated for each sampling event. PE is reported as PAR Efficiency by dividing GPP in $O_2/m^2/d$ by $mol/m^2/d$, resulting in units of g O_2/mol. PAR Efficiency is also reported as a percentage using the conversion factors employed by Knight (1980; 1983): 4.22 Kcal/g O_2 and 52.27 Kcal/mole of photons (McCree 1972).

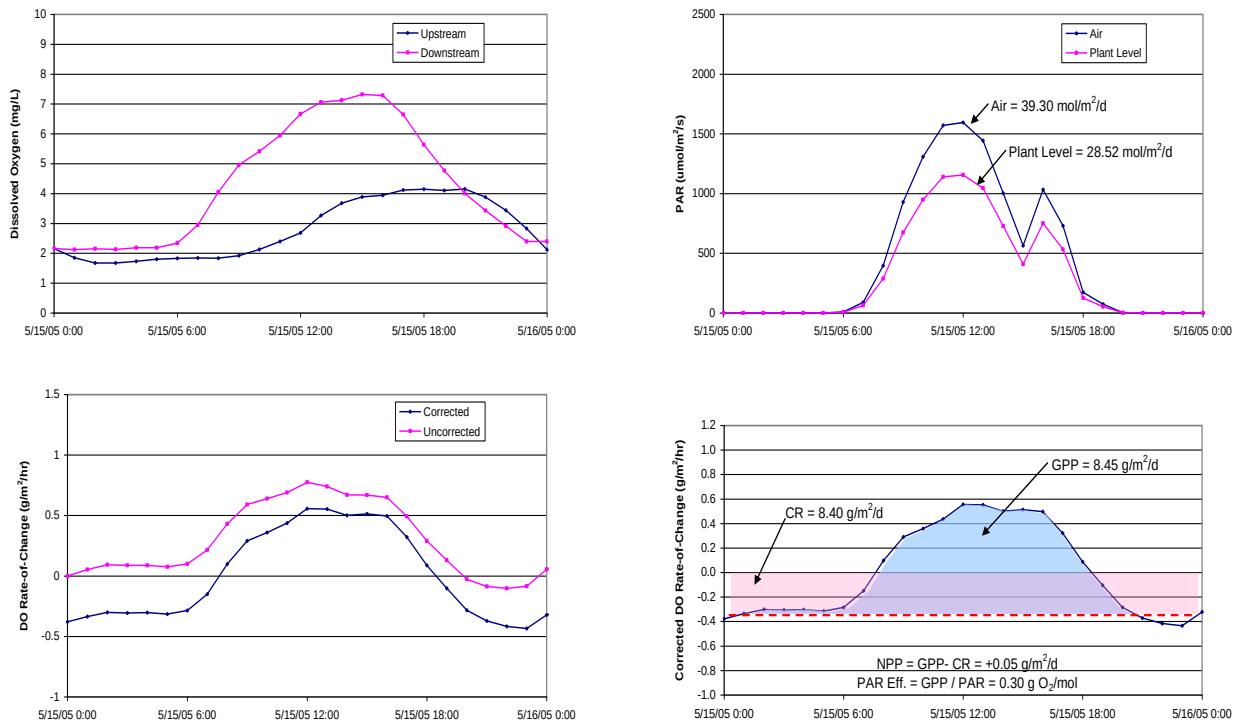


Figure 8. Example determination of ecosystem metabolism based on upstream-downstream dissolved oxygen data (from WSI 2007).

2.4.2 Nutrient Assimilation

Nutrient assimilation/dissimilation rates for TN, NOx-N, and NH_4-N were estimated for the study segment by calculating upstream-downstream changes in nutrient mass. Average nutrient mass inputs and outputs were estimated based on average water chemistry concentrations and flows over the period of study. Positive nutrient mass changes indicate assimilation/dissimilation of nutrients, while negative changes indicate an increase in nutrient mass with travel of the spring flow downstream.

2.4.3 Community Export

Community export was measured at both the upstream (WK-1) and downstream (WK-3) end of the study segment to allow an alternative method for estimating net ecosystem production within the segment. Community export of particulate suspended matter was quantified for the study segment using a plankton net suspended in the current at mid-depth (Figure 9). The mesh size on the plankton net was 153 µm. Three replicate plankton net samples were collected at the upstream and downstream end of each segment. Sample material collected in the plankton net was rinsed into a sample bottle and returned to the laboratory for wet, dry, and ash-free (combusted at an oven temperature of 450 °C) dry weight analyses. As samples were collected, the velocity of the water at the mouth of the net was measured as was the time of net deployment. These data allow calculation of the volume of water passing through the net. The amount of particulate material collected in the net was expressed on a volume and area (based

on upstream wetted-area) basis. Particulate export results were reported as dry weight (DW) and ash-free dry weight (AFDW) per upstream area per time (g DW/m^2/d and g AFDW/m^2/d, respectively). Overall particulate export for the study segment was calculated as the difference between the upstream and downstream export rates.

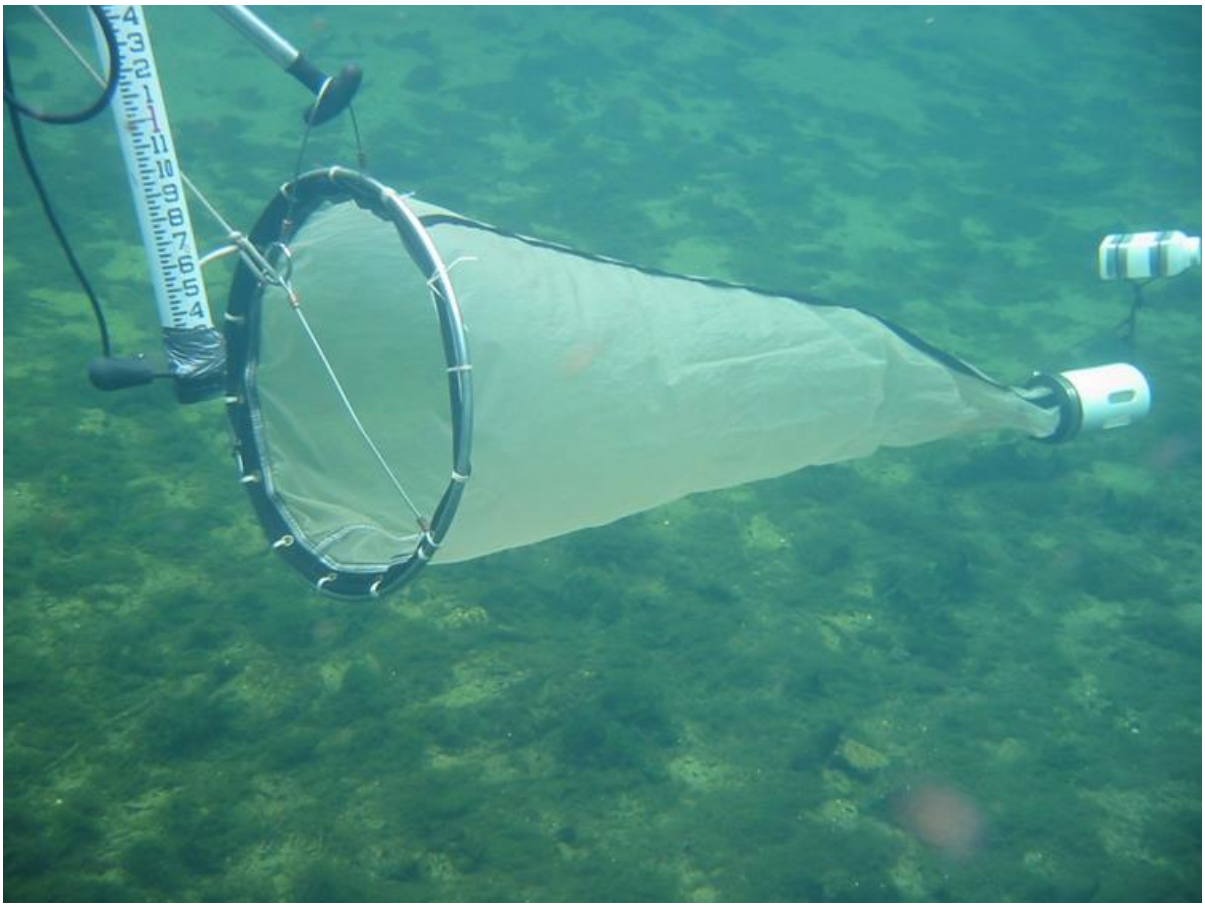


Figure 9. Image of plankton net capturing suspended material with flow meter upstream

Section 3.0 Results

3.1 Physical Environment

3.1.1 Underwater Light Transmission

The one major environmental factor that is seasonally variable in springs is the input of solar energy. The influx of light is the most important determinant of overall ecosystem primary productivity in clear-water springs. Light attenuation by dissolved and particulate matter in spring water limits solar energy available to submersed aquatic plants and other primary producers. Figure 10 and Figure 11 provide a summary of the percent transmittance and diffuse attenuation coefficient by station and by monitoring date. Detailed light measurement data are provided in Appendix A.

The percent transmittance between the stations averaged 48.3 percent at 1 m, ranging from 49.3 percent (WK-3) to 50.4 percent (WK-2), while the diffuse attenuation coefficient averaged 0.71 m^{-1} (range 0.69 to 0.74 m^{-1}).

The average percent transmittance for the entire spring run segment varied from 41.7 percent at 1 m (October 30, 2015) to 52.7 percent at 1 m (October 19, 2015), during the two baseline monitoring events. The diffuse attenuation coefficient ranged from 0.65 m^{-1} to 0.88 m^{-1} for the same time period.

Light transmittance values from the study segment were compared to other spring run systems in Florida and were less than average as shown in Figure 12. Light transmittance results from many of these systems were measured just downstream of the main spring vent (WSI 2010). Light transmittance values measured near spring vents generally are higher and show less variability than measurements farther downstream in the spring run. Much of this decline is the direct result of increasing particulate matter, resulting from the release of attached algal cells from plants and sediments with distance downstream. This release of particulate matter in spring runs is the combined result of natural causes like flow velocity and human causes from physical disturbance. The low water clarity documented in this study for the Lower Wakulla River was also the result of increased concentrations of tannic acids (black water) and particulates at the head spring (FSI 2014).

3.1.2 Stream Discharge and Current Velocity

Spring discharge is second only to solar input as one of the most important forcing functions that regulates overall spring habitat support of plant, fish, and wildlife communities. Stream discharge and velocity were measured at the downstream end of the study segment using portable flow meters.

Table 1 provides a summary of discharges measured during the baseline assessment at the downstream ends of the study segment, while Appendix B provides detailed discharge measurements. Stream discharges averaged 863 cfs and 921 cfs during the October 2015 and March 2016 events, respectively. Flow in this section of the Wakulla River was observed to be highly affected by the tide. Daily average discharge measured upstream from USGS 2327022 (Shadeville Road) is included in Table 1 for comparison.

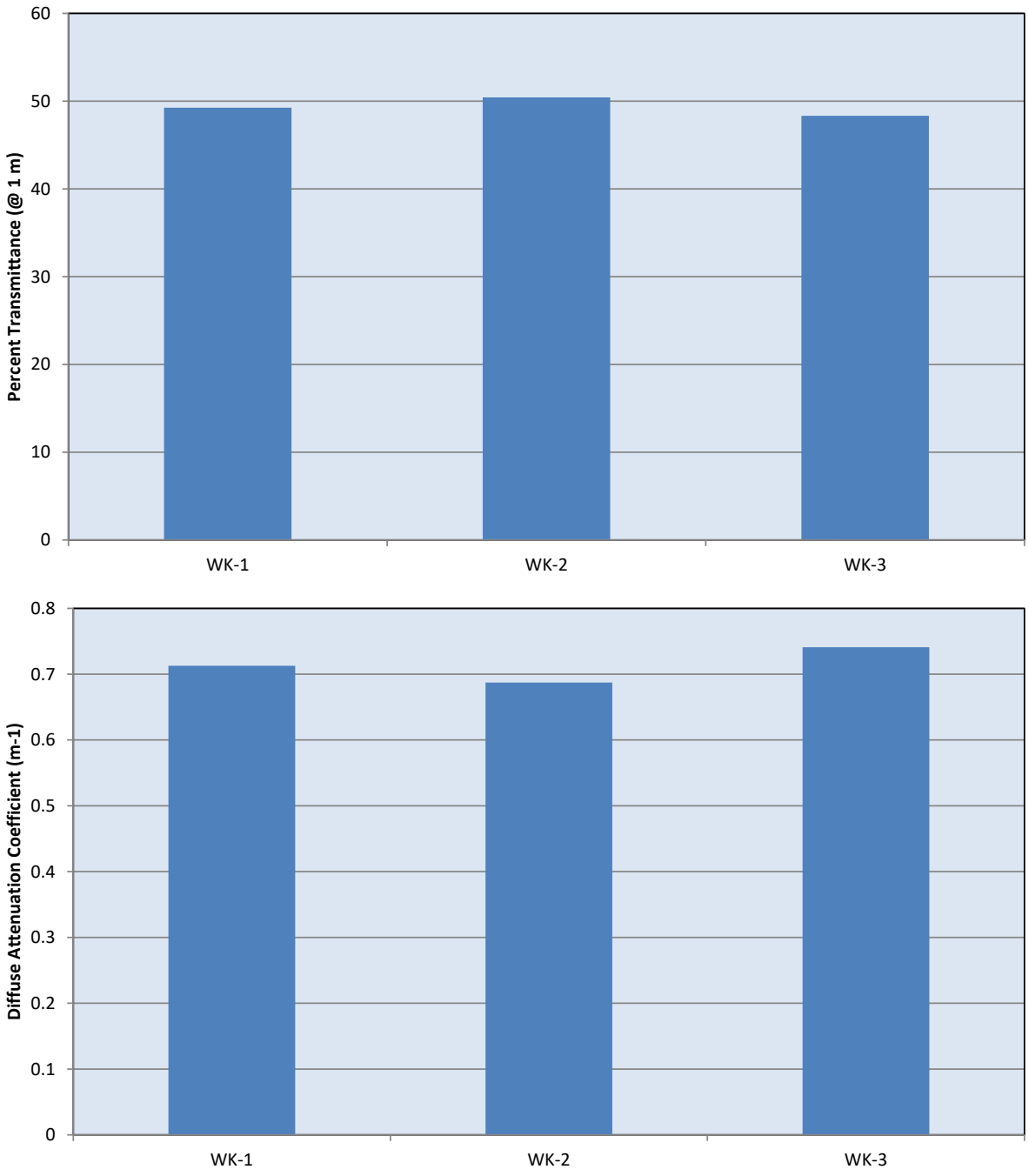


Figure 10. PAR percent transmittance (@ 1m) and diffuse attenuation coefficient estimates by station

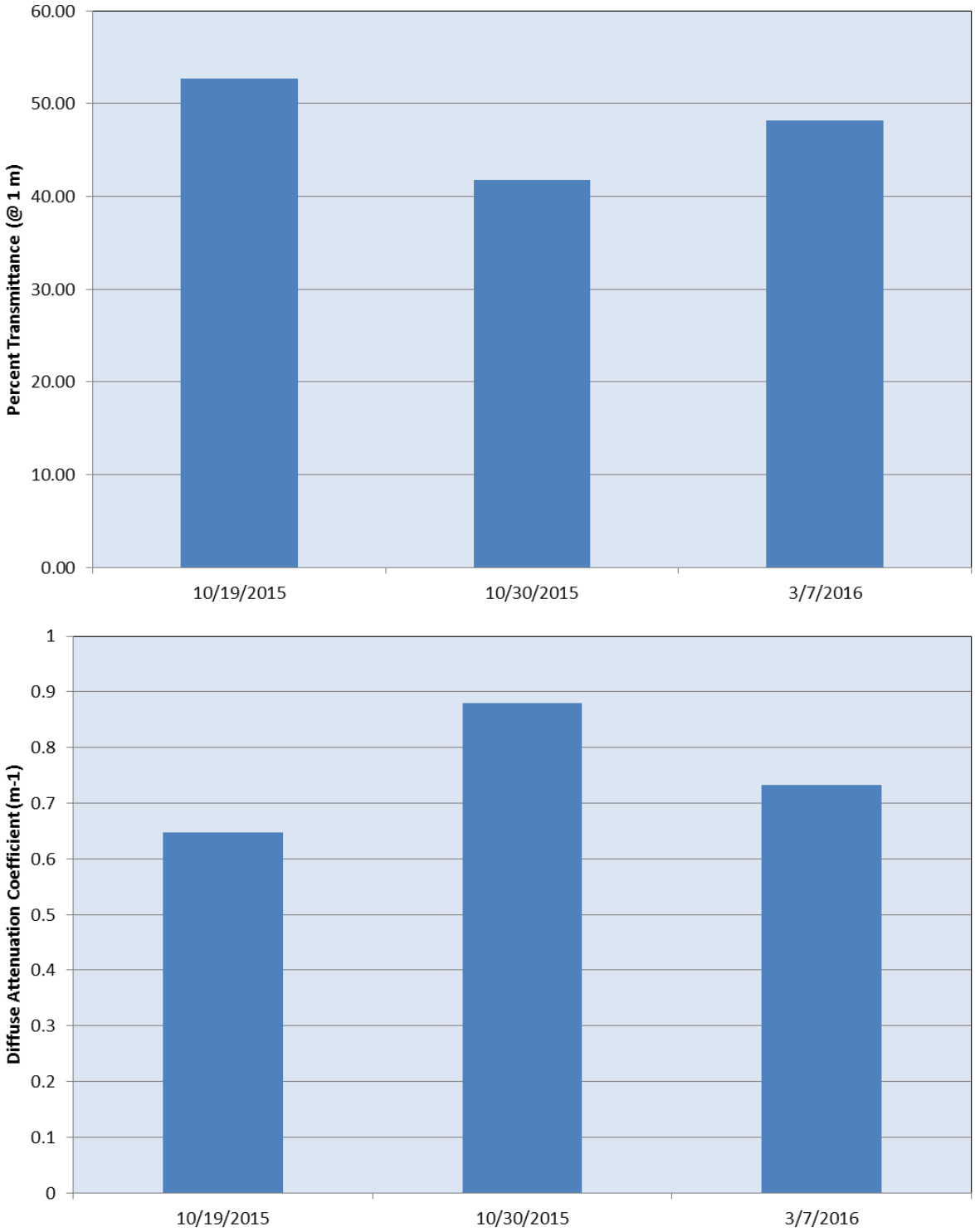


Figure 11. Average PAR percent transmittance (@ 1m) and diffuse attenuation coefficient estimates by monitoring date

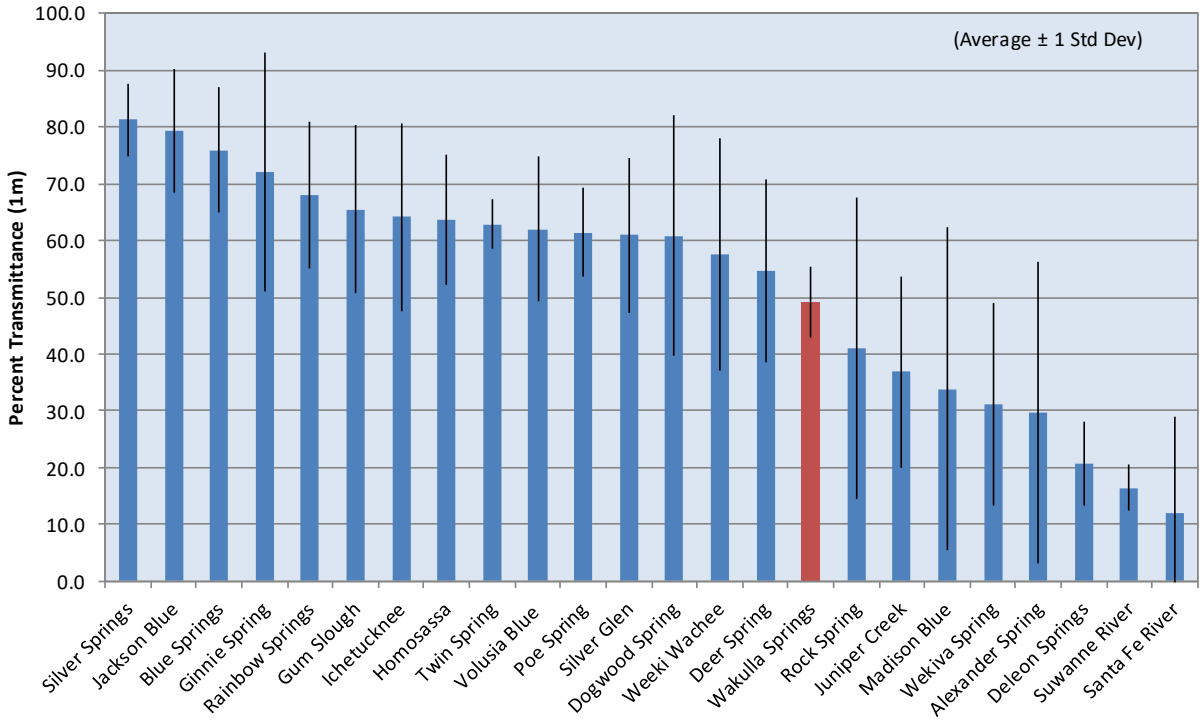


Figure 12. Average PAR percent transmittance (@ 1m) for Florida spring runs

Discharge was also measured at Sulphur Springs #1 (Figure 2) where it enters the Wakulla River in October 2016. This spring was found to contribute about 1.1 cfs.

Figure 13 provide summaries of average daily discharges along the Wakulla River for USGS 02327022 at Shadeville Road. Stream discharges averaged 708 cfs (range 201 cfs to 3,390 cfs) since 2004 displaying a marked increase over recent decades. The long-term median discharge of Wakulla Springs for the period-of-record from February 1907 until November 2007 was 344 cfs (FSI 2014). The recent discharge data indicate that average flows have more than doubled.

Table 1. Wakulla River flow measurements

Date	Station	Width (ft)	Avg. Depth (ft)	Discharge (cfs)	USGS 02327022 (cfs)
10/20/15	WK-3	259	6.5	1,087	903
10/29/15	WK-3	234	6.1	639	878
3/8/16	WK-3	177	5.4	921	679
10/29/16	Sulphur Spring #1	23.5	2.4	1.12	---

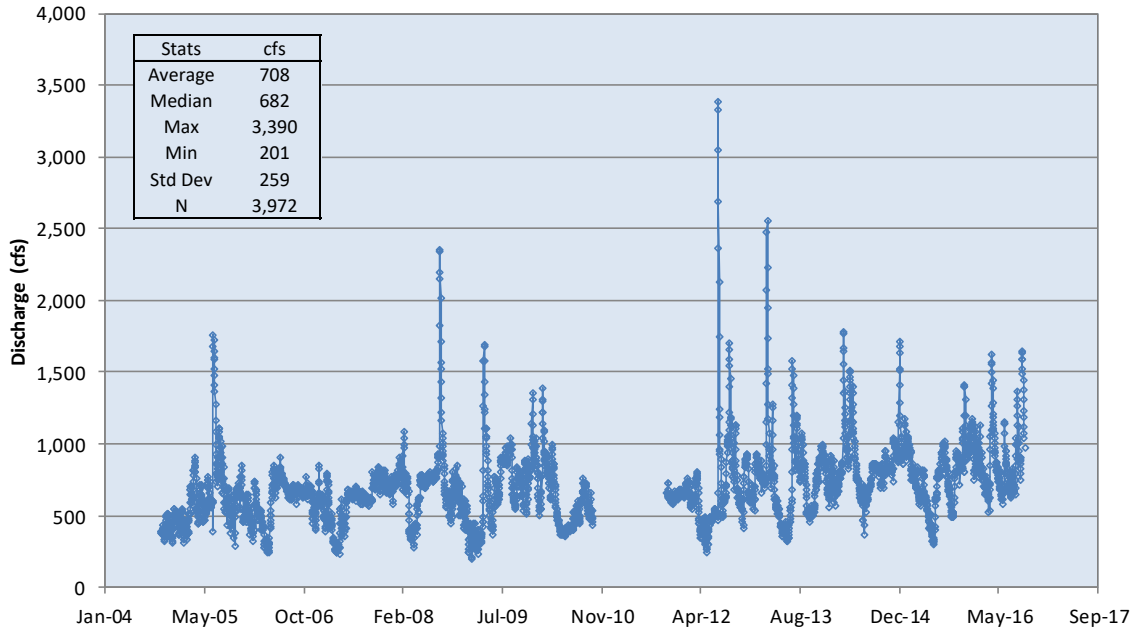


Figure 13. USGS 02327022 Wakulla River near Crawfordville, FL – daily average discharge

3.1.3 Stream Segment Morphometry

Table 2 summarizes segment wetted area and volume relative to water elevation, estimated from depth data collected within the study segment (Figure 14) with stage area/volume curves provided in Figure 15.

The average wetted surface area and volume of the study segment during the study was 154,626 ft^2 (38.2 ac) and 18,236,019 ft^3 (419 ac-ft), respectively. Nominal hydraulic residence time was estimated at 5.6 hours based on this estimated water volume and an average flow of 903 cfs during this period.

Table 2. Wakulla River stage - area / volume relationship (October 2015) for the study segment sampled during this baseline assessment

Water Depth (ft)	Area		Volume	
	(ac)	(ft^2)	(ac-ft)	(ft^3)
16	38.2	154,626	419	18,236,019
14	37.5	151,898	342	14,910,399
12	34.5	139,516	268	11,693,660
10	30.5	123,567	201	8,772,391
8	26.9	108,792	142	6,198,548
6	22.3	90,199	91.0	3,963,095
4	17.4	70,430	48.5	2,112,114
2	11.1	44,826	16.4	712,472
0	0.00	0.00	0.00	0,000

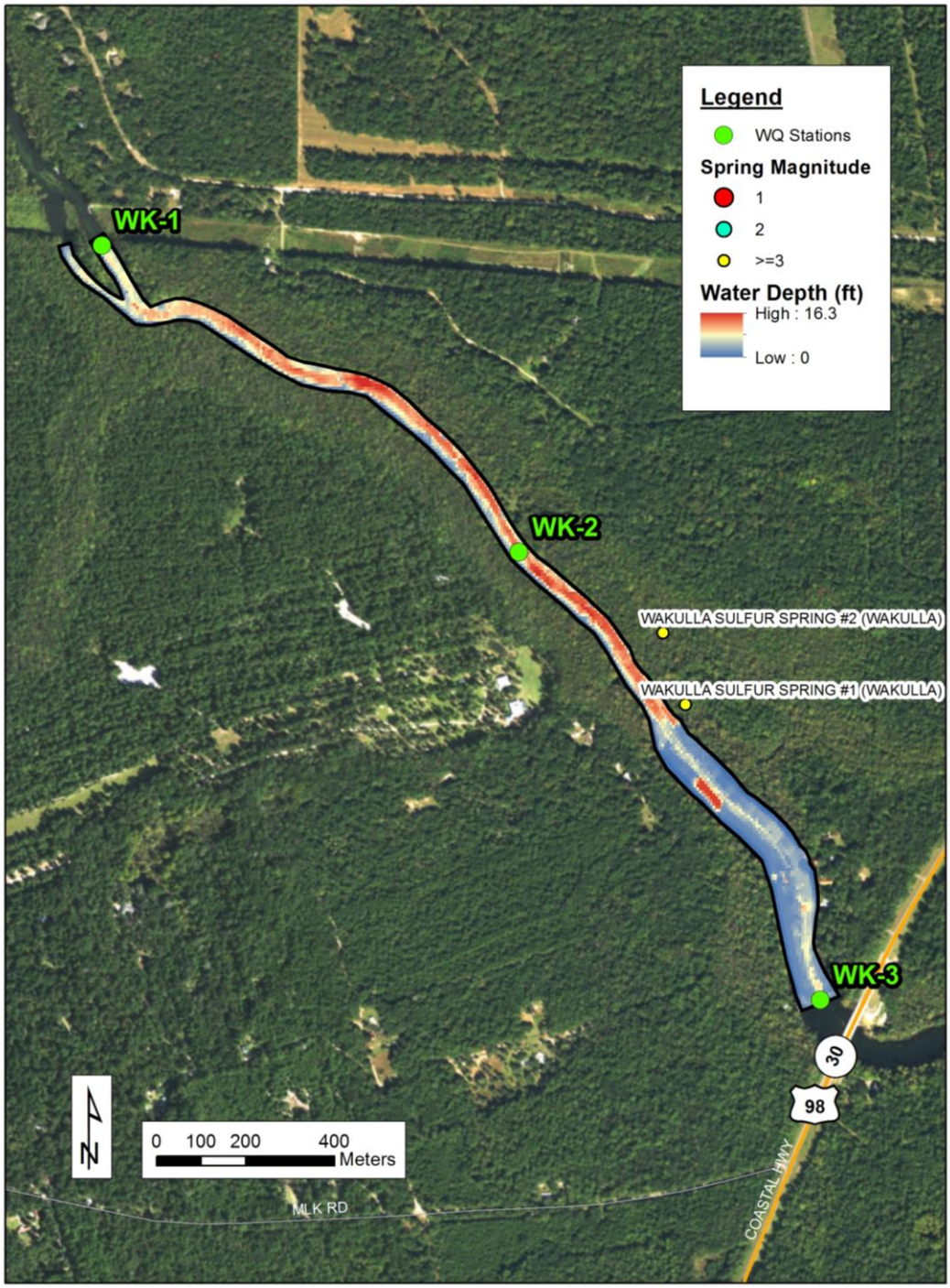


Figure 14. Wakulla River bathymetry – October 2015

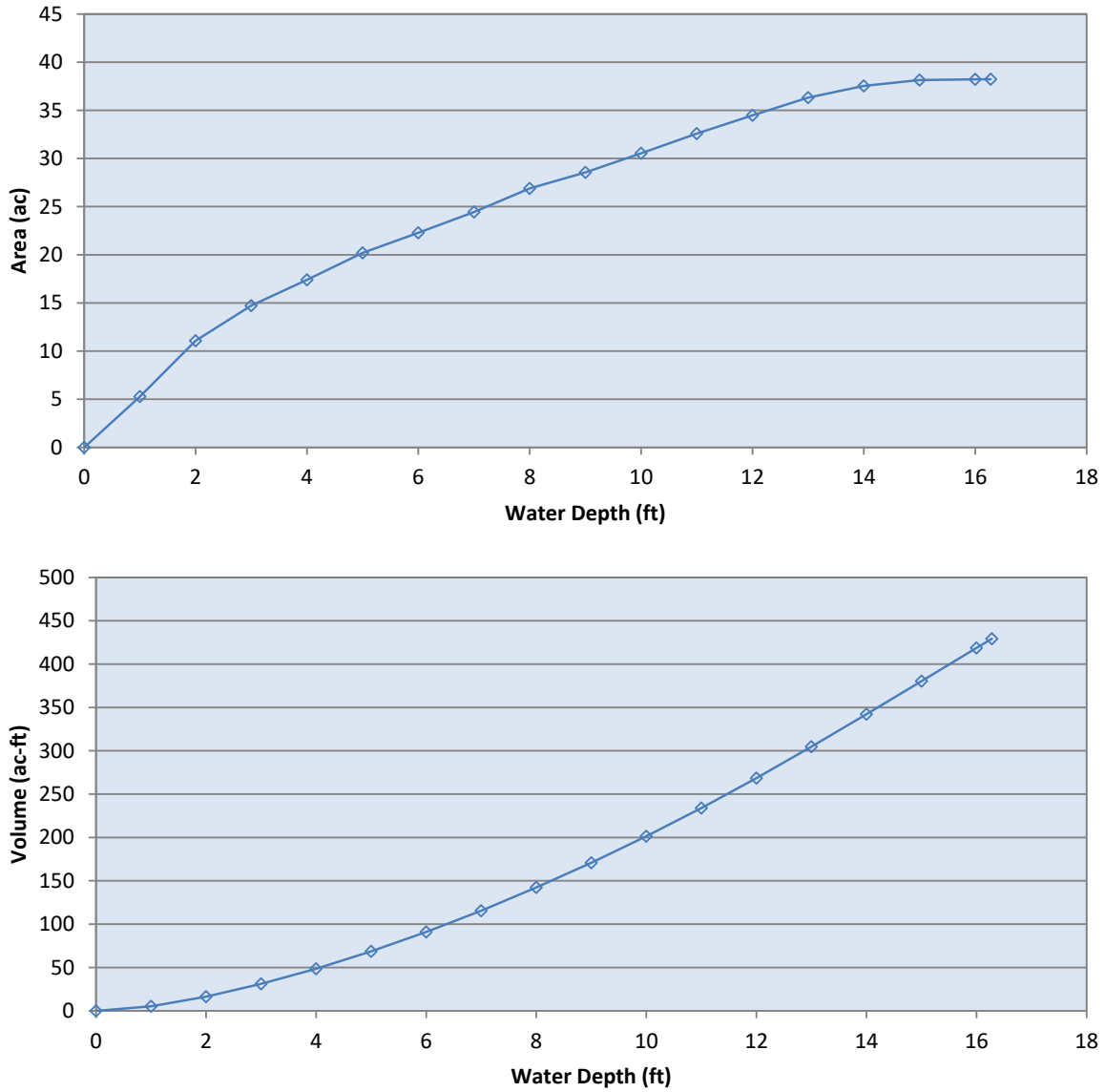


Figure 15. Wakulla River Study Segment stage area / volume curves – October 2015

3.1.4 Secchi Disk Visibility

Horizontal Secchi disk visibility measurements were collected on multiple dates at the upstream (WK-1), midpoint (WK-2), and downstream (WK-3) stations (Table 3). These measurements provide additional information concerning water clarity and the light attenuation properties of the spring run. Secchi disk visibility generally remained stable from upstream to downstream with an average difference of only 0.3 feet between WK-1 and WK-3.

Historically, water clarity in the Wakulla River has been variable due to inputs of tannic and high chlorophyll waters (FSI 2014). WSI (2010) reported Secchi disk readings of 9.2 feet in the Wakulla Spring pool in April 2009, while typical horizontal Secchi disk readings from other spring systems ranged from 200 to 300 feet.

Table 3. Horizontal Secchi Disk (ft) measurements in the Wakulla River

Date	WK-1	WK-2	WK-3
10/5/2015	13.1	10.5	---
10/19/2015	17.1	14.1	13.1
10/29/2015	13.1	12.1	17.1
10/30/2015	14.4	16.1	12.1
3/7/2016	17.1	6.9	17.1
3/17/2016	---	11.2	---
Average	15.1	11.8	14.8

3.1.5 Weather Station

Table 4 provides a monthly summary for air temperature, rainfall, solar radiation, and evapotranspiration during the study period.

Table 4. Weather Summary – University of Florida FAWN Quincy and Monticello Stations

Parameter	Stats	October 2015	March 2016
Air Temperature (C)	Average	68.3	63.1
	Min	45.3	33.1
	Max	91.2	86.3
Rainfall (in)	Total	0.44	4.57
Solar Radiation (W/m²)	Average	155.9	179.8
	Max	221.9	271.0
Evapotranspiration (in)	Total	2.75	3.05

Long-term average rainfall in the springshed is about 62 in/yr and has been relatively consistent over the entire period-of-record (Figure 16; FSI 2014).

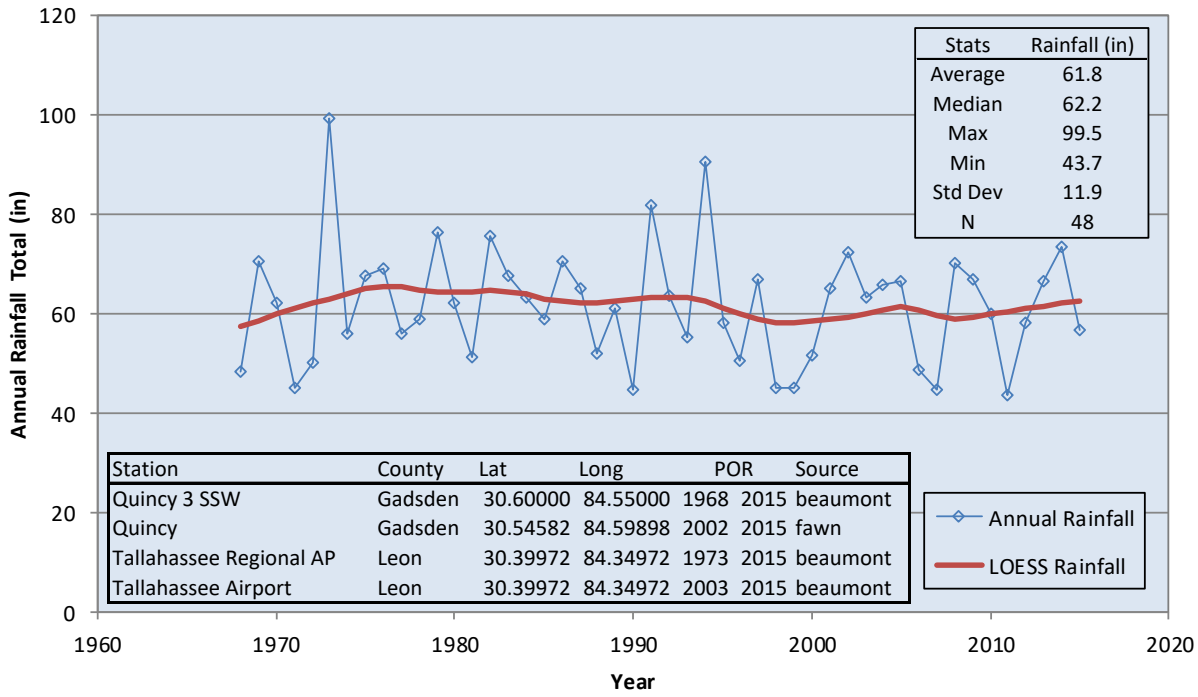


Figure 16. Annual rainfall record for Wakulla Area (1968-2015)

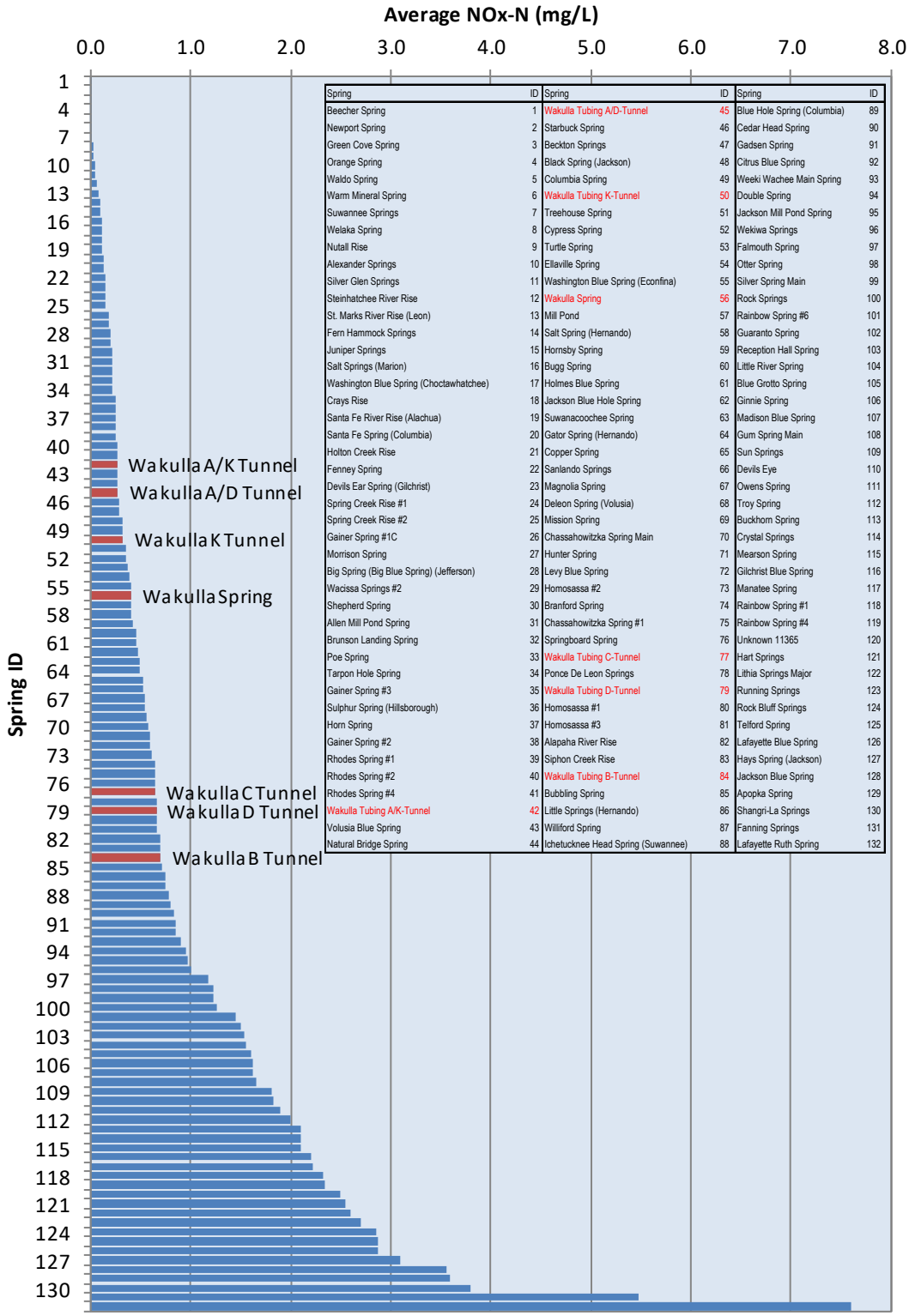
3.1.6 Water Quality

Water quality field parameters and grab samples for water chemistry analyses were collected at upstream (WK-1), midpoint (WK-2), and downstream (WK-3) stations during each 2-week sampling period. These parameters were collected to characterize water quality conditions concurrent with the other intensive sampling.

Table 5 provides a summary of average water quality grab sample results. Detailed water quality data are presented in Appendix C

Average TN concentrations decreased from 0.46 mg/L at the upstream station to 0.43 mg/L at the downstream station. The predominant form of nitrogen was NOx-N with an average low concentration of 0.33 mg/L at the downstream station to an average high concentration of 0.40 mg/L at the upstream station.

Nitrate data from the study segment were compared to other Florida springs as shown in Figure 17. The NWFWMD and FDEP have reported nitrate concentration data at Wakulla Spring from 1966 through 2014 (Figure 18). These data show an increase in nitrate at the head spring area from 0.09 mg/L in 1966 to 1.4 mg/L in 1987, with a decrease to 0.45 mg/L in 2014. The City of Tallahassee reduced nitrogen loads in the Wakulla Springshed by eliminating the use of fertilizer, removal of livestock at the Southeast Sprayfield and land application of nitrogen-containing biosolids, and completing treatment plant upgrades. Following these changes, nitrate concentrations in water from the Wakulla Spring vent declined. However, nitrate concentration reductions at Wakulla Spring appear to be at least partially the result of dilution due to increasing discharge at the spring (FSI 2014).



Spring	ID	Spring	ID	Spring	ID
Beecher Spring	1	Wakulla Tubing A/D-Tunnel	45	Blue Hole Spring (Columbia)	89
Newport Spring	2	Starbuck Spring	46	Cedar Head Spring	90
Green Cove Spring	3	Beckton Springs	47	Gadsen Spring	91
Orange Spring	4	Black Spring (Jackson)	48	Citrus Blue Spring	92
Waldo Spring	5	Columbia Spring	49	Weeki Wachee Main Spring	93
Warm Mineral Spring	6	Wakulla Tubing K-Tunnel	50	Double Spring	94
Suwannee Springs	7	Treehouse Spring	51	Jackson Mill Pond Spring	95
Welaka Spring	8	Cypress Spring	52	Wekiwa Springs	96
Nutall Rise	9	Turtle Spring	53	Falmouth Spring	97
Alexander Springs	10	Ellaville Spring	54	Otter Spring	98
Silver Glen Springs	11	Washington Blue Spring (Econfina)	55	Silver Spring Main	99
Steinhatchee River Rise	12	Wakulla Spring	56	Rock Springs	100
St. Marks River Rise (Leon)	13	Mill Pond	57	Rainbow Spring #6	101
Fern Hammock Springs	14	Salt Spring (Hernando)	58	Guaranto Spring	102
Juniper Springs	15	Hornsby Spring	59	Reception Hall Spring	103
Salt Springs (Marion)	16	Bugg Spring	60	Little River Spring	104
Washington Blue Spring (Choctawhatchee)	17	Holmes Blue Spring	61	Blue Grotto Spring	105
Crays Rise	18	Jackson Blue Hole Spring	62	Ginnie Spring	106
Santa Fe River Rise (Alachua)	19	Suwanacoochee Spring	63	Madison Blue Spring	107
Santa Fe Spring (Columbia)	20	Gator Spring (Hernando)	64	Gum Spring Main	108
Holton Creek Rise	21	Copper Spring	65	Sun Springs	109
Fenney Spring	22	Sanlando Springs	66	Devils Eye	110
Devils Ear Spring (Gilchrist)	23	Magnolia Spring	67	Owens Spring	111
Spring Creek Rise #1	24	Deleon Spring (Volusia)	68	Troy Spring	112
Spring Creek Rise #2	25	Mission Spring	69	Buckhorn Spring	113
Gainer Spring #1C	26	Chassahowitzka Spring Main	70	Crystal Springs	114
Morrison Spring	27	Hunter Spring	71	Mearson Spring	115
Big Spring (Big Blue Spring) (Jefferson)	28	Levy Blue Spring	72	Gilchrist Blue Spring	116
Wacissa Springs #2	29	Homosassa #2	73	Manatee Spring	117
Shepherd Spring	30	Branford Spring	74	Rainbow Spring #1	118
Allen Mill Pond Spring	31	Chassahowitzka Spring #1	75	Rainbow Spring #4	119
Brunson Landing Spring	32	Springboard Spring	76	Unknown 11365	120
Poe Spring	33	Wakulla Tubing C-Tunnel	77	Hart Springs	121
Tarpon Hole Spring	34	Ponce De Leon Springs	78	Lithia Springs Major	122
Gainer Spring #3	35	Wakulla Tubing D-Tunnel	79	Running Springs	123
Sulphur Spring (Hillsborough)	36	Homosassa #1	80	Rock Bluff Springs	124
Horn Spring	37	Homosassa #3	81	Telford Spring	125
Gainer Spring #2	38	Alapaha River Rise	82	Lafayette Blue Spring	126
Rhodes Spring #1	39	Siphon Creek Rise	83	Hays Spring (Jackson)	127
Rhodes Spring #2	40	Wakulla Tubing B-Tunnel	84	Jackson Blue Spring	128
Rhodes Spring #4	41	Bubbling Spring	85	Apopka Spring	129
Wakulla Tubing A/K-Tunnel	42	Little Springs (Hernando)	86	Shangri-La Springs	130
Volusia Blue Spring	43	Williford Spring	87	Fanning Springs	131
Natural Bridge Spring	44	Ichetucknee Head Spring (Suwannee)	88	Lafayette Ruth Spring	132

Figure 17. Average nitrate nitrogen concentrations in Florida springs (2001-2016)

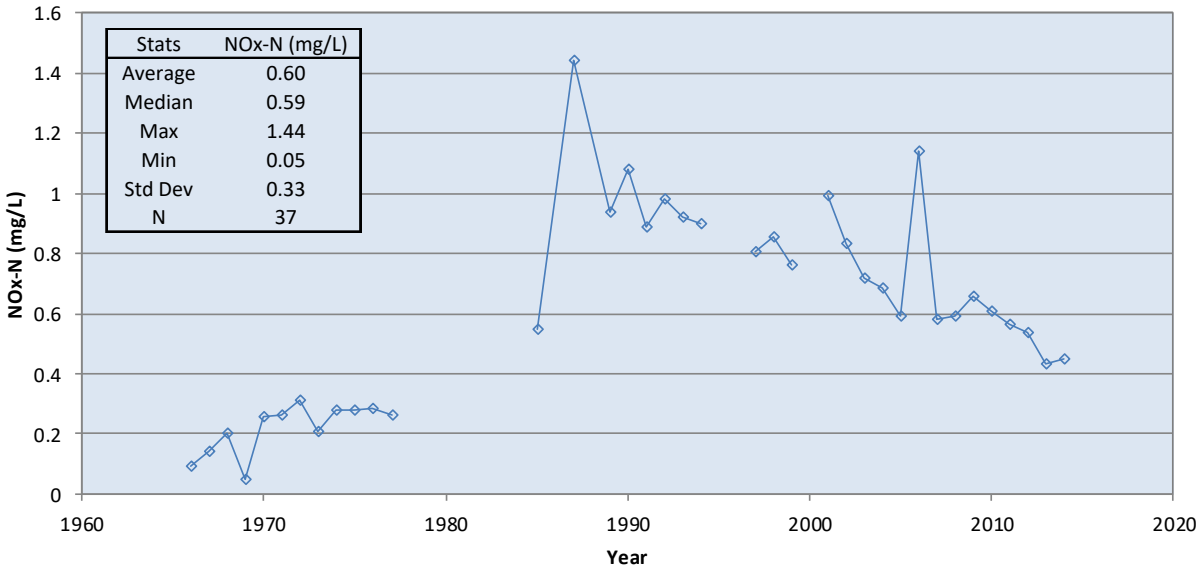


Figure 18. Wakulla Spring annual nitrate concentrations

Dissolved oxygen (DO) increased slightly from the upstream to downstream station in October 2015, while a decrease was observed in March 2015. Water temperature and pH remained relatively unchanged on average, while conductivity showed an increase during the March 2016 period. This increase is presumably due to inputs from Sulphur Springs (Figure 2, Table 6), between the middle (WK-2) and downstream (WK-3) stations. Turbidity was low throughout the Wakulla River segment with average measured values of 0.3 NTU.

Dissolved oxygen data from the study segment were compared to other Florida springs (near the spring vents) as shown in Figure 19.

Table 7 summarizes average field parameter data collected every 30 minutes with the water quality data sondes at the upstream (WK-1) and downstream (WK-3) stations during the baseline monitoring events. Detailed time series plots are presented in Appendix C.

Dissolved oxygen concentrations and pH were observed to vary in a diurnal pattern (Figure 20), showing a rise in concentration during the day due to primary productivity and decreasing concentrations at night as a result of community respiration.

Table 5. Wakulla River average water quality grab sample results

PARAMETER GROUP	PARAMETER	UNITS	WAK-1	WAK-2	WAK-3
OCTOBER 2015					
DISSOLVED OXYGEN	DO	%	55.7	54.5	58.3
	DO	mg/L	5.06	4.95	5.26
NITROGEN	NH_4-N	mg/L	0.040	0.020	0.010
	NOx-N	mg/L	0.295	0.290	0.295
	OrgN	mg/L	0.017	0.065	0.127
	TKN	mg/L	0.044	0.085	0.137
	TN	mg/L	0.352	0.375	0.432
PHYSICAL	pH	SU	7.63	7.53	7.52
	SpCond	umhos/cm	312	312	314
	Turbidity	NTU	0.3	0.3	0.4
TEMPERATURE	Wtr Temp	C	18.3	18.3	18.9
MARCH 2016					
DISSOLVED OXYGEN	DO	%	74.2	65.7	72.6
	DO	mg/L	6.68	5.76	6.76
NITROGEN	NH_4-N	mg/L	0.010	0.013	0.015
	NOx-N	mg/L	0.495	0.390	0.365
	OrgN	mg/L	0.070	0.065	0.048
	TKN	mg/L	0.068	0.068	0.050
	TN	mg/L	0.575	0.470	0.428
PHYSICAL	pH	SU	7.62	7.64	7.71
	SpCond	umhos/cm	324	325	389
TEMPERATURE	Wtr Temp	C	20.4	19.7	19.7

Table 6. Wakulla River Side Spring/Stream average water quality grab sample results.

PARAMETER GROUP	PARAMETER	UNITS	SS#1	SS#2	Stream
DISSOLVED OXYGEN	DO	%	8.6	58.7	61.0
	DO	mg/L	0.77	5.74	5.47
PHYSICAL	pH	SU	7.29	7.59	7.55
	SpCond	umhos/cm	4,066	824	1,927
TEMPERATURE	Wtr Temp	C	20.0	19.8	20.4

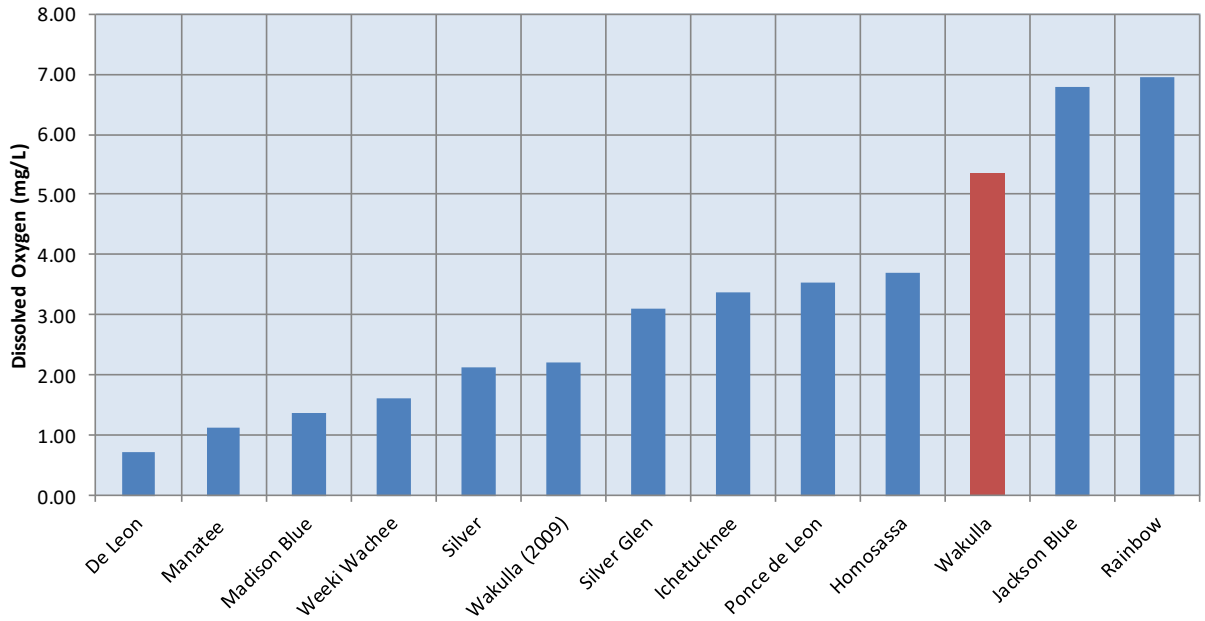


Figure 19. Average dissolved oxygen concentrations in Florida springs near the spring vents (study segment in red)

Table 7. Wakulla River average water quality sonde measurements

PARAMETER GROUP	PARAMETER	UNITS	WAK-UP	WAK-DN
October 19 – 30, 2015				
DISSOLVED OXYGEN	DO	%	62.0	66.9
	DO	mg/L	5.50	5.93
PHYSICAL	pH	SU	7.77	8.27
	SpCond	umhos/cm	320	327
	Turb	NTU	0.4	0.7
TEMPERATURE	Wtr Temp	C	21.1	21.2
March 7 - 17, 2016				
DISSOLVED OXYGEN	DO	%	78.5	80.7
	DO	mg/L	6.96	7.15
PHYSICAL	pH	SU	8.05	8.00
	SpCond	umhos/cm	321	334
TEMPERATURE	Wtr Temp	C	21.0	21.2

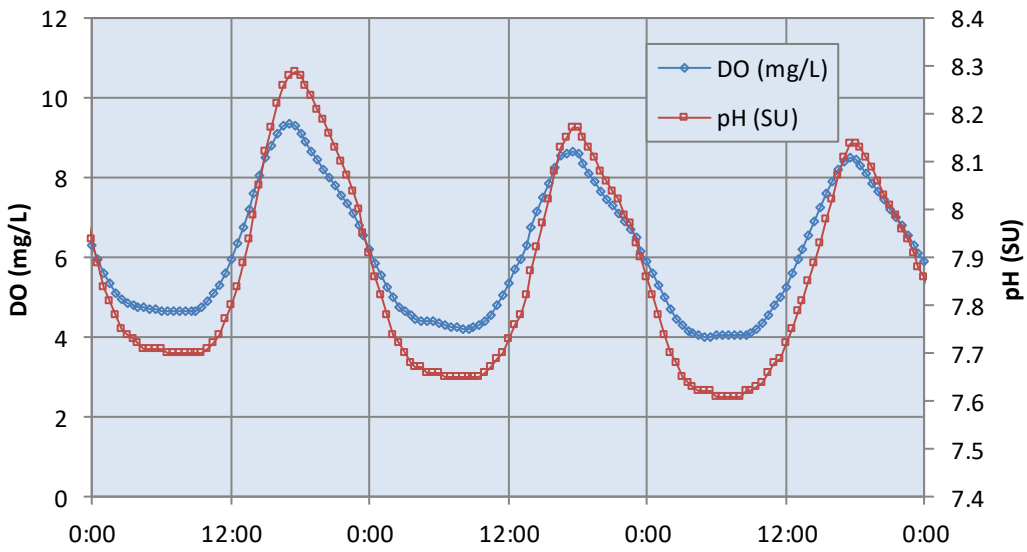


Figure 20. Typical diurnal pattern for dissolved oxygen and pH in the Wakulla River

3.2 Biology

3.2.1 Plant Community Characterization

The distribution and percent cover of aquatic plant communities (macroalgae and submerged aquatic vegetation) within the spring run at Wakulla River study area transects (Figure 2) is summarized in Table 9 and Table 10. Detailed aquatic plant data are provided in Appendix D.

A total of 4 plant and algal species or groups were identified at the Wakulla River monitoring transects during the October 2015 monitoring event. These included tape grass (*Vallisneria americana*), filamentous algae, fanwort (*Cabomba caroliniana*), and Southern-naiad (*Najas quadalupensis*). Bare sand and mud had an average percent cover of approximately 40 percent, while all aquatic vegetation combined averaged 80 percent. A range of 1 to 4 aquatic vegetation species occurred within the nine vegetation transects.

Table 8. Wakulla River aquatic vegetation summary overall average for the study segment October 2015).

Scientific Name	Common Name	Total Distance (m)	Cover		Frequency		Importance Value
			%	Relative	Absolute	Relative	
Vallisneria americana	Tape grass	203	36.0	45.1	0.667	26.1	35.6
Algae	Algae	128	22.7	28.4	0.889	34.8	31.6
Cabomba caroliniana	Fanwort	95.6	17.0	21.3	0.667	26.1	23.7
Najas guadalupensis	Southern naiad	23.6	4.18	5.24	0.333	13.0	9.1
	Total	450	79.8	100	2.56	100	100.0

Table 9. Wakulla River aquatic vegetation transect importance value summary by station (October 2015)

		Wakulla River Transects								
Scientific Name	**Common Name**	**T-1**	**T-2**	**T-3**	**T-4**	**T-5**	**T-6**	**T-7**	**T-8**	**T-9**
Algae	Algae	15.2	72.6	56.3		43.9	67.1	29.2	20.8	22.9
Cabomba caroliniana	Fanwort	32.8		43.8	100	37.5	32.9			18.8
Najas guadalupensis	Southern naiad	26.0							24.3	14.6
Vallisneria americana	Tape grass	26.0	27.4			18.6		70.8	54.9	43.8
		100	100	100	100	100	100	100	100	100

Table 10. Wakulla River aquatic vegetation transect percent cover summary by station (October 2015)

		Wakulla River Transects								
Scientific Name	**Common Name**	**T-1**	**T-2**	**T-3**	**T-4**	**T-5**	**T-6**	**T-7**	**T-8**	**T-9**
Algae	Algae	2	20	50		42	80	5	8	25
Cabomba caroliniana	Fanwort	15		30	80	32	15			15
Najas guadalupensis	Southern naiad	10							15	5
Vallisneria americana	Tape grass	10	1			3		55	75	75
		37	21	80	80	77	95	60	98	120

Aquatic vegetation has been surveyed in the Wakulla River and was summarized in the Wakulla Spring Restoration Action Plan (FSI 2014). Findings from two 2003 surveys identified microalgae coverage ranging from 41 to 51 percent near the Wakulla Spring pool area. Aquatic vascular plant coverage from the same area averaged 52 to 70 percent (hydrilla, strap-leaved sagittaria and southern naiad). WSI (2010) reported approximately 85 percent coverage of submersed aquatic vegetation, including benthic algae, in the upper spring run in 2009. The most common plants being hydrilla and tape grass. Historically, problematic aquatic plants (including hydrilla) have been managed in the upper Wakulla River by the state through the use of herbicide applications and mechanical harvesting methods.

3.2.2 General Faunal Observations

Along the spring run and upland areas, there was a total of 57 bird species observed (42 species in October 2015; 46 species in March 2016) [Figure 21]. The most commonly occurring species were the double-crested cormorant, red-winged blackbird, Northern parula, American goldfinch, turkey vulture, and common yellowthroat. Detailed bird survey data are provided in Appendix E.

Figure 22 provides a summary of the number of bird species observed during summer and winter surveys of the middle Wakulla River by FDEP from 1989 to 2015. The average number of bird species observed was 12.7 species with a range from 5 to 33 species.

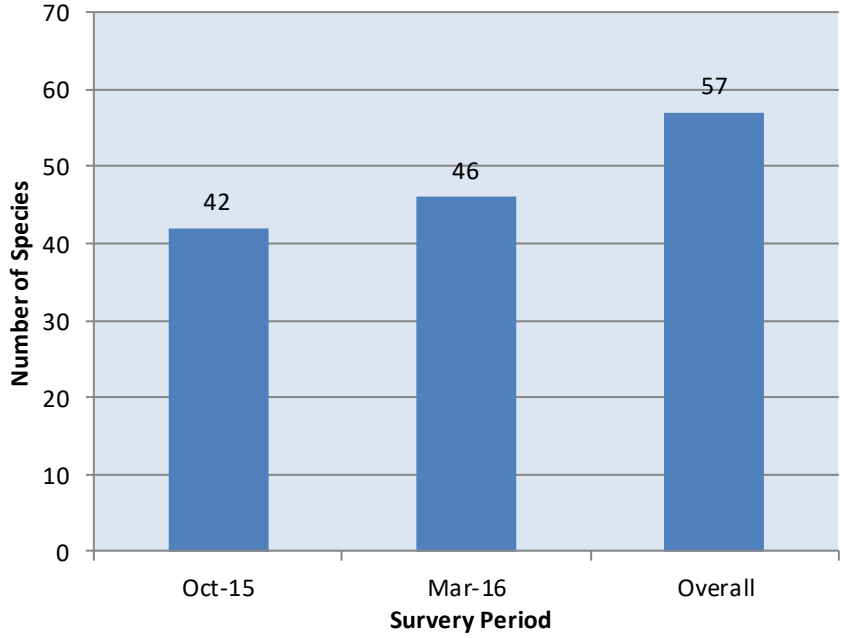


Figure 21. Wakulla River bird survey summary for 2015-2016

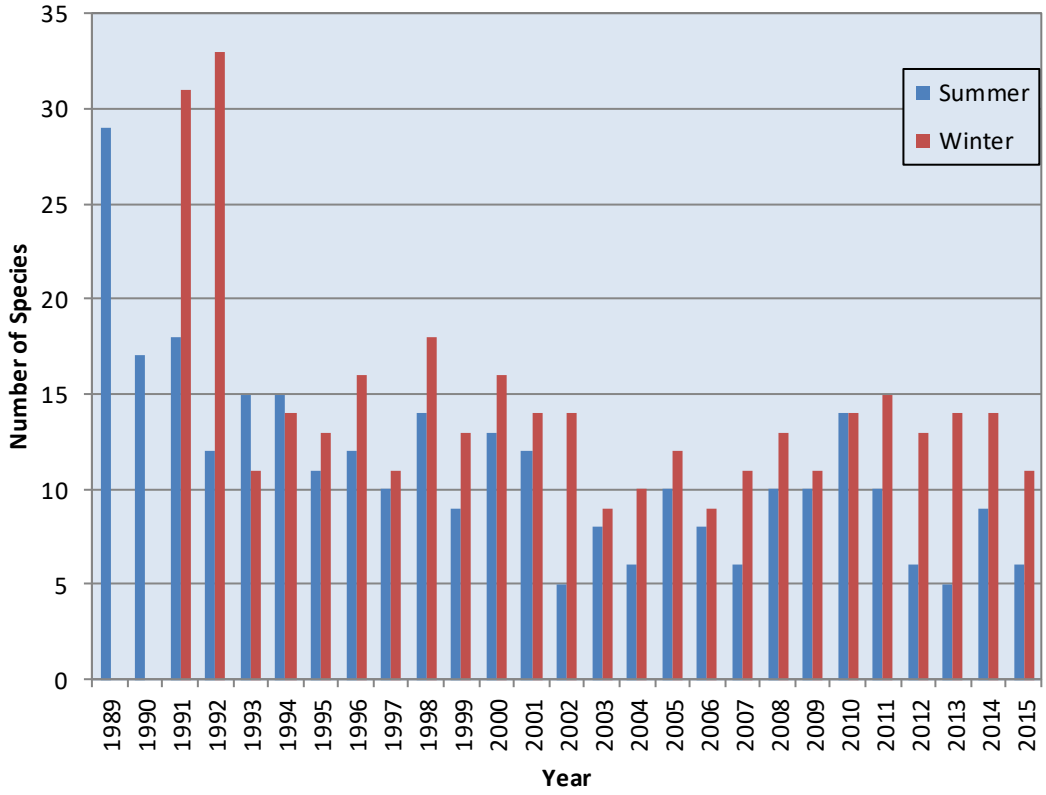


Figure 22. FDEP Middle Wakulla River bird survey summary from 1989 to 2015

3.2.3 Adult Aquatic Insects

Table 11 presents a summary of adult aquatic insect emergence rates from the Wakulla River spring run study segment. Insect emergence rates averaged 45 organisms/m²/d and 16 organisms/m²/d in October 2015 and March 2016, respectively. This equates to approximately 5,850,200 organisms/day over the study segment area on average. The most commonly collected insects were non-biting midges (*Diptera*), with 80% of the sample belonging to this family.

Figure 23 provides a summary of estimated adult aquatic insect emergence rates compared with other Florida spring run systems studied using the same emergent trap technique, including results from Wakulla Spring in 2009 (WSI 2010). The Wakulla Spring study segment had a lower than average insect emergence rate compared to the other springs studied.

Table 11. Wakulla River adult aquatic insect emergence rates

			Deployment Date				
Order	**Suborder**	**Family**	**10/19/15**	**10/29/15**	**Avg**	**3/7/16**	**Avg**
Diptera	*Nematocera*	*Ceratopogonidae*		2	1		0
		Chironomidae	71	81	76	21	21
		Tipulidae			0	1	1
Ephemeroptera				1	0.5		0
Hemiptera	*Heteroptera*	*Veliidae*			0	1	1
Lepidoptera	*Glossata*	*Pyralidae*	1		0.5	3	3
Odonata	*Anisoptera*	-	7	1	4		0
Trichoptera	-	-	2	17	9.5	3	3
Total			81	102	91.5	29	29
Emergence Rate (#/m²/d)			37	54	45	16	16

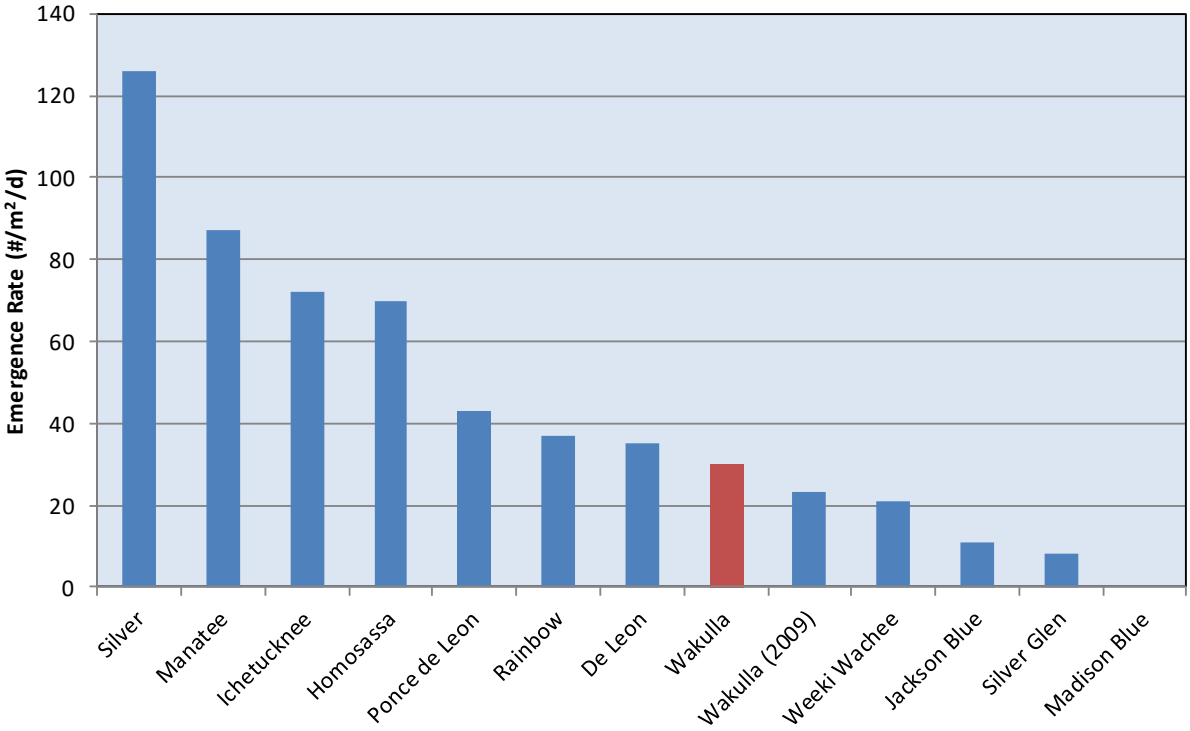


Figure 23. Wakulla River adult aquatic insect emergence rates compared to other Florida spring runs

3.2.4 Snails

Only one cluster of apple snail eggs was observed during the October 19, 2015 event. None were observed during the March 2016 monitoring periods.

3.2.5 Fish

Table 11 presents the fish survey data from October 2015 with detailed fish data are provided in Appendix F. A total of 4 fish species or groups of similar species were observed during the survey. Fish density and biomass in the Wakulla River spring run study segment averaged 214 fish/ac and 5.3 lbs/ac, respectively (**Error! Reference source not found.**). Minnows (*Notropis s p.*) and sunfish (*Lepomis sp.*) were observed at the highest densities. The Shannon-Wiener diversity index (H') was only 0.27, due to the limited number of species and uneven distribution.

Estimated fish biomass and population densities were compared with other Florida springs studied using the same visual count technique (WSI 2010). Figure 24 visually displays this comparison of the Wakulla River study segment to other Florida springs. For the study segment, the estimated fish densities and biomass were the lowest of the other studied springs.

Table 12. Wakulla River fish summary – October 2015

Scientific Name	Common Name	Count	Density (#/ac)	Biomass (lbs/ac)
Lepomis sp.	Sunfish sp.	10	4.91	0.242
Micropterus salmoides	Largemouth Bass	1	0.491	0.016
Notropis sp.	Minnows	420	206	0.750
Mugil cephalus	Striped mullet	5	2.46	4.24
	Total	436	214	5.25

Survey Area: T-1 to T-2 (0.89 ac) and T-8 to T-9 (1.14 ac); Total 2.04 ac

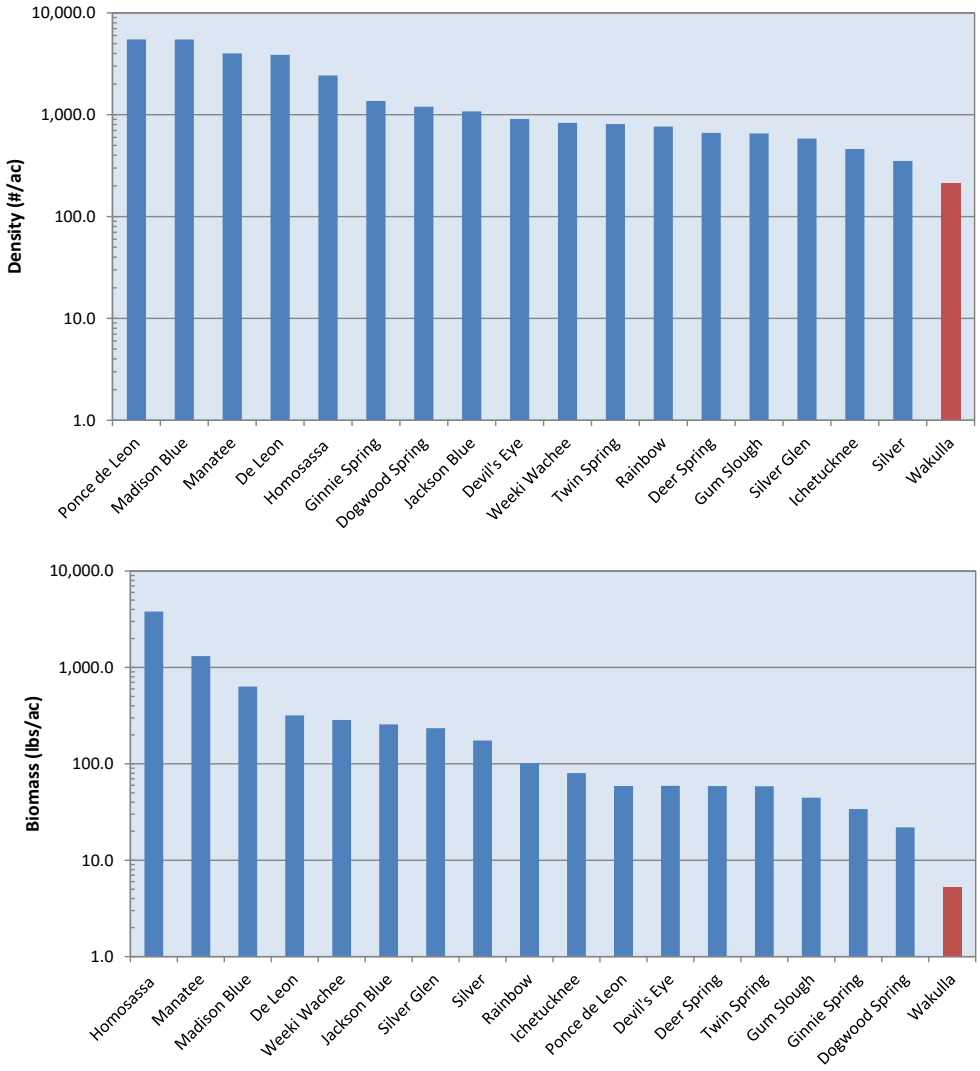


Figure 24. Wakulla River fish density and biomass compared to other Florida springs

3.2.6 Turtles

On average, an average of 45 individual turtles were observed within the study segment during wildlife surveys (49 in October 2015 and 41 in March 2016). The Suwannee cooter (*Pseudemys cocinna*) were the most common for both survey periods. This resulted in an estimated average turtle population density of 1.2 turtles/ac

Figure 25 provides a summary of turtles surveyed during the summer on the middle Wakulla River by FDEP 1989 to 2015. The average number observed from this period was 110 turtles with a range from 12 to 319.

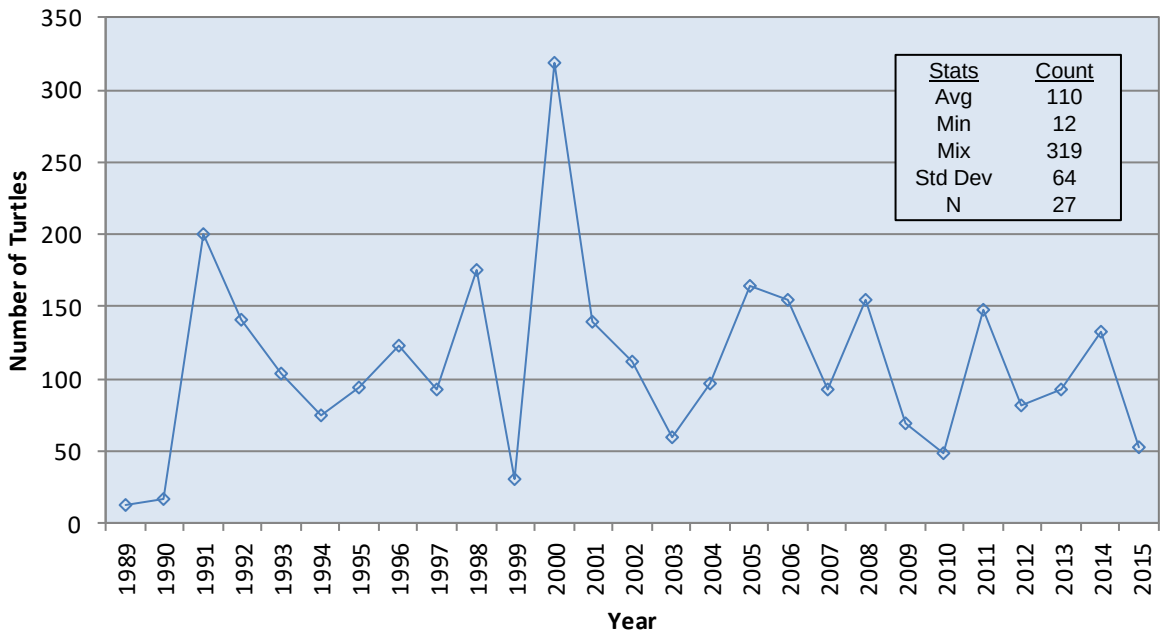


Figure 25. FDEP Middle Wakulla River turtle summer survey summary from 1989 to 2015

3.2.7 Human Use

Figure 26 provides a summary for total in-water and out-of-water activities at the downstream study segment (Highway 98) in October 2015. Detailed human use survey activities are summarized in Appendix G.

This area of the spring run received higher levels of human activity during the warmer season (October 2015). Due to the low numbers observed during the colder season (March 2016), only incidental observations of human activity were recorded (Appendix G). In October 2015, in-water activities averaged 0.6 people/ac with canoe/kayaking and power boating being the most common activities. Out-of-water activities averaged 0.5 people/ac for the same survey period, with walking and sitting being the most common. Incidental human use activities observed in the study segment during March 2016 included power boating, paddleboard, scuba, and fishing.

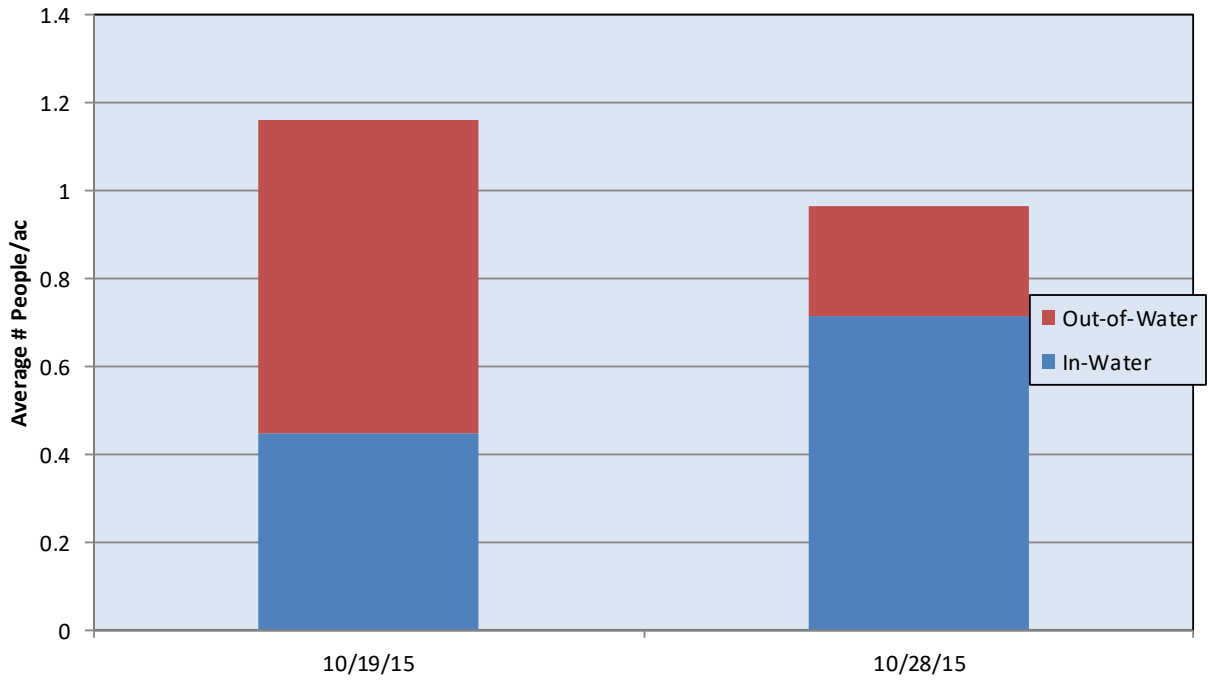


Figure 26. Wakulla River human use summary – October 2015

3.3 Ecosystem Level Monitoring

3.3.1 Ecosystem Metabolism

Table 13 provides a summary of ecosystem metabolism parameters collected in the study segment with detailed results in Appendix H. Average GPP ranged from 15.37 g $O_2/m^2/d$ (October 2015) to 21.91 g $O_2/m^2/d$ (March 2016) over the study period. CR ranged from 13.62 g $O_2/m^2/d$ (October 2015) to 22.98 g $O_2/m^2/d$ (March 2016), resulting in an average NPP of 2.62 g $O_2/m^2/d$ in October 2015, to 0.81 g $O_2/m^2/d$ in March 2016. For these data the estimated P/R ratio ranged from 1.06 (March 2016) to 1.29 (October 2015), and the photosynthetic efficiency ranged was from 7.81% (or 0.97 g O_2/mol) in March 2016, to 8.70% (or 1.08 g O_2/mol) in October 2015.

Ecosystem metabolism estimates from the study segment were compared to similar data from other Florida springs that have previously been studied (Figure 27). This comparison indicates that the study segment has a high GPP, NPP, and CR compared to other spring systems. When normalized for the amount of incident solar radiation, the study segment was found to have a photosynthetic efficiency above average compared to other Florida springs.

Figure 28 and Figure 29 shows the existing data relating photosynthetic efficiency, spring discharge, and NOx-N concentration for the studied Florida spring systems. The study segment follows the same general relationship observed for other springs. In general, spring photosynthetic efficiency increases with increasing spring discharge (Figure 28), while NOx-N concentration may have a subsidy-stress effect on photosynthetic efficiency (Figure 29).

Table 13. Rainbow River ecosystem metabolism estimates

Stats	GPP ($g\ O_2/m^2/d$)	NPP ($g\ O_2/m^2/d$)	CR ($g\ O_2/m^2/d$)	P/R Ratio	PAR (24hr) ($mol/m^2/d$)	PAR Efficiency (%)	PAR Efficiency ($g\ O_2/mol$)
October 20 – 30, 2015							
Avg	15.37	2.62	13.62	1.29	20.96	6.09	0.75
Max	22.20	5.55	22.39	2.26	31.62	8.06	1.00
Min	6.13	0.08	3.37	1.01	6.14	4.72	0.58
March 8 – 17, 2016							
Avg	21.91	0.81	22.98	1.06	31.40	5.74	0.71
Max	27.19	3.30	39.87	1.23	36.09	7.17	0.89
Min	14.93	-2.46	12.10	0.92	24.90	3.38	0.42

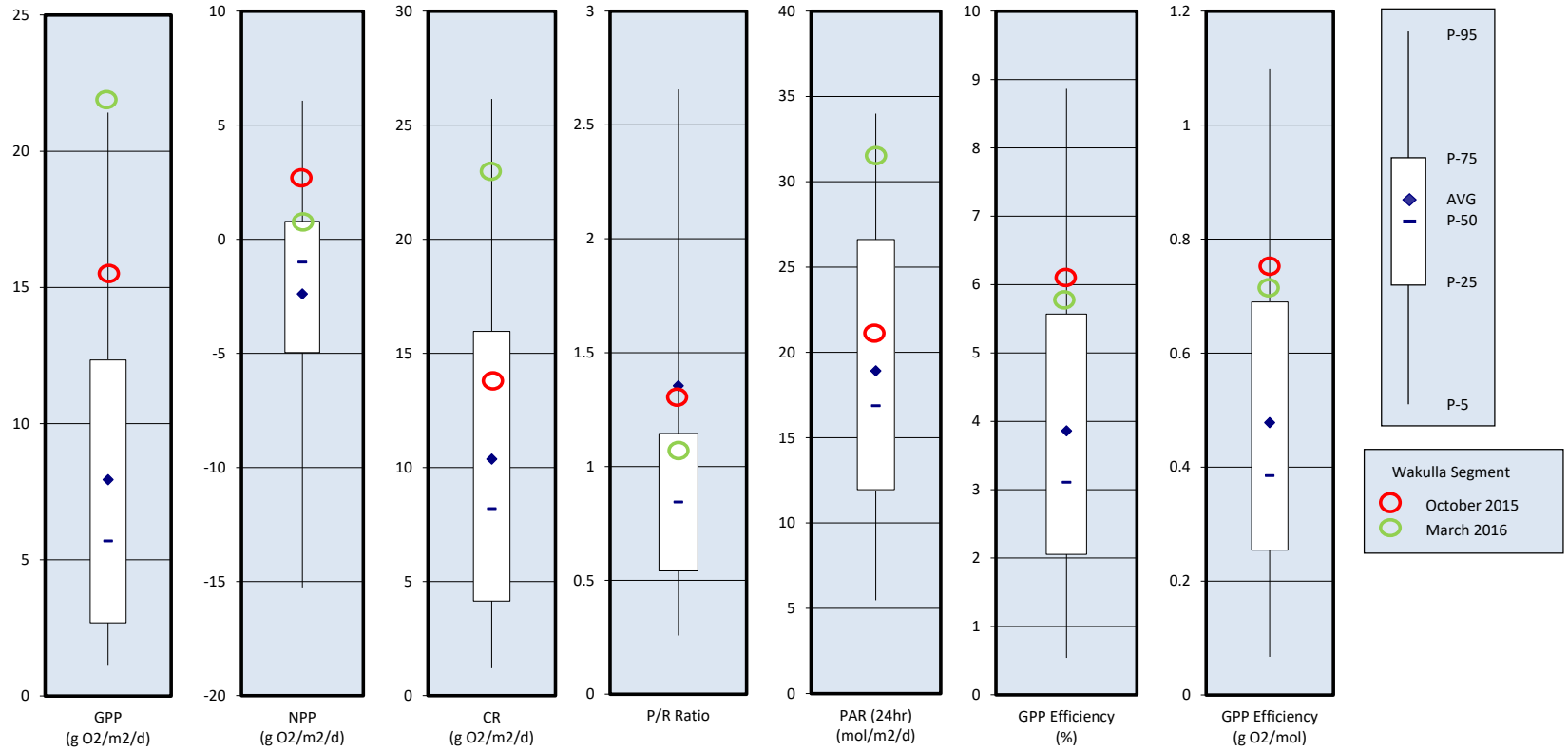


Figure 27. Comparison of ecosystem productivity and photosynthetic efficiency in Florida springs (based on historic and recent data from a total of 22 springs)

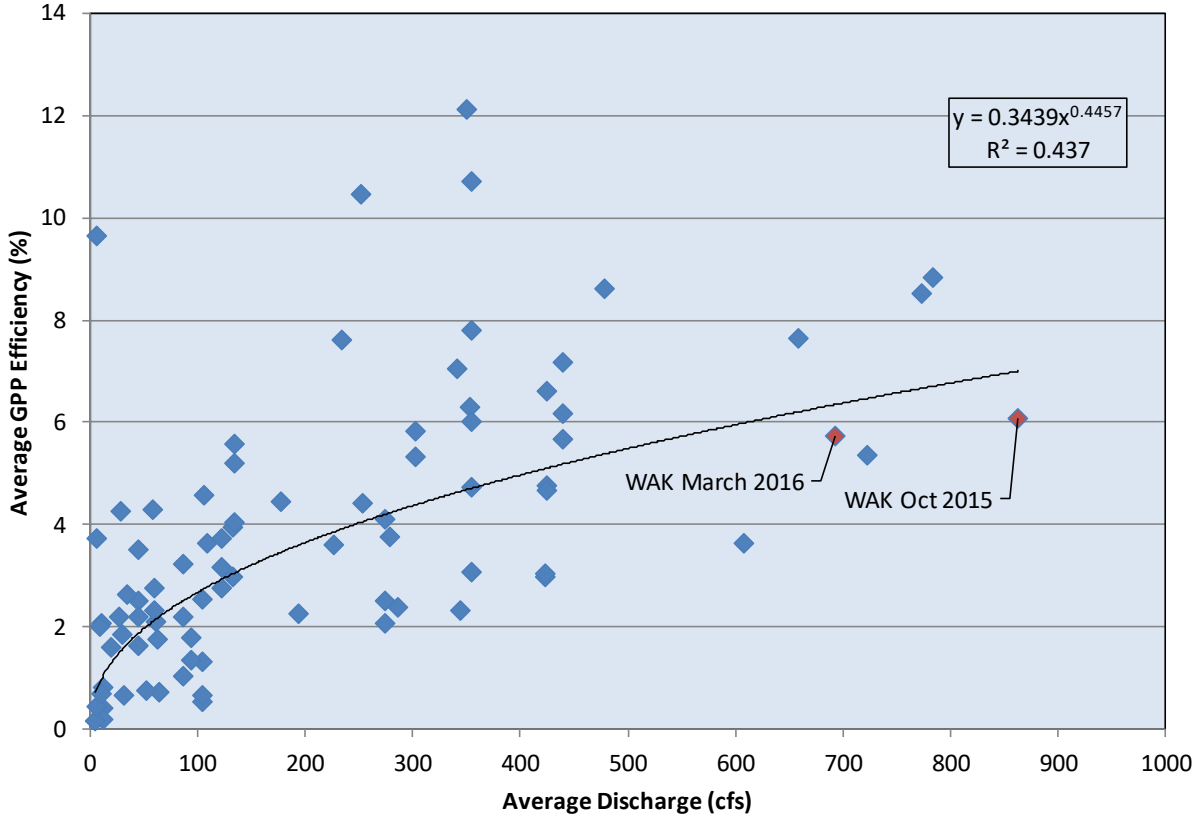


Figure 28. Gross primary productivity efficiency versus discharge in Florida springs (based on historic and recent data from a total of 22 springs)

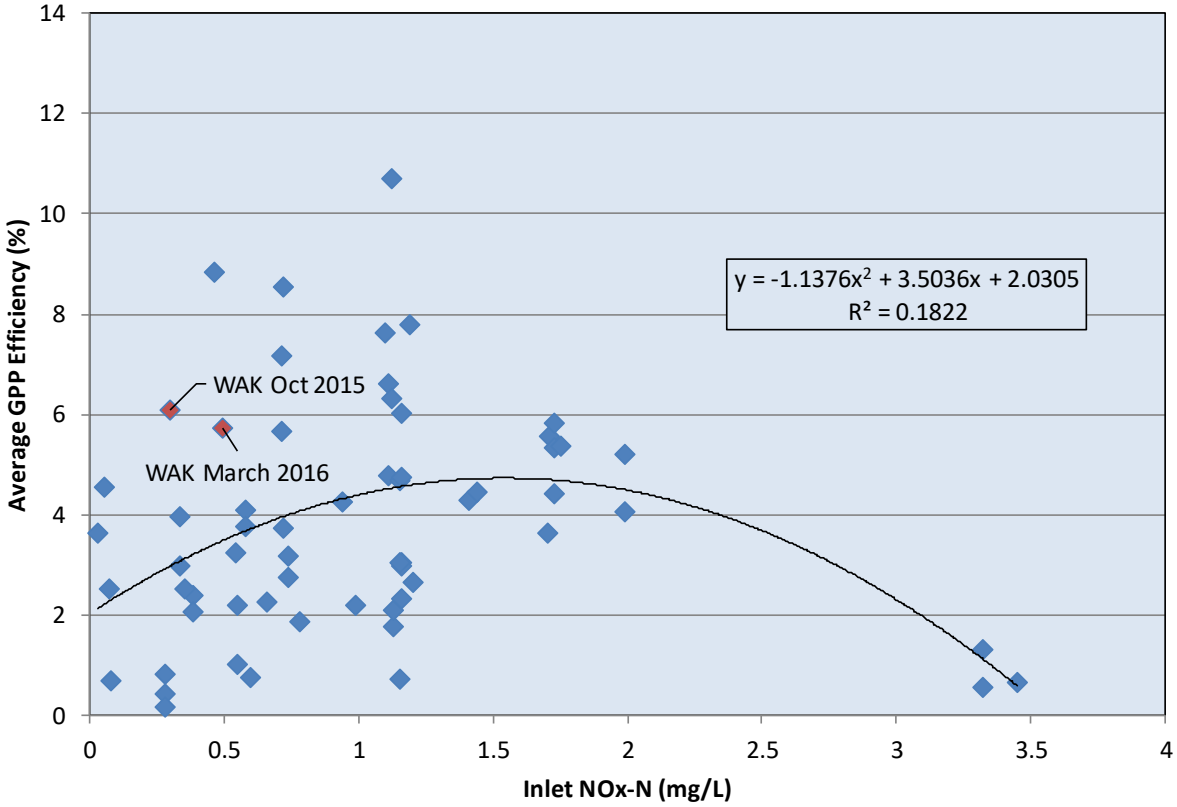


Figure 29. Gross primary productivity efficiency versus NOx-N concentration in Florida springs (based on historic and recent data from a total of 22 springs)

3.3.2 Nutrient Assimilation

Figure 30 provides a summary of the average mass removals in the study segment with details provided in Appendix I. The mass of TN was reduced by an average of 2.5 lbs/ac/d within the study segment with NOx-N being the dominant fraction (6.6 lbs/ac/d). The mass of OrgN increased 5.7 lbs/ac/d, resulting in a TKN increase of 4.8 lbs/ac/d in the study segment. NH_4-N slightly decreased within the study segment (1.6 lbs/ac/d).

Nutrient mass removal data from the study segment were compared to other Florida springs runs as shown Figure 31. This comparison indicates that the study segment mass removal rates are within ranges observed in other Florida spring runs. Average mass removals estimated during this study were very similar to those estimated at the upper Wakulla spring run during 2009, with the exception of OrgN.

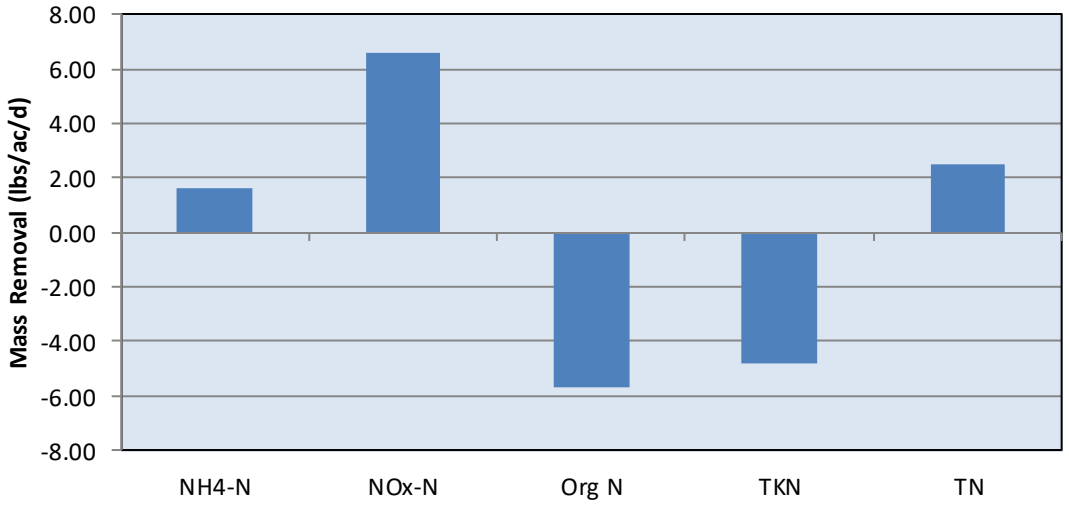


Figure 30. Wakulla River estimated nutrient mass removals

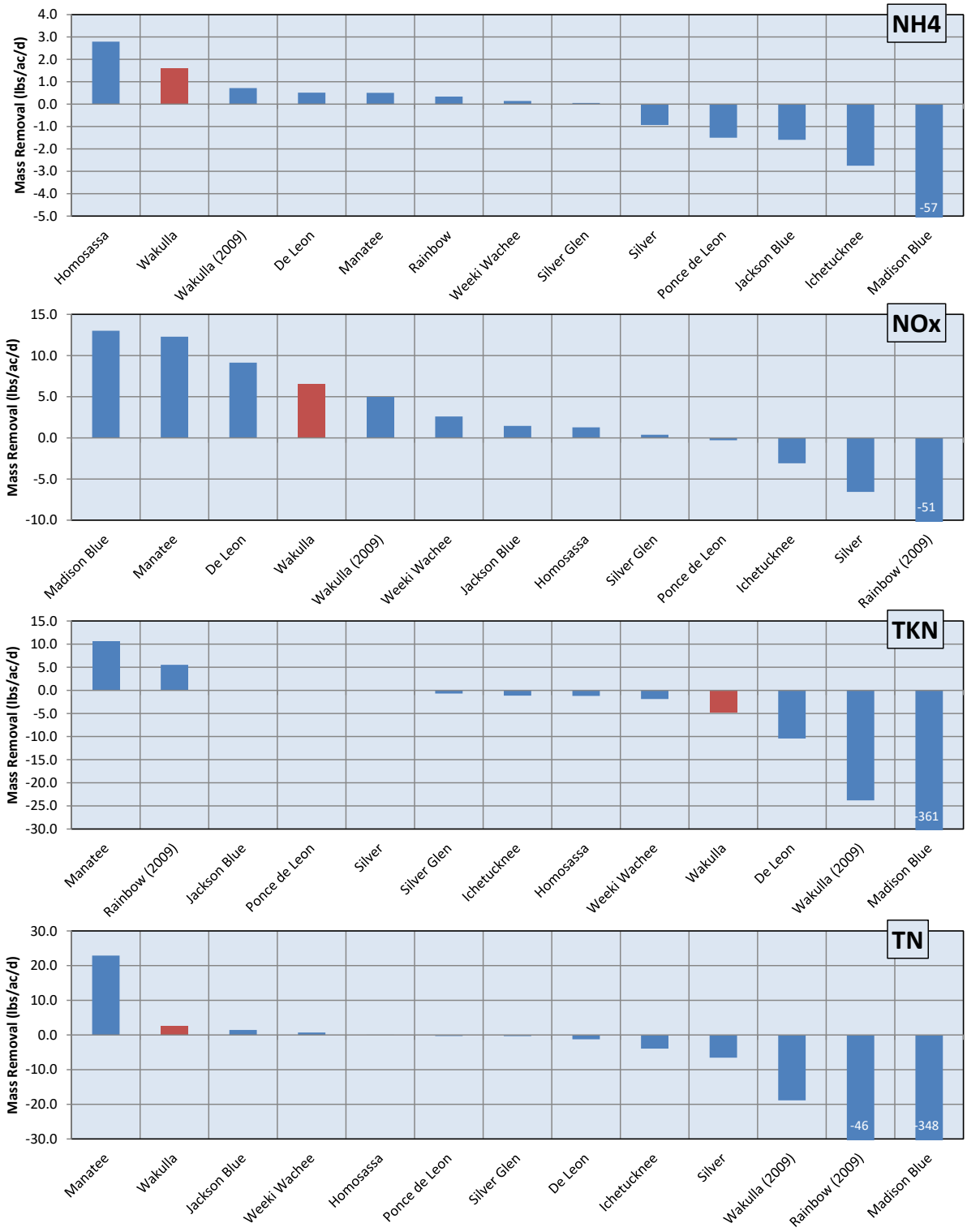


Figure 31. Nutrient mass removals for Florida springs runs

3.3.3 Community Export

Community export data for the study segment are summarized in Table 14 with detailed data provided in Appendix J. Segment particulate organic matter export rates varied widely. Positive values indicate a net production of detrital material (material leaving the study segment), while negative values indicate a net accrual of detrital material (material being deposited in the study segment). For October 2015, organic matter export rates were negative for the first event (-0.055 $g/m^2/d$) and positive for the second event (0.146 $g/m^2/d$). The estimated net organic matter export rate was positive for the March 2016 sampling events (0.043 $g/m^2/d$).

Particulate organic matter export data from the study segment were compared to other Florida spring runs as shown Figure 32.

Table 14. Wakulla River Particulate Export

Date	Station	Dry Matter (g/d)	Organic Matter (g/d)	Dry Matter ($g/m^2/d$)	Organic Matter ($g/m^2/d$)
10/20/2015	WK-1	212,424	117,221	0.355	0.196
	WK-3	183,405	106,138	0.244	0.141
	Segment	-29,019	-11,084	-0.111	-0.055
10/29/2015	WK-1	188,567	121,307	0.315	0.203
	WK-3	464,809	262,038	0.618	0.348
	Segment	276,243	140,731	0.303	0.146
3/8/2016	WK-1	121,300	66,191	0.203	0.111
	WK-3	170,866	115,366	0.227	0.153
	Segment	49,566	49,175	0.024	0.043

Segment Areas: Head Spring to WK-1 (598,930 m^2); Head Spring to WK-3 (752,709 m^2); WK-1 to WK-3 (153,779 m^2)

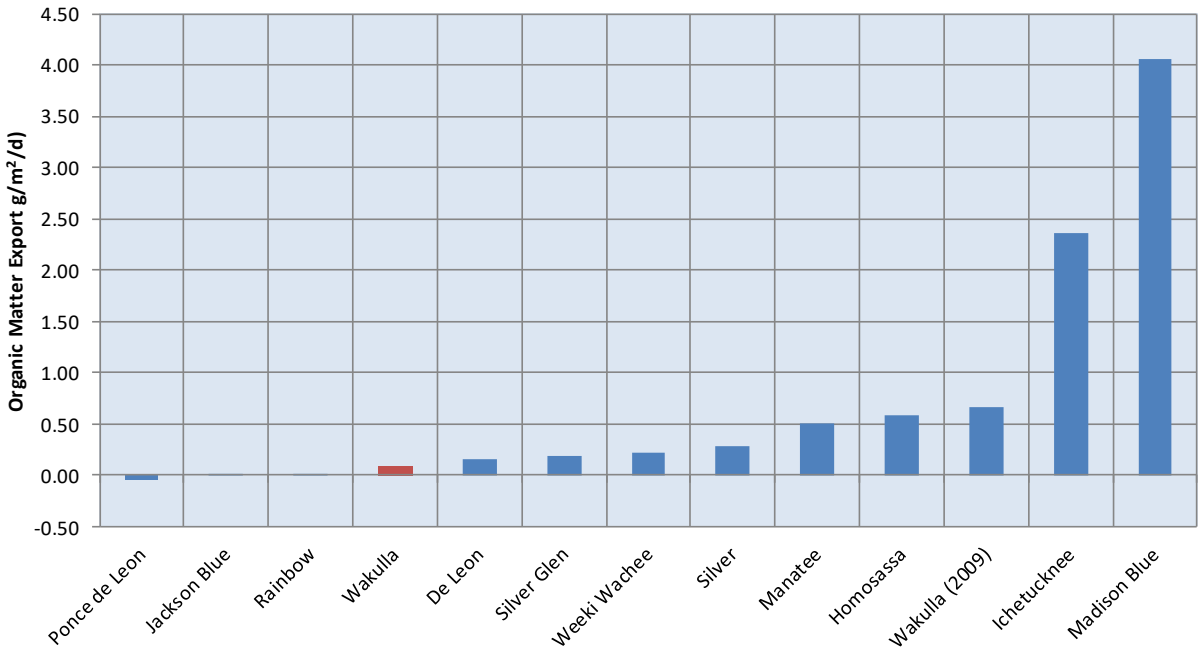


Figure 32. Organic material export in Florida spring runs

Section 4.0 Discussion

4.1 Overview

Wakulla Springs is an enigma among Florida's studied springs (FSI 2014). Nitrate levels rose for decades into the 1990s before starting a rapid decline to current levels. Significant public efforts to reduce nitrogen loading to Wakulla Springs began in the past two decades when it was confirmed that anthropogenic loading (primarily from the City of Tallahassee's spray field effluent disposal system) was the dominant source of nitrogen to area groundwaters. In fact, the City's efforts to reduce nitrogen loading from effluent disposal is currently the most expensive "springs restoration" project in the State's history. But, as pointed out by FSI (2014) the spring nitrate concentrations were already declining before the City made significant changes in their treatment process. At the same approximate time, flows from Wakulla Springs were rising, in spite of relatively constant rainfall inputs. Subsequent hydrogeological studies, aided by the unprecedented knowledge about the underground, interconnected cave system feeding groundwater to Wakulla and nearby Springs Creek springs, determined that Wakulla was pirating flows that historically went to its sister spring system on the nearby coast. A more likely explanation of the declining nitrate levels in the Wakulla River is that treatment plant upgrades are being measurably augmented by dilution from low-nitrogen groundwater.

The Wakulla River spring run baseline study segment was about 1.4 miles in length, had a wetted surface area of about 38.2 ac, a water volume of about 419 ac-ft, and an average water depth of 11 ft. The 2015/2016 monitoring data reported during this baseline study from the Wakulla River indicate that this segment is impaired in several respects, and that the ecological structure and function of the spring run is substantially impaired compared to other spring runs. Average flows in the Wakulla River have been increasing since the 1960s. The baseline flows averaged 892 cfs compared to a period-of-record average flow of 344 cfs (an 159% increase). Dissolved oxygen concentrations in the Wakulla River were generally above 5 mg/L with the exception that nighttime summer values dipped down to about 4 mg/L due to high community respiration rates. Measured pH varies around 7.6 standard units, temperature varied between 18 and 20 ^{o}C, and specific conductance varied slightly around 329 uS.

Nitrate+nitrite nitrogen concentrations at the springs feeding the Wakulla River averaged about 0.7 mg/L since 2000, about 14 times higher than the assumed background levels of this nutrient (about 0.05 mg/L) and about two times higher than the Florida numeric springs standard of 0.35 mg/L. Measured nitrate concentrations in the lower Wakulla River measured during this baseline study averaged about 0.36 mg/L, partly as a result of natural attenuation by the aquatic ecosystem estimated in this study as 252 lbs/d.

The Wakulla River baseline study segment had low water clarity (horizontal Secchi distance about 13.5 ft) and the water was noticeably colored and turbid. Overall plant and algae cover was estimated as 80% in the shallowest areas and submerged plants were noticeably sparse in the deeper areas of the channel. The cover of filamentous algae in the shallow areas was about 23% and there was a very high load of periphytic algae on eelgrass leaves. Measured

populations of insects, snails, turtles, fish, and birds were low in this river segment, indicating poor wildlife habitat support.

Gross ecosystem primary productivity was unusually high (about 19 $g/O_2/m^2/d$), as was community respiration (about 18 $g/O_2/m^2/d$), resulting in very little observed export of useful plant matter. The observed high primary productivity in this aquatic ecosystem appears to be the result of eutrophic nitrogen levels and undesirable changes in the spring run plant communities. Human use of the Wakulla River was low during the week days when sampling was conducted.

The Wakulla River Ecosystem Baseline segment was one of the most impacted spring runs studied by the Florida Springs Institute. Water clarity is very low, indicator species of a healthy spring run such as aquatic insects and mollusks are nearly absent, and populations and diversity of fish and turtles appear to be very low. Routine bird counts upstream in the Wakulla River indicate that populations of several species have declined. On the other hand, community metabolism and photosynthetic efficiency were relatively high compared to other spring runs. On a subsidy-stress curve it appears that the existing combination of elevated nitrate nitrogen and color/turbidity in the river provide a recipe for excessive algae growth and low water clarity. In spite of the regulatory efforts and money expended to-date to restore and protect this river from harm, wildlife habitat functions appears to be seriously impaired compared to other Florida spring runs.

4.2 Wakulla Spring Report Card

The 2016 Wakulla Spring report card is presented in Figure 33 with detailed data provided in Appendix K. The quantitative data assembled for this environmental health assessment indicate that the Wakulla Spring and River system received an average grade. However, the observations of low to very low populations of insects, snails, fish, turtles, and birds in this lower river segment, indicate that the river is impaired for wildlife and food chain support. Additional data collection and analysis will be important to determine the magnitude of any benefits accrued due to the City of Tallahassee's wastewater treatment upgrades.

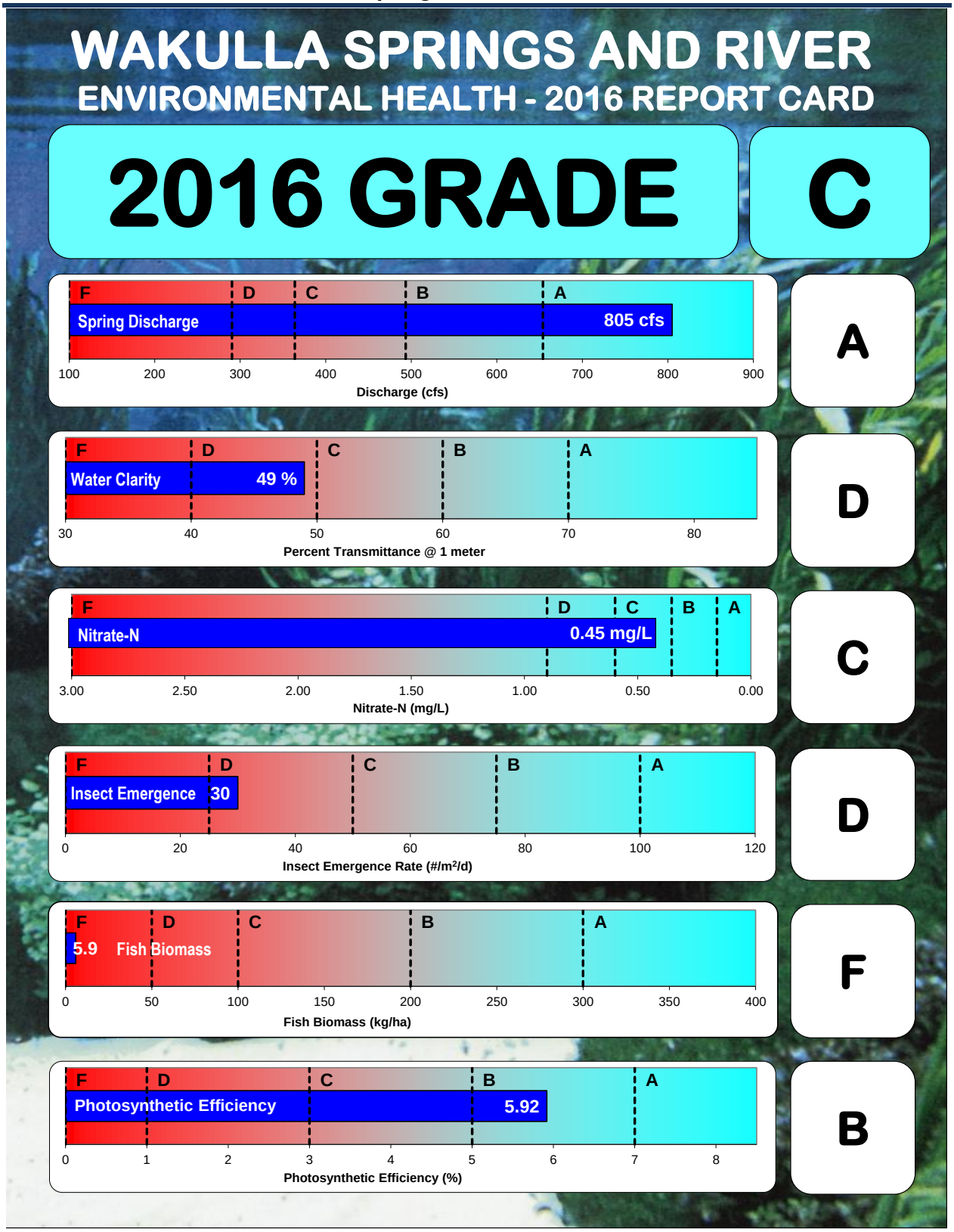


Figure 33. Wakulla Spring 2016 Report Card

Section 5.0 References

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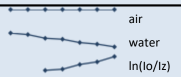
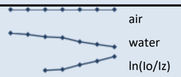
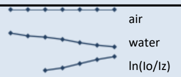
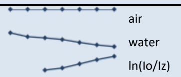
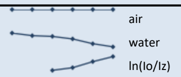
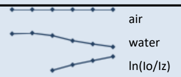
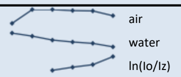
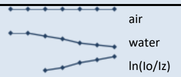
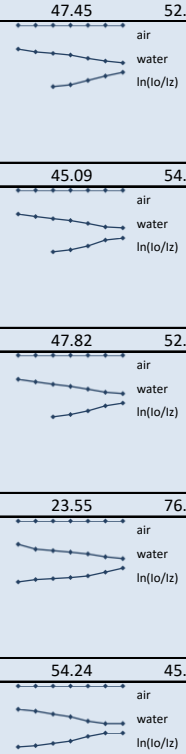
Appendix A

PAR Attenuation Estimates

Site	Stn	Date	Time	Rep	Depth (m) z	corr Air (Io)	Water (Iz)	ln(Iz)	ln(Io/Iz)	k (m-1)	k (diffuse attenuation coefficient = slope, m-1) k (m-1)	Percent Transmittance (1m)	Birgean Percentile Absorption (1m)	Flag
WAK	WK-1	10/19/2015	12:30	1	Air	1,129.7	1,129.7				0.554	57.49	42.51	
					0.03	1,129.7	1,057.4	6.96						
					0.15	1,129.7	885.4	6.79	0.244	1.599				
					0.30	1,129.7	841.5	6.74	0.295	0.966				
					0.61	1,129.7	687.4	6.53	0.497	0.815				
					0.91	1,129.7	614.0	6.42	0.610	0.667				
					1.22	1,129.7	487.1	6.19	0.841	0.690				
WAK	WK-1	10/19/2015	12:30	2	Air	1,157.4	1,157.4				0.763	46.61	53.39	
					0.03	1,157.4	1,082.1	6.99						
					0.15	1,157.4	960.1	6.87	0.187	1.226				
					0.30	1,157.4	914.9	6.82	0.235	0.771				
					0.61	1,157.4	700.4	6.55	0.502	0.824				
					0.91	1,157.4	562.7	6.33	0.721	0.789				
					1.22	1,157.4	433.3	6.07	0.983	0.806				
WAK	WK-2	10/19/2015	15:20	1	Air	1,048.2	1,048.2				0.635	53.01	46.99	
					0.03	1,048.2	920.7	6.83						
					0.15	1,048.2	866.8	6.76	0.190	1.247				
					0.30	1,048.2	771.3	6.65	0.307	1.006				
					0.61	1,048.2	625.5	6.44	0.516	0.847				
					0.91	1,048.2	512.9	6.24	0.715	0.782				
					1.22	1,048.2	443.1	6.09	0.861	0.706				
WAK	WK-2	10/19/2015	15:20	2	Air	1,043.6	1,043.6				0.598	54.97	45.03	
					0.03	1,043.6	871.6	6.77						
					0.15	1,043.6	820.8	6.71	0.240	1.576				
					0.30	1,043.6	747.0	6.62	0.334	1.097				
					0.61	1,043.6	618.1	6.43	0.524	0.859				
					0.91	1,043.6	510.0	6.23	0.716	0.783				
					1.22	1,043.6	436.6	6.08	0.871	0.715				
WAK	WK-3	10/19/2015	14:17	1	Air	1,254.7	1,254.7				0.814	44.30	55.70	
					0.03	1,254.7	1,130.7	7.03						
					0.15	1,254.7	1,092.5	7.00	0.138	0.908				
					0.30	1,254.7	971.4	6.88	0.256	0.840				
					0.61	1,254.7	741.2	6.61	0.526	0.863				
					0.91	1,254.7	591.8	6.38	0.751	0.822				
WAK	WK-3	10/19/2015	14:17	2	Air	1,068.0	1,068.0				0.517	59.62	40.38	
					0.03	1,068.0	1,088.2	6.99						
					0.15	1,068.0	1,010.0	6.92	0.056	0.366				
					0.30	1,068.0	853.2	6.75	0.225	0.737				
					0.61	1,068.0	751.6	6.62	0.351	0.576				
					0.91	1,068.0	664.4	6.50	0.475	0.519				
WAK	WK-3	10/30/2015	12:42	1	Air	1,188.0	1,188.0				0.766	46.50	53.50	
					0.03	1,230.9	1,015.0	6.92						
					0.15	1,230.9	795.6	6.68	0.436	2.864				
					0.30	1,227.7	689.1	6.54	0.578	1.895				
					0.61	1,226.6	613.5	6.42	0.693	1.137				
					0.91	1,211.6	421.2	6.04	1.057	1.156				
WAK	WK-3	10/30/2015	12:42	2	Air	1,575.0	1,575.0				0.995	36.96	63.04	
					0.03	1,539.3	970.7	6.88						
					0.15	1,499.9	924.4	6.83	0.484	3.176				
					0.30	1,510.1	778.3	6.66	0.663	2.175				
					0.61	1,489.7	594.4	6.39	0.919	1.507				
					0.91	1,398.0	396.4	5.98	1.260	1.378				
WAK	WK-2	3/7/2016	13:06	1	Air	1,368.1	1,368.1				0.770	46.29	53.71	
					0.03	1,368.1	1,362.1	7.22						
					0.15	1,368.1	1,177.6	7.07	0.150	0.984				
					0.30	1,368.1	1,004.5	6.91	0.309	1.014				
					0.61	1,368.1	746.2	6.61	0.606	0.994				
					0.91	1,368.1	625.0	6.44	0.783	0.857				
					1.22	1,368.1	513.9	6.24	0.979	0.803				

Site	Stn	Date	Time	Rep	Depth (m) z	corr Air (Io)	Water (Iz)	ln(Iz)	ln(Io/Iz)	k (m-1)	k (diffuse attenuation coefficient = slope, m-1) k (m-1)	Percent Transmittance (1m)	Birgean Percentile Absorption (1m)	Flag
WAK	WK-2	3/7/2016	13:06	2	Air	1,339.5	1,339.5				0.746	47.45	52.55	
					0.03	1,339.5	1,165.5	7.06						
					0.15	1,339.5	1,074.4	6.98	0.221	1.447				
					0.30	1,339.5	971.5	6.88	0.321	1.054				
					0.61	1,339.5	767.4	6.64	0.557	0.914				
					0.91	1,339.5	602.9	6.40	0.798	0.873				
					1.22	1,339.5	491.0	6.20	1.004	0.823				
WAK	WK-1	3/7/2016	14:01	1	Air	1,371.1	1,371.1				0.797	45.09	54.91	
					0.03	1,371.1	1,209.8	7.10						
					0.15	1,371.1	1,070.4	6.98	0.248	1.625				
					0.30	1,371.1	952.4	6.86	0.364	1.195				
					0.61	1,371.1	760.1	6.63	0.590	0.968				
					0.91	1,371.1	536.9	6.29	0.938	1.025				
					1.22	1,371.1	477.8	6.17	1.054	0.865				
WAK	WK-1	3/7/2016	14:01	2	Air	1,330.6	1,330.6				0.738	47.82	52.18	
					0.03	1,330.6	1,176.4	7.07						
					0.15	1,330.6	1,034.0	6.94	0.252	1.655				
					0.30	1,330.6	908.0	6.81	0.382	1.254				
					0.61	1,330.6	741.0	6.61	0.585	0.960				
					0.91	1,330.6	559.1	6.33	0.867	0.948				
					1.22	1,330.6	477.8	6.17	1.024	0.840				
WAK	WK-3	3/7/2016	14:39	1	Air	1,662.9	1,662.9	7.42	0.000		1.446	23.55	76.45	X
					0.03	1,662.9	1,167.7	7.06	0.354					
					0.15	1,662.9	1,016.6	6.92	0.492	3.229				
					0.30	1,662.9	865.5	6.76	0.653	2.142				
					0.61	1,662.9	685.0	6.53	0.887	1.455				
					0.91	1,662.9	391.8	5.97	1.446	1.581				
					1.22	1,662.9	212.7	5.36	2.056	1.687				
WAK	WK-3	3/7/2016	14:39	2	Air	1,228.7	1,228.7	7.11	0.000		0.612	54.24	45.76	
					0.03	1,228.7	1,137.7	7.04	0.077					
					0.15	1,228.7	994.5	6.90	0.211	1.388				
					0.30	1,228.7	865.5	6.76	0.350	1.150				
					0.61	1,228.7	656.2	6.49	0.627	1.029				
					0.91	1,228.7	536.9	6.29	0.828	0.905				
					1.22	1,228.7	537.6	6.29	0.827	0.678				



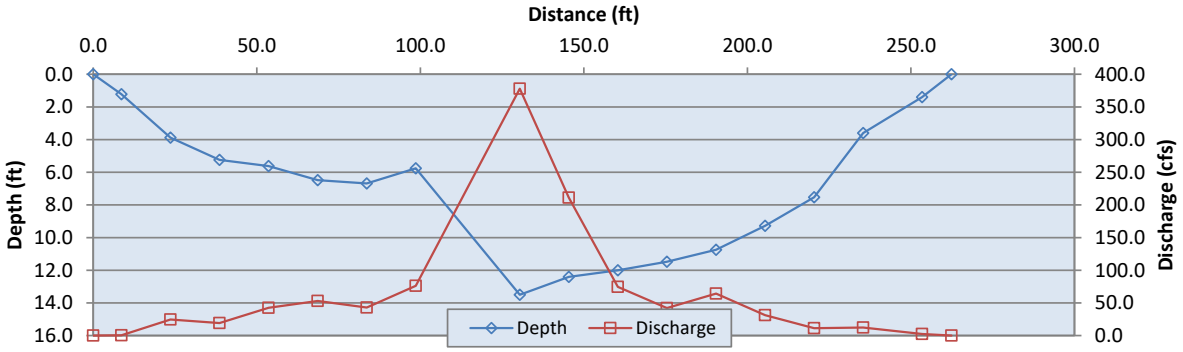
Appendix B

Stream Discharge Measurements

Wakulla Springs Baseline Assessment

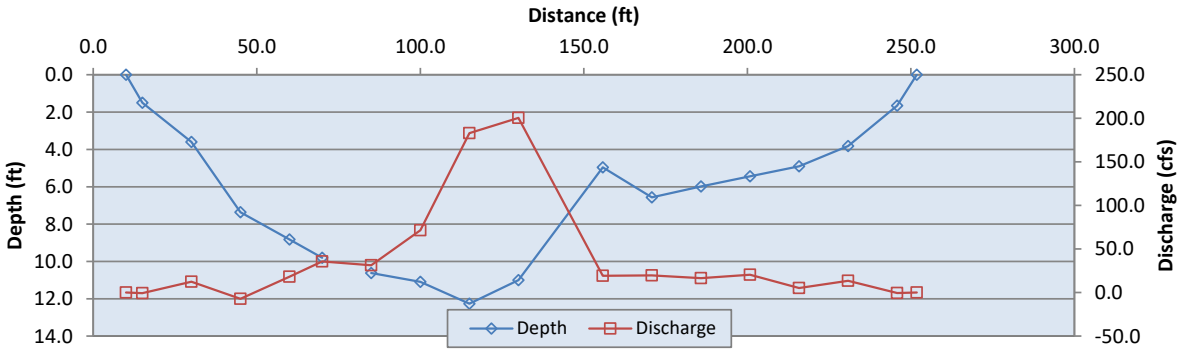
Station: Wakulla
Stn No.: WAK-3 **Start Time:** 10:04 **Staff (ft) Start:** **Field Team:** FSI
Date: 10/20/2015 **End Time:** **Staff (ft) End:** **Access:** Boat

	Distance from Initial Point (ft.)	Segment Width (ft.)	Total Depth (ft.)	Velocity (ft/s) 0.2 x depth	0.6 x depth	0.8 x depth	Segment Area (ft^2)	Discharge (ft^3/s)	(m^3/d)	(MGD)
Start	0.0	4.3	0.0		0.00		0	0.0	0	0.0
	8.6	11.8	1.2		0.03		14	0.4	1,057	0.3
	23.6	15.0	3.9	0.52		0.33	58	24.7	60,516	16.0
	38.6	15.0	5.2	0.37		0.12	79	19.3	47,114	12.4
	53.6	15.0	5.6	0.53		0.48	84	42.6	104,154	27.5
	68.6	15.0	6.5	0.74		0.35	97	53.0	129,605	34.2
	83.6	15.0	6.7	0.64		0.22	100	43.1	105,413	27.8
	98.6	21.7	5.8	0.80		0.42	125	76.2	186,539	49.3
Piling	112.8									
	116.2									
	130.4	21.7	13.5	1.53		1.05	293	377.9	924,575	244.3
	145.4	15.0	12.4	1.25		1.02	186	211.1	516,497	136.4
	160.4	15.0	12.0	0.49		0.34	180	74.7	182,759	48.3
	175.4	15.0	11.5	0.33		0.16	172	42.2	103,219	27.3
	190.4	15.0	10.7	0.52		0.28	161	64.4	157,657	41.6
	205.4	15.0	9.3	0.27		0.18	139	31.3	76,627	20.2
	220.4	15.0	7.5	0.16		0.04	113	11.3	27,634	7.3
	235.4	16.5	3.6	0.09		0.33	59	12.5	30,519	8.1
	253.4	13.5	1.4		0.13		19	2.5	6,011	1.6
End	262.4	4.5	0.0		0.00		0	0.0	0	0.0
		259	6.5	0.59	0.04	0.38	1,881	1,087	2,659,895	703

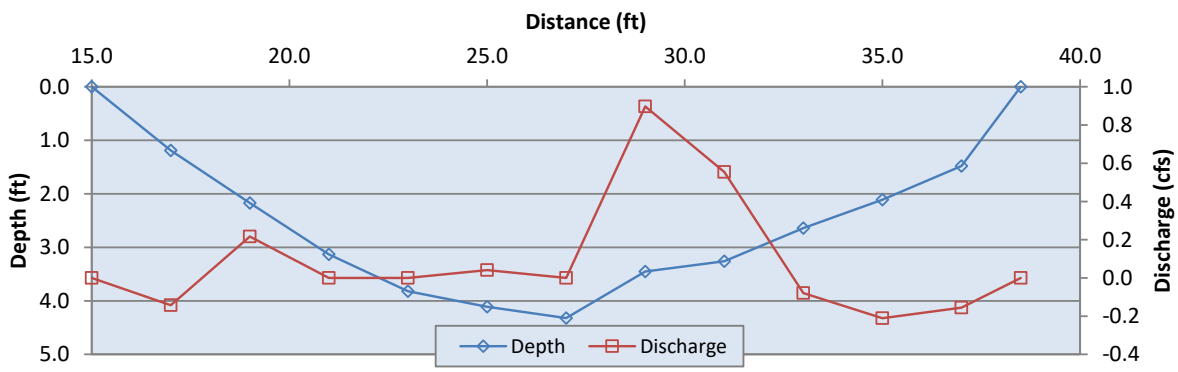


Station: Wakulla
Stn No.: WAK-3 **Start Time:** 13:25 **Staff (ft) Start:** **Field Team:** FSI
Date: 10/29/2015 **End Time:** 14:34 **Staff (ft) End:** **Access:** Boat

	Distance from Initial Point (ft.)	Segment Width (ft.)	Total Depth (ft.)	Velocity (ft/s) 0.2 x depth	0.6 x depth	0.8 x depth	Segment Area (ft^2)	Discharge (ft^3/s)	(m^3/d)	(MGD)
Start	10.0	2.5	0.0		0.00		0.00	0.0	0	0.0
	15.0	10.0	1.5		-0.05		15.00	-0.8	-1,835	-0.5
	30.0	15.0	3.6	0.35		0.11	54.00	12.4	30,386	8.0
	45.0	15.0	7.4	-0.07		-0.06	110.40	-7.2	-17,557	-4.6
	60.0	12.5	8.8	0.14		0.19	110.25	18.2	44,506	11.8
	70.0	10.0	9.8	0.40		0.33	98.00	35.8	87,514	23.1
Piling	75.0									
	78.8									
	85.0	13.7	10.6	0.31		0.12	145.49	31.3	76,532	20.2
	100.0	15.0	11.1	0.54		0.32	166.35	71.5	175,005	46.2
	115.0	15.0	12.3	1.09		0.90	183.90	183.0	447,676	118.3
	130.0	18.5	11.0	1.19		0.78	203.50	200.4	490,410	129.6
Piling	141.0									
	144.8									
	155.8	18.5	5.0	0.29		0.13	91.76	19.3	47,145	12.5
	170.8	15.0	6.6	0.25		0.15	98.55	19.7	48,222	12.7
	185.8	15.0	6.0	0.22		0.15	89.70	16.6	40,600	10.7
	200.8	15.0	5.4	0.28		0.22	81.60	20.4	49,910	13.2
	215.8	15.0	4.9	0.12		0.02	73.50	5.1	12,588	3.3
	230.8	15.0	3.8	0.42		0.05	57.30	13.5	32,944	8.7
	245.8	10.5	1.7		-0.03		17.33	-0.5	-1,272	-0.3
End	251.8	3.0	0.0		0.00		0.00	0.0	0	0.0
		234	6.1	0.40	-0.02	0.24	1,597	639	1,562,774	413



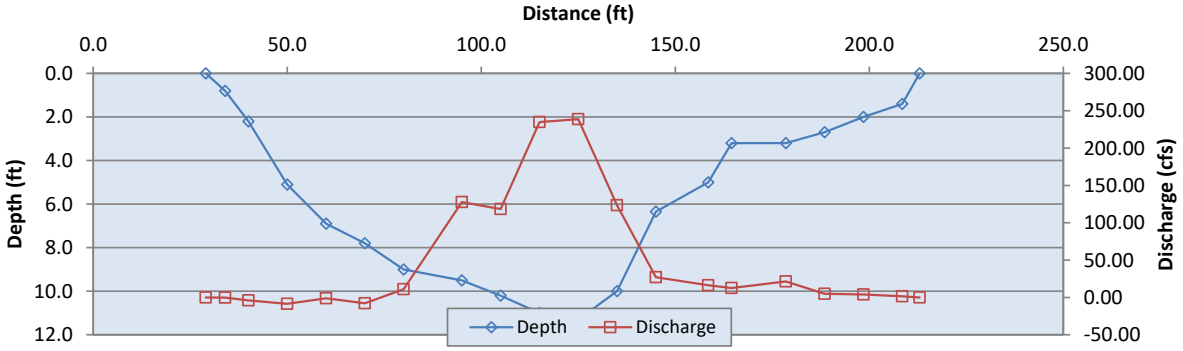
	Distance from Initial Point (ft.)	Segment Width (ft.)	Total Depth (ft.)	Velocity (ft/s) 0.2 x depth	0.6 x depth	0.8 x depth	Segment Area (ft^2)	Discharge (ft^3/s)	(m^3/d)	(MGD)
Start	15.0	1.0	0.0		0.00		0.00	0.0	0	0.0
	17.0	2.0	1.2		-0.06		2.38	-0.1	-349	-0.1
	19.0	2.0	2.2		0.05		4.34	0.2	531	0.1
	21.0	2.0	3.1	-0.07		0.07	6.26	0.0	0	0.0
	23.0	2.0	3.8	-0.06		0.06	7.64	0.0	0	0.0
	25.0	2.0	4.1	-0.01		0.02	8.22	0.04	101	0.03
	27.0	2.0	4.3	-0.08		0.08	8.64	0.00	0	0.00
	29.0	2.0	3.5	0.16		0.10	6.90	0.90	2,195	0.58
	31.0	2.0	3.3	0.10		0.07	6.52	0.55	1,356	0.36
	33.0	2.0	2.6	-0.04		0.01	5.28	-0.08	-194	-0.05
	35.0	2.0	2.1		-0.05		4.22	-0.21	-516	-0.14
	37.0	1.8	1.5		-0.06		2.59	-0.16	-380	-0.10
End	38.5	0.8	0.00		0.00		0.00	0.00	0	0.00
		23.5	2.4	0.00	-0.03	0.06	62.99	1.12	2,742	0.72



Wakulla Springs Baseline Assessment

Station: Wakulla
Stn No.: WAK-3 **Start Time:** 12:00 **Staff (ft) Start:** 0.00 **Field Team:** FSI
Date: 3/8/2016 **End Time:** 12:30 **Staff (ft) End:** 0.00 **Access:** Boat

	Distance from Initial Point (ft.)	Segment Width (ft.)	Total Depth (ft.)	Velocity (ft/s) 0.2 x depth	0.6 x depth	0.8 x depth	Segment Area (ft^2)	Discharge (ft^3/s)	(m^3/d)	(MGD)
Start	29.0	2.5	0.0		0.00		0.00	0.00	0	0.00
	34.0	5.5	0.8		-0.04		4.40	-0.18	-431	-0.11
	40.0	8.0	2.2		-0.22		17.60	-3.87	-9,473	-2.50
	50.0	10.0	5.1	-0.23	-0.13	-0.18	51.00	-8.54	-20,900	-5.52
	60.0	10.0	6.9	0.12	-0.03	-0.12	69.00	-1.04	-2,532	-0.67
	70.0	10.0	7.8	0.02	-0.20	-0.02	78.00	-7.80	-19,083	-5.04
	80.0	7.5	9.0	-0.03	0.25	0.19	67.50	11.1	27,249	7.20
Piling	82.5									
	86.0									
	95.0	14.0	9.5	0.73	1.23	0.65	133.00	128	312,379	82.5
	105.0	10.0	10.2	0.61	1.47	1.09	102.00	118	289,479	76.5
	115.0	10.0	11.0	1.74	2.16	2.48	110.00	235	574,578	151.8
	125.0	10.0	11.3	1.91	2.46	1.62	113.00	239	584,028	154.3
	135.0	10.0	10.0	1.62	1.11	1.10	100.00	124	302,152	79.8
	145.0	7.5	6.4	0.75	0.63	0.26	47.63	27.0	66,124	17.5
Piling	147.5									
	151.0									
	158.5	10.5	5.0	0.35	0.30	0.30	52.50	16.41	40,139	10.60
	164.5	10.0	3.2	0.24	0.51	0.33	32.00	12.72	31,120	8.22
	178.5	12.0	3.2	0.59	0.55	0.55	38.40	21.50	52,611	13.90
	188.5	10.0	2.7	0.16	0.17	0.23	27.00	4.9	12,056	3.18
	198.5	10.0	2.0		0.20		20.00	4.0	9,786	2.59
	208.5	7.3	1.4		0.15		10.15	1.5	3,725	0.98
End	213.0	2.3	0.0		0.00		0.00	0.00	0	0.00
		177	5.4	0.61	0.53	0.61	1,073	921	2,253,008	595



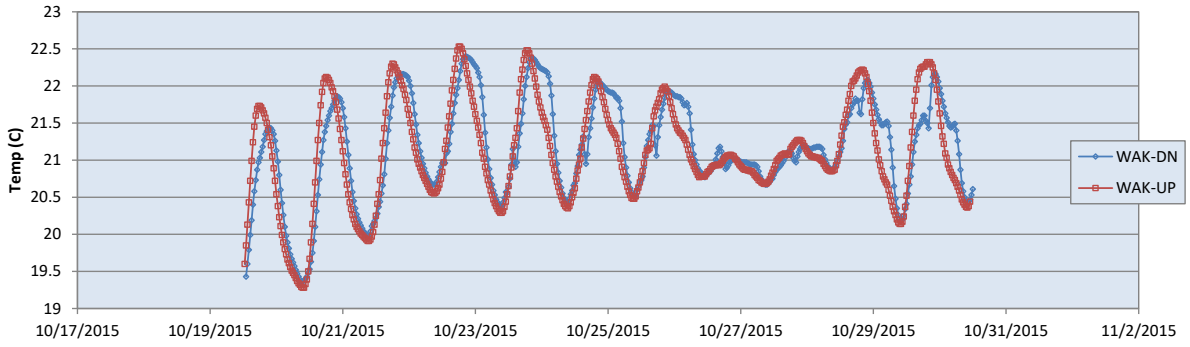
Appendix C

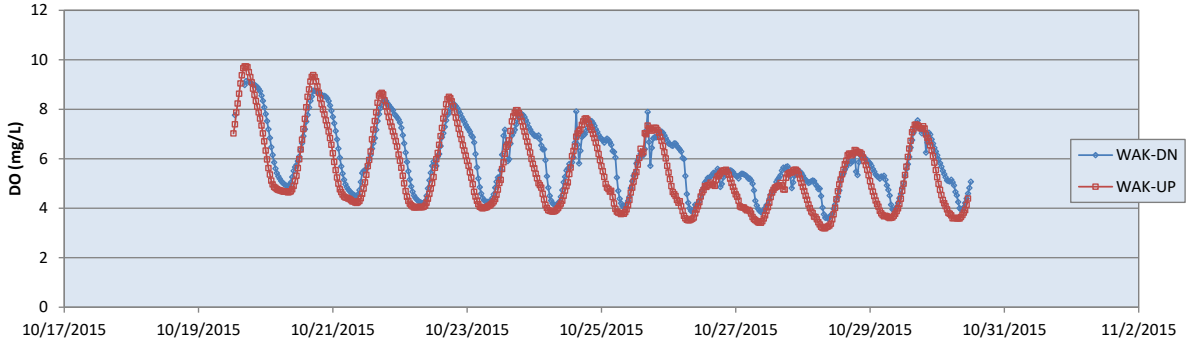
Water Quality Results

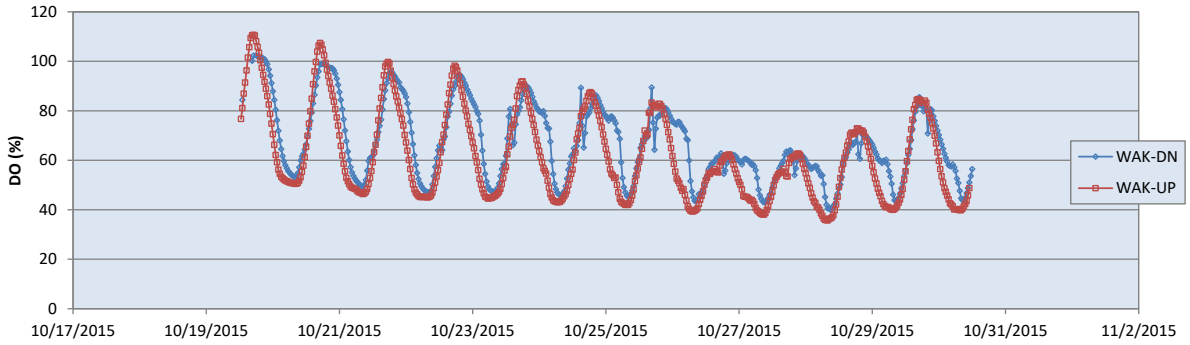
PARAMETER GROUP	PARAMETER	UNITS	Date	WK-1	WK-2	WK-3
DISSOLVED OXYGEN	DO	%	10/5/15	57.1	52.3	57.4
			10/20/15	62.2	62.9	65.9
			10/30/15	47.8	48.2	50.8
			3/7/16	90.0	74.6	85.0
			3/17/16	58.4	56.8	60.2
	DO	mg/L	10/5/15	5.13	4.70	5.17
			10/20/15	5.72	5.80	6.07
			10/30/15	4.32	4.35	4.58
			3/7/16	8.13	6.40	8.10
			3/17/16	5.23	5.12	5.41
NITROGEN	NH4-N	mg/L	10/20/15	0.060	0.020	0.010
			10/30/15	0.020	0.020	0.010
			3/7/16	0.010	0.01 U	0.020
			3/22/16	0.010	0.020	0.010
	NOx-N	mg/L	10/20/15	0.300	0.300	0.31 I
			10/30/15	0.290	0.280	0.280
			3/7/16	0.400	0.380	0.360
			3/22/16	0.590	0.400	0.370
	OrgN	mg/L	10/20/15	-0.010	0.050	0.053
			10/30/15	0.043	0.080	0.200
			3/7/16	0.100	0.100	0.055
			3/22/16	0.040	0.030	0.040
	TKN	mg/L	10/20/15	0.05 U	0.07 I	0.063 I
			10/30/15	0.063 I	0.100	0.210
			3/7/16	0.110	0.110	0.075 I
			3/22/16	0.05 U	0.05 U	0.05 U
	TN	mg/L	10/20/15	0.350	0.370	0.373
			10/30/15	0.353	0.380	0.490
			3/7/16	0.510	0.490	0.435
			3/22/16	0.640	0.450	0.420
PHYSICAL	pH	SU	10/5/15	7.19 J	6.95 J	7.12 J
			10/20/15	7.86	7.82	7.86
			10/30/15	7.83	7.81	7.83
			3/7/16	7.95	7.78	7.85
			3/17/16	7.29	7.50	7.57
	Secchi	m	10/5/15	---	3.20	---
			10/19/15	5.18	---	3.96
			10/29/15	---	3.66	---
			3/7/16	---	2.14	---
			3/17/16	---	3.35	---

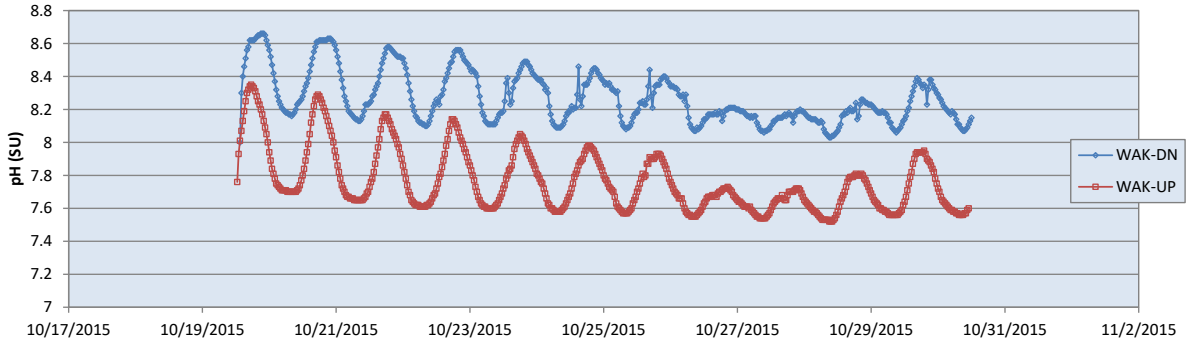
PARAMETER GROUP	PARAMETER	UNITS	Date	WK-1	WK-2	WK-3
	Secchi-H	m	10/5/15	3.96	---	---
			10/19/15	---	4.27	---
			10/29/15	3.96	---	5.18
			10/30/15	4.42	4.88	3.66
			3/7/16	5.18	---	5.18
	SpCond	umhos/cm	10/5/15	312	313	314
			10/20/15	309	309	310
			10/30/15	314	315	316
			3/7/16	324	325	400
			3/17/16	324	325	378
	Stage	ft	10/5/15	---	---	3.18
			10/29/15	---	---	1.80
			10/30/15	---	---	3.55
			3/7/16	---	---	3.66
			3/8/16	---	---	4.42
			3/17/16	---	---	3.37
	Turb	NTU	10/5/15	0.300	0.300	0.300
TEMPERATURE	Wtr Temp	C	10/5/15	20.6	20.5	20.6
			10/20/15	14.2	14.2	14.3
			10/30/15	20.2	20.2	20.3
			3/7/16	20.2	19.0	19.0
			3/17/16	20.5	20.4	20.5

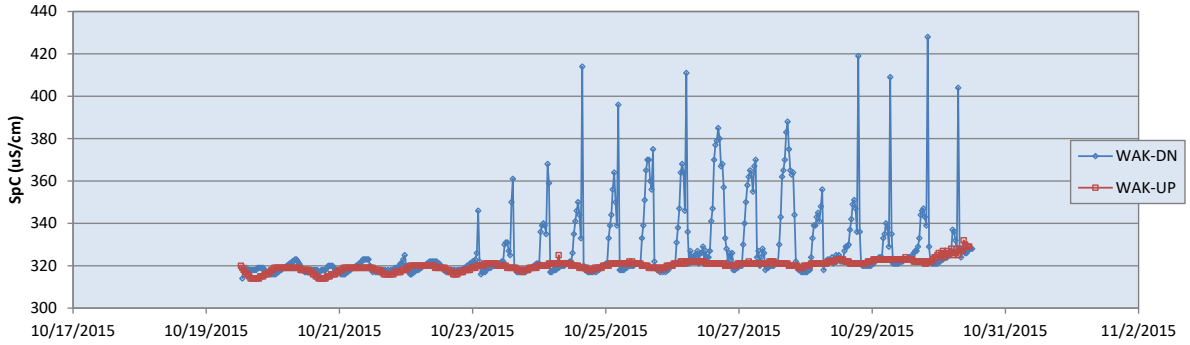
PARAMETER GROUP	PARAMETER	UNITS	Date	WAK-SS#1	WAK-SS#2	WAK-Stream
DISSOLVED OXYGEN	DO	%	10/30/15	8.10	46.5	61.0
			3/7/16	9.17	70.9	---
	DO	mg/L	10/30/15	0.720	4.16	5.47
			3/7/16	0.810	7.31	---
PHYSICAL	pH	SU	10/30/15	7.36	7.43	7.55
			3/7/16	7.22	7.74	---
	SpCond	umhos/cm	10/30/15	4,420	1,305	1,927
			3/7/16	3,713	344	---
TEMPERATURE	Wtr Temp	C	10/30/15	20.2	20.5	20.4
			3/7/16	19.8	19.2	---

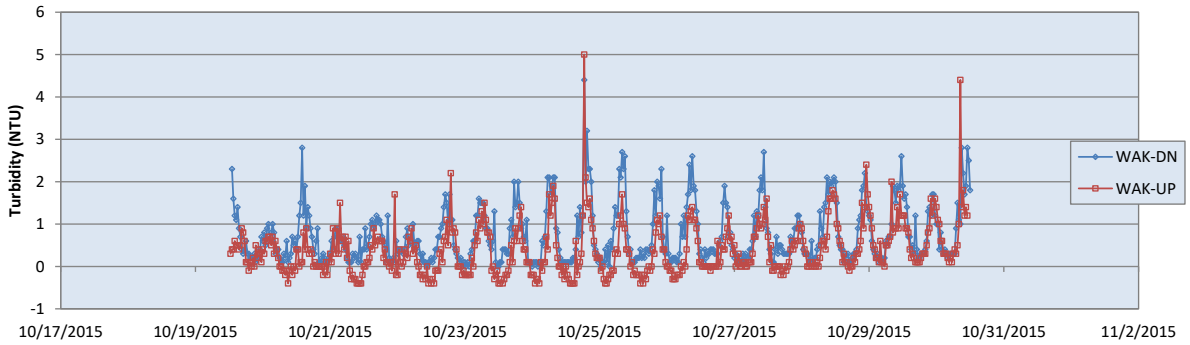

Temp (C)
23
22.5
22
21.5
21
20.5
20
19.5
19
10/17/2015
10/19/2015
10/21/2015
10/23/2015
10/25/2015
10/27/2015
10/29/2015
10/31/2015
11/2/2015
WAK-DN
WAK-UP

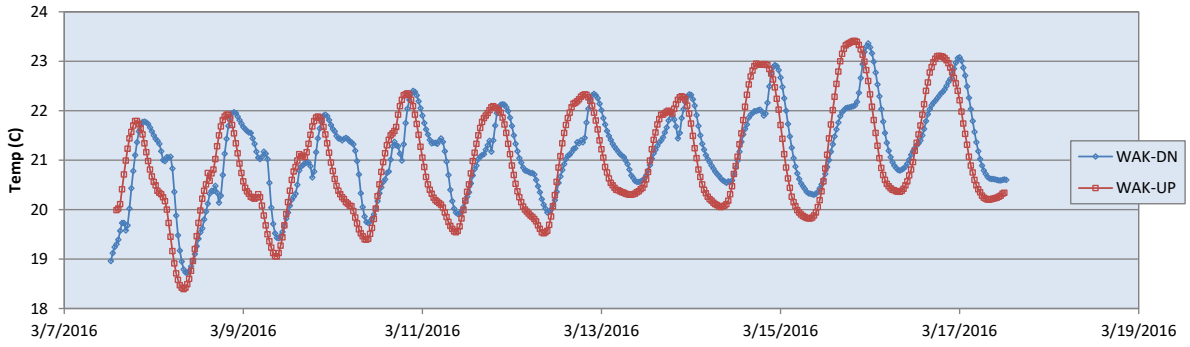

DO (mg/L)
12
10
8
6
4
2
0
10/17/2015
10/19/2015
10/21/2015
10/23/2015
10/25/2015
10/27/2015
10/29/2015
10/31/2015
11/2/2015
WAK-DN
WAK-UP

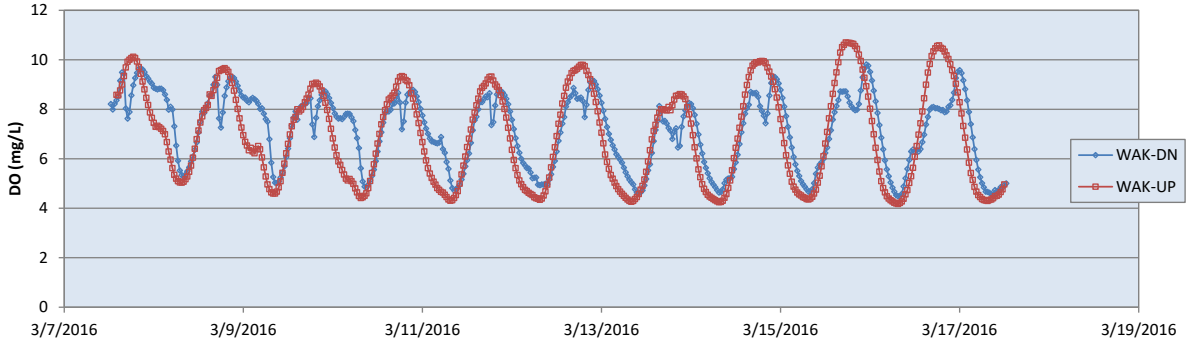

DO (%)
120
100
80
60
40
20
0
10/17/2015
10/19/2015
10/21/2015
10/23/2015
10/25/2015
10/27/2015
10/29/2015
10/31/2015
11/2/2015
WAK-DN
WAK-UP

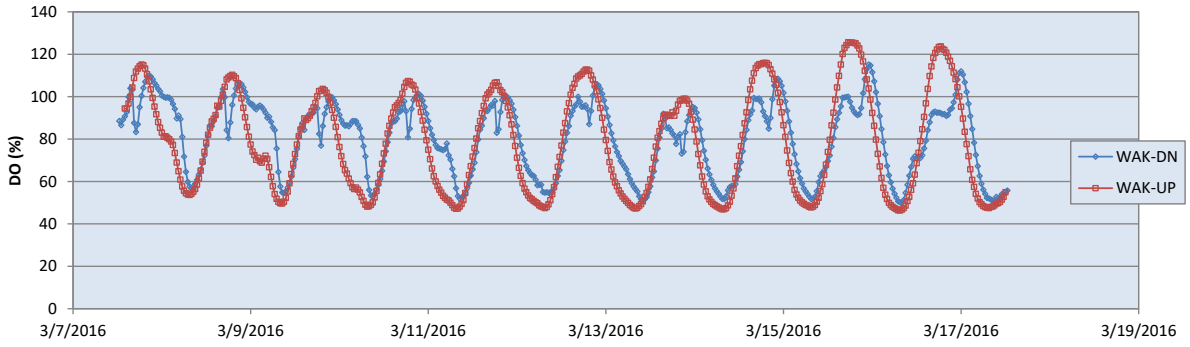

pH (SU)
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
10/17/2015
10/19/2015
10/21/2015
10/23/2015
10/25/2015
10/27/2015
10/29/2015
10/31/2015
11/2/2015
WAK-DN
WAK-UP

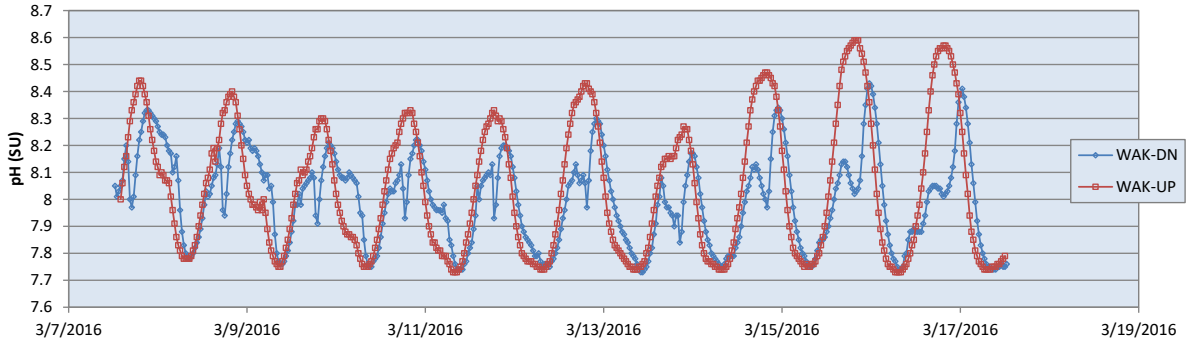

SpC (uS/cm)
440
420
400
380
360
340
320
300
10/17/2015
10/19/2015
10/21/2015
10/23/2015
10/25/2015
10/27/2015
10/29/2015
10/31/2015
11/2/2015
WAK-DN
WAK-UP

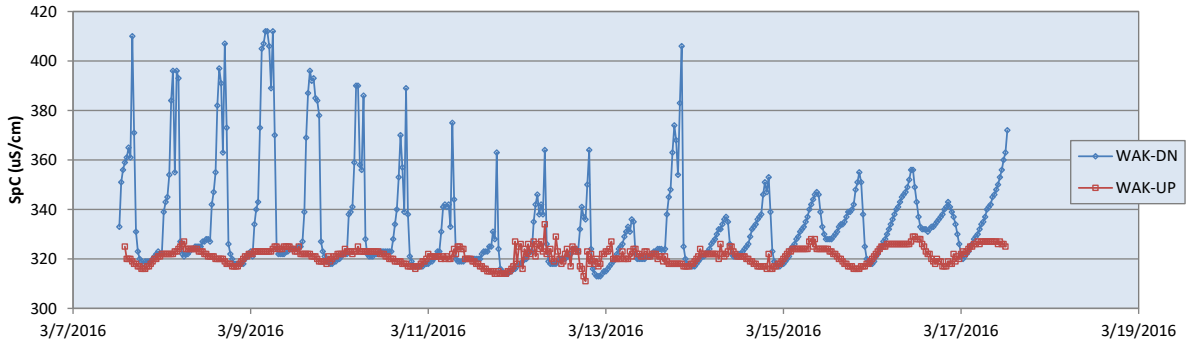

Turbidity (NTU)
6
5
4
3
2
1
0
-1
10/17/2015
10/19/2015
10/21/2015
10/23/2015
10/25/2015
10/27/2015
10/29/2015
10/31/2015
11/2/2015
WAK-DN
WAK-UP


Temp (C)
24
23
22
21
20
19
18
3/7/2016
3/9/2016
3/11/2016
3/13/2016
3/15/2016
3/17/2016
3/19/2016
WAK-DN
WAK-UP


DO (mg/L)
12
10
8
6
4
2
0
3/7/2016
3/9/2016
3/11/2016
3/13/2016
3/15/2016
3/17/2016
3/19/2016
WAK-DN
WAK-UP


DO (%)
140
120
100
80
60
40
20
0
3/7/2016
3/9/2016
3/11/2016
3/13/2016
3/15/2016
3/17/2016
3/19/2016
WAK-DN
WAK-UP


pH (SU)
8.7
8.6
8.5
8.4
8.3
8.2
8.1
8
7.9
7.8
7.7
7.6
3/7/2016
3/9/2016
3/11/2016
3/13/2016
3/15/2016
3/17/2016
3/19/2016
WAK-DN
WAK-UP


420
400
380
360
340
320
300
SpC (uS/cm)
3/7/2016
3/9/2016
3/11/2016
3/13/2016
3/15/2016
3/17/2016
3/19/2016
WAK-DN
WAK-UP

Appendix D

Aquatic Vegetation Summary

Wakulla Spring

Summary of Aquatic Vegetation - Line Intercept Method

Site	Transect	Date	Distance (m)
BA-WAK	T-1	10/19/2015	36.10

		Linear Distance (m)									Cover		Frequency		Importance
SPECIES	COMMON	A	B	C	D	E	F	G	H	Total	Percent	Relative	Absolute	Relative	Value
Algae	Algae	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.72	2.00	5.41	1.00	25.00	15.20
Cabomba caroliniana	Fanwort	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	5.42	15.00	40.54	1.00	25.00	32.77
Najas guadalupensis	Southern naiad	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	3.61	10.00	27.03	1.00	25.00	26.01
Vallisneria americana	Tape grass	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	3.61	10.00	27.03	1.00	25.00	26.01
Total		1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	13.36	37.00	100.00	4.00	100.00	100.00

Site	Transect	Date	Distance (m)
BA-WAK	T-2	10/19/2015	47.70

		Linear Distance (m)									Cover		Frequency		Importance
SPECIES	COMMON	A	B	C	D	E	F	G	H	Total	Percent	Relative	Absolute	Relative	Value
Algae	Algae	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	9.54	20.00	95.24	1.00	50.00	72.62
Vallisneria americana	Tape grass	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.48	1.00	4.76	1.00	50.00	27.38
Total		1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	10.02	21.00	100.00	2.00	100.00	100.00

Site	Transect	Date	Distance (m)
BA-WAK	T-3	10/19/2015	41.60

		Linear Distance (m)									Cover		Frequency		Importance
SPECIES	COMMON	A	B	C	D	E	F	G	H	Total	Percent	Relative	Absolute	Relative	Value
Algae	Algae	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	20.80	50.00	62.50	1.00	50.00	56.25
Cabomba caroliniana	Fanwort	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	12.48	30.00	37.50	1.00	50.00	43.75
Total		4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.16	33.28	80.00	100.00	2.00	100.00	100.00

Wakulla Spring

Summary of Aquatic Vegetation - Line Intercept Method

Site	Transect	Date	Distance (m)
BA-WAK	T-4	10/19/2015	51.60

		Linear Distance (m)									Cover		Frequency		Importance
SPECIES	COMMON	A	B	C	D	E	F	G	H	Total	Percent	Relative	Absolute	Relative	Value
Cabomba caroliniana	Fanwort	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	41.28	80.00	100.00	1.00	100.00	100.00
Total		5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	41.28	80.00	100.00	1.00	100.00	100.00

Site	Transect	Date	Distance (m)
BA-WAK	T-5	10/19/2015	46.90

		Linear Distance (m)									Cover		Frequency		Importance
SPECIES	COMMON	A	B	C	D	E	F	G	H	Total	Percent	Relative	Absolute	Relative	Value
Algae	Algae	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46	19.70	42.00	54.55	1.00	33.33	43.94
Cabomba caroliniana	Fanwort	1.88	1.88	1.88	1.88	1.88	1.88	1.88	1.88	15.01	32.00	41.56	1.00	33.33	37.45
Vallisneria americana	Tape grass	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	1.41	3.00	3.90	1.00	33.33	18.61
Total		4.51	4.51	4.51	4.51	4.51	4.51	4.51	4.51	36.11	77.00	100.00	3.00	100.00	100.00

Site	Transect	Date	Distance (m)
BA-WAK	T-6	10/19/2015	51.40

		Linear Distance (m)									Cover		Frequency		Importance
SPECIES	COMMON	A	B	C	D	E	F	G	H	Total	Percent	Relative	Absolute	Relative	Value
Algae	Algae	5.14	5.14	5.14	5.14	5.14	5.14	5.14	5.14	41.12	80.00	84.21	1.00	50.00	67.11
Cabomba caroliniana	Fanwort	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	7.71	15.00	15.79	1.00	50.00	32.89
Total		6.10	6.10	6.10	6.10	6.10	6.10	6.10	6.10	48.83	95.00	100.00	2.00	100.00	100.00

Wakulla Spring

Summary of Aquatic Vegetation - Line Intercept Method

Site	Transect	Date	Distance (m)
BA-WAK	T-7	10/19/2015	94.00

		Linear Distance (m)									Cover		Frequency		Importance
SPECIES	COMMON	A	B	C	D	E	F	G	H	Total	Percent	Relative	Absolute	Relative	Value
Algae	Algae	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	4.70	5.00	8.33	1.00	50.00	29.17
Vallisneria americana	Tape grass	6.46	6.46	6.46	6.46	6.46	6.46	6.46	6.46	51.70	55.00	91.67	1.00	50.00	70.83
Total		7.05	7.05	7.05	7.05	7.05	7.05	7.05	7.05	56.40	60.00	100.00	2.00	100.00	100.00

Site	Transect	Date	Distance (m)
BA-WAK	T-8	10/19/2015	102.60

		Linear Distance (m)									Cover		Frequency		Importance
SPECIES	COMMON	A	B	C	D	E	F	G	H	Total	Percent	Relative	Absolute	Relative	Value
Algae	Algae	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	8.21	8.00	8.16	1.00	33.33	20.75
Najas guadalupensis	Southern naiad	1.92	1.92	1.92	1.92	1.92	1.92	1.92	1.92	15.39	15.00	15.31	1.00	33.33	24.32
Vallisneria americana	Tape grass	9.62	9.62	9.62	9.62	9.62	9.62	9.62	9.62	76.95	75.00	76.53	1.00	33.33	54.93
Total		12.57	12.57	12.57	12.57	12.57	12.57	12.57	12.57	100.55	98.00	100.00	3.00	100.00	100.00

Site	Transect	Date	Distance (m)
BA-WAK	T-9	10/19/2015	91.50

		Linear Distance (m)									Cover		Frequency		Importance
SPECIES	COMMON	A	B	C	D	E	F	G	H	Total	Percent	Relative	Absolute	Relative	Value
Algae	Algae	2.86	2.86	2.86	2.86	2.86	2.86	2.86	2.86	22.88	25.00	20.83	1.00	25.00	22.92
Cabomba caroliniana	Fanwort	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	13.73	15.00	12.50	1.00	25.00	18.75
Najas guadalupensis	Southern naiad	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	4.58	5.00	4.17	1.00	25.00	14.58
Vallisneria americana	Tape grass	8.58	8.58	8.58	8.58	8.58	8.58	8.58	8.58	68.63	75.00	62.50	1.00	25.00	43.75
Total		13.73	13.73	13.73	13.73	13.73	13.73	13.73	13.73	109.80	120.00	100.00	4.00	100.00	100.00

Appendix E

Bird Survey Data

Wakulla River Bird Survey				
Species	10-21-15	10-22-15	3-17-16	High Ct.
Wood Duck		8	8	8
Gadwall	1			1
Redhead	1			1
Bufflehead			3	3
Pied-billed Grebe	12	15	7	15
Double-crested Cormorant*	4	306	44	306
Anhinga	9	10	4	10
Great Blue Heron		3	2	3
Great Egret	5	9	4	9
Little Blue Heron	1			1
Tricolored Heron			2	2
White Ibis	17	12		17
Black Vulture	2	5	8	8
Turkey Vulture	7	8	31	31
Osprey		2	3	3
Bald Eagle			1	
Sharp-shinned Hawk	1	3	1	3
Red-shouldered Hawk	10	4	4	10
Common Gallinule		4	4	4
American Coot	10	5		10
Ring-billed Gull			2	2
Belted Kingfisher	6	5	2	6
Chimney Swift		1		1
Red-bellied Woodpecker	7	9	12	12
Red-headed Woodpecker			2	2
Downy Woodpecker	1		1	1
Northern Flicker	9	11	2	11
Pileated Woodpecker	11	8	7	11
Eastern Phoebe	8	14		14
Blue-headed Vireo			6	6
Red-eyed Vireo			1	1
White-eyed Vireo	1	3	2	3
Blue Jay	8	3	2	8
American Crow	6		1	6
Barn Swallow			4	4
Tree Swallow			6	6
Carolina Chickadee	1	1	9	9
Tufted Titmouse	5	5	19	19
Carolina Wren	5	3	15	15
Blue-gray Gnatcatcher		1	10	10
Ruby-crowned Kinglet			2	2
American Robin	2			2
Gray Catbird	11	8		11
Northern Mockingbird	3	1		3
Brown Thrasher	1			1
Brown-headed Cowbird			1	1
Northern Waterthrush	1			1
Northern Parula			41	41
Yellow-throated Warbler			15	15
Pine Warbler			1	1
Yellow-rumped Warbler			2	2
Black-and-white Warbler	2		1	2
Common Yellowthroat	3	2	22	22
Northern Cardinal	15	9	17	17
Red-winged Blackbird		6	55	55
Common Grackle		4	7	7
Boat-tailed Grackle		2	1	2
American Goldfinch			37	37
Total Species	33	33	46	57

* = Double-Crested Cormorant consists of about 300 fly-overs and 6 within the river

Appendix F

Fish Counts

Location	Date	Family	Scientific Name	Common Name	Total	Density (#/ha)	Biomass (kg/ha)
Segment-1	10/20/15	*Centrarchidae*	*Lepomis sp.*	Sunfish sp.	7	19.3	0.510
			Micropterus salmoides	Largemouth Bass	1	2.76	0.042
		Cyprinidae	*Notropis sp.*	Minnows	135	373	0.615
Segment-2	10/20/15	*Centrarchidae*	*Lepomis sp.*	Sunfish sp.	3	6.49	0.085
		Cyprinidae	*Notropis sp.*	Minnows	285	617	1.02
		Mugilidae	*Mugil cephalus*	Striped mullet	5	10.8	8.47

Appendix G

Human Use Surveys

Wakulla River Human Use Survey – October 2015

	Activity	People-Hrs		# People		# People/ha	
		10/19/15	10/28/15	10/19/15	10/28/15	10/19/15	10/28/15
In-Water	Wading	0.0	0.0	0.0	0.0	0.00	0.00
	Bathing	0.0	0.0	0.0	0.0	0.00	0.00
	Swimming	0.0	0.0	0.0	0.0	0.00	0.00
	Snorkeling	0.0	0.0	0.0	0.0	0.00	0.00
	SCUBA	0.0	0.0	0.0	0.0	0.00	0.00
	Tubing	0.0	0.0	0.0	0.0	0.00	0.00
	Canoeing/ Kayaking	1.0	10.0	0.2	2.7	0.12	1.65
	Power Boating	1.0	0.8	0.2	0.2	0.12	0.12
	Tour Boating	0.0	0.0	0.0	0.0	0.00	0.00
	Fishing	0.0	0.0	0.0	0.0	0.00	0.00
	Other	7.0	0.0	1.4	0.0	0.86	0.00
	Total	9.0	10.8	1.8	2.9	1.1	1.8
Out-of-Water	Sitting	3.0	1.0	0.6	0.3	0.37	0.16
	Walking	10.0	0.8	2.0	0.2	1.24	0.12
	Sunbathing	0.0	0.0	0.0	0.0	0.00	0.00
	Nature Study	0.0	1.8	0.0	0.5	0.00	0.29
	Other	1.3	0.3	0.3	0.1	0.15	0.04
	Total	14.3	3.8	2.9	1.0	1.8	0.6
Total		23.3	14.5	4.7	3.9	2.9	2.4

Note(s):

Hours of Observations:	5.0	3.8
Survey Area (ac):	4.0	

Howard T. Odum FLORIDA SPRINGS INSTITUTE

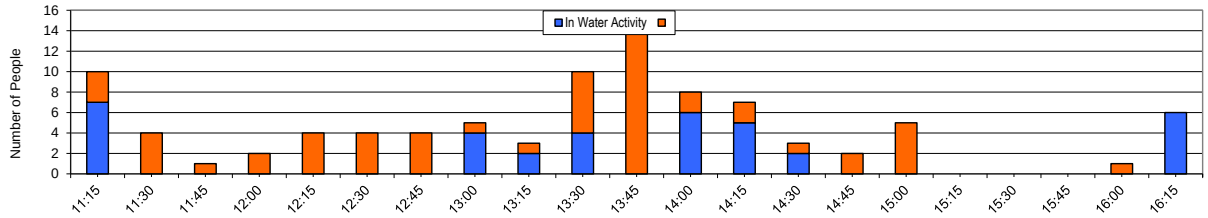
Wakulla Springs Baseline Assessment

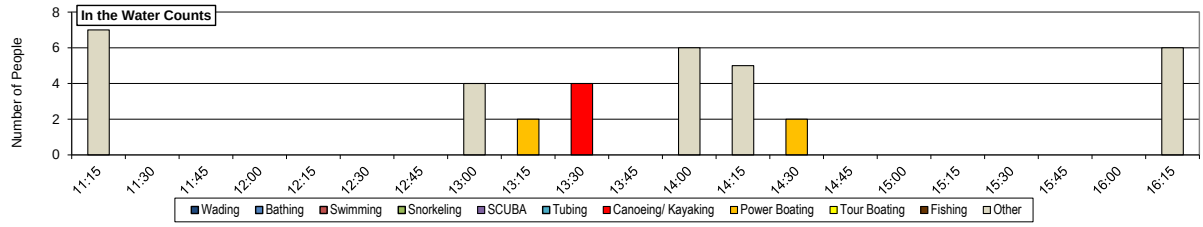
Site Wakulla River @ Boat Ramp US 98 **Date** 10/19/2015 **Survey Period** 11:15 16:15

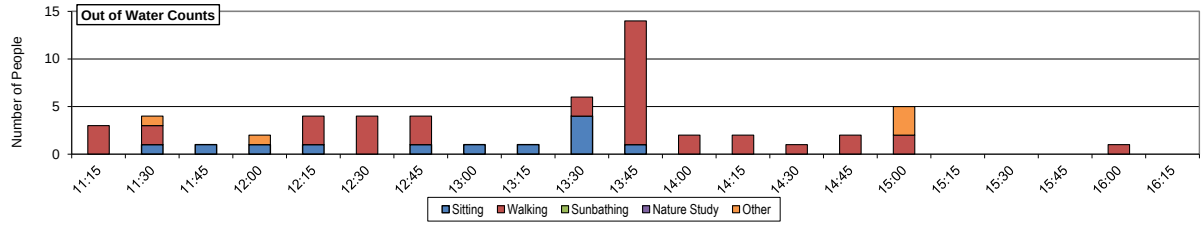
	Numbers of People																	
	In Water Activity												Out of Water Activity					
Time	Wading	Bathing	Swimming	Snorkeling	SCUBA	Tubing	Canoeing/ Kayaking	Power Boating	Tour Boating	Fishing	Other	Total	Sitting	Walking	Sunbathing	Nature Study	Other	Total
11:15											7	7		3				3
11:30												0	1	2			1	4
11:45												0	1					1
12:00												0	1				1	2
12:15												0	1	3				4
12:30												0		4				4
12:45												0	1	3				4
13:00											4	4	1					1
13:15								2				2	1					1
13:30							4					4	4	2				6
13:45												0	1	13				14
14:00											6	6		2				2
14:15											5	5		2				2
14:30								2				2		1				1
14:45												0		2				2
15:00												0		2			3	5
15:15												0						0
15:30												0						0
15:45												0						0
16:00												0		1				1
16:15											6	6						0
Total	0	0	0	0	0	0	4	4	0	0	28	36	12	40	0	0	5	57
Person-Hrs	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	7.00	9.00	3.00	10.00	0.00	0.00	1.25	14.25
Percentage	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	11.1%	11.1%	0.0%	0.0%	77.8%	100.0%	21.1%	70.2%	0.0%	0.0%	8.8%	100.0%

Note(s):
'Other' In Water Activity = Nature Study
'Other' Out of Water Activity = Fishing, Sleeping in car, and Wakulla County Sheriff performing maintenance

Average Time Interval (hrs): 0.25







Howard T. Odum FLORIDA SPRINGS INSTITUTE

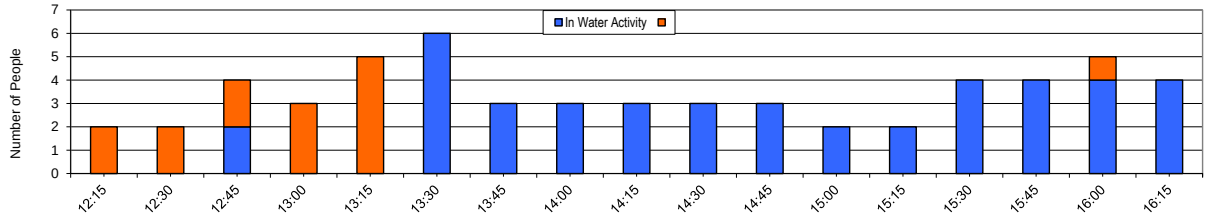
Wakulla Springs Baseline Assessment

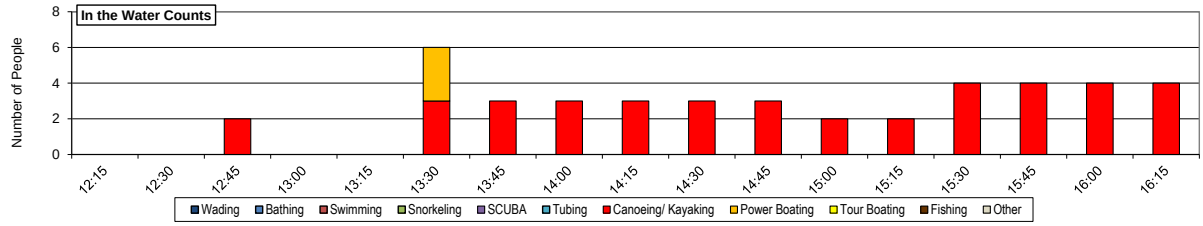
Site Wakulla River @ Boat Ramp US 98 **Date** 10/28/2015 **Survey Period** 12:15 16:00

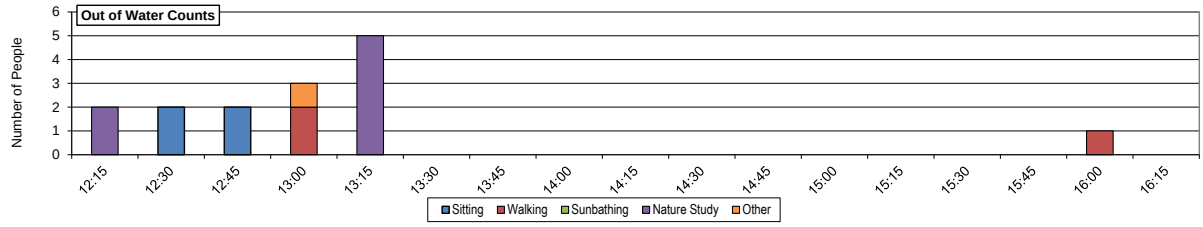
	Numbers of People																	
	In Water Activity												Out of Water Activity					
Time	Wading	Bathing	Swimming	Snorkeling	SCUBA	Tubing	Canoeing/ Kayaking	Power Boating	Tour Boating	Fishing	Other	Total	Sitting	Walking	Sunbathing	Nature Study	Other	Total
12:15												0				2		2
12:30												0	2					2
12:45							2					2	2					2
13:00												0		2			1	3
13:15												0				5		5
13:30							3	3				6						0
13:45							3					3						0
14:00							3					3						0
14:15							3					3						0
14:30							3					3						0
14:45							3					3						0
15:00							2					2						0
15:15							2					2						0
15:30							4					4						0
15:45							4					4						0
16:00							4					4		1				1
16:15							4					4						0
Total	0	0	0	0	0	0	40	3	0	0	0	43	4	3	0	7	1	15
Person-Hrs	0.00	0.00	0.00	0.00	0.00	0.00	10.00	0.75	0.00	0.00	0.00	10.75	1.00	0.75	0.00	1.75	0.25	3.75
Percentage	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	93.0%	7.0%	0.0%	0.0%	0.0%	100.0%	26.7%	20.0%	0.0%	46.7%	6.7%	100.0%

Note(s):
'Other' In Water Activity = Nature Study
'Other' Out of Water Activity = Sitting in car

Average Time Interval (hrs): 0.25





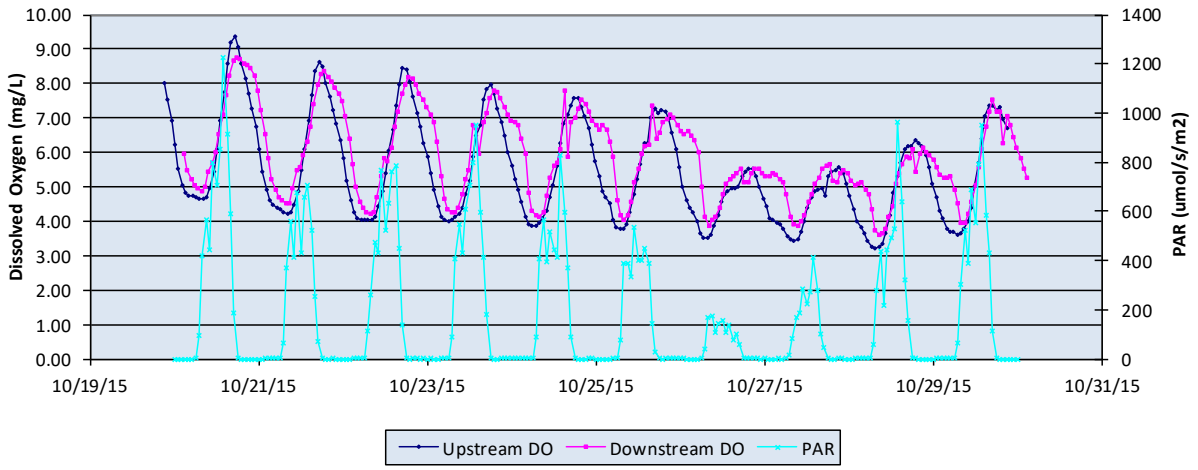


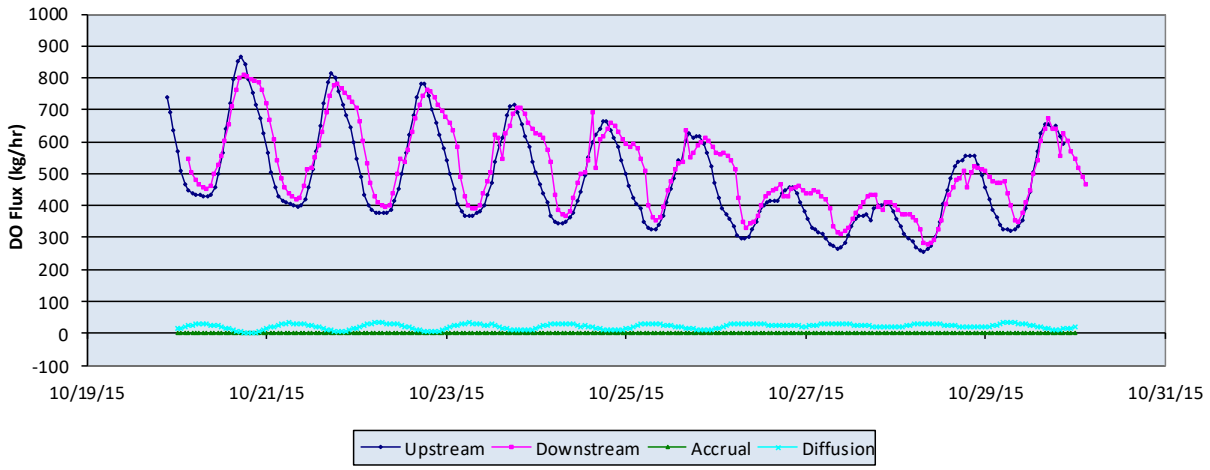
Station Description	Date	Time	Activity	Number of People	Notes
WK-2	10/29/2015	12:37	Paddleboard	2	
Near Insect trap #5	10/30/2015	10:08	Kayak	7	
Near Insect trap #5	10/30/2015	10:08	Powerboat	10	
Near Insect trap #1	10/30/2015	10:10	Paddleboard	2	
Near BM Staff	3/17/2016	11:53	Canoe	7	
Near BM Staff	3/17/2016	11:53	Fishing Boat	1	90 Hp
WK-3	3/17/2016	13:24	Kayak	1	Fishing
---	3/17/2016	---	Kayak	7	

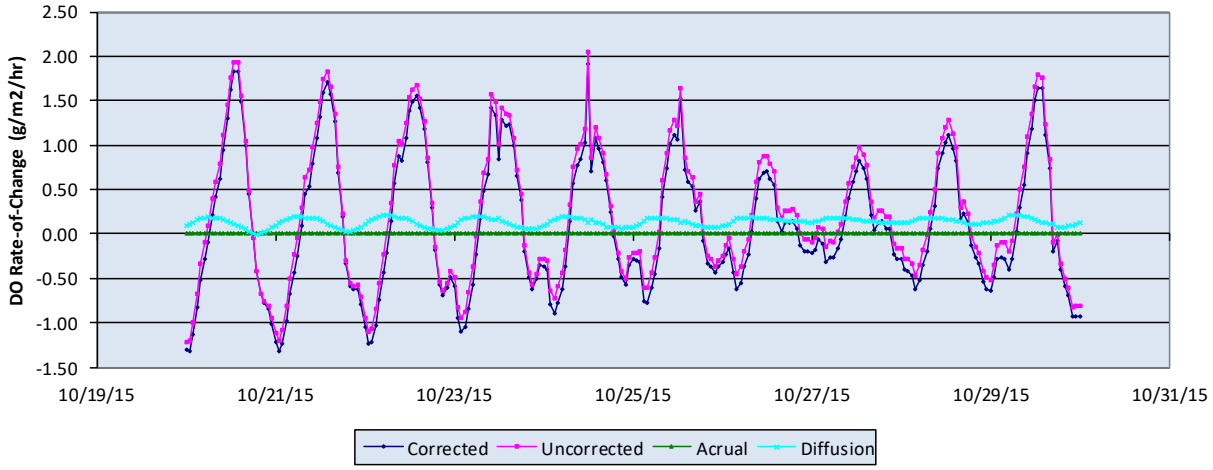
---	3/17/2016	---	Dock	2	Standing
---	3/17/2016	---	Powerboating	2	
Near Bridge	3/7/2016	11:37	Fishing	4	
Near Bridge	3/7/2016	11:37	Powerboat	4	40Hp
WP 495	3/7/2016	12:34	Kayak	2	
WP 494	3/7/2016	13:00	Kayak	4	
WP 487	3/7/2016	13:25	Kayak	2	
WP 488	3/7/2016	13:28	Kayak	3	
WK-1	3/7/2016	14:02	Powerboat	6	
WK-1	3/7/2016	14:07	Kayak	1	
WK-1	3/7/2016	14:07	Paddleboard	1	
WK-1	3/7/2016	14:07	Kayak	2	
WK-1	3/7/2016	14:07	Powerboat	2	
WK-1	3/7/2016	14:07	Scuba	1	Boat - 90 Hp
WK-1	3/8/2016	11:08	Kayak	2	
WK-1	3/8/2016	10:55	Kayak	16	
WK-1	3/8/2016	11:14	Powerboat	2	
WK-2	3/8/2016	11:23	Kayak	2	
Near Bridge	3/8/2016	11:31	Kayak	2	
WK-3	3/8/2016	11:43	Kayak	4	

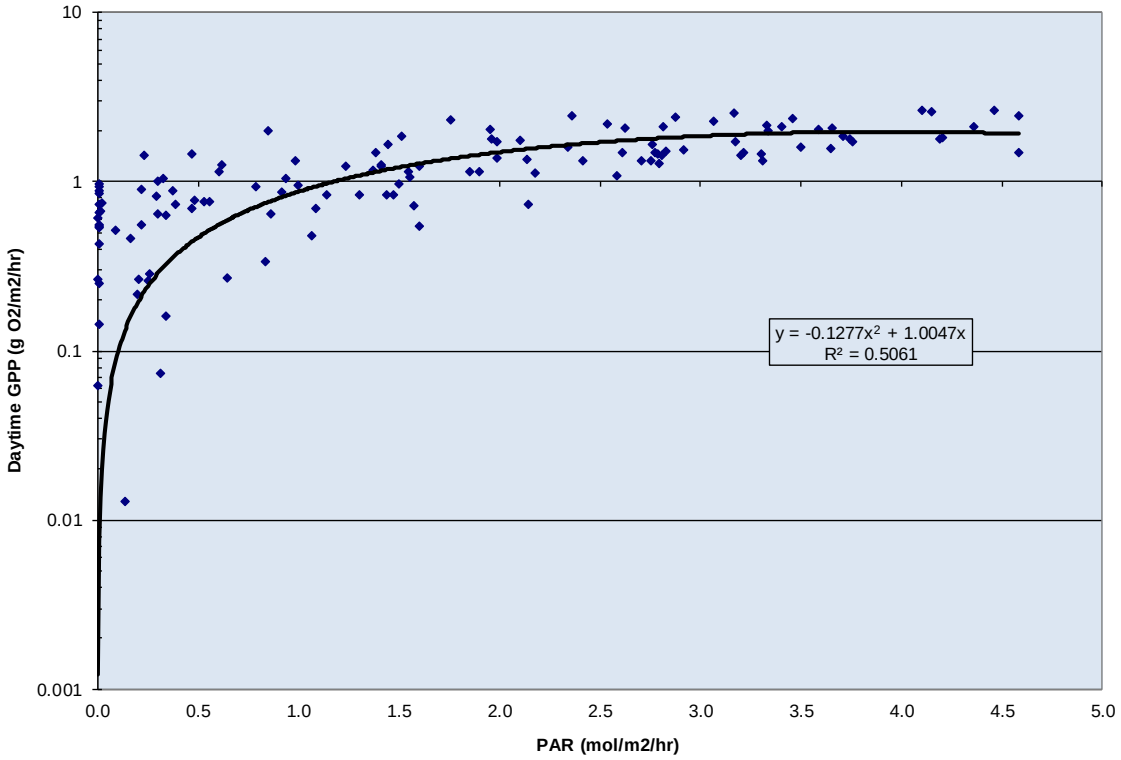
Appendix H

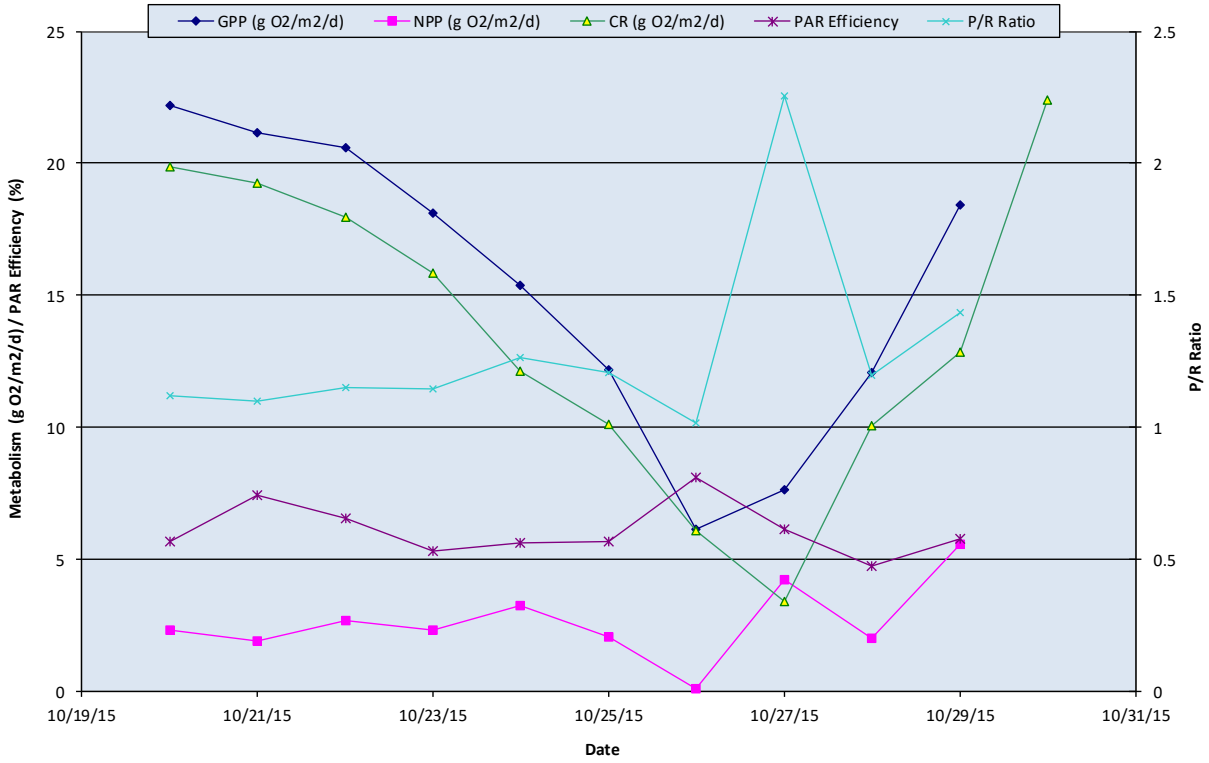
Ecosystem Metabolism Summary

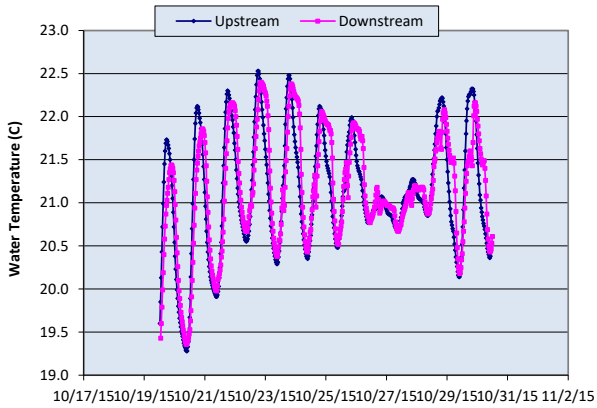

Dissolved Oxygen (mg/L)
PAR (umol/s/m2)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1400
1200
1000
800
600
400
200
0
10/19/15
10/21/15
10/23/15
10/25/15
10/27/15
10/29/15
10/31/15
Upstream DO
Downstream DO
PAR

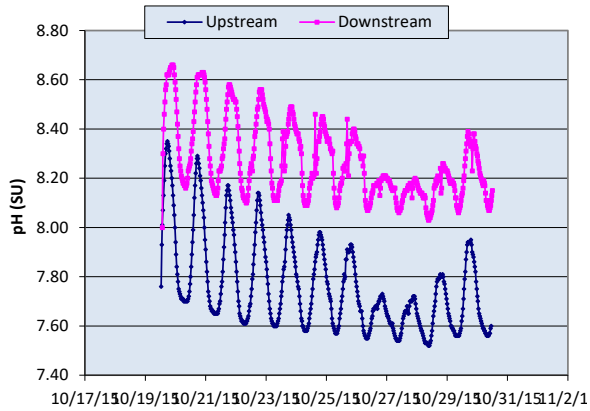

DO Flux (kg/hr)
1000
900
800
700
600
500
400
300
200
100
0
-100
10/19/15
10/21/15
10/23/15
10/25/15
10/27/15
10/29/15
10/31/15
Upstream
Downstream
Accrual
Diffusion

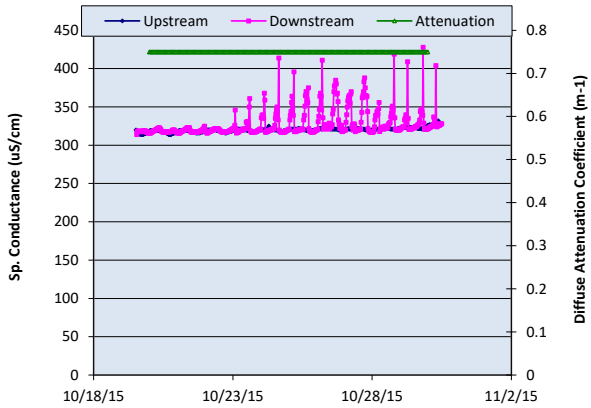

DO Rate-of-Change (g/m2/hr)
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
10/19/15
10/21/15
10/23/15
10/25/15
10/27/15
10/29/15
10/31/15
Corrected
Uncorrected
Acrual
Diffusion

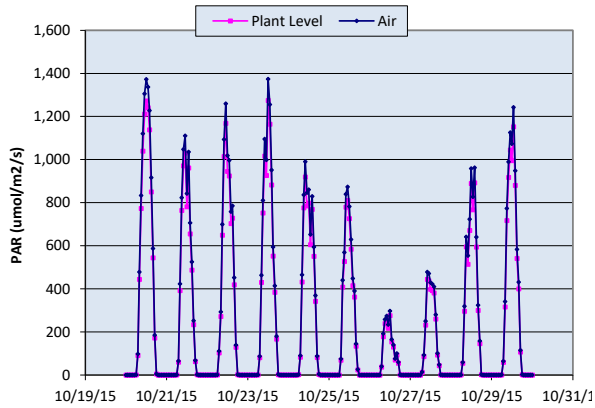

Daytime GPP (g O2/m2/hr)
PAR (mol/m2/hr)
y = -0.1277x² + 1.0047x
R² = 0.5061
10
1
0.1
0.01
0.001
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

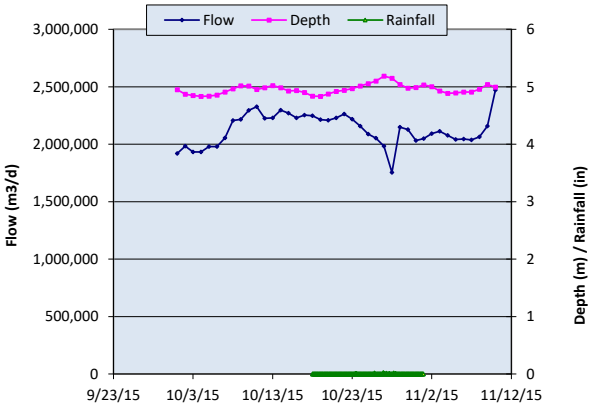

GPP (g O2/m2/d)
NPP (g O2/m2/d)
CR (g O2/m2/d)
PAR Efficiency
P/R Ratio
Metabolism (g O2/m2/d) / PAR Efficiency (%)
P/R Ratio
Date
25
20
15
10
5
0
2.5
2
1.5
1
0.5
0
10/19/15
10/21/15
10/23/15
10/25/15
10/27/15
10/29/15
10/31/15



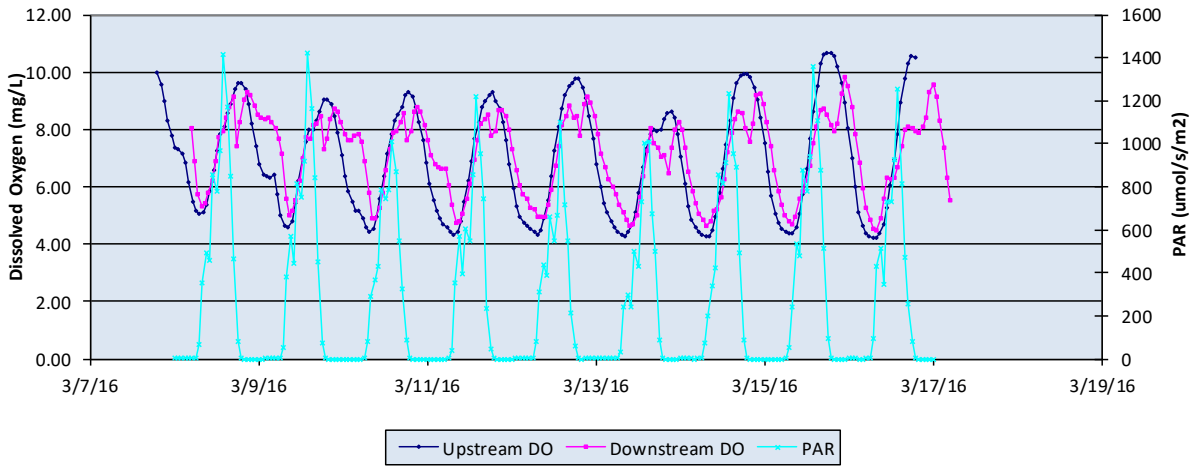


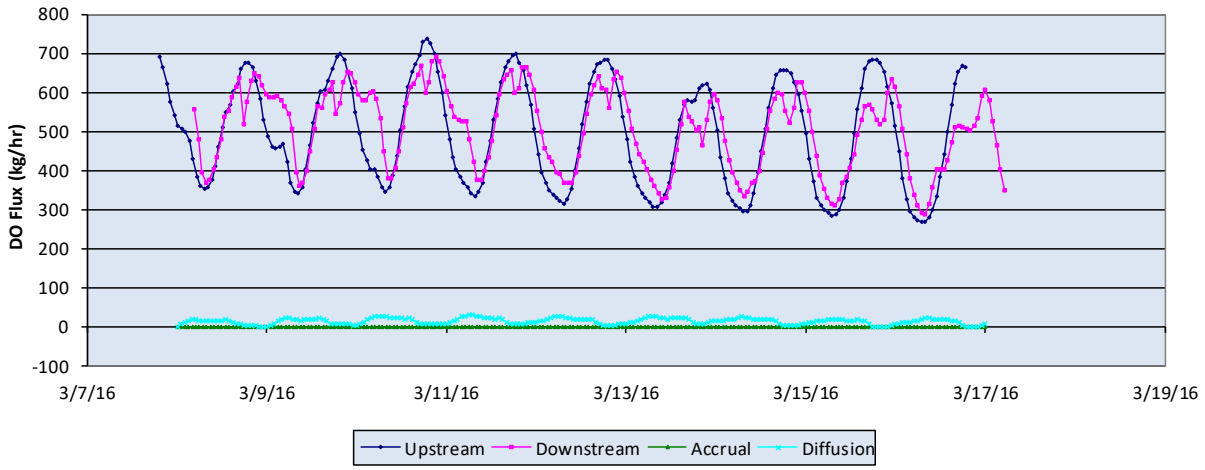


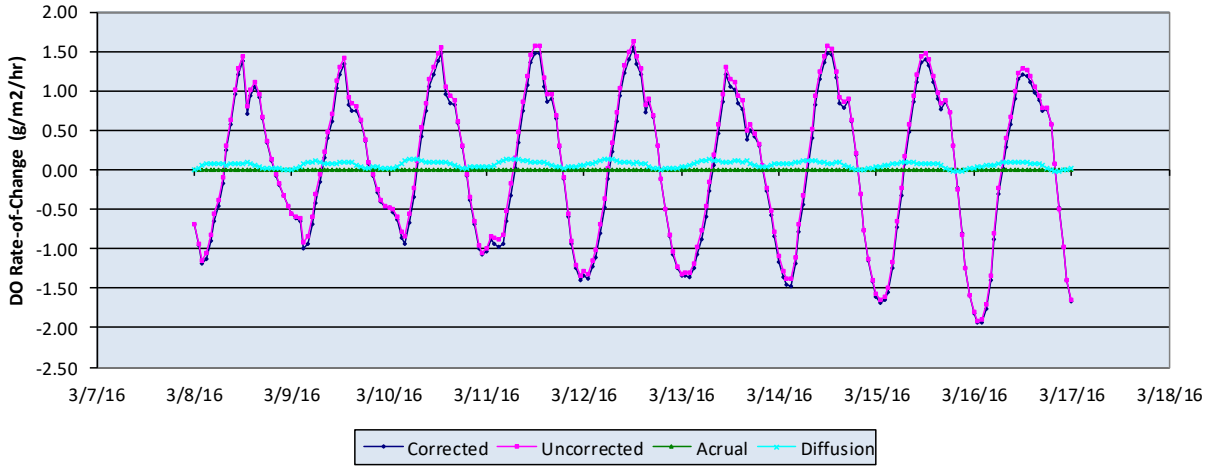


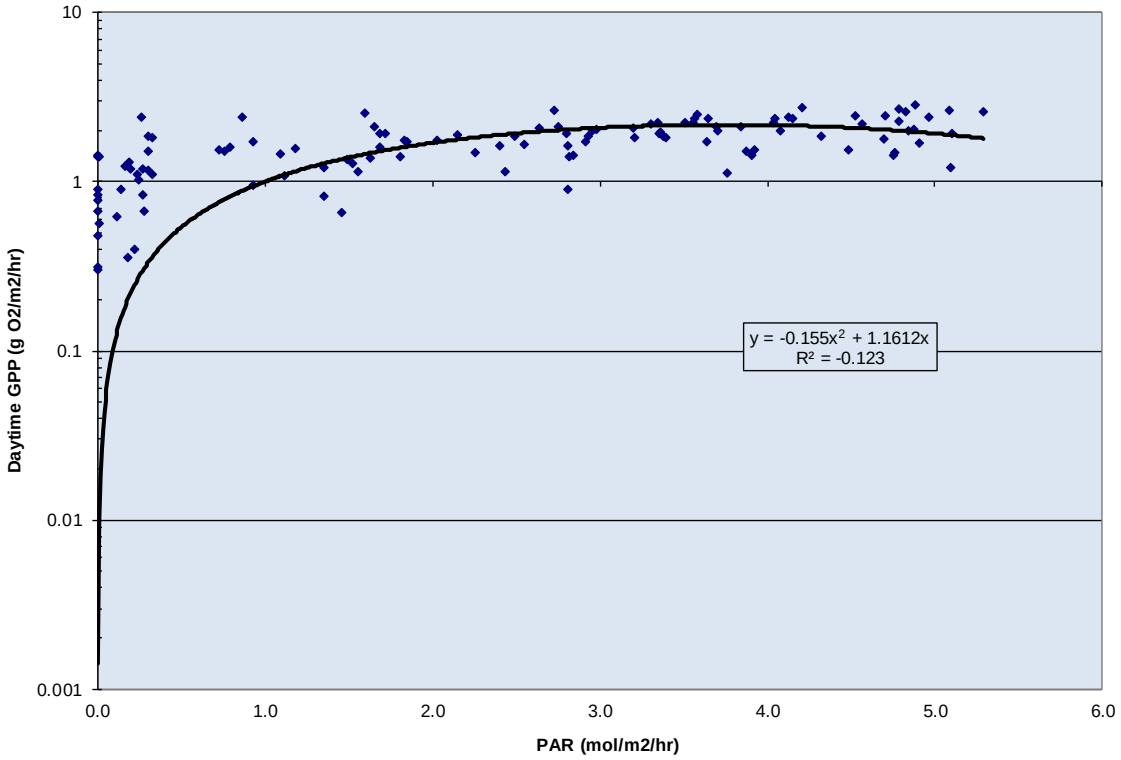


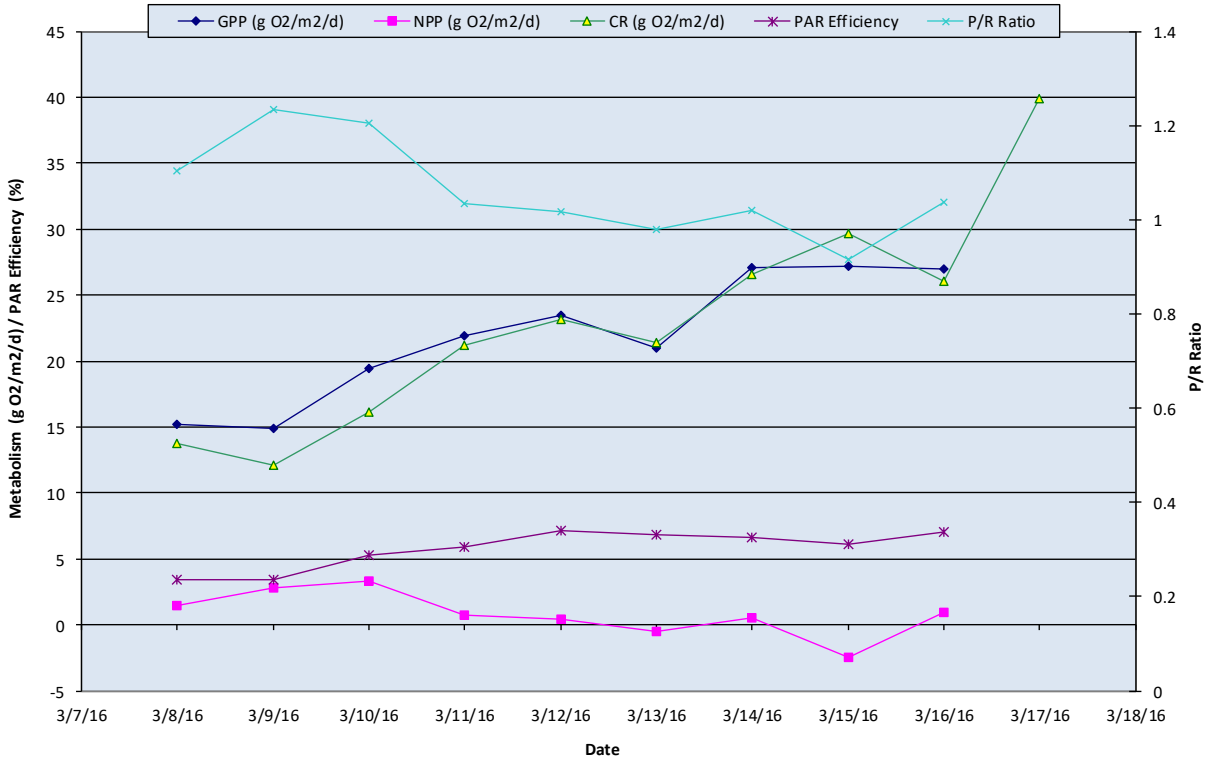
Parameter	Units	Avg	Min	Max	N
DO - up	mg/L	5.50	3.19	9.73	526
down		5.93	3.57	9.14	520
Wtr Temp - up	C	21.1	19.3	22.5	526
down		21.2	19.4	22.4	527
pH - up	SU	7.77	7.52	8.35	526
down		8.27	8.00	8.66	526
SpCond - up	uS/cm	320	314	332	526
down		327	314	428	527
Flow - up	m^3/d	2,127,268	1,754,195	2,471,042	41
Depth	m	4.96	4.83	5.19	41
Rainfall Total	in		0.2		
PAR - air	$umol/m^2/s$	289	0.0	1,423	336
plant		242	0.0	1274	241
DO rate chng	$g/m^2/hr$				
corr		0.102	-1.318	1.920	241
uncorr		0.235	-1.221	2.045	241


Dissolved Oxygen (mg/L)
PAR (umol/s/m2)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1600
1400
1200
1000
800
600
400
200
0
3/7/16
3/9/16
3/11/16
3/13/16
3/15/16
3/17/16
3/19/16
Upstream DO
Downstream DO
PAR


DO Flux (kg/hr)
800
700
600
500
400
300
200
100
0
-100
3/7/16
3/9/16
3/11/16
3/13/16
3/15/16
3/17/16
3/19/16
Upstream
Downstream
Accrual
Diffusion

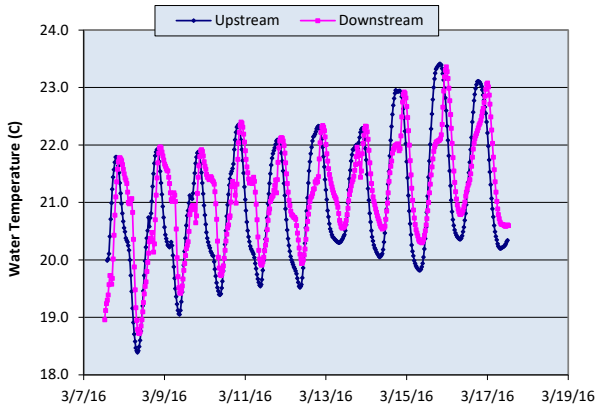

DO Rate-of-Change (g/m2/hr)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
3/7/16
3/8/16
3/9/16
3/10/16
3/11/16
3/12/16
3/13/16
3/14/16
3/15/16
3/16/16
3/17/16
3/18/16
Corrected
Uncorrected
Acrual
Diffusion

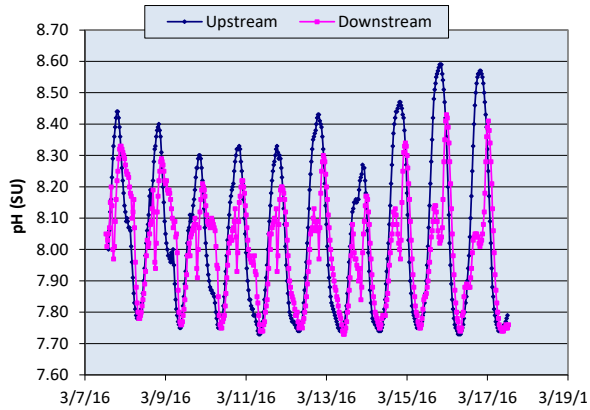

Daytime GPP (g O2/m2/hr)
PAR (mol/m2/hr)
y = -0.155x² + 1.1612x
R² = -0.123
10
1
0.1
0.01
0.001
0.0
1.0
2.0
3.0
4.0
5.0
6.0

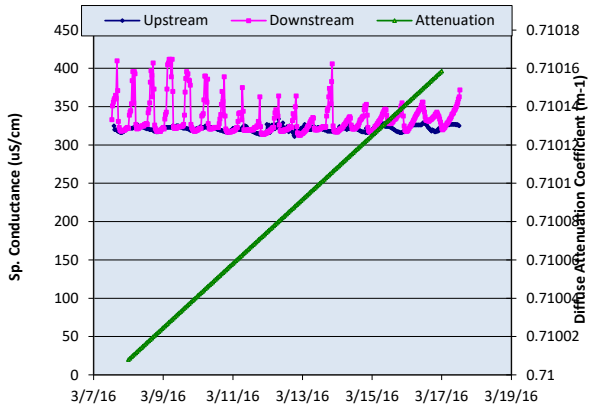

GPP (g O2/m2/d)
NPP (g O2/m2/d)
CR (g O2/m2/d)
PAR Efficiency
P/R Ratio
Metabolism (g O2/m2/d) / PAR Efficiency (%)
P/R Ratio
Date
3/7/16
3/8/16
3/9/16
3/10/16
3/11/16
3/12/16
3/13/16
3/14/16
3/15/16
3/16/16
3/17/16
3/18/16

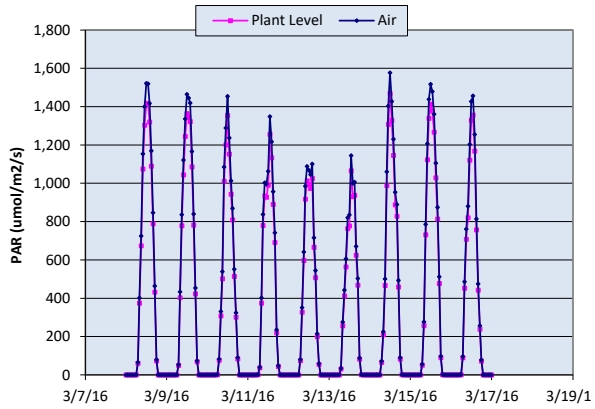
APPENDIX X

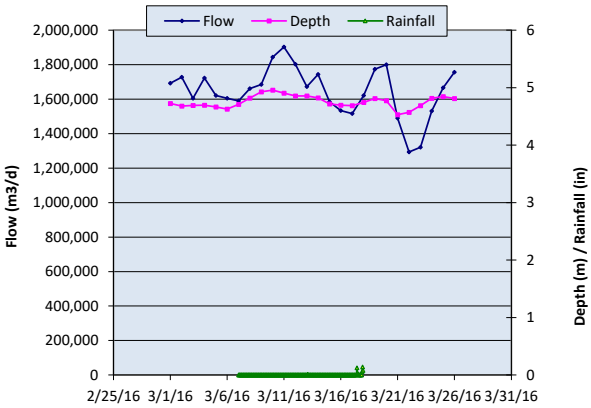
WAKULLA RIVER METABOLISM SUMMARY











Parameter	Units	Avg	Min	Max	N
DO - up	mg/L	6.96	4.17	10.70	477
down		7.15	4.48	9.81	481
Wtr Temp - up	C	21.0	18.4	23.4	477
down		21.2	18.7	23.4	481
pH - up	SU	8.05	7.73	8.59	477
down		8.00	7.73	8.43	481
SpCond - up	uS/cm	321	311	334	477
down		334	313	412	481
Flow - up	m^3/d	1,043,256	0,000	1,903,436	41
Depth	m	4.40	3.78	4.96	41
Rainfall Total	in		0.5		
PAR - air	$umol/m^2/s$	290	0.0	1,577	336
plant		362	0.0	1469	217
DO rate chng	$g/m^2/hr$				
corr		-0.005	-1.938	1.552	217
uncorr		0.059	-1.908	1.634	217

Appendix I

Nutrient Assimilation Detail

Wakulla River estimated nutrient mass removals

			Inflow (WK-1)				Outflow (WK-3)				Removal				
			Segment - Up				Segment - Down								
			Conc	Flow	Mass	Mass	Conc	Flow	Mass	Mass	Conc		Mass		
Parameter	Units	Month	(mg/L)	(m^3/d)	(kg/d)	(kg/ha/d)	(mg/L)	(m^3/d)	(kg/d)	(kg/ha/d)	(mg/L)	(%)	(kg/d)	(kg/ha/d)	(%)
NH4-N	mg/L	Oct-15	0.040	2,130,968	85.2	5.5	0.010	2,130,968	21.3	1.4	0.030	75.0	63.9	4.14	75.0
		Mar-16	0.010	1,749,302	17.5	1.1	0.015	1,749,302	26.2	1.7	-0.005	-50.0	-8.7	-0.57	-50.0
		POR	0.026	1,940,135	51.4	3.3	0.012	1,940,135	23.8	1.5	0.014	53.7	27.6	1.78	53.7
NOx-N	mg/L	Oct-15	0.30	2,130,968	629	40.7	0.30	2,130,968	629	40.7	0.000	0.0	0.0	0.00	0.0
		Mar-16	0.50	1,749,302	866	56.0	0.37	1,749,302	638	41.3	0.130	26.3	227.4	14.71	26.3
		POR	0.39	1,940,135	747	48.3	0.33	1,940,135	634	41.0	0.059	15.2	113.7	7.36	15.2
Org N	mg/L	Oct-15	0.02	2,130,968	36.2	2.3	0.13	2,130,968	270.6	17.5	-0.110	-647.1	-234.4	-15.16	-647.1
		Mar-16	0.07	1,749,302	122.5	7.9	0.05	1,749,302	84.0	5.4	0.022	31.4	38.5	2.49	31.4
		POR	0.04	1,940,135	79.3	5.1	0.09	1,940,135	177.3	11.5	-0.050	-123.5	-98.0	-6.34	-123.5
TKN	mg/L	Oct-15	0.04	2,130,968	93.8	6.1	0.14	2,130,968	291.9	18.9	-0.093	-211.4	-198.2	-12.82	-211.4
		Mar-16	0.07	1,749,302	119.0	7.7	0.05	1,749,302	87.5	5.7	0.018	26.5	31.5	2.04	26.5
		POR	0.05	1,940,135	106.4	6.9	0.10	1,940,135	189.7	12.3	-0.043	-78.4	-83.3	-5.39	-78.4
TN	mg/L	Oct-15	0.35	2,130,968	750	48.5	0.43	2,130,968	921	59.5	-0.080	-22.7	-170.5	-11.03	-22.7
		Mar-16	0.58	1,749,302	1,006	65.1	0.43	1,749,302	749	48.4	0.147	25.6	257.1	16.63	25.6
		POR	0.45	1,940,135	878	56.8	0.43	1,940,135	835	54.0	0.022	4.9	43.3	2.80	4.9

Segment Area (ha): 15.46

Appendix J

Particulate Export Detail

Station	Date	Start Time	Sample #	Upstream Area (m^2)	Time of Tow (s)	Flow Rate (m^3/s)	Net Area (m^2)	Water Velocity (m/s)	Volume Filtered (m^3)	Total Sample Volume (mL)	Laboratory Analysis					Total Sample		Dry Matter (g/m^3)	Organic Matter (g/m^3)	Dry Matter (g/d)	Organic Matter (g/d)	Dry Matter ($g/m^2/d$)	Organic Matter ($g/m^2/d$)
											Vol. Dried (mL)	Dry Wt. (g)	Ash Wt. (g)	% Ash	Ash-Free Dry Wt. (g)	Dry Wt. (g)	Ash-Free Dry Wt. (g)						
WK-1	10/20/15	13:20	35	598,930	120	25.57	0.1886	0.34	7.79	92	56	0.36	0.15	41.29	0.2090	0.585	0.3434	0.07504	0.04405	165,783	97,328	0.277	0.163
WK-1	10/20/15	13:27	54	598,930	120	25.57	0.1886	0.33	7.38	93	52	0.46	0.20	43.75	0.2610	0.830	0.4668	0.11244	0.06325	248,417	139,735	0.415	0.233
WK-1	10/20/15	13:34	88	598,930	120	25.57	0.1886	0.33	7.45	97	61	0.47	0.23	48.63	0.2430	0.752	0.3864	0.10097	0.05187	223,073	114,602	0.372	0.191
WK-3	10/20/15	11:49	43	752,709	120	25.57	0.1886	0.30	6.69	93	63	0.24	0.11	48.12	0.1240	0.353	0.1830	0.05273	0.02736	116,503	60,445	0.155	0.080
WK-3	10/20/15	12:00	69	752,709	120	25.57	0.1886	0.26	5.93	98	62	0.36	0.16	44.66	0.1970	0.563	0.3114	0.09487	0.05250	209,582	115,977	0.278	0.154
WK-3	10/20/15	12:09	28	752,709	120	25.57	0.1886	0.23	5.17	82	55	0.35	0.13	36.65	0.2230	0.525	0.3325	0.10145	0.06427	224,130	141,992	0.298	0.189
WK-1	10/29/15	14:10	53	598,930	120	24.86	0.1886	0.40	8.97	103	65	0.53	0.20	38.39	0.3290	0.846	0.5213	0.09437	0.05814	202,720	124,897	0.338	0.209
WK-1	10/29/15	14:17	21	598,930	120	24.86	0.1886	0.41	9.17	70	70	0.85	0.27	31.76	0.5780	0.847	0.5780	0.09233	0.06301	198,338	135,348	0.331	0.226
WK-1	10/29/15	14:26	44	598,930	120	24.86	0.1886	0.40	8.97	96	63	0.45	0.17	37.03	0.2840	0.687	0.4328	0.07665	0.04826	164,641	103,677	0.275	0.173
WK-3	10/30/15	10:20	42	752,709	120	24.86	0.1886	0.32	7.24	102	53	0.64	0.28	43.55	0.3630	1.237	0.6986	0.17087	0.09646	367,046	207,213	0.488	0.275
WK-3	10/30/15	10:24	57	752,709	120	24.86	0.1886	0.27	6.14	110	62	0.74	0.34	45.56	0.4050	1.320	0.7185	0.21503	0.11705	461,912	251,444	0.614	0.334
WK-3	10/30/15	10:38	26	752,709	120	24.86	0.1886	0.23	5.17	115	63	0.75	0.31	42.09	0.4320	1.362	0.7886	0.26324	0.15244	565,470	327,457	0.751	0.435

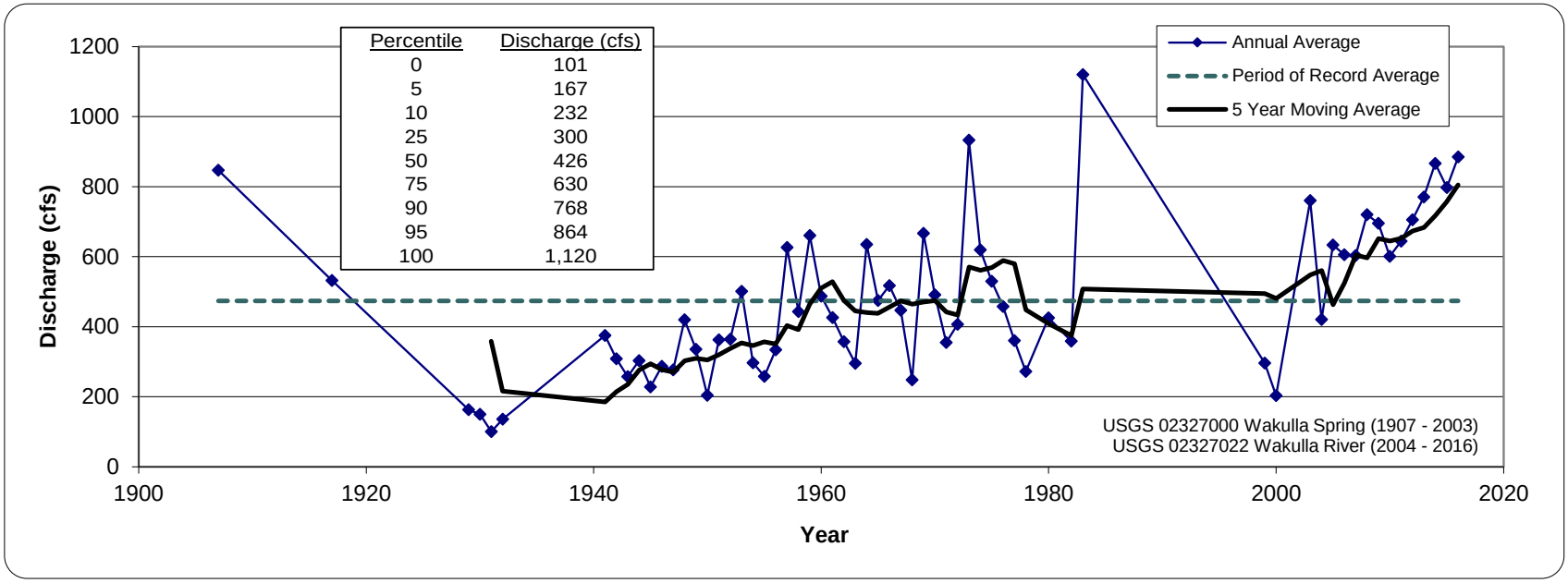
Station	Date	Start Time	Sample #	Upstream Area (m^2)	Time of Tow (s)	Flow Rate (m^3/s)	Net Area (m^2)	Water Velocity (m/s)	Volume Filtered (m^3)	Total Sample Volume (mL)	Laboratory Analysis					Total Sample		Dry Matter (g/m^3)	Organic Matter (g/m^3)	Dry Matter (g/d)	Organic Matter (g/d)	Dry Matter ($g/m^2/d$)	Organic Matter ($g/m^2/d$)
											Vol. Dried (mL)	Dry Wt. (g)	Ash Wt. (g)	% Ash	Ash-Free Dry Wt. (g)	Dry Wt. (g)	Ash-Free Dry Wt. (g)						
WK-1	3/8/16	10:38	28	598,930	120	19.23	0.1886	0.29	6.55	60	60	0.62	0.29	47.42	0.3260	0.620	0.3260	0.09462	0.04975	157,188	82,650	0.262	0.138
WK-1 *	3/8/16	10:44	17	598,930	120	19.23	0.1886	0.36	8.21	57	57	0.36	-0.44	-120.88	0.8040	0.364	0.8040	0.04435	0.09796	73,672	162,727	0.123	0.272
WK-1	3/8/16	10:50	67	598,930	120	19.23	0.1886	0.33	7.45	60	60	0.38	0.16	41.78	0.2230	0.383	0.2230	0.05142	0.02994	85,413	49,731	0.143	0.083
WK-3	3/8/16	9:51	42	752,709	120	19.23	0.1886	0.56	12.76	65	65	0.97	0.48	49.84	0.4850	0.967	0.4850	0.07578	0.03801	125,894	63,142	0.167	0.084
WK-3	3/8/16	9:58	26	752,709	120	19.23	0.1886	0.41	9.31	69	69	1.15	0.21	18.08	0.9380	1.145	0.9380	0.12297	0.10074	204,278	167,347	0.271	0.222
WK-3	3/8/16	10:08	84	752,709	120	19.23	0.1886	0.47	10.69	60	60	1.17	0.43	36.63	0.7440	1.174	0.7440	0.10981	0.06959	182,426	115,609	0.242	0.154

* flagged sample - questionable data

Appendix K

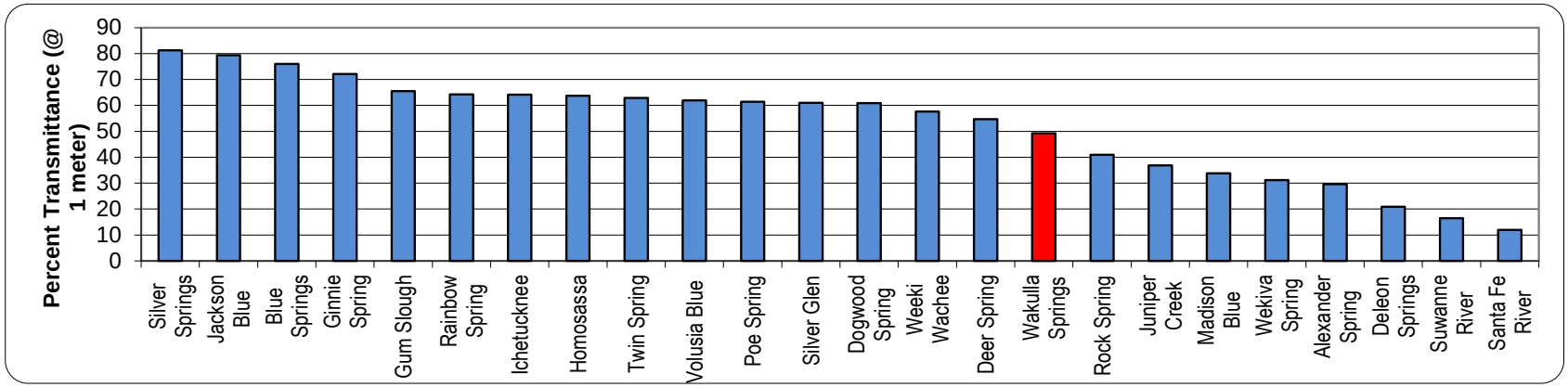
Wakulla Springs 2016 Report Card

WAKULLA SPRINGS AND RIVER



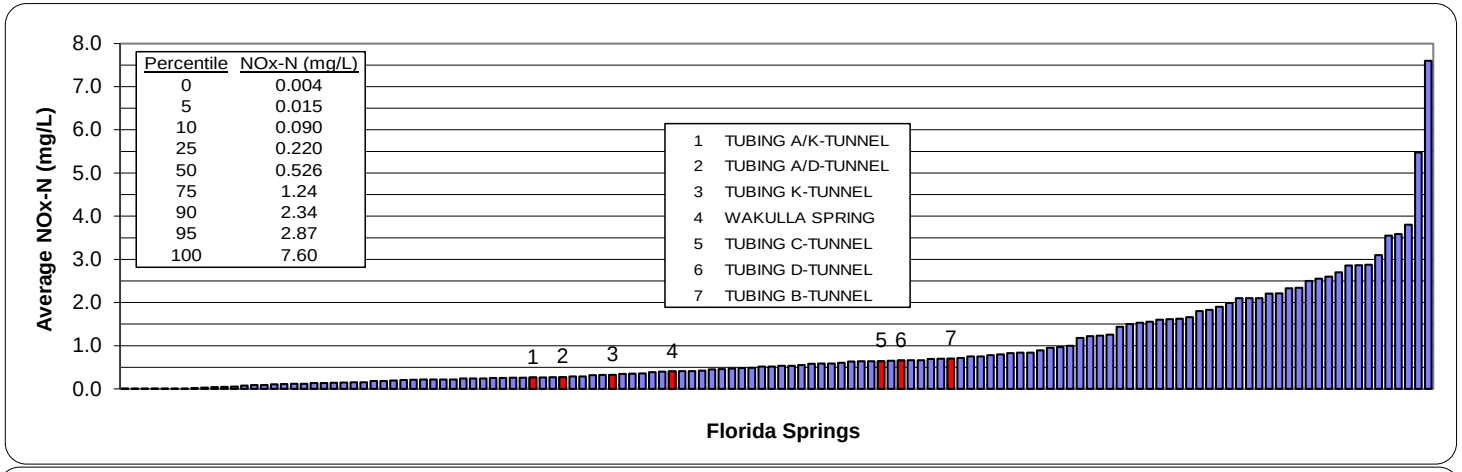
Spring Discharge	Grade	Average (2012-2016)	A: > 654 cfs B: 493 - 653 cfs C: 364 - 492 cfs D: 290 - 363 cfs F: < 289 cfs
	A	**805 cfs**	

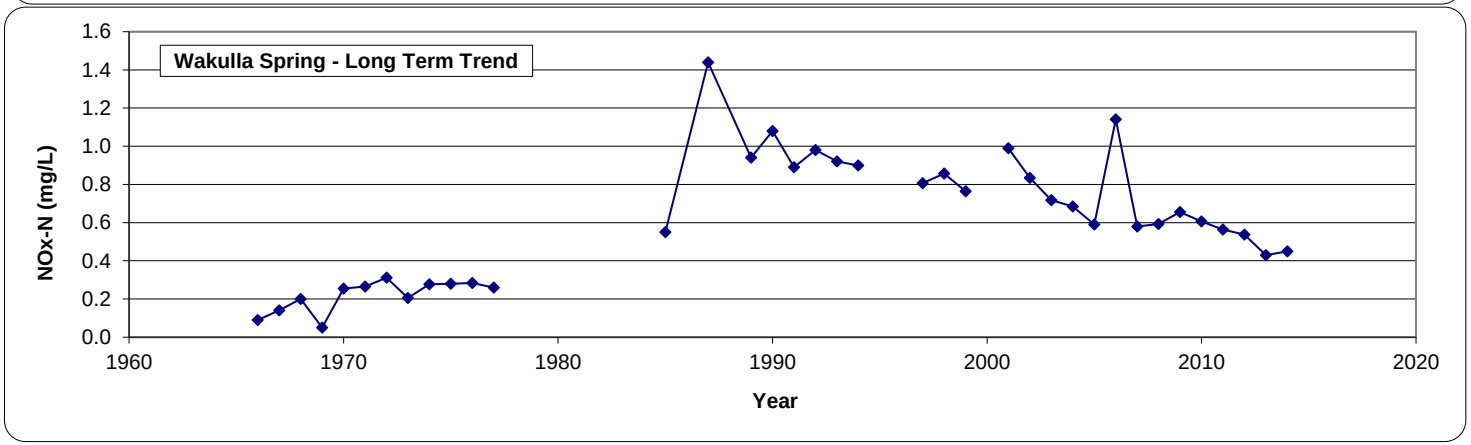
WAKULLA SPRINGS AND RIVER



Water Clarity @ Spring Run	Grade	Average (2015-2016)	A: > 70 % B: 60 - 69 % C: 50 - 59 % D: 40 - 49 % F: < 40 %
	D	**49%** Light Transmittance @ 1 meter	

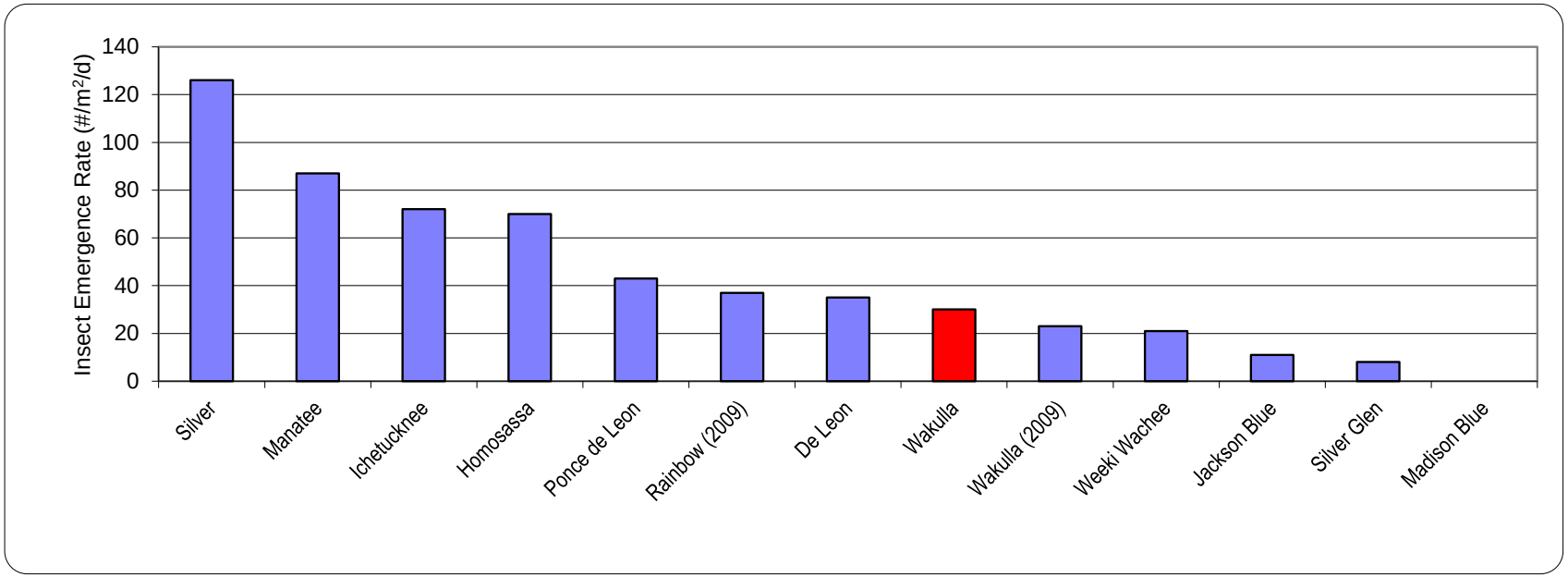
WAKULLA SPRINGS AND RIVER





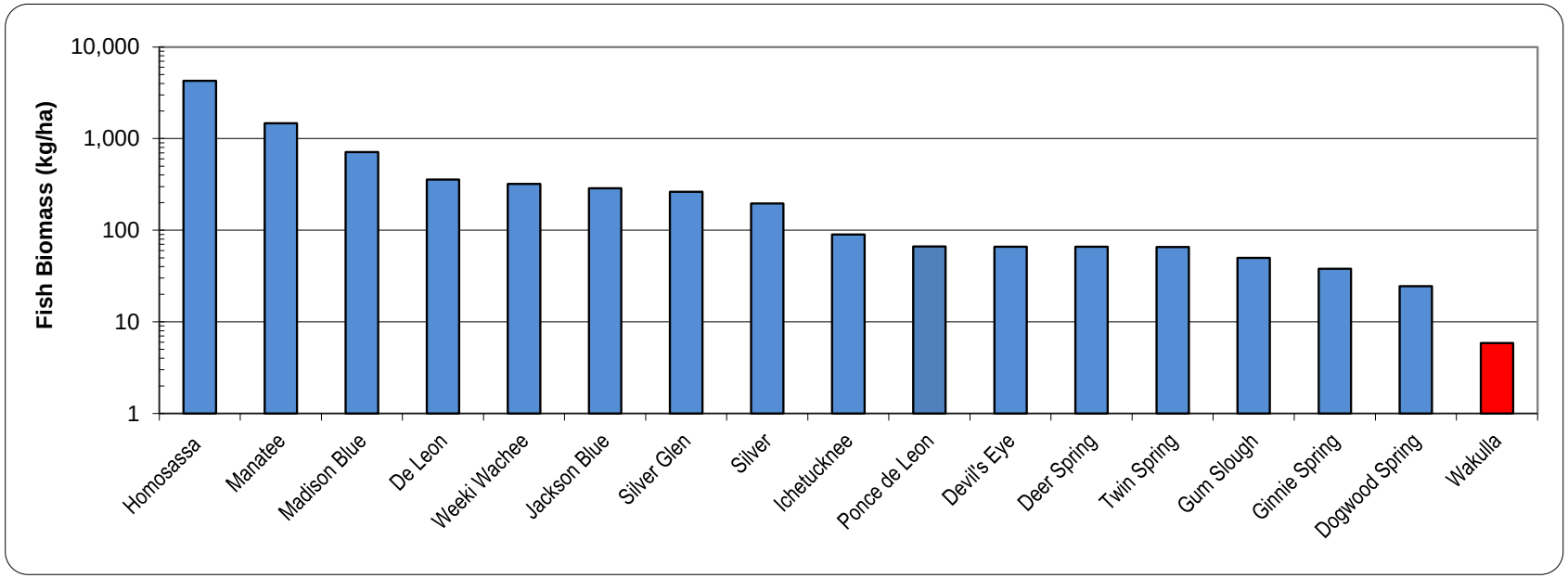
Nitrate Concentration @ Spring Boil	Grade	Average (2016)	A: < 0.15 mg/L B: 0.15 - 0.35 mg/L C: 0.36 - 0.60 mg/L D: 0.61 - 0.90 mg/L F: > 0.90 mg/L
	C	0.45 mg/L	

WAKULLA SPRINGS AND RIVER



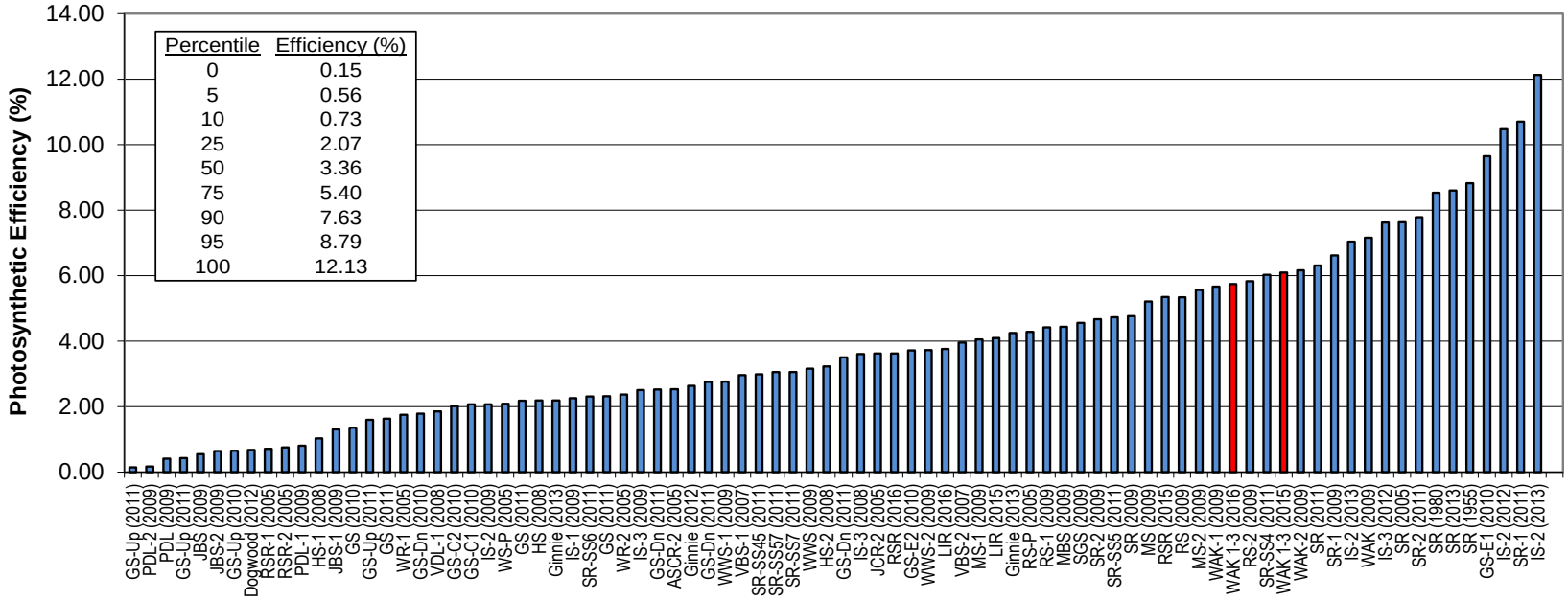
Adult Aquatic Emergence @ Spring Run	Grade	Average (2015-2016)	A: > 100 B: 75 - 99 C: 50 - 74 D: 25 - 49 F: < 24
	D	30 insects/m²/day	

WAKULLA SPRINGS AND RIVER



	Grade	Average (2016)	
Fish Biomass	**F**	**5.9** **Biomass kg/ha**	**A: > 300** **B: 200 - 299** **C: 100 - 199** **D: 50 - 99** **F: < 50**

WAKULLA SPRINGS AND RIVER



Photosynthetic Efficiency	Grade	Average (2015-2016)	A: > 7.0 B: 5.0 - 6.99 C: 3.0 - 4.99 D: 1.0 - 2.99 F: < 1.0
	B	**5.92 %**	