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Chromophoric Dissolved Organic Carbon Loading of Five Intermittent Streams Recharging Wakulla Springs, Florida

Zoe Pemberton Kulakowski

THE FLORIDA STATE UNIVERSITY

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CHROMOPHORIC DISSOLVED ORGANIC CARBON LOADING OF FIVE INTERMITTENT STREAMS RECHARGING WAKULLA SPRINGS, FLORIDA

By

ZOE PEMBERTON KULAKOWSKI

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The members of the Committee approve the Thesis of Zoe Kulakowski defended on October 18, 2010.

_____
Stephen A. Kish
Professor Directing Thesis

_____
William C. Parker
Committee Member

_____
Ming Ye
Committee Member

Approved:

_____
Lynn Dudley, Chair, Department of Earth, Ocean & Atmospheric Science

The Graduate School has verified and approved the above named committee members.

This thesis is dedicated to my son, Chris and daughter, Nicole

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LIST OF ABBREVIATIONS

A - Absorbance
AC - Absorption Coefficient
ANF – Apalachicola National Forest
BC – Black Creek
CAFWN – Capitol Area Flood Warning Network
CDOM – Chromophoric Dissolved Organic Carbon
Cfs – cubic feet per second
COAPS – Center for Ocean-Atmosphere Prediction Studies
Cms – cubic meter per second
DEP – Department of Environmental Protection
DOC - Dissolved Organic Carbon
FC – Fisher Creek
FGS – Florida Geological Survey
GFDI – Geophysical Fluid Dynamics Institute
JC – Jump Creek
LC – Lost Creek
MGY – million gallons per year
MS – Munson Slough
MSL – Mean Sea Level
NAC – Nephelometric Absorption Coefficient (reported per meter standard length)
NWFWMD – Northwest Florida Water Management District
Q – discharge either in cfs or cms
SCUBA – self-contained breathing apparatus
T - Transmittance
TOC - Total Organic Carbon
USGS - United States Geological Survey
UV – Ultraviolet light wavelengths
VIS – Visible light wavelengths
WKP – Woodville Karst Plain
WS – Wakulla Springs
WSSP – Wakulla Springs State Park

ABSTRACT

Chromophoric dissolved organic matter (CDOM) was quantified by colorimetric light absorption for five blackwater intermittent streams draining into sinks (swallets) connected to the Floridan Aquifer underlying the Woodville Karst Plain, Wakulla County, Florida. Munson Slough receives drainage from the city of Tallahassee and the other streams; Fisher Creek, Black Creek, Jump Creek, and Lost Creek drain the Apalachicola National Forest. Previously conducted dye trace injections have shown the disappearing waters contribute to the discharge of Wakulla Springs, a first magnitude spring. Stage-discharge rating curves were developed for Black Creek and Jump Creek. Wakulla Springs CDOM was determined using UV-VIS spectrophotometry with a 10 cm path length and correlated to total organic carbon concentrations. The year-long study period included a two-month long baseflow period, followed by 12 inches of precipitation, an increase in discharge from 400 cfs to 1700 cfs, and a 41- day recession curve for Wakulla Springs. The Wakulla Springs 2009 water clarity extremes contained 28 percent (poorest water clarity) to 0.5 percent (best water clarity) stream water. The total CDOM mass associated with the streams exceeds the Wakulla Springs mass following storm events, indicating that some mass bypasses Wakulla Springs or is stored in the matrix/conduit aquifer system to be later released. Total stream mass equals Wakulla Springs mass for low baseflow conditions, but for higher baseflow, Wakulla Springs mass exceeds the total stream mass, indicating Wakulla Springs is still discharging mass from the preceding storm. This delayed mass is either from aquifer matrix/conduit storage or from the slower Lost Creek pathway. The storm mass associated with any one stream exceeds the Wakulla Springs lower baseflow mass by 4 to 9 times (for the two lowest mass streams) and has the ability to affect Wakulla Springs water clarity without contribution from any other stream. All of the water filled caves connected to Wakulla Springs contribute CDOM, with wet conditions contributing 25-67 percent more CDOM. A Wakulla Springs transmittance of 99 percent would have a NAC_{254nm} of 0.1 and a TOC concentration of 0.69 mg/l. With the Wakulla Springs baseflow CDOM mass range of 600-1000 kg/day, this concentration indicates that the Floridan Aquifer clear water baseflow discharge will need to be 350-600cfs (10-17cms) to provide the necessary dilution for the bottom of the Wakulla Springs basin to be viewed with the water clarity of historic times.

Investigation of upgradient Floridan aquifer water use indicated no change for the potentiometric surface entering Florida, but declines up to 16 feet were noted for northern Leon County, based on the 2008 potentiometric surface. Groundwater withdrawals by municipalities, Consumptive Use Permits, and private wells totaled 14,500 MGY for Leon and Wakulla counties or 9 percent of the 164,000 MGY discharged by Wakulla Spring in 2009.

A decline in precipitation for the most recent decade, 1999-2009, was noted that may contribute, but groundwater use is the most likely cause of the decreased water clarity water. Wakulla Springs has an increasing trend for total dissolved solids and specific conductivity indicating a greater contribution of deep Floridan Aquifer water. More research is needed to understand vertical and lateral upgradient flow within the Floridan Aquifer and the fluctuating controls that either direct creek water to Wakulla Springs or result in it bypassing Wakulla Springs.

CHAPTER 1

INTRODUCTION

Background

Degraded superb water quality (ultra-oligotropic) at the Wakulla Springs 120 foot deep vent prevents the operation of Wakulla Springs State Park glass bottom boats. During periods of good water clarity, the flora and fauna on the bottom of the basin can be viewed by visitors. For the period of 1987-1998, the glass bottom boats operated 42 percent of the time (Bob Thompson, personal communication, 2009). In 2009, the glass bottom boats operated 3% (twelve days) of the time early in the year. Historically, the springs were known to be extremely clear, allowing constant operation of the glass-bottom boats during daylight hours (Grice and Yentsch, 1952). Commercial movies were filmed in the spring waters 1941-1977 and required constant and consistent water clarity. Tarzan, Creature of the Black Lagoon, and Airport '77 are the better known movie titles (Revels, 2002). Neither activity occurs today. Dye trace studies have demonstrated the blackwater streams of the Apalachicola National Forest and Munson Slough significantly contribute to the Wakulla Springs reduced water clarity, i.e. a natural source (Kincaid et al., 2006). These streams likely contributed in the past, so the natural source alone does not explain the longer poor water clarity periods of today.

A number of problems are recognized for Wakulla Springs. Nitrogen concentrations have been increasing from 0.1-0.33mg/l during the 1970's to greater than 1 mg/l by 1991 (FDEP, 2003) and the Tallahassee Sprayfield (Chelette et al., 2002) has been implicated as a major source. Nutrients alter the natural balance of flora and fauna, affecting habitat and water clarity (FDEP, Florida Springs Initiative, 2007). Physical removal of hydrilla, an invasive aquatic plant at Wakulla Springs was performed for many years followed by herbicide treatments that have been more successful, but have an adverse impact of removing all vegetation in the treatment zone. Hydrilla reduces sunlight penetration to the spring basin/river bottom and alters the aquatic food supply and habitat (FDEP, Florida Springs Initiative, 2007). The Limpkin, an endangered bird, has disappeared from the Wakulla River and the specific cause is not known. Finally, the water color (dark) clarity problem can be related to declining groundwater supplies within the springshed basin (FDEP, Florida Springs Initiative, 2007). The potential for declining water supplies as cause of the reduced clarity will be evaluated as part of this research. The natural stream contribution will be quantified. Figure 1 shows the five streams to be studied, their swallet (termini), Wakulla Springs, and known Floridan Aquifer conduits relative to land surface elevations of the northwest side of the Woodville Karst Plain. The five streams are, from north to south, Munson Slough, Fisher Creek, Black Creek, Jump Creek, and Lost Creek. This figure also shows the major locations for data collection.

Wakulla Springs is a well known first magnitude spring, defined as one with a discharge greater than 100 cfs (2800 l/s). The discharge volume varies widely seasonally and historically from a low of 25.2 cfs on June 18, 1931to a maximum of 1910 cfs on April 11, 1973 (Scott et

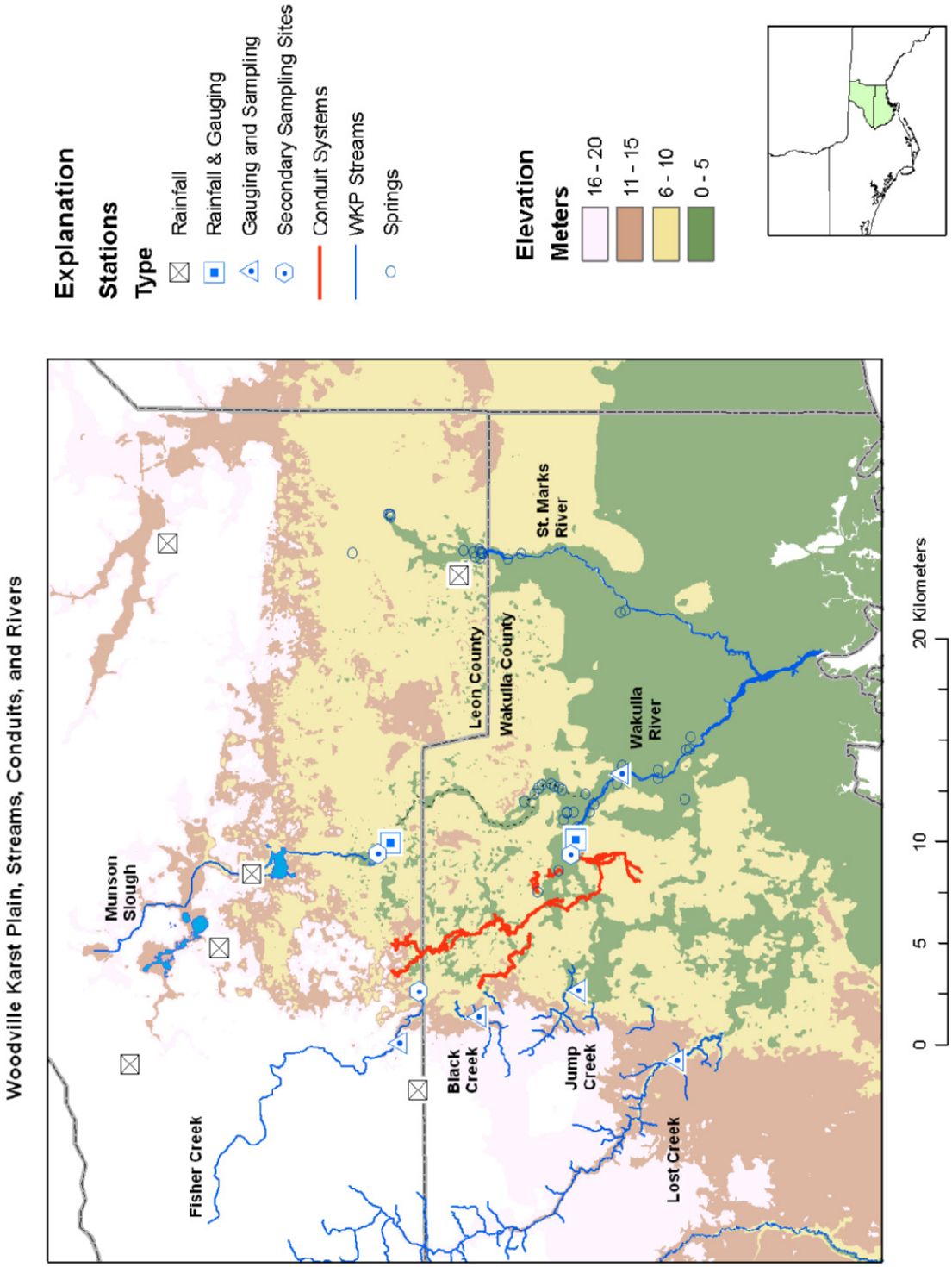

Figure 1 –Woodville Karst Plain Land Surface Elevations, Streams, and Conduits. The five streams, their swallet (terminus), Wakulla Springs (the headwaters of the Wakulla River), and known Floridan Aquifer conduits relative to land surface elevations and the major sampling stations for this study are identified. The former channels of Munson Slough and Jump Creek extending to Wakulla Springs are visible.

al., 2002). A new maximum was recorded following Tropical Storm Fay in 2008 with 2500 cfs (Richard Verdi, personal communication, 2008). The water clarity problems have increased from infrequent and short duration to routine and never ending. Historically colorless, the current Wakulla Springs water color changes range from brown to green to clear. The surface water contribution to spring flow and its effect on water clarity is not well understood. Very little is understood of the flow dynamics and how the streams and Wakulla Springs interact. This research is expected to expand our understanding and provide specific values for the Woodville Karst Plain Project Model.

Four factors control water clarity: dissolved organic carbon, mineral suspensoids, organic particulates, and phytoplankton (chlorophyll). Dissolved organic carbon (DOC) or yellow substance (Davies-Colley et al., 2003) includes humic and fulvic organic acids. Mineral suspensoids, organic particulates, and phytoplankton are all undissolved materials suspended in the water column. Mineral suspensoids would include grain sizes finer than clay (less than 1 µm in size) that might be transported from the streams and sinks to Wakulla Springs. At low water levels after a hard rain, Fisher Creek occasionally has suspended fines at its FC1 swallet. Organic particulates include small pieces of leaves and debris transported through the saturated conduit system. Both very fine sand and organic particulates (millimeter grain sizes) have been observed in the storm samples collected from the Wakulla Springs vent. Neither the very fine sand nor the organic particulates was found to affect the sample clarity within the 2cm and 10 cm path lengths for this study. Harrington et al. (2008) summarized Wakulla Spring turbidity to be low with a maximum of 1 Nephelometric Turbidity Units (NTUs) for the 2001-2006 period. The last factor, phytoplankton is present in the water column, surface sand, and vegetative matter of the Wakulla Springs vent basin. Dr. Prasad, FSU is studying the phytoplankton. In addition, the Florida Department of Environmental Protection collects annual data for the phytoplankton blooms that occur in Lake Munson and potentially feed Munson Slough.

Transmittance/Absorption

Water clarity for dissolved organic carbon is best characterized and quantified using the absorption of light. The greater the concentration of a dissolved substance, the more the solution absorbs light rays. This study will use a very small portion of the electromagnetic spectrum ranging from the near ultraviolet rays (UV) through the visible (VIS) spectrum to quantify chromophoric dissolved organic carbon in water. Dissolved organic carbon (DOC) includes decomposition compounds from plant materials (leaves, bark, grass, algae, etc.) that will pass through a 0.45µm filter and varies between surface waters due to source differences, climate, and drainage basin characteristics. Total Organic Carbon (TOC) includes the fraction of organic carbon that is in particulate form (POC) and filterable in addition to the dissolved component (Leenheer and Croue, 2003; Yacobi et al., 2003). The chromophoric component of DOC or Chromophoric Dissolved Organic Matter (CDOM) is the fraction that controls light absorption within the water column. CDOM absorption can be used as a proxy for DOC concentrations (Kowalczuk et al., 2003). Transmittance (T) is the decimal fraction (usually expressed as a percentage) of light that passes through a set path length, either 2 or 10 centimeters (cm) for this study. Absorbance (A) is the logarithm of that response. The Absorption Coefficient (AC) is equal to the negative natural log of the decimal transmittance. The following equations further describe these relationships:

$$T = I_{out}/I_{in} \qquad (1)$$

where I_{out} is the intensity of light passing through the sample and I_{in} is the initial intensity of light.

$$A = \log(1/T) \qquad (2)$$

where A is the Absorbance.

$$AC = -\ln(T/100) \qquad (3)$$

where AC is the Absorption Coefficient.

The following diagram from Sheffield Hallam University http://teaching.shu.ac.uk/hwb/chemistry/tutorials/molspec/beers1.htm graphically demonstrates the difference between percent Transmittance and Absorbance scales.

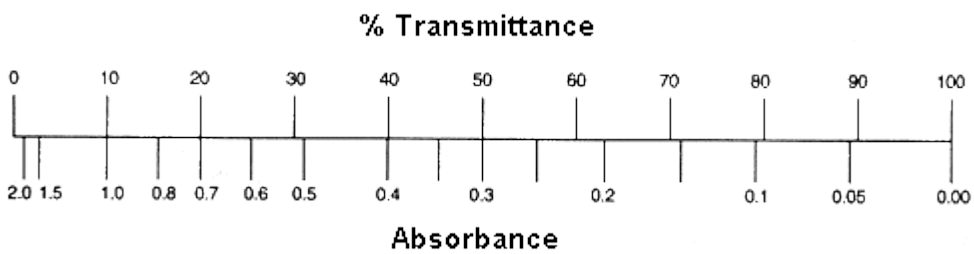

Figure 2 Transmittance and Absorption Scale Relationship. Source: Sheffield Hallam University.

The Nephelometric Absorption Coefficient (NAC) is the AC converted to the standard length of one meter. (For a 2 cm path length, the AC is multiplied by 50; a 10 cm path length is multiplied by 10.) All results in this thesis will be reported either as percent Transmittance or NAC (m^{-1}).

Davies-Colley et al. (2003) provided excellent documentation of the physical/chemical properties of yellow substance or dissolved organic carbon (DOC) in New Zealand lakes. Figure 3 on the following page reproduces their figure of "g" (or gelvin; or NAC) verses wavelength for twelve New Zealand lakes. This figure shows the relationship that allows this research to determine and compare the wavelength response of DOC concentrations at either 254 or 430 nm; the slope is unique to the sample. DOC is most strongly absorbed over the shorter UV wavelengths, allowing dilute concentrations to be quantified. The small arrow on the figure points to a slight flattening of the curve that some samples exhibit. Natural DOC is an excellent tracer in saturated groundwater conduits as it (1) does not absorb/react with the aquifer sediments, (2) behaves conservatively (travels at the same rate as groundwater in conduits), (3) is stable and persistent in the dark, and (4) biodegrades very slowly. The limitation to DOC as a tracer is that all vegetation contributes DOC entering the groundwater system at thousands of locations within the Woodville Karst Plain, complicating travel time analysis for each of the studied disappearing streams and the Wakulla Springs discharge. Katz et al. (2001) used DOC

as a effective tracer and evaluated Fisher Creek , Lost Creek, and Munson Slough as one member of a two member mixing model; the other being groundwater concentrations of DOC.

Figure 4 (left) compiles the results of Pope and Fry (1997) and Quickenden and Irvin (1980) to show the ultraviolet through visible light absorption coefficient of pure water relative to the 200-700 nanometer wavelengths. Humic compounds are strongly absorbed in the ultraviolet spectrum, but high concentrations will extend into the 400-600nm wavelength range and be seen as green (low concentrations) or yellow or brown (highest concentrations) water. Water absorbs the red (650 nm) wavelengths, but not the blue wavelengths (440nm) giving deep clear water its blue color. For the wavelength range 254 nm to 440 nm, the absorption coefficient ranges from 0.07 to less than 0.01, indicating that very little absorption occurs in the range of interest due to the properties of pure water. In contrast, the right-side figure requires an expanded y-axis to show how the presence of humic compounds will change the absorption spectra. A typical Wakulla Spring sample for June 10, 2009 is presented showing the increased sensitivity for the shorter wavelengths.

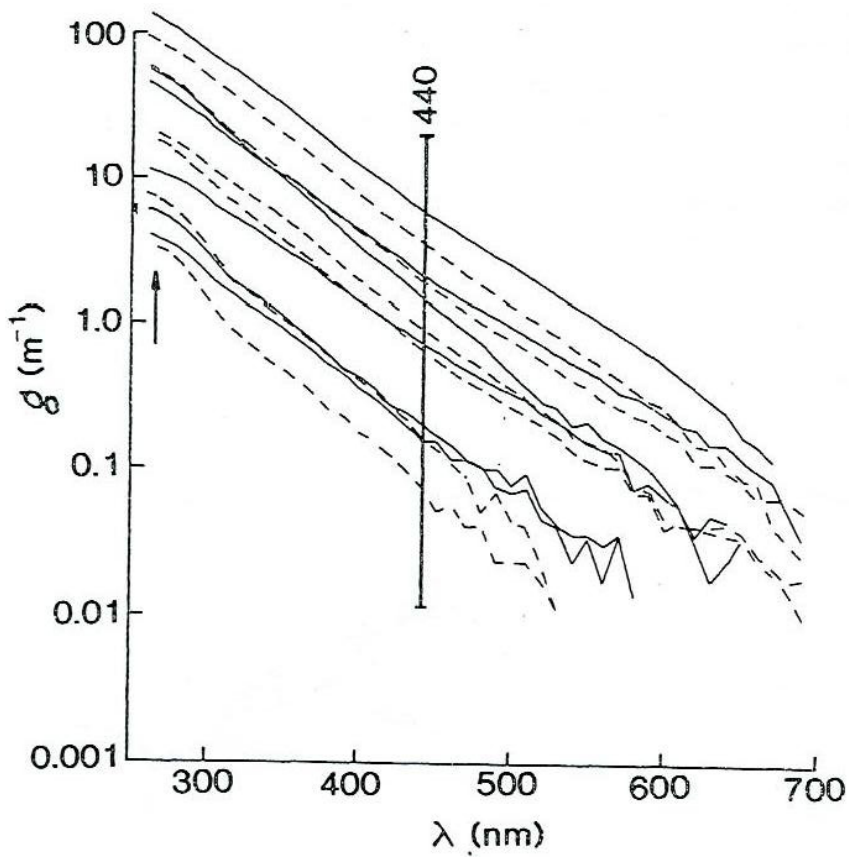

Figure 3- Absorption Coefficient (g m^{-1} or NAC m^{-1}) of New Zealand Lakes. The decline of CDOM with respect to increasing wavelength (λ) is observed. Source: Davies-Colley and Vant, 1987.

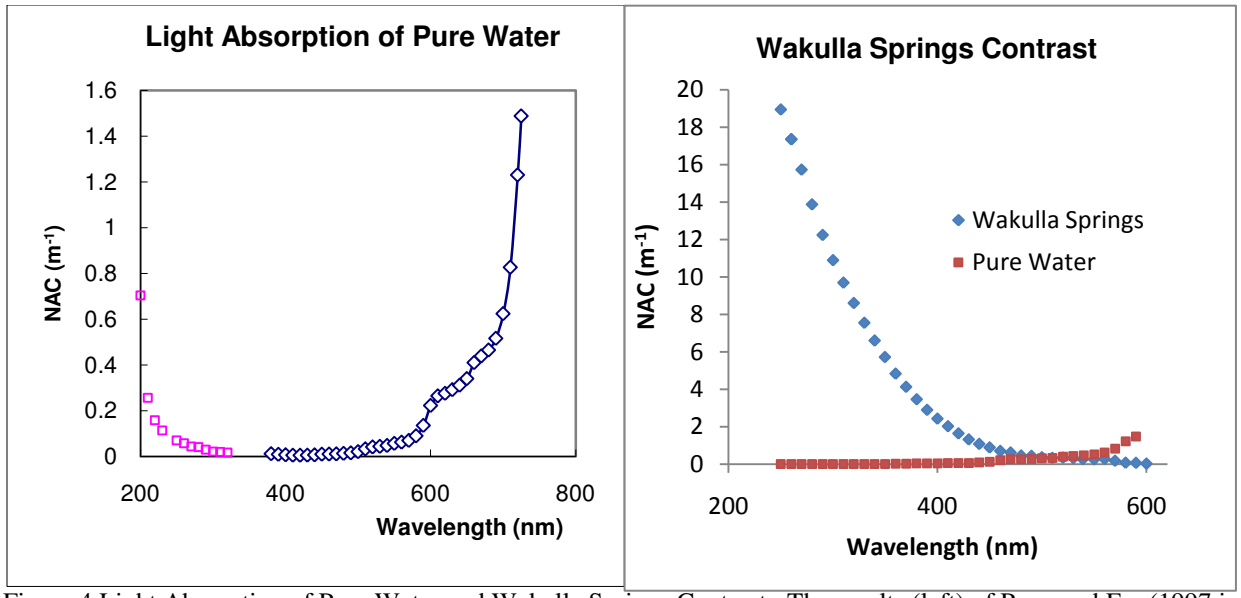

Figure 4 Light Absorption of Pure Water and Wakulla Springs Contrast. The results (left) of Pope and Fry (1997 in blue) and Quickenden and Irvin (1980 in pink) are compiled to show the ultraviolet through visible light absorption coefficient of pure water. Humic compounds are strongly absorbed in the ultraviolet spectrum, but high concentrations will extend into the 400-600nm wavelengths and be observed as green, yellow, orange, or brown colored water. The pure water absorption coefficient ranges from 0.07 to less than 0.01 for the wavelength range 254– 430 nm of interest. The right graph shows the NAC curve for the June 10, 2009 Wakulla Springs with the Pope and Fry data (note the scale change). The absorption of the humic compounds is approaching zero as the red wavelengths are being absorbed.

Physiographic Setting

The drainage basins for the study area lie in three geomorphic regions discernable on Figure 1: the Tifton Upland District, Tallahassee Hills subdistrict (elevations above 16m) and the Gulf Coastal Lowlands (elevations ranging from sea level to 15m), Woodville Karst Plain subdistrict and Apalachicola Coastal Lowlands subdistrict (Clemons et al., 1998). The Munson Slough basin begins in the Tallahassee Hills subdistrict and flows over the east-west aligned Cody Scarp (the south edge of the 16-20m elevation crossing the northern quarter of Figure 1) to enter the Gulf Coast Lowlands, Woodville Karst Plain subdistrict. The remaining stream basins begin in the Gulf Coast Lowlands, Apalachicola Coastal Lowlands subdistrict and flow into the Woodville Karst Plain subdistrict. All five streams disappear into sinks (called swallets) connected to the Floridan Aquifer; the source of the Wakulla Springs discharge.

Stratigraphy

The Woodville Karst Plain upper 100 meters stratigraphy includes the following formations from oldest to youngest: Oligocene Suwannee Limestone, Lower Miocene St Marks Formation, and the undifferentiated Recent to Pleistocene quartz sands (Rupert and Spencer, 1988). The Miocene Hawthorn Group, Miccosukee Formation and Pliocene Torreya Formation were removed from the Woodville Karst Plain by erosion associated with rising seas, but are still present north of the Cody Scarp and/or in the Apalachicola Coastal Lowlands (Rupert and Spencer, 1988; Scott, 2001). The St Marks Limestone is a fossiliferous, slightly sandy limestone (Rupert, 1988). This is the limestone that is observed in sinks, the Wakulla River channel and along the Gulf coast in Wakulla County. The unconformable contact between the St Marks

Formation and the Suwannee Limestone is approximately 27m below the water surface (approximately 2m MSL) at the Wakulla Springs vent. The Suwannee Limestone contains the entire Wakulla Springs conduit system and extends to a depth of 150m (Rupert, 1988). Retreating seas deposited the variably-thick undifferentiated Recent to Pleistocene quartz sands now covering the Woodville Karst Plain and the Apalachicola Coastal Lowlands.

Hydrogeology

Groundwater is observed in the Surficial (water-table) Aquifer that is in hydraulic communication with the underlying Floridan Aquifer in the Woodville Karst Plain (Clemons et al., 1998, Katz et al., 1997, Davis and Katz, 2007). The Floridan Aquifer is the principal regional aquifer, although some potable use of the surficial aquifer does occur. The Woodville Karst Plain is internally drained and few streams are observed. See Figure 1 that shows the Wakulla River, St Marks River and the former course of Munson Slough as the only streams within the Woodville Karst Plain. The absence of streams is due to the highly permeable unconsolidated surface sands that limit any stream to a short run before losing water to the sands and the Floridan Aquifer. During dry seasons, long sections of the five intermittent streams typically go dry, as the surficial aquifer dewaters, retaining ponded sections only in the deep holes. The swamps in the headwaters of the streams may also dry out, allowing direct inspection of any sinkholes. Vertical ground water flow is controlled by the Floridan Aquifer potentiometric surface; if lower than the water table or surface waters, recharge is downward. If the Floridan potentiometric surface is higher than the water table, upward flow occurs perhaps as a spring or as baseflow to the Wakulla and St Marks Rivers (Clemons et al., 1998, Katz et al., 1997).

North of the Cody Scarp and west of the Woodville Karst Plain, the Floridan Aquifer is considered to be confined by the still present lower permeability confining units of the Hawthorn Group, Miccosukee and Torreya Formations (Davis and Katz, 2007). The Floridan Aquifer within the Apalachicola Coastal Lowlands was deposited in a deep-water channel called the Suwannee Straits. Because of the fine-grain nature of these sediments, the Floridan Aquifer here has low original porosity and low hydraulic conductivities (Davis and Katz, 2007). As a result, the transition between the Apalachicola Coastal Lowlands and the Woodville Karst Plain includes not only the eastern limit of confining lithologies but also an increase up to three orders of magnitude in the hydraulic conductivity of the Floridan Aquifer limestone (Davis and Katz, 2007). Breaches in the confining beds occur north of the Cody Scarp as sinks and karst lakes, such as Lake Jackson, Lake Lafayette, Lake Iamonia and Lake Bradford. Munson Slough flows through Lake Munson and Eight-Mile Pond before disappearing into the Ames/Kelly swallets. Lakes Bradford, Munson (both are shown on Figure 1) and Eight-Mile Pond are karst solution depressions likely recharging the Floridan Aquifer. Oxygen and deuterium isotope analysis of groundwater near Lakes Jackson and Bradford (Katz et al., 1997) established that both lakes recharge the Floridan Aquifer.

Within the Woodville Karst Plain, the Floridan Aquifer has an extensive dendritic system (defined by groundwater tracing and cave mapping) of saturated conduits in the Suwannee Limestone that currently totals more than 70 km (Kincaid and Werner, 2008). These conduits are large enough to allow scuba divers and their multiple scooters to travel miles underground. Conduit flow rates are sufficient to move a resting diver in large tunnels and faster in smaller

tunnels to prevent swimming against the current. Calculated flow rates of 1.1-1.7 m^3/s were obtained by dye trace studies in the Cheryl and Emerald Sink conduits (Hazlett-Kincaid web page, 2003). Generally, flow rates increase with proximity to Wakulla Springs or the Leon Sinks conduit system (Kincaid and Werner, 2009). Many springs are observed and the Wakulla and St Marks Rivers receive most of their flow from groundwater.

Karst window dye tracing tests have demonstrated that dye reaches Wakulla Springs 9 to 60 days following injection at Fisher 1 swallet, Black Hole, Sullivan Sink, Ames Sink, and Lost Creek swallet. Travel distances for the dyes have been estimated to be 2500m to more than 16,000m. Most of these tests occurred during low flow conditions, so high flow conditions will likely be more rapid. The use of these dye trace times for humic contribution prediction purposes is of limited value because of the effect antecedent conditions have on water quality. Antecedent conditions and their control are presently poorly understood, but include humic storage at the ceiling and floor of the conduit system, surficial aquifer versus Floridan Aquifer potentiometric elevations, and whether the swamps and stream beds contain water. As an example, in 2008 Fisher Creek, Black Creek, and Jump Creek were not flowing and the surficial aquifer was dry. Even without stream input, Wakulla Springs water clarity was poor. The first few significant precipitation events of one inch or more yielded low stream flows that proceeded downstream only after filling the next streambed hole. Such conditions eliminate certain streams, but predictions remain difficult due to stream bed loss, aquifer storage and influence of numerous swamps and sinks closer to Wakulla Springs.

Nature of Study

The five intermittent streams that were studied are (north to south) Munson Slough, Fisher Creek, Black Creek, Jump Creek and Lost Creek. The table below shows their published drainage areas and the areas from this work. The United States Geological Survey (USGS) Florida Department of Environmental Protection (DEP) area sizes differ because of differences in the predominantly swamp sub-basins included with the main stream basin. An asterisk indicates no published value for that stream. Lost Creek and Munson Slough have the largest drainage areas, followed by Fisher Creek, Black Creek and Jump Creek, respectively. Both the USGS and DEP consider Jump Creek to be part of the Wakulla River basin area. Figure 5 shows the individual drainage basins providing surface water flow to Wakulla Springs and all of the sampled surface water stations.

Table 1 Stream Drainage Areas

Stream	USGS (Mi^2)	DEP (Mi^2)	GIS (Mi^2 / Km^2
Munson	52.9	47.81	47.8/ 123.8
Fisher	29.5	35.59	35.6/ 92.2
Black	*	15.96	15.9/ 41.3
Jump	*	*	6.7/ 17.3
Lost	70.4	47.75	47.4/ 122.7

The variable absorption of light will be used to quantify the chromophoric dissolved organic carbon concentrations that are altered principally by dilution, to quantify the blackwater stream contribution to the total Wakulla Springs discharge. The Wakulla Springs discharge is

evaluated as a mixture of two end members; the composite streams (first with Fisher Creek/ Black Creek as one end member then all the streams as one blackwater composite end member) and clear deep Floridan Aquifer water.

Historical Data

Grice and Yentsch (1952) documented the earliest known water clarity conditions for Wakulla Springs with a Secchi depth of 22 meters and an extinction coefficient (k- now called the diffuse attenuation coefficient) of 0.10. Six weeks of no rain preceded this measurement, allowing the glass-bottom boats to operate continuously. Long periods without precipitation decrease blackwater contribution, allowing good clarity at Wakulla Springs.

Other data have been collected by various groups within the Florida Department of Environmental Protection, the United States Geological Survey, and the Northwest Florida Water Management District. Most of the data is unpublished, but published data for Fisher Creek, Lost Creek, Munson Slough, River Sink, and Wakulla Springs can be found in Katz (2001) and Katz et al. (2004). Data pertinent to this work include Total Organic Carbon (TOC), Color in Platinum Color Units (PCU), turbidity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), specific conductivity, pH, and Secchi disc depth measurements. Table 2 summarizes published and unpublished Wakulla Springs (WS) and stream Total Organic Carbon (TOC) historical data. The dye injection travel times obtained by the Florida Geological Survey, Woodville Karst Plain, Groundwater Tracing program are also provided.

Table 2 – Historical TOC and Dye Test Data

Name	Period	TOC -Min	TOC -Max	TOC -Mean	Source
Fisher Creek	1997-2002	9.4	45	27	NWFWMD/Katz 2001/Katz et al 2004 /FDEP/Leon County
Black Creek	2000-2002	22	50	39	NWFWMD
Jump Creek					None
Lost Creek	1992-2006	6.3	50.1	22	FDEP/NWFWMD
Munson Slough	1992-2009	4.6	15	8	USGS/Katz et al 2004/Leon County
Wakulla Springs	1970-2009	<1	8.8	1.29	USGS/FDEP

Florida Geological Survey Dye Test Injection Travel Times

Injection	Date	Days to Reach WS	Test Condition
Fisher 1	2003	9	low-flow
Black Hole	2003	10	low-flow
Lost Swallet	5/29/2008	45	low-flow
Lost Swallet	7/14/2009	None	higher low-flow
Ames Sink	2005	20	low-flow with storm

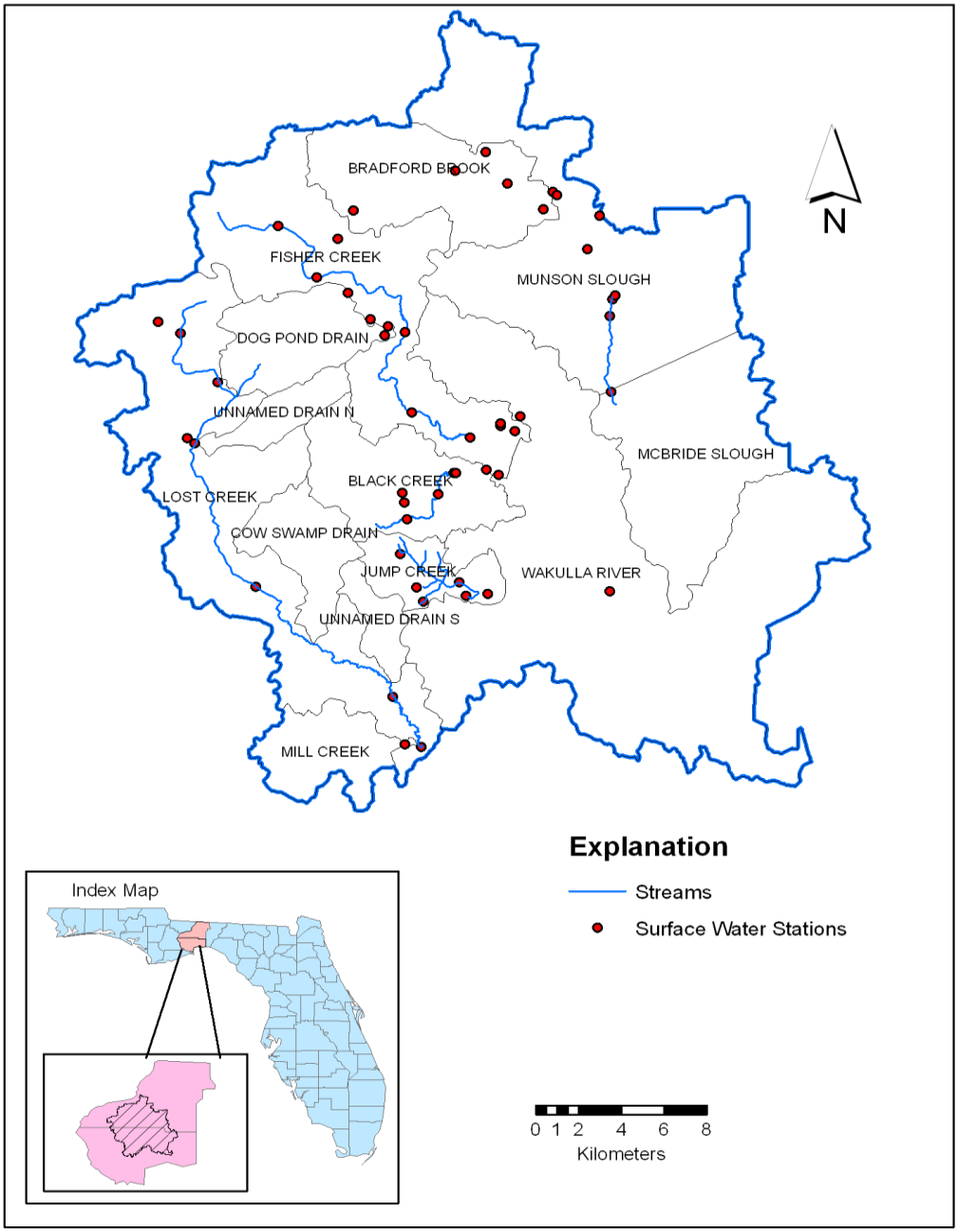

Figure 5 Wakulla Springs Drainage Basins and Surface Water Stations. Flow from the "Drains" can recharge multiple streams. See Figure 6 and Table 3 for station number, name and UTM coordinates.

CHAPTER 2

METHODOLOGY

Field Procedures

Water sampling locations on each of the five streams were selected to either coincide with the USGS stage monitoring station (Fisher and Lost creeks) and/or a location immediately upstream of the first swallet (Black Creek, Jump Creek, and Munson Slough). The numbered locations are identified on Figure 6 followed by Table 3 with the UTM coordinates, both located on the following pages due to their size. Three to five tier ladder samplers were installed in Fisher Creek, Black Creek and Jump Creek to capture water samples with stage rise during a storm. For Fisher Creek, a three tier sampler and a five-tier sampler were installed on the downstream sides of Forest Road (FR) 305 (ID 9) and Springhill Road (ID 10), respectively. Three tier ladder samplers were installed on Black Creek on the downstream side of State Road 267 (ID 19) and on Jump Creek approximately 100 feet upstream of the swallet at the natural land bridge (ID 28). These ladder samplers captured the 2008 Tropical Storm Fay event. Figure 7 shows the top of the ladder sampler and the shelf for one of the sample bottles, the staff gage and the sonar logger later installed on Black Creek at State Road 267.

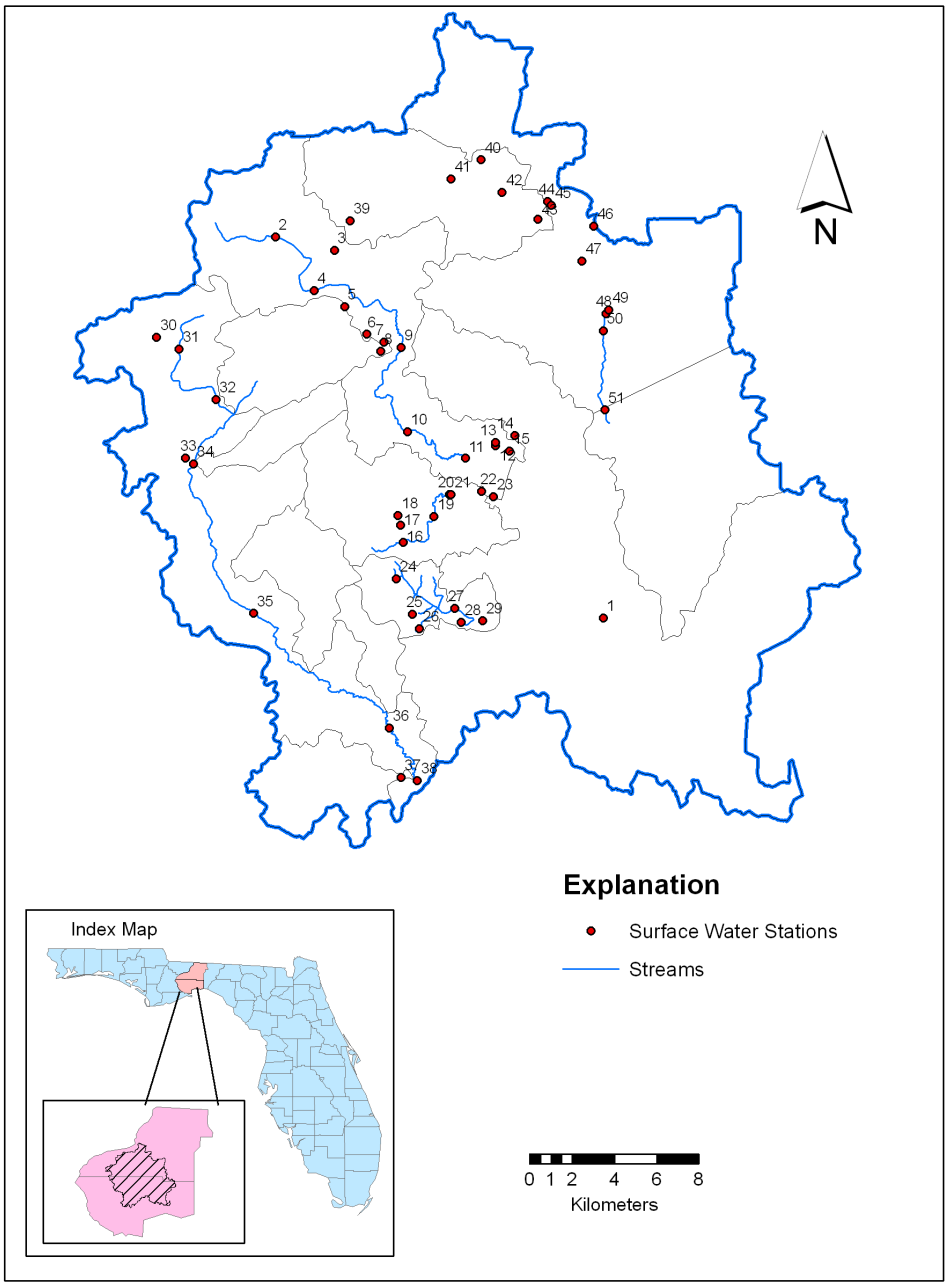

Figure 6 – Surface Water Transmittance Station Locations and Station ID

Table 3 Surface Water Transmittance Stations and UTM Location

Station ID	Surface Water Transmittance Stations	UTM coordinates (Zone 16N)	
		Easting	Northing
1	Wakulla Springs	759573	3347903
2	Fisher Creek at FR 373	743632	3365599
3	Fisher Creek at FR 376 N	746440	3365034
4	Fisher Creek at FR 376 S	745520	3363098
5	Fisher Creek W FR 305 N (gun range)	746979	3362361
6	Fisher Creek W FR 305 S	748049	3361080
7	Trib. From Clear Lake to FC	748883	3360742
8	Clear Lake	748743	3360302
9	Fisher Creek at FR 305 (swamp)	749708	3360488
10	Fisher Creek at Springhill Rd	750089	3356516
11	Fisher Creek at Fisher 1 (swallet)	752865	3355333
12	Fisher Creek at Natural Bridge	754283	3355946
13	Fisher Creek at Fisher 2 (swallet)	754263	3356089
14	Little Dismal/Hammock Sink	755184	3356452
15	Center Swamp	754951	3355714
16	Black Creek at FR 313 S	750002	3351264
17	Black Creek at FR 313 N	749859	3352073
18	Black Creek at FR 313 6th crossing	749731	3352551
19	Black Creek at SR 267 *	751430	3352525
20	Black Creek at Hilliardville	752137	3353583
21	Black Creek at Black Hole	752216	3353581
22	Mashes Branch at Roaring Sinks	753655	3353776
23	Mashes Branch at Crestwood Rd	754217	3353529
24	Jump Creek at FR 313 5th Crossing	749704	3349540
25	Jump Creek at FR 313 3rd Crossing	750511	3347878
26	Jump Creek E of FR 313 (W tributary)	750848	3347195
27	Jump Creek at Walden Lake Rd	752515	3348202
28	Jump Creek swallet	752824	3347539
29	Jump Creek at US 319	753843	3347649
30	Lost Creek at SR 267 N	738111	3360733
31	Lost Creek at SR 267 S	739192	3360189
32	Lost Creek at FR 367	740983	3357831
33	Lost Creek at FR 360	739607	3355030
34	Lost Creek at FR 309 (Brown House)	739984	3354774
35	Lost Creek at FR 350 (Pope Still)	742980	3347753
36	Lost Creek at Arran Rd	749526	3342462
37	Mill Creek at Bostic Pelt Rd	750147	3340146
38	Lost Creek at Harvey Mill Rd	750922	3340013
39	Bradford Brook at FR 301	747149	3366443
40	Bradford Brook at Sand Rd	753281	3369456
41	Bradford Brook at Aenon Church Rd	751879	3368512
42	CR 263 (Cascade Lakes)	754324	3367939
43	Lake Bradford	756043	3366709
44	CR 371 (Orange Ave)	756476	3367552
45	Lake Bradford Rd	756656	3367393
46	Munson Slough at Lake Henrietta	758686	3366436
47	Munson Slough at SR 263 (Cap Cir)	758160	3364777
48	Lake Munson at SR 319 (overflow weir)	759365	3362314
49	Lake Munson at SR 319 (boat ramp)	759492	3362499
50	Munson Slough at SR 319	759259	3361498
51	Munson Slough at Oak Ridge Rd	759421	3357747

* Staff gage zero = 29.73', Concrete Benchmark = 38.53' NAVD88

Figure 7 - Black Creek at SR 267 Photo of Installed Equipment. From back to front: ladder sampler, staff gage and sonar logger.

Stage levels were recorded using the USGS staff gages at Fisher Creek/Springhill Road and Lost Creek/Arran Road. A three foot long staff gage was installed and surveyed on Black Creek at SR 267. The Black Creek staff gage and a brass bench mark glued to the concrete culvert remain. During floods when these staff gages were submerged, depth-to-water measurements were made from the top of the concrete bridge railing/culvert. When the flood subsided, the depth-to-water/staff gage relationship for the measuring location was determined to calculate the actual flood water elevation. Two staff gages were present on Munson Slough at Oak Ridge Road, but of little value as the stage was usually below both bases (75% of visits). A three foot long staff gage was installed and surveyed on Jump Creek at the land bridge overflow, but most flows were lower than its base (or it too was flooded). At locations where no concrete was available to make depth-to-water measurements, a unique feature (such as the upper most trunk saddle of a five-trunk gum and a limestone outcrop at the Jump Creek swallet) was selected for the measurements.

Discharge measurements were made following a tag line extended across the creek where the creek flowed in a relatively straight section of consistent flow velocity with a minimum number of roots/submerged logs. Fallen debris was removed as necessary before setting up for measurements. The tag line was marked every foot. At each foot marking, the depth of the water was determined using the wading rod and recorded. For water depths less than 2.5 feet,

the wading rod was adjusted to record the flow velocity at the depth equal to 0.6 of the total depth. When the depth of water exceeds 2.5 feet, the USGS recommends that the velocity of each stream section be measured at two depths, 0.2 and 0.8 times the total water depth and the average value be used for each depth-area calculation. Most measurement events were made in water depths less than 2.5 feet. Velocity measurements were made using a Marsh McBirney (Flo-Mate 2000) flow meter (sonde with three electronic sensors on nose – gives direct velocity readings) or MJP meter (propeller that counts revolutions and requires calculations to get velocity using the relationship 30 revolutions per minute equals 0.98 feet per second). The sonde or propeller measured velocity at a depth equal to 0.6 of the total water depth. A picture of the tag line and the measurement section for Black Creek on the west side of Hilliardville Road is shown in Figure 8. Water depth and velocity measurements were made every foot starting at the right side land spit.

Figure 8 Black Creek at Hilliardville Road Photo of Tag Line. Water depth and velocity measurements were made every foot starting at the right side land spit at this stage/discharge measurement station.

Benchmarks at Fisher 1 (ID 11), Fisher Creek/FR 305 (ID 9), Black Creek/SR 267 (ID 19), and Jump Creek swallet (ID 28) were installed and surveyed. Shortly after installation, bush hog work in the Apalachicola National Forest destroyed the Fisher 1 benchmark. Fisher Creek/FR 305 and Jump Creek swallet benchmarks were later removed. The Black Creek/SR 267 benchmark remains glued to the northeast culvert concrete with an elevation of 38.53 feet

NGVD of 1927. The Black Creek staff gage was also left in place and its zero elevation is 29.73 feet.

Water samples were collected in 250 milliliter (ml) opaque brown bottles after discarding the first filling down stream of the sample location. Bottle preparation included a tap water rinse, 4 drops of 3% hydrogen peroxide, fill with tap water, and multiple tap water rinses. Creek samples were placed in a cooler on ice and if not analyzed the same day as collection (rare), were refrigerated until analysis. Samples equilibrated to room temperature prior to analysis. Most Wakulla Springs samples were not refrigerated, but kept at room temperature until spectrophotometer analysis could be performed (typically 10-24 samples per event). Each sample collected represents a discrete (snapshot in time) sample of the creek surface water or the Wakulla Springs discharge. Samples were generally collected in the morning before any afternoon rainfall on the sample day. The majority of Wakulla Springs samples were collected at 8AM by an autosampler.

Daily precipitation records for the Tallahassee Airport (1887-2009), Wakulla Springs State Park, and Capital Area Flood Warning Network stations #602, #601, #555, and #803 were obtained from the National Weather Service and the Northwest Florida Water Management District, respectively. Historical daily precipitation records were obtained from the FSU Center for Ocean-Atmospheric Prediction Studies (COAPS).

Calibration Procedures

A continuous linear-position stage logger was installed at the Jump Creek swallet (ID 28) for a period of about 10 days and removed due to the approach of Tropical Storm Fay (T.S. Fay). The calibration graph is provided as Figure 9. This calibration was performed to document the relationship between water depth and voltage reading for a linear-position sensor. The sensor slid along a narrow rod set inside a PVC pipe housing open to water flow at the base and to the atmosphere at the top. Water depth and voltage have a linear relationship defined by the graph equation. This calibration also defines the sensitivity range available for the sensor as water levels deeper and shallower than the graphed data showed a constant voltage. Using 4 AA batteries, this sensor is capable of recording water level fluctuations up to 77 millimeters. As the intended use of the sensor was to determine if the Jump Creek swallet is in direct communication with conduit flow extending to the coastline, this depth range is suitable for potential tidal fluctuations. Figure 10 is a photo of the installed logger that would have been approximately six feet under water if not removed prior to the T.S. Fay flooding.

A continuous sonar logger was installed at Black Creek on February 25, 2009 to record depth to water every 10 minutes. Before installation, the logger was calibrated in the lab to determine the range of sensitivity and the relationship between the depth-to-water and voltage. Figure 11 shows the calibration graph. Depth-to-water and voltage have a linear relationship defined by the graph stated equation. The maximum range of measured stage is a high depth-to-water of 48” to a low (no flow) depth-to-water of 118”. The lab calibration did not test the sensitivity of long distances to low water stage, but the low water levels recorded during the first month correlated well with low staff gage readings and the precipitation record.

Batteries were changed every thirty days. The first period recorded data successfully. During the first battery change, wires were inadvertently disconnected when placing the recording device back into the PVC housing which wasn't discovered until the next change visit. Data collection after that appeared erratic (and generally did not correlate well with staff gage observations), possibly due to high humidity adversely affecting the electronics.

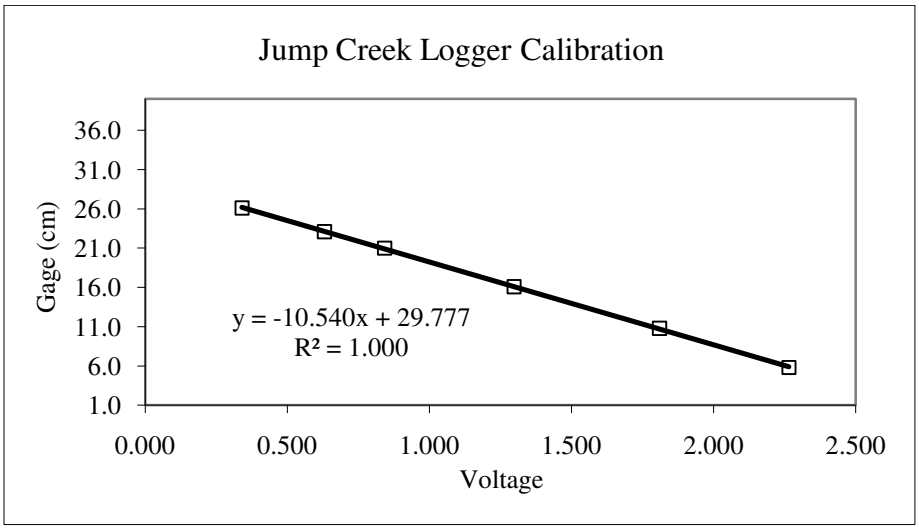

Figure 9 Jump Creek Logger Calibration. The relationship of voltage to water depth is linear.

Figure 10 Jump Creek Logger Photo of Field Location. T.S. Fay flooded the continuous linear-position stage logger area to an approximate depth six feet above this stage.

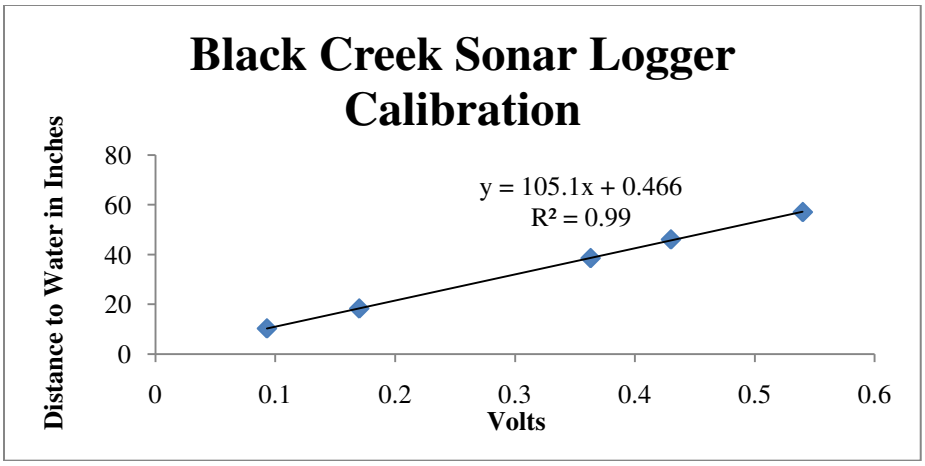

Figure 11 Black Creek Sonar Logger Calibration. The voltage to water depth relationship is linear.

Water Quality Analyses/Lab Procedures

Opaque 250-ml brown bottles were used to collect stream and Wakulla Springs samples. The stream samples were placed in a cooler with ice and generally analyzed the same day. If analysis would be delayed, the samples were stored in a refrigerator and allowed to equilibrate to room temperature prior to analysis. Creek water samples were filtered either by 0.45 or 1 micron Whatman paper filters. All creek samples were analyzed using a Lamotte Smart 2 colorimeter. The 2 centimeter quartz cell was rinsed with filtered sample, discarded and refilled. A tap water blank was compared to each sample. All samples were analyzed relative to the blue wavelength, 430 nm. The dry season and wet season complete basin rounds included all four wavelengths of the colorimeter: 430 nm, 520 nm, 570 nm, and 620 nm. Particulate matter or discoloration from the creek samples was rarely observed on the filters. Munson Slough was the exception, showing a ring of fine algae on the filters of late spring 2009 samples. The pH analysis of the samples was added in the spring of 2009.

Analytical Uncertainty

The Wakulla Springs samples exhibited a wide range of light absorption. NAC values from the clearest water samples (minimum NAC/m was 1.51) to the NAC values in the 30's have an uncertainty of +/- 0.01, but the uncertainty increases for the values greater than 40 due to the low percentage of light that passed through the sample to +/- 0.1. The United States Geological Survey rates the quality of their discharge data; a fair rating has a relative uncertainty of 8 percent (Turnipseed and Sauer, 2010) and this conservative value was assigned to the discharge data used in this study. According to the FDEP SPAN Lab staff (Personal communication with Tim Fitzpatrick and Colin Wright, 2010), the uncertainty associated with the TOC analyses was 20 percent. R Core Development Team software (2010) was used to calculate the linear correlation uncertainty between NAC and TOC. The compounded uncertainty for the NAC to TOC calculations was +/- 0.23. The compounded uncertainty for the mass calculated using the NAC and TOC data was +/- 0.26. In most figures, the total uncertainty is smaller than the size of the symbols used to graph the data. The uncertainty has been added to the figures where it is greater than the size of the symbols. In spite of the uncertainty between the values, the relative proportional relationships between the NAC values, the TOC concentrations, and the mass values of the streams and Wakulla Springs water samples are maintained by the data and reflected in the conclusions.

Transmittance/Absorption

The absorption of light by the ultraviolet (UV: 200-400 nm) through the visible (VIS: 400-800nm) wavelength range was used to characterize and quantify the CDOM. The greater the concentration of a dissolved substance, the more the solution absorbs light. Transmittance (T) is the decimal fraction (usually expressed as a percentage) of light that passes through a set path length, either 2 or 10 centimeters (cm) for this study. Absorbance (A) is the logarithm of that response. The Absorption Coefficient (AC) is equal to the negative natural log of the decimal transmittance. The following equations further describe these relationships:

$$T=I_{out}/I_{in} \qquad (1)$$

where I_{out} is the intensity of light passing through the sample and I_{in} is the initial intensity of light.

$$A=\log(1/T) \qquad (2)$$

where A is the Absorbance.

$$AC = -\ln (T/100) \qquad (3)$$

where AC is the Absorption Coefficient. The Nephelometric Absorption Coefficient (NAC) is the AC converted to the standard length of one meter. (For a 2 cm path length, the AC is multiplied by 50; a 10 cm path length is multiplied by 10.) All results in this thesis will be reported either as percent Transmittance or NAC (m^{-1}).

Most Wakulla Springs samples were analyzed by a laboratory spectrophotometer. The colorimeter was used for Wakulla Springs samples from August 2008 to February 2009, but did not have the sensitivity of the ultraviolet wavelengths necessary for the dilute concentrations. The Oceanoptics USB 4000 Ultraviolet/Visible Light (UV/VIS) spectrophotometer was turned on at least 45 minutes prior to analysis to warm up, minimizing thermal drift from the DT-mini-2 lamp. Organic free water was used for the baseline blank until it was realized that its plastic container released organic compounds that were part of the spectrophotometer clear water curve. Tap water was then substituted as the blank, after allowing the water to run a few minutes first. The 10 cm long quartz cell was rinsed with either the blank or the sample as appropriate, discarded and refilled prior to each analysis. Sample analysis recorded the light transmission for the UV/VIS spectrum from 200-800 nm wavelength range. For the 10 cm path length, the difference between high purity water and tap water was approximately 1-2 percent at the 254 nanometer wavelength.

Ocean Optics indicates that the accuracy of the USB4000 to be 0.01 (m^{-1}) with a 1cm cuvette. The amount of absorbed light is measured as the difference between I_{in} and I_{out}. A decrease in light intensity due to scattering is very low for the Wakulla Springs samples due to the extremely low turbidity. Very low concentrations of CDOM will also have very low absorbance values that represent a very small difference between very large I_{in} and I_{out}. When this difference is less than 1%, the uncertainty in the measurement of each of these two light intensities may become larger than the difference between them. Very high concentrations are limited by the very small amount of light (again using 1%) that passes through the sample and

the sensitivity of the detector. For this research, a 10 cm cuvette was used, improving the accuracy of low concentrations by 10 fold and decreasing the amount of light received for high concentrations. NACs greater than 40/m and less than 0.1/m should be used qualitatively only ("presence" in very high concentrations or very low concentrations, respectively and at a minimum checked to see if these data alter the conclusions).

The spectrophotometer-colorimeter response differences were compared using various dilutions (100%-10%) of 4-11-2009 Fisher Creek water. The transmittance data was converted to nephelometric absorption coefficients (NAC for a standard path length of 1 meter) removing the path length differences between the two instruments. Data from the two instruments compare well as shown in Figures 12 and 13. The result differences are constant and independent of concentration, including the 100% concentration sample.

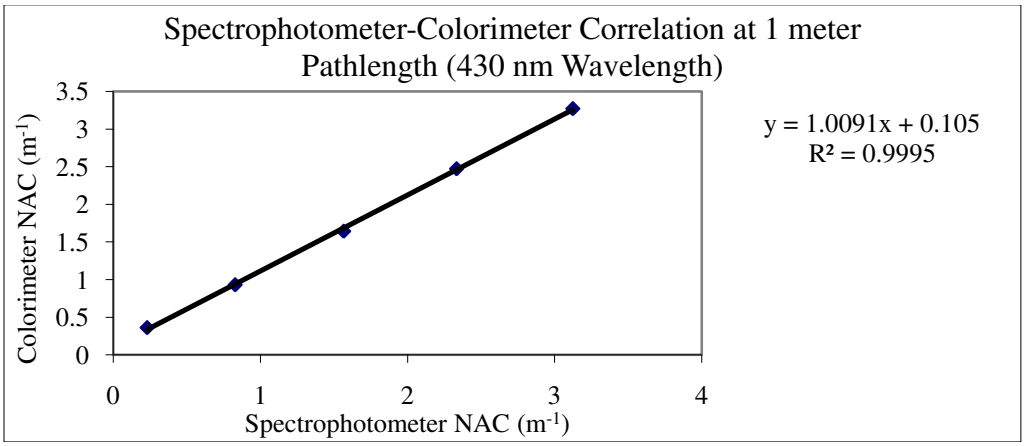

Figure 12 Spectrophotometer-Colorimeter Correlation. The results are relative to a 1 meter path length (430 nm Wavelength) for 10-100% dilution samples.

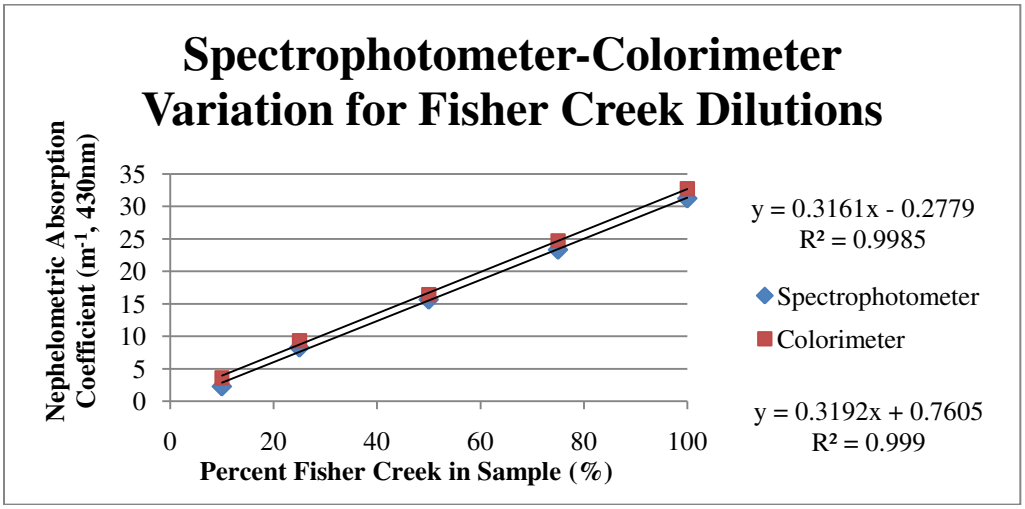

Figure 13 Spectrophotometer-Colorimeter Variation for Fisher Creek Dilutions. Minimal variation independent of concentration occurs between the two instruments used in the study, even for the high NAC values suspect of large errors due to the very small amount of light passing through the sample. These results suggest that the 100% sample contained no greater error than the other data since it falls on the same line. For the 4-11-2009 undiluted sample, the colorimeter/spectrophotometer NAC_{430nm} values were 32.7 and 31.2, respectively, a 2% difference.

Calculations

A sample of April 11, 2009 Fisher Creek water was used to prepare a series of dilution samples (monitoring standard) down to a 0.5% dilution. The absorption coefficients were calculated for the 254 and 430 nanometer wavelengths. The Fisher Creek NAC and dilution data were plotted to use the Wakulla Springs NAC data (as "x") to solve for "Percent of Fisher Creek in the Sample" (as "y"). (See Chapter 3 Results, Figure 52 for more detail.) This absorption – concentration relationship was used with the specific Wakulla Springs UV-VIS results, assuming Fisher Creek was the only blackwater contributor and the stream concentration was constant over the time period. (Neither assumption is valid but this allows a rough approximation.) If the Wakulla Springs transmittance exceeded 90% at 254 nm, i.e. a relatively clear sample, the selected equation was:

Percent Fisher Creek in the sample = $0.2796(NAC_{254}) + 0.0066$. (4)

Wakulla Springs samples with transmittance less than 90% at 254 nm, or poorer water clarity used the equation:

Percent Fisher Creek in the sample = $3.0575(NAC_{430}) + 0.1662$ (5)

Most of the study data reflected the poor water clarity conditions and utilized the NAC_{430} equation.

CHAPTER 3

RESULTS

Fisher Creek

Fisher Creek has a drainage basin that stretches from Lake Talquin in southwest Leon County into northern Wakulla County and covers 92.2 square kilometers (35.59 km^2/29.9 mi^2 per the USGS) according to the Florida Department of Environmental Protection. Field observations during August 2009 indicate that surface water from the Dog Pond Drain (28.4 km^2) and Unnamed Drain North (11.4 km^2) drain on both extremities to both Fisher Creek and Lost Creek. It should also be noted that the extreme southeast end of the Fisher Creek Florida DEP defined basin (south of New Light Church Road) includes land that is part of the Black Creek drainage basin; this section is part of the laterally continuous swamps of Mashes Branch. The headwaters-to-swallet longitudinal profile of Fisher Creek is shown in Figure 14.

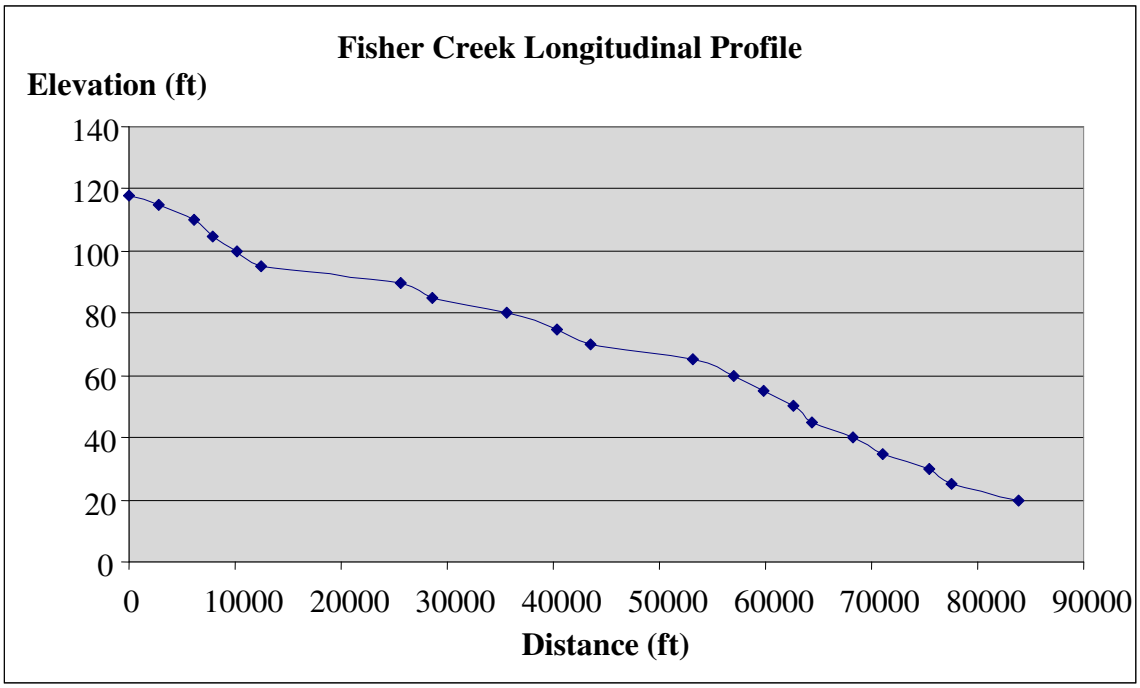

Figure 14 - Fisher Creek Longitudinal Profile. This longitudinal profile headwaters to swallet displays a relatively constant gradient (0.0011) broken only by the major swamps. Fisher Creek is a disappearing stream into three major sinks; Fisher 1, Sullivan and Fisher 2.

Rather than exhibiting the concave-upward profile typical of most streams and rivers with a steep gradient upstream and a flatter gradient downstream, Fisher Creek displays a relatively constant gradient. This constant gradient is broken only by the more gentle gradients through the major swamps located where the long continuous lines at 20,000 and 50,000 feet are observed. Lewis (1945) demonstrated in the lab that stream channels in uniform sand develop linear profiles, but when tributaries increase the discharge, a concave profile develops. Fisher Creek

has no tributaries and flows in a well-defined channel carved into Pleistocene sands east of Springhill Road before disappearing into a sink (the Fisher 1 swallet, ID 11). This linear stream profile may indicate that Fisher Creek maintains a relatively constant flow rate with minimal discharge increase. Fisher 1 is visible during long dry periods; otherwise it is located on the southeast end of a long lake filling the stream bed. The sink is able to accept 3-5 cfs, but starts to over flow when the Fisher Creek discharge is 6 cfs. The Fisher Creek over flow drains to Sullivan and Fisher 2 (also swallets). No flow measurements were made at Sullivan, but Fisher 2 (ID 13) can accept more than 15 cfs.

Fisher Creek drains into three major sinks: Fisher 1, Sullivan and Fisher 2. Mixed species forests and swamps form the headwaters of Fisher Creek. The Fisher Creek channel becomes better defined south of the Forest Road 305 (ID 9) swamp. When creek discharge exceeds the Fisher Creek 1 (FC1) swallet capacity of 3-5 cfs, the water forms a blackwater lake to a depth of approximately 14 feet. An overflow channel located on the south side approximately 300 feet upstream of the swallet activates when the water level is approximately one foot lower. Survey work at FC1 did not include the overflow elevation or the location of the sonar data logger. The overflow fills various depressions to the east and eventually drains to Sullivan Sink and Fisher 2 (ID 13 or FC2 - located in the Leon Sinks Geological State Park). Sullivan Sink is a karst window able to accept high flow volumes. FC2 can also accept high flow volumes as observed November 25, 2008 (not measured but the United States Geological Survey reported a daily discharge of 105 cfs upstream at Springhill Road) and August 16, 2009 (discharge of 15 cfs compared to the upstream 18 cfs reported by the USGS).

Numerous stream bed hikes during the drought conditions of 2008, west and east of Springhill Road revealed a predominantly fine to very fine sandy bottom. A 0-1' massive intermittent layer of dark brown loosely cemented sand and silt was observed in the base and swale-shaped banks west of Springhill Road. Upstream of these observations, the channel contained deep water-filled holes that did not dry out. East of Springhill Road and west of the Sam Marks Road terminus, the dark brown cemented sand layer formed the stream bottom base and was also observed as a boulder field in the predominantly dry stream bed (see Figure 15). This cemented unit pinched out at Sam Marks Road crossing. Before breaching and when present, this cemented layer likely limits vertical leakage into the Floridan Aquifer. The mapped Leon Sinks saturated conduits trend northwest in the area of Fisher Natural Bridge (ID 12) and Sullivan Sink. Maxi-Blow Tunnel enters the Leon Sinks conduit system further to the northwest (between ID 10 and 12 locations) and if the northwest trend is extended upgradient, would eventually cross the Fisher Creek FR 305 (ID 9) swamp. This particular swamp has many perennial round ponds that are likely karst features surrounded by impenetrable vegetation. These ponds retained water through out 2008.

The USGS monitoring station at Springhill Road (ID 10) provided the stage/discharge data that is used for this study. No tributaries discharge to Fisher Creek downstream of this location and these stage/discharge data were used for this study. Supplemental measurements of stage were made during sample collection, including depth to water below the edge of the bridge when the USGS staff gage was submerged by flood waters.

Figure 15 Dry Fisher Creek Stream Bed. The June 10, 2007 photo of the Fisher Creek stream bed west of Springhill Road shows typical no-flow conditions. The center boulders were also observed east of Springhill Road but upstream of Sam Mark's Road.

On July 9, 2009, a sonar data logger was installed at the eastern end of an earthen boat ramp at the terminus of Sam Marks Road to record the Fisher 1 (FC1) swallet pool elevation and to determine the stage of overflow to Sullivan and Fisher 2 swallets. Figure 16 is a photo taken on November 21, 2009 of the logger device with the overflow on the opposite side of the pool close to the center of the picture. No overflow was occurring at this time as the water level was approximately six inches below the overflow mouth.

Figure 17 shows the typical response for the FC1 pool. The overflow activates when the stage reaches 1-1.5 feet and discharge is greater than 6 cfs. The days with wide stage oscillations are due to the daytime air temperature changes from 75-95 degrees Fahrenheit and cloud cover changes. The temperature effect on the speed of sound increases from 1133 feet per second to 1154 feet per second, explaining a surface water elevation change of 0.2-0.5 feet. The blackwater will absorb solar radiation, increasing the temperature of shallow waters. At higher discharges of 5 cfs and greater (see the Figure 17 discharge), the rate of incoming flow is high enough to keep the water moving and deep enough to offset the potential temperature effects. As an example of the temperature effect, see July 15, 2009 (approximately record number 550) when 1.19 inches of rain fell.

Figure 16 Flooded Fisher Creek 1 Swallet and Overflow. The FC1 sonar data logger (left) and the overflow location (center are both shown for November 21, 2009. The surface water elevation was six inches below the mouth of the overflow.

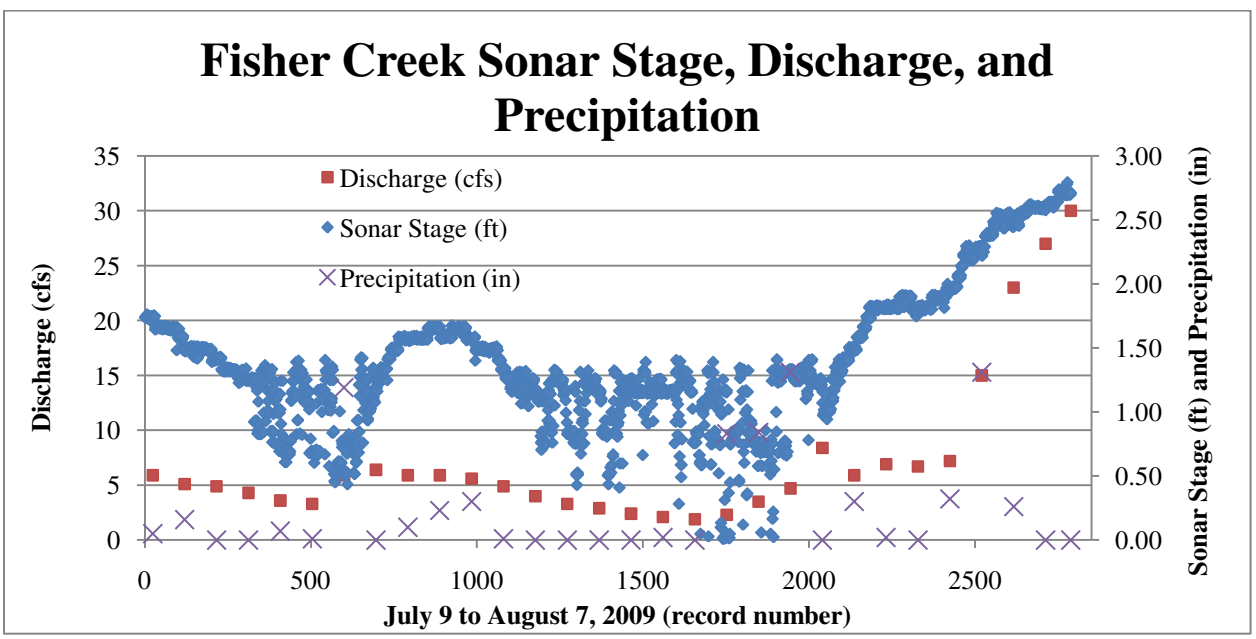

Figure 17 Fisher Creek Sonar Stage, Discharge, and Precipitation. The daily stage fluctuations of the FC1 swallet pool are due to temperature changes for flows less than 6cfs.

Figure 18 presents the Fisher Creek transmittance and precipitation (using the CAFWN #602 station) data for August 2008 to October 2009. The three big discharge events were Tropical Storm Fay (T.S. Fay) in August 2008, Hurricane Paloma (H. Paloma) November 13-14, 2008 and the March-April 2009 storm. In all cases the transmittance initially decreased and then increased with further precipitation. The T.S. Fay and H. Paloma events generated more rainfall than the March-April 2009 storm, but do not have any corresponding Wakulla Springs data because the collection of Wakulla Springs spectrophotometer data began in 2009. H. Paloma was unique in that rainfall occurred only on the western ends of the Fisher Creek and Lost Creek basins and resulted in recharge at all swallets for each stream. The Fisher Creek transmittance range is 44-84% with a mean of 61 percent for 28 samples. In 2009, a time series analysis (using R Core software) of stage and precipitation data for Fisher Creek was performed and indicated a four day lag, i.e. stage reflected the precipitation four days prior. Other statistical evaluations used provisional discharge that was later revised by the USGS and NFWMD. Computer problems prevented a rerun of these statistical evaluations. Figure 19 shows the discharge and NAC data for August 2008 to October 2009. Note that NAC increases with the precipitation events, often with the NAC peak increase trailing the discharge peak.

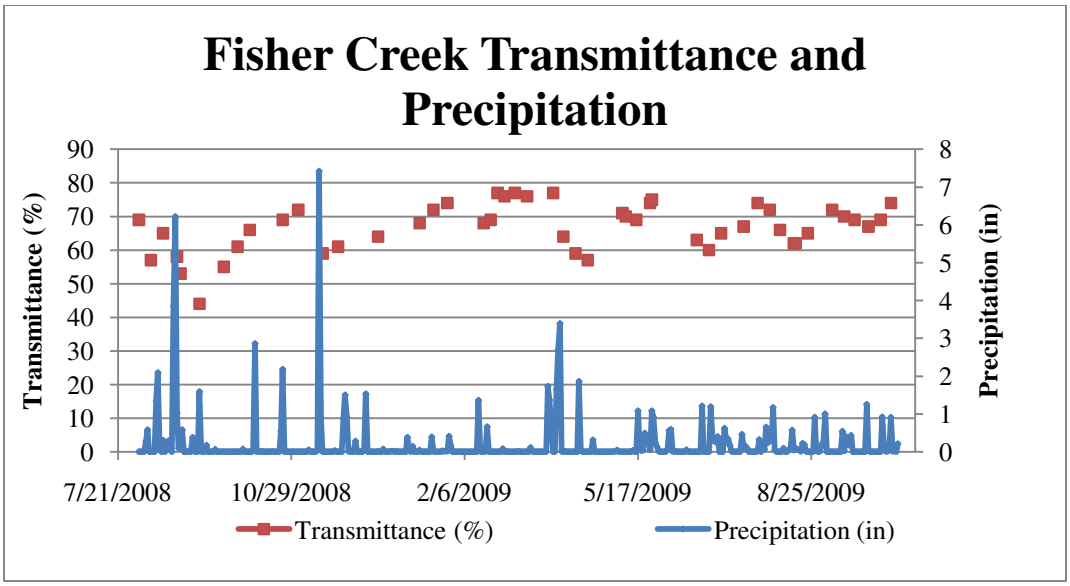

Figure 18 Fisher Creek Transmittance and Precipitation, 8/2008-10/2009. The three big precipitation events were T.S. Fay in August 2008, H. Paloma in November 13-14, 2008, and the March-April 2009 storm. Note that transmittance initially decreased and then increased with further precipitation.

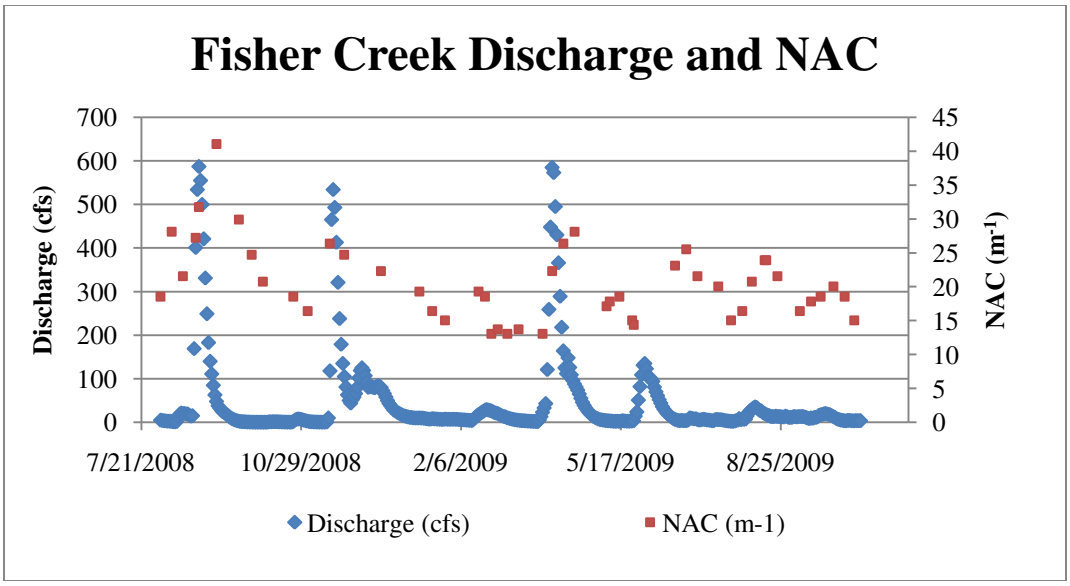

Figure 19 Fisher Creek Discharge and NAC, 8/2008- 10/2009. Note that NAC increases with the precipitation events, often with the NAC peak increase trailing the discharge peak.

Black Creek

Black Creek has a drainage basin of 41.3 square kilometers that stretches from Apalachicola National Forest Road 309 to U.S Highway 319, mostly in Wakulla County with some acreage in southern Leon County. Field observations during August 2009 indicate that surface water from the Cow Swamp Drain (21.3 km^2) provides surface water to both Black Creek and Lost Creek. The headwaters-to-swallet longitudinal profile of Black Creek is shown in Figure 20.

Black Creek is similar to Fisher Creek in that it displays a relatively constant gradient except where it steepens along the last 2000 feet approaching Black Hole (ID 21). This linear stream profile suggests that Black Creek maintains a relatively constant flow rate, increasing only where the gradient increases. This constant gradient is broken only by the more gentle gradients through the major swamps depicted as long continuous lines beginning at 1,500 and 15,000 feet above. Swamps provide the headwaters for Black Creek and flow occurs in swale-like features until reaching State Road 267 (also known as Bloxham Cutoff) where Black Creek has a well defined-incised channel continuing to Black Hole. At Black Hole, Black Creek disappears into the sink pool and drains into a saturated conduit that trends west, but has not been fully explored by SCUBA divers (Personal communication with Cal Jamison, 2009). Black Hole experiences flood pulses from the Floridan Aquifer that are strong enough to push the blackwater out of the sink and back in to the stream channel (observed on 1-27-2008, 6-14-2008, and 11-25-2008). In flooded conditions, Black Hole is unable to accept all of the incoming flow and the excess drains to nearby Mermaid Sink for a short period generally less than a day. Mermaid Sink also receives overflow from Mashes Branch. In 2003, dye was injected into Black Hole that entered the Leon Sinks conduit system 68 hours later at the same place as dye injected into Fisher 1 (arrived 49 hours after injection) (Kincaid, 2006). These dye injections were performed during low flow conditions to minimize the amount of dye needed and to maximize mass recovery. Black Creek is a significantly shorter drainage basin than Fisher

Creek, resulting in its flow peaking and starting recession before Fisher Creek peaks. This could result in Black Creek and Fisher Creek arriving at the Leon Sinks conduit system at the same time.

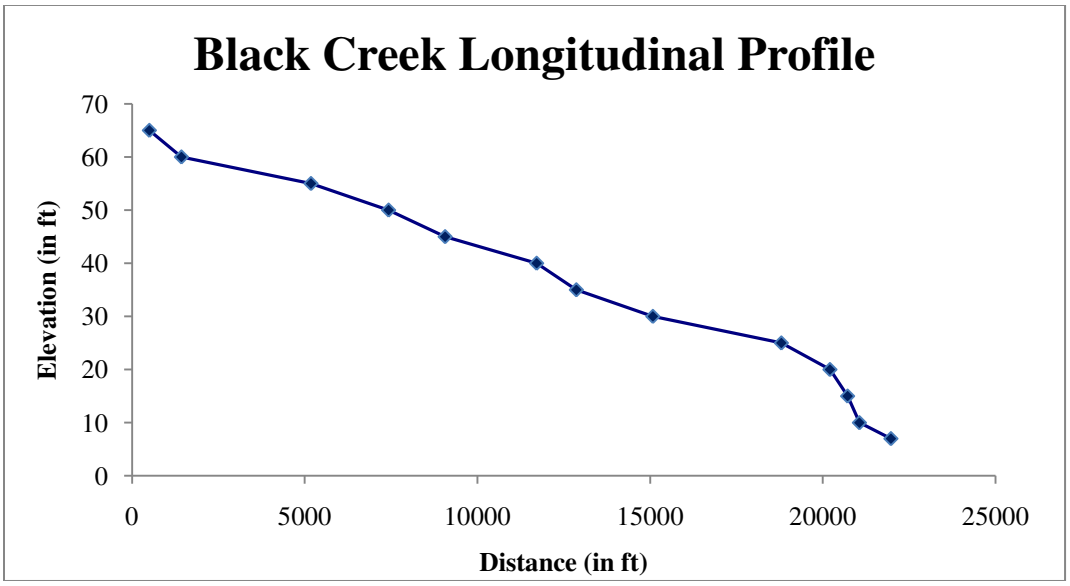

Figure 20 Black Creek Longitudinal Profile. The headwaters to swallet displays a relatively constant gradient (0.0025) broken only by the major swamps observed at 1500 and 15,000 feet. The creek bed gradient shows a significant increase approaching Black Hole at 20,000 feet. Black Creek is a disappearing stream into three major named sinks; Black Hole, Roaring Sink and Mermaid Sink (high stage only).

Black Creek bifurcates north of State Road 267 and the eastern deeper channel is known as Mashes Branch. Roaring Sink (ID 22) is one of the sinks receiving Mashes Branch flow. With a deeper channel, Mashes Branch receives flow longer than the channel to Black Hole. An additional unnamed creek crosses State Road 267 to the southeast of the Black Creek crossing. This creek and the unnamed disappearing stream that flows to the west of the Zion Hill Church are likely part of the Black Creek drainage basin as they flow towards Mashes Branch but are captured by sinks. The Chip's Hole conduit system is located between Mashes Branch and the sinks capturing both unnamed streams. Dye testing has not been performed on Mashes Branch sinks or the sinks capturing the unnamed streams to understand the Chip's Hole conduit system sources and destination. The Chip's Hole conduit system is believed to drain into the Leon Sinks conduit system.

At Black Creek State Road 267 (ID 19), a three foot long staff gage and a ladder sampler were installed near the northeast shoreline. Very fine white sand and organic particulate were observed in the ladder sample bottles after major precipitation events. Safety considerations prevented timely recovery of the samples, so this research relies on the discrete sample data. A continuous sonar logger was installed on Black Creek on February 25, 2009 to record depth to water every 10 minutes. Batteries needed to be changed every thirty days. The first period recorded data successfully and is shown in Figure 21 corrected with the initial field stage reading and the daily precipitation from Capital Area Flood Warning Network (CAFWN) Station #803.

This type of logger records birds, bugs, or other items that move between the device and the water level; these anomalies have been removed. (Precipitation did not occur on most of these days so it was not the reason for the anomalies.) Note the diurnal stage variation due to the temperature changes and the rapid stage response to 0.24 inch rainfall on 3/16/2009. The stage rise starting on 3/31/2009 flooded the forest floor and deposited a new layer of fine white sand with a maximum thickness of four inches decreasing with distance from the Black Creek channel.

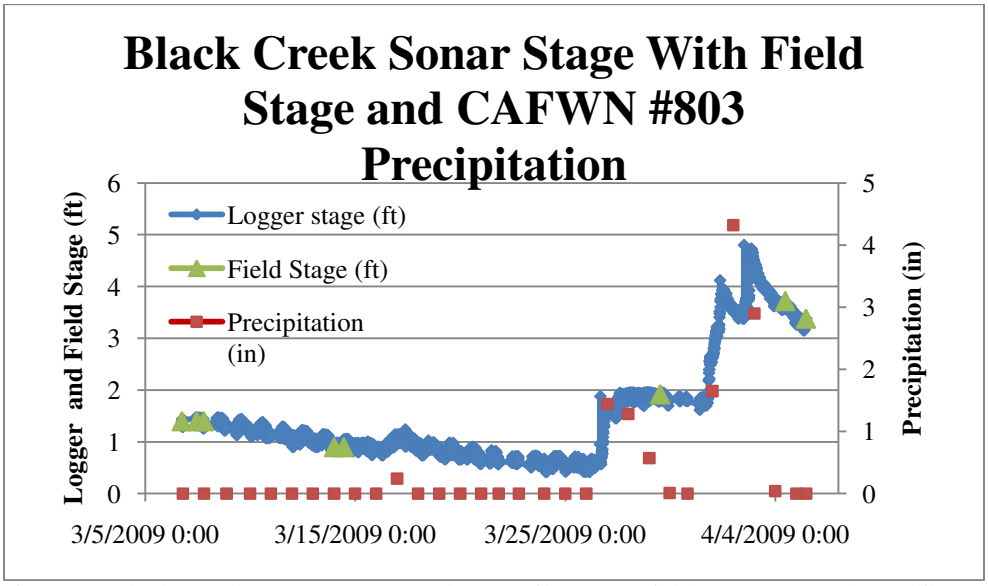

Figure 21 Black Creek Sonar Stage, March to April 2009. Field stage was used to calibrate the sonar stage. Daily precipitation from Capital Area Flood Warning Network Station #803 is included. Note the diurnal stage variation due to the temperature variation and the rapid response to 0.24 inch rainfall on 3/16/2009.

During the battery change at the end of the first month, wires became disconnected when placing the equipment pieces back into the ground PVC pipe. This problem wasn't discovered until the next battery change. Data collection the following month appeared to have problems, possibly due to high humidity adversely affecting the electronics. On August 7, 2009, the data logger was vandalized. Figure 22 shows the May to August 2009 logger data, staff gage readings, and precipitation amounts for the period. Although a high stage response would be expected after the May 26, 2009 precipitation of 2.28 inches, a stage of 5 feet is not realistic because flow leaves the channel and floods the forest floodplain above a stage of 3.3 feet. The 2008 T.S. Fay precipitation totaled 8.72 inches over a three-day period and produced a stage of 4.38 feet. The March 26-April 3, 2009 total precipitation was 12.21 inches (maximum 3-day precipitation was 4.21 inches) resulting in a 4.7-foot logger stage. The late July part of the logger stage again responds with the field stage observations, after correcting to the July 17, 2009 stage. In summary, the logger data for March 6 to April 4, May 7-31 and July 17 to August 7, 2009 periods were considered valid and selected to supplement field stage measurements for daily discharge estimates.

Discharge measurements on Black Creek were made approximately 75 feet down stream of State Road 267 at a natural root weir in order to measure flow during most flow conditions. (At the SR 267 culvert, no flow was detected with the Marsh McBirney flow meter in the deep pool.) Flow measurements were made at State Road 267 only during flooded conditions with a 15 foot long wading rod (a 20 foot long rod would be better). See Appendix A for the data and details.

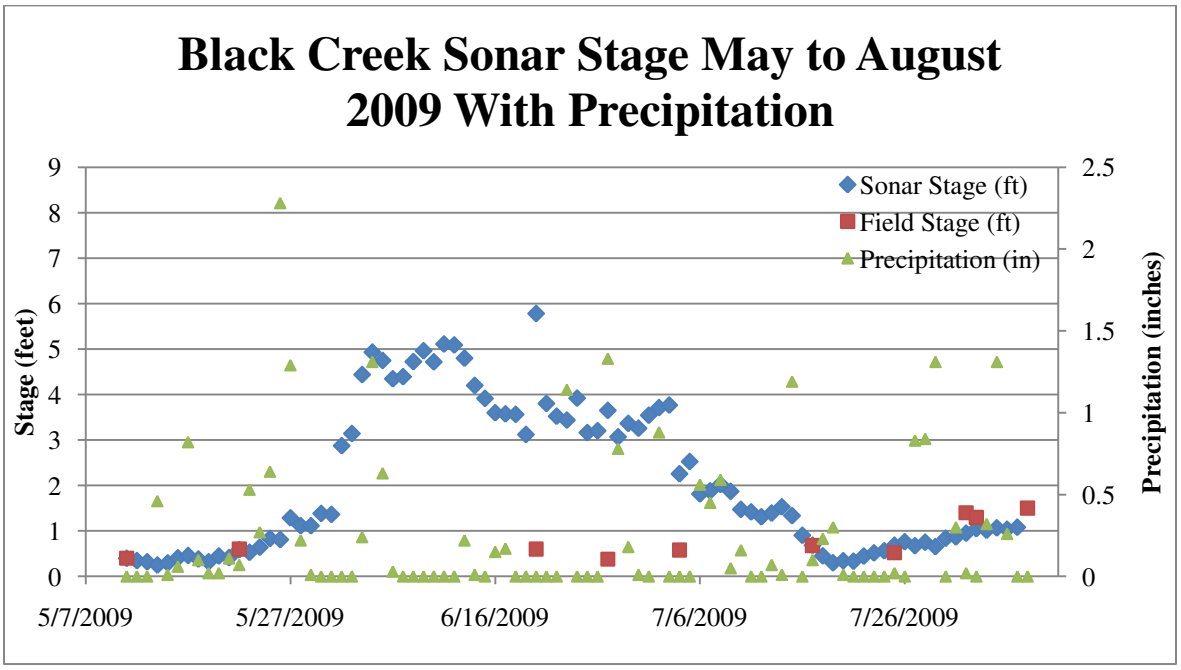

Figure 22 Black Creek Sonar Stage, May to August 2009. Field stage was used to calibrate the sonar stage. Daily precipitation from Capital Area Flood Warning Network Station #803 is included. The June to July logger stage is not supported by the field stage observations. The late July part of the logger stage again responds with the field stage observations, after correcting to the July 17, 2009 stage.

Figure 23 presents the transmittance and stage data collected during this study with the precipitation record (CAFWN #803). The two big discharge events were Tropical Storm Fay (T.S. Fay) August 2008 and March-April 2009 storm. In both cases the transmittance initially decreased and then increased with further precipitation. The Black Creek transmittance range is 27-66 percent with a mean of 48 percent for 48 samples. Figure 24 shows the stage, NAC, and discharge data for 2009. Figure 25 shows the Black Creek transmittance change between SR 267 and downstream Black Hole relative to stage. There is a noticeable decline in transmittance following a significant rise (1 foot or more) in stage. Generally, the transmittance stays the same or may drop a few percentage points from SR 267 to Black Hole. The two exceptions on the graph are (1) the first flowing conditions following the 2007-2008 drought with transmittances of 37-27 percent and (2) November 25, 2008 when a flood pulse occurred at Black Hole giving a transmittance of 91 percent relative to the (low) flowing Black Creek transmittance of 61 percent. The water temperature was noticeably warmer (no thermometer was available to quantify) than all other creek stations that day. At Black Hole, there was no evidence of creek inflow into the sink and the creek contained clear water until the first upstream pool.

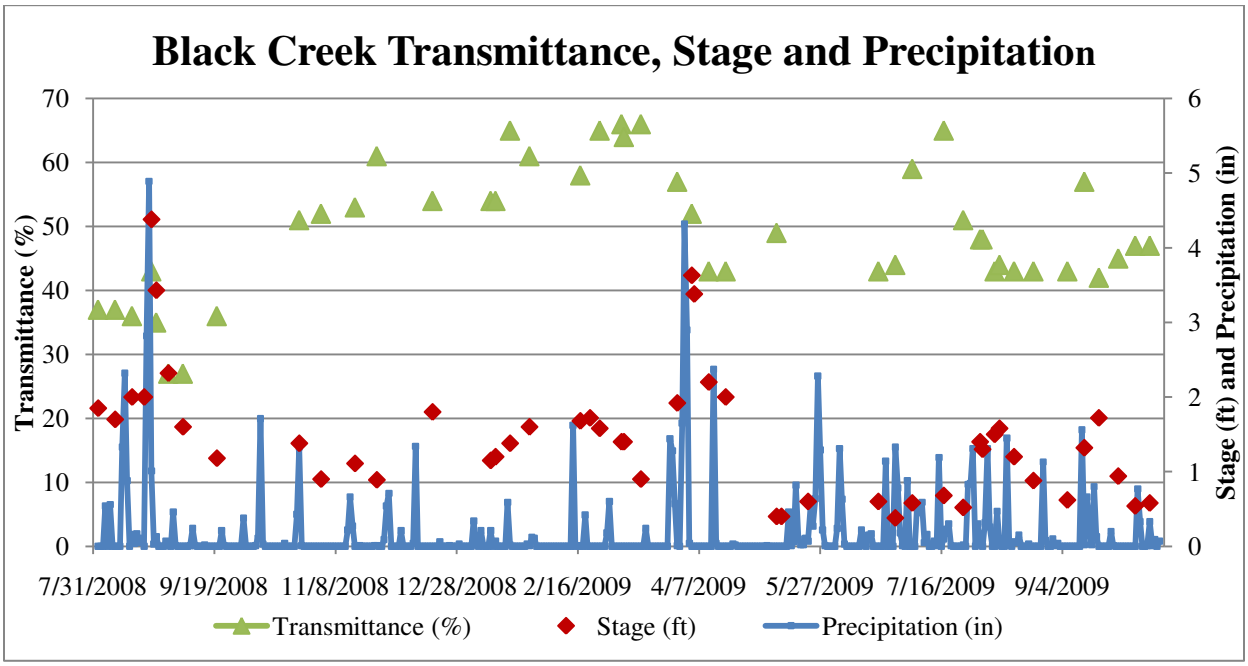

Figure 23 Black Creek Transmittance, Stage and Precipitation, 2008-2009. Note that the transmittance associated with the two largest precipitation events, initially drops and then rises with additional precipitation.

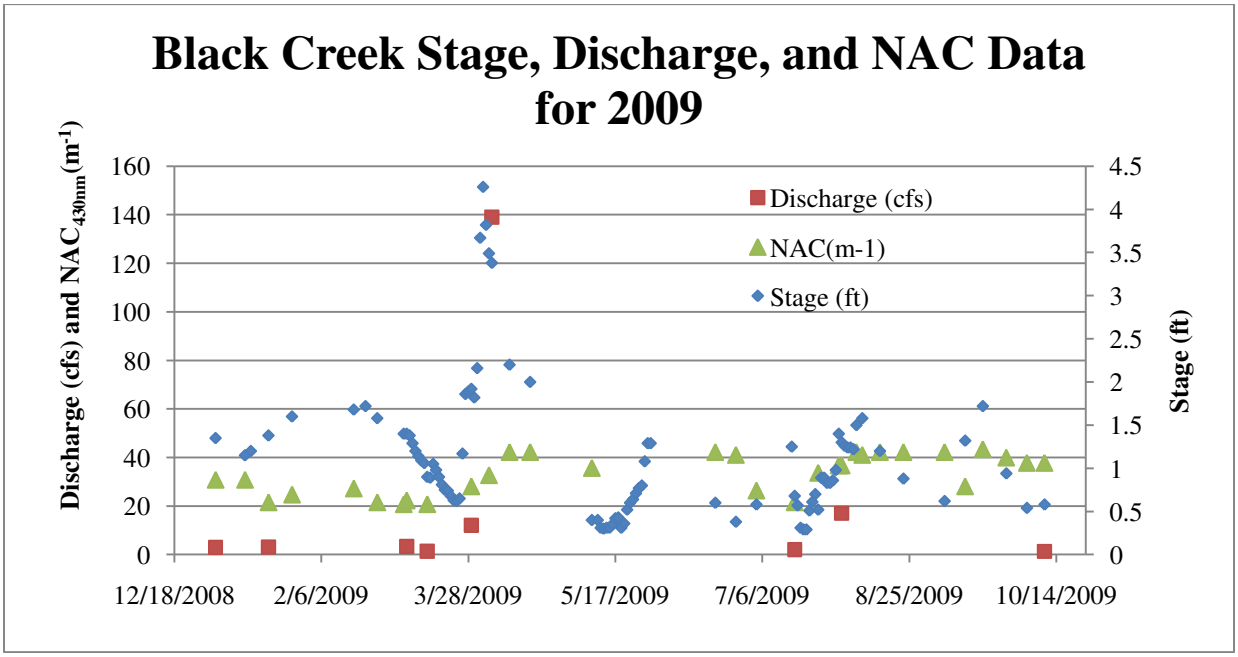

Figure 24 Black Creek 2009 Stage, Discharge, and NAC.

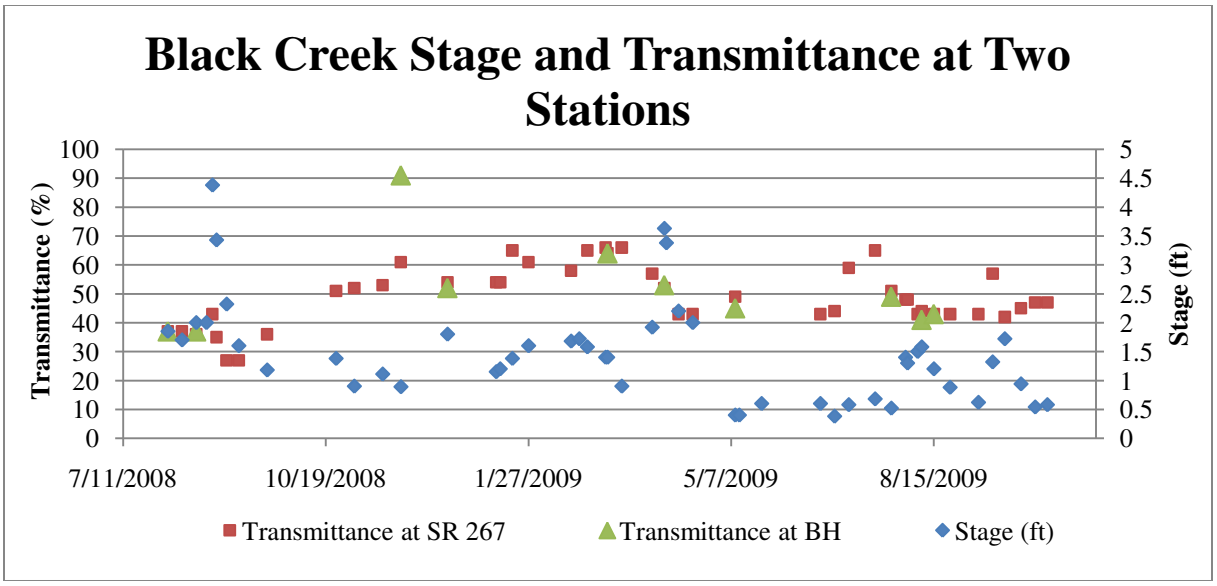

Figure 25 Black Creek Stage and Transmittance at Two Stations; at SR 267 and Black Hole relative to the stage at SR 267. Typical conditions oscillate between 40 and 64% transmittance with a decline in transmittance following sufficient precipitation. (See April and August 2009 above.). The two transmittance exceptions on the graph are the first flowing conditions following the 2007-2008 drought with transmittances of 37-27 percent and the November 26, 2008 flood pulse at Black Hole with a transmittance of 91 percent.

Jump Creek

The Jump Creek sub-drainage basin covers 17.3 square kilometers in Wakulla County of the Department of Environmental Protection (DEP) Wakulla River basin on its west side. Its headwaters are various swamps of the Apalachicola National Forest (ANF). Jump Creek crosses Walden Lake Road in two places; a south culvert crossing and a north three-pipe configuration. The north crossing flows for a longer period of time with velocities high enough to be measured. Water depth at the south crossing prevents measurable velocities except during high flow conditions. There are also two crossings at U.S. Highway 319 with the southern flow path being more dominant. Both crossings terminate in swamps on the east side of U.S 319. Most of the creek flow drains to the Jump Creek swallet located west of U.S. Highway 319. During lower flow periods and when the Floridan potentiometric surface is low, this flow becomes interflow under a land bridge and upwells into the deep pool located on the west side of the land bridge. This visible spring discharge behavior was observed and measured at 19 cfs on September 19, 2009. The Jump Creek swallet is able to accept flows significantly higher than 19 cfs, but when flow was 75 cfs (April 4, 2009), the swallet was observed to be extensively flooded approximately 6 feet above typical levels.

A staff gage was installed on the upstream side of the land bridge and surveyed. The floods of T.S. Fay and March/April 2009 had an elevation greater than 106 feet MSL. The staff gage was moved from the land bridge to the swallet on 9/20/2008 retaining the vertical elevation so that all data stay relative.

A continuous float displacement logger was installed at the Jump Creek swallet for a short period from August 17-21, 2008 and removed due to the approach of T.S. Fay. Figure 26 compares the data to the barometric pressure variation and with a graph of the Spring Creek tides

for the same period. The surface water level at Jump Creek responds directly to the diurnal tidal cycle indicating that the swallet is in direct communication with the groundwater conduit system surrounding Wakulla Springs (Loper et al., 2005). The barometric pressure decline for the approach of Tropical Storm Fay is expected, but the stable response of the Jump Creek swallet water level for half a day preceded a decline of almost 1 inch. Water level typically rises under a declining barometric pressure. Figure 27 presents the Wakulla Springs stage and discharge response for the same period. Note that with the declining barometric pressure, its stage increases and discharge initially decreases.

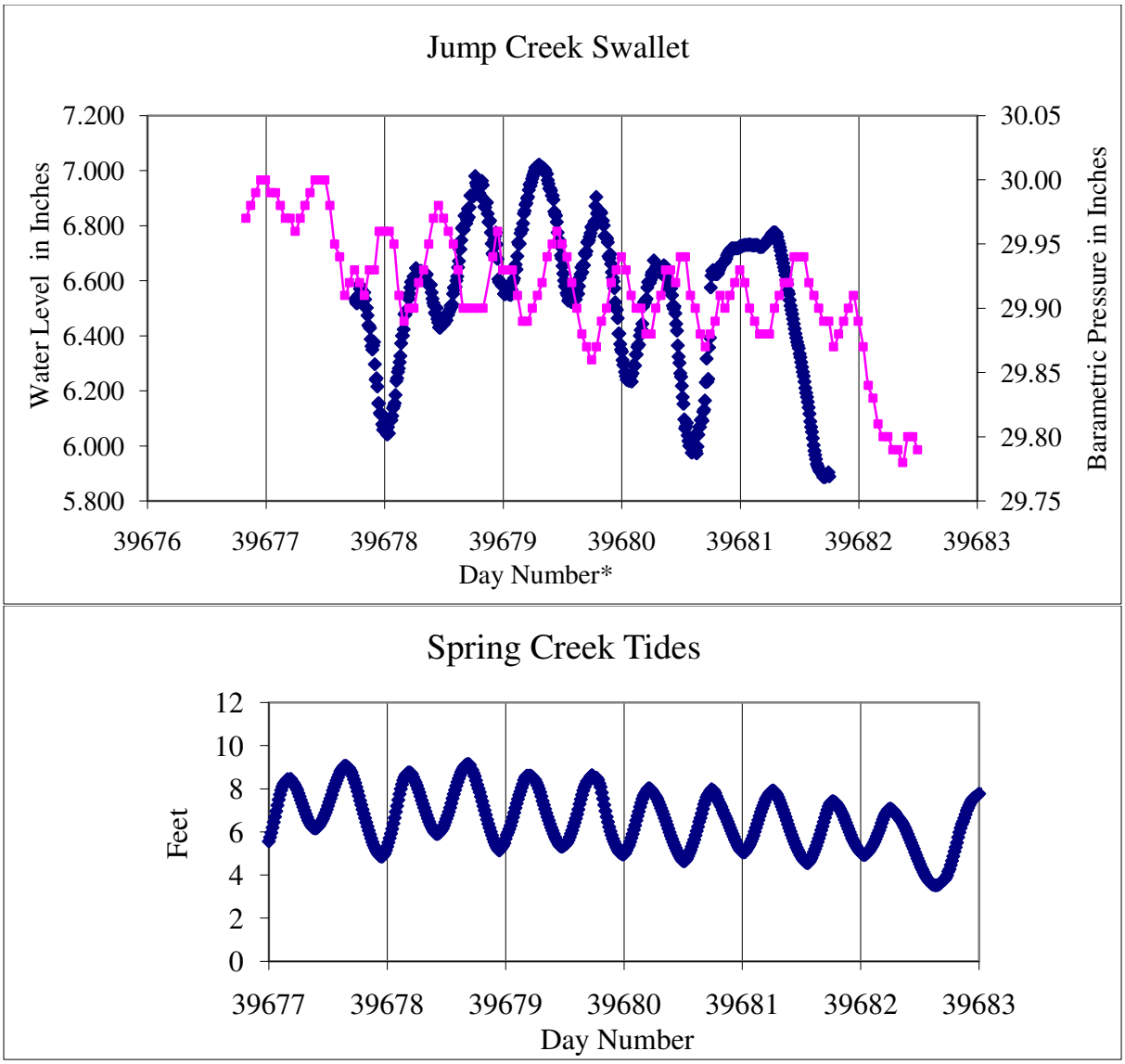

Figure 26 Jump Creek Stage and Barometric Pressure Response to T.S. Fay. Stage data for August 17-21, 2008 in advance of T.S. Fay is presented. The diurnal tidal response of the swallet water level indicates the swallet has a direct connection to the conduits of Wakulla Springs. The barometric pressure decline for the approaching storm is expected, but the stable response of the Jump Creek swallet water level for half a day preceded a decline of almost 1 inch. Water level typically rises under a declining barometric pressure. Figures from S. Kish, personal communication, 2008. *Day Number 39676 was August 16, 2008.

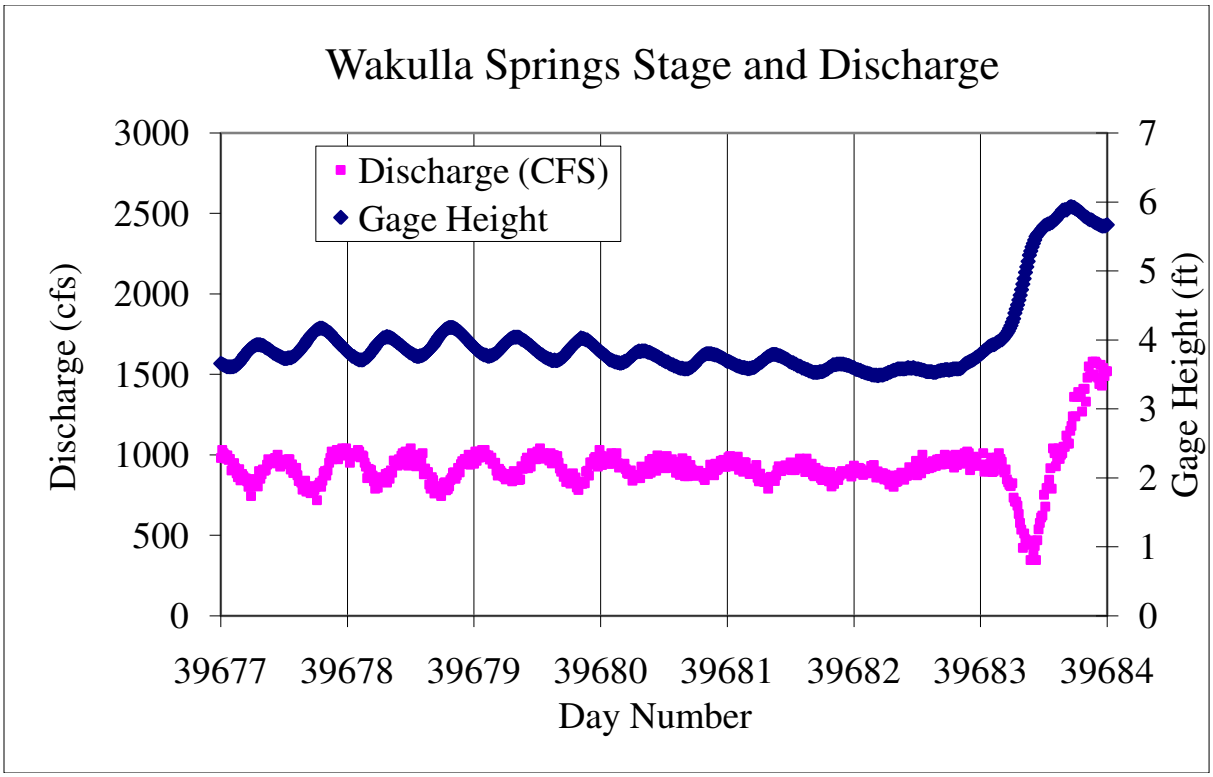

Figure 27 Wakulla Springs Stage and Discharge Response to T.S. Fay. Note that with the declining barometric pressure, its stage increased and the discharge initially decreased. Figure from S. Kish, personal communication, 2008. *Day Number 39677 was August 17, 2008.

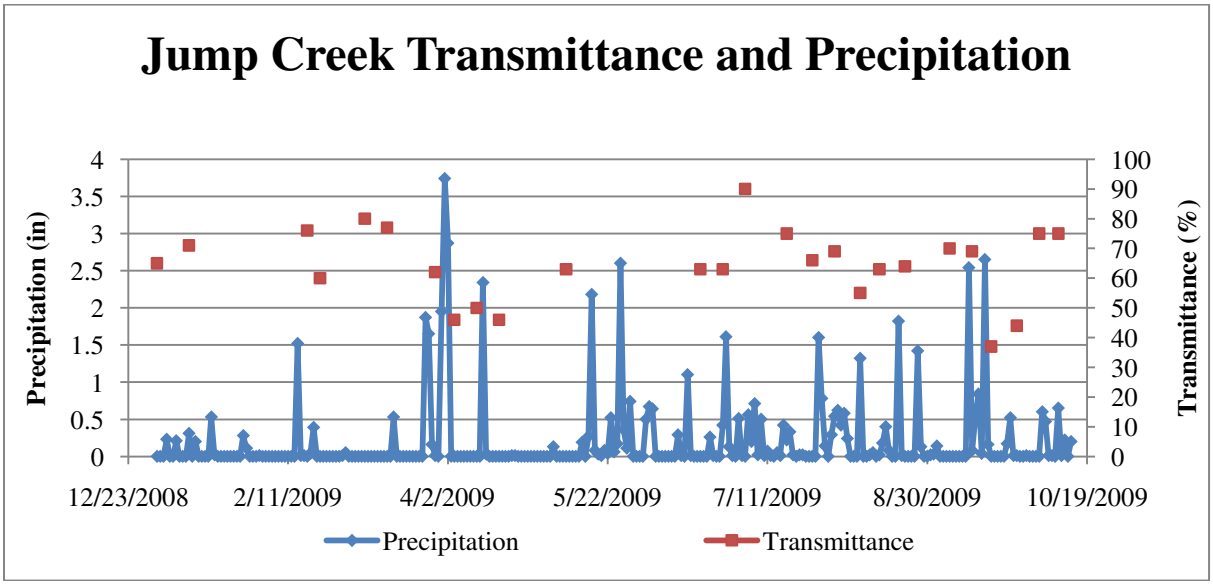

Figure 28 Jump Creek Transmittance and Precipitation, 2009. Note that the transmittance drops with precipitation and then rises with further precipitation.

Figure 28 presents the Jump Creek transmittance and precipitation (using the WSSP station) data for January to October 2009. With precipitation, the transmittance initially decreased and then increased with further precipitation. The Jump Creek transmittance range is 37-90% with a mean of 64 percent for 30 samples.

Lost Creek

Lost Creek has a long linear drainage basin of 122.7 square kilometers that extends near Lake Talquin on the northwest end in Leon County to Crawfordville in Wakulla County. The Dog Pond Drain (28.4 km^2) and Unnamed Drain North (11.4 km^2) drain on both extremities to contribute additional flow to both Fisher Creek and Lost Creek. Part of Cow Swamp (21.3 km^2) and all of Unnamed Drain South (9.3 km^2) drain to Lost Creek. All of the Mill Creek drainage basin discharges to Lost Creek downstream of the USGS Arran Road stage monitoring station. Lost Creek drains to the Lost Creek swallet located on the north side of Harvey Mill Road. The Lost Creek swallet will accept at least 100 cfs, but at a depth to surface water of 239 inches (6.07m) below the white spot (area on the north concrete rail that appears to have been bleached) on the Harvey Mill Road Bridge, the excess surface water bypasses the Lost Creek swallet and continues southward. Two dye injections during low flow conditions have shown that for very low conditions, flow from the Lost Creek swallet either reaches Wakulla Springs in 44 to 89 days, or at slightly higher conditions, all of the flow bypasses Wakulla Springs to discharge at Spring Creek. The Lost Creek transmittance range is 35-81 percent with a mean of 55 percent for 33 samples.

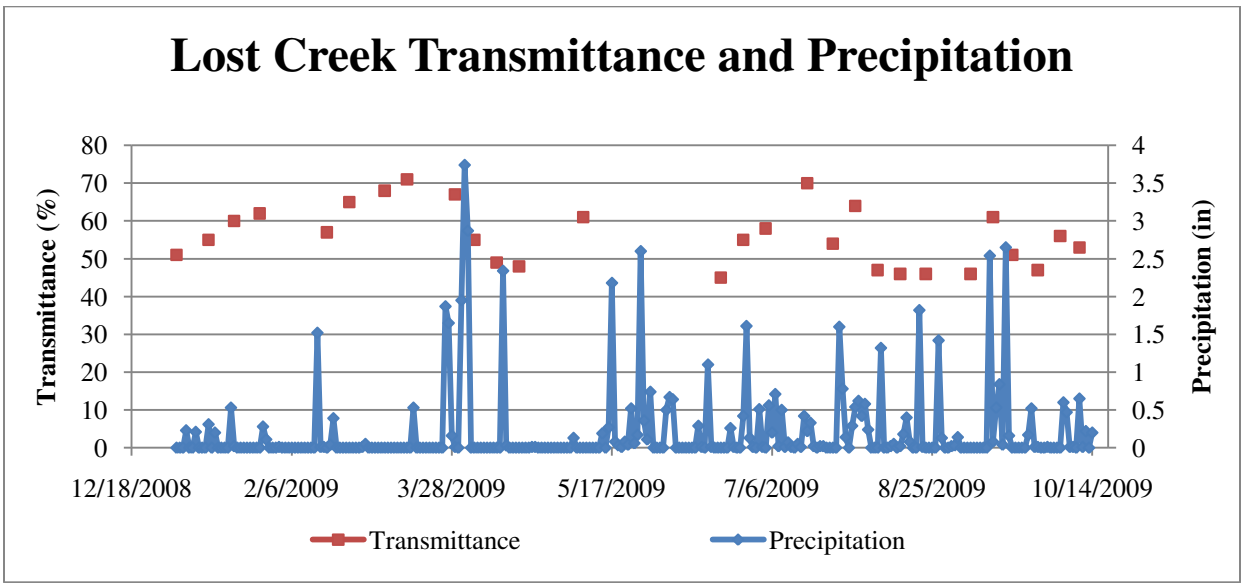

Figure 29 Lost Creek Transmittance and Precipitation, 2009. Note that the transmittance drops with high precipitation and then rises with further precipitation.

Munson Slough

The Munson Slough drainage basin covers 123.8 square kilometers of Leon County. This area does not include the Godby Ditch, Central Drainage Ditch, St. Augustine Branch basins, and the internally-drained Fred George basin that are also part of the Munson Slough

basin. These latter basins were not specifically studied because all flow enters Munson Slough and samples were collected of the downstream composite flow. The Bradford Brook basin (50.6 km^2) includes internal drains (sinkholes) in the lake bottoms and overflows into the Munson Slough basin. Munson Slough drains urban Tallahassee and flows through Lake Henrietta (a stormwater treatment facility), Lake Munson and Eightmile Pond. The NWFWMD stage monitoring station is located on Capitol Circle Southwest upstream of Lake Munson. Munson Slough shows a rapid stage response to precipitation as shown in the Figure 30 plot of 2008-2009 data. This rapid stage response to precipitation is due to the high percentage of impervious surfaces (buildings, roads, parking lots, etc.) upgradient and the rapid collection of runoff by drainage ditches.

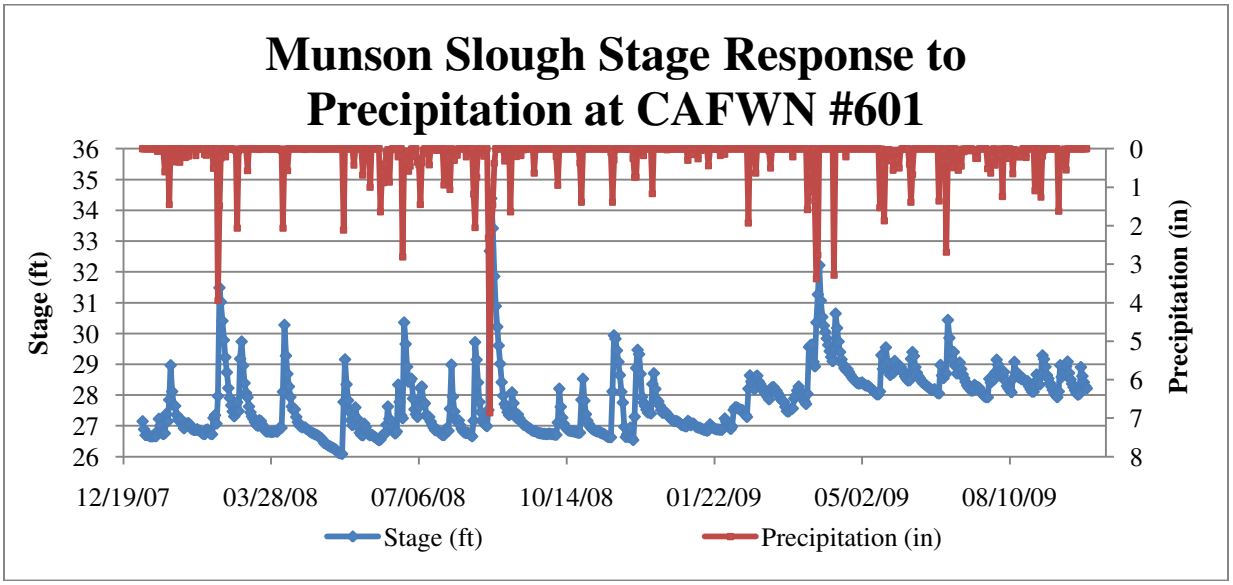

Figure 30 Munson Slough Stage Response to Precipitation. Northwest Florida Water Management District continuous stage data for Munson Slough shows its rapid response to rainfall.

The discharge of Munson Slough dramatically increases in response to high rainfall and most storm events produce discharges less than 250 cfs. Figure 31 shows three events with flows of 500 cfs or greater. The March/April 2009 event is discussed in this thesis. The discharge of 2100 cfs associated with T.S. Fay (August 2008) is not visible on the graph due to overlap with the precipitation.

Munson Slough at Oak Ridge Road was the primary sampling location as it is immediately upstream of the Ames 1 and 2 and Kelly Sinks (swallets) that drain to Wakulla Springs (established through dye tracing by other research- Hazlett-Kincaid, 2005). The dye tests documented travel time from Ames and Kelly sinks to be 20 days to Wakulla Spring discharge for low flow conditions. The Munson Slough transmittance ranges from 80-96 percent with a mean of 90 percent for 21 samples. The lowest value of 80% occurred during T.S. Fay in August 2008. Munson Slough shows a drop in transmittance following high discharge events on Figure 32.

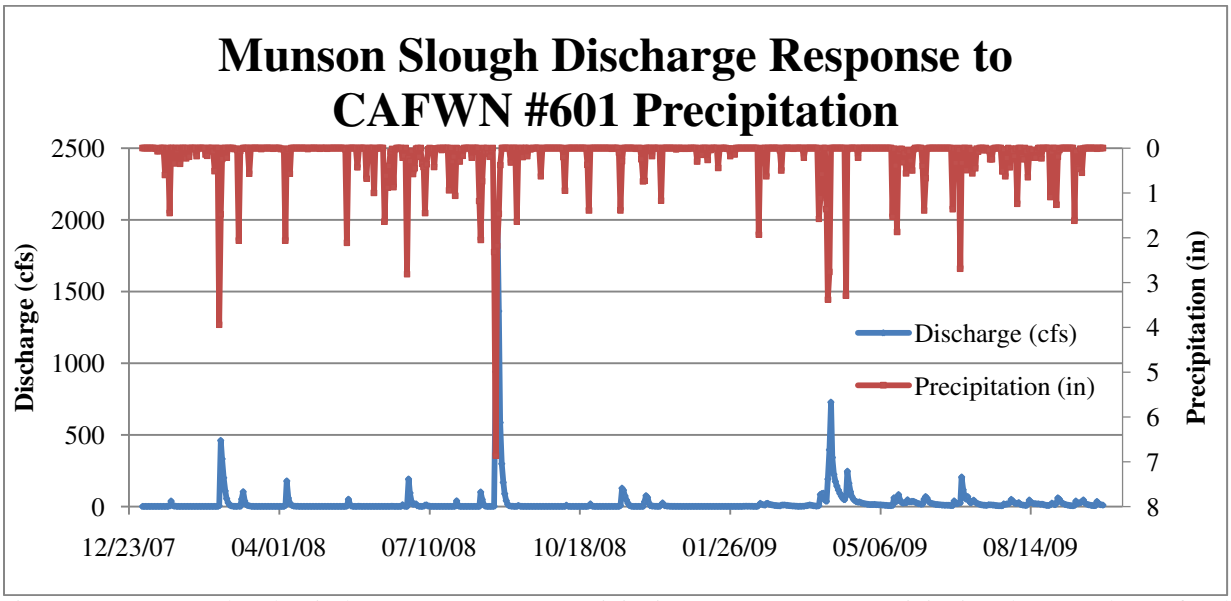

Figure 31 Munson Slough Discharge Response to Precipitation. NWFWMD precipitation data are shown for the period January 1, 2008 to October 1, 2009. The T.S. Fay discharge in August 2008 was 2100 cfs.

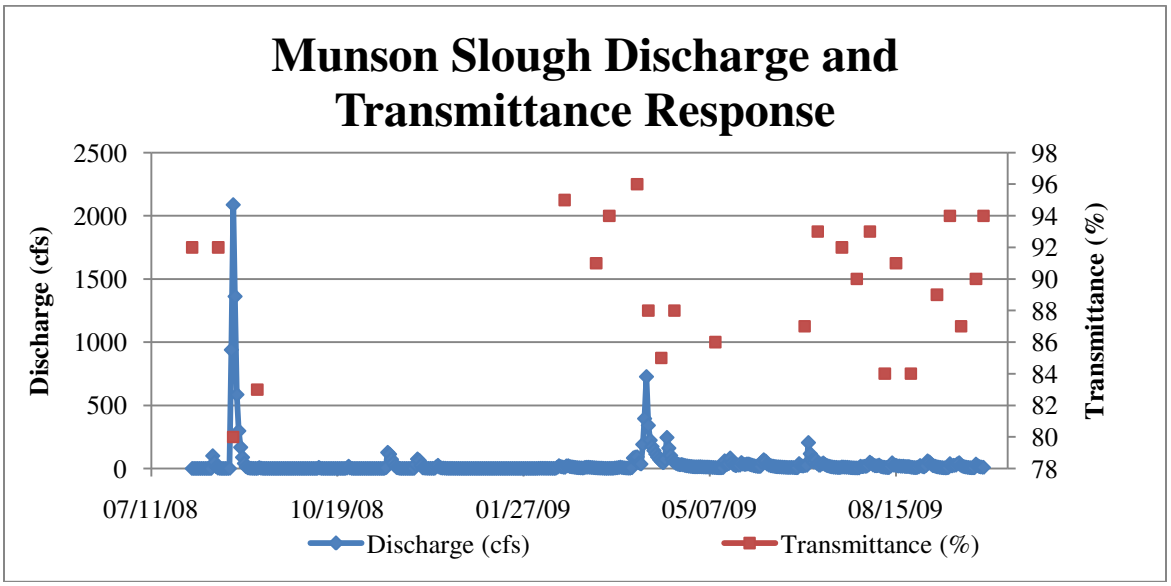

Figure 32 Munson Slough Discharge and Transmittance Response. Munson Slough shows a drop in transmittance following high discharge events.

Figure 33 presents the effect an algal bloom can have on water clarity. Beginning in the late spring of 2009, Munson Slough contained fluorescent green patches of algae covering the sediment and a split pea-soup color to the water. The algal mass was uniformly distributed giving the water column an opaque appearance rather than any clarity. Sample filtration produced a very fine green ring on the filters. These fine particulates were unique to this location and this specific period.

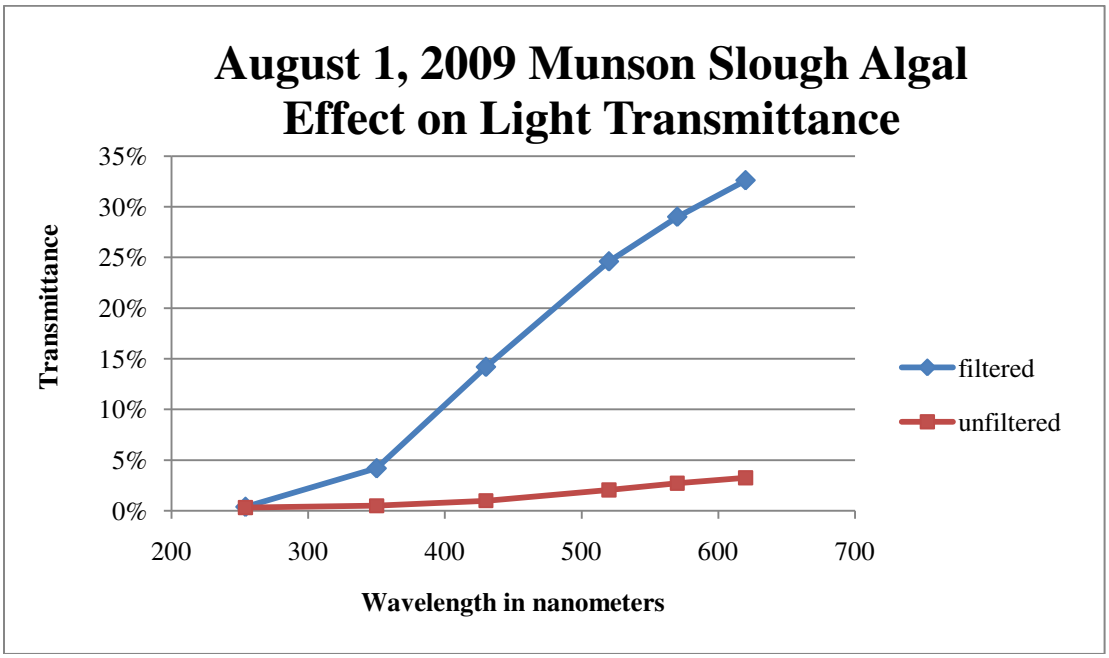

Figure 33 Munson Slough Algal Effect on Light Transmittance. Notice that the concentration of CDOM in the sample is very low at 254 nm.

Dry/Wet Variations

Complete sampling rounds were performed in May (dry) and August (wet) 2009 of all stream stations (see Figure 5) to document transmittance and pH associated with dry and wet conditions.

The stream pH varies with the seasons and with rainfall events. Munson Slough generally has a constant pH around 7.0, likely reflecting groundwater recharge from the Floridan Aquifer. Fisher Creek has a constant pH around 4.0, indicative of the swamps it drains. The pH of Black Creek, Jump Creek and Lost Creek all rise and fall to either of these extremes with rainfall (all pH values dropped from the March-April, 2009 event that produced high flow volumes from the swamps). The pH data is summarized in Figure 34.

If any differences were noted between dry and wet conditions, the data trended to lower transmittance and pH values. These data are presented in Figures 35-39. The Fisher Creek transmittance dropped a few percent to 20 percent and the pH stayed the same to dropping one pH unit. The wet season pH across the stations tended to have less variation and was a constant 4 for Fisher Creek. The wet condition pH change to a constant 4 was most significant for Black Creek. Only the headwaters of Black Creek exhibited transmittance differences. Jump Creek and Munson Slough were exceptions to this general trend, with rising transmittance and pH for the wet conditions for those stations approaching their swallets. Interflow with a discharge increase was documented for Jump Creek. This rising transmittance and pH for Jump Creek and Munson Slough likely reflects groundwater recharge and dilution.

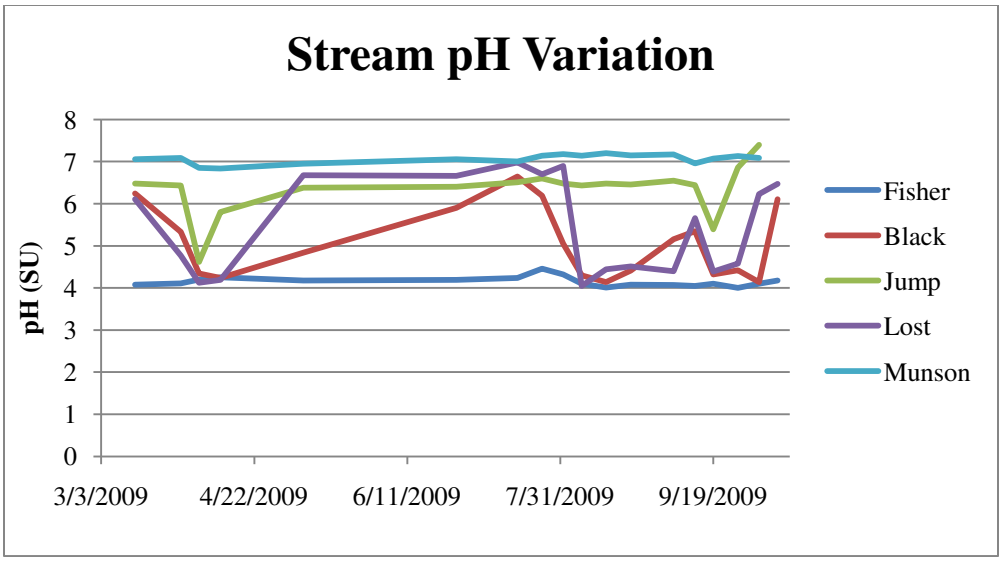

Figure 34 Stream pH variation is bounded by the low pH of Fisher Creek (pH 4.0) and the high pH of Munson Slough (pH of 7.0). The lowest pH values occur when the swamps are discharging.

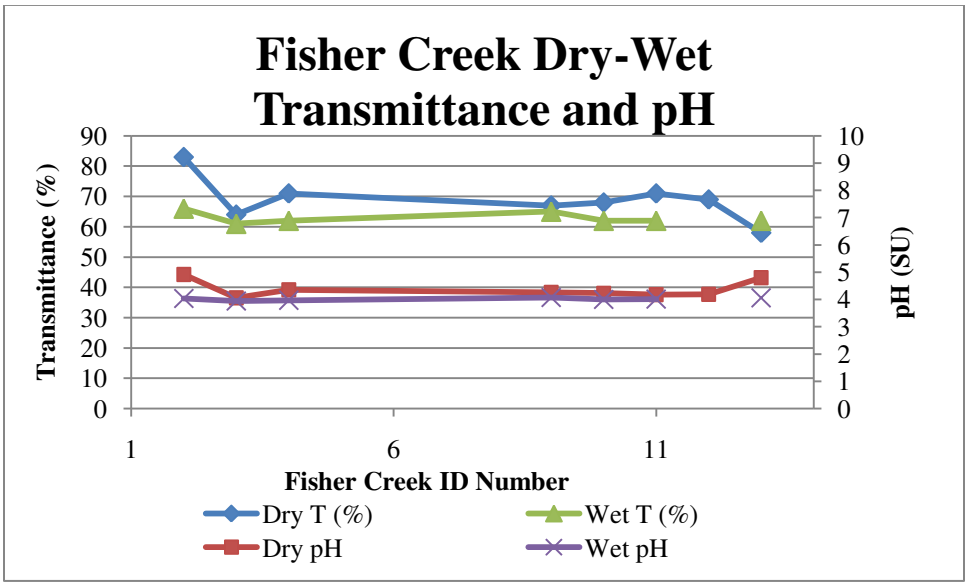

Figure 35 Fisher Creek Dry-Wet Transmittance and pH. Dry and wet conditions mainly differ by a drop in transmittance and pH. Note that less variation between stations occurs during wet conditions.

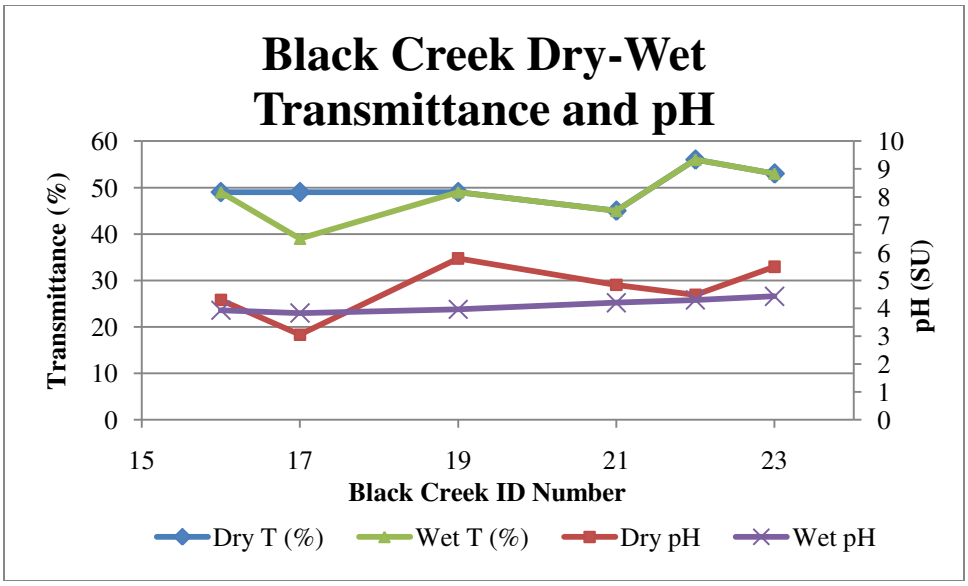

Figure 36 Black Creek Dry-Wet Transmittance and pH. Other than Black Creek at FR 313N (ID 17), the transmittance did not change between dry and wet conditions. Wet conditions have a lower pH and less pH variation between stations.

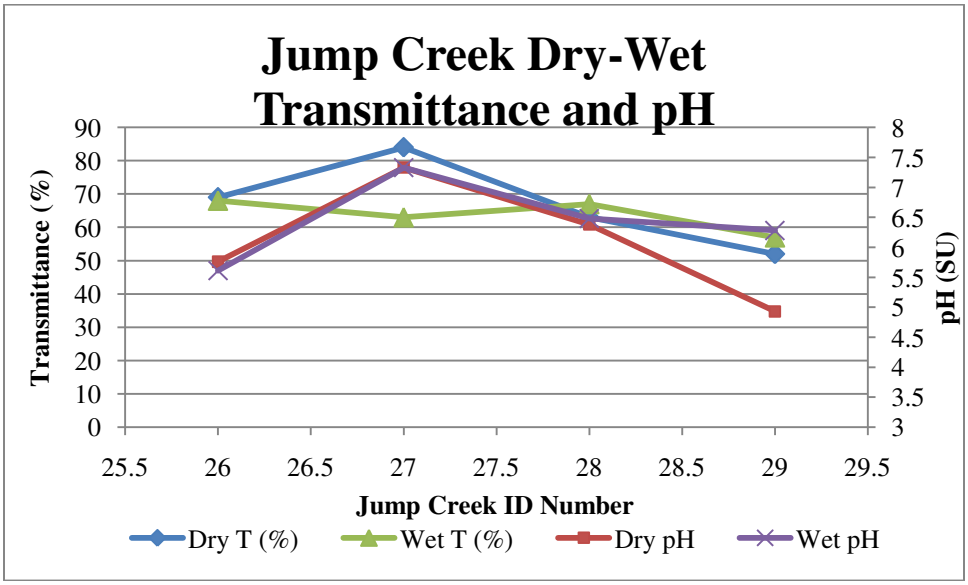

Figure 37 Jump Creek Dry-Wet Transmittance and pH. Jump Creek shows a 20% drop in transmittance at Walden Lake Road (ID 27), followed by a slight improvement at the swallet (ID 28) and US Highway 319 (ID 29). The pH rise from 5 to 6.3 at this later location is surprising due to the mature swamp vegetation. The observed interflow and discharge increase though the land bridge explains the pH increase from groundwater dilution.

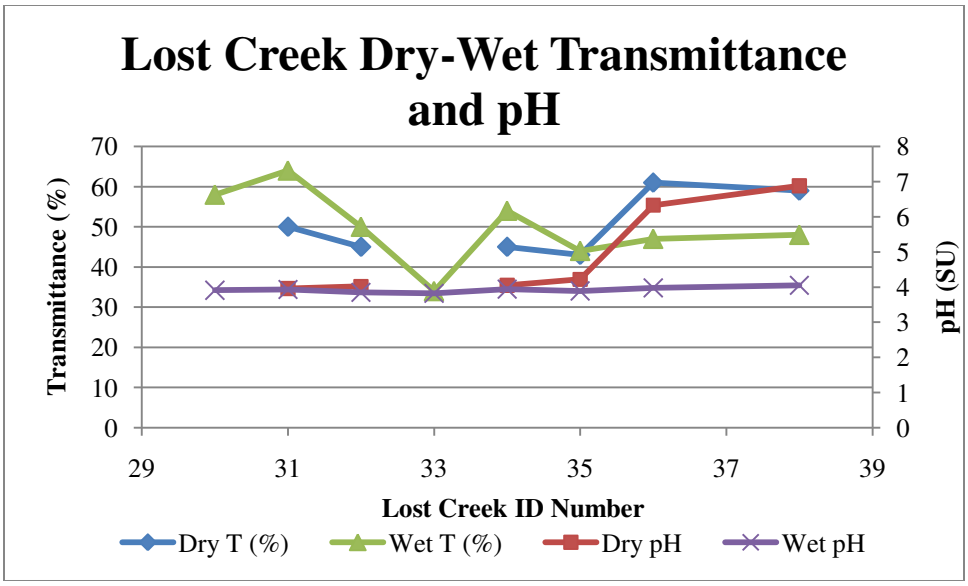

Figure 38 Lost Creek Dry-Wet Transmittance and pH**.** Lost Creek shows an overall decline in transmittance from headwaters to swallet in wet conditions (60 to 48%). The wet condition pH is a relatively stable 4.0.

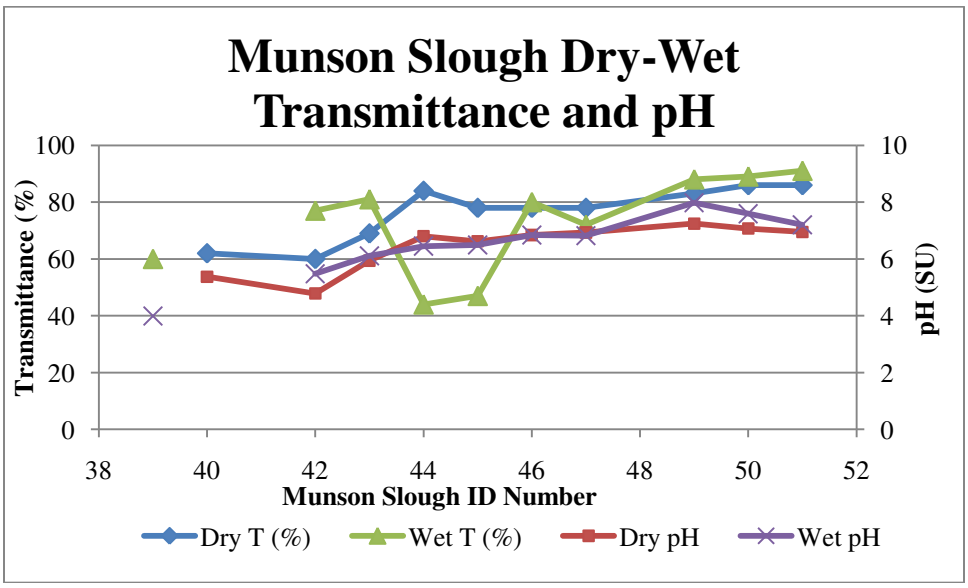

Figure 39 Munson Slough Dry-Wet Transmittance and pH. The wet condition drop in transmittance occurs in the vicinity of Black Swamp (Orange Avenue - ID 44 and 46). Wet conditions appear to improve Munson Slough transmittance and produce more pH variation.

Wakulla Springs

The United States Geological Survey collected continuous stage and discharge information downstream of Wakulla Springs on the Wakulla River October 2004 to July 2010. Wakulla Springs is the headwaters for the Wakulla River. Figure 40 displays this data with precipitation data for the Wakulla Springs State Park. Wakulla Springs responds rapidly to precipitation events and declines slowly, with recovery possibly taking six weeks or more. This

"flashy" response is due in part to the network of conduits/tunnels connecting to Wakulla Springs and the rapid recharge of runoff.

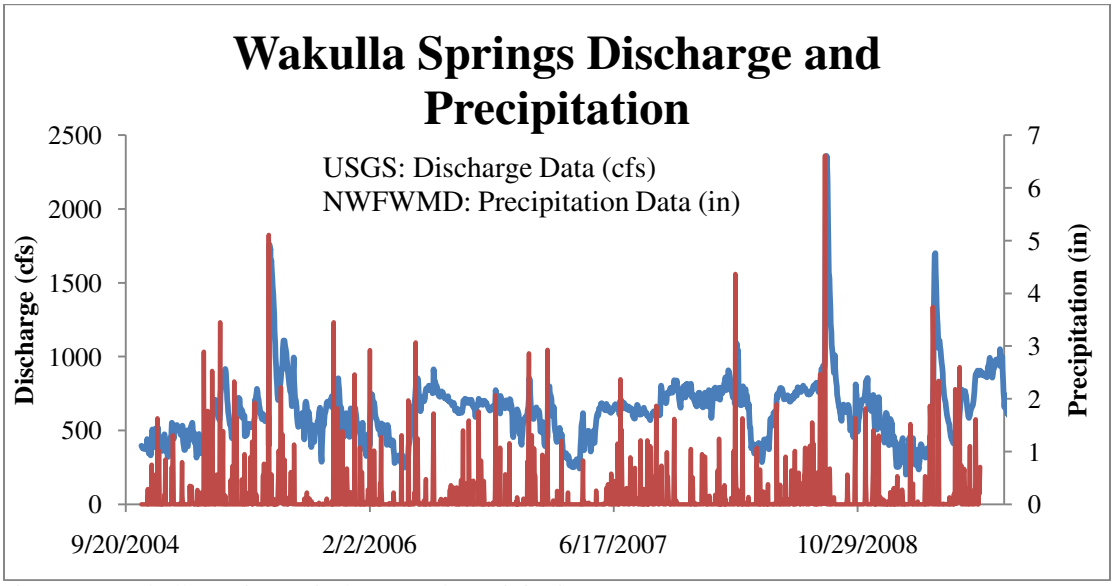

Figure 40 Wakulla Springs Discharge and Precipitation

Wakulla Springs exhibits a duirnal tidal signal that has a forty-five minute delay from the tides at St Marks. Still this response is faster than the tidal signal recorded at the Wakulla River USGS Station approximately one mile down stream from Wakulla Springs (Loper et al 2005). A faster response at the spring vent suggests a significant conduit network to allow the tidal signal to travel 16 kilometers (10 miles) inland and upgradient faster than up the river channel. Loper et al (2005) evaluated the Wakulla Springs response to the passage of Hurricanes Frances (a drop in Wakulla Spring discharge with abnormally low tide) and Ivan (significant increase in discharge associated with an abnormally high tide). The following USGS graph for March through May 2009 shows the Wakulla River hydrograph with the tidal cycle in and out of phase with the moon tides except where masked by the rise of flood events.

Surface water samples were collected at Wakulla Springs at the discharge vent and analyzed initially with the LaMotte Smart 2 colorimeter for CDOM, but the visible wavelengths did not have the UV sensitivity needed for the (relatively) dilute water. Groundwater samples from the feeder tunnels (from monitor wells) were also obtained for two events concurrent with Florida Geological Survey quarterly monitoring. Using the spectrophotometer, the transmittance response for wavelengths 200-800 nm was determined. All Wakulla Springs surface water and feeder tunnels groundwater samples displayed similar featureless UV-VIS absorption curves with the highest absorption associated with the short wavelengths and absorption declining to zero with increasing wavelength. Humic compounds were present in all of the samples analyzed during this research (Appendix D). The Wakulla Springs transmittance range is 1-86 percent (at 254 nm) with a mean of 37 percent for 155 samples. This wide range in the transmittance for Wakulla Springs water clarity is a reflection of the creek water arrival and flow subsidence.

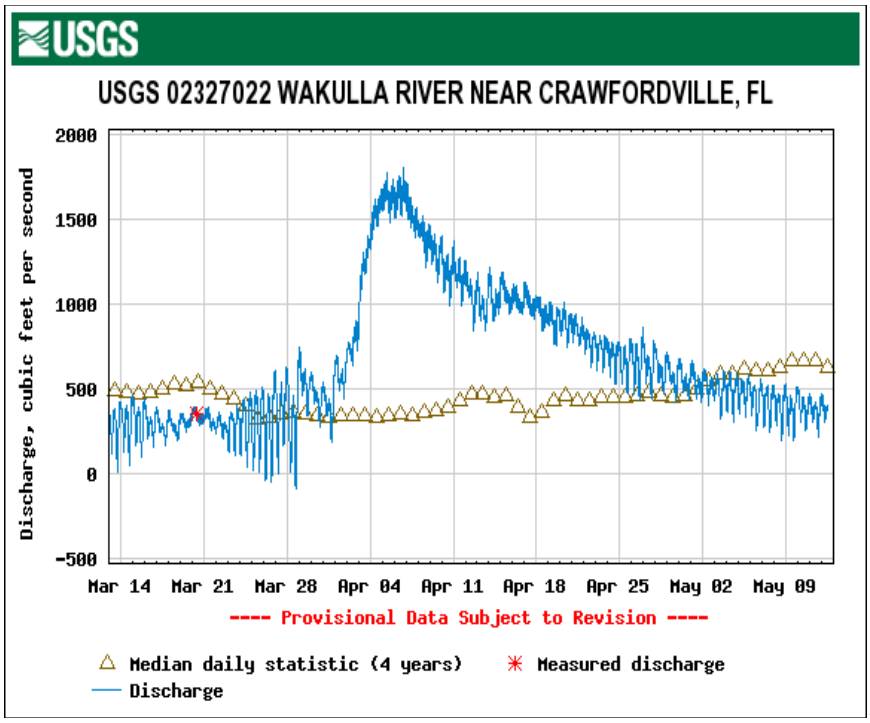

Figure 41 USGS Wakulla River Hydrograph. Tidal influence on the stage of the Wakulla River is shown for March 13-May 13, 2009.

Figure 42 shows the extreme transmittance results for the Wakulla Springs Main Vent and K-Tunnel relative to the wavelengths 254, 320, 430, 520, 570, and 620nm. Concurrently collected K-Tunnel data tracks the Wakulla Springs transmittance response, but is 5-15% lower in transmittance indicative of its upgradient connection to the Leon Sinks Conduit System and the blackwater streams.

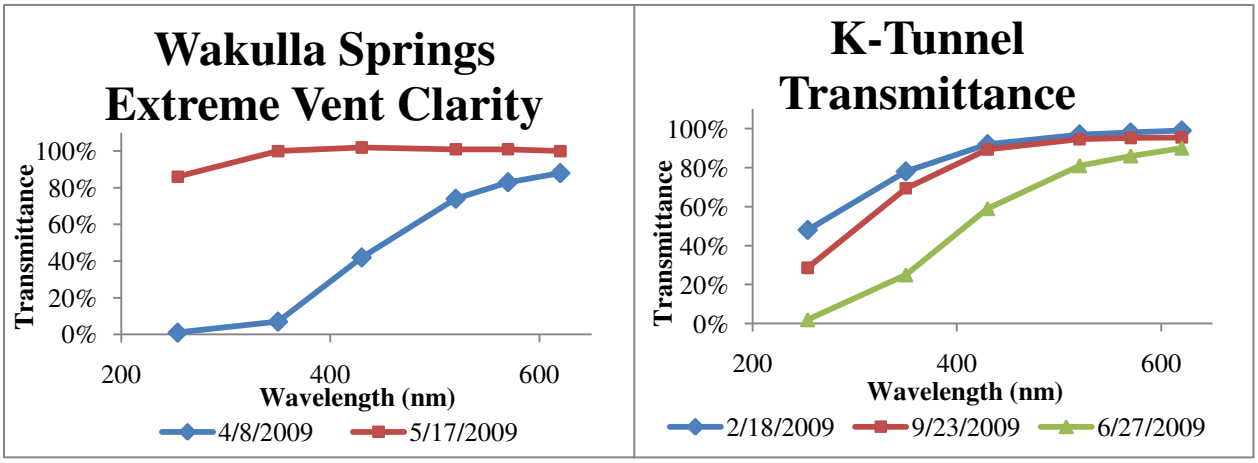

Figure 42 Wakulla Springs Extreme Vent Clarity and K-Tunnel Variation showing the transmittance response for Wakulla Springs best and poorest water clarity with the response of K-Tunnel believed to be the main source of creek CDOM.

The primary tunnels feeding Wakulla Springs were sampled on February 18 (dry season conditions) and September 23, 2009 (wet season conditions). The percent transmittance of the two sets of samples are presented in Figure 43. The vent tower sample was collected at the spring water surface and the vent tube is collected approximately 300 feet below land surface. The Vent tube location was not sampled in September due to an abundance of ticks in that area. Improved water clarity occurs during dry conditions, but all of the tunnels contribute CDOM to the Wakulla Springs discharge.

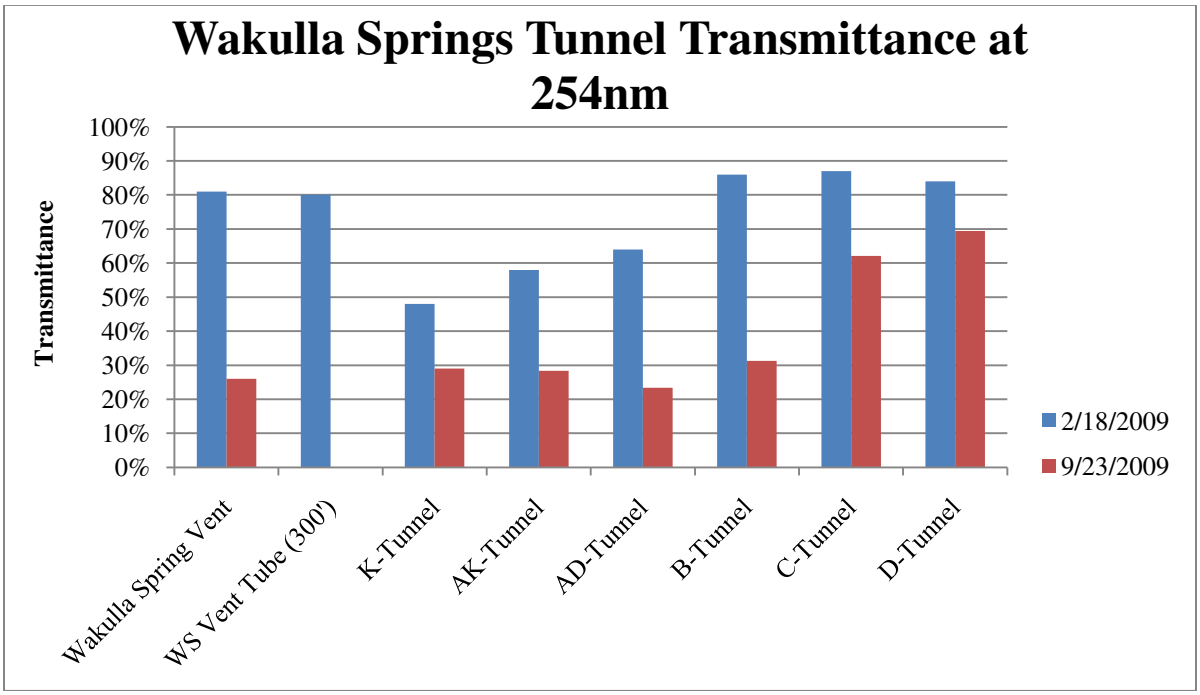

Figure 43 Wakulla Springs Tunnel Transmittance Differences between dry season and wet season conditions shows reduced transmittance during wet conditions. Each of the main tunnels feeding Wakulla Springs contains CDOM.

Figure 44 presents the NAC_{254} to NAC_{430} relationship for all of the Wakulla Springs data collected during 2009. The March-April flood event data has been separated to show the slope change that reflects freshly leached organic matter. Five of the flood event data points have NACs (at 254nm) around 40 that have higher uncertainities due to the very low light able to penetrate the sample path length. The one blue outlier is the June 14, 2009 sample that may be valid data. On May 26, 2009, 2.6 inches of rain fell that produced a Lost Creek peak discharge of 500cfs on May 29/30, 2009. See the section evaluating the February 14, 2009 storm.

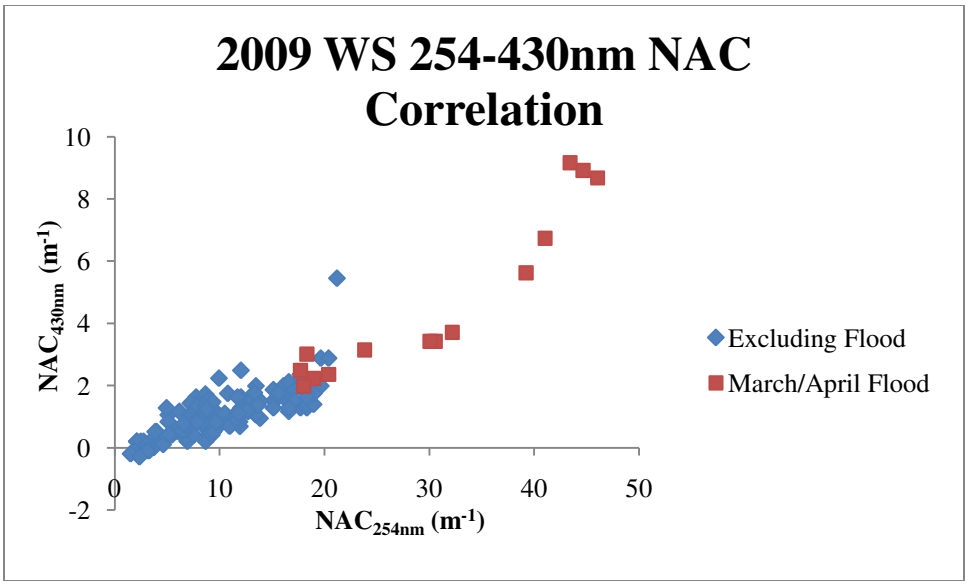

Figure 44 2009 Wakulla Springs 254-430nm NAC Correlation. All 2009 Wakulla Springs data is shown. The March-April flood event data has been separated to show the slope change that reflects freshly leached organic matter.

Discharge and Mass Balance of Specific Precipitation Events

March-April 2009 Event. All of the creek and Wakulla Springs discharge results were examined to select the optimum period for dissolved organic carbon analysis. The objective of this analysis is to separate discharge variations from CDOM variations into smaller time intervals to gain an understanding of how the sources (streams) and the destination (Wakulla Springs) change in loading and concentration during an event. Figure 45 displays the entire year discharge data for the largest stream drainage basins relative to Wakulla Springs. The dominant feature on the graph is the discharge associated with the March 26 to April 3, 2009 rainfall. Recorded rainfall at Wakulla Spring State Park, the Tallahassee Airport, and Capitol Area Flood Warning Network Stations #601, 602, 555, and 803 indicate 10.8-12.5 inches total of rain fell over the study area during this period. Extensive flooding occurred throughout the Wakulla Springs basin. The stage rise at Wakulla Springs overturned an automated sampler and flooded the concrete boat dock. This rainfall event was selected for detailed study as the Wakulla Springs hydrograph and those of the feeder streams were well-defined and separate from preceding and following conditions. The February to March two-month long base flow conditions that preceded the event are equally important to understand the effect stream discharge has on Wakulla Springs discharge and will be evaluated separately.

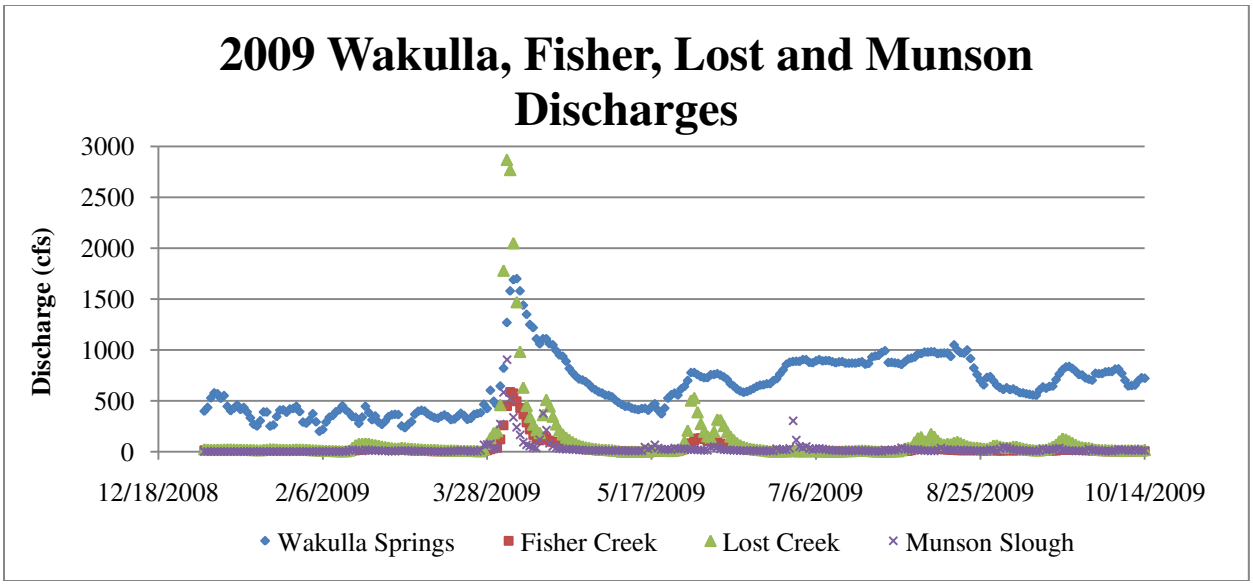

Figure 45 2009 Wakulla, Fisher, Lost and Munson Discharges. Continuous discharge reported by the USGS (Wakulla, Fisher and Lost) and NWFWMD (Munson Slough) for 2009. The dominant feature is the discharge associated with the March 26 to April 3, 2009 period rainfall.

Rosenau et al. (1977) reported Wakulla Springs stage and precipitation for a very similar spring flood event that occurred in 1973. These historical results were compared to the 2009 event to see if the discharge response differed across the thirty-six year span. Figure 46 compiles the data aligned at the peak stage for the two events: March 10-April 30, 1973 and March 9-April 29, 2009. The 2009 stage hydrograph was reduced to the same width/period as the 1973 hydrograph to compare details: for the 2009 precipitation of 11.82 inches total, the stage rose 3.55 feet; for the 1973 precipitation of 18.5 inches total, the stage rose 4 feet. The 2009 recession curve dropped 2.5 feet compared to the 1973 curve drop of 2 feet for the same period, but this was a reasonable difference considering that 7 more inches of rain fell in 1973. Finally, the last two data points of the 1973 curve were adjusted relative to the 2009 stage to directly compare the two recession curves. Very little difference was noted in the hydrograph response between the two events as displayed in Figure 47. A significant change would be reflected by a slope change indicating quicker or slower recession. This indicates that the spring response to rainfall recharge has not changed significantly in the past 36 years.

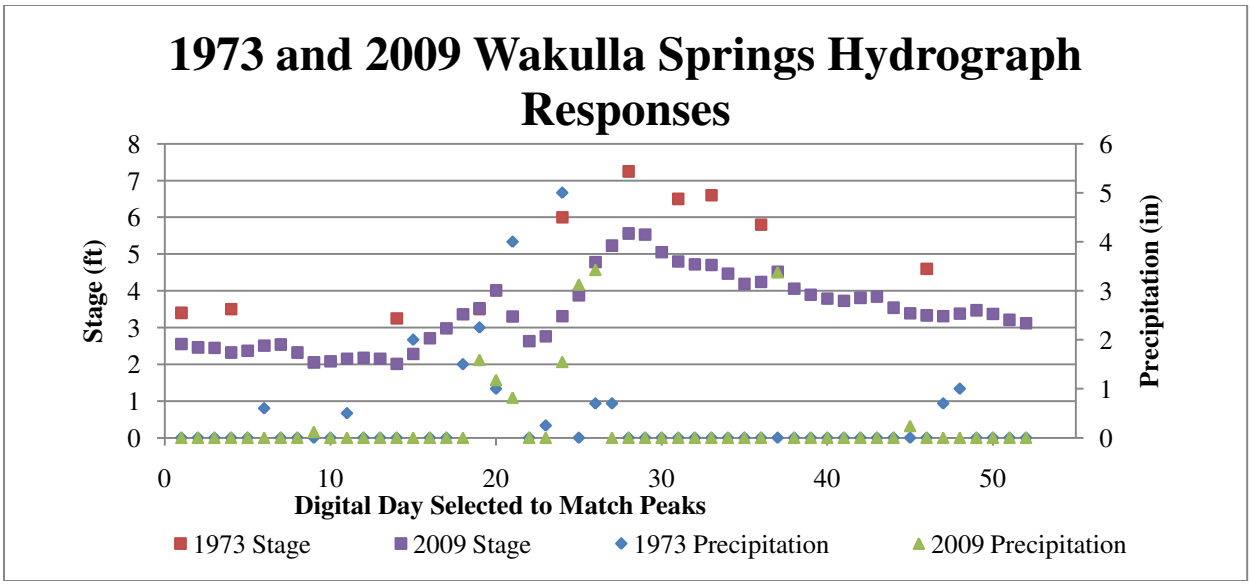

Figure 46 1973 and 2009 Wakulla Springs Hydrograph Responses. The stage and precipitation of two very similar spring storms, March 10-April 30, 1973 and March 9-April 29, 2009, are compared by aligning the peaks of the hydrographs. The 1973 event started with a higher stage (1.25 feet higher), received 7 more inches of rainfall, and rose 0.5 feet higher than the 2009 event. The 1973 recession curve dropped less (2 feet) compared to the 2009 drop (2.5 feet) for the same period. In 1973, no precipitation occurred during the 19-day recession period. In 2009, 2.34 inches of rain fell on digital day 36.

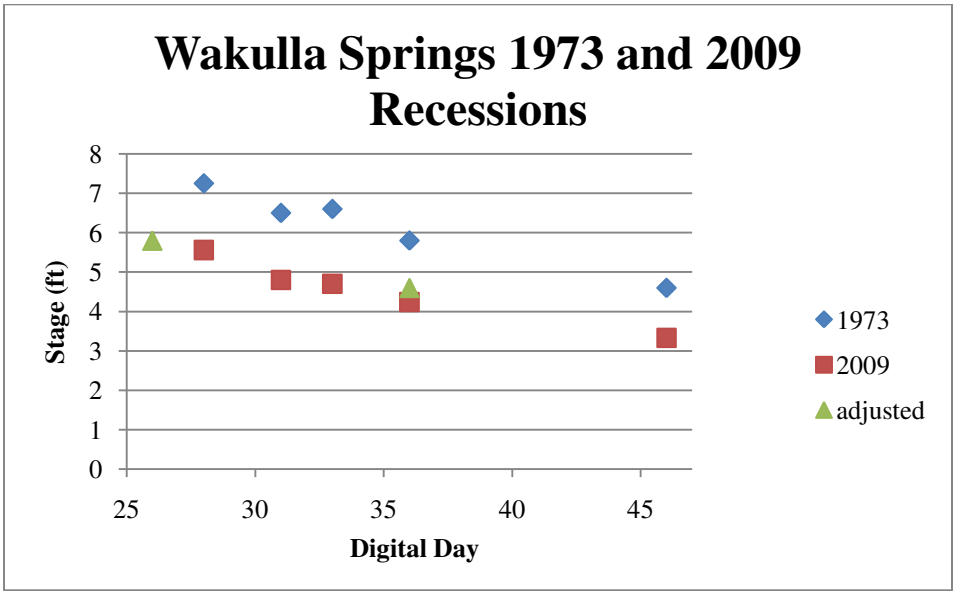

Figure 47 Wakulla Springs 1973 and 2009 Recessions. Flood events 36 years apart show similar curves and no significant change. The last two data points of the 1973 curve were adjusted relative to the 2009 stage to directly compare the two recession curves.

The entire discharge versus NAC curve for the March-April, 2009 Wakulla Springs flood event is provided below, including the two points representing the hydrograph rise. The shape of the hydrograph rise reflects the characteristics of a storm event. In this case the sharp rise is the direct result of heavy basin–wide precipitation. A hydrograph recession curve reflects the water

delivery system (surface water basin size, conduit, fractures, matrix, etc). The lack of slope breaks (points of an obvious slope change) in the Wakulla Springs recession curve in Figure 48 suggests that the Wakulla discharge is a continual release of water from both the conduit system and aquifer matrix. Figure 48 shows that the NAC increases with increase in discharge for the rise portion of the hydrograph. After peaking, the NAC declines with the discharge. The recession curve fits a polynomial equation with an R^2 of 0.98. If the NAC values greater than/equal to 40 are dropped, no change occurs to the R^2, so they remain in this presentation.

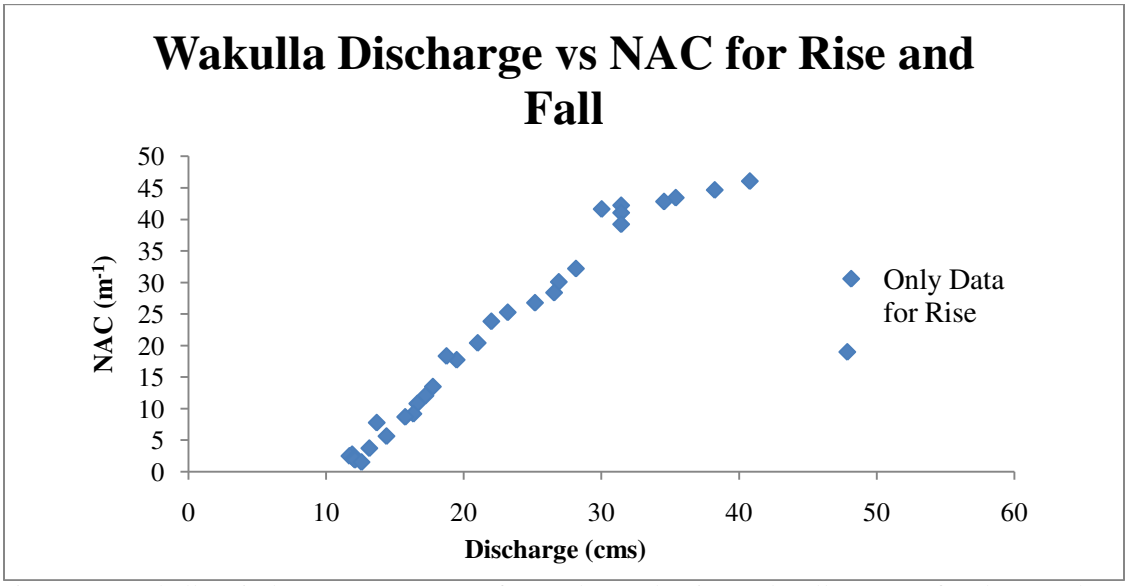

Figure 48 Wakulla Discharge Versus NAC for Hydrograph Rise and Fall. Data for the March – April 2009 precipitation event is shown.

The detailed analysis was performed on the period March 1 to May 31, 2009. The selected period includes initial baseflow conditions and the storm hydrograph rise and fall. The end of the recession curve was interrupted by a new storm event arriving on May 18, 2009. Figures 49 and 50 show the Wakulla Springs discharge relative to that of the streams, separating Lost Creek and Munson Slough to show Jump Creek (at a different scale). Most of the Lost Creek discharge bypasses Wakulla Springs and flows to Spring Creek on the Gulf of Mexico coastline. A low flow dye injection test performed at the Lost Creek swallet in 2008 detected dye discharging at Wakulla Springs approximately 60 days later (Kincaid, 2008), indicating that its contribution to Wakulla Springs water clarity would arrive as the contribution from the remaining streams subsided. Other dye injection tests indicated a travel time of 20 days from Ames Sink and Kelly Sink (Munson Slough water quality) to reach Wakulla Springs. The Munson Slough stage/discharge monitoring station at Capitol Circle SW is approximately three miles upstream of its swallets, further complicating its contribution to the Wakulla Springs discharge. All dye tests were performed at low flow conditions and travel times would be longer than those of high flow conditions. As Fisher Creek and Black Creek have the fastest dye testing travel times (9 and 10 days, respectively, Hazlett-Kincaid, 2004) and their flow enters the Leon Sinks conduit system at the same location, their dissolved organic carbon (DOC) will be evaluated first. Note that Black Creek discharge peaks 1-2 days before Fisher Creek due to a

smaller drainage basin, offsetting the dye travel time differences. No dye tests have been performed on Jump Creek and its loading contribution is much lower than Fisher and Black Creek, but it has the closest swallet to Wakulla Springs.

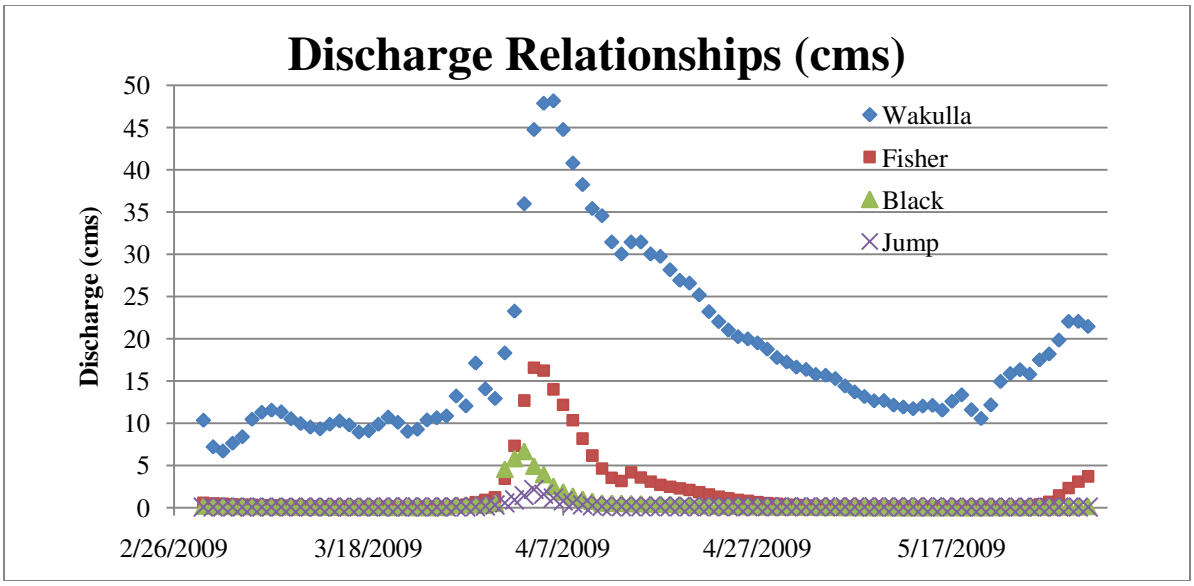

Figure 49 Wakulla, Fisher, Black, and Jump Discharge hydrographs for the detailed study period March 1 to May 31, 2009. The discharge of Black Creek peaks first, followed by Fisher Creek and Jump Creek 1-2 days later and Wakulla Springs 2 more days later. Jump Creek is included because its swallet is 3 miles and closest to the Wakulla Springs vent.

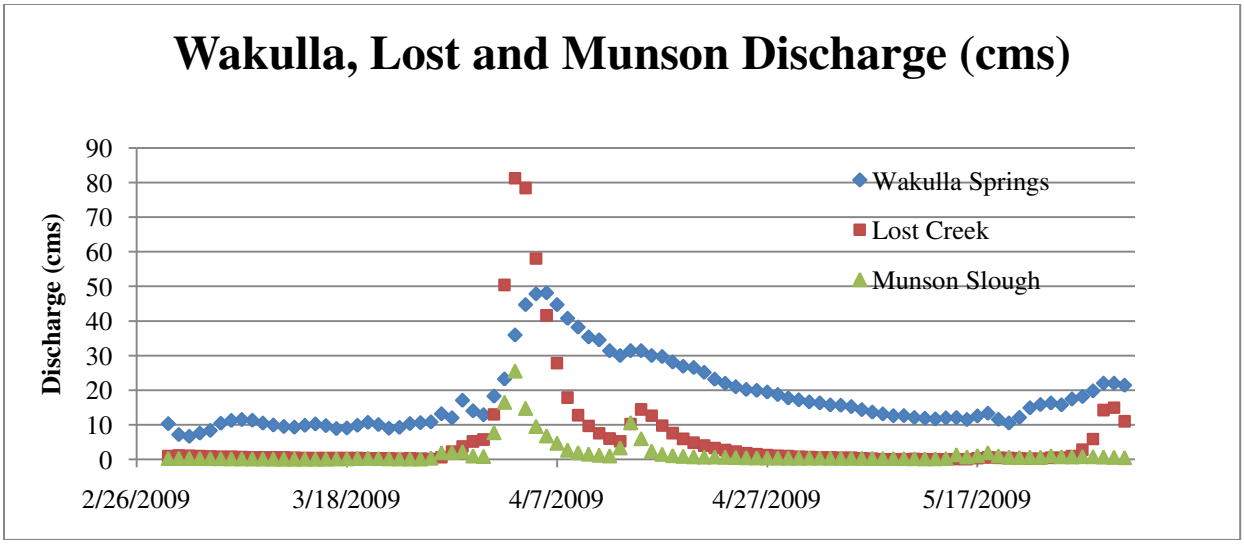

Figure 50 Wakulla, Lost and Munson Discharge hydrographs for the detailed study period March 1 to May 31, 2009. Most of the Lost Creek discharge bypasses Wakulla Springs and flows to Spring Creek on the Gulf of Mexico coastline. Lost Creek and Munson Slough peak in discharge 2 days before Wakulla Springs.

Figure 51 summarizes the available NAC data for each of the studied surface waters for the March-April Event. The collection of weekend stream samples is apparent, but considering

that the stream dissolved organic concentrations did not change rapidly, this appears to be acceptable for mass estimates. The loss of Wakulla Springs samples from the flood overturned auto sampler raises the question of Wakulla NAC immediately prior to the storm.

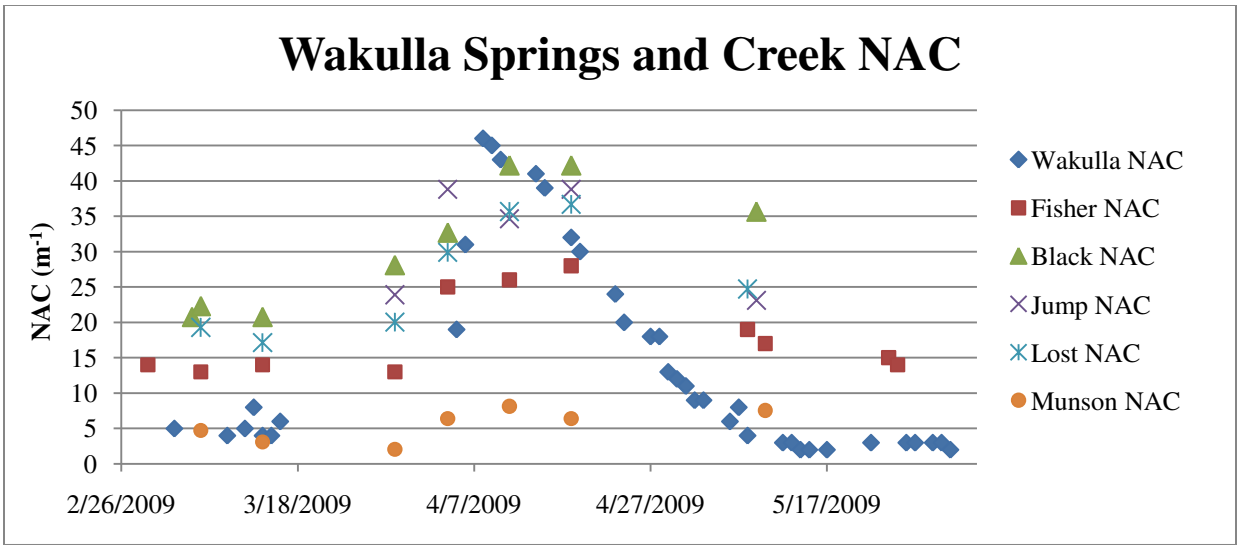

Figure 51 Wakulla Springs and Creek NAC (WS NAC_{254nm} and creek NAC_{430nm}) results to be used and extrapolated for mass calculations. The highest uncertainty (+/- 0.1) is associated with the Wakulla Springs NAC_{254nm} for the values greater than 40 and within the symbol size.

Mass Calculations

A series of dilution samples (monitoring standard) were prepared of April 11, 2009 Fisher Creek water down to a 0.5% dilution. The absorption coefficients were calculated for the 254 and 430 nanometer wavelengths. The Fisher Creek NAC and dilution data were plotted to use the Wakulla Springs NAC data (x-axis) to solve for "Percent of Fisher Creek in the Sample" (y-axis). Figure 51 is the resulting graph. This absorption – concentration relationship was used with the specific Wakulla Springs UV-VIS results, assuming Fisher Creek was the only blackwater contributor and the stream concentration was constant over the time period. (Neither assumption is valid but this allows a rough approximation.) If the Wakulla Springs transmittance exceeded 90% at 254 nm, i.e. a relatively clear sample, the selected equation was:

Percent Fisher Creek in the sample = $0.2796(NAC_{254}) + 0.0066$. (4)

Wakulla Springs samples with transmittance less than 90% at 254 nm, or poorer water clarity used the equation:

Percent Fisher Creek in the sample = $3.0575(NAC_{430}) + 0.1662$ (5)

Most of the study data reflected the poor water clarity conditions and utilized the NAC_{430} equation.

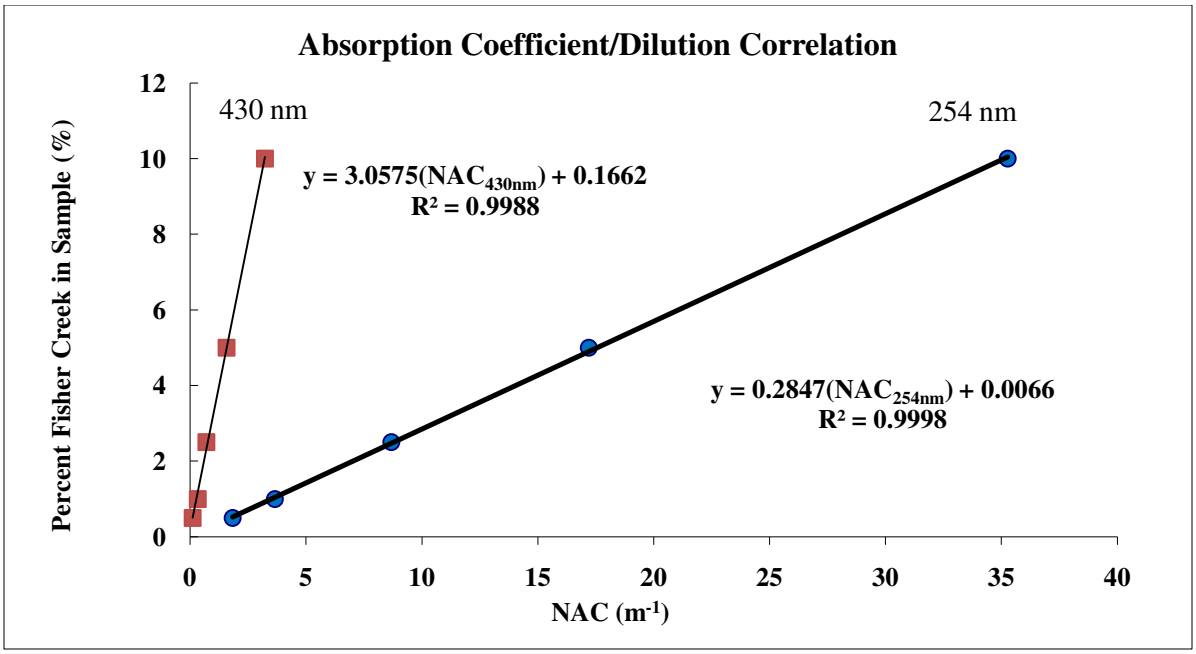

Figure 52 Absorption Coefficient/Dilution Correlation. This relationship was used to calculate the percentage of Fisher Creek water in a Wakulla Springs sample. In reality, the percentage of creek water was a composite of all five streams and numerous other sources of CDOM, but this is a reasonable estimate. The uncertainty associated with NAC is +/- 0.01 for the displayed concentrations.

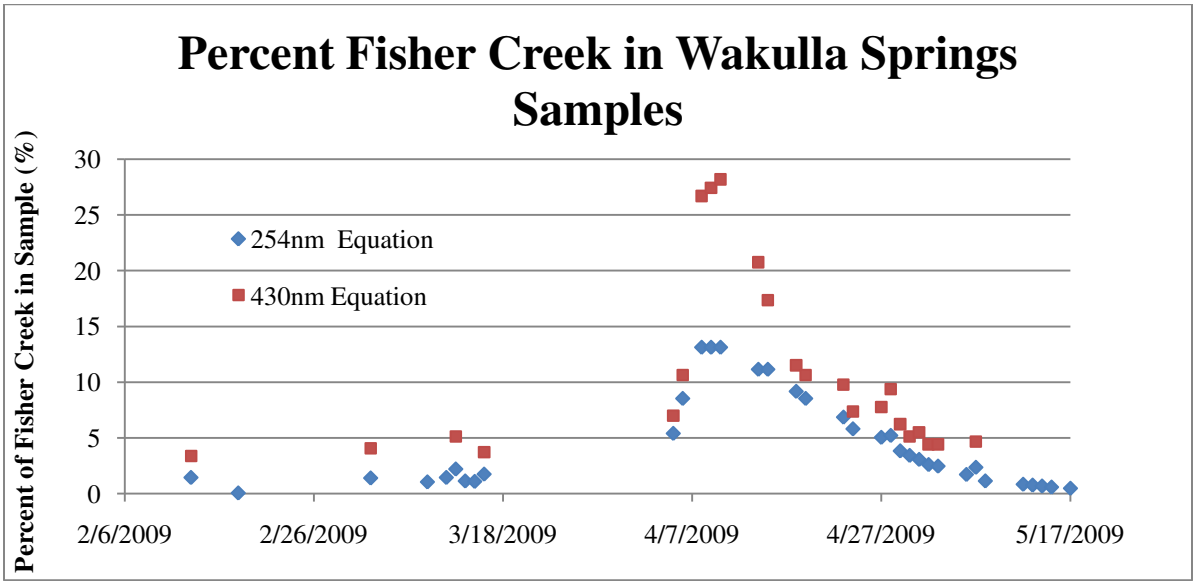

Figure 53 Percent Fisher Creek in Wakulla Springs Samples. Using the results of the 4-11-09 sample dilution experiment, all samples are represented by the 254 equation (best for good water clarity such as greater than 90% transmittance) for comparison. The peak poor water clarity is represented by the 430nm equation, required for high concentrations and indicating a maximum of 28% creek water. For the poor water clarity peak differences of 28 and 13 percent creek water, the observed difference is related to the CDOM absorption behavior of decreasing sensitivity with increasing wavelength. The 13 percent creek water (254nm) is likely too low due to the high NAC for this wavelength.

Figure 53 presents the results of this estimate, including treatment of all samples by the 254nm equation (as if all had water clarity 90% transmittance or better) to show the differences. The extreme water clarity samples, April 8, 2009 for poorest and May 17, 2009 for clearest contained 28% and 0.5% Fisher Creek water, respectively or presented another way were diluted 72% and 99.5%. Both samples represented the extremes for 2009 for the data collected. Again, Wakulla Springs water clarity is affected by a composite of CDOM sources in addition to the water from Fisher Creek, but this is a reasonable approximation.

The Florida Geological Survey, FDEP Wakulla Springs Initiative conducts quarterly sampling of Wakulla Springs that include Total Organic Carbon (TOC) analysis. As no TOC analyses were performed on any creek samples during this study, their TOC data were used for this work to develop a correlation curve. At Wakulla Springs, TOC is approximately equal to DOC due to the general absence of particulate organic matter (minor amounts were observed a few days following peak discharges). Four events with positive TOC detections coincided with spectrophotometer data permitting a TOC-NAC correlation. Figure 54 presents the TOC-NAC correlation relative to the 254 and 430 nm wavelengths. The correlation is excellent for the 254nm wavelength that provides the greatest sensitivity for dilute CDOM. The correlation for 430nm is poorer because of the decreased sensitivity at the longer wavelengths and the resultant low absorption coefficients. This low NAC range combined with a low TOC range of concentrations with only four points lowers the R^2.

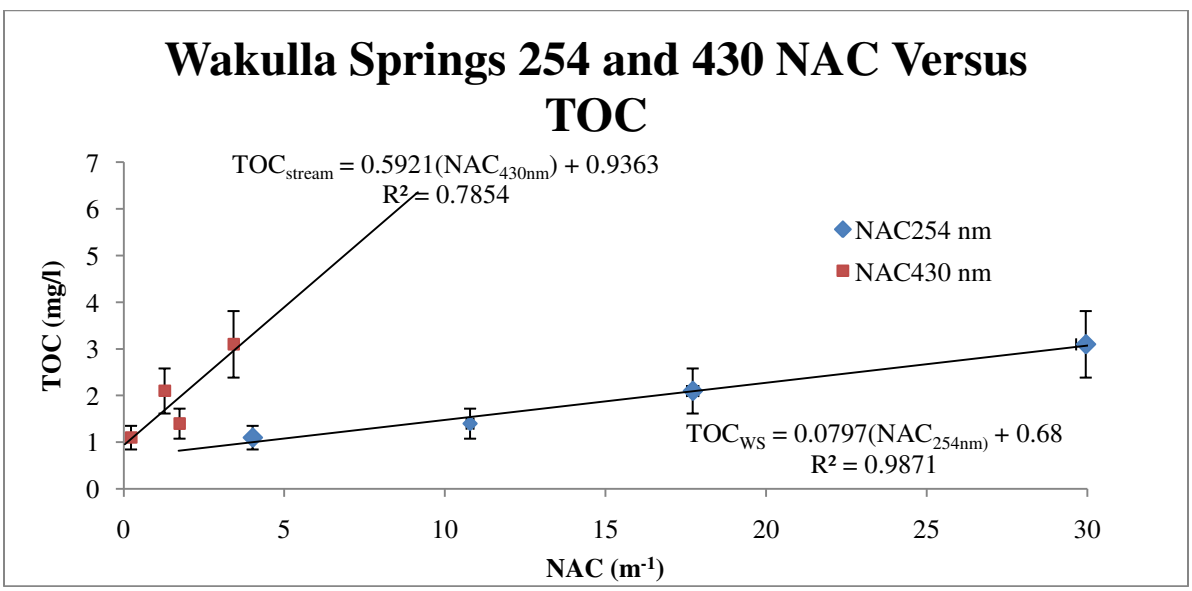

Figure 54 Wakulla Springs 254 and 430 NAC Versus TOC. With TOC data collected by the FDEP Wakulla Springs Initiative on the same day as transmittance/absorbance samples, these linear correlations were used to determine Wakulla Springs and individual creek TOC/DOC concentrations for mass balance calculations. TOC is considered equivalent to DOC for Wakulla Springs and all creek samples were filtered.

TOC analyses typically have a detection limit of 1 mg/l. Of 12 samples collected from Wakulla Springs during 2009, only six samples contained detectable TOC. Three of the four samples used for the NAC-TOC correlation were collected during this study period and the other was collected June 9, 2009. The following equations were used to calculate the TOC

concentration for each sample at Wakulla Spring (using the 254nm spectrophotometer data) and for each creek (using the 430nm colorimeter data);

$$TOC_{WS} = 0.0797(NAC_{254}) + 0.68 \qquad (6)$$

$$TOC_{Stream} = 0.5921(NAC_{430}) + 0.9363 \qquad (7)$$

The Fisher Creek 4-11-2009 sample had a TOC concentration of 16.6 to 19.4 mg/l, calculated using the NAC_{430} of 26.38 (4-11-09 analysis) and 31.23 (5-16-09 analysis of the same sample) in the TOC_{Stream} equation. The 4-11-09 analysis was performed the same day of sample collection. The dilution experiment was performed more than a month later and the bottle had been tightly closed since sample collection. (Each sample had its own bottle and was collected at the same time; the colorimeter sample was collected first.) The maximum NAC_{430} for any Fisher Creek sample during the March to May 2009 period was 28, indicating that the 4-11-2009 sample was one of the most concentrated Fisher Creek CDOM samples collected during the detailed study period.

The TOC results were used with the daily discharge to calculate daily mass in kg per day for each creek and for Wakulla Springs. This calculation was:

$$Mass = Q * TOC * 86.4 \qquad (8)$$

where Q is discharge in cubic meters per second, TOC is in mg/l, and 86.4 is a unit conversion factor.

The mass for Wakulla Springs, Fisher Creek and Black Creek were calculated first. These creeks have the largest discharge volumes, the highest CDOM loading, the fastest low-flow travel times established by dye tests (9 days to 10 days, respectively), and the streams enter the Leon Sinks Conduit System at the same place. Figure 55 presents the mass in kg/day for Wakulla Springs, Fisher Creek and Black Creek, showing that Black Creek mass peaks one day before and begins declining before Fisher Creek mass peaks. The net result is the arrival of Black Creek and Fisher Creek into the Leon Sinks Conduit System at the same time and at the same place allowing their analysis as one source. Creek data was collected approximately every weekend and required extrapolation between sample dates for mass balance. In general, stream concentrations remained relatively constant except after a high precipitation event, so extrapolation has minimal effect. High precipitation events produced higher concentrations of dissolved organics (from leaching) that generally peaked after the discharge peaked. Wakulla Springs clarity and thus concentrations change rapidly, even within a few hours time, making extrapolation problematic. The early part of the Wakulla Springs data curve was lost due to the flood discharge overturning the Wakulla Springs auto sampler. This information is critical to mass calculations. A baseline mass of 1000 kg/day was assumed for March 31 as the beginning of the Wakulla Springs curve and linearly extrapolated to the April 5th data. The five estimated missing days are identified on the graph. Figure 56 presents the Wakulla Springs and Jump Creek mass rise and fall with Fisher Creek and Black Creek mass combined.

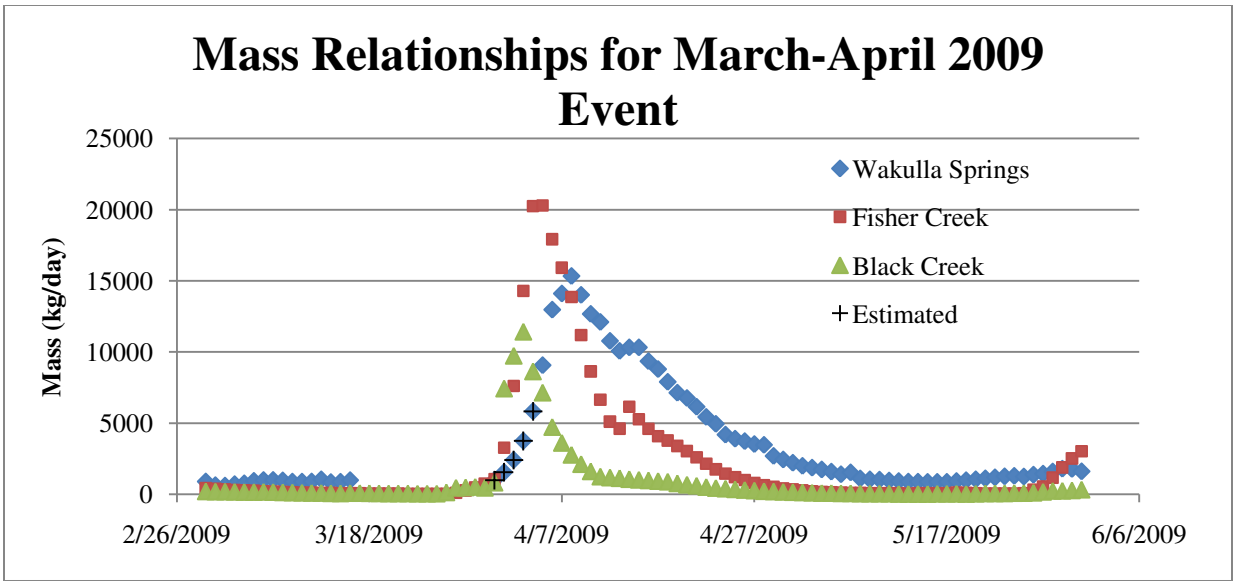

Figure 55 Mass Relationships for March-April 2009 Event. Time-series mass behavior of Fisher Creek and Black Creek relative to Wakulla Springs are presented. Note that Black Creek mass peaks first followed by Fisher Creek 1-2 days later and Wakulla Springs 4 days later. The "+" denotes Wakulla Springs samples that were lost and have been estimated for this analysis.

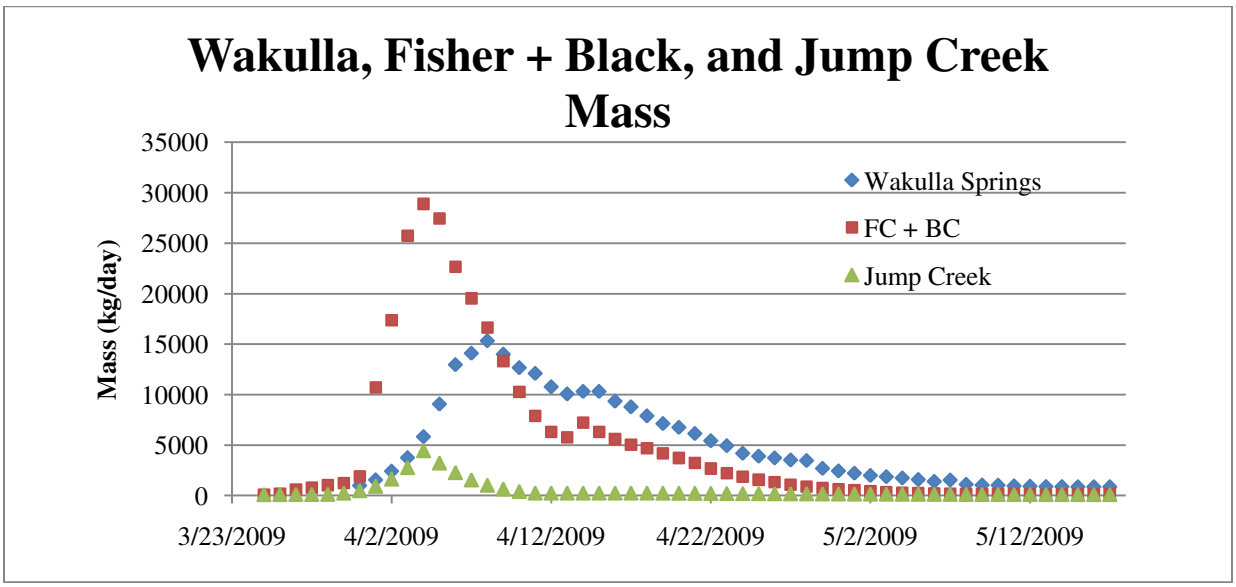

Figure 56 Wakulla, Fisher + Black, and Jump Creek Mass. Fisher and Black Creek have a composite mass curve. The mass of Fisher and Black Creek and Jump Creek peaks 4 days before the mass of Wakulla Springs.

The Figure 57 mass associated with Lost Creek greatly exceeds that of Wakulla Springs, but most of this mass bypasses the Lost Creek swallet as surface water, eventually recharging downstream and discharging at Spring Creek. Munson Slough mass is visibly less than the Wakulla Springs mass. The Munson Slough mass peaks a day before Lost Creek and 5 days before the Wakulla Springs mass peaks.

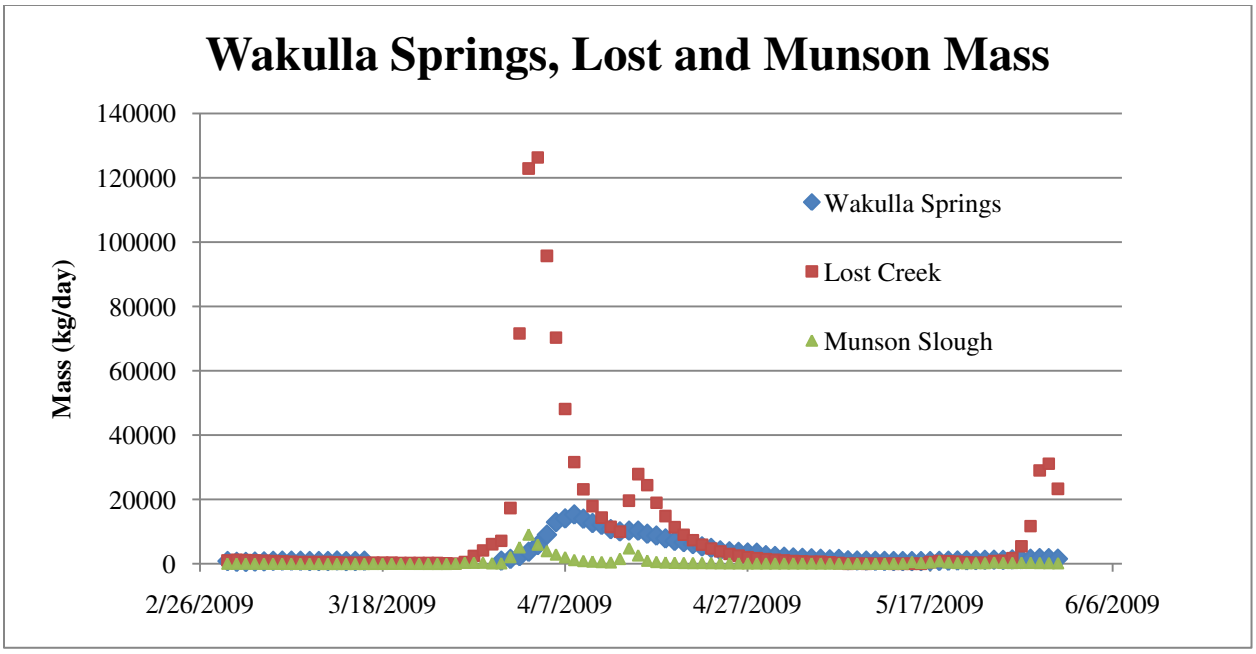

Figure 57 Wakulla Springs, Lost and Munson Mass. The mass associated with Lost Creek greatly exceeds that of Wakulla Springs, but most of this mass bypasses the Lost Creek swallet.

Table 4 summarizes the mass associated with baseflow, best and poorest water clarity conditions during the study period at Wakulla Springs and each of the creeks. The first observation is the difference between the total creek mass and that of Wakulla Springs for the baseflow and lowest mass. For example baseflow conditions at Wakulla discharge more mass than all of the creeks combined (548 kg/day for the creeks and 871 kg/day for Wakulla). This means the Wakulla Springs baseflow is still discharging mass from the last storm event and mass from additional sources not quantified. Considering the 2008 dye test on Lost Creek with the low flow condition travel time of 60 days (in detail: dye arrival started at 45 days with the first peak occurring at 56 days), it is possible that the Wakulla Springs baseline mass is mostly due to the slower Lost Creek source. As indicated in the table, creek behavior 4-5 days prior is important and this is indicated by the total creek mass (incoming source) for the extreme (clear and poor) conditions observed at Wakulla Springs. This 4-5 days prior period does not consider the travel time differences between the creeks.

The highest daily mass for combined Fisher and Black Creek was 29,000 kg/day declining down to 17,000 kg/day on April 8, 2009 in contrast to 15,000 kg/day for Wakulla Springs on its poorest water clarity day. If the mass associated with Fisher and Black creeks exceeds the Wakulla Springs mass without the other creek contribution, mass is being “lost” or stored between the swallets and the discharge location. The Leon Sinks conduit system is a direct “pipeline” to Wakulla Springs, but there are three tunnels south of the A/K tunnel meter that could siphon all or part of the flow south to Spring Creek. These three tunnels cover a distance less than a mile in a region that scuba divers have observed to be a shifting groundwater divide sending flow north to Wakulla Springs or south to Spring Creek. The Fisher/Black entry point into the Leon Sinks conduit system is approximately 6 miles (10 Km) from Wakulla Springs and loss due to absorption along the pathway (such as recharge to the aquifer matrix) is

also possible. Screaton et al. (2004) documented loss to the matrix that did not return to the conduit system after the flood passed within the Santa Fe River Sink and Rise conduits. Finally, scuba divers observed humic water at ceilings and on the floors of rooms, documenting storage within the conduit system until turbulent flow conditions return with the next storm event.

Table 4 Wakulla Springs and Creek CDOM Mass Summary for March-April 2009 Event

CDOM Mass Summary	**Wakulla Springs**		**FC+BC**	**JC**	**MS**	**LC**	**Total**
March-April 2009 Event	Q (cms)	kg/day	kg/day	kg/day	kg/day	kg/day	Creek
Baseflow Average	10	871	139	53	47	308	548
Lowest mass on any day	7	606	94	43	16	125	278
Clearest Water Clarity 5/17/09	13	869	138	111	493	547	1290
Creek lowest mass			106	111	90	42	349
Days prior to 5/17/09			4	0	4	4	
Poorest Water Clarity 4/8/09	41	15300	16600	1030	1220	31600	50500
Creek highest mass			28900	4440	9140	126000	169000
Days prior to 4/8/09			4	4	5	4	

Mass Balance for March-April Event	Total kg	Estimated	Total
FC+BC total mass for Mar-26 to May 13	274000		
Wakulla total mass for …April 5 to May 26	244000	14600	259000
JC total mass for March 30 to May 9	25600		
MS total mass for March 26 to May 6	52000		
LC total mass for March 27 to May 6	846000		

Figure 58 depicts stream baseflow behavior approximately one month before the March-April 2009 event and shows that the streams do not exhibit baseflow conditions at the same discharge, the same time or for the same length of time. Note that Munson Slough and Black Creek initially respond to rainfall on March 26 and the remaining creeks respond the following day. The days that Wakulla Springs clarity allowed glass-bottom boat operation are also shown. The USGS (2009 Water-Data Report) characterizes their Fisher Creek discharge data as good for discharges greater than 10cfs, but fair below 10cfs (the "fair" accuracy is 8% or +/- 0.8cfs, Turnipseed and Sauer, 2010). The net result is a potential underestimation of the discharge and mass, however, the data/observations suggest that this uncertainty is not critical because Fisher Creek had no effect on Wakulla Springs water clarity at a discharge up to 28 cfs (see the discussion that follows regarding the February 14, 2009 rain event when Fisher Creek was flowing but Black Creek, Jump Creek and Munson Slough were not. Fisher Creek flow at 28 cfs may be important if these other creeks are also flowing or Lost Creek has been flowing for a longer period of time). In addition, for the baseflow period March 8 to March 27 when the Fisher Creek discharge stayed below 10 cfs, the Fisher Creek transmittance ranged from 76-77% (3 measurements). At 10cfs, the transmittance variation with the discharge accuracy could yield a maximum mass difference of 20 kg (at 10cfs) to 24 kg (at 10.8 cfs) for the two concentration differences. The mean of the USGS reported discharges for this period was 4.06 cfs, yielding a more likely potential difference of 8 kg. The remaining period where Fisher Creek discharge dropped below 10 cfs, May 2 to May 25, has a greater transmittance range of 58-75% (5

measurements: 71%, 70%, 58%, 74%, and 75%). The TOC concentration range for these transmittance values is 9.45-17.06 mg/l occurring with a mean discharge of 3.5 cfs (0.1cms), yielding a mass range of 82-147 kg. An 8% accuracy could increase the mass range to 89-159 kg or 7-12 kg more.

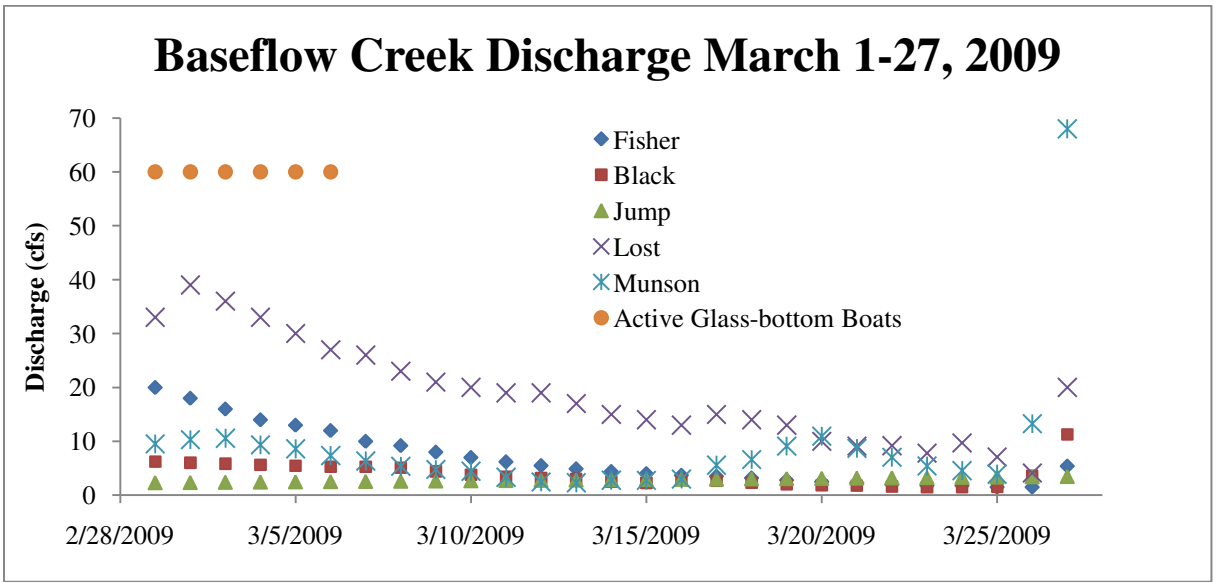

Figure 58 Baseflow Creek Discharge, March 1-27, 2009. Baseflow conditions for the five streams preceding the March-April event that began March 26, 2009. Black Creek and Munson Slough respond to rainfall immediately and the remaining creeks respond a day later. Note that both Lost Creek (basin is distant southwest side of the study area) and Munson Slough (north and east side of the study area) respond to rain events (between March 15 and 20) that the centrally located streams did not receive.

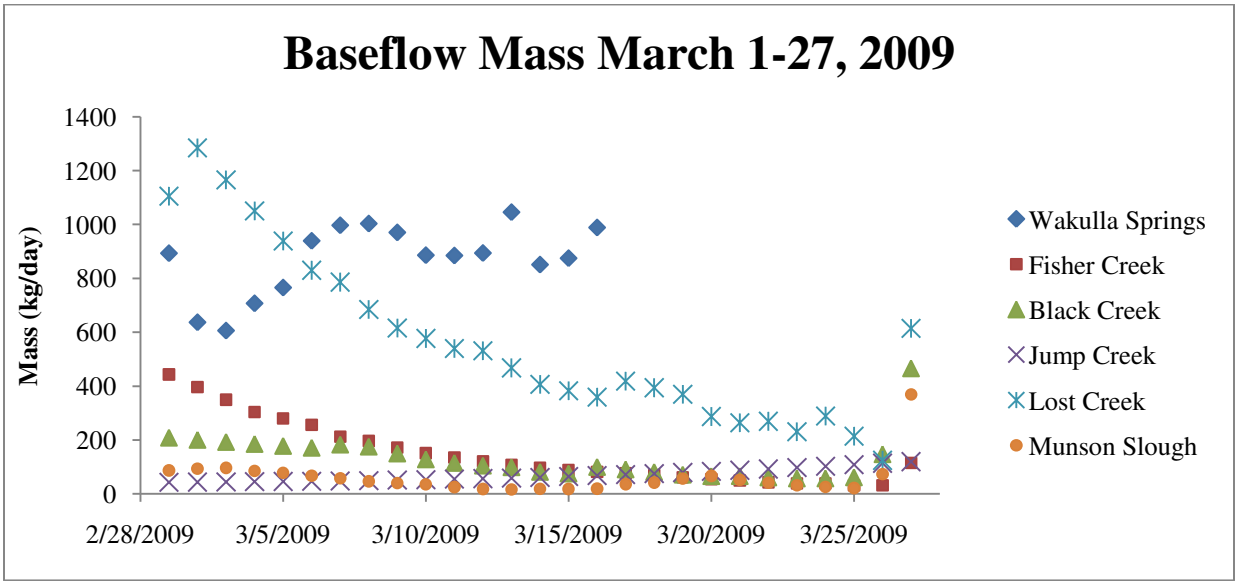

Figure 59 Baseflow Mass, March 1-27, 2009. This period precedes the March-April 2009 event. See the February 14, 2009 rain event discussion of the increasing Wakulla Springs mass beginning March 4, 2009.

Daily baseflow mass for all streams and Wakulla Springs is presented in Figure 59. Wakulla Springs samples for March 17 to April 4, 2009 were lost when the autosampler overturned. The mass of Lost Creek and Fisher Creek is declining from the February 14, 2009 rain event to be discussed later. Black Creek, Jump Creek and Munson Slough have mass associated with their baseflow conditions for the entire period shown.

Figure 60 presents the conditions one week in advance of the best clarity of May 17, 2009. Wakulla mass dropped below 900 kg/day with an average discharge of 400cfs (12cms). Individual stream mass was less than 200 kg/day each, until May 15, when the mass of Munson Slough increased. Lost Creek mass increased two days later. Best clarity occurs when Wakulla Springs and all of the creeks are discharging at baseflow conditions. The Spring of 2009 baseflow water clarity conditions are best summarized with discharge – NAC data in Figure 61. The best clarity data are represented by May 15 and 17, 2009 samples with NACs less than 2.0 m^{-1}. As would be expected, these samples correspond to higher baseflow rates with lowest organic mass (greater dilution of the natural organics).

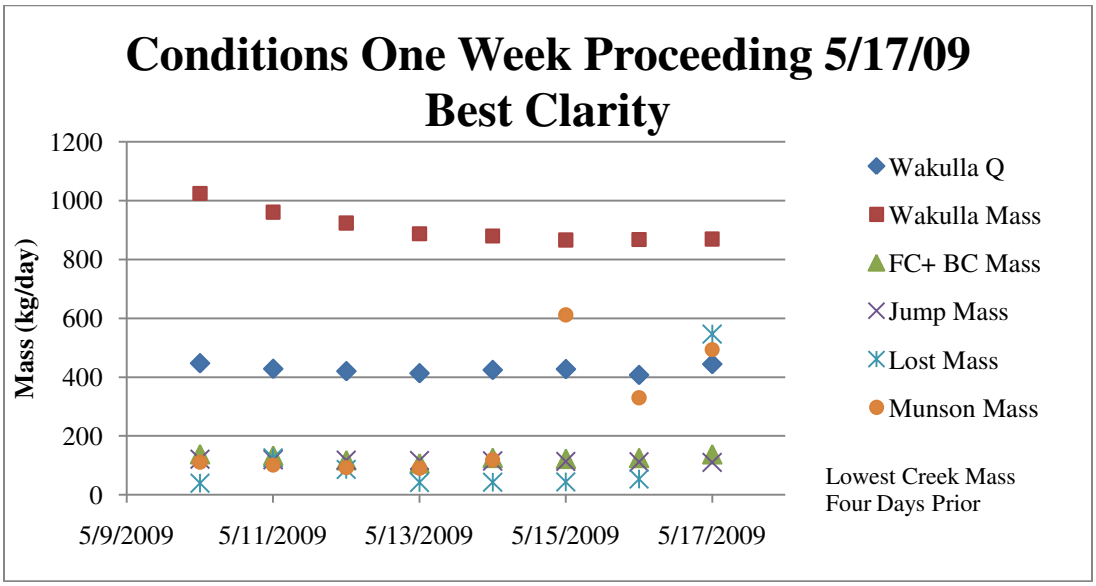

Figure 60 Conditions One Week Proceeding 5/17/09 Best Clarity of 2009. Wakulla Springs had an average discharge of 400 cfs and its mass was dropping. The mass of all of the creeks was also low, but Munson Slough and Lost Creek mass started increasing towards the end of the week. Best clarity occurs when Wakulla Springs and all of the creeks are discharging at baseflow conditions.

Unpublished Secchi Depth data collected by Wakulla Springs State Park staff (Scott Savery, personal communication, 2010) as a measure of water clarity was plotted with NAC for all of 2009 (Figure 62). The March-April 2009 data lie on the right side of the graph and exhibit poor water clarity. The pure water NAC of Quickenden and Irvin (1980) was paired with the depth of the Wakulla Springs basin 100 feet (30.48m) to show the position of optimum water clarity. The pure water of Quickenden and Irvin (1980) would not occur in nature, but had a NAC_{254nm} of 0.1/m. The clearest water samples from Wakulla Springs were for May 15 and May 17, 2009 with Secchi depth measurements of 55 and 45 feet respectively. The NAC_{254nm} data were 1.86 and 1.51/m, respectively. Secchi depth measurements generally have an

uncertainty of +/- 5 feet, depending on the time of day, degree of sunlight, if taken in the boat shadow, etc.

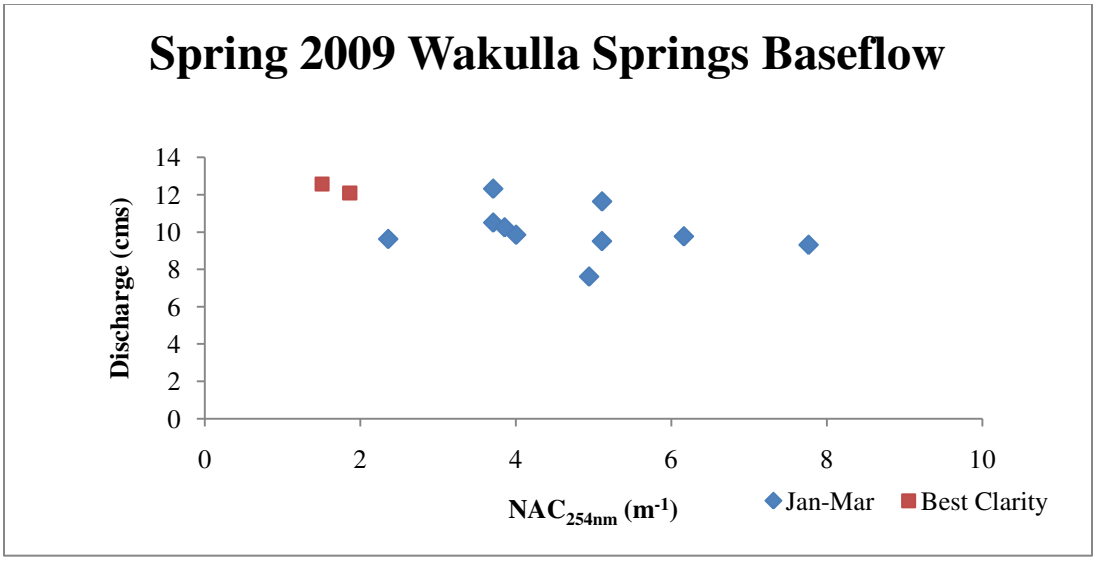

Figure 61 Spring 2009 Wakulla Springs Baseflow. Data shows that the best clarity occurs with lowest CDOM (quantified as NAC) and highest discharge (providing greater dilution).

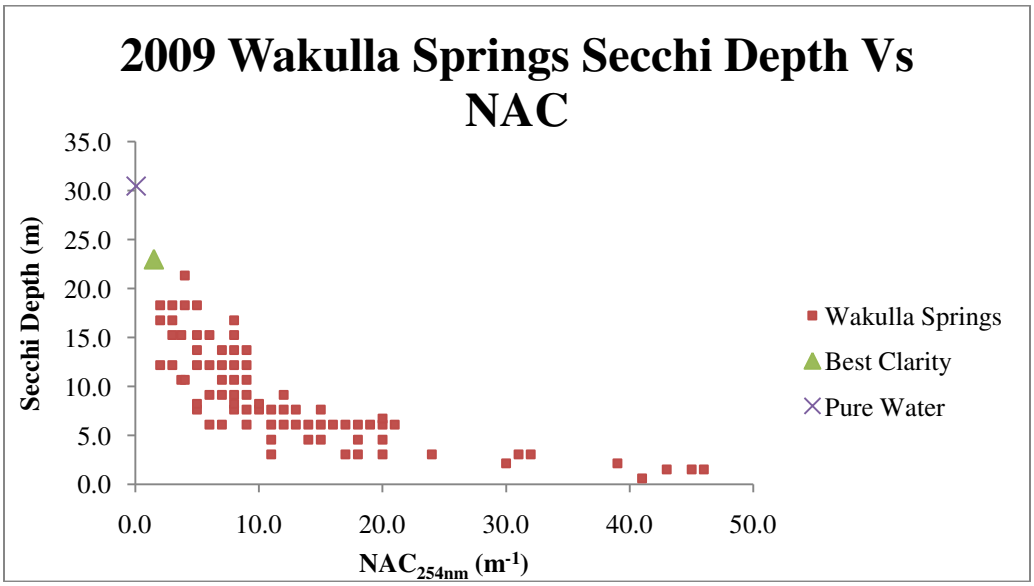

Figure 62 2009 Wakulla Springs Secchi Depth versus NAC. Data relative to the best clarity and the pure water sample of Quickenden and Irvin (1980) relative to Secchi depth data. The greater the depth the Secchi Disc can be viewed, the lower the NAC value and the CDOM concentration at the Wakulla Spring vent. Secchi Depth Data source: Savery (2010).

Figure 63 compares the low and high discharge ranges of USGS daily discharge data for 2004 through 2009 associated with 80 feet and deeper Secchi depth data (Scott Savery, personal communication, 2010). The total annual precipitation is added as a possible control. The widest discharge range occurs during years with the lowest total rainfall. Low rainfall minimizes stream

CDOM source. Total precipitation relative to the low and high discharge is plotted in Figure 64, again showing the widest separation for low rainfall years. The average rainfall range is 60 inches for the last 30 years, 56 inches for the last 10 years. (The precipitation averages are discussed in detail in Discussion, Precipitation.)

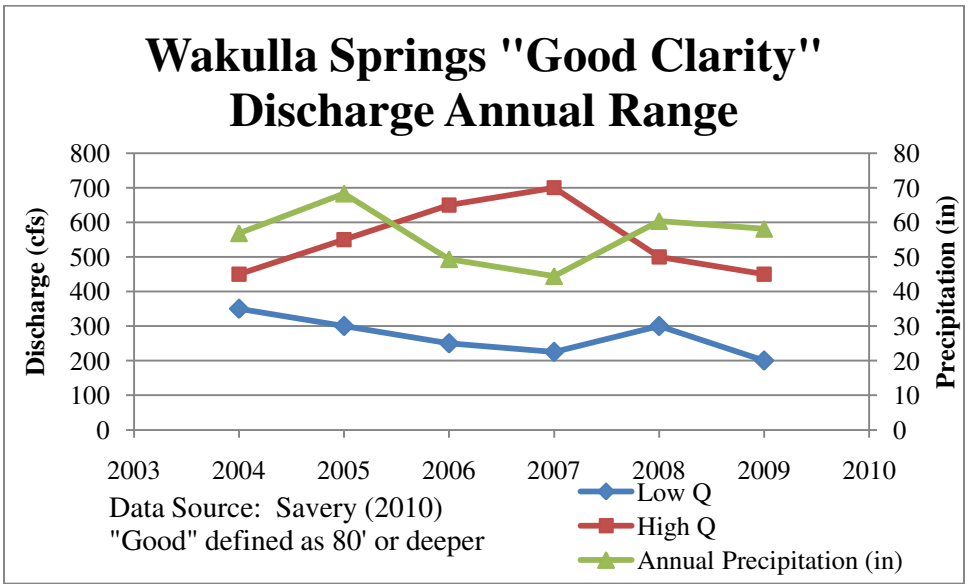

Figure 63 Wakulla Springs "Good Clarity" Discharge Annual Range. The annual range of discharges associated with good water clarity is plotted with the annual total precipitation. The most interesting observation is that the widest discharge range occurs during years with the lowest rainfall total. This very limited time period suggests that the low discharge may be declining.

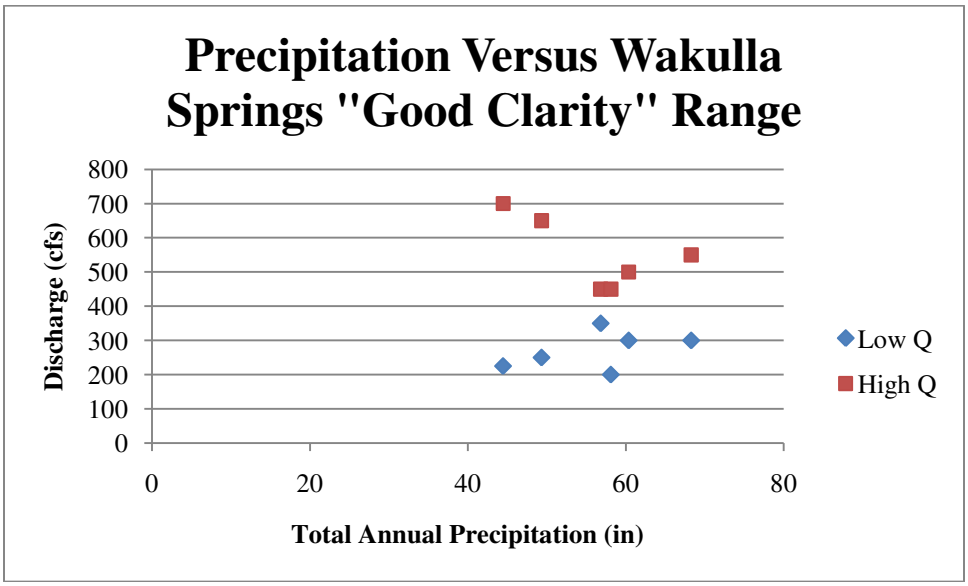

Figure 64 Precipitation Versus Wakulla Springs "Good Clarity" Range. The total annual precipitation for 2004-2009 is plotted relative to the low and high discharge range for Secchi Depths of 80 feet and deeper that are considered to be "good clarity".

Optimum water clarity at Wakulla Springs requires an NAC value less than the 1.51/m observed for the best water clarity of 2009 on May 17, 2009. Using Equation (6), this equates to a TOC of 0.8 mg/l. The concurrent Secchi Depth was 45 feet (55' for 5/15/09, the second best 2009 water clarity with NAC_{254nm} of 1.86 and TOC of 0.83 mg/l). These best water clarity samples contained 0.5% creek water that remains too high for the desired water clarity. A Wakulla Springs transmittance of 99% would have a NAC_{254nm} of 0.1 and a TOC concentration of 0.69 mg/l and allow the bottom of the Wakulla Springs basin to be viewed with the water clarity of historic times. The NAC254nm of Quickenden and Irving, (1980) pure water yields the same TOC of 0.69 mg/l, supporting this value as the optimum concentration. This concentration is below the 1 mg/l method detection limit for TOC. With the Wakulla Springs baseflow CDOM mass range of 600-1000 kg/day, this concentration indicates that the clear water base flow discharge will need to be 350-600cfs (10-17cms) to provide the necessary dilution.

Figure 65 presents the conditions one week before the poorest water clarity of April 8, 2009. Both the Wakulla Springs discharge and mass were increasing. The composite Fisher and Black Creek mass peaked on day four and then declined. Munson Slough and Jump Creek peaked on days three and four, respectively and then declined. The Lost Creek mass peaked at 126,000 kg/day on the fourth day and isn't included because of the slower transport time for its migration pathway. Poorest water clarity at Wakulla Springs occurs 2-3 days after the Wakulla Springs discharge peaks.

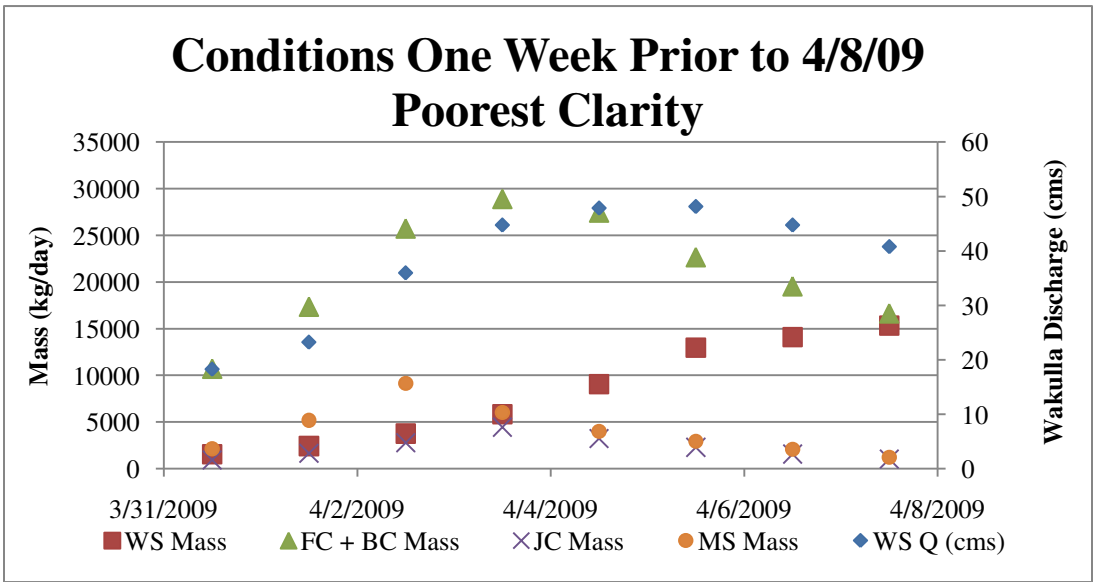

Figure 65 Conditions One Week Prior to 4/8/09 Poorest Clarity. Wakulla Springs discharge and mass were increasing as the composite Fisher and Black Creek, Munson Slough and Jump Creek mass peaked on days four, three and four, respectively and were also declining. Poorest water quality at Wakulla Springs occurs 2-3 days after its discharge peaks.

The mass totals for Jump Creek and Munson Slough in Table 4 indicate that they provide the lowest daily mass with the maximums of 4439 and 9142 kg/day, respectively. Even so, these amounts are four to nine times the mass that discharges at Wakulla Springs during baseflow

conditions. As a result, isolated heavy rainstorms over either basin could affect Wakulla Springs water clarity without any contribution from one of the other streams.

Ignoring travel time differences between the creeks, the daily creek mass was totaled to compare to Wakulla Springs daily mass and is presented in Figure 66. The mass associated with Lost Creek is substantially larger than the mass associated with the rest of the creeks and Wakulla Springs. Total Creek mass (without Lost Creek) is also greater than that of Wakulla Springs by approximately 112,000 kg (Table 4 summarizes mass results.). To show how the mass changes during the rise and decline of the Wakulla Springs hydrograph, Wakulla Springs mass is plotted relative to total creek mass (with Lost Creek) in Figure 67. The Wakulla Springs hydrograph is broken up into the same sections for clarification in Figure 68. When the total creek mass peaks, the discharge at Wakulla Springs is still increasing to peak two days later, followed by Wakulla mass peaking another two days later. Note that the decline increase from new precipitation alters the slope during the recession curve of "MarApr Decline" to "Decline Part 2". The "2nd storm rise" (green triangles) begins with higher Wakulla Springs mass than the March-April storm due to mass held in storage.

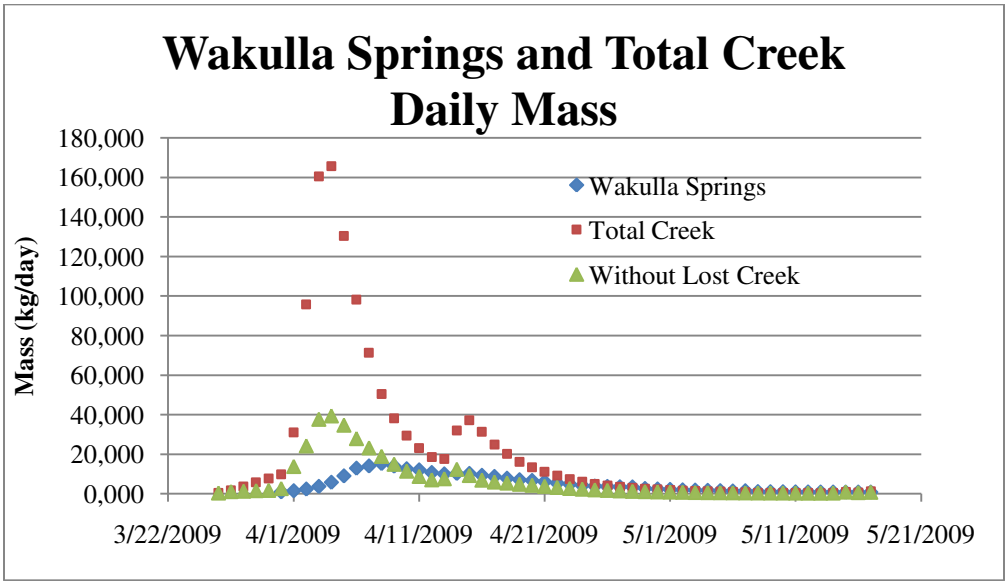

Figure 66 Wakulla Springs and Total Creek Daily Mass. Mass associated with Lost Creek is substantially greater than the rest of the total creek mass and the mass of Wakulla Springs. Total Creek mass without Lost Creek exceeds the Wakulla Springs mass by 112,000 kg.

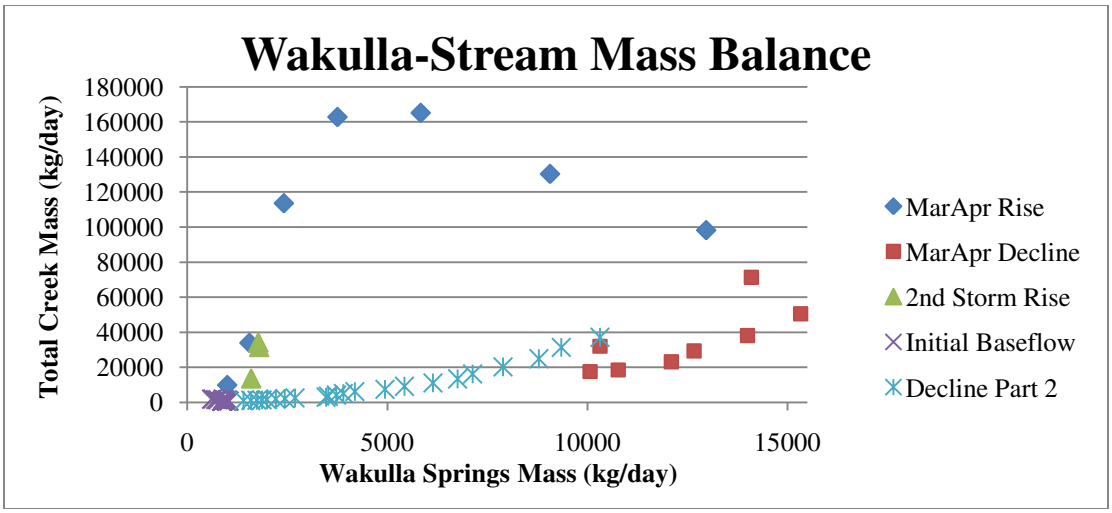

Figure 67 Wakulla-Stream Mass Balance. Mass changes during the rise and decline of the Wakulla Springs hydrograph begins with (1) initial baseflow, (2) MarApr rise, (3) MarApr decline, (4) Decline Part 2, and (5) 2nd storm rise.

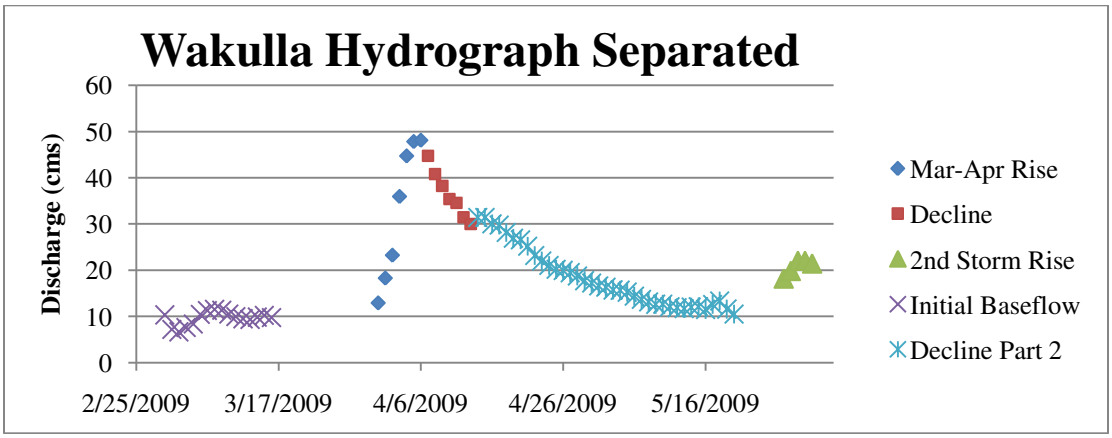

Figure 68 Wakulla Springs Hydrograph Separated is broken up into the same sections as in Figure 67 for clarification

Figure 69 shows the log-transformed mass associated with each individual stream and Wakulla Springs. This plot suggests that Wakulla Springs discharges the stream mass over a very long period, long after the streams have resumed baseflow. If the 5-17-09 new storm event is assumed to have contributed no new mass to the system to May 31, 2009 (54 days after Wakulla mass peaked), Wakulla Springs had discharged 267,000 Kg total and still 7,000 Kg short of the Fisher and Black Creek mass total. This suggests mass by passing Wakulla Springs or storage/loss with in the system.

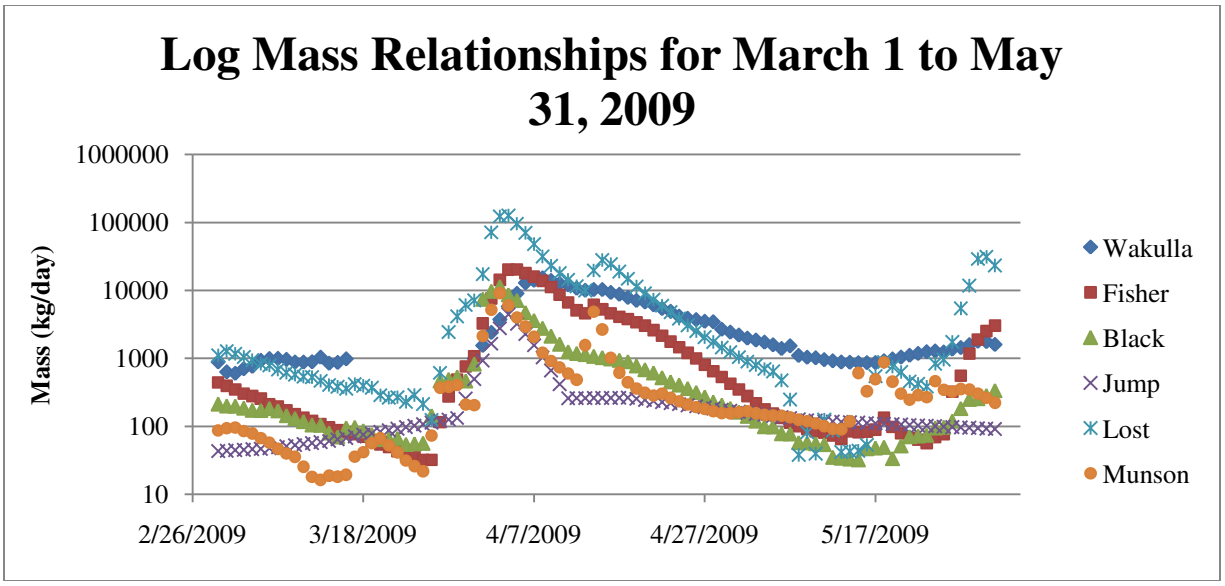

Figure 69 Log Mass Relationships for March 1 to May 31, 2009. Creek mass greatly exceeds mass discharged at Wakulla Springs indicating storage, absorption, or bypass of mass occurs between recharge and discharge locations.

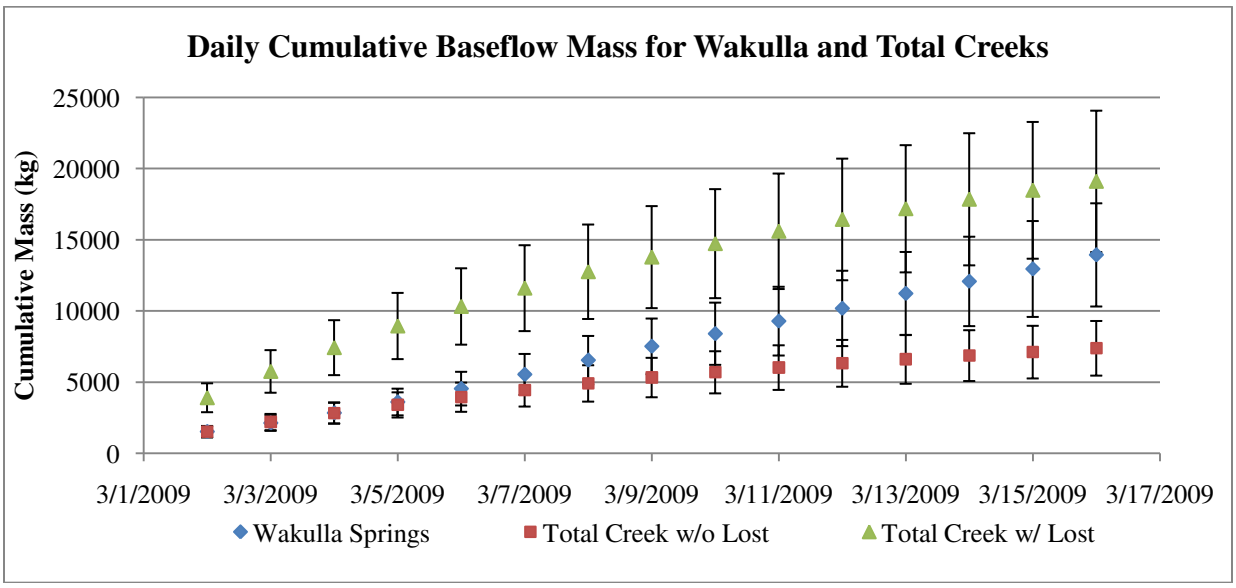

Figure 70 Daily Cumulative Baseflow Mass for Wakulla and Total Creeks, with and without Lost Creek. For low baseflow conditions, the total mass from the creeks without Lost Creek equals the Wakulla Springs mass, but for higher baseflow conditions, Wakulla Springs is discharging additional mass, likely from Lost Creek. Most mass of Lost Creek (the difference between total creek with and with/out Lost Creek) bypasses Wakulla Springs. The compounded uncertainty associated with the variables of this calculation eventually overlaps.

Figure 70 shows the daily cumulative baseflow mass for Wakulla Springs and the creek totals, with and without Lost Creek. For low baseflow conditions, the total mass from the creeks without Lost Creek equals the Wakulla Springs mass, but for higher baseflow conditions Wakulla Springs is discharging additional mass, likely from Lost Creek or storage. Most mass of Lost Creek (the difference between total creek with and with/out Lost Creek) bypasses Wakulla Springs. The compounded uncertainty associated with the variables of this calculation

eventually overlaps for the higher baseflow conditions. Figure 71 adds the daily cumulative March-April 2009 storm mass (including the estimated first 5 days of the Wakulla Springs storm hydrograph rise) to the above baseflow mass for Wakulla Springs and the creek totals without Lost Creek. Even when Lost Creek mass is excluded; the total creek cumulative storm mass greatly exceeds that of Wakulla Springs by 103,000 kg, suggesting mass storage/loss in the system. The compounded uncertainty of the cumulative totals eventually overlaps.

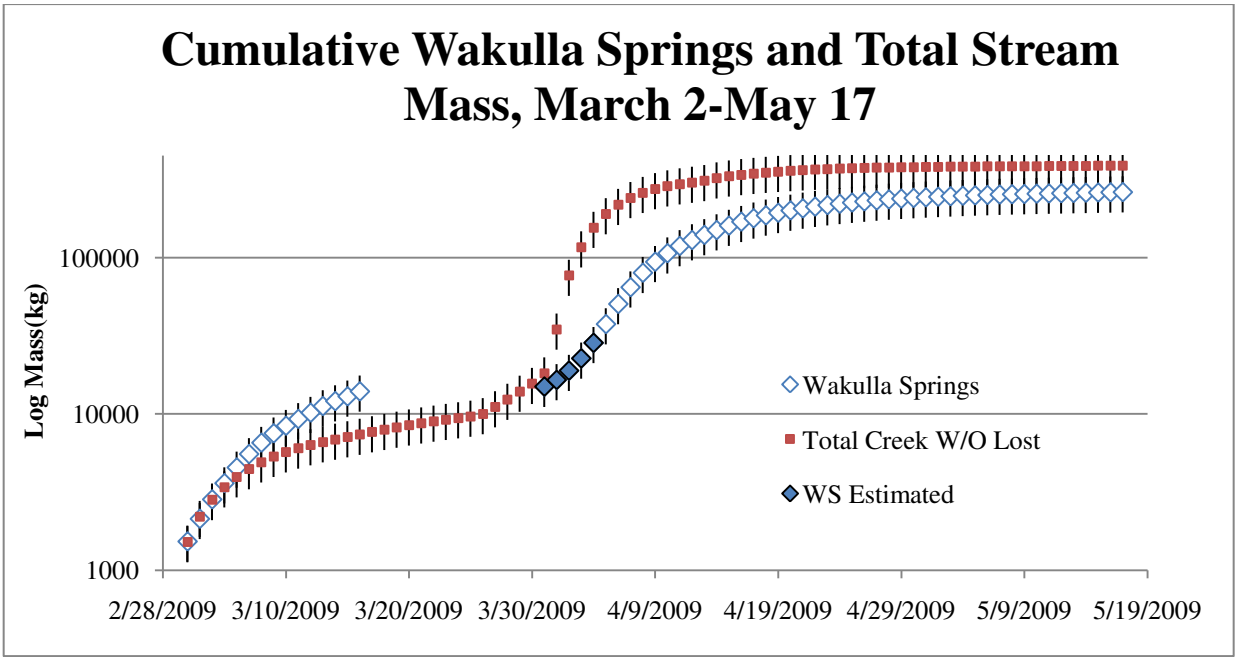

Figure 71 Cumulative Wakulla Springs and Total Stream Mass, March 2-May 17, 2009. Three aspects are evident: (1) stream mass equals Wakulla Springs mass at low baseflow , (2) stream mass is less than Wakulla Springs mass at higher baseflow and (3) stream mass is less than Wakulla Springs mass at the beginning of storm discharge, but rapidly exceeds Wakulla Springs mass. The total creek cumulative storm mass greatly exceeds that of Wakulla Springs by 103,000 kg even when Lost Creek mass is excluded, suggesting mass storage/loss in the system. The compounded uncertainty associated with the variables of this calculation eventually overlaps.

Figure 72 includes Wakulla Springs estimated mass for the missing period by repeating the prior 14 days baseflow mass with the creek mass for March 2 to May 17, 2009. The break in the Wakulla Springs cumulative mass curve are the samples lost from the overturned autosampler during the Wakulla Springs flood. Three different conditions are evident: (1) stream mass equals Wakulla Springs mass at low baseflow conditions, (2) stream mass is less than Wakulla Springs mass at higher baseflow conditions and (3) stream mass is less than Wakulla Springs mass at the beginning of storm discharge, but rapidly exceeds Wakulla Springs mass. If the information in this graph is considered in regard to the declining water clarity of Wakulla Springs and old-timers recollection that the springs did not stay dark for long following a storm event, it seems that a decline in the volume of clear water would be an easy explanation for the water clarity change. In the past Wakulla Springs had a larger volume of clear water to dilute the slower storm mass released from storage between storm events. It is also possible that higher historic flows resulted in more stream mass by passing Wakulla Springs. Presently, even for low baseflow conditions (the best clarity conditions fail to match historic clarity), it seems Wakulla

Springs needs more clear water to dilute the natural source from the creeks. The slower release from storage for Wakulla Springs mass may have been there all along but wasn't noticed due to the greater availability of water for dilution. The compounded uncertainty of Figure 71 applies.

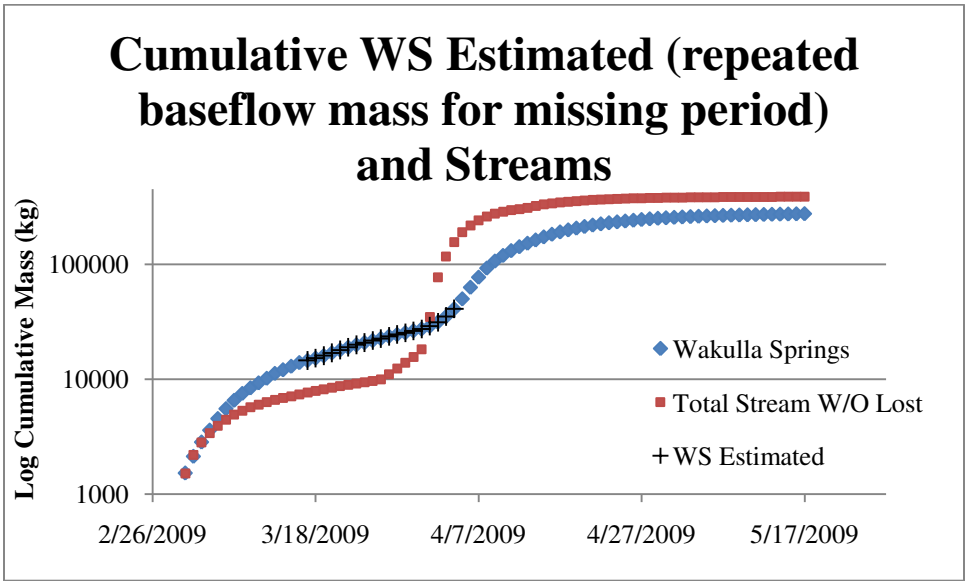

Figure 72 Cumulative Wakulla Springs Estimated Mass and Streams. For the Wakulla Springs missing period, the earlier baseflow mass was repeated to calculate a complete curve.

When several sources are potentially contributing to another source water quality, an end-member mixing analysis is typically performed. The most simple case assumes two dissimilar waters (end-members containing multiple or different diagnostic dissolved analyte) mix, causing mutual dilution of the analytes present in both waters. The analyte concentration in the blended water is directly dependent on the relative percentage from each end-member water. Assuming dilution from mixing is the only mechanism that affects final concentration in the blended water (i.e. there are no other non-conservative processes such as adsorption or precipitation that would preferentially remove a constituent from solution), then two such constituents will plot on a X-Y graph for varying percentages of blending as a straight line. If the line is more curvilinear, it would be an indication that one or both analytes do not behave conservatively. Sodium and chloride are considered conservative ions in groundwater and would plot as a straight line. CDOM participates in absorption and precipitation reactions and thus is generally considered to be a non-conservative analyte. Considering the extensive network of conduits conveying sinkhole surface water to groundwater to Wakulla Springs, the flow network may be an important control resulting in the CDOM behaving as a conservative analyte.

The non-linear regression technique of Stegmon and Markager (2003, and Kaas, 2000) was used to evaluate a two-end member mixing of the creek CDOM mass and Wakulla Springs. This technique requires fitting an exponential equation to the absorption coefficient spectra for the 300-400nm wavelength range. The spectral slope of each exponential fit equation is plotted on the y-axis relative to the NAC_{375nm} on the x-axis for each sample. The spectrophotometer data for all of the Wakulla Springs samples during the study period were compared to the

discrete samples obtained from Fisher Creek (5-31-2010), Black Creek (5-31-2010), and Lake Munson (2-18-2009: only sample of the study period). The slope defines how the chromophoric dissolved organic carbon declines with increasing wavelength within that selected wavelength range. The slope will change if another wavelength range is selected. The NAC at 375 nm was selected as the reference wavelength as used by Stedmon and Markager (2003). Figure 73 indicates conservative mixing (i.e. dilution) is the primary explanation between the two source waters for the mass that reaches Wakulla Springs.

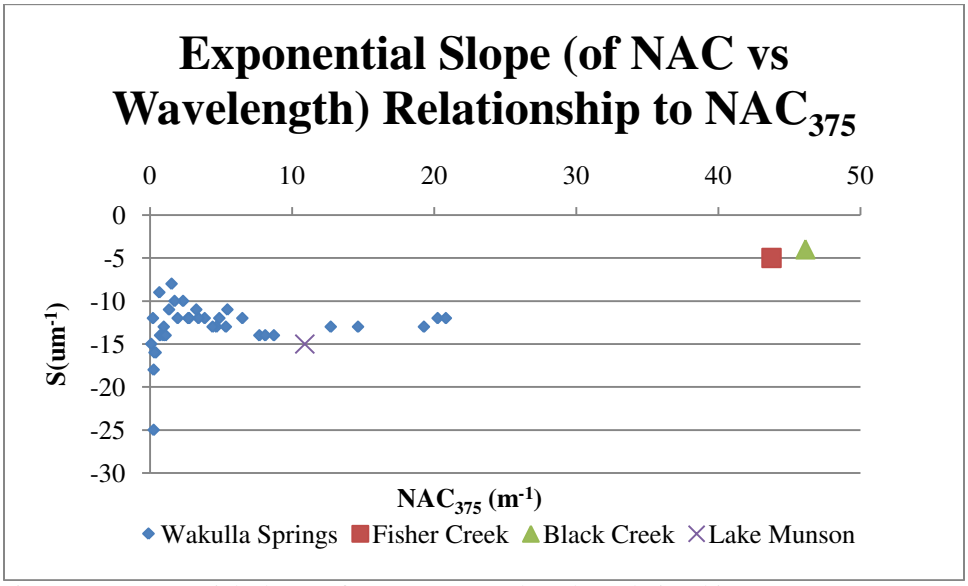

Figure 73 Exponential Slope (of NAC vs. Wavelength) Relationship to NAC_{375}. Conservative mixing (i.e. dilution) is the primary explanation between the two source waters for the mass that reaches Wakulla Springs.

February 14, 2009 Storm. Further examination of the entire baseflow period back to January 1, 2009 and the glass-bottom boat record indicated a February 14, 2009 precipitation event that appeared to be related to an arrival of dark water. Figure 74 shows a two month period with very minor rain produced low creek discharges and Wakulla Springs average base flow of 360 cfs. Wakulla Springs clarity improved February 22 through March 6, 2009, allowing the glass-bottom boats to operate. During the night following March 6, 2009, the Wakulla Springs discharge turned dark, ending glass-bottom boat operation (Bob Thompson, personal communication, March, 2009). The February 14, 2009 rain event produced 1-2 inches over the Tallahassee area, arriving at Wakulla Springs 21 days later (the number of days between February 15 to March 7). Two weeks of no rainfall preceded this event as shown Figure 74. All of the streams were flowing at low flow conditions.

The Wakulla Springs NAC data for the period February 13 to March 22, 2009 is poor for variable conditions as depicted in Figure 75 of NAC and discharge (left). Lost Creek conditions are better characterized for CDOM associated with the hydrograph rise and fall. Extrapolated mass for Wakulla Springs and the three major streams is presented on the right. Figure 75 (right) also shows the actual dates of data for Wakulla Springs. Lost Creek mass peaked first with 3355 kg/day followed by Fisher Creek mass at 835 kg/day. Munson Slough mass remained low.

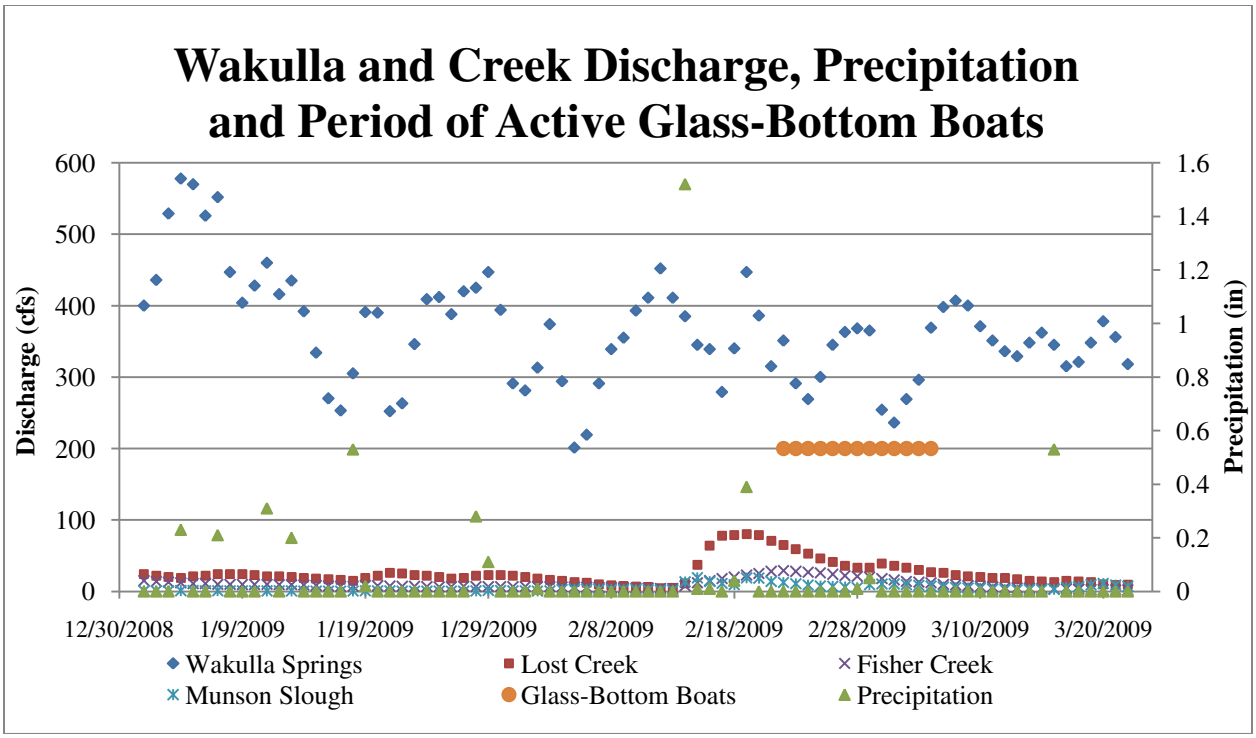

Figure 74 Wakulla and Creek Discharge, Precipitation and Period of Active Glass-Bottom Boats surrounding the February 14, 2009 precipitation event that resulted in a discharge rise for Lost Creek. Wakulla Springs clarity remained poor until February 22 through March 6, 2009, allowing the glass-bottom boats to operate. Overnight, water clarity declined and it appears Lost Creek was the source. This flood event was significantly larger than the dye tracing conditions (less than 1 cfs versus 80 cfs) so travel time likely would have been quicker (45 days for start of dye arrival, 56 days for the first dye peak to arrive, Kincaid et al 2008). Munson Slough lacked sufficient mass to be a possibility and Fisher Creek mass would have arrived before March 1 (the low flow travel time).

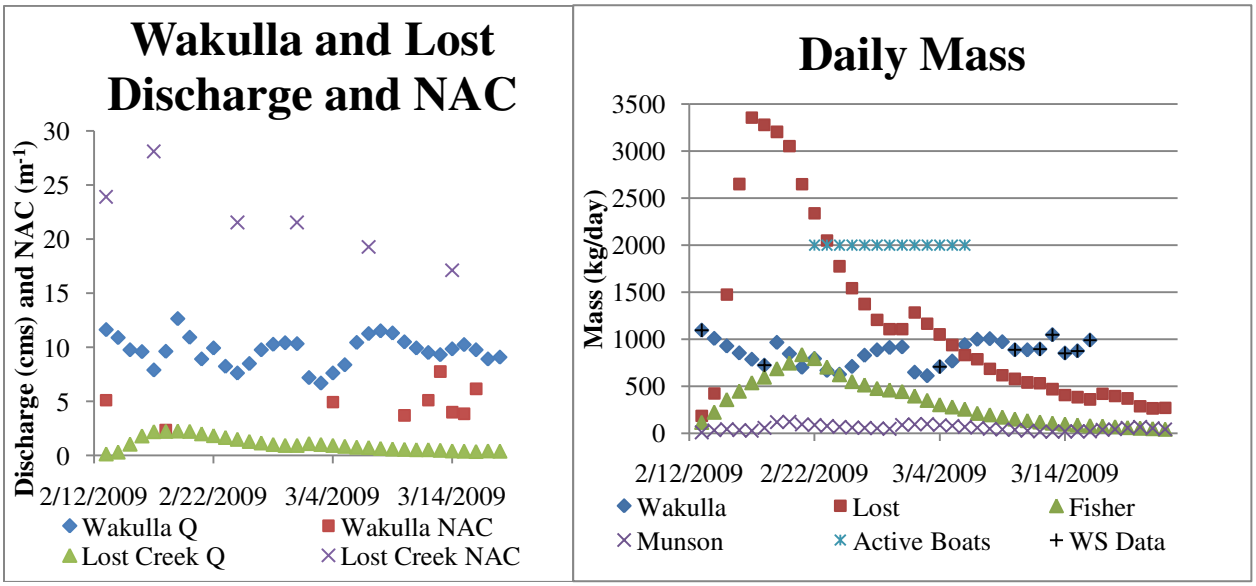

Figure 75 Wakulla and Lost Discharge, NAC and Daily Mass, February 14, 2009 Rain. The mass from Lost Creek was the likely source that arrived at Wakulla Springs on March 7, ending active glass-bottom boat operation. The Daily Mass figure identifies actual data for Wakulla Springs; note the March 4, 2009 sample represents the glass-bottom boat operation and this result (4.96 NAC (m^{-1})) suggested less than optimum clarity.

Lost Creek and Fisher Creek had well-defined mass and discharge hydrographs from the February 14, 2009 precipitation as presented in Figure 76. The mass (maximum 835 kg/day) and discharge (<1cms or 29 cfs) associated with Fisher Creek did not affect Wakulla Springs water clarity. Within the low flow dye injection test travel time of 9 days (Fisher Creek had higher flow from the February 14, 2009 precipitation than the low flow test conditions and would have arrived at Wakulla Springs in less time than 9 days), no water clarity decline at Wakulla Springs was observed to stop glass-bottom boat operation. Figure 75 (right) does show an increase in mass for Wakulla Springs from 626-916 kg/day (February 24 to March 1) that is likely Fisher Creek mass. Figure 75 also shows a decline in mass with a second mass rise beginning March 4th. The Lost Creek flood event was significantly larger than the dye tracing conditions (less than 1 cfs versus 80 cfs) so travel time likely would have been quicker (45 days for start of dye arrival, 56 days for the first dye peak to arrive, Kincaid et al 2008). The sudden dark water arrival at Wakulla Springs occurred 17 days after the Lost Creek mass peaked or 21 days after the rainfall event. (If the dark water arrival had been continuous without a period of glass-bottom boat operation, release from aquifer storage would be a more likely explanation.)

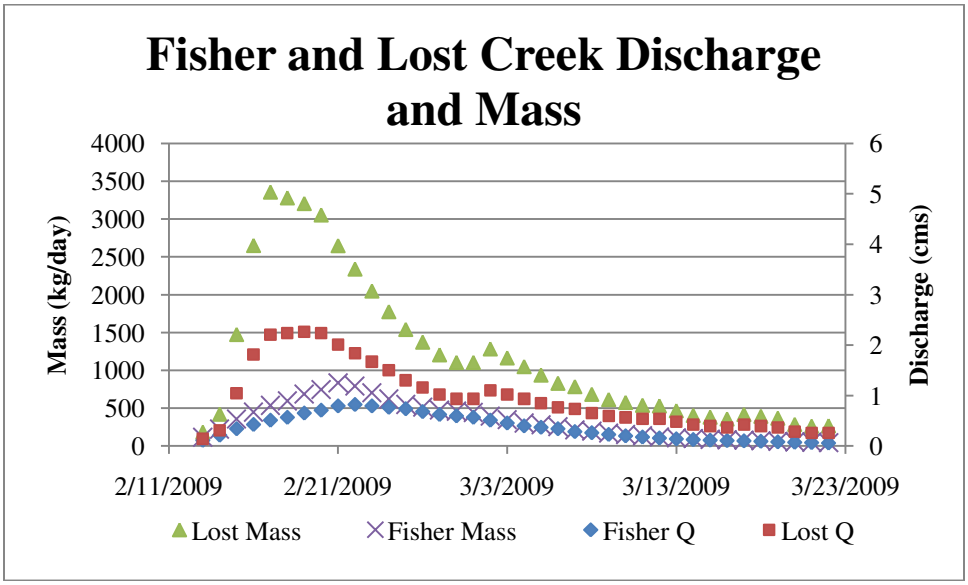

Figure 76 Fisher and Lost Creek Discharge and Mass, February 14, 2009.

Figure 77 shows the relationship of Wakulla Springs mass to Lost Creek mass for the February 14, 2009 precipitation. The dates February 13-14 and March 14-16 represent conditions when Lost Creek mass is low, but Wakulla Springs is still discharging mass from a previous storm. February 15 to March 3 represents high mass for Lost Creek that has not yet arrived at Wakulla Springs. The March 4-13 represents the arrival of the Lost Creek mass at Wakulla Springs.

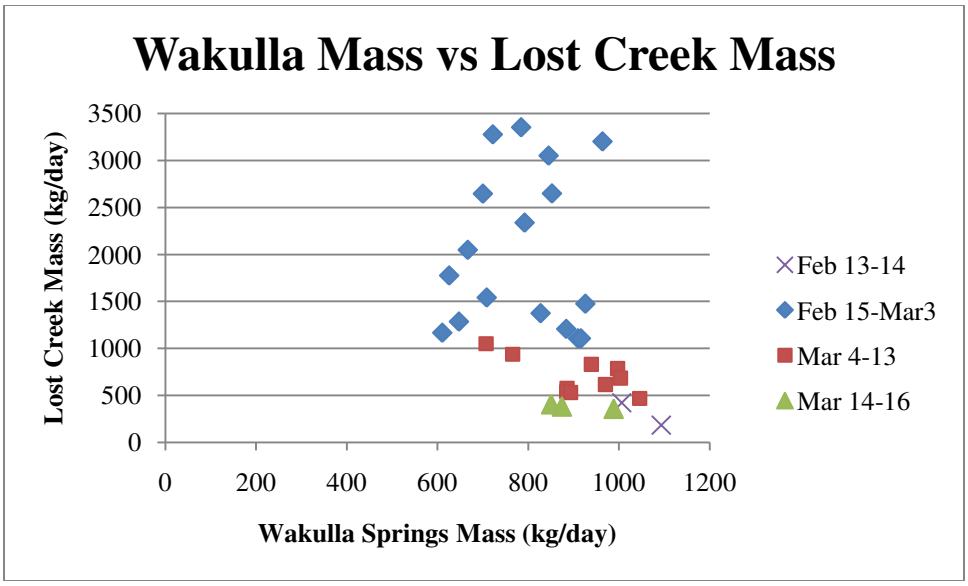

Figure 77 Wakulla Mass vs. Lost Creek Mass, February 14, 2009 precipitation. The dates February 13-14 and March 14-16 represent conditions when Lost Creek mass is low, but Wakulla Springs is still discharging mass from a previous storm. February 15 to March 3 represents high mass for Lost Creek that has not yet arrived at Wakulla Springs. The March 4-13 represents the arrival of the Lost Creek mass at Wakulla Springs.

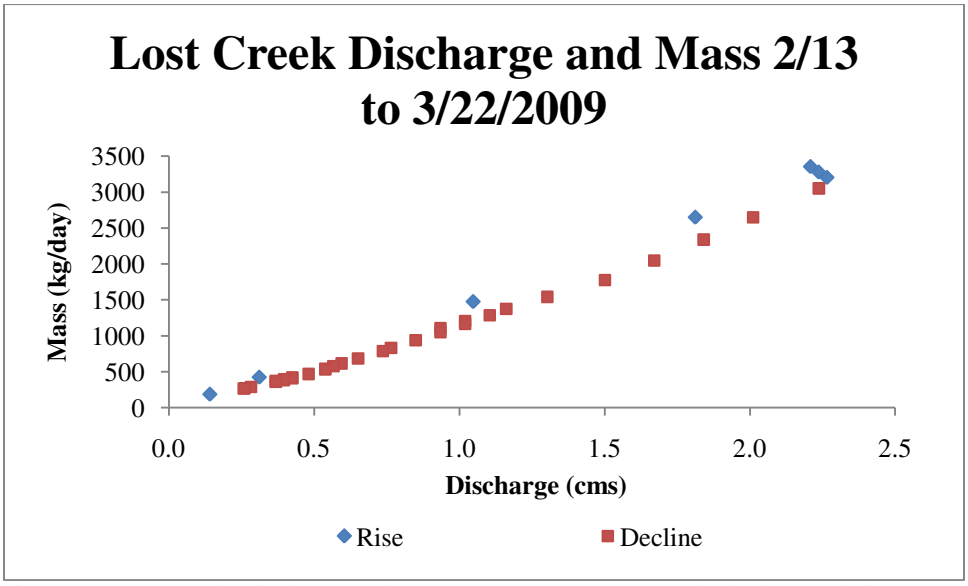

Figure 78 Lost Creek Discharge and Mass, 2/13 to 3/22/2009. The hydrograph rise occurs quickly, taking 5 days to reach the discharge peak. The decline is represented by more than a month span on the figure and has yet to reach its pre-event discharge.

Figure 78 shows the Lost Creek relationship of discharge to mass for the hydrograph rise and fall. The rise occurs quickly, taking 5 days to reach the discharge peak. The decline is represented by more than a month span on the figure and has yet to reach its pre-event discharge. Fisher Creek also shows a rapid rise to its hydrograph and increase in mass in Figure 79. The decline shows two slopes, the first representing the decline of storm runoff and the second

represents storm related groundwater recharge slowly released to Fisher Creek. Note that the maximum discharge for Fisher Creek was less than 1cms (maximum 29cfs); not important for the Wakulla Springs baseflow conditions following the February 14, 2009 event.

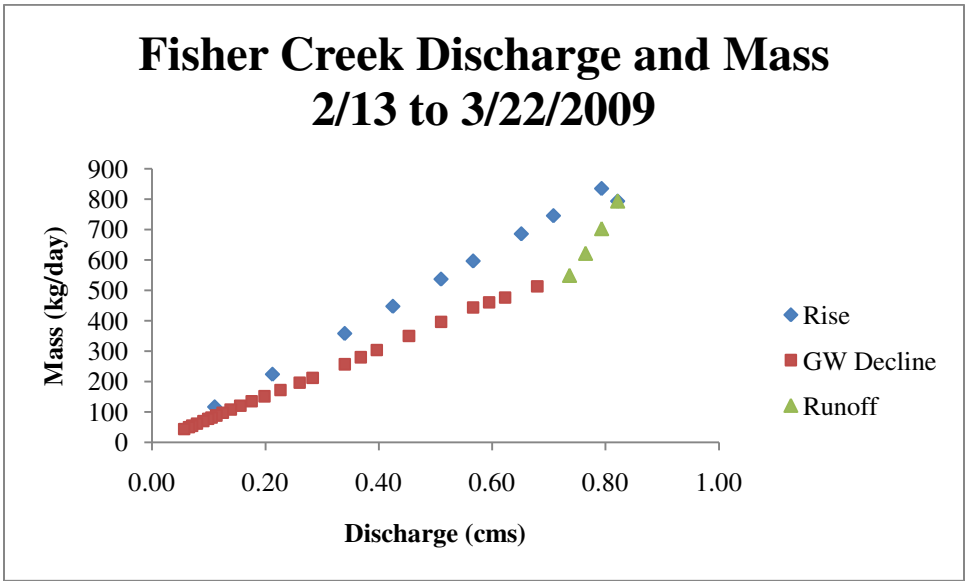

Figure 79 Fisher Creek Discharge and Mass, 2/13 to 3/22/2009 that includes the rise (blue), the stormwater runoff decline (green), and the groundwater decline (red).

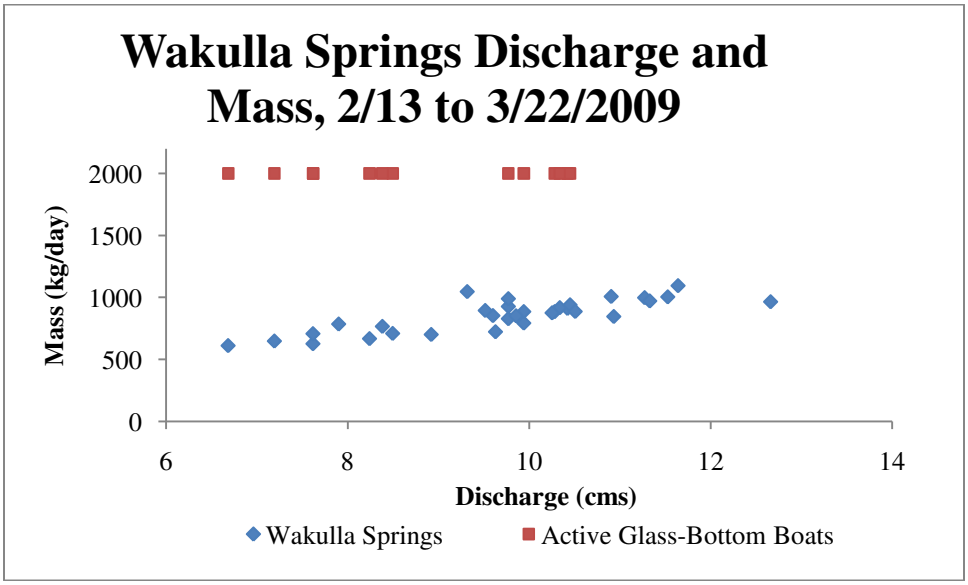

Figure 80 Wakulla Springs Discharge and Mass, 2/13 to 3/22/2009 show no separation because the discharge was baseflow and the February 14, 2009 rainfall was too low to alter this condition. The dates of active glass-bottom boat operation are shown to emphasize the variation in the CDOM concentrations.

Figure 80 shows the Wakulla Springs discharge versus mass plot for the February 14, 2009 event. No separation into rise and fall hydrograph segments occurs because the discharge was baseflow and the February 14, 2009 rainfall was too low to alter this condition. The dates of

active glass-bottom boat operation are shown to emphasize the variation in the CDOM concentrations during this period.

Table 5 summarizes the mass totals for the affected streams and Wakulla Springs for the period February 13 to March 16, the last day of the recession curve represented by actual Wakulla Springs data. (March 17 to April 4, 2009 samples were lost due to the flooding that overturned the automated sampler.) The maximum daily mass associated with Munson Slough was 121 kg/day, approximately the same as its baseflow mass to the Wakulla Springs best water clarity of 5/17/2009, eliminating it as a possibility for any Wakulla Springs water clarity decline. Fisher Creek maximum mass occurred on 2/21/2009, seven days after the rain event. Fisher Creek discharge for this event reached 29 cfs (<1 cms) greatly exceeding the discharge during the dye testing (<1cfs), so travel time to Wakulla Springs would have been shorter than 9 days, with the peak potentially arriving February 26 to March 1 (the low flow travel time of 9 days). Recall that at a discharge greater than 6 cfs, Fisher Creek overflows the first swallet, potentially flowing to Sullivan and Fisher 2 swallets. No mass arrival prior to March 7 affected Wakulla Springs water clarity. With the elimination of Munson Slough and Fisher Creek, only Lost Creek remains as a potential source. The Lost Creek flood event was significantly larger than the dye tracing conditions (less than 1 cfs for the dye test versus 80 cfs) so travel time likely would have been quicker (45 days for start of dye arrival, 56 days for the first dye peak to arrive, Kincaid et al 2008). The total mass contributed by Munson Slough and Fisher Creek totals 14,835 kg or approximately half of that discharged at Wakulla for this time period. The Lost Creek mass totaled 43,378 kg, more than the Wakulla Springs 27,291 kg for the same period. This mass estimate is qualified because the lack of Wakulla Springs data after March 16 omits mass that should be included.

At this time it is not possible to compare the Lost Creek swallet surface water elevation to the relative Wakulla Springs stage elevation for this specific period to see if a gradient exists to support Lost Creek as a source. That data is currently being compiled by another worker (Scott Barrett Dyer). Spring Creek was discharging at flow rates higher than either Lost Creek dye trace injection test period.

Table 5 February 14, 2009 Event CDOM Mass Summary

CDOM Mass Summary	**Wakulla Springs**		**FC**	**LC**	**MS**
	Q (cms)	kg/day	kg/day	kg/day	kg/day
Poor Water Clarity Arrival 3/7/2009	11	997	212	786	58
Creek highest mass			835	3400	121
Days after 2/14/09 rain		21	7	3	6
Days prior to 3/7/2009			14	18	15
Poorest Water Clarity 3/13/2009	9	1050	108	468	16
Mass Balance for Feb 14, 2009 Event		Total kg			
WS total mass for Feb 13 to March 16 period		27300			
FC total mass for Feb 13 to March 16 period		12100			
LC total mass for Feb 13 to March 16 period		43400			
MS total mass for Feb 13 to March 16 period		1780			

CHAPTER 4

DISCUSSION – WHY HAS WAKULLA SPRINGS CLARITY DECLINED?

There are four possible causes of darker water observed at Wakulla Springs: (1) increased vegetation density, change in the vegetation type, or change in the management practices (such as burning of undergrowth) in the contributing drainage basins producing higher concentrations of dissolved organic carbon, (2) increased precipitation over the black water stream drainage basins increasing runoff (more rain means the streams flow longer than historically), (3) subsurface collapse in the conduit system or a like mechanism to alter groundwater flow path(s), and (4) increased upgradient groundwater withdrawals of the clear water baseflow of Wakulla Springs. Each will be discussed separately below.

Vegetation Analysis

One of the possible contributions to the decreased clarity at Wakulla Springs is increased vegetation density that would increase the dissolved organic carbon (DOC) concentration in surface water. Meyer, Wallace and Eggert (1998) demonstrated that there is a positive relationship between DOC and the amount of litter in a stream channel. Kominoski et al. (2007) found that leaf litter grown in higher CO^2 conditions leaches higher concentrations of refractory DOC. De Wit et al. (2007) studied Norwegian catchments weekly over an 18-year period, documenting an increase in dissolved organic carbon (DOC) due to a decrease in acid aerial deposition of chloride, sulfate and nitrate. They proposed that increased humic charge and reduced ionic strength – both of which increase organic matter solubility- as the connecting explanation behind the DOC increase and sulfate/nitrate deposition. Dawson et al (2009) observed increased DOC and UV absorption in two Scotland, UK moorland catchments over a 22 year period that were attributed to "enhanced heterotrophic decomposition of organic matter". Historical surface water DOC concentrations would be the most reliable indicator of a change in this regard, but such data has not been found earlier than 1992 for any of the streams. In addition, frequent measurement periods rarely exceeded two years, preventing any trend analysis with concurrent periods of excellent Wakulla Springs clarity. Wakulla Springs limited data extend back to 1970. Table 6 summarizes the historic total organic carbon data analyzed by the Northwest Florida Water Management District, United States Geological Survey, and Florida Department of Environmental Protection. No data is available for Jump Creek. The data show the highest TOC concentrations occur during the fall and winter months (new fallen leaf supply- see Meyer et al. 1998) and after rainfall following extended dry periods (Biron et al., 1999).

Table 6 Summary of Historic Total Organic Carbon Data of NWFWMD, USGS, and FDEP

Stream	TOC -Minimum	TOC -Maximum	TOC -Mean	Samples
Fisher Creek	9.4	45	27	25
Black Creek	22	50	39	24
Jump Creek				0
Lost Creek	6.3	50.1	22	22
Munson Slough	4.6	15	8	30
Wakulla Springs	<1	8.8	1.29	196

Historical aerial photos were evaluated to determine if Apalachicola National Forest management practices have varied to result in surface water concentration changes. The Fisher Creek drainage basin is the largest basin with the most significant DOC loading of the five basins in this study. It covers 9219 hectares, with 3281 hectares considered wetland conditions. Figure 81 shows the wetland acreage relative to the basin boundaries and the main creek flow path/channel. Three specific areas of the Fisher Creek basin were selected: northwest, midbasin, and sink sections. The northwest section was selected because the wetland vegetation covers approximately half of the acreage. The mid basin section represents a transition zone where the creek occupies a defined channel and has less contributing wetlands. The sink section is immediately upgradient of the first swallet, Fisher Creek 1 (FC1) where part of the flow recharges the Floridan Aquifer. The sink section has the smallest percentage of wetland acreage. The three specific areas are shown on Figure 82.

Three years of photos were selected: 1937, 1973, and 2004 (36 and 31 years apart, respectively). The 1937 photography was obtained from the United States Department of Agriculture and the 1973/2004 photography was obtained from the Florida Department of Transportation. Wetlands were defined as hydric conditions, such as ponds, herbaceous wetlands, swamps, and pond pine. Uplands are defined as the remaining acreage. Figures 83, 84, and 85 provide the aerials for each of these years with the hydric vegetation boundaries.

The Figure 83 northwest photo wetlands comprise 854 hectares of the total 1693 hectares in this section of the Fisher Creek basin, i.e. approximately half of the photo. The physical limits of the hydric conditions within the northwest area do not show any significant changes (changes are less than 5%) between the three time periods. The 1937 photo upland areas are the least densely vegetated of the three periods, characteristic of the native long-leaf pine forests (Henderson, 2006). Harvesting practices in the 1937 era included a concurrent cutting of all of the upland areas and some of the swamp, particularly in the center of the southern one third of the photo. In 1937, the historical photo indicates that 60 percent of the area had been harvested. Pine plantation management included a shift to planting slash or loblolly pine at a greater density for faster maturity than the native long-leaf pine forests (Henderson, 2006). By 1973, the aerial photos indicate harvesting practices changed to select small contiguous upland areas, approximating 10 percent of the photo area. The remaining acreage continued to grow and increase vegetation density. The 2004 aerial photo indicates no additional harvesting activities since 1973 and the vegetation cover appears denser and more mature, but this could also be due to the quality of the 2004 image. The DOC contribution from the northwest area could have an increasing trend over these three periods as the vegetation cover is denser today than that of 1937.

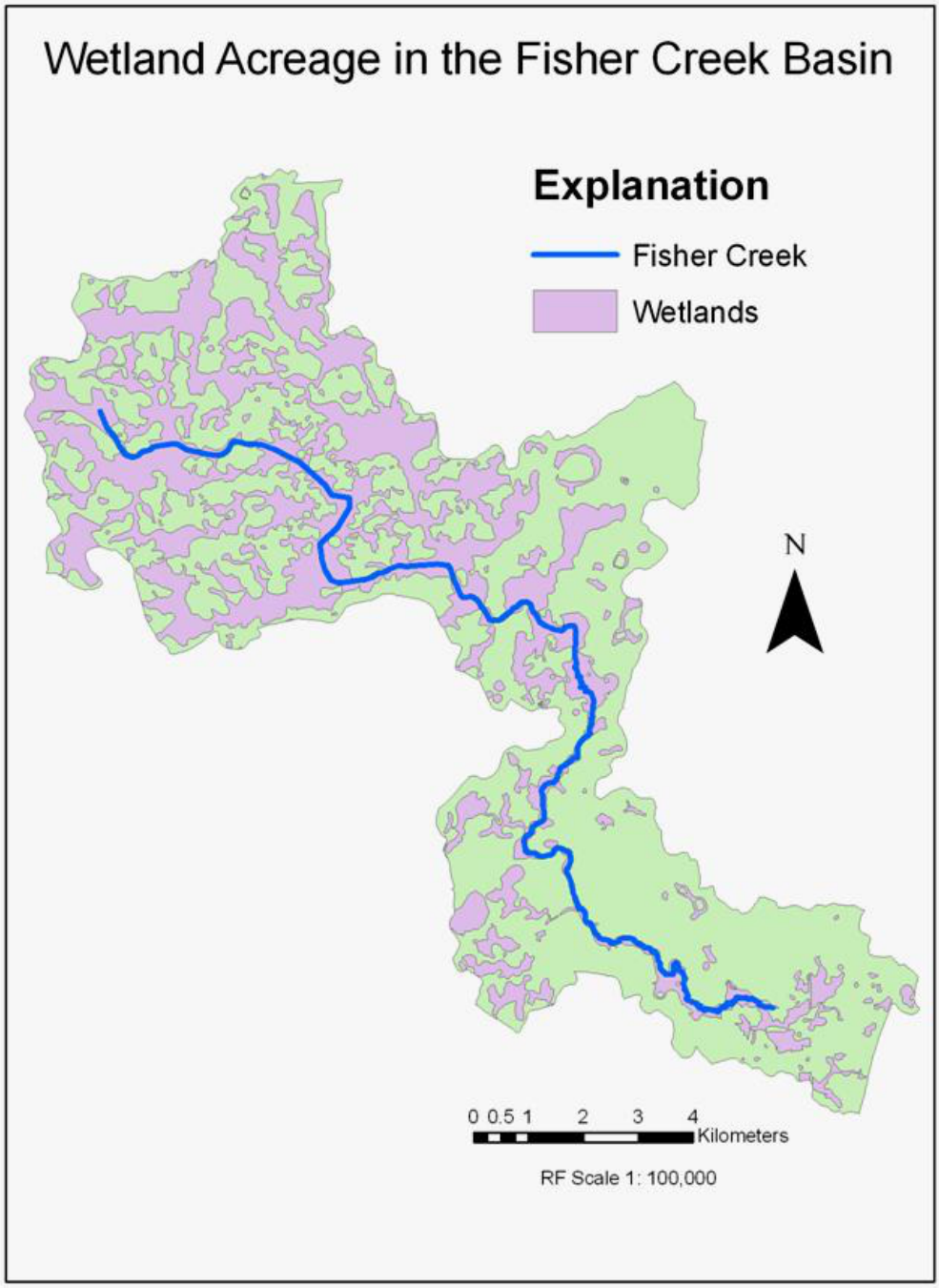

Figure 81 Fisher Creek Drainage Basin Wetland Acreage. Data Source: Northwest Florida Water Management District, Tallahassee-Leon County Water Atlas

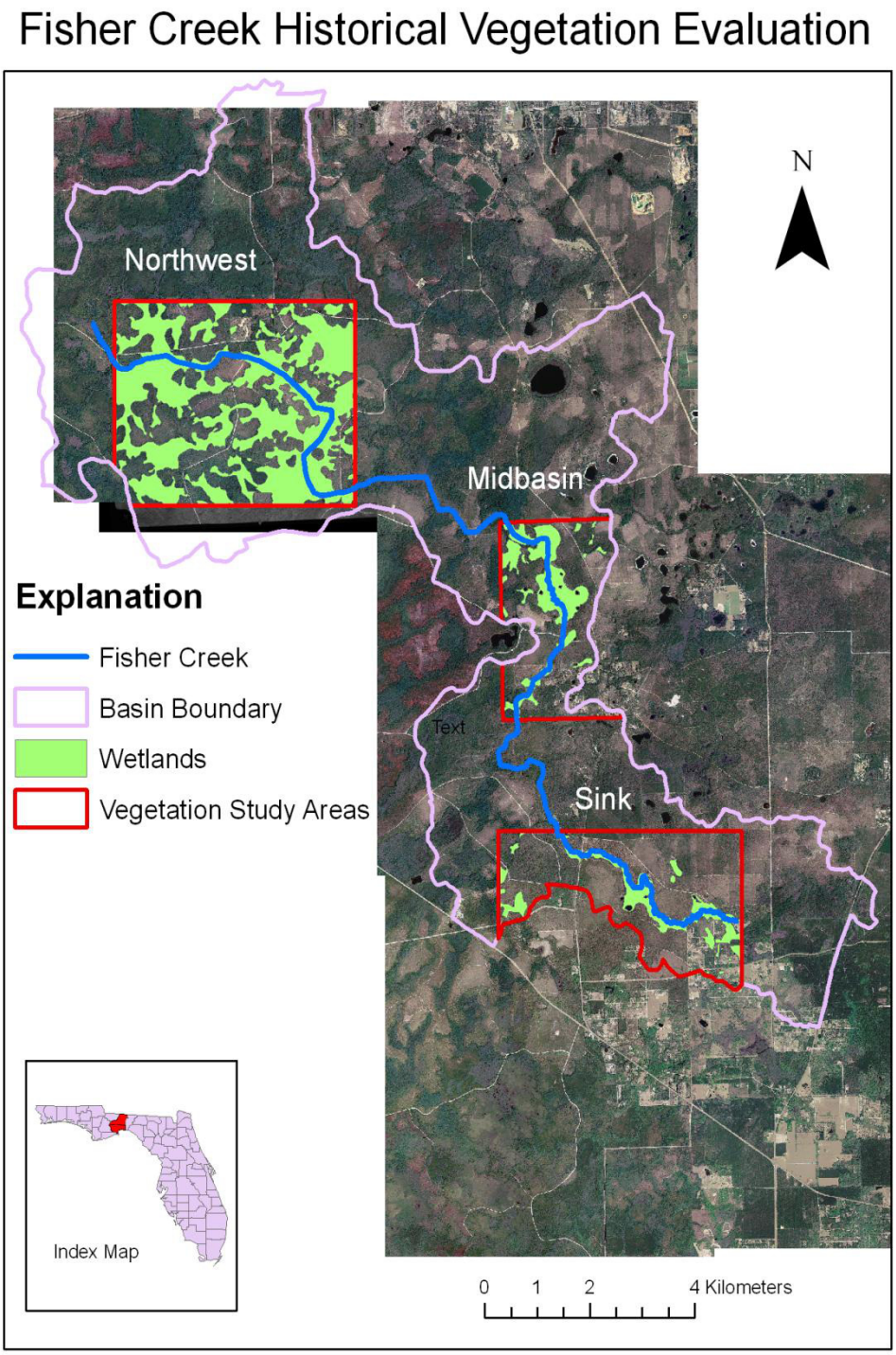

Figure 82 Fisher Creek Historical Vegetation Analysis. Three specific areas were selected to represent different wetland coverage and upland characteristics. The red outline shows the limits of the aerial photography for each study area. Data Source: 2004 Base photo from Florida Department of Transportation

The Figure 84 wetlands of the midbasin photos of Fisher Creek cover 163 hectares of the 620 hectares of the Fisher Creek midbasin, or approximately one fourth of the photo. The physical limits of the hydric conditions within the midbasin area appear to be the same between the three time periods (changes are less than 5 percent). The 1937 vegetation appears to be less dense than the subsequent periods. Harvesting of small discrete areas occurred prior to the 1973 photo, but over all, the vegetation of the 1973 and 2004 photos has a slightly denser appearance than that of 1937. The 2004 photo has fewer sparsely vegetated areas than the 1973 photo with approximately 20 percent greater coverage. The DOC contribution from the midbasin area could have an increasing trend over these three periods as the vegetation cover is denser today than that of 1937.

The Figure 85 sink photos cover 879 hectares of the Fisher Creek basin of which 134 hectares are wetlands, i.e. approximately one sixth of the photo basin area. The physical limits of the hydric conditions within the sink area show no changes between the three time periods (changes are less than 5 percent). The vegetation cover appears relatively constant between the three time periods. Harvesting occurred in the 1970s near the Fisher Creek channel. Residential homestead acreage has increased; from none in 1937 to a few obvious parcels in 1973 to more in 2004 for acreage beyond the Apalachicola National Forest boundaries. Overall, the DOC contribution from the sink area should be the same today or less than that contributed in the past. In the spring of 2008 after a controlled burn of the sink area, this author walked over the burned area and observed deep depressions of leaves that remained. If the controlled burns of today do not burn all the accumulated vegetative material that was burned in the past, this could be a significant source of DOC. Yang et al. (2002) documented the release of DOC from Everglades peats more than 10,000 years old.

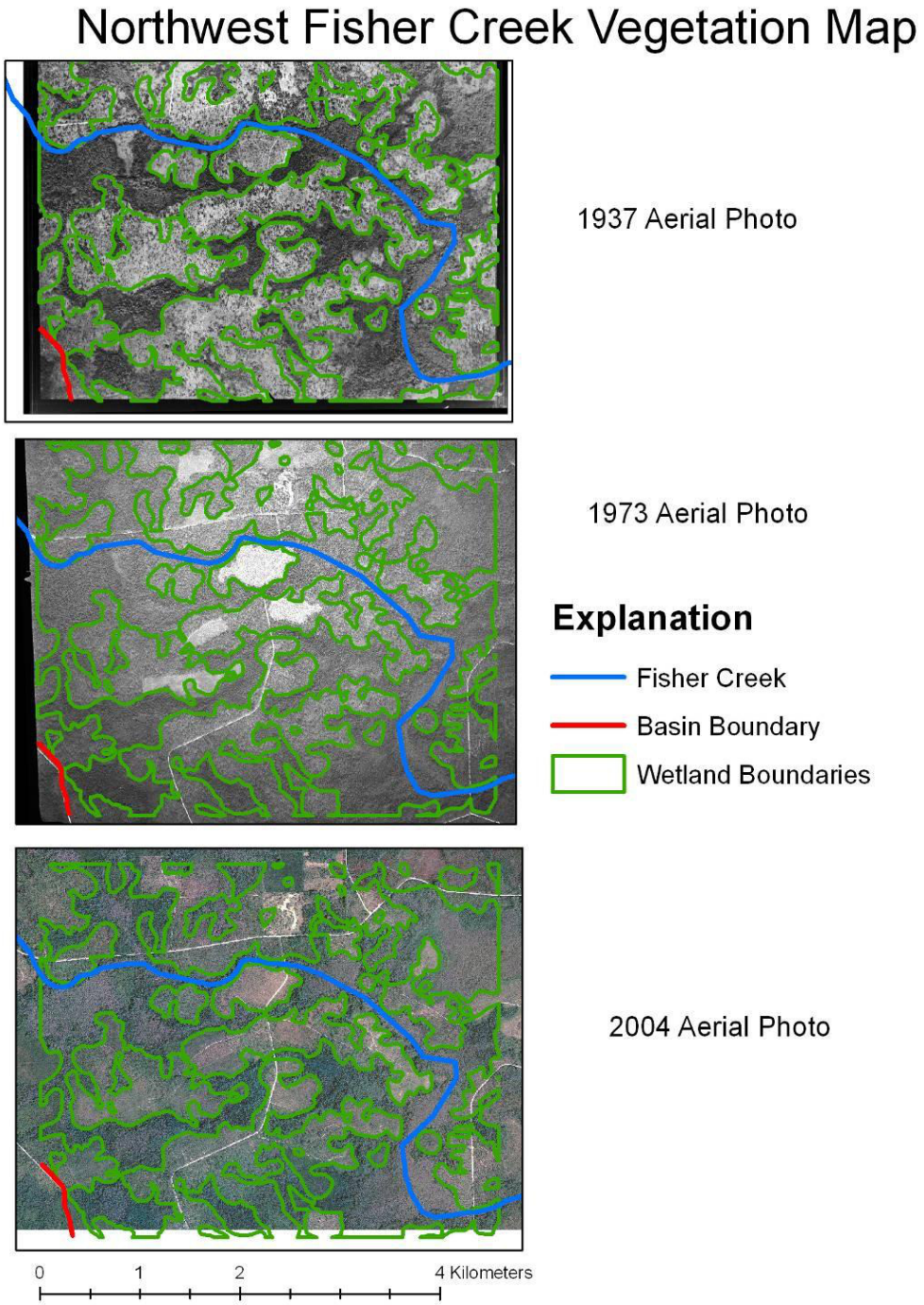

Figure 83 Northwest Fisher Creek Historical Aerials. The boundaries of hydric vegetation appear consistent with no changes. Vegetation density could have an increasing trend from 1937 to 2004.

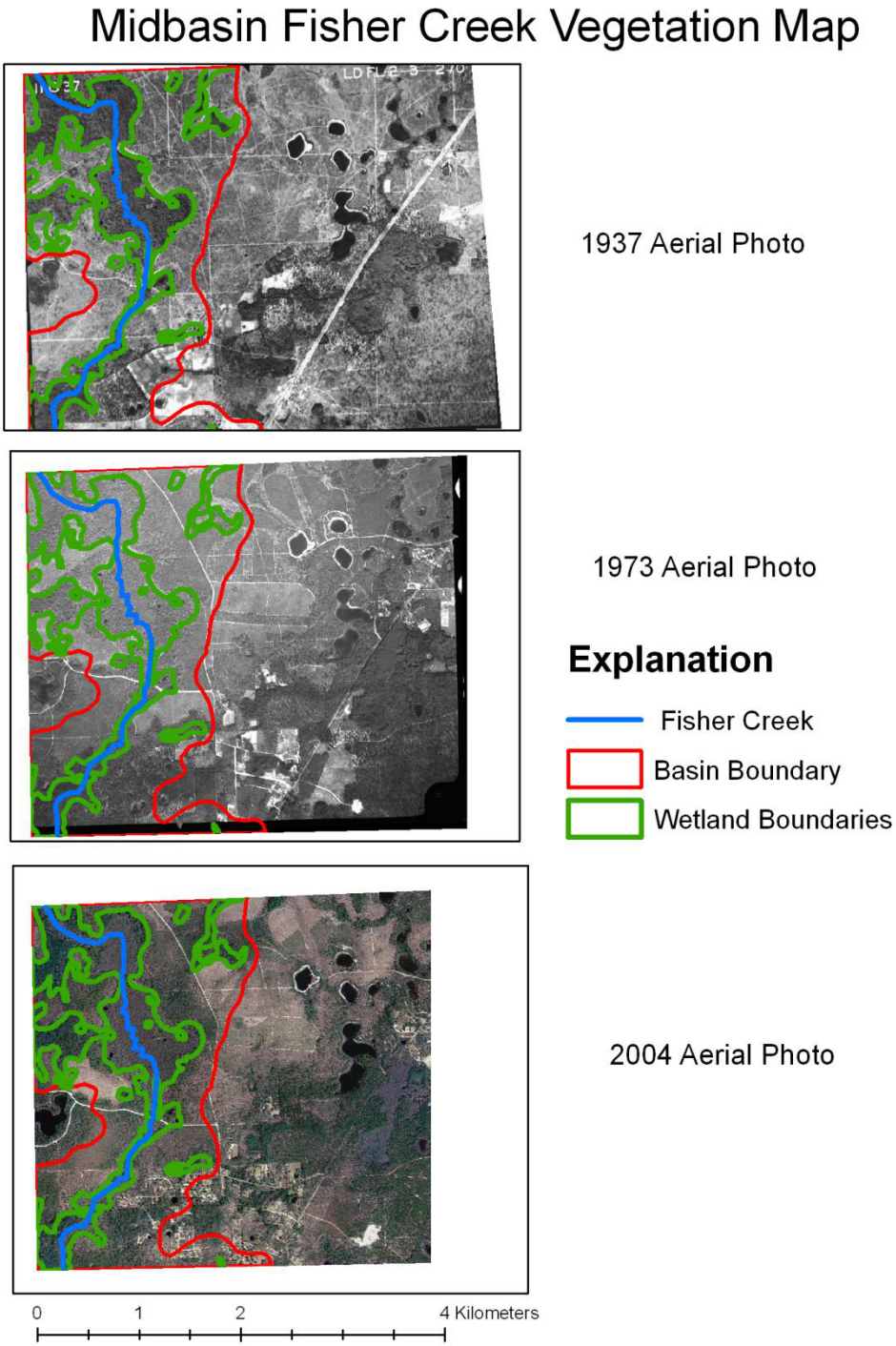

Figure 84 Midbasin Fisher Creek Historical Aerials. The boundaries of hydric vegetation appear consistent with no changes. Vegetation density could have an increasing trend from 1937 to 2004.

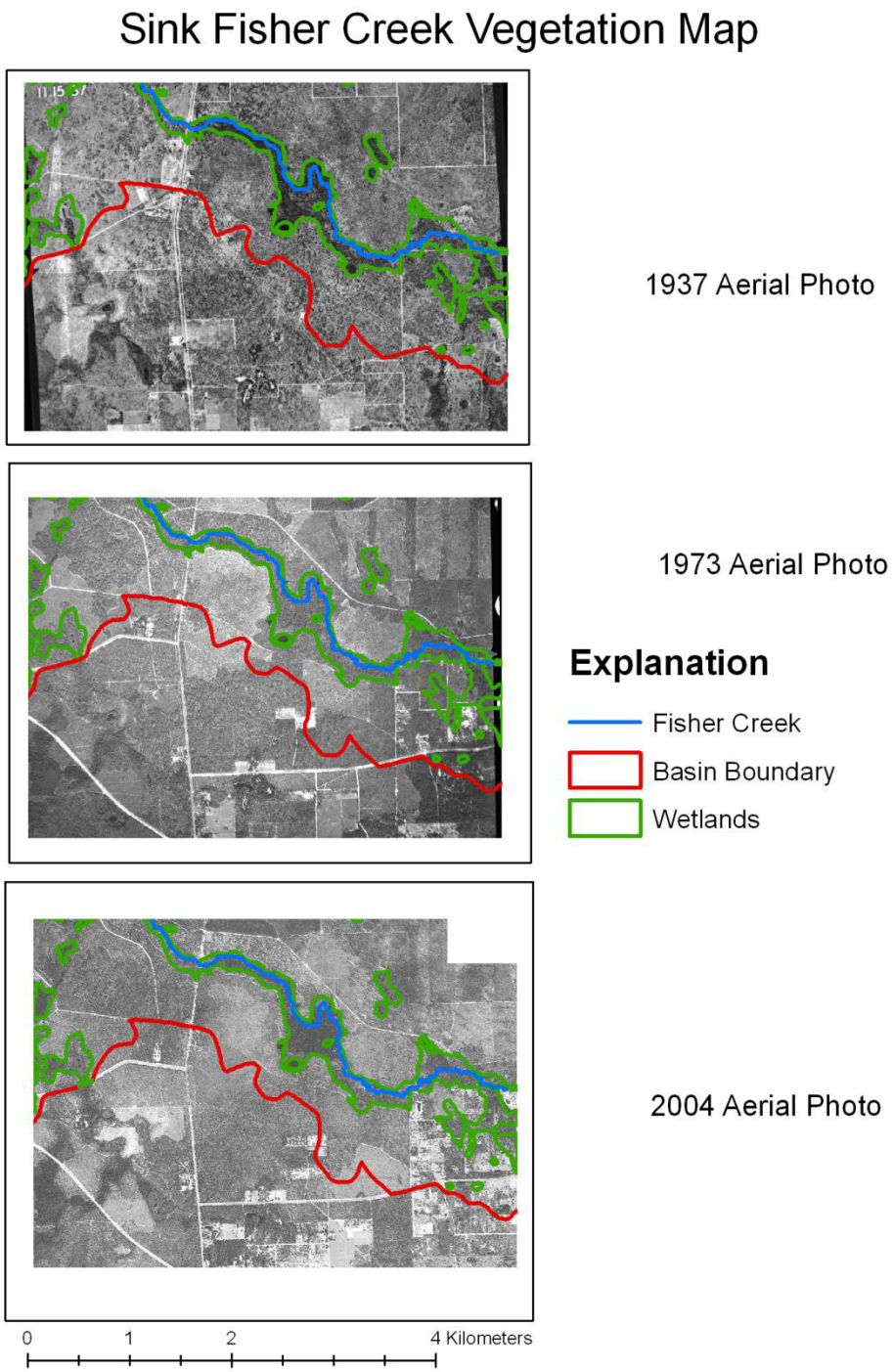

Figure 85 Sink Fisher Creek Historical Aerials. The physical limits of hydric vegetation appear consistent with no changes. Vegetation density with the sink area appears to be the same as in 1937 and 1973.

Precipitation

Historic precipitation data for the entire period of record, 1886-2009, was obtained for the Tallahassee regional area from the Center for Ocean-Atmospheric Prediction Studies (COAPS), Florida State University. A number of locations have been used to collect rainfall data during the period of record up to six miles apart; this could affect annual values. The climate of the study area is humid subtropical with an average annual temperature of 67^0 F (Davis and Katz, 2007). The precipitation average for the entire 123 year period is 58.93 inches, with an average of 61.54 inches for the last 60 years and an average of 60.04 inches for the last 30 years. A 10-year moving average shows relatively constant conditions for the 1910-1940 dry period, the same for the 1964-1981 wet period, and a declining precipitation trend for the last 30 years (1979-2009). A declining precipitation trend over the same 30 year period as the decreased water clarity at Wakulla Springs does not support an increase in black water stream discharge as the cause.

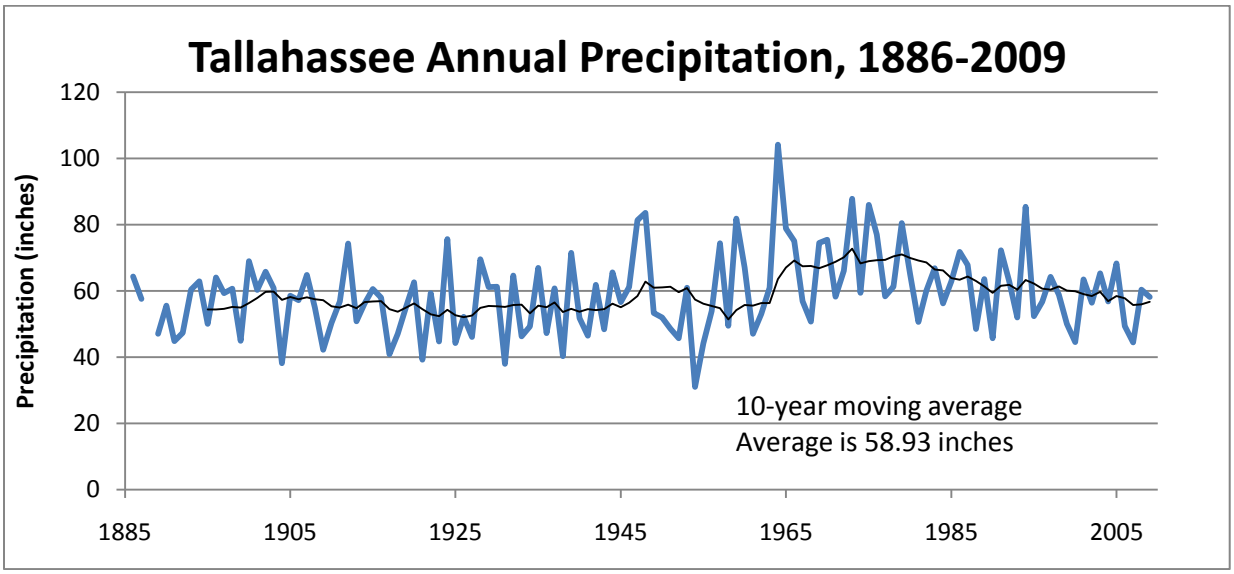

Figure 86 Tallahassee Annual Precipitation, 1886-2009. The line depicting the 10-year moving average shows constant conditions for the 1910-1940 dry period, the same for the 1964-1981 wet period, and a declining trend for the past 30 years (1979-2009). Precipitation Data Source: National Oceanic and Atmospheric Administration.

The potential effect of precipitation trends on groundwater levels can be evaluated using graphs showing the annual cumulative departure from the historical average rainfall. Figure 85 shows the cumulative departure drier (i.e. a net deficit) than average conditions during 1910-1940 (a downward slope) and wetter than average conditions during 1964-1981 (an upward slope). The cumulative departure curve shows wetter than average conditions continuing until 2006 and suggests normal deviations in rainfall 1985-2009.

The cumulative departure was recalculated for the last 60 years (1949-2009) using the sixty-year period average of 61.54 inches and is shown in Figure 86. The most significant changes are a less severe 1950's departure rising from -200 or less to -100 inches and a now apparent decline for the period of 1999-2007. Also important is the 1974-2006 period that has a

cumulative departure of +50 inches above the rainfall average for the last 60 years. The previously viewed decline of the 10-year moving average for the entire record is delayed on the 60-year cumulative graph until 1999, corresponding with the most recent drought. The departure conditions of 1976-1999 were relatively stable oscillating from 47 to 75 inches for this 23 year period.

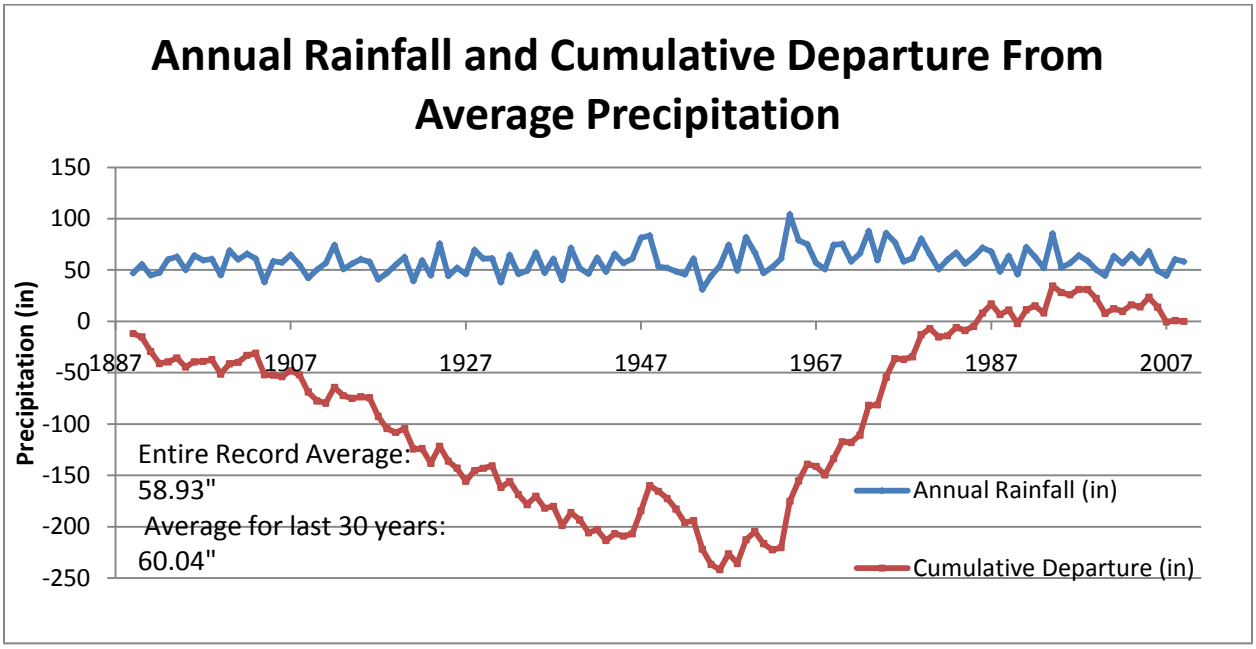

Figure 87 Annual Rainfall and Cumulative Departure. Tallahassee regional area rainfall for 1889-2009 and the cumulative departure from the average for that 120 year period are presented. The 1910-1940 dry period and the 1964-1981 wet period dominate the graph. Precipitation data source: National Oceanic and Atmospheric Administration.

Both the 10-year moving average and the cumulative departure from average rainfall declining periods suggest that rainfall changes may be a potential cause of the observed decline in Wakulla Springs water clarity. The glassbottom boats need clear water to allow the bottom of the spring to be viewed. The glass bottom boat operation record is compared to the precipitation of the past 30 years. The glassbottom boat operation data was provided by Scott Savery (personal communication, 2010), Wakulla Springs State Park (WSSP). A thirty year period for the rainfall data was selected because this length of time includes the period of observations of declining clarity. Figure 89 shows two important details: (1) the glassbottom boat operation is inversely related to the amount of rainfall. The glass-bottom boats are able to operate more often when rainfall is low. (2) Boat operation has declined in more recent years and the plot suggests that there is another control more important than the annual rainfall record. The inverse relationship is generally absent 1995 to 2009.

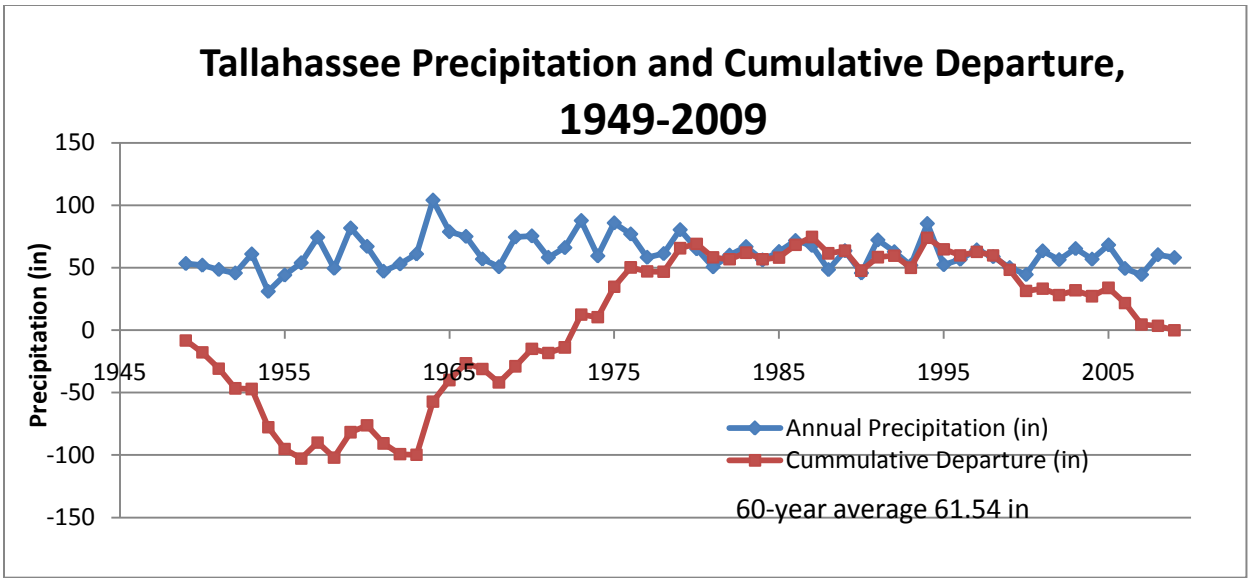

Figure 88 Tallahassee Precipitation and Cumulative Departure, 1949-2009. The maximum departure of 1950-1963, the wet period of 1964-1979, the stable conditions of 1975-1999, and the dry period of 1999-2007 are observed. Precipitation data source: National Oceanic and Atmospheric Administration.

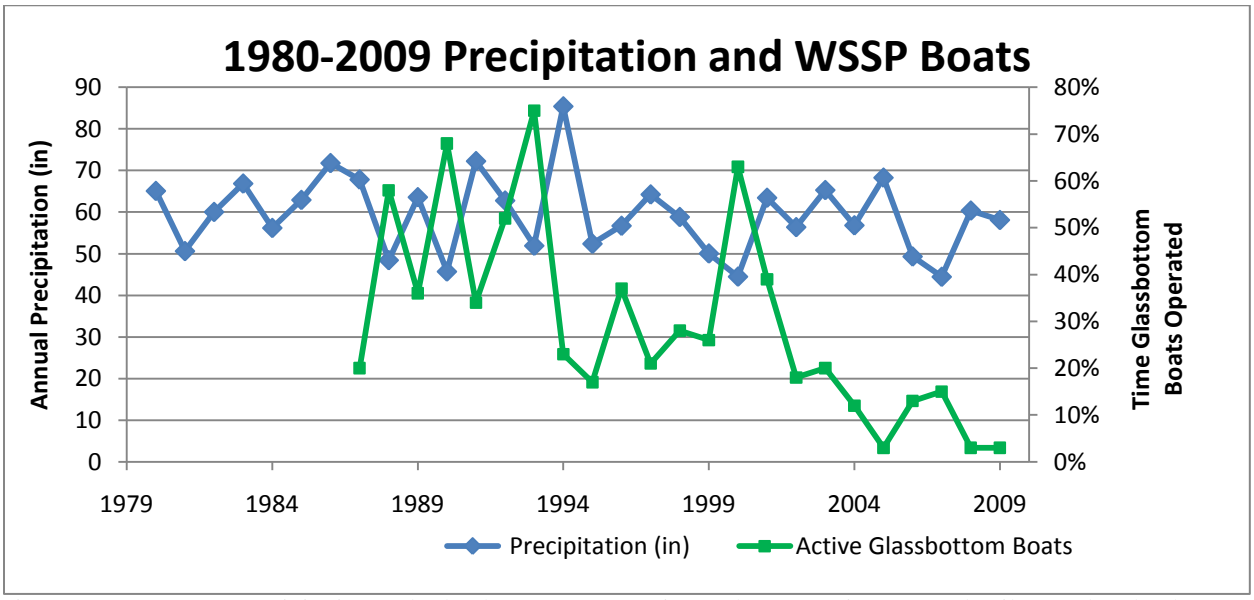

Figure 89 1980-2009 Precipitation and Glassbottom Boats. Figure shows two important details: (1) the glassbottom boat operation is inversely related to the amount of rainfall. The glass-bottom boats are able to operate more often when rainfall is low. (2) Boat operation has declined during the last 10 years and the plot suggests that there is another control more important than the rainfall. Precipitation data source: National Oceanic and Atmospheric Administration and Boat Operation Data from Savery, 2010.

The data were separated into two sets: one of the years showing the inverse relationship of precipitation and boat operation (1987-1994 and 2000) and one of the years where the relationship is absent (1995-2009, excluding 2000). The year 2000 was included in the first set because it was a year of extreme drought over the southeastern United States (National Oceanic Atmospheric Administration, 2000). Florida had its 40th driest November in 2000. The

separated data are shown in Figure 90. The inverse relationship data is linear with an R^2 of 0.7 for the precipitation range of 44.5-85.5 inches with a range of 20-75 percent for boat operation. The later data set shows no pattern for the precipitation range of 44.5-68.3 inches with the range of 3-39 percent for boat operation.

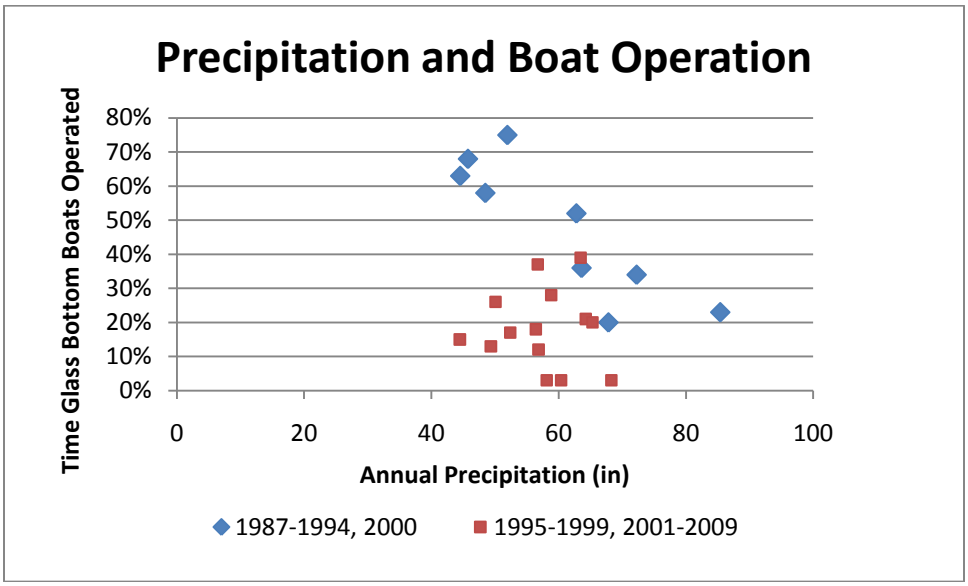

Figure 90 Precipitation and Boat Operation. The inverse relationship between the separated sets of glassbottom boat operation and precipitation data is shown. The precipitation for the inverse years ranges from 44.5-85.5 inches with a range of 20-75 percent for boat operation. The remaining years show no pattern for the precipitation range of 44.5-68.3 inches with the range of 3-39 percent for boat operation.

The last 30 years of the 60-year cumulative rainfall departure curve is plotted with the record of Wakulla Springs glassbottom boat operations in Figure 91. The cumulative departure curve declines in a pattern similar to the glassbottom operation record and suggests that recent dry conditions have been an important influence on poor water clarity, in contrast to the inverse relationship between rainfall and boat operation observed above in Figure 89. However, recall that the 1974-2006 period on Figure 88 had a cumulative departure of +50 inches above the rainfall average for the last 60 years, suggesting the aquifer should have an ample supply of water. These graphs do not explain why historical clarity permitted constant glassbottom boat operation that is not possible today. The poor water clarity events of the past did not last long, and the Wakulla Springs discharge quickly returned to good clarity.

Periodic measurements of discharge have been made at Wakulla Springs from 1907-2009. These measurements represent random frequencies and discharge conditions. Figure 92 indicates that the Wakulla Springs discharge has been slowly increasing. The large number of measurements made in the 1930's during a prolonged drought may introduce bias to fit equations. To demonstrate how field measurements fall on the Wakulla Springs continuous discharge response, the field measurements for the Wakulla Springs 2004-2010 period of continuous stage/discharge monitoring are shown below in Figure 93. The slowly increasing trend of the Wakulla Springs discharge may be the result of the increased rainfall recovery from

the 1964-1987 wet period following the extreme 1910-1940's drought. Recall also that the 60-year cumulative rainfall departure shows a surplus over average rainfall 1985-2006.

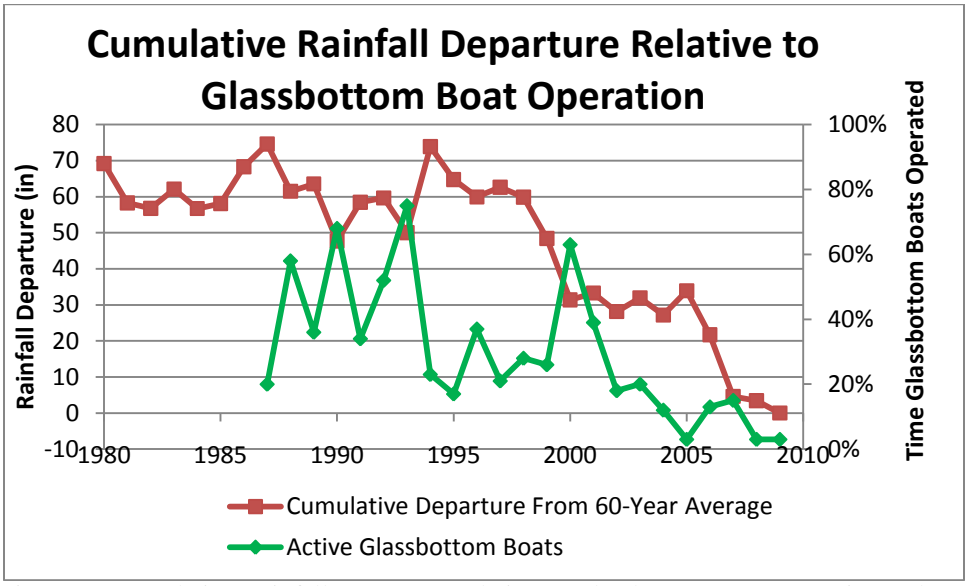

Figure 91 Cumulative Rainfall Departure Relative to Glassbottom Boat Operation. The past 30 years of the 60-year cumulative rainfall departure curve are shown with the Wakulla Springs record of glassbottom boats operation. Both data sets show declining trends. Note that 2005, 2008, and 2009 boat operation only occurred for 3 percent (11 days) of each year. Precipitation data source: National Oceanic and Atmospheric Administration and Boat Operation Data from Savery, 2010.

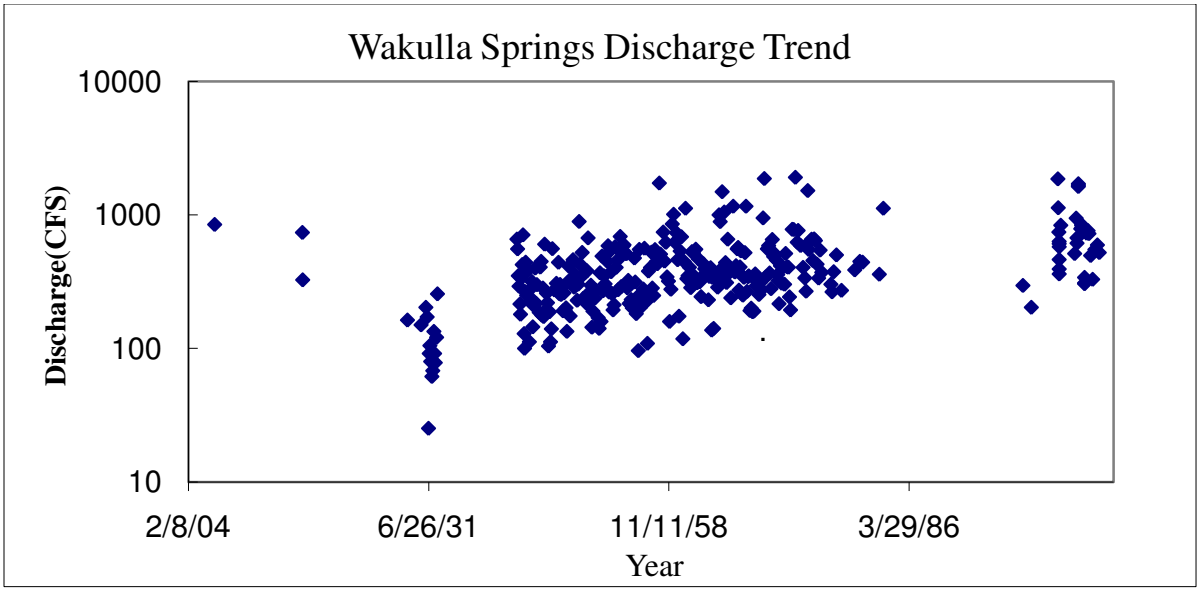

Figure 92 Wakulla Springs Discharge Trend. USGS Wakulla Springs discharge measurements made 1907-2009 shows an increasing trend. The R^2 is 0.178, possibly due to the numerous measurements made in the 1930s during a severe drought. This increasing trend is most likely due to the increasing precipitation that occurred 1964-1987 (See Figures 87 and 88).

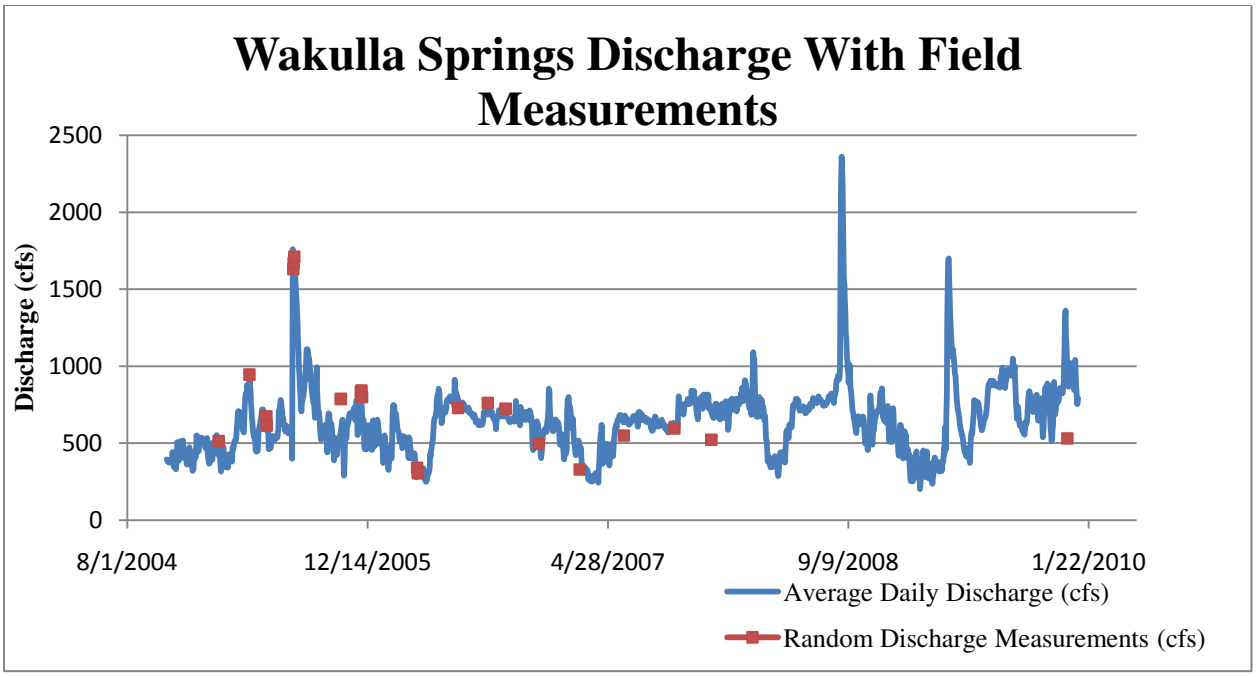

Figure 93 Wakulla Springs Discharge With Field Measurements. USGS continuous stage/discharge data for Wakulla Springs 2004-2009, including four dates of two to three measurements collected 1-3 hours apart. An upward trend in the discharge is observed in spite of the drier than normal conditions of 2006-2007. The maximum peak corresponds to the discharge associated with T.S. Fay, setting a new maximum of 2500 cubic feet per second (cfs) (Richard Verdi, 2008).

During the 100-year period of discharge measurements, Tallahassee and the surrounding area has experienced extensive development and a significant increase in the amount of impervious land surface coverage. An increase in impervious surfaces reduces rainfall infiltration and groundwater recharge, resulting in significant increases in runoff volumes and downstream peak discharges (U.S. Soil Conservation Service, 1986, U.S. EPA, 1993, Konrad 2005). Much of the runoff likely drains to the numerous karst features of the Wakulla Springs springshed clustered to the northwest and north of Wakulla Springs. Northwest Florida Water Management District (2009) documented numerous sinks north and south (majority are south) of the Cody Scarp, many with a direct connection to the Floridan Aquifer.

As the complete precipitation record shows a decreasing trend for the past 30 years, the upgradient development of the Wakulla Springs springshed could be a likely explanation for the increasing trend for the Wakulla Springs discharge. Reduced percolation upgradient above the Cody Scarp reduces the rainfall contribution to the slower flowing aquifer baseflow and gives the increased runoff from impervious surfaces a potentially faster travel time to Wakulla Springs. Conditions in the Woodville Karst Plain (WKP) allow rapid percolation due to the direct hydraulic communication between the surface sands and the highly transmissive underlying limestone, so even with extensive development on the WKP, development would have minimal effect on groundwater elevation. Davis and Katz (2007) reported a southward trend of decreasing apparent groundwater age consistent with increasing recharge to the Florida Aquifer as groundwater moves southward. Extensive development northward of the Cody Scarp could

change where the recharge occurs, resulting in greater runoff to downstream lakes/wetlands or low gradient surfaces where increased flooding would be observed.

Another possibility being explored by USGS research is that the Wakulla Springs discharge increase is due to Wakulla Springs capturing flow that previously went to Spring Creek. The freshwater flows could be from Lost Creek or part of the Leon Sinks conduit system discharge. During these periods, Spring Creek takes in salt water instead of discharging freshwater (Hal Davis, Personal Communication, 2010). Wakulla Springs has an increasing trend for total dissolved solids and specific conductivity indicating a greater contribution of deep Floridan Aquifer water (Rick Copeland, personal communication, 2009; FDEP data). In summary, the apparent discharge increase at Wakulla Springs needs additional research scrutiny to understand what is happening and how the system controls change under various conditions.

Subsurface Collapse

Subsurface collapse in the conduit system or a like mechanism to alter groundwater flow path(s) is another possible change that could increase the mass of DOC migrating to Wakulla Springs. Such a collapse could connect a swamp directly with the Floridan or result in faster transit to Wakulla Springs. Subsurface collapse would also be able to direct creek water away from Wakulla Springs. On November 21, 1991 at Indian Springs, subsurface conduit sand collapsed blocking the small restriction used by divers to enter and exit the cave resulting in scuba diver Parker Turner's death. The land surface support crew for the dive team witnessed a 1' drop in the sink water surface and a reversal of the normal spring run. After 30 minutes, the sink water surface had returned to its original level (Gavin, 1991, Nof and Paldor, 2010). As shown in Figure 47, the Wakulla Springs hydrograph recession responses of 1973 and 2009 rain events show no obvious change from this or other unknown events during the 36-year period. Water will always follow the easiest path and the steepest gradient. If water pressures become too great, new paths form. A good analogy would be of storm water pipes and the pipe breaks that occur during extreme precipitation events. The acid pH of the creek water will be constantly reacting with the limestone of the aquifer and developing new flow paths. Willett (2006) used dissolved carbonate concentrations in spring discharge to conclude that 4.8×10^5 m^3/ year of limestone is lost annually from the North and Central Florida karst areas. Karst processes are most active above and at the water table, but some dissolution occurs deeper and depends on the residence time and recharge water properties.

Upgradient Groundwater- Georgia Groundwater

Long-term groundwater elevation changes are typically evaluated using long-term groundwater monitoring wells. For the area surrounding Wakulla Springs, long-term monitor wells are not available and no detailed potentiometric maps have been prepared other than those of Chelette et al. (2002) for January 1999, August 1999, and March 2000. The closest long-term USGS well is the Crawfordville, Florida well located on the immediate east side of the Sopchoppy River, continuously monitored since 1974. This well is located to the west of Wakulla Springs and beyond its springshed. Accordingly, changes to the Floridan Aquifer potentiometric surface were evaluated using long-term groundwater records from Georgia and published potentiometric maps for Florida.

Groundwater withdrawals up gradient of Wakulla Springs could reduce the potentiometric surface of the Floridan Aquifer and thus reduce the gradient and volume of the

clear water component of the Wakulla Spring discharge. Gradient changes could also change the direction of flow or routing of water for both the creek water and the clear water. Creek water that formerly bypassed Wakulla Springs may be captured. The Floridan Aquifer is the source of the clear water component and the Wakulla Springs baseflow. Figure 94 shows the USGS Cairo, Georgia long-term trend of the Floridan Aquifer potentiometric surface at a location due up gradient of Tallahassee for August 21, 1964 to September 2, 2009. The potentiometric lows show an increasing trend from 1970 to 2000. This increasing trend compares well to the cumulative departure wet period of 1964-1987. It also indicates that potentiometric levels entering Leon County have not been declining from increased upgradient withdrawals. The potentiometric levels of the 1990's in Cairo, GA were relatively stable, fluctuating from 130-140 feet below land surface. (The USGS report the groundwater data as depth-to-water rather than the usual groundwater elevation relative to a specified surface.) Since 2000, the potentiometric surface has fluctuated approximately 5 feet lower than that of the 1990's consistent with the declining precipitation discussed earlier in this Chapter. Using the USGS land surface elevation of 204.54 feet NGVD 1929 for the Cairo, GA monitor well, a recent groundwater elevation range of 58-69 feet is calculated for the flow coming into Leon County (for 2000-2009). Cairo, GA is approximately 11 miles north of the GA/FL State line and due north and upgradient of Tallahassee. The United States Geological Survey 1980 Pre-development Floridan Aquifer Potentiometric Map shows a range of 62-64 feet for the Georgia-Florida State line (USGS, 1990) that is within the range recorded during the last 10 years for the Cairo, GA location.

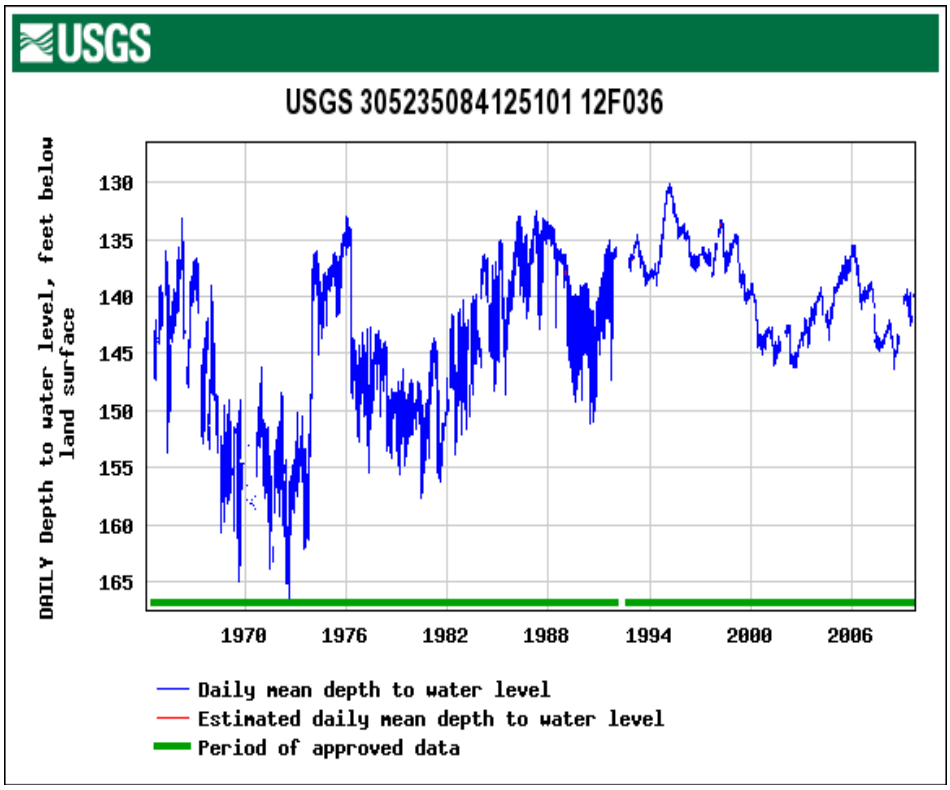

Figure 94 - Cairo, GA USGS Floridan Aquifer Potentiometric Surface. This figure shows the groundwater fluctuation August 21, 1964 to September 2, 2009 and that the surface has been stable 1999-2009. Cairo, GA is immediately up gradient of Tallahassee and Wakulla Springs and located approximately 11 miles north of the GA/FL State line.

Florida Groundwater

Historic potentiometric maps prepared by the United States Geological Survey (Pre-development, USGS, 1990; Johnson and Bush, 1988), Northwest Florida Water Management District (1986, 1991, 1995, 1998, 2000, and 2008, NWFWMD) and Florida Geological Survey (FGS) were obtained and reviewed. Maps that represented baseflow conditions were selected, eliminating the potential influence of tropical storms and hurricanes. The USGS, May 1980 potentiometric map has been annotated as Figure 95 to show fixed locations surrounding Leon County that are shown on all of the selected historic potentiometric maps. Figures 96 and 97 were prepared by reading the likely potentiometric elevation for each fixed location and for each map period assuming the map author(s) were accurate in their interpretation. These values were used to estimate changes in the potentiometric surface for Leon and Wakulla counties for trend analysis. The seven locations are displayed north to south by their representative number on Figure 96 with each line segment depicting the potentiometric elevation of each location for that particular year. Figure 97 displays the potentiometric elevation for all years at each fixed location. The locations are shown in Figure 95 and listed below in Table 7 with their assigned number used in Figure 96.

Table 7 Fixed Locations in Universal Mercator, North American Datum 1983

		Easting	Northing
1	Northeast Leon County at GA/FL line	786730	3397234
2	Northwest Leon County at GA/FL line	760460	3397996
3	West Leon County line at US Hwy 90	748890	3374292
4	East Leon County line at last angle	780971	3370544
5	Southwest Leon/Wakulla line	719888	3354271
6	Center top angle of Leon/Wakulla line	764664	3355590
7	Southeast Leon/Wakulla line	781292	3352737

The pre-development potentiometric elevations were obtained from the USGS Groundwater Atlas of the United States (Downloaded from usgs.gov/ha/ha730, 1990). (Note: the Groundwater Atlas pre-development potentiometric map was modified from Johnson and Bush, 1988 who used a 20' contour interval except for a 10' contour line added along the Florida coastline. This 10' contour line was mislabeled 20' on the Groundwater Atlas pre-development potentiometric map. As Johnson and Bush, 1988 included springs, such as Wakulla Springs, in their analysis, their 10' contour interval appears valid. Accordingly, the pre-development potentiometric elevations for the Center (6) and Southeast (7) fixed locations reflect the Johnson and Bush 1980 contour elevation for pre-development conditions.) The remaining potentiometric maps represent May through July (late spring to early summer) to compare aquifer baseflow conditions. Of all the potentiometric maps examined, the 1986 and 1991 maps used the largest number of wells and therefore have the greatest control for the potentiometric contours. May/June 2000 and May 2008 potentiometric elevations were the lowest for the first four fixed locations and lower than the pre-development, 1986 and 1991 periods. Figure 97 presents the same data but relative to each fixed location for all potentiometric map years. Four locations show a decreasing trend of 4-16 feet with the northwest Leon County location at the

Florida/Georgia line showing the most decline (16 feet). Two locations, southwest (SW) and

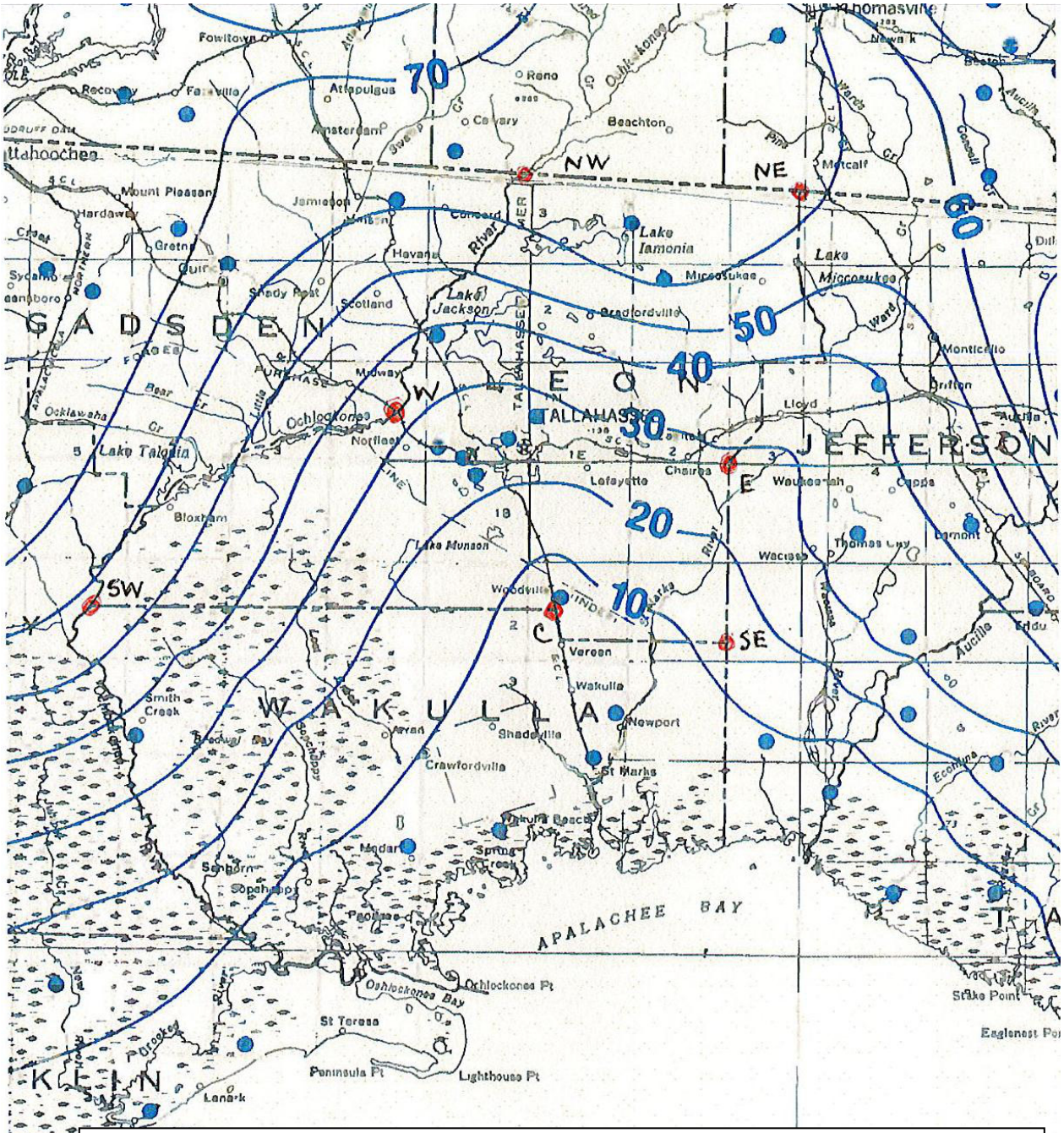

Figure 95 Excerpt of the May 1980 Floridan Aquifer Potentiometric Map by Johnston, Healy, and Hayes, 1981 modified to show the fixed locations (red circles) selected to evaluate potentiometric surface elevation changes/trend. The blue circles designate well locations Johnston et al, 1981 used to contour the Floridan Aquifer potentiometric surface.

center (C) Leon/Wakulla County line show zero decline in the potentiometric surface. The southwest location (SW) is surrounded by the immense acreage of the Apalachicola National Forest with minimal water withdrawal. The center (C) location is less than a mile up gradient of Wakulla Springs and shows the most stable potentiometric elevation of all of the fixed locations. The southeast (SE) location had an increase of 4 feet between the pre-development and 2008 potentiometric elevations. The aquifer recharge from T.S. Fay and H. Paloma in August and November 2008 may have altered the decreasing trend for northern Leon County. The observed declines between pre-development (1980) and 2008 potentiometric elevations on both figures may reflect the combined effect of water use and a declining precipitation trend.

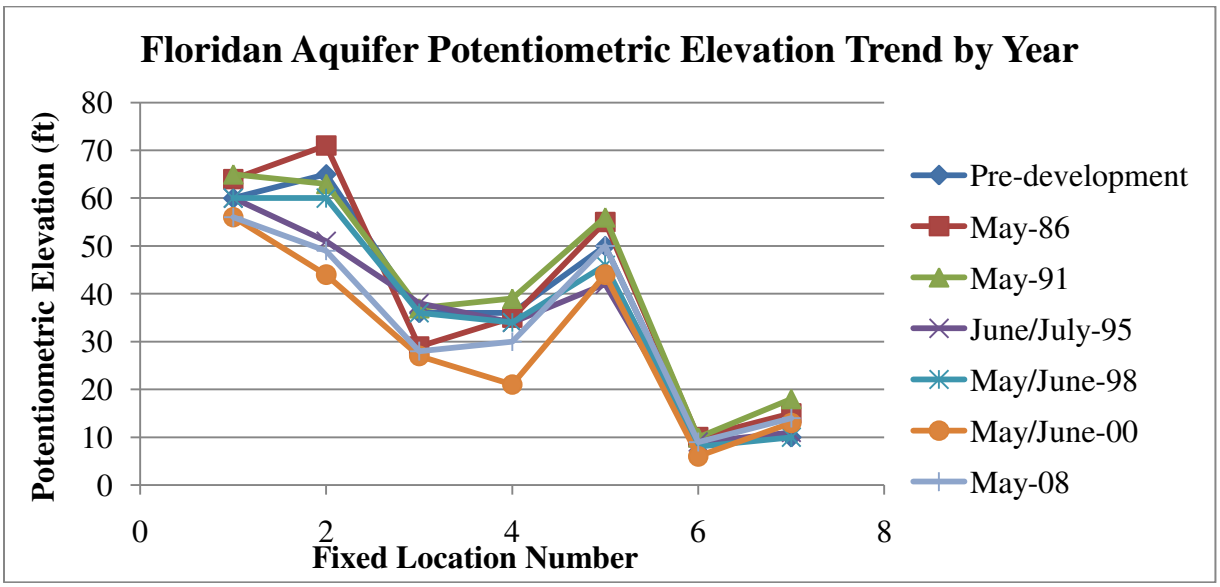

Figure 96 Floridan Aquifer Potentiometric Elevation Trend by Year. The potentiometric elevation was determined for seven fixed locations displayed north to south from each published Floridan Aquifer Potentiometric map for trend evaluation. Comparison of 1980 to 2008 potentiometric elevations: four locations show a decline of 4-16 feet with the NW Leon County location at the Florida/Georgia line (2) showing the most decline (16 feet), SW and Center locations show no change, and the SE location shows an increase of 4 feet. The aquifer recharge from T.S. Fay and H. Paloma in August and November 2008 may have altered this trend.

Figure 98 shows the City of Tallahassee (COT) Consumptive Use Permit annual withdrawals for 1996-2009. For 1996 and 1997, the City withdrew approximately 9000 million gallons per year (MGY). The volume increased in 1998 to 11000 MGY and has stayed in the range of 10000-12000 MGY through 2009. Significant declines in glassbottom boat operation at Wakulla Springs were observed before the start of the presented COT withdrawal record.

Commercial/Industrial, private potable, and irrigation well withdrawals can be significant and can also affect the Floridan Aquifer potentiometric surface. Table 8 shows the 2009 Consumptive Use Withdrawals for all Leon and Wakulla County permits. The FSU and FAMU campuses receive their drinking water and irrigation water from the COT, and also withdraw water on campus for cooling/heating purposes. Both universities return this cooling/heating water to the Floridan Aquifer on their respective campuses, minimizing any impact on the potentiometric surface from these withdrawals. The volume shown in Table 8 for FAMU (4337

million gallons per year) is their cooling/heating water volume. The volume withdrawn and returned by the FSU campus is 11,323 million gallons per year (Personal communication, Alan Peck, 2010). Figure 99 shows the private well trend numbers in Leon and Wakulla Counties. The source of the data for both counties is the Northwest Florida Water Management District.

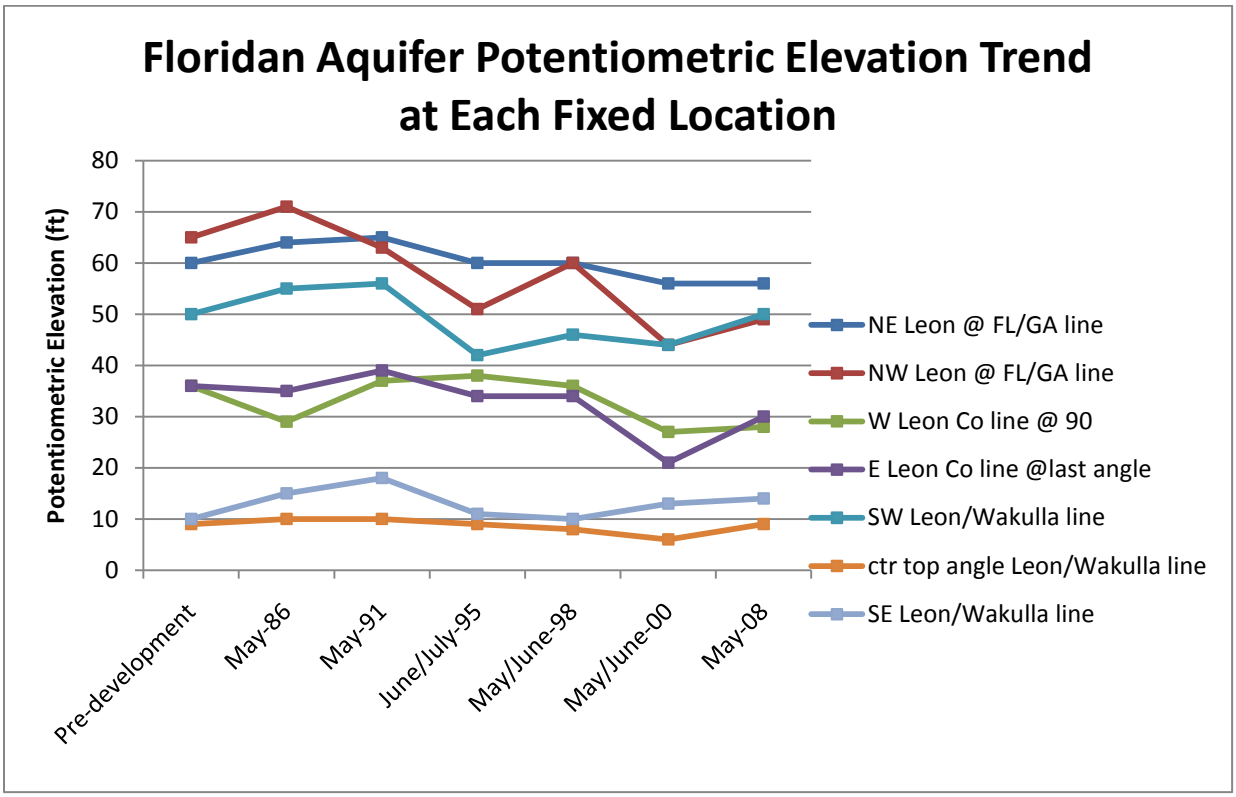

Figure 97 Floridan Aquifer Potentiometric Elevation Trend at Each Fixed Location. The potentiometric elevation trend of seven published Floridan Aquifer Potentiometric maps is shown for each fixed location. Four locations show a decreasing decline of 4-16 feet with the NW Leon County location at the Florida/Georgia line showing the most decline (16 feet), two locations show no change (SW and C) and one location (SE) increased by 4 feet between pre-development and 2008 potentiometric elevations.

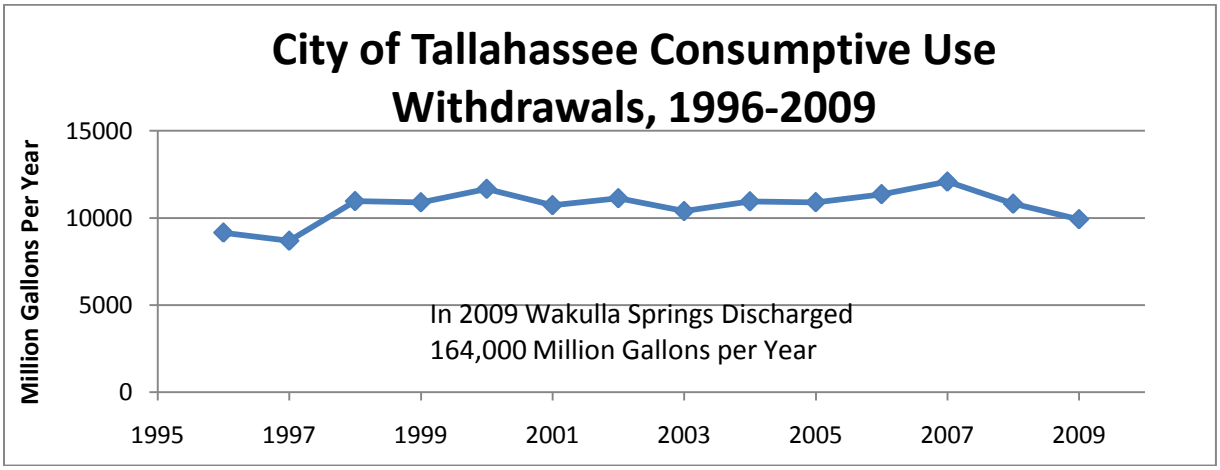

Figure 98 City of Tallahassee Consumptive Use Withdrawals, 1996-2009. These annual withdrawals are public water supply. Data source: NWFWMD.

Table 8 2009 Consumptive Use Permit Withdrawals with Northwest Florida Water Management District

Leon County	MGY	Wakulla County	MGY
COT	9924	TEC-Wakulla	330
FAMU	4337	City of Sopchoppy	288
TEC-Bradfordville	521	St Marks-Powder	262
TEC-Lake Jackson	248	WincoUtilities	114
Horseshoe Plantation	152	Purdom Generating	120
TEC-Meadows	136	Panacea Water System	88
Ayavalla Land Co	104	Wakulla-Riversink	10
Orchard Pond	99		
TEC-LCR West	93		
TEC-Leon	89		
FSU-Seminole GC	53		
Golf Enterprises -Killearn	46		
FSU-Magnetic Lab	41		
Golden Eagle-Golf &CC	35		
TEC Leon South	34		
Alfred Maclay	5		
Rowe-MeadowHills	0.01		
Rowe-PlantEstates	0.01		
Rowe-Brewster	0.009		
Rowe-Sedgefield	0.008		
Rowe-N.LakeMeadows	0.007		
Rowe-BuckLake	0.006		
Elliot Property	0		
TEC-Kiper	0		

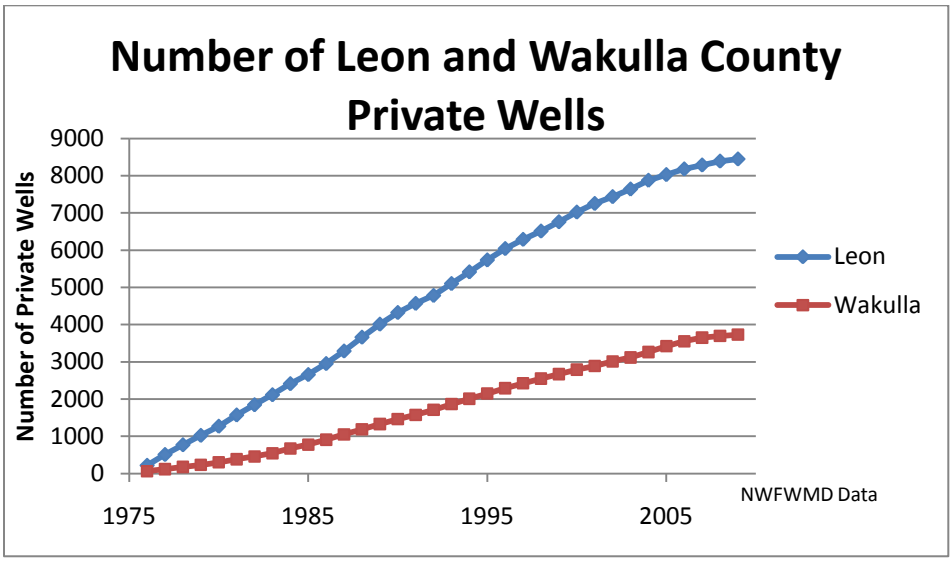

Figure 99 Number of Leon and Wakulla County Private Wells.

Both the COT withdrawals, Table 8 (2009 Consumptive Use Withdrawals) and Figure 99 (number of private wells) document high use of the aquifer. Using 2000 Census population data and the 2006 estimate for the City of Tallahassee, the 2000 and 2006 per capita water use was 77,425 and 71,498 gallons per year, respectively. Using 2 persons per household (the Census

range was 2.17-2.57 persons), a total of 12,000 private wells for the two counties and 71,000 gallons per year, an estimate of 1700 million gallons per year total is obtained. The total withdrawn from the Floridan Aquifer in 2009 is 14,500 million gallons per year in the two-county area. (This figure excludes the FSU/FAMU water volumes withdrawn and re-injected.) In contrast, Wakulla Springs discharged 164,000 million gallons per year for all of 2009. Withdrawals are 9% (18% if the FSU/FAMU volumes are included) of the volume discharged at Wakulla Springs for 2009.

CHAPTER 5

CONCLUSIONS

The five studied streams; Fisher Creek, Black Creek, Jump Creek, Lost Creek and Munson Slough, all contribute chromophoric dissolved organic carbon (CDOM) to the discharge at Wakulla Springs. Any one stream is capable of affecting Wakulla Springs water clarity during baseflow conditions. All streams contributed to the Wakulla Springs water clarity decline from the March-April 2009 storm. Through the process of elimination, Lost Creek was the only possible stream source for the March 7-13, 2009 Wakulla Springs water clarity decline from the February 14, 2009 precipitation. Conservative mixing (i.e. dilution) is the primary explanation between the two source waters (creek water and Floridan Aquifer water) for the total creek mass that reaches Wakulla Springs. Optimum water clarity at Wakulla Springs depends on the volume of clear water in the Floridan Aquifer exceeding the creek composite CDOM mass. This research has found the optimum water clarity concentration of DOC to be 0.69 mg/l.

Four possible causes of darker/reduced water clarity water observed at Wakulla Springs 1985-2009 are:

(1) Vegetation density – Fisher Creek vegetation density in the northern two evaluated areas has increased from 1937 conditions, primarily from open long-leaf pine to planted pine by 1973. Harvesting practices changed from widespread clear-cut, including portions of the swamp in 1937 to small contiguous areas by 1973. In 2004, larger areas of the Sink section have been cleared for homestead acreage. Prescribed burns were observed two years apart for the Sink section of Fisher Creek, but burning was discouraged in the 1940-1970's. It is possible that the changes may have increased the DOC stream concentrations.

(2) Increased precipitation – Recent precipitation has been declining 1999-2009, but the variation is within the historic range of conditions. A decline in precipitation indicates that the streams are contributing lower discharges than in the past. The cumulative rainfall departure declines similar to the glass-bottom boat operation record. It is possible that the combination of declining precipitation with higher groundwater use is adversely impacting Wakulla Springs

(3) Subsurface collapse –The documented 1991 conduit collapse at Indian Springs does not appear to have altered the recession behavior of Wakulla Springs between 1973 and 2009. The Wakulla Springs discharge has a slowly increasing trend that may be the result of (a) the cumulative rainfall departure recovery from the extreme 1910-1940 drought rather than a subsurface flow path change, (b) extensive development above the Cody Scarp altering where the stormwater runoff recharges, perhaps at a lower elevation, and (c) potentiometric changes that alter flow gradients and directions and allow Wakulla Springs to capture more water.

(4) Upgradient groundwater withdrawals – Georgia groundwater elevations flowing south into Florida are estimated to vary between 58-69 feet (NGVD 1929) for 2000-2009 in Cairo, Georgia, located approximately 11 miles north of the Georgia-Florida State line. The USGS 1980 pre-development groundwater elevation for the Georgia-Florida State line north of Tallahassee ranged from 62-64 feet. Georgia groundwater elevations entering Florida appear to be unchanged from pre-development conditions. Florida groundwater elevation trend analysis suggests that some declines have occurred in the northern Leon County area. Groundwater withdrawals in Leon and Wakulla counties totaled 19,000 MGY for 2009 or 9 percent of the total Wakulla Springs discharge (164,000 MGY) for the same period. The observed declines between pre-development (1980) and 2008 potentiometric elevations may reflect the combined effect of groundwater use and a recent declining precipitation trend.

APPENDICES

A. BLACK CREEK AND JUMP CREEK RATING CURVES

Rating curves were developed for Black Creek and Jump Creek to relate water stage to flow rate. To make discharge measurements, a tag line was extended across the creek where the creek flowed in a relatively straight section of consistent flow with a minimum number of roots. The tag line was marked every foot. At each foot marking, the depth of the water was determined and recorded. For water depths less than 2.5 feet, the wading rod was adjusted to record the flow velocity at the depth equal to 0.6 of the total depth. When the depth of water exceeds 2.5 feet, the USGS recommends that the velocity of each stream section be measured at two depths, 0.2 and 0.8 times the total water depth and the average value be used for each depth-area calculation. Most measurement events were made in water depths less than 2.5 feet. Velocity measurements were made using a Marsh McBirney flow meter (sonde with three electronic sensors on nose giving a direct velocity reading) or a propeller meter (counts revolutions and requires calculations to get velocity). Discharge is equal to the sum of each tag line section width (w – one foot in most cases) times water depth (b) times the velocity (v) expressed by the following equation:

$$Q=\Sigma(w*b*v) \qquad (9)$$

For the more abundant stage data, linear interpolation worked reasonably well to fill the gaps. The stage-discharge pairs and selected critical stage observations were evaluated by all Excel regressions, noting the specific equation variables and the R-squared value. The best equations were entered into an Excel column to calculate the discharge from the observed stage. The computed discharge was compared to the measured discharge to determine the best equation for low, medium and high discharges. The best fit polynomial equation was applied to the linear interpolated stage data set to compute a complete discharge data set. Stream rating curves are often approximated using a power or polynomial function (Hornberger et al., 1998).

Black Creek

Rating curves were developed for two locations on Black Creek; at SR 267 and at Hilliardville Road. The later location was included to determine the volumes of flow going to Black Hole and Mashes Branch. See Table A9 for the specific discharge data. Figure A98 shows the stage and discharge data for Black Creek at SR 267 with best-fit polynomial equation. This polynomial equation was used to calculate discharge from Black Creek stage data for dissolved organic carbon (DOC) mass calculations. Figure A99 is a photo of the Black Creek at SR 267 root weir discharge measurement station.

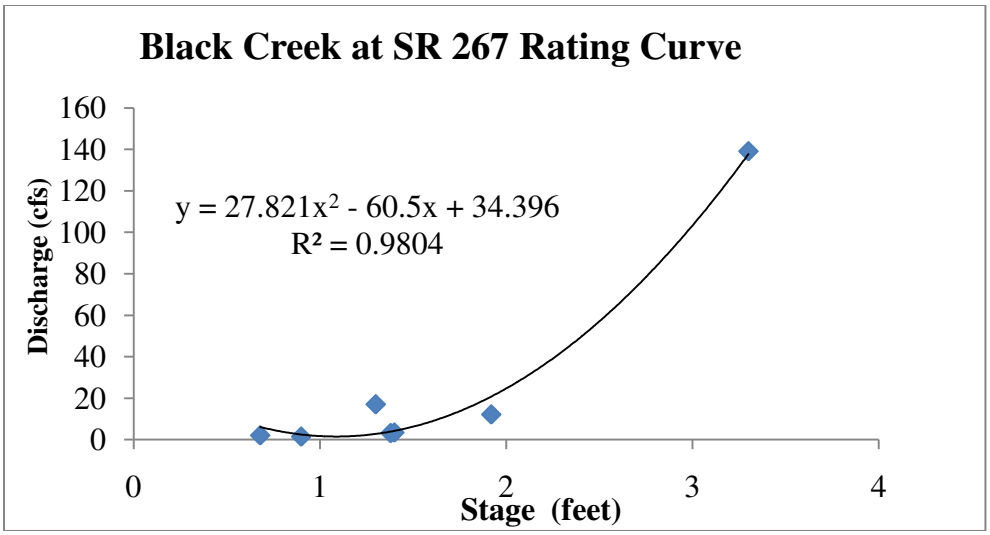

Figure A98 Black Creek at SR 267 Rating Curve. This stage/discharge relationship with best-fit polynomial equation was used for mass calculations.. The adjacent forest floor was flooded during the 139 cfs measurement.

Figure A99 Black Creek Natural Root Weir. 8/1/2009 photo of location used for BC @267 discharge measurements.

The natural root weir was the best location for measurements considering the deep pools (no measureable velocity) and extensive root problems (causes inaccurate readings including back flow conditions), but every storm event changed the physical conditions by adding more wood debris/leaves structure or transporting the previous blockage away. A small part of the flow takes a bypass channel located on the west side (downstream of the cypress knee visible above) approximately 20 feet upstream of the root weir at staff gage elevations greater than 1.4'. The final note is that most flow occurs in the main channel at a stage of 2.32', but at a stage of 3.38' flow extended over the forest floor to a maximum eighteen inch water depth (there are shallow depressions in the forest floor). The maximum 139 cfs measurement was made at the SR 267 culvert and included all flow (including that flooding the forest floor). Black Creek bifurcates down stream of the root weir with some flow going to Black Hole and the rest into Mashes Branch. At a staff gage reading of 0.9 for the pool upstream of the root weir, flow was entering the mouth of the channel to Black Hole, but the base elevation of this flow depends on the height of the root weir mass and the volume of flow passing thru the root weir. Mashes Branch is the deeper channel of the two and receives flow for a longer period of time, as a swamp system that eventually drains to Roaring Sink. Stage and discharge measurements were also made on Black Creek at Hilliardville Road to quantify the separating flow.

Figure A100 Black Creek at Hilliardville Road. This stage/discharge measurement station with the tag line is on the west side of the road upstream of where flow enters Black Hole (swallet). Water depth and velocity measurements were made every foot starting at the right side land spit.

The Black Creek at Hilliardville Road station is good for rating curve measurements. The stream bottom is stable and regular, trees are few in the section, there are very few roots, the velocity is fast and consistent, and the stream section is straight. On a couple of visits, the flow here was greater than that entering the mouth of the segment to Black Hole (see 5/9/2009 and 10/4/2009 observations). There is a pond located on the west side of Hilliardville Road that may be the source of this additional discharge. Accordingly, these measurements should be cautiously used without further work. The Black Creek at Hilliardville Road rating curve is shown Figure A101.

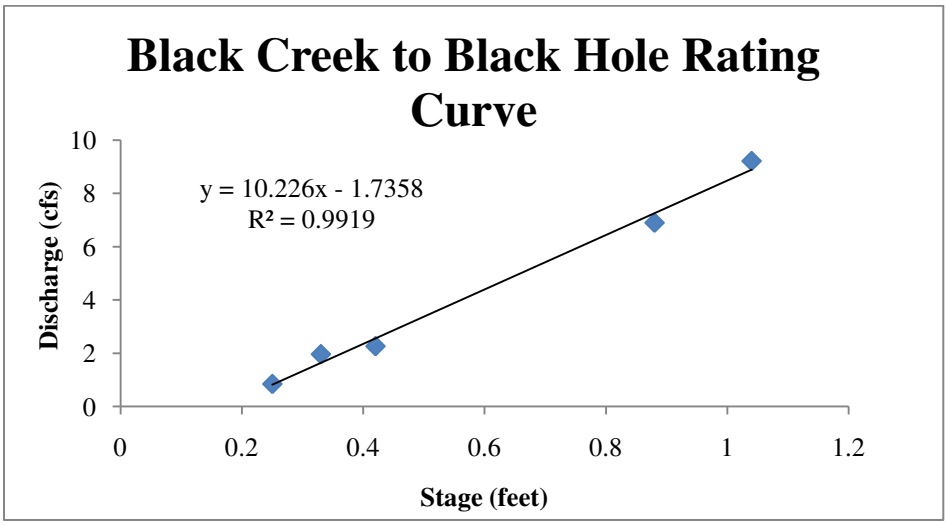

Figure A101 Black Creek to Black Hole Rating Curve. A water depth of 108 inches (9 ft) has been measured with all flow restricted to the channel, passing through the culvert (included back flow conditions).

A surveyed benchmark with an elevation of 38.53' was glued to the northeastern edge of the SR 267 bridge culvert crossing Black Creek. Figure A102 presents the channel profile surveyed on the north side of the road of what appeared to be a permanent pool as it did not dry out during the drought of 2007-2008.

The same location was re-measured during the collection of high-flow velocity for discharge calculations. The cross section profile and velocity are shown in Figure A103. Eighteen-inch thick concrete support walls were present at 10, 21, and 30 feet. At 10 feet, the measurement reflects a 6 inch water column width; all other measurements were for a one foot thick water column width (skipping the 18 inch concrete intervals at 21 and 30 feet). The highest velocity occurs in the center-most culvert. This same culvert extruded a large rectangular shaped leaf mat a couple inches thick on August 16, 2008.

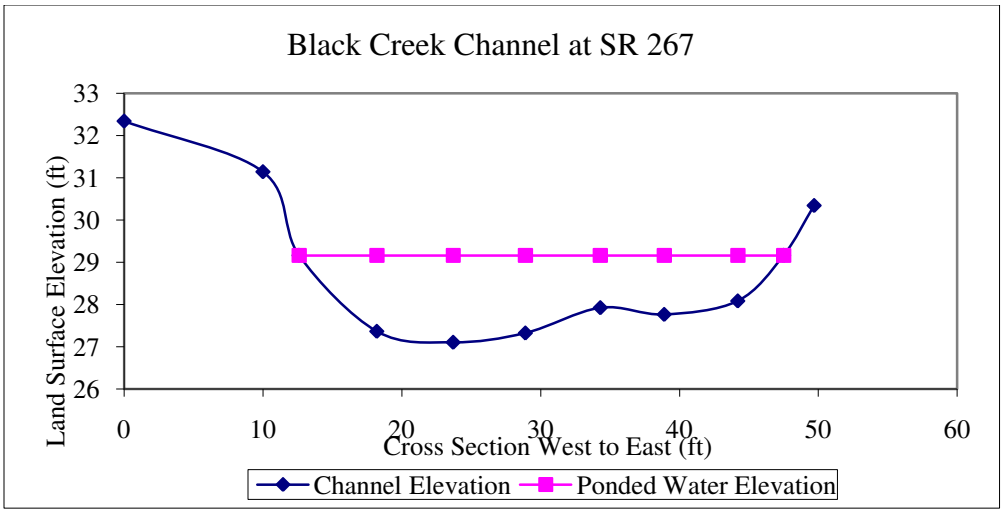

Figure A102 Black Creek Channel at SR 267. Stream profile on the north side of State Road 267 during no-flow conditions; this pool did not dry out during 2008.

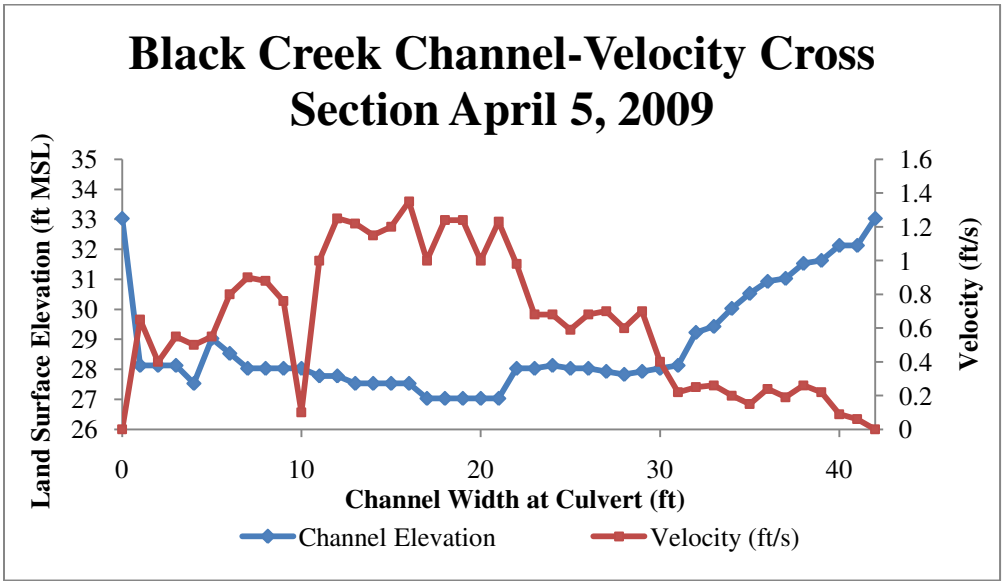

Figure A103 Black Creek Channel-Velocity Cross Section, April 5, 2009. High flow conditions channel profile for Black Creek at State Road 267. For this event, flow extended into and flooded the forest floor depositing a new layer of clean very fine to fine white sand up to 4 inches thick that thinned with distance from the channel.

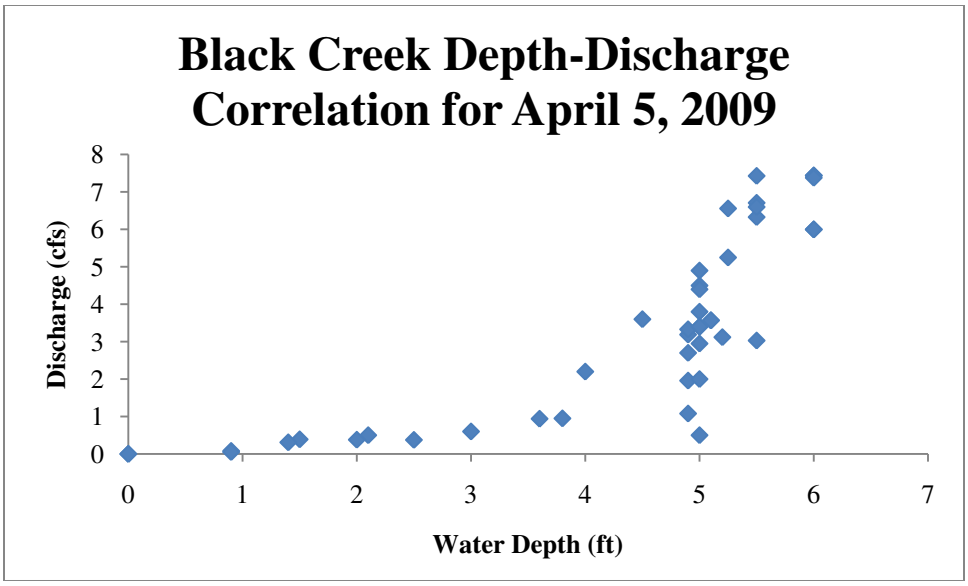

Figure A104 Black Creek Depth-Discharge Correlation, April 5, 2009. A direct relationship is expected between velocity or discharge with water depth. These results and the lower R^2 =0.63 are likely due to the frictional influence of the three internal concrete culvert supports.

The linear correlation of the velocity versus discharge for the April 5, 2009 event is shown below with an excellent R^2 =0.98.

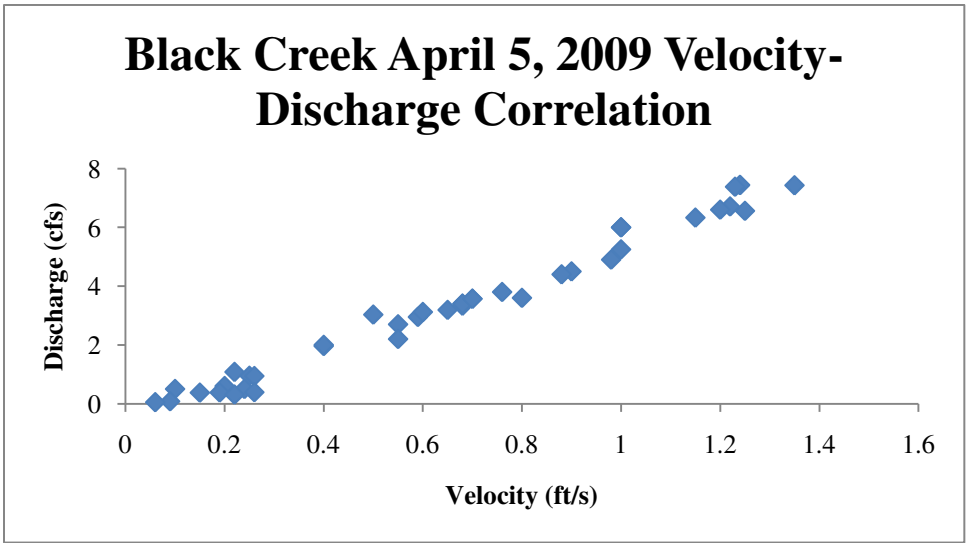

Figure A105 Black Creek April 5, 2009 Velocity-Discharge Correlation.

Table A9 summarizes the Black Creek and Jump Creek stage and discharge data used for rating curves.

Table A9 Black Creek and Jump Creek Stage Discharge Data

Date	Stage (ft)	Q (cfs)	Notes
Black Creek SR267			
1/19/2009	1.38	3.11	MJP
3/7/2009	1.4	3.38	MJP
3/14/2009	0.9	1.41	Marsh McBirney flow meter
3/29/2009	1.92	12.1	Marsh McBirney
4/5/2009	3.3	139	measurement made at SR 267
7/17/2009	0.68	2	Marsh McBirney
8/2/2009	1.3	17	Marsh McBirney
Black Creek to BH			
2/25/2009	0.42	2.26	MJP
3/7/2009	0.33	1.96	MJP
3/14/2009	0.25	0.84	Marsh McBirney
3/29/2009	1.04	9.22	Marsh McBirney
8/2/2009	0.88	6.9	Marsh McBirney
Jump Creek WLR			assumed 2' elevation for base of center culvert pipe
5/13/2008	1.99	0	
8/31/2008	3.35	7.1	Marsh McBirney
2/21/2009	2.83	1.62	MJP
3/29/2009	3	4.77	S crossing also flowing, Marsh McBirney
4/4/2009	4.1	75.87	only measurement that includes S crossing
4/11/2009	3.1	5.3	S crossing flow too low to measure
7/17/2009	2.7	0.34	Marsh McBirney
8/1/2009	2.65	0.64	Marsh McBirney
8/15/2009	2.6	0.43	Marsh McBirney
9/19/2009	3.4	16	Marsh McBirney
Jump Creek Swallet			swamp floor flow measurements
2/17/2009		2.76	MJP
2/24/2009		2.4	MJP
3/7/2009		0.37	MJP, minimum as filament algae hindered propeller rotation
3/14/2009		0.24	Marsh McBirney
3/29/2009		5.27	Marsh McBirney
4/18/2009		2.99	Marsh McBirney
9/19/2009		19	Marsh McBirney

Jump Creek

The Jump Creek stage and discharge measurements were made at the Whidden Lake Road crossings. There are two crossings: a south culvert and a north crossing that consists of three pipes; two 48” pipes and one 36” pipe. The north crossing was active longer than the south crossing. Only one measurement event includes measurements for the south crossing; generally flow was too low (deep pool prevented measureable velocities) to be measured even though visible. For the north crossing, an online pipe flow calculator was used to compute the flow rates using the depth-of-water in each of the pipes, pipe diameter and the applicable measured velocity. Figure A106 presents the stage and discharge data for Jump Creek at Whidden Lake Road with the best-fit polynomial equation. This best fit polynomial equation was applied to the linear interpolated stage data set to compute a complete discharge data set.

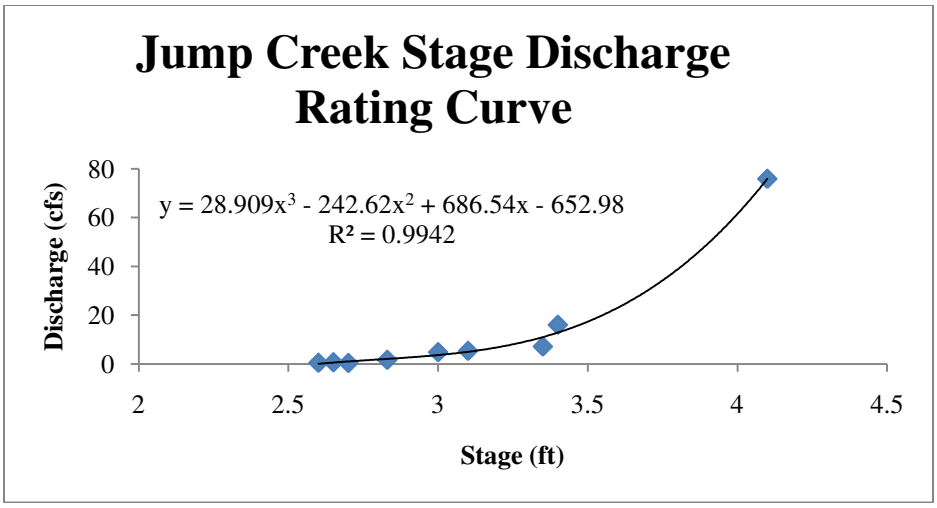

Figure106 Jump Creek Stage/Discharge Rating Curve. The Jump Creek at Whidden Lake Road on the east side of the road was the location of these measurements. The maximum stage/discharge pair is the only data that includes measurements for both the south and north crossings.

A few Jump Creek measurement events were made in the swamp immediately up stream of the swallet but downstream of two deep pools separated by a land bridge that is part of the stream bottom. The deep pool on the west side of the land bridge exhibited spring boil on September 19, 2009 (Figure A107). The flow volume leaving the spring boil pool was greater (19cfs) than the minor flow crossing the land bridge (0.35cfs) into the same pool. This one event indicates there is a significant subsurface connection (interflow) though the land bridge that allows Jump Creek flow to drain to the swallet without flowing over the land bridge. Discharge at Whidden Lake Road was 16 cfs, indicating a 3cfs increase on the downgradient side of the deep pool. Other dates with a dry land bridge had discharges of 0.25-5.29 cfs for this interflow component.

Fisher Creek

Discharge measurements were made of Fisher Creek on the east side of the Springhill Road Bridge on March 30, 2008 from 11:57A to 12:30P. The water depth was measured every foot using a tag line stretched across the creek. Water depth any where along the creek transect was less than a foot so these measurements represent low stage conditions. The measurements yielded a discharge of 8.45 cubic feet per second (cfs). As a check, the co-located United States Geological Survey (USGS) stage/discharge station reported a daily discharge of 4.7 cfs for this date. The difference between these values may be related to conditions when the USGS collects discharge data. If their measurements are made exclusively during periods of higher flow, the resulting stage/discharge curve, and thus their discharge estimate may be inaccurate at lower stages.

The measured Fisher Creek cross section from bank-to-bank is shown below and shows that Fisher Creek was deepest on the south side of the creek for the transect. (Past tense is used because storm events transport significant quantities of sand. The T.S Fay event deposited a soft sand delta at the transect location and altered the flow dynamics from a continuous hard bed to one where shallow water of one foot depth meets 2.5 feet deep water at the original stream bed.)

Measurements were made every foot on a transect located between the bridge supports and the USGS staff gage. After measuring the water depth at each location, the wading rod was adjusted to record the flow velocity at the depth equal to 0.6 of the total depth. The graph below shows the relationship of velocity (pink curve) to stream depth (navy curve). Velocity increases as the water depth increases. This is due to a decrease in frictional effects with increasing water depth and distance to the sides and bottom of the channel.

Figure A107 Jump Creek September 19, 2009 Spring Boil west of the land bridge exhibiting spring boils in a deep pool with discharge flowing west to the swallet.

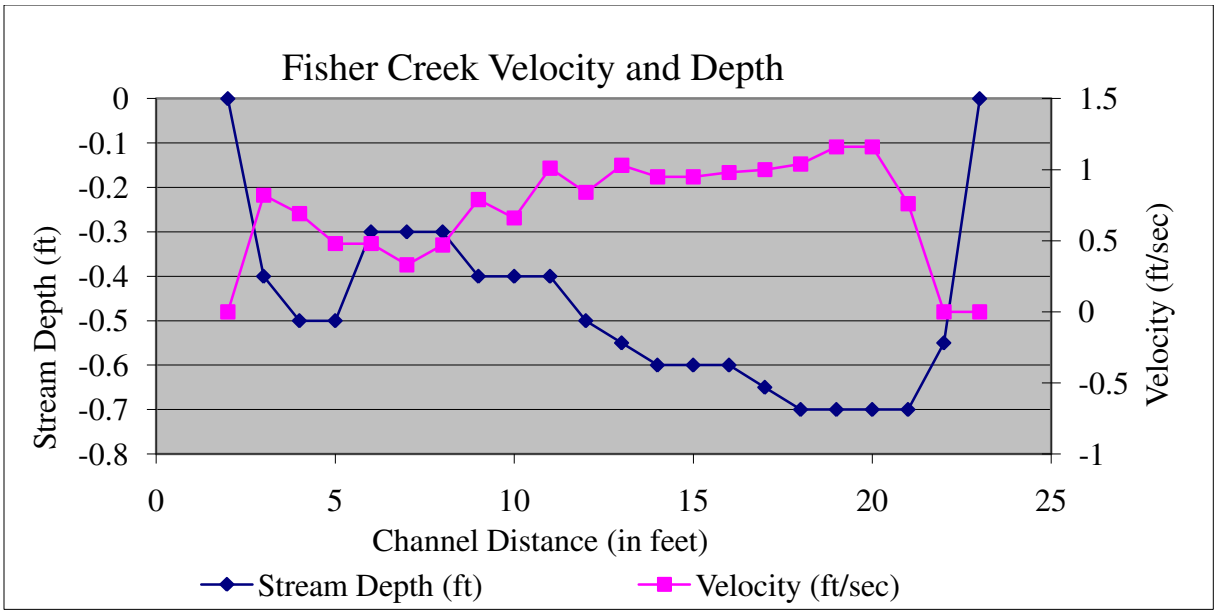

Figure A108 Fisher Creek Velocity and Depth. Velocity increases with water depth.

Figure A109 demonstrates the direct relationship between velocity and water depth.

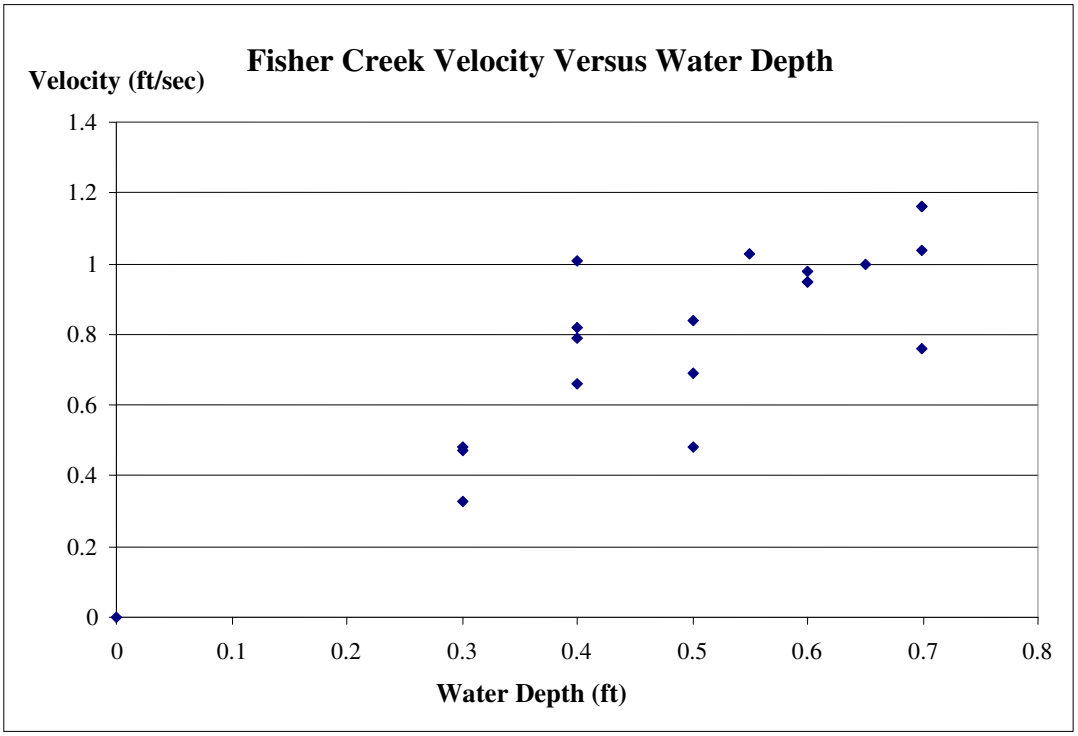

Figure A109 Fisher Creek Velocity Versus Depth linear relationship.

APPENDICES

B. MONITORING STANDARD

The April 11, 2009 Fisher Creek sample was used as a reference stock solution, and diluted to 10%, 5%, 1%, 2.5%, and 0.5%. The undiluted sample (100%) and the dilutions were evaluated for absorption behavior relative to UV-VIS wavelengths. The results are presented below with the linear equations and R^2 relative to NAC (per meter).

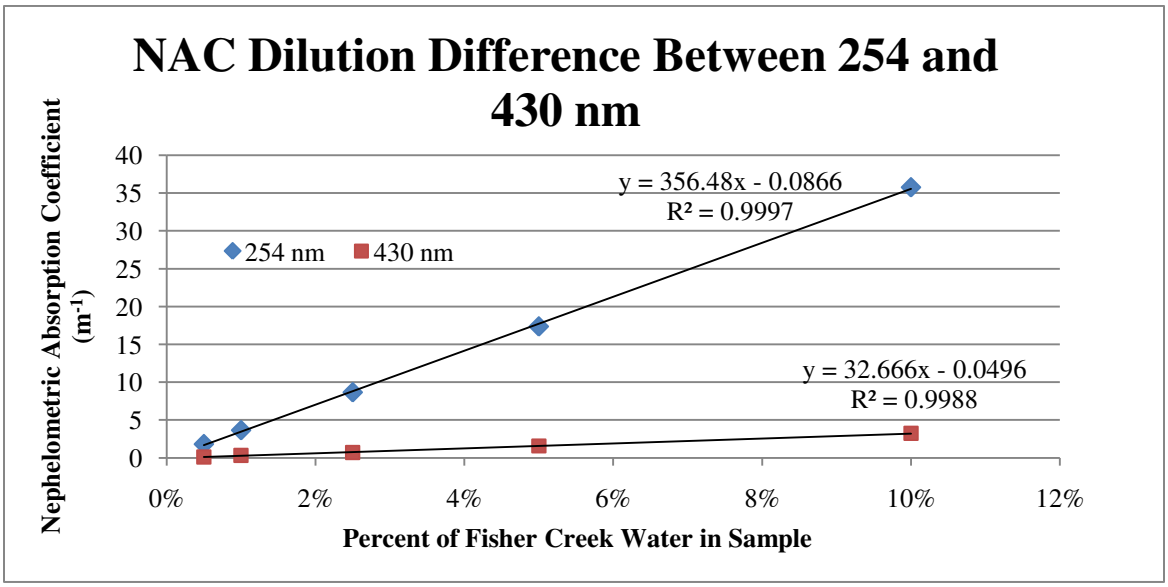

Figure B110 NAC Dilution Difference Between 254 and 430 nm. The differences in absorption coefficient (m^{-1}) linear response are shown for wavelengths 254 and 430nm used in this study with regard to various dilutions of the April 11, 2009 sample from Fisher Creek.

Figure B111 demonstrates that the absorption coefficient changes predictably with changing concentrations of Fisher Creek. This is the behavior described by Beer-Lambert Law

$$A = \varepsilon * C * L \qquad (10)$$

where A = absorbance, ε = molar absorptivity, C = concentration (moles per liter), and L = path length for absorbance data (cm). Molar absorptivity and concentration analyses were not performed from this work, but this behavior allows the absorption – concentration relationship to be estimated. UV-VIS work on DOC concentrations up to 1.4 g/l by Langhals et al (2000) showed concentrations less than 0.1g/l (or 100 mg/l) conformed well to Beer-Lambert Law.

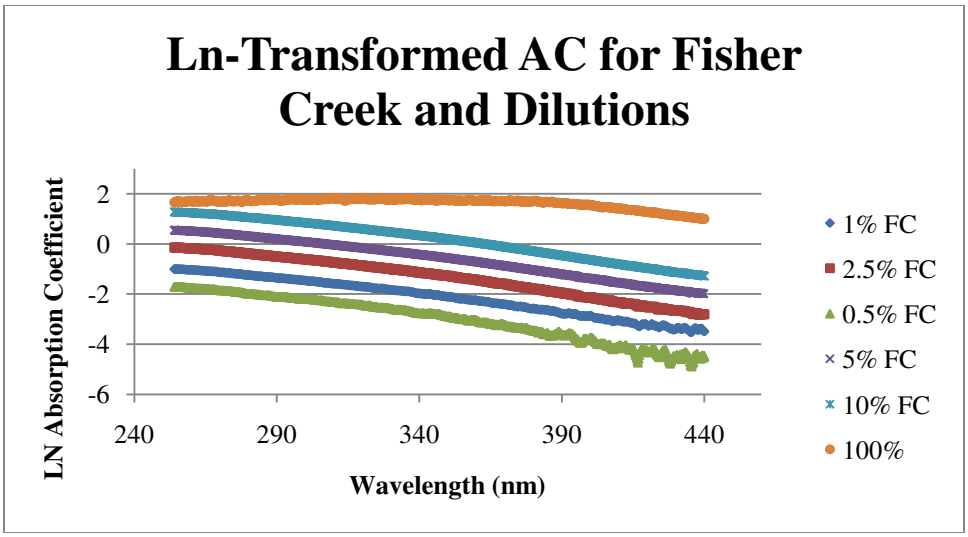

Figure B111 Ln-Transformed AC for Fisher Creek and Dilutions. The best sensitivity occurs for the shorter wavelengths and the relationship is constant for multiple dilutions (and different concentrations) of the same sample.

The Fisher Creek CDOM becomes more concentrated with age in a tightly closed bottle. Fisher Creek was sampled on April 11, 2009 and analyzed the same day with a colorimeter yielding a Nephelometric Absorption Coefficient (NAC_{430nm}) of 26. Subsequent analyses of the same sample on May 16 and 23, 2009 using the spectrophotometer gave NAC_{430nm} of 31 each. These NAC differences are not explained by the sensitivity differences of the spectrophotometer and colorimeter that for 430nm NAC would be 31.23 and 32.70, respectively (see Methodology and Figures 12 and 13). Because the bottle stayed tightly closed, evaporation is an unlikely explanation. This is not a lasting change as a repeat analysis a year later (May 31, 2010) shows an absorption decline in concentration (Figure B112). Table B10 and Figure B113 present the NAC values for May 16 and 23, 2009 and May 31, 2010. The data show a shift toward the shorter wavelengths with time. Bacteria degrade CDOM (Meyer et al., 1987; Moran and Hodson, 1990; Helms et al., 1998) but this is recognized to be a very slow process relative to groundwater flow in a conduit network. Yacobi et al. (2003) reported most of the DOC (>50%) to be in the small molecular-sized fraction. Bricaud et al. (1981) observed frequent changes to the absorption values during long-term storage of samples, but without a discernable pattern for their 105 seawater samples (absorption coefficient range at 375 nm: 0.06-4.2/m^{-1}).

Table B10 Fisher Creek 4/11/2009 Sample Used for Dilutions

	NAC (m^{-1})	NAC (m^{-1})	NAC (m^{-1})	NAC (m^{-1})
Wavelength	4/11/2009	5/16/2009	5/23/2009	5/31/2010
254		52.38	54.33	48.57
430	26	31.23	31.19	24.93
440		27.23	27	21.63

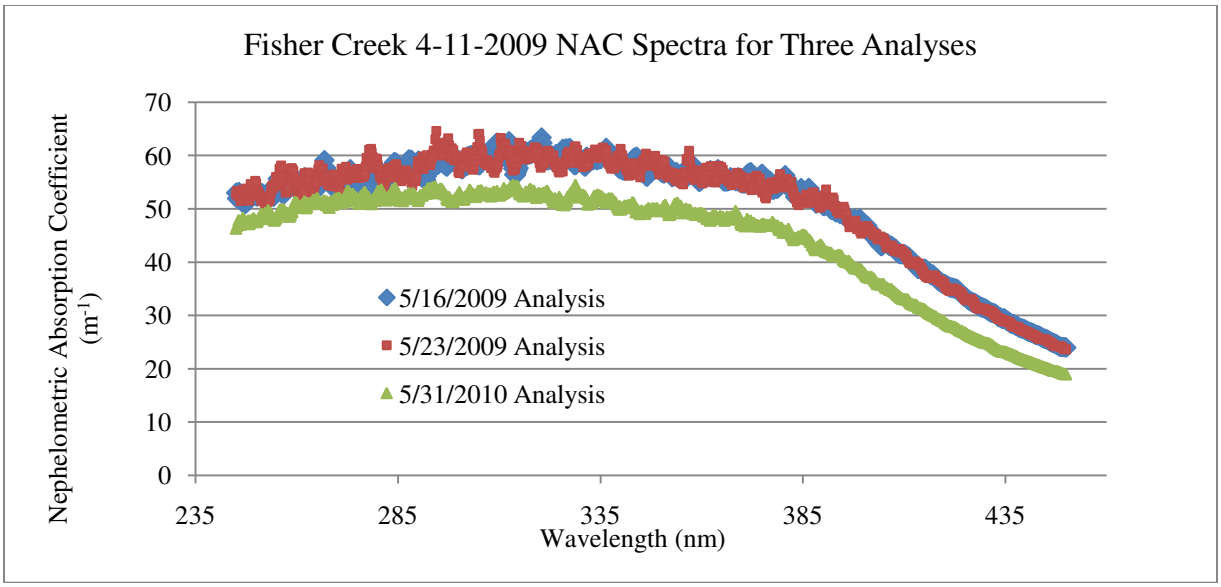

Figure B112 Fisher Creek 4-11-2009 NAC Spectra for Three Analyses.

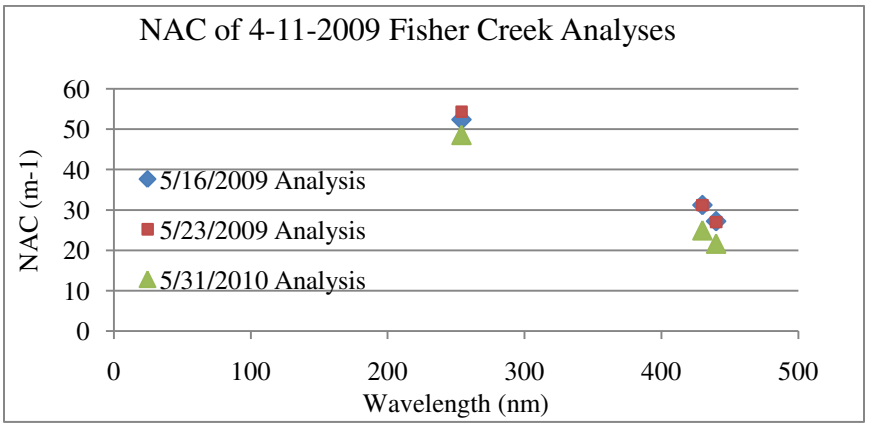

Figure B113 NAC of 4-11-2009 Fisher Creek Analyses. The changes over time are shown for the chromophoric dissolved compounds for the 254, 430, and 440 nanometer wavelengths.

Figure B114 (top graphs) show the Excel linear equation slope and intercept changes for the seven-day period (May 16-23, 2009) for wavelength range of 400-450 nm. The bottom two graphs show the polynomial equations for the same seven-day period (May 16-23, 2009) for wavelength range of 245-500 nm. Fisher Creek contains significantly higher DOC than seawater (absorption coefficient range at 375 nm: 53-56/m^{-1}). The changes between the week span were such that not only did the fit equations change but so did the R^2 of the fit.

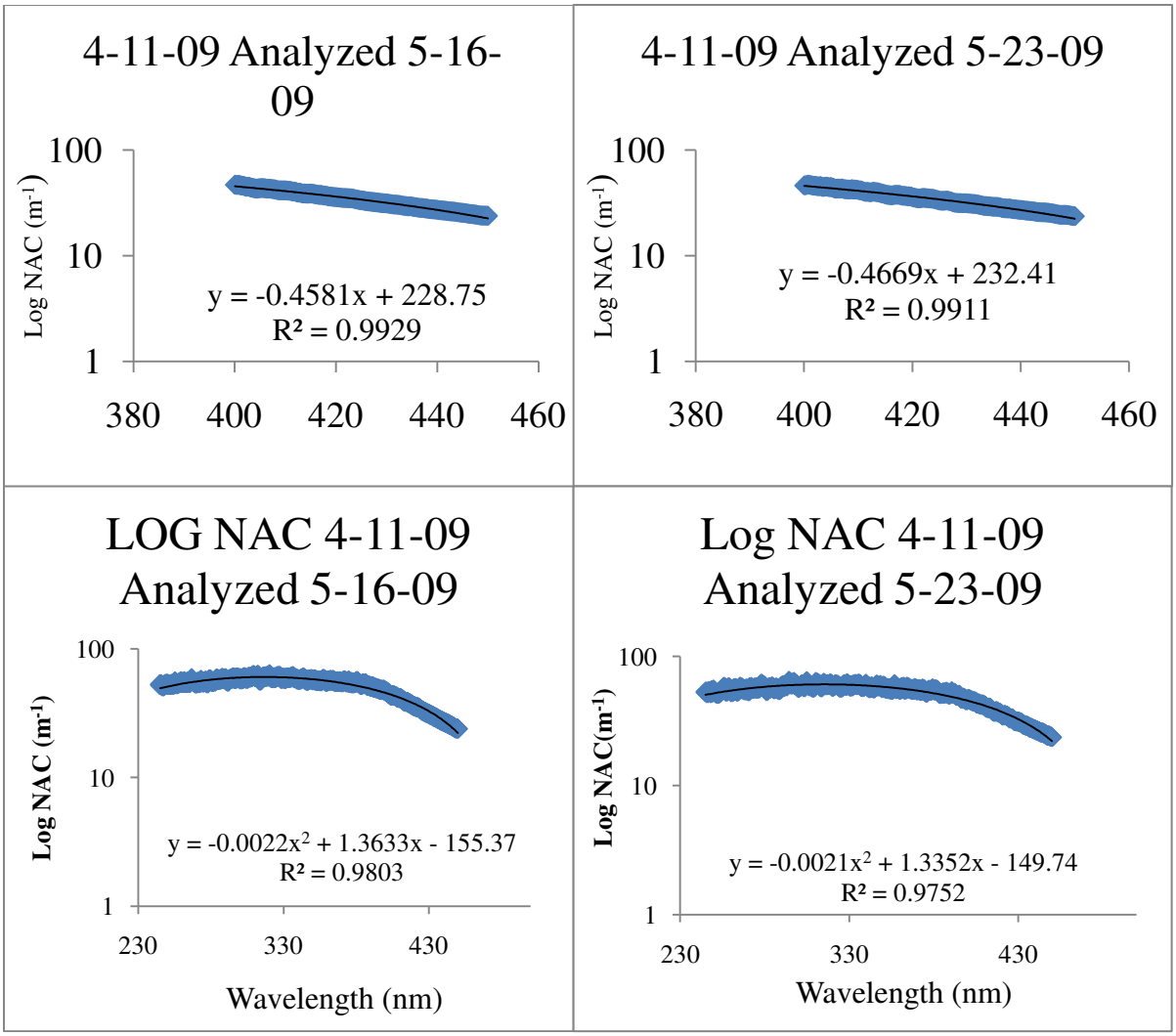

Figure B114 Linear and Polynomial Fit Equations of 4-11-2009. These analyses were performed a week apart and reflect changes that occurred while the sample bottle was tightly closed. Bacterial decay of the CDOM is the likely explanation.

Figure B115 provides the fit equations for the various dilution of the 4-11-2009 sample for wavelengths 254 to 440 nm. If the exponential equation provided a reasonable fit with a good R^2, it was selected. For the 100 percent sample of Fisher Creek, the polynomial equation provided the best fit. The spectral slope of the exponential equations are widely reported in the scientific literature as a defining characteristic of the CDOM in a sample (Helms et al., 1998). Because "S" will change over varied wavelength ranges, it is necessary to specify and use the range typical in the literature for the study objective (Stedmon et al., 2000).

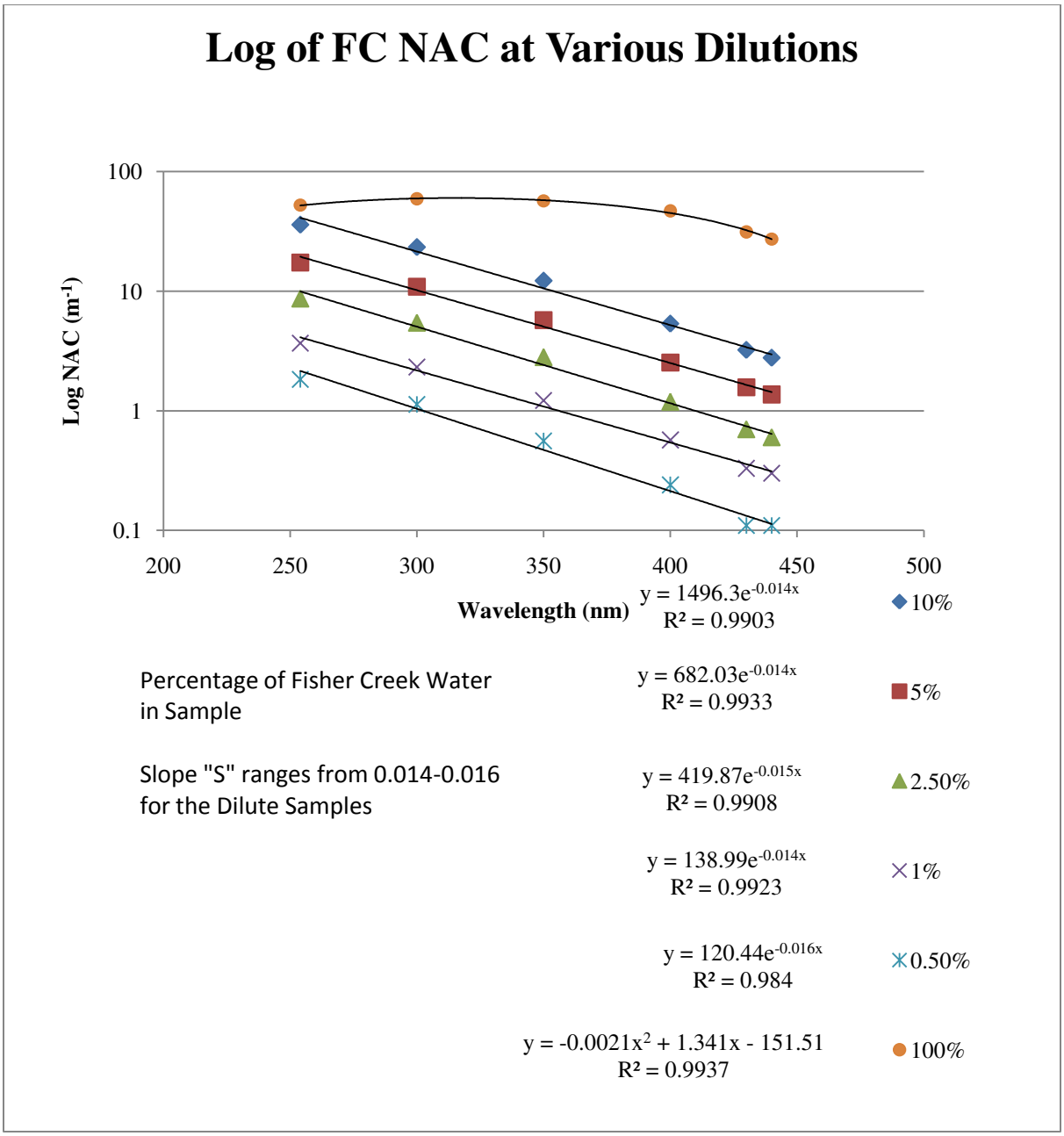

Figure B115 Fisher Creek Log NAC 4-11-2009 Sample Dilutions. The NAC values correspond to the selected 254, 300, 350, 400, 430, and 440 wavelengths.

C. ABSORPTION COEFFICIENTS

Use of the spectrophotometer to analyze Wakulla Springs and one each from Munson Slough, Black Creek and Fisher Creek samples generated curves reflecting the CDOM absorption response. In general, all of the curves were fairly similar; variations were due to the age (freshly leached versus well-weathered) and concentration. Figure C116 shows the transmittance and NAC for the clearest water sample from Wakulla Springs collected during 2009. "Organic-free" water from a plastic container that leached organics was used as the blank and required correction to remove this unwanted organic signature. The transmittance curve gradually increases with increasing wavelength with a leveling off response once reaching 300 nm. The NAC curve rapidly declines and approaches zero NAC at 320 nm.

Figure C117 separates the absorption spectra of 5/17/2009 into the UV and VIS parts with their fit equations. The May 17, 2009 UV wavelength curve shows a good correlation for decreasing absorption with increasing wavelength. The VIS wavelengths show more variation for the low absorption values (0.3 change in absorption over 140nm length). Fit equations to describe the absorption curve are very dependant on the specific part of the curve selected.

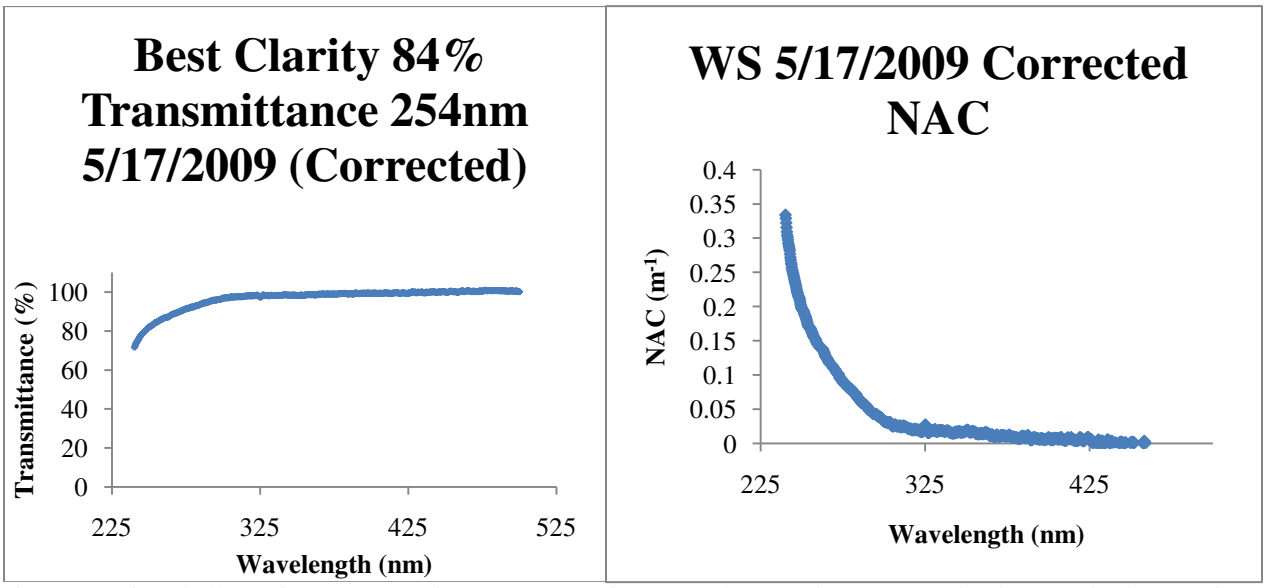

Figure C116 Wakulla Springs Best Clarity 84% Transmittance and NAC, 5/17/2009. The data required correction for plastic container organics found to be present in the blank sample.

April 8, 2009 was the poorest water quality sampled at Wakulla Springs during 2009. The transmittance and NAC graphs for the absorption response are Figure C118. The transmittance curve shows that essentially no light was transmitted for the UV wavelengths until the wavelength was 325 nm and greater. The curve then gradually increases in transmittance with increasing wavelength. With regard to the 4/8/2009 NAC graph, the curve begins with a plateau to 300 nm and then follows a gradual decline with increasing wavelength.

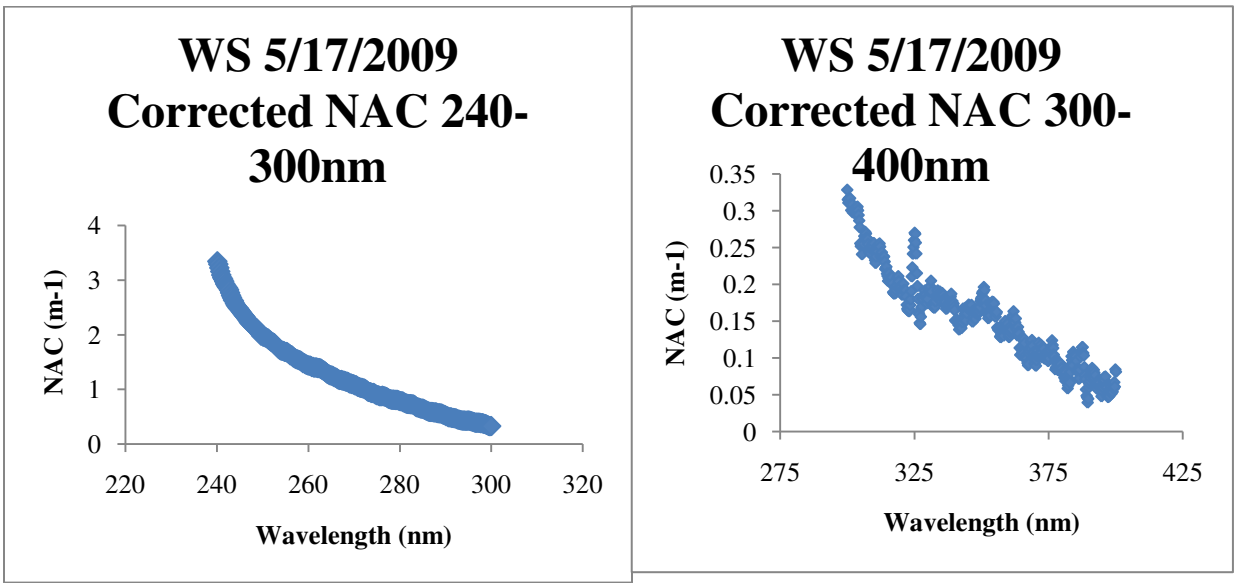

Figure C117 Wakulla Springs UV absorption spectra of 5/17/2009 into the two UV segments with their fit equations $y = 12819e^{-0.035x}$, $R^2 = 0.9947$ and $y = 26.056e^{-0.015x,}$ $R^2 = 0.8915$, respectively. The fit equation is very dependant on the specific wavelength range selected.

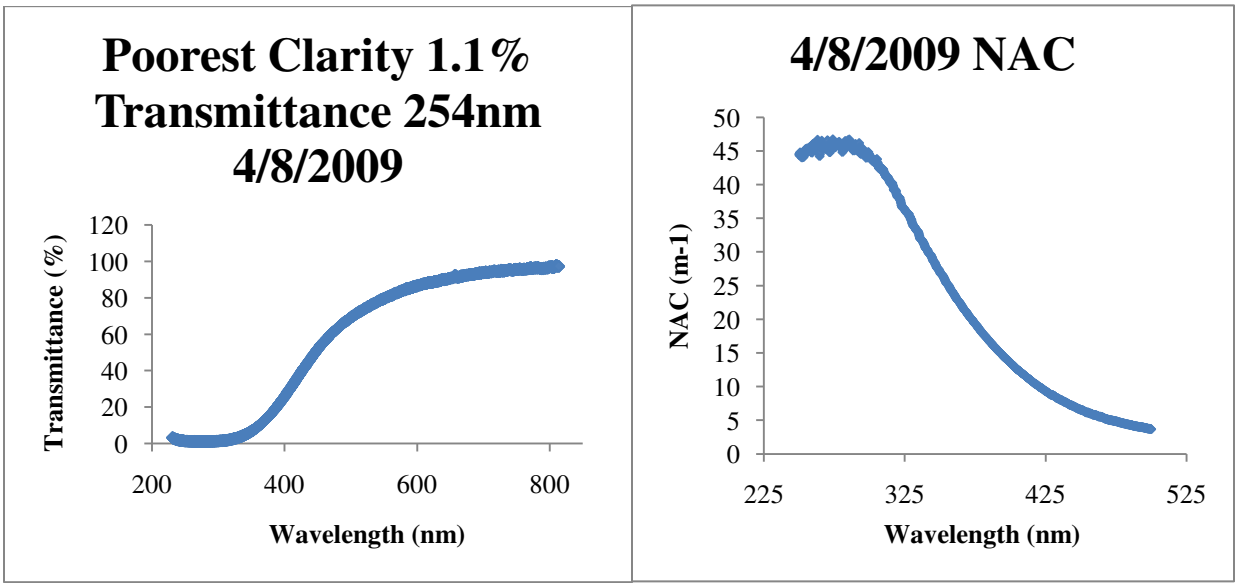

Figure C118 Wakulla Springs Poorest Clarity 1.1% Transmittance and NAC, 4/8/2009

Stegmon and Markager (2003) commented that conversion to log scale actually introduced error into the equations by increasing the weight applied to the longer wavelengths. Figure C119 displayes two different sections of the poorest water quality NAC curves without log-transformation followed by the same data log-transformed. The equations calculated by the Microsoft Excel software are identical for either case. The UV wavelength curve shows more variation for the high absorption values and a rise in absorption with increasing wavelength, but

absorption at these high values exceeds the high end sensitivity of the spectrophotometer. Good correlation for decreasing absorption with increasing wavelength occurs for the VIS wavelengths.

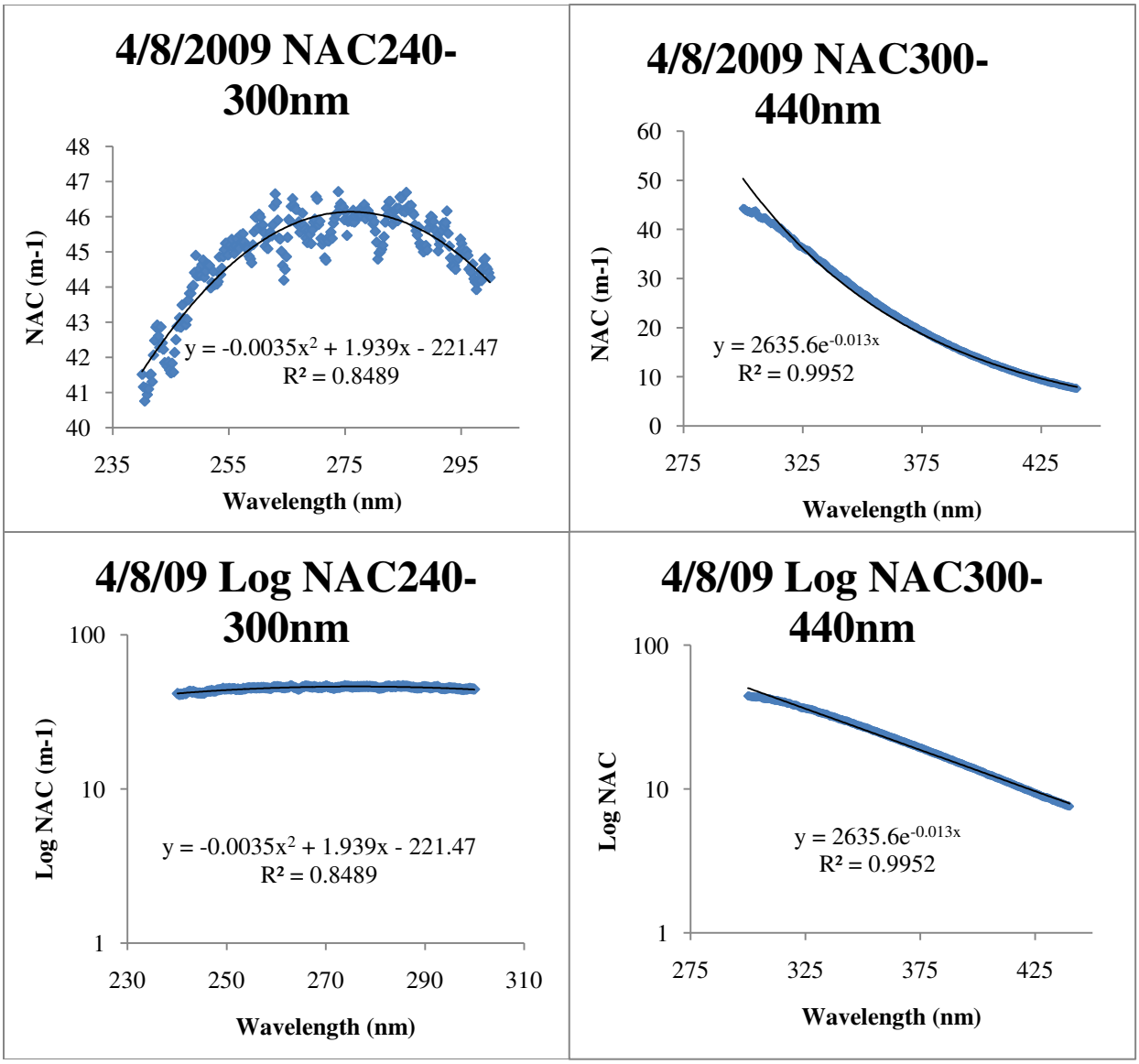

Figure C119 UV and VIS NAC Curves Without and With Log-transformation for April 8, 2009. Microsoft Excel software produces the same equation for either treatment.

Figure C120 shows the Absorption Coefficient spectra differences between the best and poorest water clarity Wakulla Springs samples for the wavelengths 330-450 nm. The best fit polynomial equations have very different constants for all terms.

The two wavelengths used to quantify CDOM water quality differences are 254 and 430 nanometers. Figure C121 displays the relationship between these two wavelengths. As

previously commented, the very high and low NAC values have qualified precision and should be considered qualitatively only.

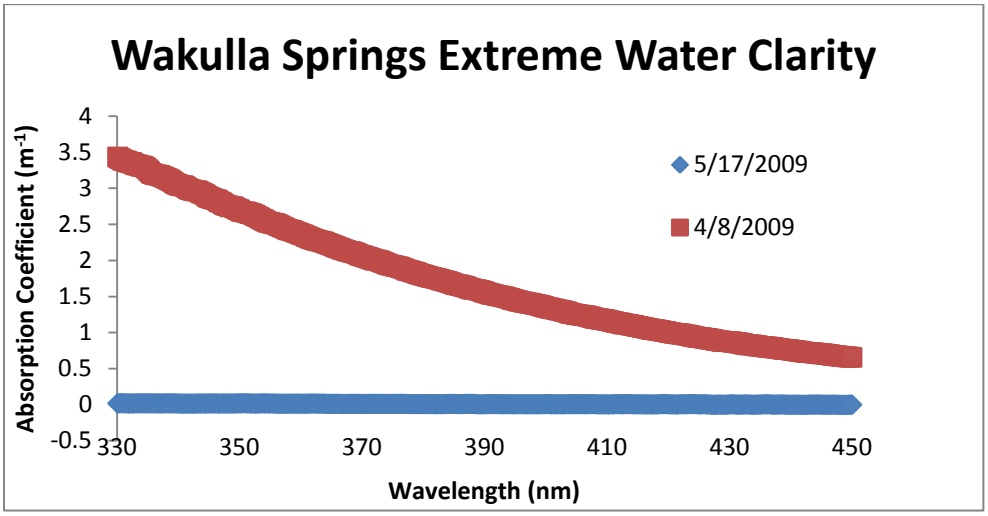

Figure C120 Wakulla Springs Extreme Water Clarity Spectra. This shows the differences between the best (5/17/2009) and poorest (4/8/2009) water clarity during 2009 for the wavelengths 330-450 nm.

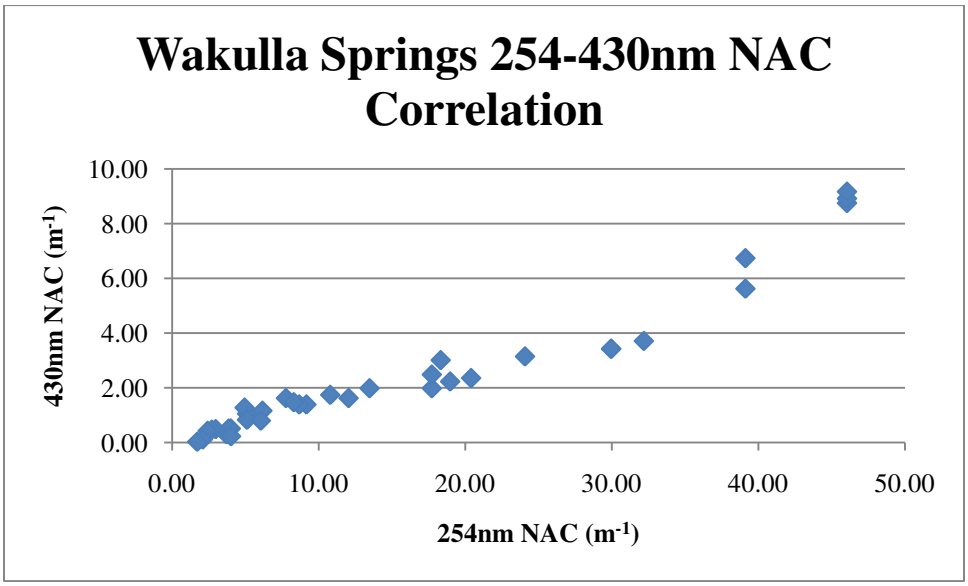

Figure C121 Wakulla Springs 254-430nm NAC Correlation.

The streams Fisher Creek and Black Creek and Lake Munson each had one sample analyzed by the spectrophotometer. Fisher Creek and Black Creek NAC curves are presented together in Figure C122 first to show the similarities and then separately in Figures C123 and C124. The May 31, 2010 curves of Fisher and Black Creek are closely aligned and yield similar exponential equations. Neither equation describes the nonlinear wavelength (shorter than 420 nm) portions of the curves. The Lake Munson NAC graph clearly represents lower CDOM

concentrations; at a wavelength of 450 nm, it has a NAC of 4.5 compared to the Black Creek NAC of 18 and Fisher Creek NAC of 15.

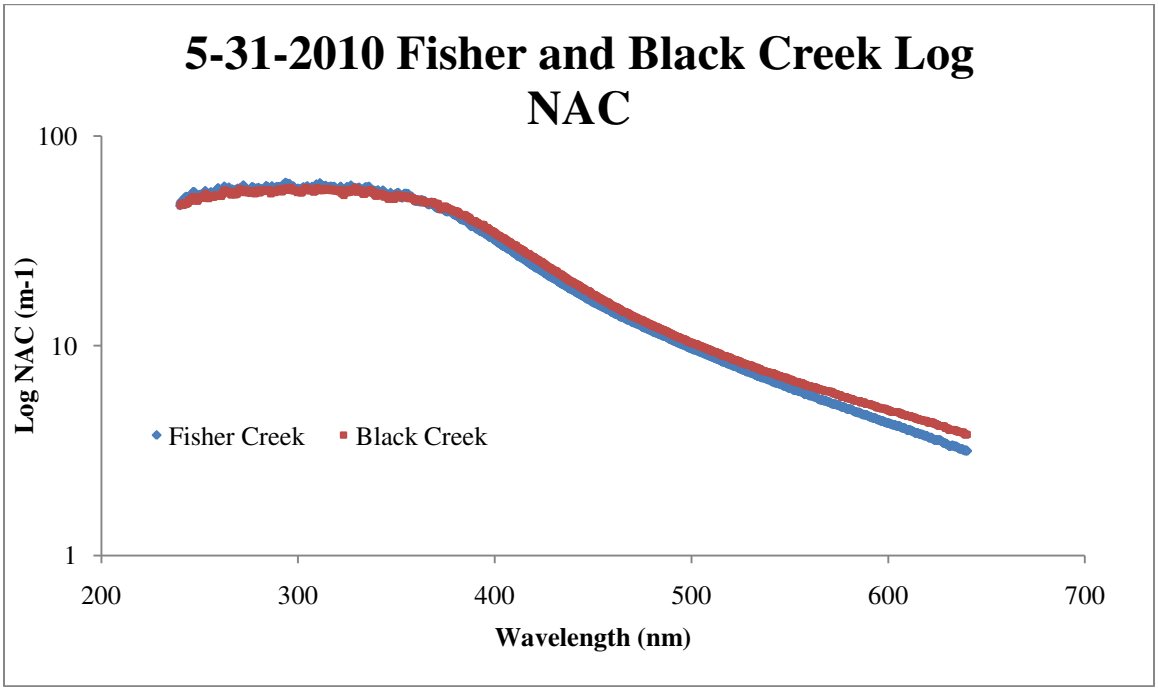

Figure C122 May 31, 2010 Fisher and Black Creek Log NAC. The response is not linear below a wavelength of 420 nm. This occurs because the CDOM concentrations are too high for the greater sensitivity of the shorter wavelengths. Figures C123 and C124 present the individual Fisher and Black Creek curves for the 400-500 wavelength range.

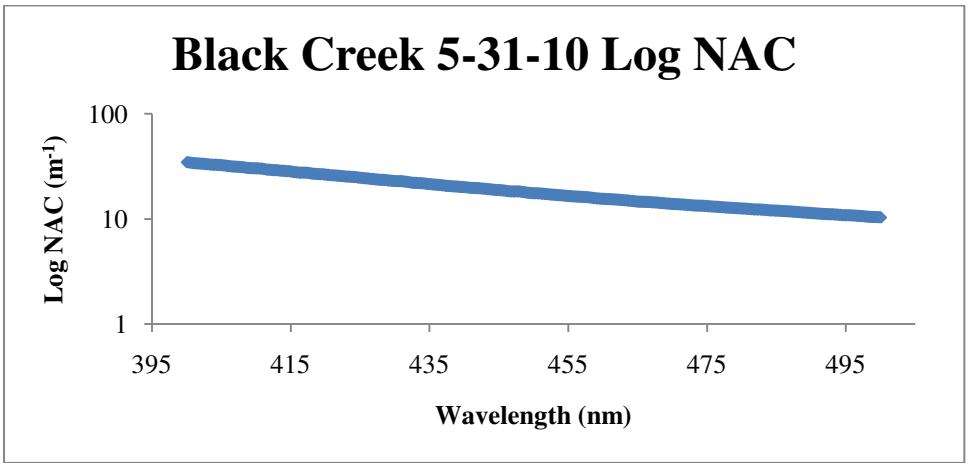

Figure C123 Black Creek 5-31-10 Log NAC curve for 400-500nm.

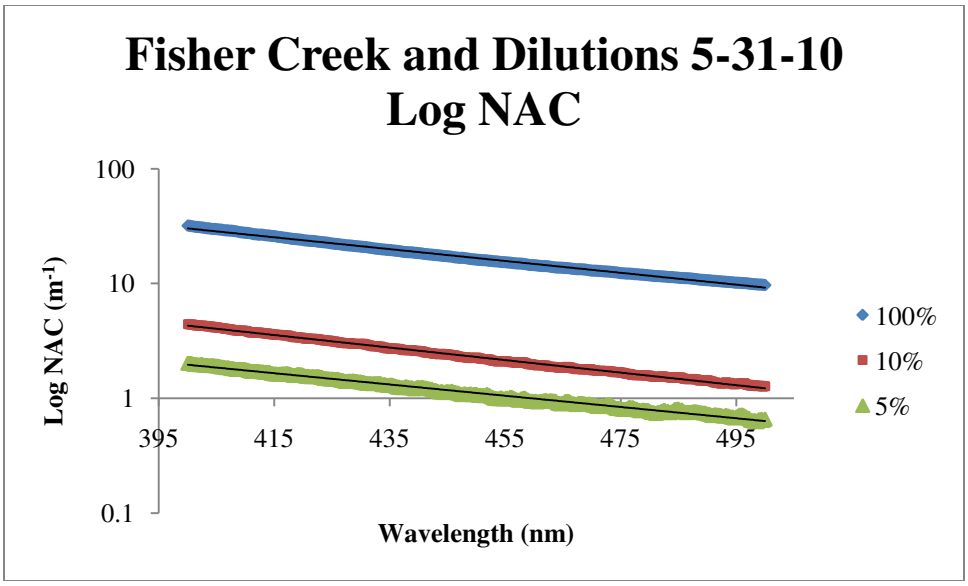

Figure C124 Fisher Creek and Dilutions 5-31-2010 Log NAC curves for 400-500nm.

As an example of the equation and R^2 differences that can occur for the same wavelength segment, Figure C125 presents the Fisher and Black Creek curves with the exponential (left), then the polynomial fit equations (right).

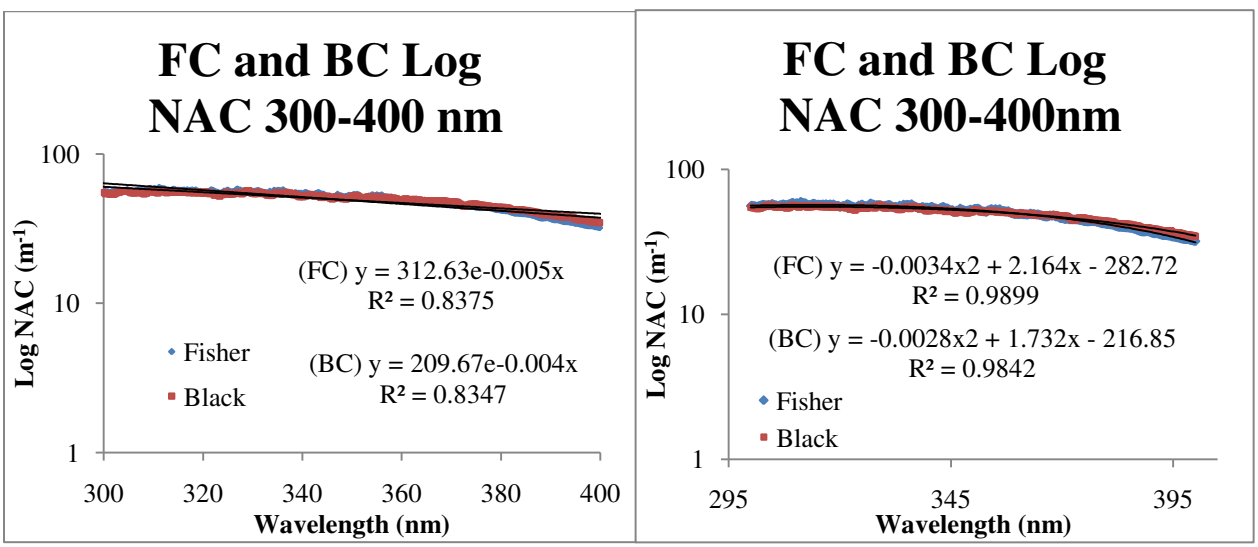

Figure C125 Fisher and Black Creek Exponential and Polynomial Fit Equations. Different streams and the same wavelength range will have very different fit equations with similar R^2 values.

Figure C126 presents the exponential equation and R^2 changes that occur for different wavelength sections of the same samples; first for 370-440nm (top), followed by 440-565nm (bottom).

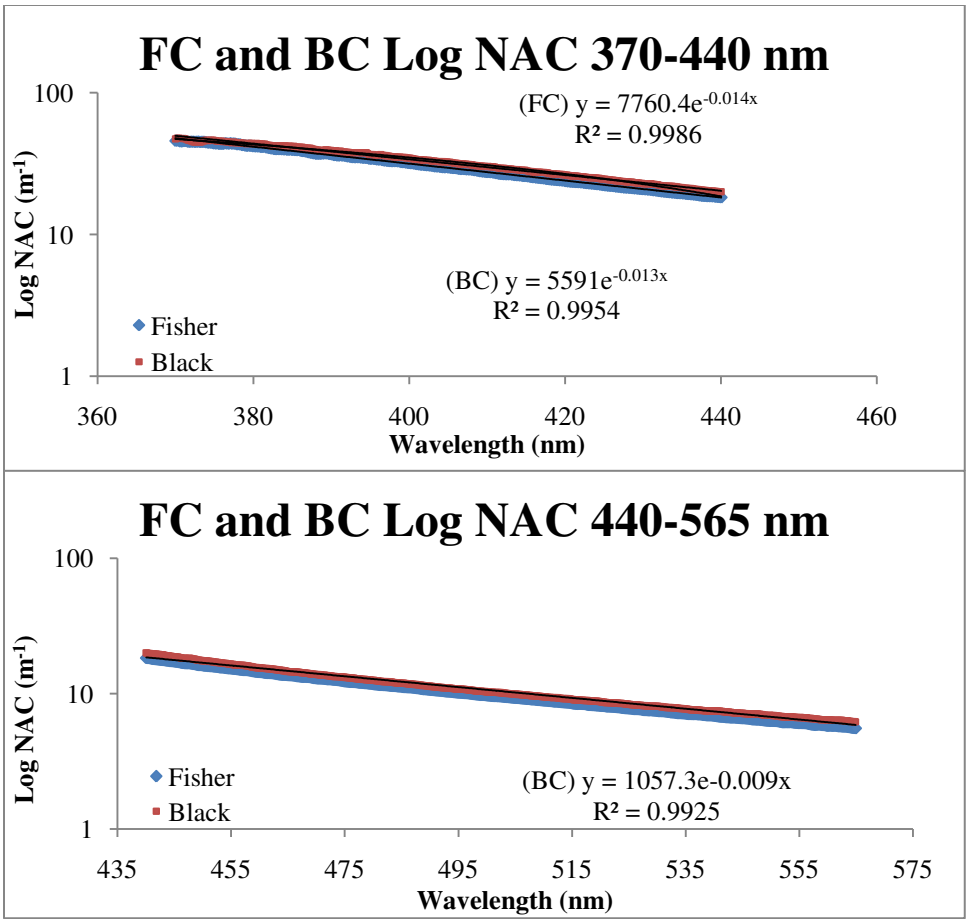

Figure C126 FC and BC Log NAC for 370-440 and 440-565 nm.

The complete Log NAC curve for Lake Munson is shown in Figure A127. Munson Slough flows into Lake Munson (North end) and if the lake level is high enough, flow discharges over a weir (South end) into the channelized Munson Slough that eventually drains into Ames Sink.

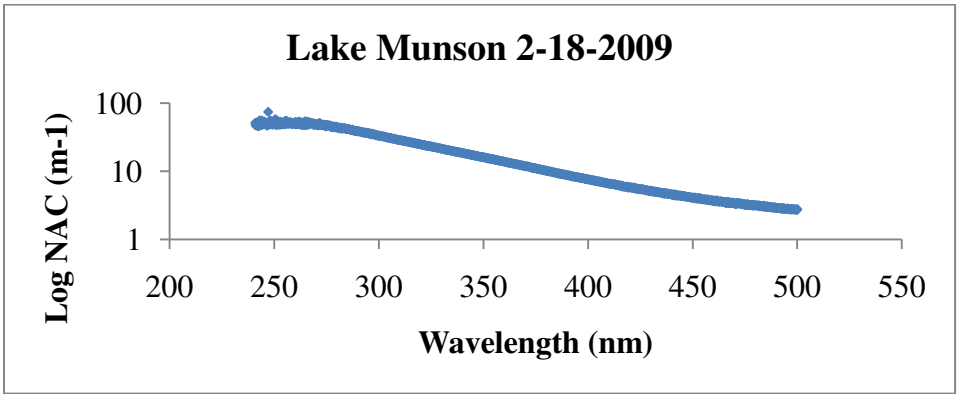

Figure C127 Lake Munson 2-18-2009 Log NAC Curve.

Blanks

A blank is used in the spectrophotometer analysis to remove absorption associated with the water component. Tap water was routinely used for this purpose as the Tallahassee water supply is extracted from the same aquifer that discharges twelve miles to the south at Wakulla Springs. Tallahassee uses chlorine as a disinfectant, and the Tallahassee Annual Report gives the water supply distribution concentration range as 0.73-0.84 mg/l (City of Tallahassee, 2010). Ormeci (2010) documented the absorbance of chlorine at a concentration of 5 mg/l to be low (0.002 –this would be an NAC_{254} of 0.46 m^{-1}) at 254nm and zero at 350nm. The presence of chlorine at one-fifth of the test concentration should not significantly affect the results of this work. The clearest (5-17-09) Wakulla Springs sample had an NAC_{254} of 1.51. Figure A128 shows the light intensity change associated with several blank types analyzed. "Commercial" is store-purchased distilled water. "Plastic" is water from the plastic de-ionized water container kept in the lab. "Glass" is water stored in a glass container at the FSU Magnetic Laboratory. "Groundwater" is a sample of the tap water. The decreased intensity of the groundwater sample (range 96.6-100) may be due to other analytes present in the water after treatment.

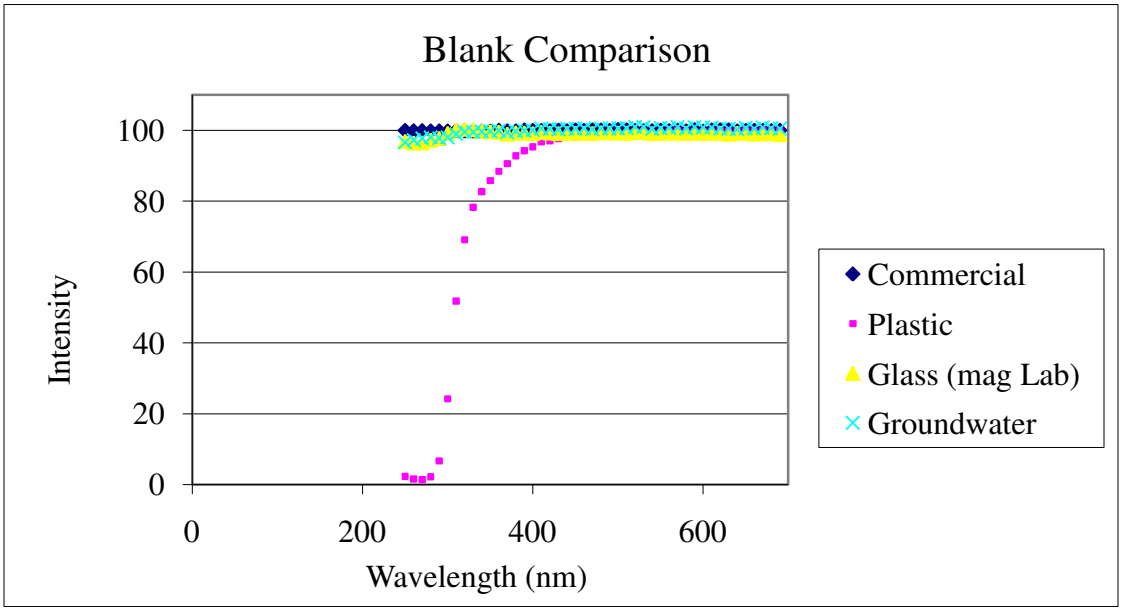

Figure C128 Blank Comparison of the light intensity changes associated with several blank types analyzed.

Spectrophotometer Stabilization

The spectrophotometer was tested to evaluate potential drift over time. The input light intensity response drifted upward with time as shown in Figure C129. This was realized early on, implementing a procedure to turn the instrument at least 45 minutes (the dashed blue line in the figure) before use. Rapid change in the light intensity occurred initially as the instrument warmed. The light intensity stabilized after 80 minutes, and shows a very slight upward drift in intensity there on. Potential drift was continually checked by reanalyzing the blank water and comparing it to the original blank spectra. This resulted in repeat analyses for some samples; the corrected data have been used for this work.

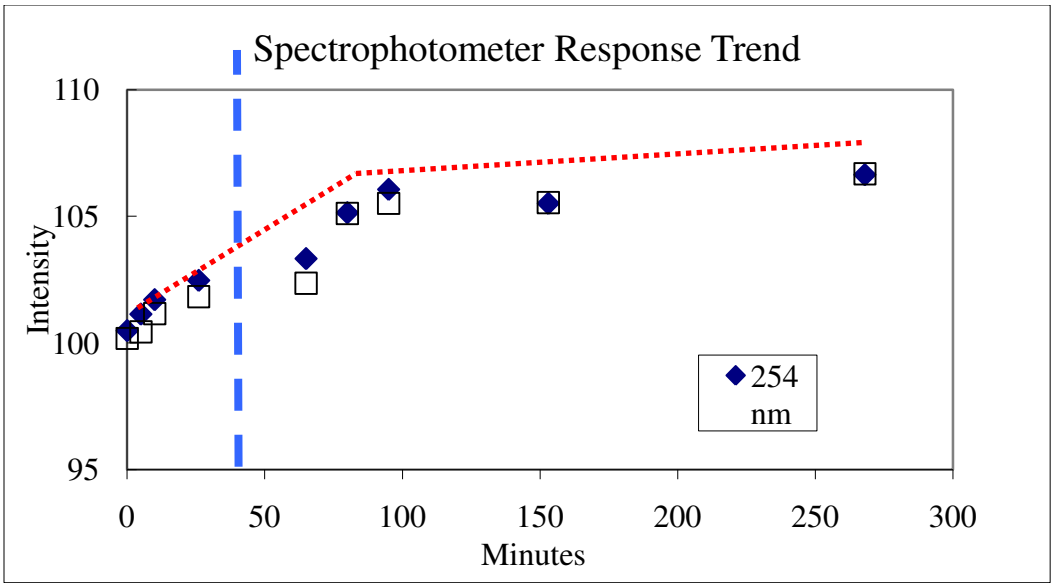

Figure C129 Spectrophotometer Response Trend: spectrophotometer input light intensity response drifted upward with time and required allowing the instrument to warm up at least 45 minutes before use.

APPENDICES

D. HISTOGRAMS

Histograms

Histograms were prepared to show the range in transmittance measured for each of the streams and Wakulla Springs. Black Creek has the lowest mean transmittance for CDOM (48%), followed by Lost Creek (55%), Fisher Creek (61%), Jump Creek (64%), and Munson Slough (90%).

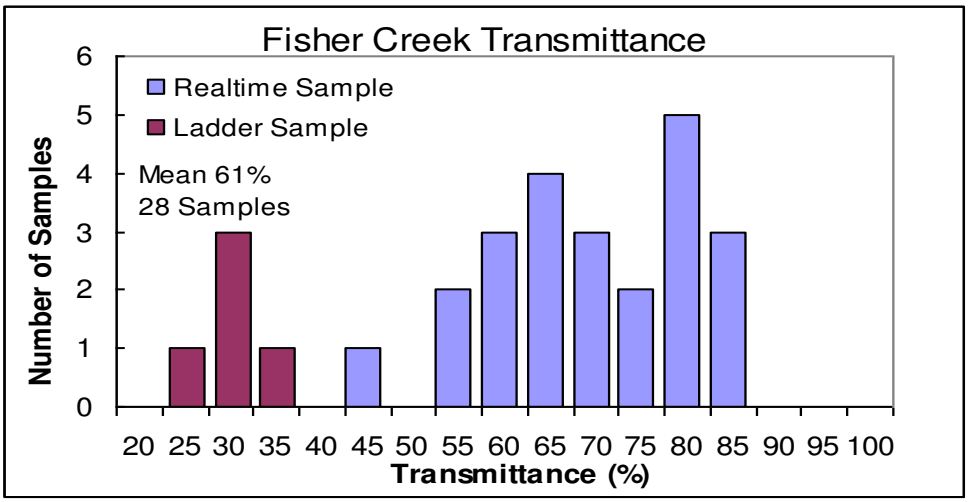

Figure D130 Fisher Creek Transmittance Histogram

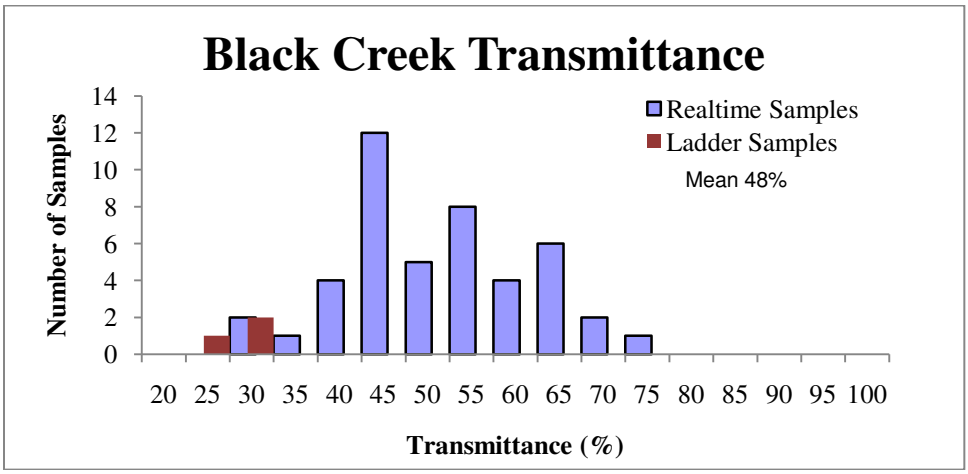

Figure D131 Black Creek Transmittance Histogram

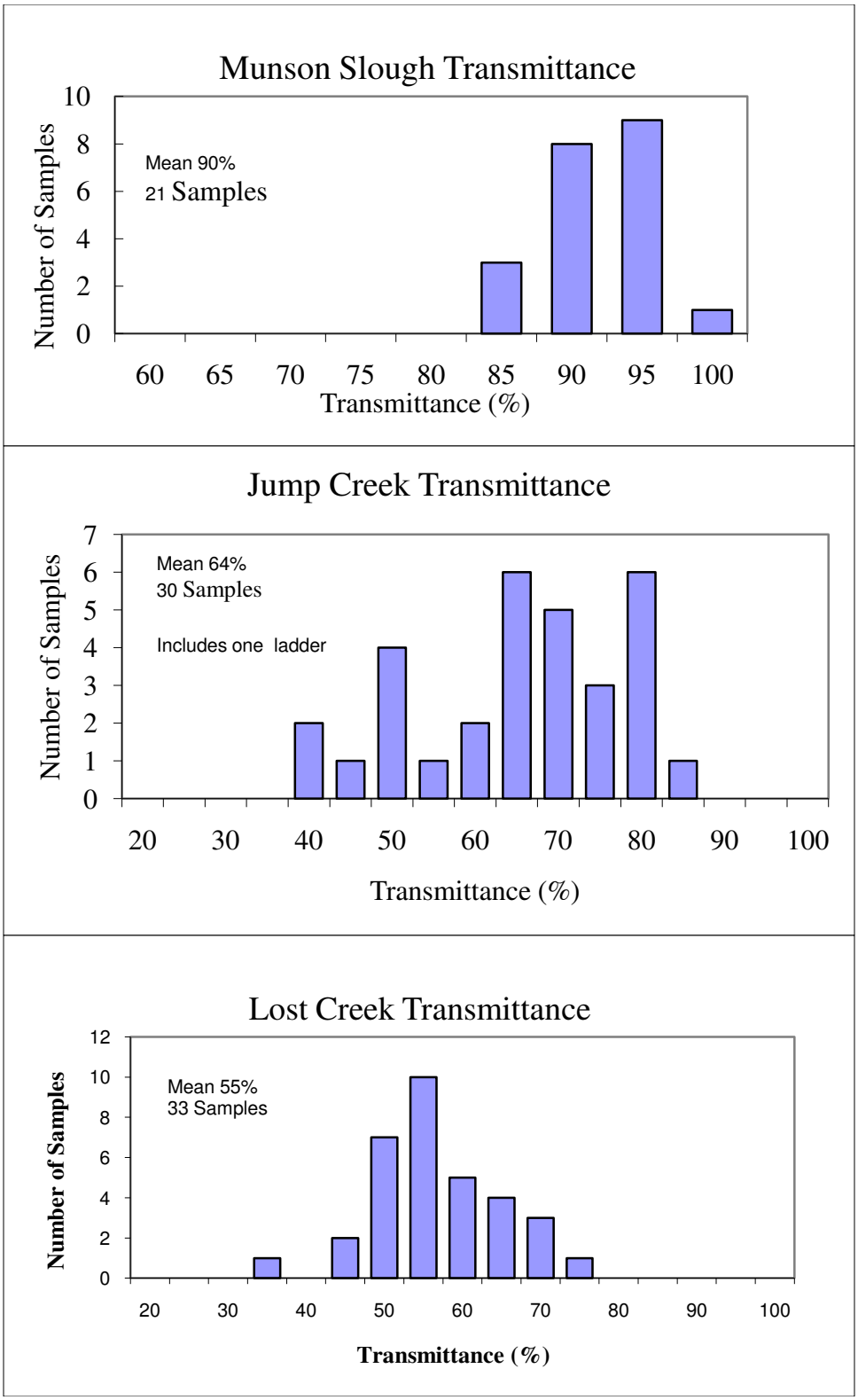

Figure D132 Munson Slough, Jump Creek, and Lost Creek Transmittance Histograms

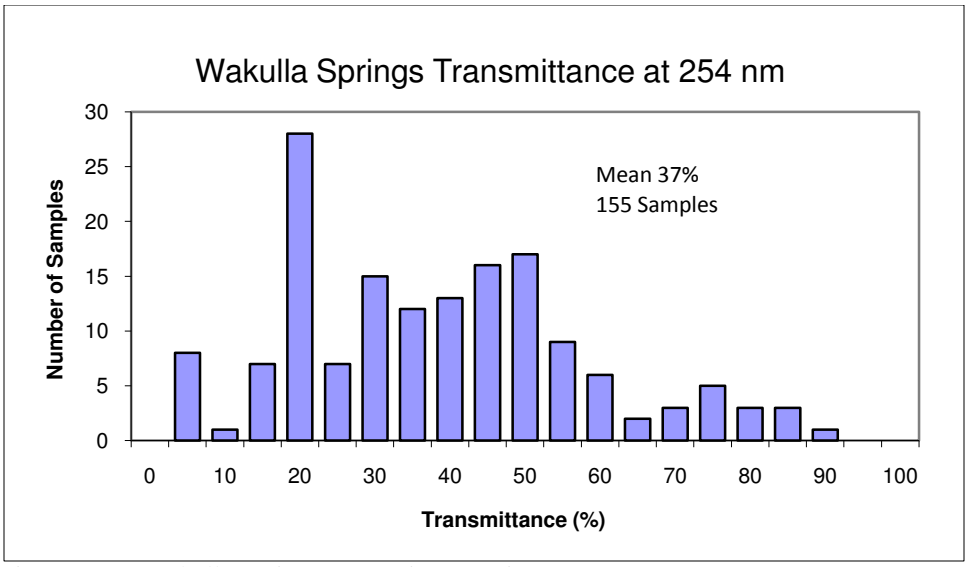

Figure D133 Wakulla Springs Transmittance Histogram

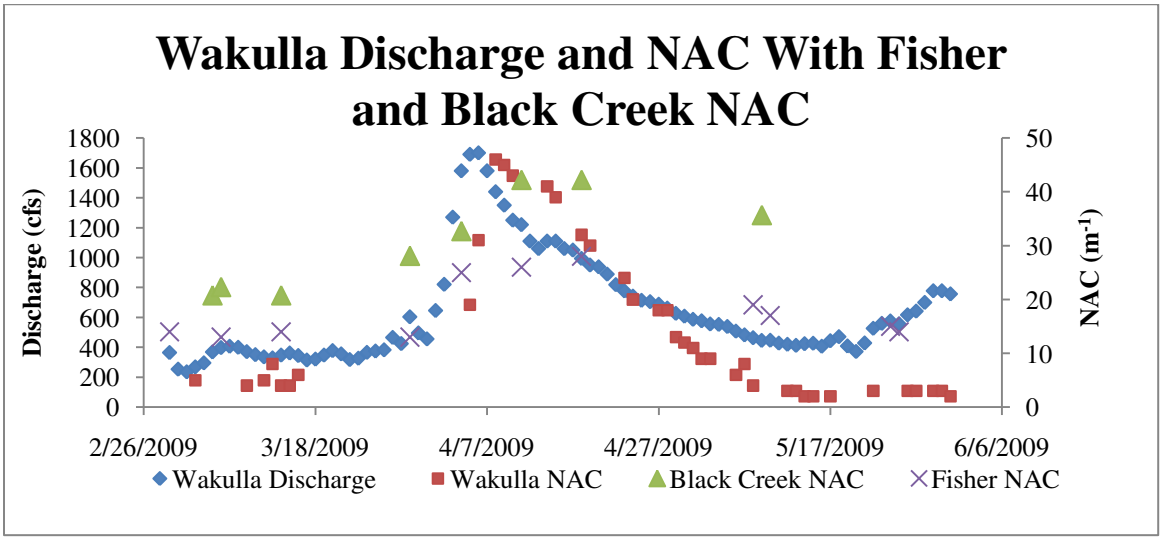

Figure D134 Wakulla Springs Discharge and NAC Vs Fisher and Black Creek NAC

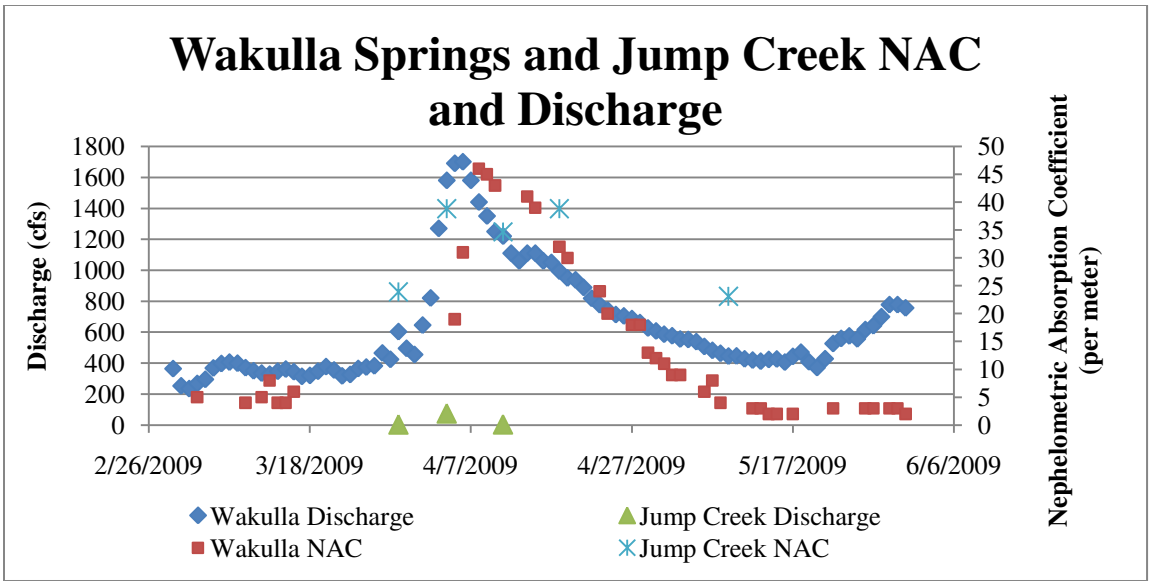

Figure D135 Wakulla Springs and Jump Creek Discharge and NAC.

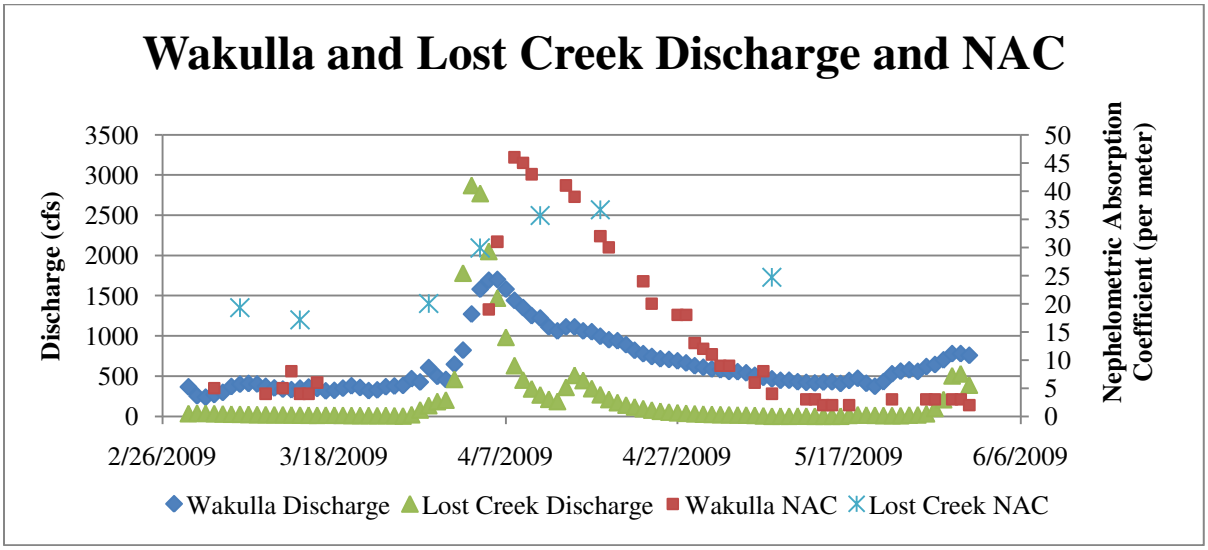

Figure D136 Wakulla Springs and Lost Creek Discharge and NAC.

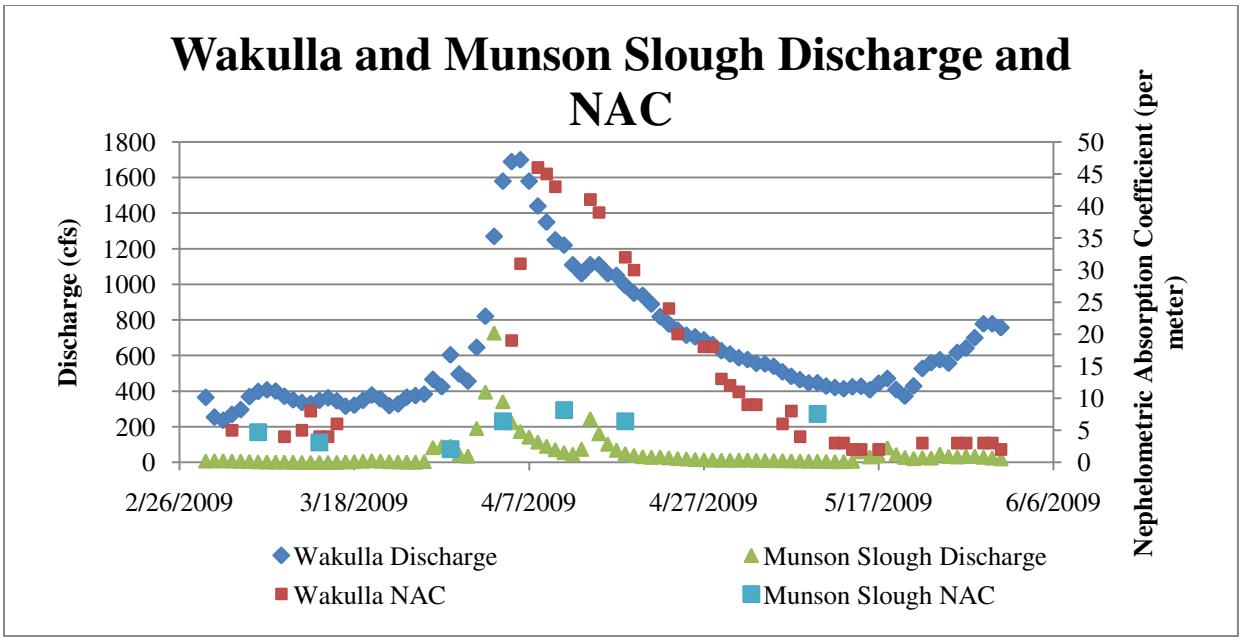

Figure D137 Wakulla Springs and Munson Slough Discharge and NAC.

APPENDICES

E. DATA

Table E11 – Blank Evaluation

Commercial		**Plastic Container**		**Mag Lab Glass**		**Ground Water**	
WL - nm	Intensity	WL - nm	Intensity	WL - nm	Intensity	WL - nm	Intensity
250.14	100.0	250.14	2.3	250.14	96.9	250.14	96.6
260.19	99.8	260.19	1.6	260.19	96.5	260.19	97.2
270.21	99.9	270.21	1.4	270.21	96.5	270.21	97.7
280.21	99.8	280.21	2.2	280.21	97.3	280.21	98.1
290.19	99.8	290.19	6.7	290.19	97.7	290.19	97.8
300.15	99.8	300.15	24.2	300.15	99.1	300.15	98.0
310.08	99.9	310.08	51.8	310.08	100.1	310.08	98.9
319.99	99.8	319.99	69.1	319.99	100.3	319.99	99.5
330.09	99.8	330.09	78.3	330.09	100.2	330.09	99.5
340.16	99.8	340.16	82.7	340.16	99.7	340.16	99.7
350.21	99.7	350.21	85.8	350.21	99.6	350.21	99.7
360.23	100.0	360.23	88.4	360.23	99.5	360.23	99.9
370.22	99.8	370.22	90.6	370.22	98.9	370.22	99.4
380.19	99.8	380.19	92.8	380.19	99.3	380.19	99.7
390.13	100.1	390.13	94.2	390.13	99.2	390.13	99.9
400.04	99.9	400.04	95.3	400.04	99.1	400.04	100.0
410.13	99.9	410.13	96.7	410.13	99.5	410.13	100.5
420.19	99.8	420.19	97.0	420.19	99.3	420.19	100.4
430.23	100.0	430.23	97.6	430.23	99.1	430.23	100.2
440.23	99.8	440.23	98.1	440.23	99.1	440.23	100.4
450.2	100.1	450.2	98.1	450.2	99.2	450.2	100.5
460.15	99.9	460.15	98.6	460.15	99.2	460.15	100.6
470.06	100.1	470.06	98.6	470.06	99.2	470.06	100.2
480.15	100.0	480.15	99.1	480.15	99.4	480.15	100.5
490.2	99.9	490.2	99.1	490.2	99.3	490.2	100.5
500.22	100.2	500.22	99.1	500.22	99.3	500.22	100.5
510.21	100.1	510.21	99.2	510.21	99.2	510.21	100.6
520.16	99.9	520.16	99.6	520.16	99.4	520.16	101.0
530.08	99.9	530.08	99.7	530.08	99.4	530.08	100.9
540.16	99.9	540.16	99.2	540.16	99.1	540.16	100.4
550.21	100.0	550.21	99.4	550.21	99.3	550.21	100.6
560.22	99.9	560.22	99.8	560.22	99.2	560.22	100.7
570.2	100.0	570.2	100.0	570.2	99.3	570.2	100.9
580.14	99.8	580.14	99.7	580.14	99.1	580.14	100.5
590.04	100.1	590.04	99.7	590.04	99.3	590.04	100.9
600.1	99.7	600.1	99.7	600.1	99.2	600.1	100.8
610.12	100.1	610.12	99.8	610.12	99.2	610.12	100.8
620.09	100.1	620.09	100.0	620.09	99.3	620.09	100.5
630.03	100.1	630.03	99.7	630.03	98.9	630.03	100.4
640.12	99.8	640.12	99.7	640.12	99.2	640.12	100.3
650.17	99.9	650.17	100.0	650.17	99.3	650.17	100.6
660.17	100.0	660.17	99.8	660.17	98.9	660.17	100.5
670.13	100.0	670.13	99.9	670.13	99.0	670.13	100.8
680.05	99.9	680.05	99.9	680.05	99.2	680.05	100.6
690.11	100.0	690.11	99.8	690.11	98.8	690.11	100.5
700.12	99.9	700.12	99.8	700.12	99.5	700.12	100.7

Table E12 – Wakulla Springs and Streams, March 1 –May 31, 2009

March 26 to April 2009 event			254nm	m-1	mg/l	kg/day	WSmass			430nm	m-1	mg/l	kg/day
	WSQ(cfs)	WSQ(cms)	WS T(%)	WS NAC	WS TOC	WSmass	Estimated	FC Q(cfs)	FC Q(cms)	FC T(%)	FC NAC	FC TOC	FCmass
3/1/2009	365	10.34			1	893		20	0.57	76	13.72	9.06	443
3/2/2009	254	7.19			1.02	636		18	0.51			9.00	396
3/3/2009	236	6.68			1.05	606		16	0.45			8.93	350
3/4/2009	269	7.62	61	4.94	1.07	707		14	0.40			8.87	304
3/5/2009	296	8.38			1.06	765		13	0.37			8.80	280
3/6/2009	369	10.45			1.04	939		12	0.34			8.74	257
3/7/2009	398	11.27			1.02	997		10	0.28	77	13.07	8.67	212
3/8/2009	407	11.53			1.01	1003		9.2	0.26			8.73	196
3/9/2009	400	11.33			0.99	970		8	0.23			8.78	172
3/10/2009	371	10.51	69	3.71	0.98	886		7	0.20			8.84	151
3/11/2009	351	9.94			1.03	885		6.2	0.18			8.89	135
3/12/2009	336	9.52	60	5.11	1.09	894		5.5	0.16			8.95	120
3/13/2009	329	9.32	46	7.77	1.30	1046		4.9	0.14			9.00	108
3/14/2009	348	9.86	67	4.00	1.00	851		4.4	0.12	76	13.72	9.06	98
3/15/2009	362	10.25	68	3.86	0.99	875		4	0.11			9.03	88
3/16/2009	345	9.77	54	6.16	1.17	989		3.7	0.10			9.01	82
3/17/2009	315	8.92						3.5	0.10			8.98	77
3/18/2009	321	9.09						3.2	0.09			8.96	70
3/19/2009	348	9.86						2.8	0.08			8.93	61
3/20/2009	378	10.70						2.5	0.07			8.90	54
3/21/2009	356	10.08						2.3	0.07			8.88	50
3/22/2009	318	9.01						2	0.06			8.85	43
3/23/2009	327	9.26						1.8	0.05			8.83	39
3/24/2009	366	10.37						1.8	0.05			8.80	39
3/25/2009	375	10.62						1.5	0.04			8.78	32
3/26/2009	383	10.85						1.5	0.04			8.75	32
3/27/2009	466	13.20						5.4	0.15			8.72	115
3/28/2009	425	12.04						13	0.37			8.70	277
3/29/2009	604	17.11						23	0.65	77	13.07	8.67	488
3/30/2009	496	14.05						33	0.93			9.41	760
3/31/2009	456	12.91				1000	1000	43	1.22			10.21	1074
4/1/2009	646	18.29				1554	1554	121	3.43			11.08	3280
4/2/2009	821	23.25				2415	2415	259	7.33			12.02	7617
4/3/2009	1270	35.97				3753	3753	448	12.69			13.04	14295
4/4/2009	1580	44.75				5833	5833	585	16.57	64	22.31	14.15	20252
4/5/2009	1690	47.86	15	18.97	2.19	9064		573	16.23			14.47	20287
4/6/2009	1700	48.14	4.7	30.58	3.12	12965		495	14.02			14.80	17924
4/7/2009	1580	44.75			3.68	14097		430	12.18			15.13	15924
4/8/2009	1440	40.78	1	46.05	4.35	15328		366	10.37			15.48	13862
4/9/2009	1350	38.23	1.15	44.65	4.24	14002		289	8.18			15.83	11194
4/10/2009	1250	35.40	1.3	43.43	4.14	12666		218	6.17			16.19	8636
4/11/2009	1220	34.55		42.82	4.05	12098		164	4.64	59	26.38	16.56	6644
4/12/2009	1110	31.44		42.22	3.97	10771		125	3.54			16.70	5107
4/13/2009	1060	30.02		41.63	3.88	10066		112	3.17			16.84	4616
4/14/2009	1110	31.44	1.65	41.04	3.80	10315		148	4.19			16.99	6152
4/15/2009	1110	31.44	1.98	39.22	3.80	10315		126	3.57			17.13	5282

Table E12 – Continued

March 26 to April 2009 event			254nm	m-1	mg/l	kg/day	WSmass			430nm	m-1	mg/l	kg/day
	WSQ(cfs)	WSQ(cms)	WS T(%)	WS NAC	WS TOC	WSmass	Estimated	FC Q(cfs)	FC Q(cms)	FC T(%)	FC NAC	FC TOC	FCmass
4/16/2009	1060	30.02			3.60	9348		109	3.09			17.28	4609
4/17/2009	1050	29.74			3.42	8787		96	2.72			17.43	4094
4/18/2009	994	28.15	4	32.19	3.25	7893		88	2.49	57	28.11	17.58	3785
4/19/2009	950	26.90	4.94	30.08	3.07	7131		81	2.29			17.18	3404
4/20/2009	938	26.56		28.38	2.94	6755		74	2.10			16.78	3039
4/21/2009	889	25.18		26.77	2.82	6142		65	1.84			16.40	2609
4/22/2009	819	23.19		25.26	2.71	5429		55	1.56			16.03	2157
4/23/2009	777	22.00	9.23	23.83	2.60	4941		46	1.30			15.66	1763
4/24/2009	742	21.01	13	20.40	2.31	4187		39	1.10			15.30	1460
4/25/2009	714	20.22			2.23	3900		33	0.93			14.95	1207
4/26/2009	705	19.97			2.16	3728		28	0.79			14.61	1001
4/27/2009	688	19.48	17	17.72	2.09	3522		23	0.65			14.28	804
4/28/2009	662	18.75	16	18.33	2.14	3467		19	0.54			13.95	649
4/29/2009	627	17.76	26	13.47	1.75	2690		16	0.45			13.63	534
4/30/2009	608	17.22	30	12.04	1.64	2439		13	0.37			13.32	424
5/1/2009	587	16.62	34	10.79	1.54	2212		11	0.31			13.02	350
5/2/2009	577	16.34	40	9.16	1.41	1991		9	0.25			12.72	280
5/3/2009	556	15.75	42	8.68	1.37	1866		7.2	0.20			12.43	219
5/4/2009	553	15.66			1.28	1739		6	0.17			12.15	178
5/5/2009	539	15.26			1.20	1588		5.3	0.15			11.87	154
5/6/2009	508	14.39	57	5.62	1.13	1402		4.7	0.13			11.60	133
5/7/2009	483	13.68	46	7.77	1.30	1535		4.1	0.12			11.33	114
5/8/2009	464	13.14	69	3.71	0.98	1108		3.7	0.10	71	17.12	11.08	100
5/9/2009	446	12.63			0.96	1043		3.3	0.09			11.28	91
5/10/2009	447	12.66			0.94	1024		3	0.08	70	17.83	11.50	84
5/11/2009	428	12.12			0.92	961		2.7	0.08			12.28	81
5/12/2009	420	11.89	76	2.74	0.90	924		2.3	0.07			13.11	74
5/13/2009	413	11.70	78	2.48	0.88	887		1.9	0.05			14.01	65
5/14/2009	424	12.01	81	2.11	0.85	880		2.3	0.07			14.96	84
5/15/2009	427	12.09	83	1.86	0.83	866		2.1	0.06			15.98	82
5/16/2009	407	11.53			0.81	867		2	0.06	58	27.24	17.06	84
5/17/2009	444	12.57	86	1.51	0.80	869		2.3	0.07			15.93	90
5/18/2009	471	13.34			0.82	925		3.7	0.10			14.87	135
5/19/2009	409	11.58			0.85	984		2.9	0.08			13.89	99
5/20/2009	372	10.54			0.87	1048		2.5	0.07			12.96	79
5/21/2009	429	12.15			0.89	1115		2.3	0.07			12.10	68
5/22/2009	527	14.92	74	3.01	0.92	1186		2.3	0.07			11.30	64
5/23/2009	560	15.86			0.92	1257		2.2	0.06			10.55	57
5/24/2009	576	16.31			0.91	1289		2.9	0.08	74	15.06	9.85	70
5/25/2009	557	15.77			0.91	1243		3.3	0.09	75	14.38	9.45	76
5/26/2009	617	17.47	75	2.88	0.91	1373		14	0.40			9.45	324
5/27/2009	642	18.18	74	3.01	0.92	1445		24	0.68			9.45	555
5/28/2009	700	19.82			0.93	1594		51	1.44			9.45	1180
5/29/2009	778	22.03	72	3.29	0.94	1793		82	2.32			9.45	1897
5/30/2009	778	22.03	73	3.15	0.93	1772		109	3.09			9.45	2521
5/31/2009	757	21.44	79	2.36	0.87	1608		131	3.71	75	14.38	9.45	3030

Table E12 – Continued

			430nm	m-1	mg/l	kg/day	kg/day			430nm	m-1	mg/l	kg/day
	BC Q(cfs)	BC Q(cms)	BC T(%)	BC NAC	BC TOC	BCmass	FC+BCmass	JC Q(cfs)	JCQ(cms)	JC T(%)	JC NAC	JC TOC	JCmass
3/1/2009	6.24	0.18	65	21.54	13.69	209	653	2.34	0.07	80	11.16	7.54	43
3/2/2009	5.80	0.16			13.60	193	589	2.38	0.07			7.54	44
3/3/2009	5.37	0.15			13.51	177	527	2.42	0.07			7.54	45
3/4/2009	4.97	0.14			13.42	163	467	2.46	0.07			7.54	45
3/5/2009	4.58	0.13			13.33	149	429	2.50	0.07			7.54	46
3/6/2009	4.23	0.12	66	20.78	13.24	137	393	2.54	0.07			7.54	47
3/7/2009	**3.38**	0.10	64	22.31	14.15	117	329	2.58	0.07	80	11.16	7.54	48
3/8/2009	3.89	0.11			14.02	133	330	2.62	0.07			7.69	49
3/9/2009	2.65	0.07			13.89	90	262	2.66	0.08			7.85	51
3/10/2009	1.86	0.05			13.76	63	214	2.70	0.08			8.01	53
3/11/2009	1.58	0.04			13.63	53	188	2.75	0.08			8.17	55
3/12/2009	1.51	0.04			13.50	50	170	2.79	0.08			8.33	57
3/13/2009	1.53	0.04			13.37	50	158	2.83	0.08			8.50	59
3/14/2009	**1.41**	0.04	66	20.78	13.24	46	143	2.88	0.08	77	13.07	8.67	61
3/15/2009	2.59	0.07			13.49	85	174	2.92	0.08			9.00	64
3/16/2009	1.54	0.04			13.75	52	133	2.96	0.08			9.34	68
3/17/2009	1.83	0.05			14.01	63	139	3.01	0.09			9.69	71
3/18/2009	2.48	0.07			14.28	87	157	3.06	0.09			10.05	75
3/19/2009	3.64	0.10			14.55	130	191	3.10	0.09			10.43	79
3/20/2009	4.67	0.13			14.83	169	224	3.15	0.09			10.82	83
3/21/2009	4.86	0.14			15.11	180	230	3.20	0.09			11.23	88
3/22/2009	6.12	0.17			15.40	231	274	3.25	0.09			11.65	93
3/23/2009	7.32	0.21			15.69	281	320	3.29	0.09			12.09	97
3/24/2009	7.58	0.21			15.99	297	335	3.34	0.09			12.55	103
3/25/2009	6.83	0.19			16.30	272	304	3.39	0.10			13.02	108
3/26/2009	3.49	0.10			16.61	142	174	3.45	0.10			13.51	114
3/27/2009	13.00	0.37			16.93	538	654	3.50	0.10			14.01	120
3/28/2009	19.43	0.55			17.25	820	1097	3.55	0.10			14.54	126
3/29/2009	**12.10**	0.34	57	28.11	17.58	520	1009	3.60	0.10	62	23.90	15.09	133
3/30/2009	16.44	0.47			18.00	724	1484	6.45	0.18			16.29	257
3/31/2009	25.71	0.73			18.44	1160	2234	11.56	0.33			17.59	497
4/1/2009	160.78	4.55			18.89	7431	10710	19.97	0.57			19.00	929
4/2/2009	206.23	5.84			19.35	9762	17379	32.78	0.93			20.52	1646
4/3/2009	235.91	6.68			19.82	11438	25733	51.04	1.45			22.16	2767
4/4/2009	174.37	4.94	52	32.70	20.30	8659	28912	75.83	2.15	46	38.83	23.93	4439
4/5/2009	**139.00**	3.94			21.02	7148	27436	55.92	1.58			23.56	3223
4/6/2009	123.73	3.50			21.77	6590	24513	40.11	1.14			23.19	2276
4/7/2009	101.87	2.88			22.54	5618	21542	27.90	0.79			22.83	1559
4/8/2009	82.16	2.33			23.34	4693	18554	18.78	0.53			22.48	1033
4/9/2009	64.61	1.83			24.17	3821	15015	12.26	0.35			22.14	664
4/10/2009	49.20	1.39			25.03	3014	11649	7.81	0.22			21.79	417
4/11/2009	35.95	1.02	43	42.20	25.92	2280	8924	4.94	0.14	50	34.66	21.46	260
4/12/2009	34.20	0.97			25.92	2169	7277	4.88	0.14			21.79	260
4/13/2009	32.50	0.92			25.92	2062	6677	4.82	0.14			22.14	261
4/14/2009	30.85	0.87			25.92	1957	8108	4.75	0.13			22.48	261
4/15/2009	29.24	0.83			25.92	1854	7137	4.69	0.13			22.83	262

Table E12 – Continued

			430nm	m-1	mg/l	kg/day	kg/day			430nm	m-1	mg/l	kg/day
	BC Q(cfs)	BC Q(cms)	BC T(%)	BC NAC	BC TOC	BCmass	FC+BCmass	JC Q(cfs)	JCQ(cms)	JC T(%)	JC NAC	JC TOC	JCmass
4/16/2009	27.67	0.78			25.92	1755	6364	4.63	0.13			23.19	263
4/17/2009	26.15	0.74			25.92	1659	5753	4.57	0.13			23.56	263
4/18/2009	24.68	0.70	43	42.20	25.92	1565	5350	4.51	0.13	46	38.83	23.93	264
4/19/2009	20.97	0.59			25.72	1320	4724	4.45	0.13			23.37	255
4/20/2009	17.59	0.50			25.53	1098	4138	4.39	0.12			22.83	245
4/21/2009	14.53	0.41			25.33	900	3509	4.34	0.12			22.30	237
4/22/2009	11.79	0.33			25.14	725	2882	4.28	0.12			21.78	228
4/23/2009	9.37	0.27			24.94	572	2335	4.23	0.12			21.28	220
4/24/2009	7.28	0.21			24.75	441	1901	4.17	0.12			20.78	212
4/25/2009	5.51	0.16			24.56	331	1539	4.12	0.12			20.30	204
4/26/2009	4.06	0.12			24.37	242	1243	4.06	0.12			19.83	197
4/27/2009	2.94	0.08			24.19	174	977	4.01	0.11			19.37	190
4/28/2009	2.14	0.06			24.00	126	774	3.96	0.11			18.92	183
4/29/2009	1.66	0.05			23.82	97	631	3.91	0.11			18.48	177
4/30/2009	1.50	0.04			23.64	87	511	3.86	0.11			18.05	170
5/1/2009	1.67	0.05			23.46	96	446	3.81	0.11			17.63	164
5/2/2009	2.16	0.06			23.28	123	403	3.76	0.11			17.22	158
5/3/2009	2.98	0.08			23.10	168	387	3.71	0.11			16.83	153
5/4/2009	4.12	0.12			22.92	231	409	3.66	0.10			16.43	147
5/5/2009	5.58	0.16			22.74	310	464	3.61	0.10			16.05	142
5/6/2009	7.36	0.21			22.57	406	540	3.57	0.10			15.68	137
5/7/2009	9.47	0.27			22.40	519	632	3.52	0.10			15.32	132
5/8/2009	11.90	0.34			22.23	647	747	3.48	0.10			14.96	127
5/9/2009	14.65	0.41	49	35.67	22.06	790	882	3.43	0.10	63	23.10	14.61	123
5/10/2009	14.65	0.41			21.44	768	853	3.39	0.10			14.61	121
5/11/2009	14.65	0.41			20.84	747	828	3.34	0.09			14.61	120
5/12/2009	18.31	0.52			20.26	908	982	3.30	0.09			14.61	118
5/13/2009	18.75	0.53			19.70	904	969	3.26	0.09			14.61	116
5/14/2009	18.31	0.52			19.15	858	942	3.21	0.09			14.61	115
5/15/2009	18.31	0.52			18.62	834	917	3.17	0.09			14.61	113
5/16/2009	16.63	0.47	56	28.99	18.10	737	820	3.13	0.09			14.61	112
5/17/2009	13.89	0.39			18.54	630	720	3.09	0.09			14.61	111
5/18/2009	13.53	0.38			18.99	628	763	3.05	0.09			14.61	109
5/19/2009	18.31	0.52			19.45	872	970	3.01	0.09			14.61	108
5/20/2009	16.22	0.46			19.92	791	870	2.97	0.08			14.61	106
5/21/2009	10.46	0.30			20.40	522	590	2.93	0.08			14.61	105
5/22/2009	8.11	0.23			20.90	415	478	2.89	0.08			14.61	103
5/23/2009	7.07	0.20			21.40	370	427	2.85	0.08			14.61	102
5/24/2009	5.47	0.15			21.92	293	363	2.82	0.08			14.61	101
5/25/2009	4.31	0.12			22.45	237	313	2.78	0.08			14.61	99
5/26/2009	3.80	0.11			23.00	214	538	2.74	0.08			14.61	98
5/27/2009	1.51	0.04			23.56	87	642	2.70	0.08			14.61	97
5/28/2009	2.65	0.07			24.13	156	1336	2.67	0.08			14.61	95
5/29/2009	2.65	0.07			24.71	160	2057	2.63	0.07			14.61	94
5/30/2009	3.01	0.09			25.31	186	2708	2.60	0.07			14.61	93
5/31/2009	4.23	0.12	43	42.20	25.92	268	3298	2.56	0.07	63	23.10	14.61	92

Table E12 – Continued

			430nm	m-1	mg/l	kg/day			430nm	m-1	mg/l	kg/day
	LC Q(cfs)	LC Q(cms)	LC T(%)	LC NAC	LC TOC	LCmass	MS Q(cfs)	MS Q(cms)	MS T(%)	MS NAC	MS TOC	MSmass
3/1/2009	33	0.93	65	21.54	13.69	1105	9.53	0.27	91	4.72	3.73	87
3/2/2009	39	1.10			13.46	1284	10.28	0.29			3.73	94
3/3/2009	36	1.02			13.23	1165	10.57	0.30			3.73	96
3/4/2009	33	0.93			13.00	1050	9.36	0.27			3.73	85
3/5/2009	30	0.85			12.78	938	8.61	0.24			3.73	79
3/6/2009	27	0.76			12.57	830	7.36	0.21			3.73	67
3/7/2009	26	0.74	68	19.28	12.35	786	6.34	0.18	91	4.72	3.73	58
3/8/2009	23	0.65			12.16	684	5.35	0.15			3.57	47
3/9/2009	21	0.59			11.97	615	4.78	0.14			3.42	40
3/10/2009	20	0.57			11.79	577	4.44	0.13			3.28	36
3/11/2009	19	0.54			11.61	540	3.31	0.09			3.14	25
3/12/2009	19	0.54			11.43	531	2.45	0.07			3.01	18
3/13/2009	17	0.48			11.25	468	2.31	0.07			2.89	16
3/14/2009	15	0.42	71	17.12	11.08	407	2.78	0.08	94	3.09	2.77	19
3/15/2009	14	0.40			11.18	383	2.74	0.08			2.72	18
3/16/2009	13	0.37			11.29	359	2.97	0.08			2.68	19
3/17/2009	15	0.42			11.40	418	5.58	0.16			2.63	36
3/18/2009	14	0.40			11.51	394	6.61	0.19			2.59	42
3/19/2009	13	0.37			11.62	370	9.12	0.26			2.54	57
3/20/2009	10	0.28			11.73	287	10.94	0.31			2.50	67
3/21/2009	9.1	0.26			11.85	264	8.69	0.25			2.46	52
3/22/2009	9.2	0.26			11.96	269	7.01	0.20			2.42	41
3/23/2009	7.8	0.22			12.08	230	5.42	0.15			2.38	32
3/24/2009	9.7	0.27			12.19	289	4.56	0.13			2.34	26
3/25/2009	7.1	0.20			12.31	214	3.9	0.11			2.30	22
3/26/2009	4.1	0.12			12.43	125	13.28	0.38			2.26	73
3/27/2009	20	0.57			12.55	614	67.99	1.93			2.22	369
3/28/2009	79	2.24			12.67	2449	71.65	2.03			2.18	382
3/29/2009	133	3.77	67	20.02	12.79	4163	77.59	2.20	96	2.04	2.14	407
3/30/2009	183	5.18			13.62	6099	35.07	0.99			2.45	210
3/31/2009	202	5.72			14.50	7168	30.11	0.85			2.79	206
4/1/2009	459	13.00			15.44	17341	273.24	7.74			3.18	2127
4/2/2009	1780	50.41			16.44	71598	583.19	16.52			3.63	5179
4/3/2009	2870	81.28			17.50	122912	902.61	25.56			4.14	9142
4/4/2009	2770	78.45	55	29.89	18.64	126306	520.93	14.75	88	6.39	4.72	6017
4/5/2009	2050	58.06			19.09	95752	336.73	9.54			4.86	4001
4/6/2009	1470	41.63			19.55	70334	240.12	6.80			4.99	2934
4/7/2009	982	27.81			20.03	48130	165.15	4.68			5.14	2076
4/8/2009	630	17.84			20.52	31630	94.16	2.67			5.28	1217
4/9/2009	451	12.77			21.02	23194	68.75	1.95			5.43	914
4/10/2009	341	9.66			21.53	17965	54	1.53			5.59	738
4/11/2009	266	7.53	49	35.67	22.06	14355	42.64	1.21	85	8.13	5.75	600
4/12/2009	212	6.00			22.14	11485	35.51	1.01			5.59	486
4/13/2009	184	5.21			22.23	10007	117.8	3.34			5.43	1566
4/14/2009	360	10.20			22.31	19656	375.62	10.64			5.28	4855
4/15/2009	509	14.41			22.40	27900	211.87	6.00			5.14	2663

Table E12 – Continued

			430nm	m-1	mg/l	kg/day			430nm	m-1	mg/l	kg/day
	LC Q(cfs)	LC Q(cms)	LC T(%)	LC NAC	LC TOC	LCmass	MS Q(cfs)	MS Q(cms)	MS T(%)	MS NAC	MS TOC	MSmass
4/16/2009	445	12.60			22.49	24487	83.66	2.37			4.99	1022
4/17/2009	344	9.74			22.58	19004	52.02	1.47			4.86	618
4/18/2009	268	7.59	48	36.70	22.67	14863	38.55	1.09	88	6.39	4.72	445
4/19/2009	209	5.92			22.24	11375	31.08	0.88			4.75	361
4/20/2009	170	4.81			21.83	9081	26.66	0.76			4.78	312
4/21/2009	140	3.96			21.42	7339	24.21	0.69			4.81	285
4/22/2009	116	3.29			21.03	5968	25.6	0.72			4.84	303
4/23/2009	95	2.69			20.63	4797	22.04	0.62			4.87	262
4/24/2009	78	2.21			20.25	3865	19.52	0.55			4.90	234
4/25/2009	63	1.78			19.87	3064	17.42	0.49			4.93	210
4/26/2009	53	1.50			19.50	2529	15.89	0.45			4.96	193
4/27/2009	44	1.25			19.14	2061	14.77	0.42			4.99	180
4/28/2009	38	1.08			18.79	1747	13.59	0.38			5.02	167
4/29/2009	32	0.91			18.44	1444	12.69	0.36			5.05	157
4/30/2009	28	0.79			18.09	1240	12.53	0.35			5.08	156
5/1/2009	24	0.68			17.76	1043	12.97	0.37			5.11	162
5/2/2009	21	0.59			17.43	895	13.32	0.38			5.14	168
5/3/2009	19	0.54			17.10	795	12.28	0.35			5.17	155
5/4/2009	17	0.48			16.78	698	11.56	0.33			5.21	147
5/5/2009	16	0.45			16.47	645	11.25	0.32			5.24	144
5/6/2009	12	0.34			16.17	475	11.11	0.31			5.27	143
5/7/2009	6.4	0.18			15.87	248	10.5	0.30			5.30	136
5/8/2009	1	0.03	61	24.71	15.57	38	9.61	0.27			5.34	125
5/9/2009	2.1	0.06			15.88	82	9.07	0.26			5.37	119
5/10/2009	1	0.03			16.20	40	8.37	0.24	86	7.54	5.40	111
5/11/2009	3.1	0.09			16.53	125	7.66	0.22			5.38	101
5/12/2009	2.1	0.06			16.86	87	7.02	0.20			5.37	92
5/13/2009	1	0.03			17.19	42	6.92	0.20			5.35	91
5/14/2009	1	0.03			17.54	43	9.09	0.26			5.33	119
5/15/2009	1	0.03			17.89	44	46.98	1.33			5.32	611
5/16/2009	1.2	0.03			18.25	54	25.41	0.72			5.30	330
5/17/2009	12	0.34			18.61	547	38.16	1.08			5.28	493
5/18/2009	19	0.54			18.99	883	68.18	1.93			5.27	879
5/19/2009	16	0.45			19.37	758	35.43	1.00			5.25	455
5/20/2009	13	0.37			19.76	628	23.74	0.67			5.24	304
5/21/2009	9.3	0.26			20.15	459	19.3	0.55			5.22	246
5/22/2009	8.4	0.24			20.56	423	22.68	0.64			5.20	289
5/23/2009	7.5	0.21			20.97	385	21.16	0.60			5.19	269
5/24/2009	16	0.45			21.39	837	36.46	1.03			5.17	461
5/25/2009	18	0.51			21.82	961	27.36	0.77			5.15	345
5/26/2009	32	0.91			22.25	1743	25.68	0.73			5.14	323
5/27/2009	98	2.78			22.70	5443	28.37	0.80			5.12	356
5/28/2009	207	5.86			23.16	11728	28.03	0.79			5.11	350
5/29/2009	503	14.24			23.62	29070	24.28	0.69			5.09	302
5/30/2009	528	14.95			24.09	31127	21.22	0.60			5.07	264
5/31/2009	388	10.99	45	39.93	24.58	23332	17.97	0.51	87	6.96	5.06	222

Table E13 - Wakulla Springs Colorimeter and Spectrophotometer
Wakulla Springs Vent/end of Glass Bottom Boat Dock

		Transmittance (%) by wavelength in nanometers							
Date	Time	254	350	430	520	570	620	FGS ID#	
8/14/2008				91					colorimeter
9/19/2008				98					colorimeter
9/23/2008				97					colorimeter
10/10/2008				100					colorimeter
10/16/2008				99					colorimeter
11/19/2008				97					colorimeter
11/20/2008				99					colorimeter
11/21/2008				100					colorimeter
11/24/2008				95					colorimeter
11/6/2008				97					colorimeter
12/5/2008				97					colorimeter
12/17/2008				96					colorimeter
11/25/2008				94					colorimeter
1/13/2009				96					colorimeter
2/13/2009	1300			100					colorimeter
2/13/2009	1300	60	83	90	93	94	95		spectrophotometer
2/18/2009	1230	81	96	98	99	99	99		spectrophotometer
3/4/2009	1400	61	83	88	92	94	95		spectrophotometer
3/10/2009	1230	69	90	97	99	99	99		spectrophotometer
3/12/2009	600	60	84	92	95	96	96		spectrophotometer
3/13/2009	600	46	74	85	90	91	92		spectrophotometer
3/14/2009	600	67	88	95	96	97	96		spectrophotometer
3/15/2009	600	68	87	95	97	97	97		spectrophotometer
3/16/2009	600	54	80	89	93	94	94		spectrophotometer
4/5/2009	1430	15	51	80	91	94	96		spectrophotometer
4/5/2009	1640	16.5	53	82	93	95	97		spectrophotometer
4/6/2009		4.7	33	71	89	92	94		spectrophotometer
4/8/2009		1	7	42	74	83	88		spectrophotometer
4/9/2009		1.15	6	41	76	85	91		spectrophotometer
4/10/2009		1.3	5	40	74	84	90		spectrophotometer
4/14/2009		1.65	13	51	79	86	90		spectrophotometer
4/15/2009		1.98	16	57	84	90	94		spectrophotometer
4/18/2009		4	28	69	91	96	98		spectrophotometer
4/19/2009		4.94	31	71	92	96	98		spectrophotometer
4/23/2009		9.23	40	73	88	92	95		spectrophotometer
4/24/2009		13	47	79	92	95	97		spectrophotometer
4/27/2009		17	51	78	90	93	95		spectrophotometer
4/28/2009		16	48	74	86	89	91		spectrophotometer
4/29/2009		26	59	82	92	94	96		spectrophotometer
4/30/2009		30	62	85	93	95	96		spectrophotometer
5/1/2009		34	64	84	92	94	96		spectrophotometer
5/2/2009		40	68	87	94	95	96		spectrophotometer
5/3/2009		42	69	87	94	95	96		spectrophotometer
5/6/2009	1930	57	85	95	96	96	96		spectrophotometer
5/7/2009	1910	46	77	89	92	92	92		spectrophotometer
5/8/2009	1048	69	94	100	101	101	100		spectrophotometer
5/12/2009		76	94	98	97	97	96		spectrophotometer
5/13/2009	600	78	95	98	97	97	96		spectrophotometer
5/14/2009	600	81	96	98	98	97	96		spectrophotometer
5/15/2009	1443	83	99	101	101	100	99		spectrophotometer
5/17/2009	1507	86	100	102	101	101	100		spectrophotometer
5/22/2009	1400	73.8	95	99	100	100	99		spectrophotometer
5/26/2009	1932	75	94	101	101	100	100		spectrophotometer
5/27/2009	1648	74	95	101	101	100	100		spectrophotometer
5/29/2009	1350	72	94	101	100	100	99		spectrophotometer
5/30/2009	1846	73	94	101	101	101	99		spectrophotometer
5/31/2009	1727	79	98	103	102	102	100		spectrophotometer
6/4/2009	1931	50	84	98	100	100	99		spectrophotometer
6/8/2009	1735	19	60	89	97	99	99		spectrophotometer
6/9/2009	1723	17	57	88	96	98	98		spectrophotometer
6/10/2009	1708	16	57	88	97	98	98		spectrophotometer
6/11/2009	1451	16	57	87	96	98	98		spectrophotometer
6/11/2009	1530	15	56	87	96	98	98		spectrophotometer

Table E13 – Continued

		Transmittance (%) by wavelength in nanometers							
Date	Time	254	350	430	520	570	620	FGS ID#	
6/12/2009	1655	18	57	83	92	94	94		spectrophotometer
6/14/2009	1615	12	38	58	65	67	68		spectrophotometer
6/14/2009	1932	17	55	82	93	95	96		spectrophotometer
6/17/2009	600	14	49	75	86	89	90	VR1#1	spectrophotometer
6/18/2009	600	13	48	75	87	90	91	VR1#2	spectrophotometer
6/19/2009	600	18	55	82	91	93	94	VR1#3	spectrophotometer
6/20/2009	600	19	57	83	92	93	94	VR1#4	spectrophotometer
6/21/2009	600	18	56	82	92	94	94	VR1#5	spectrophotometer
6/22/2009	600	17	54	81	91	93	93	VR1#6	spectrophotometer
6/23/2009	600	17	53	79	89	92	92	VR1#7	spectrophotometer
6/24/2009	600	19	56	81	90	92	93	VR1#8	spectrophotometer
6/25/2009	600	20	57	82	92	94	94	VR1#9	spectrophotometer
6/26/2009	600	19	56	81	90	92	93	VR1#10	spectrophotometer
6/27/2009	600	14	53	82	93	96	97	VR1#11	spectrophotometer
6/28/2009	600	15	55	84	95	97	98	VR1#12	spectrophotometer
6/29/2009	600	15	55	84	95	98	99	VR1#13	spectrophotometer
6/30/2009	600	18	56	83	94	97	98	VR1#14	spectrophotometer
7/1/2009	600	20	60	85	95	96	98	VR1#15	spectrophotometer
7/2/2009	600	22	61	86	94	96	97	VR1#16	spectrophotometer
7/15/2009	2000	42	81	93	96	96	96		spectrophotometer
7/16/2009	800	43	82	93	96	96	96		spectrophotometer
7/17/2009	800	43	82	93	96	96	96		spectrophotometer
7/18/2009	800	42	79	91	94	95	95		spectrophotometer
7/18/2009	2000	48	86	96	98	98	98		spectrophotometer
7/19/2009	800	51	87	97	98	98	98		spectrophotometer
7/20/2009	800	47	85	96	98	98	98		spectrophotometer
7/21/2009	800	45	81	92	94	94	94		spectrophotometer
7/22/2009	800	39.5	77	94	99	100	100	BDR2#02	spectrophotometer
7/23/2009	800	30	63	78	85	86	87	BDR2#04	spectrophotometer
7/24/2009	800	38	76	94	99	100	100	BDR2#06	spectrophotometer
7/25/2009	800	41	79	96	101	101	101	BDR2#08	spectrophotometer
7/26/2009	800	39	78	95	100	101	101	BDR2#10	spectrophotometer
7/27/2009	800	42	80	98	102	102	102	BDR2#12	spectrophotometer
7/28/2009	800	36	74	91	96	97	97	BDR2#14	spectrophotometer
7/29/2009	800	37	74	91	96	96	97	BDR2#16	spectrophotometer
7/30/2009	800	39.6	79	96	100	101	101	BDR2#18	spectrophotometer
7/31/2009	800	39	78	95	100	100	101	BDR2#20	spectrophotometer
8/1/2009	800	48	81	92	95	96	97	BDR3#02	spectrophotometer
8/2/2009	800	46	76	87	92	92	93	BDR3#04	spectrophotometer
8/3/2009	800	49	79	90	93	94	94	BDR3#06	spectrophotometer
8/4/2009	800	56	86	95	97	97	97	BDR3#08	spectrophotometer
8/5/2009	800	58	88	96	98	99	99	BDR3#10	spectrophotometer
8/6/2009	800	63	92	99	100	101	101	BDR3#12	spectrophotometer
8/7/2009	800	37	68	80	84	85	86	R4-02B	spectrophotometer
8/8/2009	800	43	79	91	95	96	96	R4-04	spectrophotometer
8/9/2009	800	43	79	92	96	97	97	R4-06	spectrophotometer
8/10/2009	800	37	74	90	94	95	95	R4-08	spectrophotometer
8/11/2009	800	34	74	91	95	96	96	R4-10	spectrophotometer
8/12/2009	800	31	68	85	90	90	90	R4-12	spectrophotometer
8/13/2009	800	28	67	87	95	97	100	R4-14	spectrophotometer
8/14/2009	800	30	68	88	95	96	96	R5-02	spectrophotometer
8/15/2009	800	27	65	86	93	95	95	R5-04	spectrophotometer
8/16/2009	800	25	64	86	93	95	95	R5-06	spectrophotometer
8/17/2009	800	22	59	83	91	93	93	R5-08	spectrophotometer
8/18/2009	800	21	60	85	94	95	95	R5-10	spectrophotometer
8/19/2009	800	17	56	82	92	94	94	R5-12	spectrophotometer
8/20/2009	800	16	55	82	91	93	94	R5-14	spectrophotometer
8/21/2009	800	16	57	84	95	97	98	BDR6-02	spectrophotometer
8/22/2009	800	16	57	85	96	98	99	R6-04	spectrophotometer
8/23/2009	800	18	61	86	97	99	100	R6-06	spectrophotometer
8/24/2009	800	19	61	88	97	99	100	R6-08	spectrophotometer
8/25/2009	800	22	64	88	97	99	100	R6-10	spectrophotometer
8/26/2009	800	25	68	91	99	100	101	R6-12	spectrophotometer
8/27/2009	800	21	61	84	94	96	97	R6-14	spectrophotometer
8/28/2009	800	26	68	90	98	99	100	R6-16	spectrophotometer

Table E13 – Continued

		Transmittance (%) by wavelength in nanometers							
Date	Time	254	350	430	520	570	620	FGS ID#	
8/29/2009	800	28	68	89	97	99	99	R6-18	spectrophotometer
8/30/2009	800	34	73	91	98	99	99	R6-20	spectrophotometer
8/31/2009	800	32	73	91	98	99	99	R6-22	spectrophotometer
9/1/2009	800	40.1	72.6	88	94.4	95.8	97	BDR7-02	spectrophotometer
9/2/2009	800	48.6	79.6	93.3	98.8	99.9	100.6	BDR7-04	spectrophotometer
9/3/2009	800	42.1	71.4	84.2	91.9	93.5	94.6	BDR7-06	spectrophotometer
9/4/2009	800	45.4	78	91.5	96.8	98	98.7	BDR7-08	spectrophotometer
9/5/2009	800	51.3	81.4	93.7	98.6	99.6	100.1	BDR7-10	spectrophotometer
9/6/2009	800	52.3	83.4	94.8	99.3	100.1	100.8	BDR7-12	spectrophotometer
9/7/2009	800	59.2	85.3	96	100	101	101.4	BDR7-14	spectrophotometer
9/8/2009	800	59.8	85.7	95.9	99.5	100.6	101	BDR7-16	repeat analysis 9-26-09 49% 254nm
9/9/2009	800	48.6	46	86.7	91.2	92	93.8	BDR8-02	outlier on 254/350 correlation plot
9/10/2009	800	45.6	75.9	87.5	92.6	93.9	95	BDR8-04	spectrophotometer
9/11/2009	800	48	78.9	90.4	95.1	95.9	96.8	BDR8-06	v high particulate; some suspended
9/12/2009	800	49.4	79.6	91.2	96.1	96.9	98	BDR8-08	spectrophotometer
9/13/2009	800	51.4	81.4	92.9	97	98.3	99.2	BDR8-10	spectrophotometer
9/14/2009	800	50.9	82.1	92.9	97.3	97.9	98.8	BDR8-12	spectrophotometer
9/15/2009	800	51.7	81.5	92.6	96.9	97.6	98.3	BDR8-14	spectrophotometer
9/16/2009	800	41.1	73	85.7	91.4	93.5	94.5	BDR8-16	spectrophotometer
9/17/2009	800	39.3	73	86.3	92.2	93.9	94.9	BDR8-18	spectrophotometer
9/18/2009	800	43.7	78.1	90	93.5	94.6	95	BDR9-02	spectrophotometer
9/19/2009	800	43.5	77.4	90.4	94.6	95.9	95.8	BDR9-04	spectrophotometer
9/20/2009	800	42.1	75.2	87.5	91.2	92.3	92.5	BDR9-06	spectrophotometer
9/21/2009	800	41.7	75.7	88.5	93.2	94.2	94.6	BDR9-08	spectrophotometer
9/22/2009	800	46	79.2	91.5	94.9	95.7	95.2	BDR9-10	spectrophotometer
9/23/2009	800	45.6	79.2	92.1	95.9	96.7	96.3	BDR9-12	spectrophotometer
9/24/2009	800	38	76.7	92.2	96.6	97.5	97.3	BDR9-14	spectrophotometer
9/25/2009	800	35	71.8	89.6	95.3	96.4	96.6	BDR9-16	spectrophotometer
9/26/2009	800	26.4	63.7	83.8	91.2	93.1	93.7	BDR9-18	spectrophotometer
9/27/2009	800	30.4	69.2	88.8	95.1	96.4	96.4	BDR9-20	spectrophotometer
9/28/2009	800	31.2	70.4	89.4	95.5	96.8	96.7	BDR9-22	spectrophotometer
9/29/2009	800	25.5	65.8	87.2	94.2	95.6	96	BDR9-24	spectrophotometer
9/30/2009	800	33	74	91.6	96.4	97.5	97.8	BDR10-02	spectrophotometer
10/1/2009	800	30.3	74.8	93.4	98.4	99.4	99.5	BDR10-04	spectrophotometer
10/2/2009	800	30.4	72.2	92	97.4	98.2	98.4	BDR10-06	spectrophotometer
10/3/2009	800	28.4	69.4	88.8	95.2	96.4	97.1	BDR10-08	spectrophotometer
10/4/2009	800	33.3	75	93.3	98	98.7	99	BDR10-10	spectrophotometer
10/5/2009	800	33.5	75	93.3	98.3	99	99.4	BDR10-12	spectrophotometer
10/6/2009	800	31.3	72.9	91.4	96.9	97.8	98.4	BDR10-14	spectrophotometer
10/7/2009	800	30.7	71.6	89.6	95.2	96.6	96.9	BDR10-16	spectrophotometer

Table E14 – Wakulla Springs Tunnels

Location		Transmittance (in decimal form) by wavelength in nanometers					
Sally Ward	Time	254	350	430	520	570	620
4/5/2009		0.43	0.72	0.89	0.95	0.97	0.98
WS Vent Tube							
2/18/2009		0.79	0.92	0.95	0.95	0.96	0.95
WS Vent							
9/23/2009	1438	0.254	0.644	0.821	0.896	0.92	0.932
C Tunnel							
2/18/2009		0.87	0.98	0.99	0.99	0.99	0.99
9/23/2009	1538	0.621	0.87	0.931	0.955	0.964	0.97
B Tunnel							
2/18/2009		0.86	0.97	0.98	0.99	0.99	0.99
9/23/2009	1606	0.313	0.689	0.809	0.876	0.9	0.913
D Tunnel							
2/18/2009		0.85	0.97	0.99	1	0.99	0.99
9/23/2009	1658	0.692	0.881	0.927	0.95	0.96	0.965
AD Tunnel							
2/18/2009		0.65	0.89	0.95	0.97	0.97	0.97
9/23/2009	1638	0.234	0.63	0.85	0.93	0.95	0.96
AK Tunnel							
2/18/2009		0.58	0.85	0.95	0.98	0.98	0.99
9/23/2009	1545	0.286	0.654	0.846	0.919	0.939	0.948
K Tunnel							
2/18/2009		0.48	0.78	0.92	0.97	0.98	0.99
9/23/2009	1800	0.286	0.694	0.894	0.946	0.953	0.955
6/27/2009	600	0.02	0.25	0.59	0.81	0.86	0.9
Maxi- Blow							
5/23/2009	300	0.21	0.66	0.91	0.96	0.97	0.97
Lake Munson							
2/18/2009		0.007	0.2	0.6	0.79	0.83	0.86

Table E15 – Wakulla Springs and Stream Data, January 1 to October 14, 2009
Data from USGS: Discharge and Stage for Wakulla Springs, Fisher Creek, and Lost Creek
Data from NWFWMD: Stage and Discharge for Munson Slough

	WSQ(cfs)	WSNAC	ActiveBoat	FCstage	FC Q(cfs)	FC 430T	FC430NAC	BC Stage	BC Q(cfs)	BC 430T	BC430NAC	JC stage	JC Q(cfs)
1/1/2009	400	3.71		10.56	15	0.64	22.3	1.35	3	0.54	30.81	2.85	0.7
1/2/2009	436			10.51	14								
1/3/2009	529			10.47	13								
1/4/2009	578			10.46	12								
1/5/2009	570			10.43	11								
1/6/2009	526			10.39	11								
1/7/2009	552			10.38	10								
1/8/2009	447			10.36	9.8								
1/9/2009	404			10.35	9.6								
1/10/2009	428			10.35	9.6								
1/11/2009	460			10.36	9.8	0.68	19.3	1.15		0.54	30.81	2.67	
1/12/2009	416			10.34	9.5								
1/13/2009	435	3.71		10.34	9.5			1.2					
1/14/2009	392			10.31	8.9								
1/15/2009	334			10.29	8.3								
1/16/2009	270			10.25	7.5								
1/17/2009	253			10.23	7								
1/18/2009	305			10.23	7.1								
1/19/2009	391			10.28	8.3	0.72	16.4	1.38	3.11	0.65	21.54		
1/20/2009	390			10.25	7.8								
1/21/2009	252			10.24	7.4								
1/22/2009	263			10.22	7.1								
1/23/2009	346			10.21	6.9								
1/24/2009	409			10.2	6.6								
1/25/2009	412			10.18	6.3								
1/26/2009	388			10.19	6.5								
1/27/2009	420			10.21	7.1	0.74	15.1	1.6		0.61	24.71		
1/28/2009	425			10.2	6.8								
1/29/2009	447			10.19	6.7								
1/30/2009	394			10.19	6.7								
1/31/2009	291			10.19	6.6								
2/1/2009	281			10.19	6.8								
2/2/2009	313			10.19	6.8								
2/3/2009	374			10.18	6.7								
2/4/2009	294			10.16	6.3								
2/5/2009	201			10.15	6								
2/6/2009	219			10.14	5.7								
2/7/2009	291			10.12	5.5								
2/8/2009	339			10.11	5.2								
2/9/2009	355			10.09	4.9								
2/10/2009	393			10.08	4.6								
2/11/2009	411			10.06	4.4								
2/12/2009	452			10.05	4.1								
2/13/2009	411	5.11		10.03	3.9								

Table E15 – Continued

	WSQ(cfs)	WSNAC	ActiveBoat	FCstage	FC Q(cfs)	FC 430T	FC430NAC	BC Stage	BC Q(cfs)	BC 430T	BC430NAC	JC stage	JC Q(cfs)
2/14/2009	385			10.21	7.5								
2/15/2009	345			10.39	12								
2/16/2009	339			10.54	15								
2/17/2009	279			10.63	18	0.68	19	1.68		0.58	27.24		2.76
2/18/2009	340	2.36		10.7	20								
2/19/2009	447			10.8	23								
2/20/2009	386			10.88	25								
2/21/2009	315			10.96	28	0.69	19	1.72				2.83	1.62
2/22/2009	351		1000	10.98	29								
2/23/2009	291		1000	10.96	28								
2/24/2009	269		1000	10.94	27								2.4
2/25/2009	300		1000	10.9	26	0.77	13	1.58		0.65	21.54		
2/26/2009	345		1000	10.85	24								
2/27/2009	363		1000	10.79	22								
2/28/2009	368		1000	10.73	21								
3/1/2009	365		1000	10.72	20	0.76	14						
3/2/2009	254		1000	10.64	18								
3/3/2009	236		1000	10.57	16								
3/4/2009	269	4.9	1000	10.51	14								
3/5/2009	296		1000	10.45	13								
3/6/2009	369		1000	10.4	12			1.4		0.66	20.78		
3/7/2009	398			10.34	10	0.77	13	1.4	3.38	0.64	22.31		0.37
3/8/2009	407			10.29	9.2			1.38					
3/9/2009	400			10.25	8			1.29					
3/10/2009	371	3.7		10.2	7			1.2					
3/11/2009	351			10.16	6.2			1.14					
3/12/2009	336	5.1		10.12	5.5			1.09					
3/13/2009	329	7.8		10.09	4.9			1.06					
3/14/2009	348	4.0		10.06	4.4	0.76	14	0.9	1.41	0.66	20.78		0.25
3/15/2009	362	3.9		10.04	4			0.89					
3/16/2009	345	6.2		10.02	3.7			1.05					
3/17/2009	315			10	3.5			0.98					
3/18/2009	321			9.98	3.2			0.9					
3/19/2009	348			9.96	2.8			0.81					
3/20/2009	378			9.94	2.5			0.75					
3/21/2009	356			9.92	2.3			0.74					
3/22/2009	318			9.9	2			0.68					
3/23/2009	327			9.89	1.8			0.63					
3/24/2009	366			9.89	1.8			0.62					
3/25/2009	375			9.87	1.5			0.65					
3/26/2009	383			9.87	1.5			0.82					
3/27/2009	466			10.13	5.4			1.73					
3/28/2009	425			10.46	13			1.89					
3/29/2009	604			10.81	23	0.77	13	1.92	12.1	0.57	28.11	3	4.77
3/30/2009	496			11.08	33			1.82					
3/31/2009	456			11.33	43			2.02					

Table E15 – Continued

	WSQ(cfs)	WSNAC	ActiveBoat	FCstage	FC Q(cfs)	FC 430T	FC430NAC	BC Stage	BC Q(cfs)	BC 430T	BC430NAC	JC stage	JC Q(cfs)
4/1/2009	646			12.71	121			3.48					
4/2/2009	821			14.53	259			3.8					
4/3/2009	1270			16.48	448			3.99					
4/4/2009	1580			17.47	585	0.61	25	3.58		0.52	32.70	4.1	75.87
4/5/2009	1690	19		17.39	573			3.38	139				
4/6/2009	1700	31		16.86	495								
4/7/2009	1580			16.37	430								
4/8/2009	1440	46.1		15.79	366								
4/9/2009	1350	44.7		15.02	289								
4/10/2009	1250	43.4		14.22	218								
4/11/2009	1220			13.54	164	0.59	26	2.2		0.43	42.20	3.1	5.3
4/12/2009	1110			12.97	125								
4/13/2009	1060			12.75	112								
4/14/2009	1110	41		13.32	148								
4/15/2009	1110	39		12.99	126								
4/16/2009	1060			12.71	109								
4/17/2009	1050			12.49	96								
4/18/2009	994	32		12.34	88	0.57	28	2		0.43	42.20		
4/19/2009	950	30		12.22	81								
4/20/2009	938			12.08	74								
4/21/2009	889			11.89	65								
4/22/2009	819			11.68	55								
4/23/2009	777	23.8		11.46	46								
4/24/2009	742	20.4		11.27	39								
4/25/2009	714			11.1	33								
4/26/2009	705			10.95	28								
4/27/2009	688	17.7		10.82	23								
4/28/2009	662	18.3		10.7	19								
4/29/2009	627	13.5		10.58	16								
4/30/2009	608	12.0		10.48	13								
5/1/2009	587	10.8		10.39	11								
5/2/2009	577	9.2		10.32	9								
5/3/2009	556	8.7		10.25	7.2								
5/4/2009	553			10.19	6								
5/5/2009	539			10.15	5.3								
5/6/2009	508	5.6		10.12	4.7								
5/7/2009	483	7.8		10.08	4.1								
5/8/2009	464	3.7		10.06	3.7	0.68	19						
5/9/2009	446			10.03	3.3			0.4		0.49	35.67	2.1	
5/10/2009	447			10.01	3	0.71	17						
5/11/2009	428			9.98	2.7			0.4					
5/12/2009	420	2.7		9.96	2.3			0.31					
5/13/2009	413	2.5		9.92	1.9			0.3					
5/14/2009	424	2.1		9.95	2.3			0.31					
5/15/2009	427	1.9		9.94	2.1			0.31					
5/16/2009	407			9.93	2	0.58	27	0.35		0.56			

Table E15 – Continued

	WSQ(cfs)	WSNAC	ActiveBoat	FCstage	FC Q(cfs)	FC 430T	FC430NAC	BC Stage	BC Q(cfs)	BC 430T	BC430NAC	JC stage	JC Q(cfs)
5/17/2009	444	1.5		9.96	2.3			0.42					
5/18/2009	471			10.06	3.7			0.43					
5/19/2009	409			10	2.9			0.31					
5/20/2009	372			9.97	2.5			0.36					
5/21/2009	429			9.95	2.3			0.52					
5/22/2009	527	3.0		9.96	2.3			0.6					
5/23/2009	560			9.95	2.2			0.64					
5/24/2009	576			10	2.9	0.74	15	0.71					
5/25/2009	557			10.03	3.3	0.75	14	0.77					
5/26/2009	617	2.9		10.46	14			0.8					
5/27/2009	642	3.0		10.84	24			1.08					
5/28/2009	700			11.48	51			1.29					
5/29/2009	778	3.3		12.04	82			1.29					
5/30/2009	778	3.1		12.45	109								
5/31/2009	757	2.4		12.75	131								
6/1/2009	738			12.79	135								
6/2/2009	727			12.63	123								
6/3/2009	728			12.38	105								
6/4/2009	757	7		12.33	101								
6/5/2009	759			12.32	100								
6/6/2009	767			12.22	94								
6/7/2009	752			12.02	81								
6/8/2009	735	17		11.84	70								
6/9/2009	712	18		11.67	61								
6/10/2009	668	18		11.51	52								
6/11/2009	645	18		11.34	44								
6/12/2009	615	17		11.17	36								
6/13/2009	596	21		11.02	30								
6/14/2009	584	18		10.87	25								
6/15/2009	592			10.71	20								
6/16/2009	605			10.57	17								
6/17/2009	622	20		10.45	14								
6/18/2009	641	20		10.34	11								
6/19/2009	654	17		10.22	8.3								
6/20/2009	657	17		10.13	6.3	0.63	23	0.6		0.43	42.20	2.58	
6/21/2009	667	17		10.06	5								
6/22/2009	668	18		10.01	4								
6/23/2009	698	18		9.96	3.4								
6/24/2009	716	17		10.03	4.4								
6/25/2009	764	16		9.99	3.7								
6/26/2009	804	17		9.98	3.7								
6/27/2009	859	20		9.99	3.7	0.6	26	0.38		0.44	41.05		
6/28/2009	879	19		10.05	4.8								
6/29/2009	886	19		10.29	9.9								
6/30/2009	889	17		10.27	9.4								
7/1/2009	888	16		10.23	8.4								

Table E15 – Continued

	WSQ(cfs)	WSNAC	ActiveBoat	FCstage	FC Q(cfs)	FC 430T	FC430NAC	BC Stage	BC Q(cfs)	BC 430T	BC430NAC	JC stage	JC Q(cfs)
7/2/2009	905	15		10.19	7.5								
7/3/2009	904			10.21	8								
7/4/2009	878			10.12	6.1	0.65	22	0.58		0.59	26.38	2.6	
7/5/2009	874			10.06	4.9								
7/6/2009	892			10.08	5.4								
7/7/2009	905			10.13	6.3								
7/8/2009	892			10.16	6.8								
7/9/2009	896			10.11	5.9								
7/10/2009	895			10.07	5.1								
7/11/2009	884			10.06	4.9								
7/12/2009	874			10.02	4.3								
7/13/2009	882			9.98	3.6								
7/14/2009	886			9.96	3.3								
7/15/2009	870	9		10.11	5.9								
7/16/2009	870	8		10.14	6.4			1.25					
7/17/2009	871	8		10.11	5.9	0.67	20	0.68	2	0.65	21.54	2.7	0.34
7/18/2009	870	9		10.11	5.9			0.57					
7/19/2009	877	7		10.1	5.6			0.31					
7/20/2009	884	8		10.06	4.9			0.29					
7/21/2009	860	8		10.01	4			0.29					
7/22/2009	868	9		9.96	3.3			0.51					
7/23/2009	930	12		9.93	2.9			0.61					
7/24/2009	940	10		9.89	2.4			0.7					
7/25/2009	946	9		9.87	2.1	0.7	18	0.52		0.51	33.67	1.82	0
7/26/2009	975	9		9.85	1.9			0.89					
7/27/2009	992	9		9.88	2.3			0.89					
7/28/2009	877	10		9.97	3.5			0.83					
7/29/2009	878	10		10.05	4.7			0.83					
7/30/2009	873	9		10.23	8.4			0.86					
7/31/2009	869	9		10.11	5.9			0.98					
8/1/2009	857	7		10.16	6.9	0.69	19	1.4		0.48	36.70	2.65	0.64
8/2/2009	884	8		10.15	6.7			1.3	17	0.48	36.70		
8/3/2009	911	7		10.18	7.2			1.26					
8/4/2009	919	6		10.49	15			1.24					
8/5/2009	929	5		10.79	23			1.24					
8/6/2009	961	5		10.92	27			1.22					
8/7/2009	964	10		11.02	30	0.66	20.8	1.5		0.43	42.20		
8/8/2009	979	8		11.1	33	0.66	20.8						
8/9/2009	978	8		11.13	35			1.58		0.44	41.05	2.71	
8/10/2009	982	10		11.12	34								
8/11/2009	981	11		11.01	30								
8/12/2009	963	12		10.91	27								
8/13/2009	968	13		10.9	26								
8/14/2009	970	12		10.77	22								
8/15/2009	970	13		10.7	20	0.62	23.9	1.2		0.43	42.20	2.6	0.43
8/16/2009	937	14		10.62	18	0.62	23.9						

Table E15 – Continued

	WSQ(cfs)	WSNAC	ActiveBoat	FCstage	FC Q(cfs)	FC 430T	FC430NAC	BC Stage	BC Q(cfs)	BC 430T	BC430NAC	JC stage	JC Q(cfs)
8/17/2009	1050	15		10.56	16								
8/18/2009	1000	16		10.49	15								
8/19/2009	972	18		10.44	13								
8/20/2009	968	18		10.44	13								
8/21/2009	1000	18		10.44	13								
8/22/2009	916	18		10.46	14								
8/23/2009	823	17		10.44	13	0.65	21.5	0.88		0.43	42.20	2.3	
8/24/2009	760	17		10.42	13								
8/25/2009	701	15		10.4	13								
8/26/2009	657	14		10.37	12								
8/27/2009	730	16		10.39	12								
8/28/2009	738	14		10.47	14								
8/29/2009	696	13		10.42	13								
8/30/2009	653	11		10.36	11								
8/31/2009	629	11		10.32	11								
9/1/2009	612	9		10.35	11								
9/2/2009	629	7		10.42	13								
9/3/2009	610	9		10.4	13								
9/4/2009	617	8		10.39	12								
9/5/2009	600	7		10.4	13								
9/6/2009	580	7		10.42	13	0.72	16.4	0.62		0.43	42.20	2.5	
9/7/2009	578	5		10.43	13								
9/8/2009	569	5		10.42	13								
9/9/2009	564	7		10.38	12								
9/10/2009	557	8		10.33	11								
9/11/2009	555	7		10.26	9								
9/12/2009	609	7		10.23	8.4								
9/13/2009	637	7		10.31	10	0.7	17.8	1.32		0.57	28.11	3.08	
9/14/2009	624	7		10.25	8.8								
9/15/2009	642	7		10.35	11								
9/16/2009	645	9		10.35	11								
9/17/2009	709	9		10.37	12								
9/18/2009	765	8		10.53	16								
9/19/2009	807	8		10.59	17	0.69	18.6	1.72		0.42	43.38	3.4	16
9/20/2009	833	8		10.63	18								
9/21/2009	838	9		10.67	19								
9/22/2009	818	8		10.69	20								
9/23/2009	791	8		10.67	19								
9/24/2009	758	10		10.63	18								
9/25/2009	754	11		10.58	17								
9/26/2009	724	13		10.5	15								
9/27/2009	713	12		10.41	13	0.67	20	0.94		0.45	39.93	2.79	
9/28/2009	703	12		10.32	11								
9/29/2009	771	14		10.23	8.5								
9/30/2009	767	11		10.16	6.7								
10/1/2009	768	12		10.1	5.6								

Table E15 – Continued

	WSQ(cfs)	WSNAC	ActiveBoat	FCstage	FC Q(cfs)	FC 430T	FC430NAC	BC Stage	BC Q(cfs)	BC 430T	BC430NAC	JC stage	JC Q(cfs)
10/2/2009	784	12		10.04	4.6								
10/3/2009	787	13		10	4								
10/4/2009	788	11		9.96	3.3	0.69	18.6	0.54		0.47	37.75	2.58	
10/5/2009	812	11		9.95	3.1								
10/6/2009	814	12		10.02	4.2								
10/7/2009	770	12		10.01	4.1								
10/8/2009	702			9.98	3.6								
10/9/2009	646			9.96	3.4								
10/10/2009	651			9.95	3.1	0.74	15.1	0.58	1.3	0.47	37.75	2.58	0.6
10/11/2009	654			9.99	3.8								
10/12/2009	698			9.98	3.6								
10/13/2009	727			9.98	3.6								
10/14/2009	722	6		9.99	3.7								

Table E15 – Continued

	JC 430T	JC430NAC	LCstage	LCQ	LC T	LC430NAC	MSstage	MS Q	MS 430T	MS430NAC
1/1/2009	0.65	21.54	2.88	24	0.51	33.67	27.02	0.81	0.9	5.27
1/2/2009			2.82	22			26.99	0.75		
1/3/2009			2.76	20			26.98	0.73		
1/4/2009			2.75	19			27.16	1.17		
1/5/2009			2.79	21			27.13	1.09		
1/6/2009			2.82	22			27.02	0.8		
1/7/2009			2.87	24			27.07	0.93		
1/8/2009			2.89	24			27.07	0.92		
1/9/2009			2.87	24			27.01	0.78		
1/10/2009			2.86	23			26.96	0.69		
1/11/2009	0.71	17.12	2.81	21	0.55	29.89	26.94	0.66		
1/12/2009			2.8	21			26.94	0.65		
1/13/2009			2.76	20			26.91	0.61		
1/14/2009			2.76	19			26.89	0.58		
1/15/2009			2.72	18			26.87	0.54		
1/16/2009			2.68	17			26.86	0.52		
1/17/2009			2.63	16			26.84	0.49		
1/18/2009			2.61	15			26.87	0.54		
1/19/2009			2.74	19	0.60	25.54	27.05	0.88		
1/20/2009			2.82	22			26.99	0.75		
1/21/2009			2.93	26			26.94	0.65		
1/22/2009			2.91	25			26.91	0.6		
1/23/2009			2.86	23			26.89	0.57		
1/24/2009			2.82	22			26.88	0.56		
1/25/2009			2.76	20			26.88	0.55		
1/26/2009			2.72	18			26.87	0.54		
1/27/2009			2.73	19	0.62	23.90	26.87	0.55		
1/28/2009			2.82	22			26.94	0.68		
1/29/2009			2.86	23			27.24	1.43		
1/30/2009			2.85	23			27.14	1.11		
1/31/2009			2.82	22			27.02	0.81		
2/1/2009			2.78	20			26.96	0.7		
2/2/2009			2.69	18			26.9	0.59		
2/3/2009			2.65	16			26.98	0.81		
2/4/2009			2.6	15			27.52	2.67		
2/5/2009			2.55	13			27.6	3.12		
2/6/2009			2.52	12			27.6	3.15		
2/7/2009			2.49	9.8			27.57	2.96		
2/8/2009			2.45	8.3			27.54	2.79		
2/9/2009			2.44	7.8			27.52	2.67		
2/10/2009			2.41	6.9			27.51	2.61		
2/11/2009			2.39	6.1			27.41	2.11		
2/12/2009			2.34	4.4			27.36	1.86		
2/13/2009			2.35	5			27.29	1.58		

Table E15 – Continued

	JC 430T	JC430NAC	LCstage	LCQ	LC T	LC430NAC	MSstage	MS Q	MS 430T	MS430NAC
2/14/2009			2.47	11			28.21	13.55		
2/15/2009			3.18	37			28.64	19.09		
2/16/2009			3.76	64			28.44	14.03		
2/17/2009	0.76	13.72	4.02	78	0.57	28.11	28.31	11.35		
2/18/2009			4.02	79			28.19	9.34	0.95	2.56
2/19/2009			4.04	80			28.6	18.89		
2/20/2009			4.01	79			28.63	18.67		
2/21/2009	0.60	25.54	3.87	71			28.44	13.97		
2/22/2009			3.75	65			28.36	12.41		
2/23/2009			3.61	59			28.27	10.74		
2/24/2009			3.48	53	0.65	21.54	28.17	9.01		
2/25/2009			3.34	46			28.08	7.68		
2/26/2009			3.2	41			28.02	6.93		
2/27/2009			3.07	36			27.94	6.06		
2/28/2009			2.98	33			27.86	5.17		
3/1/2009			2.97	33			28.2	9.53		
3/2/2009			3.12	39			28.25	10.28		
3/3/2009			3.05	36			28.26	10.57		
3/4/2009			2.95	33			28.19	9.36		
3/5/2009			2.85	30			28.14	8.61		
3/6/2009			2.78	27			28.05	7.36		
3/7/2009	0.8		2.74	26	0.68	19.28	27.97	6.34	0.91	4.72
3/8/2009			2.66	23			27.87	5.35		
3/9/2009			2.6	21			27.81	4.78		
3/10/2009			2.56	20			27.78	4.44		
3/11/2009			2.53	19			27.62	3.31		
3/12/2009			2.5	19			27.48	2.45		
3/13/2009			2.45	17			27.46	2.31		
3/14/2009	0.77		2.37	15	0.71	17.12	27.54	2.78	0.94	3.09
3/15/2009			2.33	14			27.54	2.74		
3/16/2009			2.3	13			27.57	2.97		
3/17/2009			2.35	15			27.89	5.58		
3/18/2009			2.3	14			27.99	6.61		
3/19/2009			2.29	13			28.15	9.12		
3/20/2009			2.24	10			28.28	10.94		
3/21/2009			2.21	9.1			28.15	8.69		
3/22/2009			2.21	9.2			28.02	7.01		
3/23/2009			2.17	7.8			27.88	5.42		
3/24/2009			2.23	9.7			27.79	4.56		
3/25/2009			2.2	7.1			27.71	3.9		
3/26/2009			2.16	4.1			28.04	13.28		
3/27/2009			2.58	20			29.56	67.99		
3/28/2009			3.92	79			29.62	71.65		
3/29/2009	0.62	23.90	4.8	133	0.67	20.02	29.64	77.59	0.96	2.04

Table E15 – Continued

	JC 430T	JC430NAC	LCstage	LCQ	LC T	LC430NAC	MSstage	MS Q	MS 430T	MS430NAC
3/30/2009			5.53	183			29.08	35.07		
3/31/2009			5.79	202			28.93	30.11		
4/1/2009			8.14	459			30.36	273.24		
4/2/2009			13.28	1780			31.27	583.19		
4/3/2009			15.73	2870			32.22	902.61		
4/4/2009	0.46	38.83	15.52	2770	0.55	29.89	31.07	520.93	0.88	6.39
4/5/2009			14	2050			30.54	336.73		
4/6/2009			12.55	1470			30.26	240.12		
4/7/2009			11	982			30.05	165.15		
4/8/2009			9.5	630			29.84	94.16		
4/9/2009			8.3	451			29.63	68.75		
4/10/2009			7.36	341			29.43	54		
4/11/2009	0.50	34.66	6.6	266	0.49	35.67	29.24	42.64	0.85	8.13
4/12/2009			6	212			29.1	35.51		
4/13/2009			5.64	184			29.46	117.8		
4/14/2009			7.53	360			30.65	375.62		
4/15/2009			8.75	509			30.18	211.87		
4/16/2009			8.25	445			29.74	83.66		
4/17/2009			7.38	344			29.4	52.02		
4/18/2009	0.46	38.83	6.63	268	0.48	36.70	29.16	38.55	0.88	6.39
4/19/2009			5.96	209			29	31.08		
4/20/2009			5.46	170			28.88	26.66		
4/21/2009			5.04	140			28.81	24.21		
4/22/2009			4.68	116			28.85	25.6		
4/23/2009			4.36	95			28.75	22.04		
4/24/2009			4.08	78			28.66	19.52		
4/25/2009			3.82	63			28.59	17.42		
4/26/2009			3.6	53			28.52	15.89		
4/27/2009			3.42	44			28.48	14.77		
4/28/2009			3.26	38			28.42	13.59		
4/29/2009			3.11	32			28.38	12.69		
4/30/2009			2.99	28			28.37	12.53		
5/1/2009			2.88	24			28.39	12.97		
5/2/2009			2.8	21			28.41	13.32		
5/3/2009			2.75	19			28.36	12.28		
5/4/2009			2.69	17			28.32	11.56		
5/5/2009			2.65	16			28.3	11.25		
5/6/2009			2.53	12			28.3	11.11		
5/7/2009			2.41	6.4			28.26	10.5		
5/8/2009			2.22	1	0.61	24.71	28.21	9.61		
5/9/2009	0.63	23.10	2.28	2.1			28.17	9.07		
5/10/2009			2.22	1			28.13	8.37	0.86	7.54
5/11/2009			2.28	3.1			28.07	7.66		
5/12/2009			2.25	2.1			28.02	7.02		

Table E15 – Continued

	JC 430T	JC430NAC	LCstage	LCQ	LC T	LC430NAC	MSstage	MS Q	MS 430T	MS430NAC
5/13/2009			2.13	1			28.02	6.92		
5/14/2009			2.08	1			28.12	9.09		
5/15/2009			2.2	1			29.3	46.98		
5/16/2009			2.24	1.2			28.85	25.41		
5/17/2009			2.53	12			28.97	38.16		
5/18/2009			2.74	19			29.55	68.18		
5/19/2009			2.65	16			29.09	35.43		
5/20/2009			2.55	13			28.8	23.74		
5/21/2009			2.49	9.3			28.65	19.3		
5/22/2009			2.47	8.4			28.77	22.68		
5/23/2009			2.46	7.5			28.72	21.16		
5/24/2009			2.67	16			29.11	36.46		
5/25/2009			2.71	18			28.9	27.36		
5/26/2009			3.06	32			28.85	25.68		
5/27/2009			4.4	98			28.93	28.37		
5/28/2009			5.9	207			28.92	28.03		
5/29/2009			8.68	503			28.82	24.28		
5/30/2009			8.88	528			28.72	21.22		
5/31/2009			7.75	388			28.61	17.97		
6/1/2009			6.62	273			28.53	15.96		
6/2/2009			5.74	197			28.47	14.67		
6/3/2009			5.15	153			28.48	14.8		
6/4/2009			4.93	139			29.18	43.23		
6/5/2009			5.66	196			29.4	52.35		
6/6/2009			7.02	316			29.27	45.1		
6/7/2009			6.96	311			28.91	27.63		
6/8/2009			6.35	253			28.73	21.44		
6/9/2009			5.66	194			28.62	18.33		
6/10/2009			5.07	149			28.55	16.48		
6/11/2009			4.55	115			28.47	14.61		
6/12/2009			4.1	85			28.4	13.2		
6/13/2009			3.72	64			28.37	12.51		
6/14/2009			3.41	49			28.33	11.79		
6/15/2009			3.15	38			28.28	10.91		
6/16/2009			2.96	31			28.25	10.27		
6/17/2009			2.8	25			28.21	9.62		
6/18/2009			2.67	21			28.17	9.03		
6/19/2009			2.56	17			28.17	9.02		
6/20/2009	0.63	23.10	2.46	14	0.45	39.93	28.19	9.34		
6/21/2009			2.4	10			28.14	8.64		
6/22/2009			2.25	3.7			28.07	7.61		
6/23/2009			2.21	2.7			28.05	7.41		
6/24/2009			2.26	4.3			28.98	30.74		
6/25/2009			2.28	4.9			28.64	19.12		

Table E15 – Continued

	JC 430T	JC430NAC	LCstage	LCQ	LC T	LC430NAC	MSstage	MS Q	MS 430T	MS430NAC
6/26/2009			2.24	3.6			28.55	16.57		
6/27/2009	0.63	23.10	2.25	3.8	0.55	29.89	28.68	20.24	0.87	6.96
6/28/2009			2.34	7.9			28.7	33.91		
6/29/2009			2.41	11			30.44	303.44		
6/30/2009			2.32	6.6			29.86	113.25		
7/1/2009			2.22	2.9			29.36	49.54		
7/2/2009			2.36	8.3			29.16	39.78		
7/3/2009			2.29	5			29.4	52.98		
7/4/2009	0.90	5.27	2.31	5.7	0.58	27.24	28.95	29.53	0.93	3.63
7/5/2009			2.31	5.8			28.7	20.53		
7/6/2009			2.34	7.2			28.92	29.8		
7/7/2009			2.26	4			29.06	33.86		
7/8/2009			2.22	2.8			28.85	25.5		
7/9/2009			2.23	2.9			28.67	19.71		
7/10/2009			2.19	2.2			28.55	16.49		
7/11/2009			2.18	2			28.43	13.71		
7/12/2009			2.16	1.5			28.32	11.48		
7/13/2009			2.22	2.9			28.24	10.16		
7/14/2009			2.25	3.7			28.21	9.66		
7/15/2009			2.32	6.3			28.14	8.58		
7/16/2009			2.32	6.4			28.15	8.71		
7/17/2009	0.75	14.38	2.31	5.9	0.70	17.83	28.33	11.67	0.92	4.17
7/18/2009			2.38	9.3			28.29	10.96		
7/19/2009			2.42	12			28.26	10.53		
7/20/2009			2.46	14			28.24	10.09		
7/21/2009			2.43	12			28.16	8.81		
7/22/2009			2.38	9.2			28.07	7.66		
7/23/2009			2.3	5.6			28	6.67		
7/24/2009			2.24	3.8			27.95	6.16		
7/25/2009	0.66	20.78	2.2	2.8	0.54	30.81	27.93	5.88	0.9	5.27
7/26/2009			2.2	3.5			27.93	5.98		
7/27/2009			1.98	1			28.53	16.11		
7/28/2009			2.21	2.6			28.41	13.39		
7/29/2009			2.24	3.5			28.51	15.7		
7/30/2009			2.3	5.4			28.5	15.47		
7/31/2009			2.3	5.3			28.74	23.05		
8/1/2009	0.69	18.55	2.5	14	0.64	22.31	29.15	38.44	0.93	3.63
8/2/2009			2.98	32			28.99	30.94		
8/3/2009			3.15	38			28.75	22.28		
8/4/2009			3.23	41			28.61	18.11		
8/5/2009			4.17	92			28.64	19.51		
8/6/2009			4.83	133			28.75	22.29		
8/7/2009			4.99	144			28.46	14.38		
8/8/2009			4.37	103	0.47	37.75	28.3	11.17		

Table E15 – Continued

	JC 430T	JC430NAC	LCstage	LCQ	LC T	LC430NAC	MSstage	MS Q	MS 430T	MS430NAC
8/9/2009	0.55	29.89	4.07	84			28.22	9.83	0.84	8.72
8/10/2009			5.4	174			28.15	8.72		
8/11/2009			5.04	147			28.09	7.86		
8/12/2009			4.47	109			28.53	18.81		
8/13/2009			4.02	81			29.08	35.43		
8/14/2009			3.84	70			28.73	21.63		
8/15/2009	0.63	23.10	3.97	77	0.46	38.83	28.72	21.39	0.91	4.72
8/16/2009			3.9	74			28.57	16.93	0.88	6.39
8/17/2009			4.17	90			28.57	16.93		
8/18/2009			4.26	96			28.51	15.48		
8/19/2009			4.08	84			28.54	16.28		
8/20/2009			3.8	68			28.46	14.49		
8/21/2009			3.54	55			28.45	14.25		
8/22/2009			3.35	46			28.45	14.27		
8/23/2009	0.64	22.31	3.25	42	0.46	38.83	28.28	10.93	0.84	8.72
8/24/2009			3.22	41			28.19	9.4		
8/25/2009			3.1	36			28.11	8.21		
8/26/2009			3	32			28.11	8.1		
8/27/2009			2.93	30			28.31	12.18		
8/28/2009			3.25	42			28.67	19.88		
8/29/2009			3.65	60			28.52	15.75		
8/30/2009			3.71	63			28.34	11.97		
8/31/2009			3.47	52			28.66	25.2		
9/1/2009			3.31	44			29.29	45.7		
9/2/2009			3.21	40			29.17	38.89		
9/3/2009			3.28	43			28.92	28.41		
9/4/2009			3.47	51			28.65	19.13		
9/5/2009			3.44	50			28.54	16.2		
9/6/2009	0.70	17.83	3.24	41	0.46	38.83	28.39	13.02	0.89	5.83
9/7/2009			2.99	32			28.28	10.75		
9/8/2009			2.8	25			28.17	9.01		
9/9/2009			2.65	20			28.08	7.69		
9/10/2009			2.53	16			27.99	6.66		
9/11/2009			2.42	13			27.93	5.95		
9/12/2009			2.41	13			28.12	9.99		
9/13/2009	0.69	18.55	2.57	19	0.61	24.71	28.97	30.49	0.94	3.09
9/14/2009			2.61	21			28.59	17.62		
9/15/2009			2.95	34			28.71	20.8		
9/16/2009			3.32	50			28.72	21.5		
9/17/2009			3.65	67			28.94	29.32		
9/18/2009			4.22	103			29.09	35.45		
9/19/2009	0.37	49.71	4.62	129	0.51	33.67	28.72	21.18	0.87	6.96
9/20/2009			4.49	122			28.51	15.47		
9/21/2009			4.21	104			28.37	12.44		

Table E15 – Continued

	JC 430T	JC430NAC	LCstage	LCQ	LC T	LC430NAC	MSstage	MS Q	MS 430T	MS430NAC
9/22/2009			3.94	86			28.26	10.56		
9/23/2009			3.62	67			28.16	8.93		
9/24/2009			3.36	53			28.07	7.64		
9/25/2009			3.16	44			28.01	6.86		
9/26/2009			3.05	39			28.04	7.82		
9/27/2009	0.44	41.05	3	37	0.47	37.75	28.91	27.71	0.9	5.27
9/28/2009			2.93	32			28.62	18.33		
9/29/2009			2.74	22			28.42	13.46		
9/30/2009			2.59	21			28.29	11.02		
10/1/2009			2.47	17			28.18	9.24	0.94	3.09
10/2/2009			2.48	17			28.08	7.71		
10/3/2009			2.41	15			27.97	6.41		
10/4/2009	0.75	14.38	2.47	16	0.56	28.99	27.9	5.62	0.94	3.09
10/5/2009				14			28.21	11.72		
10/6/2009				12			28.81	24.22		
10/7/2009			2.41	13			28.64	19.11		
10/8/2009			2.44	14			28.39	13.04		
10/9/2009			2.48	15			28.27	10.58		
10/10/2009	0.75	14.38	2.39	12	0.53	31.74	28.4	14.46		
10/11/2009			2.47	15			28.77	23.14		
10/12/2009			2.45	15			28.48	14.95		
10/13/2009			2.38	12			28.33	11.79		
10/14/2009			2.56	18			28.26	10.5		

Table E15 – Continued
Precipitation in inches

	602	601	555	803	WSSP	Tallahassee
1/1/2009	0	0	0	0	0	0
1/2/2009	0	0	0	0	0	0
1/3/2009	0	0	0	0	0	0
1/4/2009	0.38	0.3	0.38	0.34	0.23	0.29
1/5/2009	0.03	0.01	0.01	0.02	0	0
1/6/2009	0	0	0	0	0	0
1/7/2009	0.14	0.15	0.24	0.21	0.21	0.09
1/8/2009	0	0	0	0	0	0
1/9/2009	0	0	0	0	0	0
1/10/2009	0	0	0	0	0	0
1/11/2009	0.04	0.26	0.18	0.21	0.31	0.19
1/12/2009	0	0	0	0	0	0
1/13/2009	0	0.04	0.13	0.07	0.2	0.01
1/14/2009	0	0	0	0	0	0
1/15/2009	0	0	0	0	0	0
1/16/2009	0	0	0	0	0	0
1/17/2009	0	0	0	0	0	0
1/18/2009	0.39	0.44	0.52	0.59	0.53	0.36
1/19/2009	0.01	0.01	0.01	0.02	0.02	0.03
1/20/2009	0	0	0	0	0	0
1/21/2009	0	0	0	0	0	0
1/22/2009	0	0	0	0	0	0
1/23/2009	0	0	0	0	0	0
1/24/2009	0.02	0.01	0	0	0	0.02
1/25/2009	0.01	0.01	0	0	0	0
1/26/2009	0.02	0.18	0.03	0.03	0	0.1
1/27/2009	0.01	0.01	0	0.01	0	0
1/28/2009	0.41	0.01	0.18	0.12	0.28	0.09
1/29/2009	0.16	0.14	0.14	0.11	0.11	0.09
1/30/2009	0	0	0	0	0	0
1/31/2009	0	0	0	0	0	0
2/1/2009	0	0	0	0	0	0
2/2/2009	0	0	0	0	0.01	0
2/3/2009	0	0	0	0	0	0
2/4/2009	0	0	0	0	0	0
2/5/2009	0	0	0	0	0	0
2/6/2009	0	0	0	0	0	0
2/7/2009	0	0	0	0	0	0
2/8/2009	0	0	0	0	0	0
2/9/2009	0	0	0	0	0	0
2/10/2009	0	0	0	0	0	0
2/11/2009	0	0	0	0	0	0
2/12/2009	0	0	0	0	0	0

Table E15 – Continued
Precipitation in inches

	602	601	555	803	WSSP	Tallahassee
2/13/2009	0	0	0	0	0	0
2/14/2009	1.36	1.93	1.87	1.62	1.52	0
2/15/2009	0.01	0.01	0.01	0	0.01	1.87
2/16/2009	0	0.01	0	0.01	0.01	0
2/17/2009	0	0	0	0	0	0
2/18/2009	0.01	0	0.02	0	0.04	0
2/19/2009	0.66	0.63	0.52	0.42	0.39	0.01
2/20/2009	0	0	0	0	0	0.51
2/21/2009	0	0	0	0	0	0
2/22/2009	0	0	0	0	0	0
2/23/2009	0	0	0	0	0	0
2/24/2009	0	0	0	0	0	0
2/25/2009	0	0	0	0	0	0
2/26/2009	0	0	0	0	0	0
2/27/2009	0	0	0	0	0	0
2/28/2009	0.08	0.05	0.08	0.18	0.01	0
3/1/2009	0	0.5	0.79	0.6	0.05	0.11
3/2/2009	0.01	0	0	0	0	0.03
3/3/2009	0	0	0	0	0	0
3/4/2009	0	0	0	0	0	0
3/5/2009	0	0	0	0	0	0
3/6/2009	0	0	0	0	0	0
3/7/2009	0	0	0	0	0	0
3/8/2009	0	0	0	0	0	0
3/9/2009	0.01	0.01	0	0	0	0
3/10/2009	0	0	0	0	0	0
3/11/2009	0	0	0	0	0	0
3/12/2009	0	0	0	0	0	0
3/13/2009	0	0	0	0	0	0
3/14/2009	0	0	0	0	0	0
3/15/2009	0	0	0	0	0	0
3/16/2009	0.11	0.21	0.29	0.24	0.53	0
3/17/2009	0.01	0	0	0	0	0.12
3/18/2009	0	0	0	0	0	0
3/19/2009	0	0	0	0	0	0
3/20/2009	0	0	0	0	0	0
3/21/2009	0	0	0	0	0	0
3/22/2009	0	0	0	0	0	0
3/23/2009	0	0	0	0	0	0
3/24/2009	0	0	0	0	0	0
3/25/2009	0	0	0	0	0	0
3/26/2009	1.73	1.58	1.68	1.44	1.87	0
3/27/2009	1.37	1.11	1.21	1.28	1.65	1.59

Table E15 – Continued
Precipitation in inches

	602	601	555	803	WSSP	Tallahassee
3/28/2009	0.68	0.58	0.46	0.57	0.16	1.18
3/29/2009	0	0	0.01	0.01	0.01	0.82
3/30/2009	0	0	0	0	0	0
3/31/2009	1.64	1.36	1.62	1.65	1.95	0
4/1/2009	2.69	3.38	4.18	4.32	3.74	1.55
4/2/2009	3.39	2.76	3.34	2.9	2.87	3.13
4/3/2009	0.01	0	0	0.04	0	3.43
4/4/2009	0	0	0	0	0	0
4/5/2009	0.01	0	0	0	0	0
4/6/2009	0	0	0	0	0	0
4/7/2009	0	0	0	0	0	0
4/8/2009	0	0	0	0	0	0
4/9/2009	0	0	0	0	0	0
4/10/2009	0	0	0	0	0	0
4/11/2009	0	0	0	0	0	0
4/12/2009	0	0	0	0	0	0
4/13/2009	1.86	3.29	2.73	2.37	2.34	0
4/14/2009	0.03	0.02	0.05	0.04	0.03	3.38
4/15/2009	0	0	0	0	0	0
4/16/2009	0	0	0	0	0	0
4/17/2009	0	0	0	0	0	0
4/18/2009	0	0	0	0	0	0
4/19/2009	0	0	0	0	0	0
4/20/2009	0	0	0	0	0	0
4/21/2009	0.31	0.21	0.05	0.03	0	0
4/22/2009	0	0	0	0.02	0.01	0.24
4/23/2009	0	0	0	0	0.01	0
4/24/2009	0	0	0	0	0	0
4/25/2009	0	0	0	0	0	0
4/26/2009	0	0	0	0	0	0
4/27/2009	0	0	0	0	0	0
4/28/2009	0	0	0	0	0	0
4/29/2009	0	0	0	0	0	0
4/30/2009	0	0	0	0	0	0
5/1/2009	0	0	0	0	0	0
5/2/2009	0	0	0	0	0	0
5/3/2009	0	0	0	0	0	0
5/4/2009	0.01	0	0	0	0	0
5/5/2009	0.04	0	0.04	0.01	0.13	0
5/6/2009	0	0	0	0	0	0
5/7/2009	0	0	0	0	0	0
5/8/2009	0	0	0	0	0	0
5/9/2009	0	0	0	0	0	0

Table E15 – Continued
Precipitation in inches

	602	601	555	803	WSSP	Tallahassee
5/10/2009	0	0	0	0	0	0
5/11/2009	0	0	0	0	0	0
5/12/2009	0	0	0	0	0	0
5/13/2009	0	0	0	0	0	0
5/14/2009	0.03	1.53	1.5	0.46	0.19	0
5/15/2009	0	0.01	0.02	0.01	0	2
5/16/2009	0	0.39	0.05	0.06	0.27	0
5/17/2009	1.08	1.87	0.67	0.82	2.18	0
5/18/2009	0.06	0.09	0.17	0.1	0.08	0.93
5/19/2009	0.03	0.02	0.021	0.02	0.03	0.05
5/20/2009	0.04	0.02	0.02	0.02	0.01	0.01
5/21/2009	0.49	0.31	0.14	0.11	0.08	0
5/22/2009	0.2	0.11	0.09	0.07	0.04	0.38
5/23/2009	0.31	0.56	0.78	0.53	0.52	0.12
5/24/2009	0.05	0.04	0.03	0.27	0.06	0.6
5/25/2009	1.08	0.07	0.16	0.64	0.17	0.01
5/26/2009	0.91	0.28	1.66	2.28	2.6	0.48
5/27/2009	0.24	0.5	0.04	1.29	0.36	0.39
5/28/2009	0.13	0.03	0.31	0.22	0.11	1.53
5/29/2009	0.01	0	0.06	0.01	0.74	0
5/30/2009	0	0	0	0	0	0.05
5/31/2009	0	0	0	0	0	0
6/1/2009	0	0	0	0	0	0
6/2/2009	0	0	0	0	0	0
6/3/2009	0.06	0.4	0.72	0.24	0.5	0
6/4/2009	0.56	1.39	0.7	1.31	0.67	0.18
6/5/2009	0.59	0.67	0.62	0.63	0.64	1.27
6/6/2009	0.01	0.01	0.01	0.03	0	0.59
6/7/2009	0	0	0	0	0	0
6/8/2009	0.01	0	0	0	0	0
6/9/2009	0	0	0	0	0	0
6/10/2009	0	0	0	0	0	0
6/11/2009	0	0	0	0	0	0
6/12/2009	0	0	0	0	0	0
6/13/2009	0	0	0	0.22	0.29	0
6/14/2009	0.05	0	0	0.01	0.01	0
6/15/2009	0	0	0	0	0	0
6/16/2009	0	0	0	0.15	1.1	0
6/17/2009	0	0	0	0.17	0.01	0
6/18/2009	0	0	0	0	0	0
6/19/2009	0	0	0	0	0	0
6/20/2009	0	0	0	0	0	0
6/21/2009	0	0	0	0	0	0

Table E15 – Continued
Precipitation in inches

	602	601	555	803	WSSP	Tallahassee
6/22/2009	0	0	0	0	0	0
6/23/2009	1.21	1.36	0.25	1.14	0.26	0
6/24/2009	0	0.01	0.01	0	0.01	0.62
6/25/2009	0	0.33	0	0	0	0
6/26/2009	0	0	0	0	0	0
6/27/2009	0	0.04	0.23	1.33	0.42	0
6/28/2009	1.19	2.69	1.87	0.78	1.61	0
6/29/2009	0.29	0.33	0.07	0.18	0.13	2.65
6/30/2009		0	0	0.01	0.01	0.22
7/1/2009	0.25	0	0	0	0	0
7/2/2009	0.4	0.49	0.37	0.88	0.51	0
7/3/2009	0	0.01	0	0	0.01	0.68
7/4/2009	0	0	0	0	0	0
7/5/2009	0	0.04	0.71	0	0.56	0
7/6/2009	0.62	0.56	0.35	0.56	0.2	0
7/7/2009	0.32	0.41	0.25	0.45	0.71	0.53
7/8/2009	0.34	0.45	0.31	0.59	0.02	0.45
7/9/2009	0.17	0.01	0.7	0.05	0.5	0.12
7/10/2009	0.01	0.08	0.76	0.16	0.01	0.04
7/11/2009	0	0	0.02	0	0.07	0
7/12/2009	0	0	0	0	0.01	0.15
7/13/2009	0	0	0	0.07	0	0
7/14/2009	0	0.05	0.01	0.01	0.05	0
7/15/2009	0	0	0.04	1.19	0.01	0
7/16/2009	0.46	0.02	0.06	0	0.42	0
7/17/2009	0.09	0.05	0.54	0.1	0.22	0.66
7/18/2009	0.15	0.25	0.27	0.23	0.33	0.13
7/19/2009	0.09	0.25	0.13	0.3	0.02	0.2
7/20/2009	0	0.01	0	0.01	0	0.16
7/21/2009	0	0	0	0	0.02	0
7/22/2009	0	0	0	0	0.02	0
7/23/2009	0	0	0	0	0	0
7/24/2009	0	0	0	0	0	0
7/25/2009	0.01	0	0	0.02	0	0
7/26/2009	0.32	0.52	0	0	0	0
7/27/2009	0	0.03	0.07	0.83	1.6	0.58
7/28/2009	0.11	0.63	0.36	0.84	0.78	0
7/29/2009	0.06	0.22	0.96	1.31	0.14	0.06
7/30/2009	0.65	0	0.39	0	0	0.36
7/31/2009	0.24	0.43	0.41	0.3	0.29	0
8/1/2009	0.4	0.01	0.01	0.02	0.54	0.33
8/2/2009	0.29	0.06	0.05	0	0.62	0.51
8/3/2009	1.17	0.18	0.09	0.32	0.42	0.15

Table E15 – Continued
Precipitation in inches

	602	601	555	803	WSSP	Tallahassee
8/4/2009	0.04	0.01	0.31	1.31	0.58	0.13
8/5/2009	0	1.24	0.15	0.26	0.24	0
8/6/2009	0	0	0	0	0	0
8/7/2009	0	0	0	0	0	0
8/8/2009	0	0.2	0.48	0.47	0	0
8/9/2009	0.09	0.25	0	0.01	1.32	0.01
8/10/2009	0	0	0	0	0	0
8/11/2009	0	0.07	0.03	0	0	0
8/12/2009	0.04	0.65	0.4	1.45	0.02	0.06
8/13/2009	0.07	0.02	0.06	0.02	0.05	0.1
8/14/2009	0.57	0.06	0.01	0	0	0.01
8/15/2009	0.04	0.04	0.1	0.06	0.02	0.28
8/16/2009	0.09	0.21	0.27	0.05	0.18	0.03
8/17/2009	0.06	0.21	0.22	0.15	0.4	0.12
8/18/2009	0.05	0.04	0.41	0	0.08	0.11
8/19/2009	0.01	0	0	0	0	0.01
8/20/2009	0.22	0	0.24	0	0	0
8/21/2009	0.19	0.23	0.24	0.03	1.82	0
8/22/2009	0.01	0	0.01	0	0.01	0.36
8/23/2009	0	0	0	0	0	0
8/24/2009	0	0	0	0	0	0
8/25/2009	0	0	0	0	0	0
8/26/2009	0	0	0	0	0	0
8/27/2009	0.91	1.09	1.11	1.13	1.42	0
8/28/2009	0.03	0.08	0.13	0.08	0.13	0.92
8/29/2009	0	0	0	0	0	0.06
8/30/2009	0.01	0	0.01	0	0	0
8/31/2009	0.18	1.26	0.61	0.1	0.02	0
9/1/2009	0.25	0.19	0.12	0.01	0.03	0.43
9/2/2009	1	0.04	0.05	0.04	0.14	0.05
9/3/2009	0	0	0	0	0	0.06
9/4/2009	0	0	0	0	0	
9/5/2009	0	0	0	0	0	
9/6/2009	0	0	0	0	0	
9/7/2009	0	0	0	0	0	
9/8/2009	0	0	0	0	0	
9/9/2009	0	0	0	0	0	
9/10/2009	0	0	0	0	0	
9/11/2009	0	0	0	0	0	
9/12/2009	0.54	1.62	1.57	1.56	2.54	
9/13/2009	0.02	0.07	0.02	0.02	0.08	
9/14/2009	0.4	0.42	0.51	0.66	0.53	
9/15/2009	0.19	0.46	0.67	0.27	0.84	

Table E15 – Continued
Precipitation in inches

	602	601	555	803	WSSP	Tallahassee
9/16/2009	0.17	0.01	0.01	0.02	0.04	
9/17/2009	0.43	0.55	0.84	0.8	2.65	
9/18/2009	0	0.01	0.21	0.13	0.16	
9/19/2009	0	0	0	0	0	
9/20/2009	0	0	0	0	0	
9/21/2009	0	0	0	0	0	
9/22/2009	0	0	0	0	0	
9/23/2009	0	0	0	0	0	
9/24/2009	0	0	0.23	0.2	0.17	
9/25/2009	0	0	0.03	0.01	0.52	
9/26/2009	1.25	0	0	0	0.01	
9/27/2009	0.02	0.01	0.01	0	0.01	
9/28/2009	0	0	0	0	0	
9/29/2009	0	0	0	0	0	
9/30/2009	0	0	0	0	0.01	
10/1/2009	0	0	0	0	0	
10/2/2009	0	0	0	0	0	
10/3/2009	0	0	0	0	0	
10/4/2009	0	0	0	0	0	
10/5/2009	0.92	0.62	0.74	0.77	0.6	
10/6/2009	0.07	0.36	0.51	0.33	0.47	
10/7/2009	0.01	0.01	0.02	0	0.01	
10/8/2009	0.01	0	0	0	0.01	
10/9/2009	0.08	0	0	0.01	0	
10/10/2009	0.91	0.55	0.36	0.33	0.65	
10/11/2009	0.01	0.01	0.01	0.01	0.01	
10/12/2009	0.07	0.03	0.24	0.09	0.22	
10/13/2009	0	0	0	0	0	
10/14/2009	0.21	0.37	0.53	0.07	0.2	

Table E16 – Sample Corrections Due to Plastic Container Organics

	254 T	430 T	440T	254NAC	430NAC
2/18/2009					
5/15/2009	81.2	98.9	99.2	2.09	0.11
5/17/2009	84.3	99.7	100	1.71	0.03
5/6/2009	54.6	92.3	93.3	6.05	0.80
5/7/2009	43.6	86.3	87.2	8.30	1.47
5/8/2009	66.9	97.7	98.4	4.02	0.23
5/12/2009	74.3	95.2	95.7	2.97	0.49
5/13/2009	76.3	95.4	95.6	2.70	0.47
5/14/2009	78.5	95.8	96.3	2.42	0.43
5/15/2009	81.2	98.9	99.2	2.08	0.11
5/17/2009	84.3	99.7	100	1.71	0.03
*** Vent (not vent tube): Bad sample do not use**					

Table E17 - UV VIS Spectrophotometer Stabilization Evaluation

Time	Part of Day	Min from start	254	350	430
1:00	0.041666667	0.0	100.49	100.27	100.18
1:05	0.045138889	5.0	101.14	100.85	100.44
1:10	0.048611111	10.0	101.71	101.19	101.16
1:26	0.059722222	26.0	102.47	101.92	101.83
2:05	0.086805556	65.0	103.33	102.84	102.36
2:20	0.097222222	80.0	105.14	105.65	105.11
2:35	0.107638889	95.0	106.06	106.12	105.51
3:33	0.147916667	153.0	105.51	106.08	105.54
5:28	0.227777778	268.0	106.64	106.87	106.68

Table E18- K-Tunnel Spectrophotometer Results

		Transmittance (%) by wavelength in nanometers							
Date	Time	254	350	430	520	570	620	FGS ID#	
2/18/2009		48	78	92	97	98	99		spectrophotometer
6/19/2009	600	4	32	67	89	92	94	KR1#1	spectrophotometer
6/20/2009	600	4	34	71	89	92	94	KR1#2	spectrophotometer
6/21/2009	600	5	37	74	90	94	96	KR1#3	spectrophotometer
6/22/2009	600	5	37	74	90	94	95	KR1#4	spectrophotometer
6/23/2009	600	7	42	76	90	93	94	KR1#5	spectrophotometer
6/24/2009	600	5	35	68	84	88	90	KR1#6	spectrophotometer
6/25/2009	600	8	44	78	92	95	97	KR1#7	spectrophotometer
6/26/2009	600	8	42	75	89	92	94	KR1#8	spectrophotometer
6/27/2009	600	2	25	59	81	86	90	KR1#9	spectrophotometer
6/28/2009	600	6	41	75	91	94	96	KR1#10	spectrophotometer
6/29/2009	600	8	44	77	92	95	96	KR1#11	spectrophotometer
6/30/2009	600	7	44	75	90	93	95	KR1#12	spectrophotometer
7/1/2009	600	10	44	74	87	90	92	KR1#13	spectrophotometer
7/2/2009	600	10	46	73	85	89	91	KR1#14	spectrophotometer
7/18/2009	600	31	75	92	97	97	96	KR3#1	spectrophotometer
7/18/2009	1800	33	77	94	97	97	97	KR3#2	spectrophotometer
7/19/2009	600	31						KR3#3	analysis apparently wasn't saved
7/19/2009	1800	34	76	93	97	97	96	KR3#4	spectrophotometer
7/20/2009	600	37	78	93	96	97	97	KR3#5	spectrophotometer
7/20/2009	1800	37	79	94	98	99	98	KR3#6	spectrophotometer
7/21/2009	600	41	82	96	99	99	98	KR3#7	spectrophotometer
8/5/2009	600	35	71	85	89	90	90	KR6-02	spectrophotometer
8/6/2009	600	33	72	88	92	93	93	KR6-04	spectrophotometer
8/7/2009	600	35	73	88	93	93	93	KR6-06	spectrophotometer
8/8/2009	600	37	74	90	94	95	94	KR6-08	spectrophotometer
8/9/2009	600	18	49	67	74	76	78	KR6-10	spectrophotometer
8/10/2009	600	22	62	83	90	91	91	KR6-12	spectrophotometer
8/11/2009	600	19	59	83	90	91	91	KR6-14	spectrophotometer
8/12/2009	600	18	60	86	94	95	95	KR6-16	spectrophotometer
8/13/2009	600	15	50	74	83	85	86	KR6-18	spectrophotometer
8/19/2009	600	9	47	81	95	97	99	KR8-02	spectrophotometer
8/20/2009	600	8	43	78	92	95	97	KR8-04	spectrophotometer
8/21/2009	600	6	38	72	88	91	93	KR8-06	spectrophotometer
8/22/2009	600	6	42	77	92	95	97	KR8-08	spectrophotometer
8/23/2009	600	7	41	74	90	93	95	KR8-10	spectrophotometer
8/24/2009	600	8	46	80	94	96	97	KR8-12	spectrophotometer
8/25/2009	600	10	49	82	95	97	98	KR8-14	spectrophotometer
8/26/2009	600	11	48	80	93	96	97	KR8-16	spectrophotometer
8/27/2009	600	12	51	83	95	97	99	KR8-18	spectrophotometer
8/28/2009	600	15.2	54	83	95	97	99	KR9-02	spectrophotometer
8/29/2009	600	20	60	87	97	99	100	KR9-04	spectrophotometer
8/30/2009	600	22.6	62	87	97	99	100	KR9-06	spectrophotometer
8/31/2009	600	26.1	66	89	99	101	101	KR9-08	spectrophotometer
9/1/2009	600	29.4	68	91	99	100	101	KR9-10	spectrophotometer
9/2/2009	600	24	62	85	94	96	98	KR9-12	spectrophotometer
9/3/2009	600	34.7	72	92	99	100	101	KR9-14	spectrophotometer
9/8/2009	1200	29.2							Kish did not save analysis
9/9/2009	600	35.3	71	87	93	95	95	KR10-02	particulates; some suspended
9/10/2009	600	38.9	75	90	96	97	98	KR10-04	spectrophotometer
9/11/2009	600	38	74	89	95	97	97	KR10-06	spectrophotometer
9/12/2009	600	40	75	91	96	97	98	KR10-08	spectrophotometer
9/13/2009	600	36	73	89	95	96	97	KR10-10	spectrophotometer
9/14/2009	600	37	73	90	96	97	98	KR10-12	spectrophotometer
9/15/2009	600	27	60	76	83	85	86	KR10-14	v fine particulate
9/16/2009	600	34	71	87	94	95	96	KR10-16	few particulates
9/17/2009	600	40						KR10-18	Kish did not save analysis
9/18/2009	600	26.8	63.4	79.2	85.3	87.1	88.1	KR11-02	fine particulates
9/19/2009	600	36.9	72.7	88.2	92	93	93.4	KR11-04	fine particulates
9/20/2009	600	35.6	71.4	88	92.7	93.5	94.1	KR11-06	spectrophotometer
9/21/2009	600	44.5	78.4	92.3	95.4	95.5	95.6	KR11-08	particulates
9/22/2009	600	35.5	70.7	87	91.3	92	92	KR11-10	particulates
9/23/2009	600	28.6	69.4	89.4	94.6	95.3	95.5	KR11-12	spectrophotometer
9/24/2009	600	18.7	55.8	78.1	85.9	87.4	88.2	KR11-14	spectrophotometer

Table E18 – Continued

		Transmittance (%) by wavelength in nanometers							
Date	Time	254	350	430	520	570	620	FGS ID#	
9/25/2009	600	19.2	58.7	83.9	92.2	93.3	93.7	KR11-16	f and c particulates
9/26/2009	600	16.8	60.2	86.2	95	96.4	97.5	KR11-18	fine particulates
9/27/2009	600	16.4	58.4	83	91.1	92.8	93.8	KR11-20	fine particulates
9/28/2009	600	18.5	63.1	88.7	96.5	97.7	98.5	KR12-06	spectrophotometer
9/29/2009	600	15.4	58.6	87	95.8	97.3	98.1	KR12-08	coarse particulates
9/30/2009	600	12	52	81.3	92	94.3	95.6	KR12-10	spectrophotometer
10/1/2009	600	13.4	55.6	85.6	95.3	97.4	98.2	KR12-12	spectrophotometer
10/2/2009	600	12.7	53.4	83.5	93.6	95.9	96.8	KR12-14	spectrophotometer
10/3/2009	600	11.8	47.4	74.4	84.9	87.5	89.1	KR12-16	spectrophotometer
10/4/2009	600	11.6	44.7	67.9	77.4	80.2	81.8	KR12-18	spectrophotometer
10/5/2009	600	14.3	56.4	84.8	94.4	96.5	97.3	KR12-20	spectrophotometer
10/6/2009	600	17.2	61.2	88.2	96.7	88.1	98.4	KR12-22	spectrophotometer
10/7/2009	600	14.4	54.8	80.1	89.1	91.4	92.4	KR12-24	spectrophotometer

Table E19 – Stream Dry-Wet Conditions Data

Dry Creek Conditions				
Fisher Creek - entire basin at baseflow conditions 5/8/09				
Location	Absorbance	Transmittance	pH	Site #
FR 373	0.08	83%	4.92	2
FR 376 N	0.2	64%	4.06	3
FR 376 S	0.15	71%	4.35	4
FR 305	0.17	67%	4.26	9
Springhill Rd	0.17	68%	4.23	10
FC1	0.15	71%	4.18	11
Natural Bridge	0.16	69%	4.19	12
FC2	0.24	58%	4.8	13
Black Creek - entire basin at baseflow conditions 5/9/09				
Location	Absorbance	Transmittance	pH	
FR 313 S	0.31	49%	4.3	16
FR 313 N	0.41	39%	3.05	17
SR 267	0.31	49%	5.79	19
Black Hole	0.35	45%	4.84	21
Roaring Sink	0.25	56%	4.48	22
Crestwood	0.28	53%	5.49	23
Jump Creek - entire basin at baseflow conditions 5/9/09				
Location	Absorbance	Transmittance	pH	
E of FR 313	0.16	69%	5.76	26
WLR	0.07	84%	7.33	27
swallet	0.2	63%	6.38	28
US 319	0.28	52%	4.93	29
Lost Creek - entire basin at baseflow conditions 5/8/09				
SR 267	0.3	50%	3.96	31
FR 367	0.34	45%	4.02	32
FR 309 (Brown House)	0.34	45%	4.05	34
FR 350 (Pope Still)	0.37	43%	4.22	35
Arran Rd	0.21	61%	6.33	36
swallet	0.23	59%	6.88	38
Munson Slough - entire basin at baseflow conditions 5/10/09				
Location	Absorbance	Transmittance	pH	
Sand Rd	0.2	62%	5.37	40
Cascade Lakes	0.22	60%	4.78	42
Lake Bradford	0.16	69%	5.94	43
Orange Ave	0.07	84%	6.8	44
Lake Bradford Rd	0.11	78%	6.62	45
Lake Henrietta	0.11	78%	6.84	46
Capitol Circle	0.11	78%	6.93	47
Lake Munson	0.08	83%	7.24	49
US 319	0.06	86%	7.07	50
Ames	0.06	86%	6.95	51
Wet Creek Conditions				
Fisher Creek - entire basin at wet conditions 8/15-16/09				
Location	Absorbance	Transmittance	pH	Site #
FR 373	0.18	66	4.04	2
FR 376 N	0.21	61	3.94	3
FR 376 S	0.2	62	3.97	4
FR 305	0.19	65	4.07	9
Springhill Rd	0.21	62	4	10
Fisher 1	0.21	62	4.01	11
Fisher 2	0.21	62	4.06	13
Black Creek - entire basin at wet conditions 8/15-16/09				
FR 313 S	0.31	49	4.3	16
FR 313 N	0.41	39	3.05	17
SR 267	0.31	49	5.79	19
Black Hole	0.35	45	4.84	21
Roaring Sink	0.25	56	4.48	22
Crestwood	0.28	53	5.49	23

Table E19 – Continued

Jump Creek - entire basin at wet conditions 8/9/09				
E of FR 313	0.17	68	5.61	26
WLR	0.2	63	7.33	27
JC Swallet	0.17	67	6.48	28
US 319	0.25	57	6.28	29
Lost Creek - entire basin at wet conditions 8/15/09				
SR 267 N	0.24	58	3.91	30
SR 267 S	0.19	64	3.93	31
FR 367	0.3	50	3.85	32
FR 360	0.46	34	3.82	33
FR 309 (Brown House)	0.27	54	3.94	34
FR 350 (Pope Still)	0.36	44	3.89	35
Arran Rd	0.32	47	3.98	36
HMR/Swallet	0.32	48	4.05	38
Munson Slough - entire basin at wet conditions 8/16/09				
Bradford Brook at FR 301	0.23	60	3.99	39
CR 263 (Cascade Lakes)	0.11	77	5.48	42
Lake Bradford	0.09	81	6.11	43
CR 371 (Orange Ave)	0.35	44	6.45	44
Lake Bradford Rd	0.33	47	6.49	45
SpHR Lake Henrietta	0.1	80	6.84	46
SR 263 (Cap Cir)	0.14	72	6.82	47
Lake Munson (SR 319)	0.06	88	7.98	49
SR 319	0.05	89	7.59	50
ORR/Ames Sink	0.04	91	7.2	51

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BIOGRAPHICAL SKETCH

Zoe Kulakowski

Zoe Kulakowski completed her Bachelors of Science in Geology in the Fall 1978 at The Florida State University. She worked for the U.S Department of Maps, Aerospace and Aeronautical Charts, St Louis, Missouri 1979-1980 as a geodesist. Returning to Florida, she was employed as a geologist with the Mine Reclamation Program, Florida Bureau of Geology, Florida Department of Natural Resources. In 1984 she joined the Florida Department of Environmental Regulation as an Environmental Specialist in the Cleanup Program. In the Fall of 2005, she enrolled in the Master's degree program part-time at The Florida State University while still working as a Florida licensed Professional Geologist with the Technical Support Section, Bureau of Waste Cleanup, Department of Environmental Protection.

Zoe enjoys working on contaminant assessment/remediation issues and a wide variety of environmental problems. She is active in the community and with the Buck Lake Alliance, a citizens group interested in responsible growth and wise use of our natural resources. During off hours, she can often be found hiking trails, bicycling the St. Marks Trail, or canoeing our beautiful north Florida rivers.