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Ichetucknee Springs: Measuring the Effects of Visitors on Water Quality Parameters through Continuous Monitoring.

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ICHETUCKNEE SPRINGS: MEASURING THE EFFECTS OF VISITORS ON WATER QUALITY PARAMETERS THROUGH CONTINUOUS MONITORING

by

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ABSTRACT

Ichetucknee Springs System is in north central Florida, under the jurisdiction of the Suwannee River Water Management District (SRWMD). The Ichetucknee River is one of the most pristine spring-fed rivers in Florida and became a state park in 1970. Over 400,000 people visited the Ichetucknee Springs State Park in 2016. From that total, over 130,000 people came during the tubing season alone (Memorial Day to Labor Day). During the tubing season, only 750 visitors per day are allowed to launch from the North Launch, near the Ichetucknee Head Spring. The park enforces visitor usage of the river during these time frames to protect the integrity of the aquatic vegetation and aquatic organisms in the northern portion of the River.

The objective of this study is to evaluate the response of water quality from the Head Spring to the seasonal changes in visitor numbers to the Park. Water quality parameters were continuously monitored and recorded by a SRWMD station using a YSI EXO2 and SUNA nitrate sensor: temperature, turbidity, pH, specific conductivity, dissolved oxygen content, and nitrates (NO2+NO3). Water quality data from April 2015 to September 2017 was reviewed and processed into max daily values that were compared to daily visitor counts. Results from the statistical analysis indicate there is a significant difference in turbidity from the Head Spring during the tubing season and outside the tubing season (Kruskal-Wallis, $p<0.001$), which results from higher visitor counts during the weekends of the tubing season. However, due to inconsistency of water quality readings and equipment damage, some data were lost or outside the range of monitoring capabilities; which may have resulted in decreased correlation between water quality and daily visitor counts. Continued evaluation of water quality by continuous monitoring is warranted as it can assist the SRWMD and Ichetucknee Springs State Park Staff better monitor and evaluate the health of the Ichetucknee Springs System.

ACKNOWLEDGMENTS

First and foremost, I must thank my advisor, Dr. Arvind Singh. Thank you for being patient with me during these last few years and supporting me in completing my coursework and thesis. Dr. Singh always made time for me to visit and responded to my emails on unreasonably short notices. I am very thankful for the opportunity to work with him these past few years.

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Special recognition is due to my coworkers at Amec Foster Wheeler, now Wood. Dr. Nirjhar Shah, Dr. Mary Szafraniec, Dr. John Kiefer, and Lance Lumbard, MS, were incredibly patient with all my thesis related questions. Dr. Shah provided invaluable statistics guidance and Dr. Szafraniec was my water quality guru. Without their review, guidance, and patience, I would have had a meltdown at work. Thank you for giving me the time and space to pursue my own research. I promise to get back to work!

Final words of gratitude and love go to my family. They have supported me through all my professional, academic, and harebrained endeavors. They are the lighthouse that guides me home.

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CHAPTER 1: INTRODUCTION

The Florida Springs are one of the most valuable natural resources in the State of Florida. They provide Floridians and tourists with environmental, social, and economic benefits that exceed their dollar value. One of the crown jewels of the State is the Ichetucknee Springs System. Ichetucknee Springs is located in North Central Florida, between Suwannee and Columbia County, near Fort White. Ichetucknee Springs is a first magnitude spring group, discharging up to 23.7 million gallons per day (MGD) (USGS, 2010). The Head Spring, eight other named springs, and many more unnamed springs, feed the 5.5 mile Ichetucknee River; which leads into the Santa Fe River (near U.S. Highway 27); before reaching the Suwannee River; and finally discharging into the Gulf of Mexico (Figure 1).

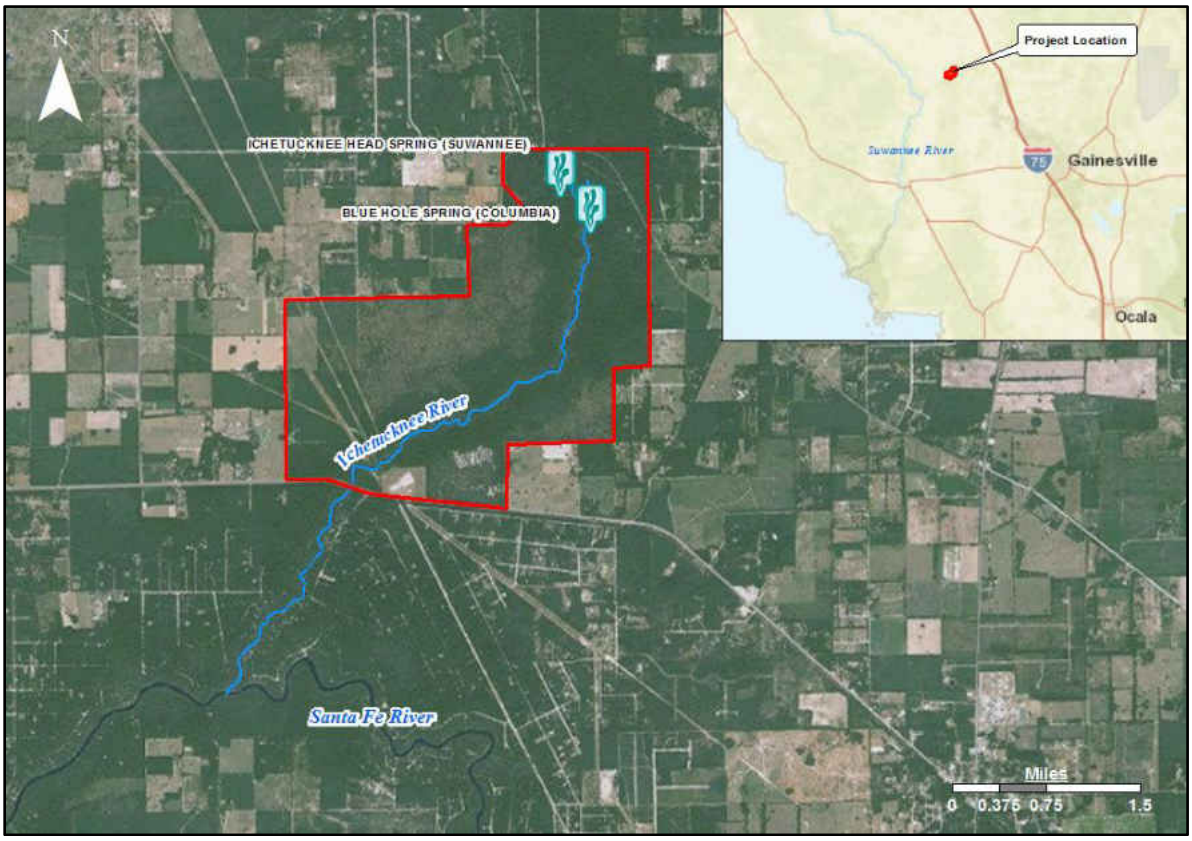

Figure 1: Project Location – Ichetucknee River and Springs

Ichetucknee Springs State Park (ISSP) is the 2,280 acre park that surrounds the Head Spring, Blue Hole Springs, four other named springs, and 3.2 miles of the Ichetucknee River. The river flows an additional 2.3 miles before discharging into the Santa Fe River (Florida State Parks, 2017) The Park is open every day of the year from 8:00 a.m. until sundown. The ISSP features hiking trails, picnic areas, canoeing, kayaking, tubing, swimming, and diving. No camping is allowed within the park, but there are independent campgrounds nearby (Figure 2) (Florida State Parks, 2017). Within the park, visitors can swim in both the Head Spring and Blue Hole Spring year round. From October to March, Blue Hole is open to certified cave divers. Park staff record how many visitors visit the park daily, how many access the North Launch, and keep an annual log for Florida Parks Service (FPS).

In 2015, ISSP had 481,603 visitors, the highest year on record. In 2005, ten years prior, there were only 151,749 visitors (Table 2). In order to protect the integrity of the Ichetucknee River, in 2011, ISSP set restrictions on when visitors can access the river from the North End of the park, starting from the North Launch (Figure 2). From Memorial Day until Labor Day, visitors can tube, kayak, or swim from the North Launch, and float through the grass beds and hammocks to the end of the park, usually a three-hour float. During the tubing season, only 250 visitors per day are allowed to launch from the North End. On weekends and holidays, that limit can be reached before 9 am. The Midpoint Launch is open year round (Figure 2) and does not limit how many visitors can use it. Visitors can take a trolley from the end of the park back to the Midpoint, as many times as they'd like. No food or alcohol is allowed in the river, even though there are cases where some visitors sneak them in.

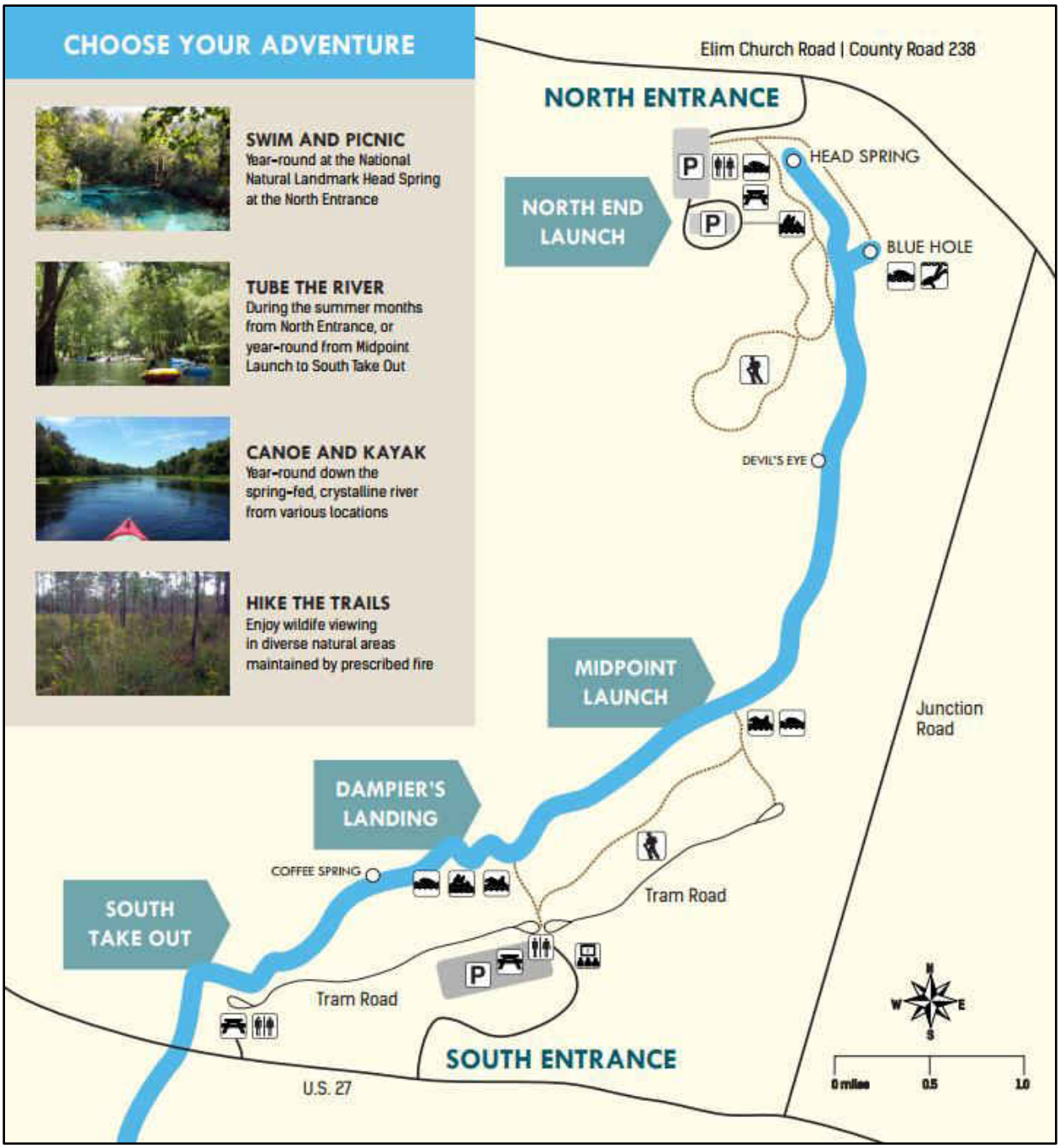

Figure 2: Ichetucknee State Park Map (Florida State Parks, 2017)

With significant increases in visitors over the last ten years, the Suwanee River Water Management District (SRWMD), part of Florida Department of Environmental Protection

(FDEP), and the Florida Park Service (FPS) have growing concerns for the integrity of the spring run, the surrounding ecosystem, and the water quality of the springs as it makes its journey to the Suwannee River. In 2014, in partnership with FDEP and the United States Geological Survey (USGS), SRWMD installed a Submersible Ultraviolet Nitrate Analyzer (SUNA) and YSI EXO2 in the Ichetucknee Head Spring and in Blue Hole Spring. The SUNA uses ultraviolet light technology to measure nitrate-nitrogen concentrations and the EXO2 measures: temperature, conductivity, dissolved oxygen, pH, dissolved organic matter, and turbidity (SRWMD, http://www.mysuwanneeriver.com/index.aspx?nid=267). This equipment allows for real-time water quality monitoring, collecting every hour, which is then checked by SRWMD before being uploaded to a SRWMD website called the "Springs Dashboard." The Springs Dashboard pairs the water quality data with the stage and discharge information collected by the USGS. This is accessible to the public and can be found here: http://www.mysuwanneeriver.org/dashboards/index.html

The objective of this research is to assess the impacts of increasing visitor numbers to changes in the water quality, which is continuously monitored in the Ichetucknee Head Spring. To do so, visitor logs provided by the ISSP staff and continuous water quality data provided by the SRWMD are utilized to assess if there are changes in water quality that correlate to event, seasonal, and/or annual increases in visitors.

Understanding the effects of humans on spring environments is integral to protecting and improving the flora and fauna in spring ecosystems. If it is shown that changes in water quality correlate to high numbers of visitors, then extra measures can be taken to protect the integrity of Ichetucknee Springs. The proposed research makes two contributions to this effort: (1) combining and utilizing information from two distinct sources: continuous monitoring data by

SRWMD and visitor logs provided by ISSP staff, and (2) studying if there is a pattern in water quality changes that correlates to event, seasonal, and annual visitor increases. These complimentary contributions may, ultimately, lead to a stronger understanding of how recreational usage affects the water quality of the Ichetucknee Springs.

The proposed research will be provided to ISSP Staff and SRWMD staff that assisted with this project. This research provides a more interdisciplinary approach to utilizing and evaluating continuous water quality data; by combining it with visitor logs and evaluating both sets of data based on ISSP visitor seasons, a more sociological approach is used in evaluating water quality. This research may help them have a better understanding of the effectiveness of the steps they have taken to protect their springs (e.g. limiting visitors to the North Launch) and what future changes may be implemented to further protect Ichetucknee Spring.

CHAPTER 2: DESCRIPTION OF STUDY DOMAIN

2.1 Introduction

The Ichetucknee System in in north central Florida, straddling across west Columbia County and east Suwannee County. It is under the SRWMD jurisdiction, a subsect of the Florida Department of Environmental Projection (FDEP). The Ichetucknee River (henceforth "River") travels through the Ichetucknee Springs State Park (ISSP) for 3.2 miles, to US 27, and then another 2.3 miles until it connects to the Santa Fe River, which ultimately flows to the Suwannee River (Florida Springs Institute, 2012). The Ichetucknee Spring system is one of the largest in Florida and became a state park in 1970 (2280 acres). In 1972 the first magnitude Head Spring was declared a National Natural Landmark by the U.S. Department of Interior (Florida Springs Institute, 2012)

2.2 Population and Land Use

2.2.1 Population

In 2010, approximately 100,000 people lived within the Ichetucknee Springshed Basin (400 square miles). The largest urban area near the Ichetucknee River Basin is Lake City, which in 2010 had a population of approximately 12,050 (United States Census Bureau, 2010). Both Columbia and Suwannee County populations grew by over 10,000 people from 2000 to 2010.

Table 1: County Census Populations

County	Year 2000	Year 2010	Population Growth	% Increase
Columbia County	56,513	67,531	11,018	19%
Suwannee County	34,844	51,551	16,707	48%

Source: U.S. Census Bureau, 2010 Census; Census 2010 Summary File 1, Geographic Header Record G001.

2.2.2 Land Use

As of 2014, land uses within the Ichetucknee River Basin were predominately forests and tree plantations (32%), water bodies (17%), agricultural (16%), urban (15%), utilities and services (9%), rangelands (8%), rural & unknown land (2%), and wetlands (1%) (SRWMD, 2014).

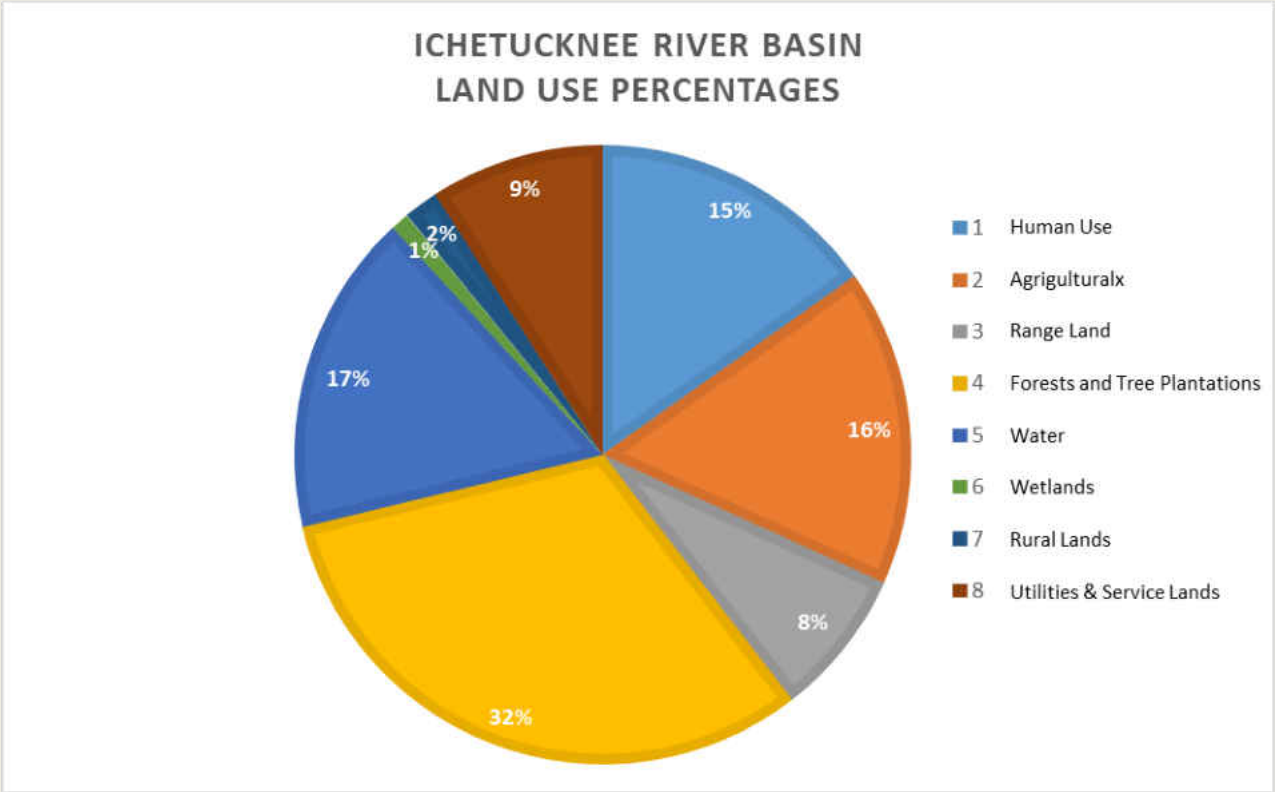

Figure 3: Ichetucknee River Basin Land Use Percentages (SRWMD, 2014)

In 2004, about 18% of the Springshed basin is in urban, transportation, commercial, and built-up land uses (Florida Springs Institute, 2012). Upland forests comprise about 44% of the basin and are dominated by pine plantations and other coniferous forests; agricultural land uses comprise about 23% of the basin and are dominated by cropland and pasture; wetlands and water

about 11%; and prairie, scrub, and rangelands about 3% of the Springshed (Florida Springs Institute, 2012). This data indicates that land uses in the Ichetucknee Springs Basin are gradually changing from rural agricultural/forestry to urban land uses and pine plantations.

2.2.3 Agriculture

In 2015, the USGS completed an agricultural land-use survey of counties in the SRWMD. They investigated seven counties (Alachua, Gilchrist, Hamilton, Lafayette, Levy, Madison, and Suwannee) that accounted for 88 percent of the SRWMD irrigated acreage (Figure 4). They found that: "irrigated cropland totaled 26,927 acres in Suwannee County; 16,511 acres in Madison County; 14,862 acres in Hamilton County; and 14,155 in Gilchrist County" (Marella, et.al 2016). Corn (primarily for silage) and peanuts were the primary irrigated crops in Suwannee, Madison, and Gilchrist Counties; vegetables were the primary irrigated crop in Hamilton County. Other counties with substantial irrigated acres include Levy (10,122 acres), Alachua (9,547 acres), and Lafayette (8,110 acres) (Marella, et.al 2016).

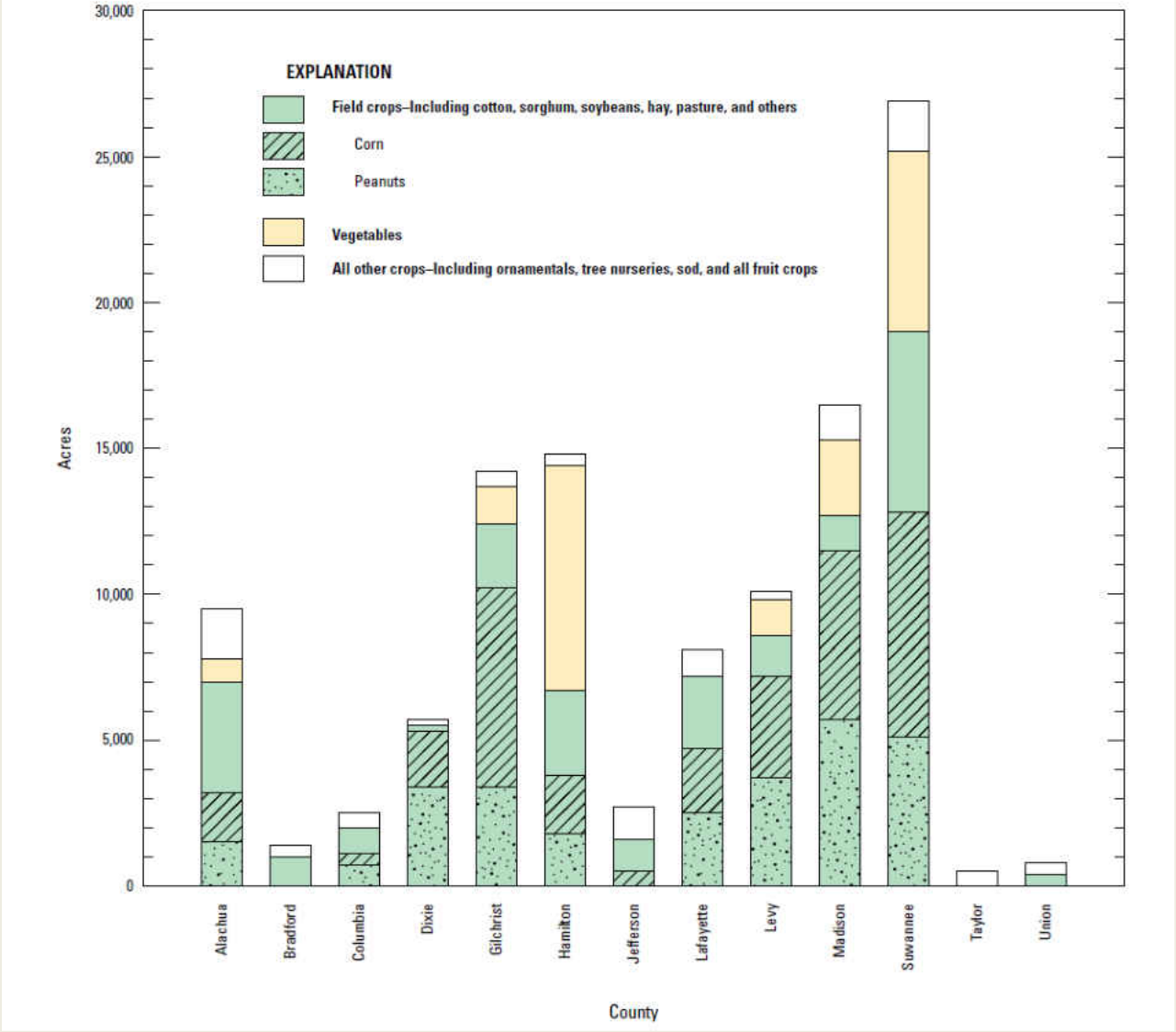

Figure 4: Distribution of Inventoried Irrigated Crops by County (Marella et.al, 2016).

2.3 Water Usage

2.3.1 Florida Statewide Usage

From 2000 to 2010, total water consumption by the State of Florida has decreased from 20,147 MGD to 14,988 MGD (5159 MGD reduction). Both freshwater and saltwater

consumption have decreased since 2000. “Estimates for 2000 are higher than previous years because prolonged drought conditions throughout the State led to increased water demands for all irrigation purposes (agriculture, recreational, and residential lawns) and greater evaporation losses” (Marella, et.al, 2016).

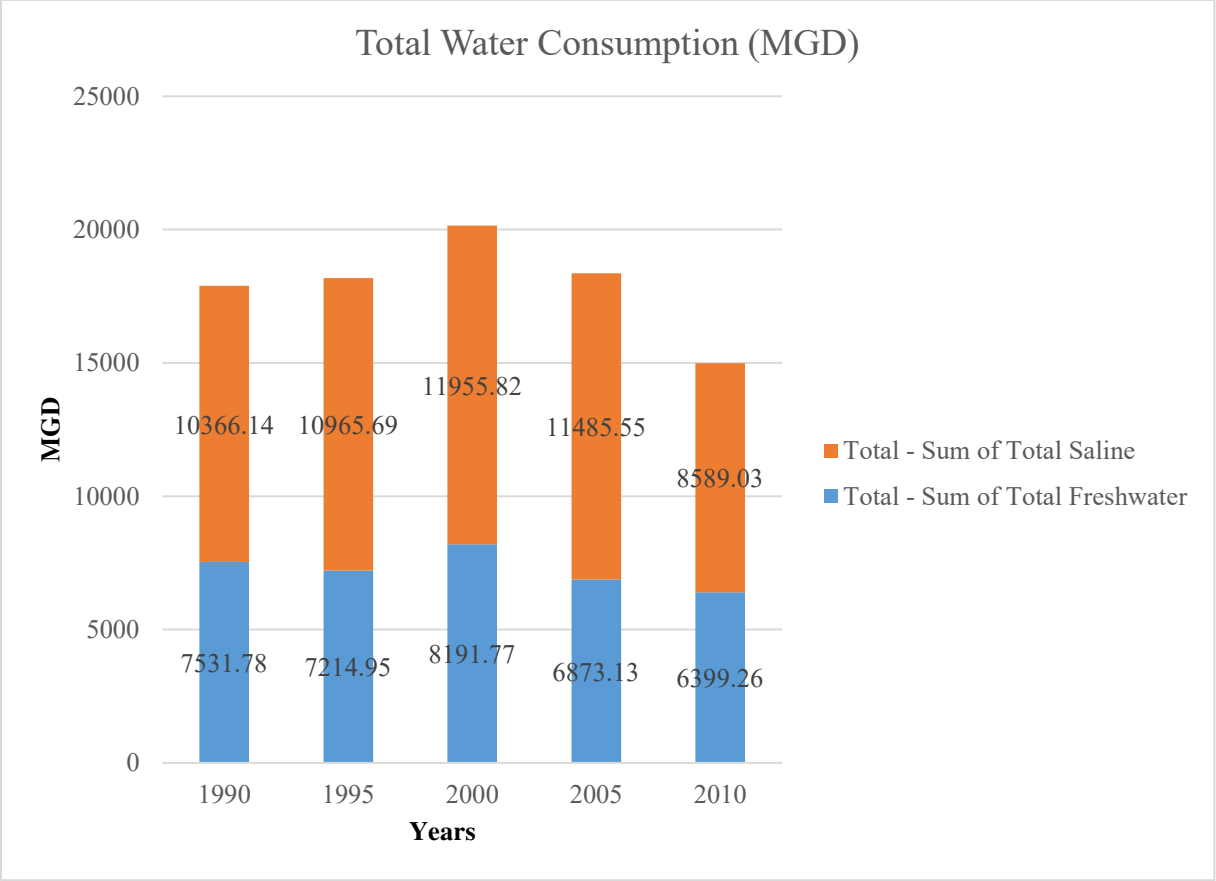

Figure 5: Statewide Total Water Consumption (Marella, 2014).

Overall freshwater consumption has decreased since 2000. Groundwater consumption has decreased by 909.5 MGD and surface water consumption has decreased by 4,249.8 MGD. This equates to a 23% percent reduction in surface water consumption and 2% reduction in groundwater consumption.

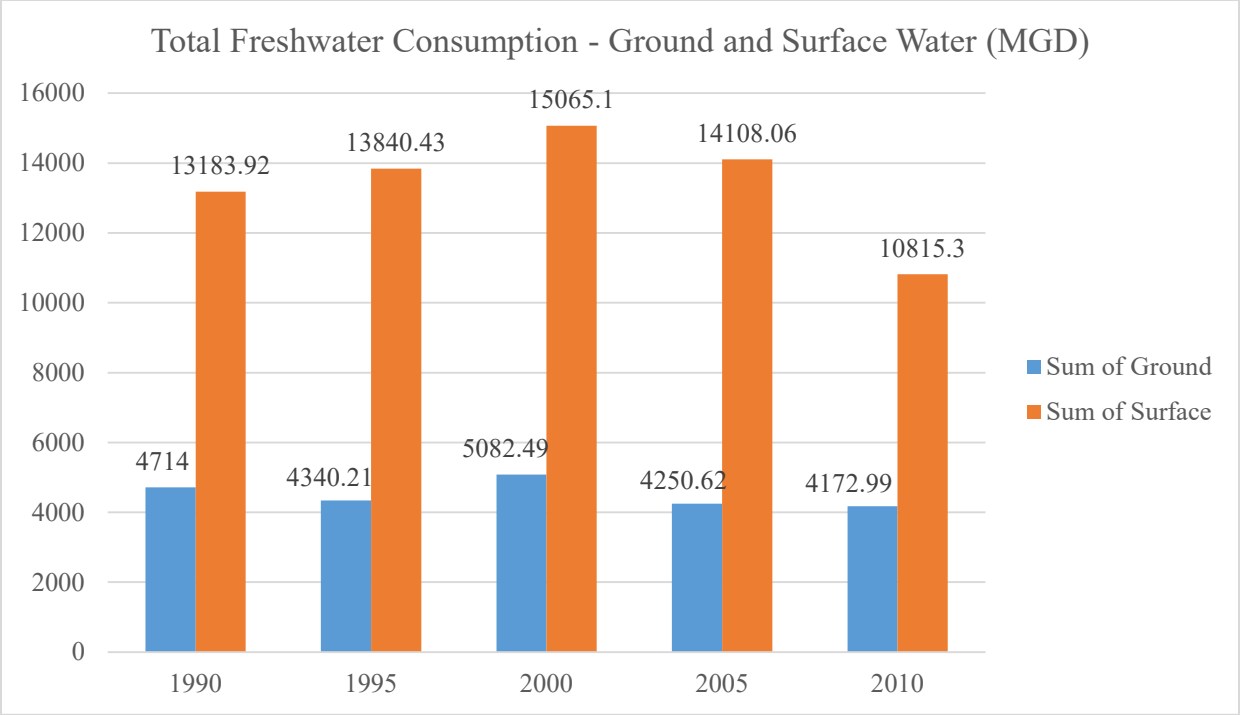

Figure 6: Statewide Freshwater Water Consumption (Marella, 2014).

Looking specifically at groundwater consumption, we see that the Floridan Aquifer is the largest provider of groundwater across the State (60%) followed by the Biscayne Aquifer (18%) and Surficial Aquifer System (13%). Though total consumption has decreased since 2000, withdrawal from the Floridan Aquifer remained relatively steady between 2005 (2527 MGD) and 2010 (2571 MGD) (Marella, 2014).

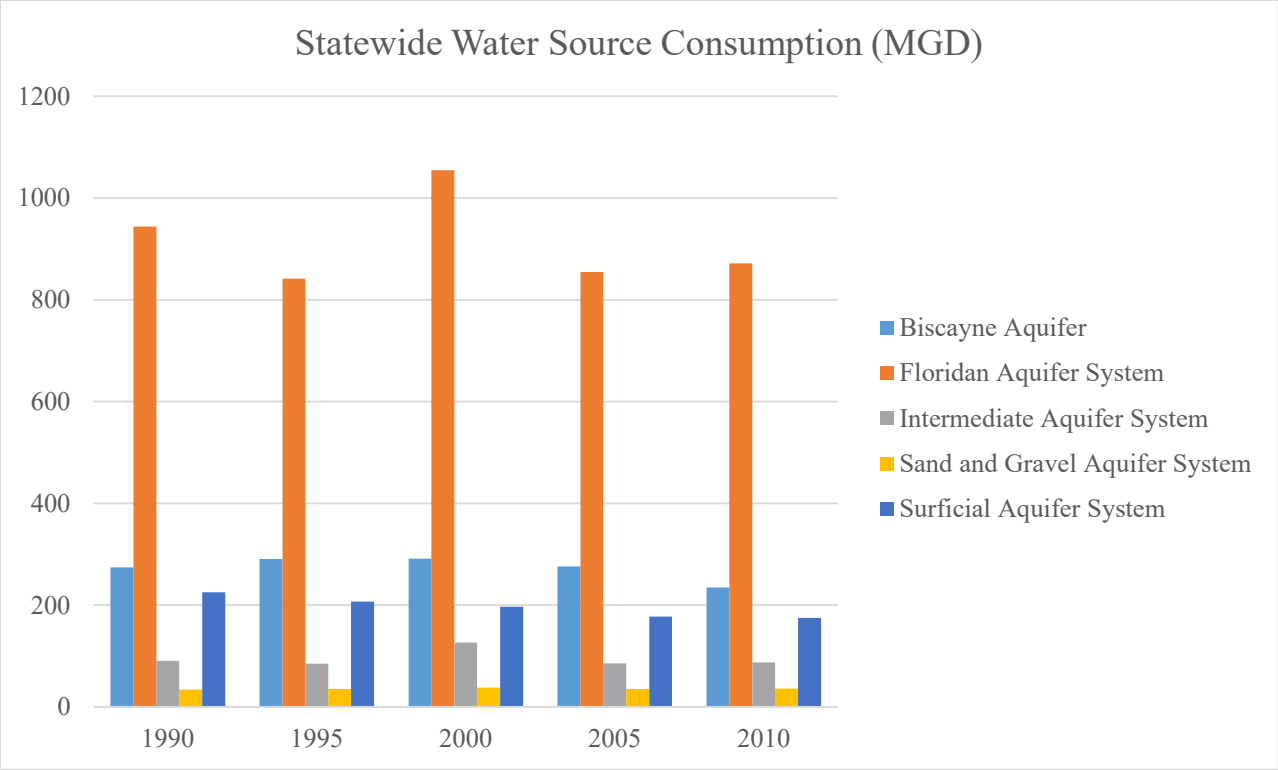

Figure 7: Statewide Water Source Consumption (Marella, 2014).

Across the State, groundwater consumption has decreased since 2000; however between 2005 and 2010, there has been an increase in agricultural use of groundwater (up 112.35 MGD). Power generation has consumed more water in 2010 than the previous 25 years, (50 MGD). There has been a decrease in public use of groundwater (189 MGD) despite the spike in population. Groundwater use has steadily decreased for Commercial-Industrial Mining and Domestic self-supplied (Marella, 2014).

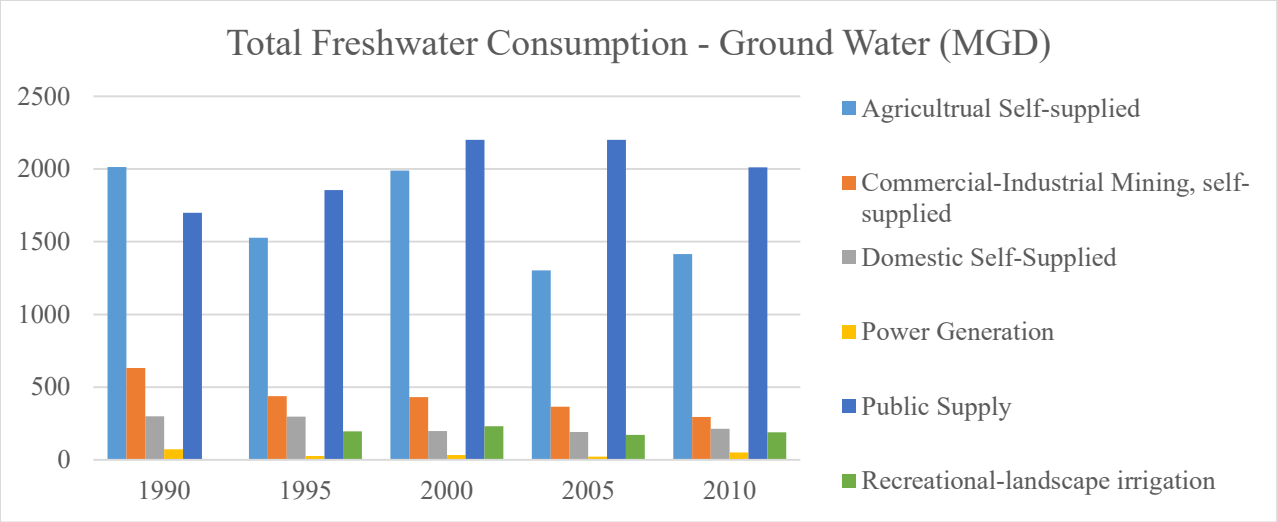

Figure 8: Statewide Freshwater Consumption – Groundwater (Marella, 2014).

Most of the surface water consumed is by Power Generation, but that has decreased within the last ten years (reduced by 3444 MGD). This may be attributed to the rise in alternative energy sources in Florida in the last decade (Marella, 2014).

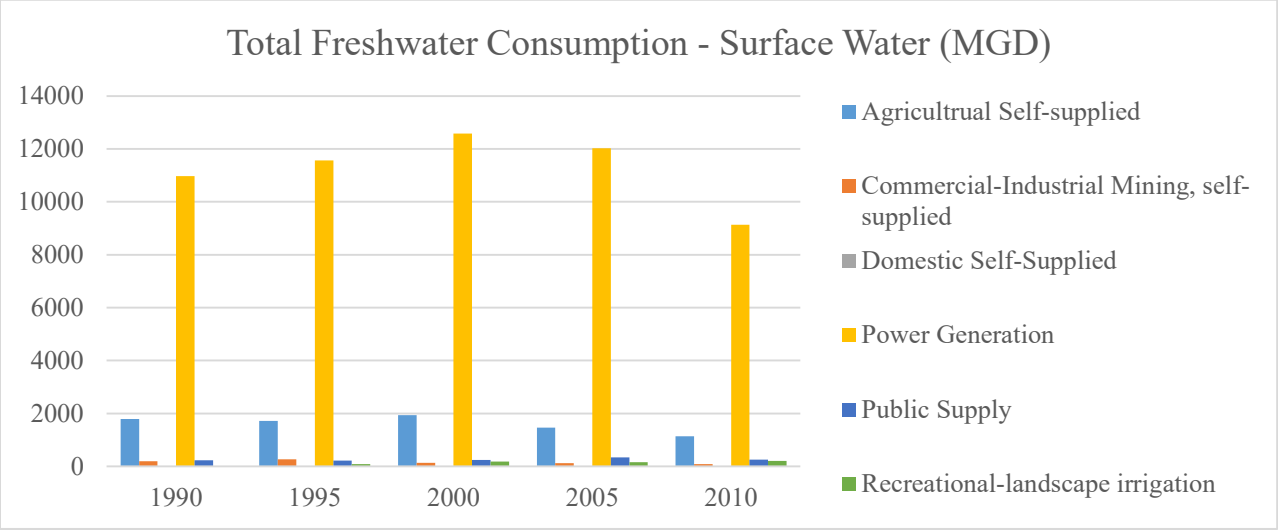

Figure 9: Statewide Freshwater Consumption – Surface Water (Marella, 2014).

In Florida, agriculture was the largest consumer of freshwater in 2010, accounting for 40 % of total freshwater withdrawals (2551 MGD), followed by public supply at 35 % (2251 MGD). Power generation accounted for 10% of the water consumed (613 MGD), commercial-industrial mining (378 MGD) and recreational-landscape irrigation (391.93 MGD) each accounted for 6% of usage, and domestic self-supply accounted for 3% (214 MGD) Focusing on groundwater withdrawal, public supply (2012 MGD) accounted for 48 % of consumption and agricultural self-supplied (1414 MGD) accounted for 34% (Marella, 2014). From surface water withdrawal, 51% was consumed for Agricultural Use (1137 MGD) and 25% went to power generation (570 MGD). This indicates that even though agriculture is the largest consumer of water for the State, public use is the largest consumer of groundwater withdrawal for the State of Florida (Marella, 2014).

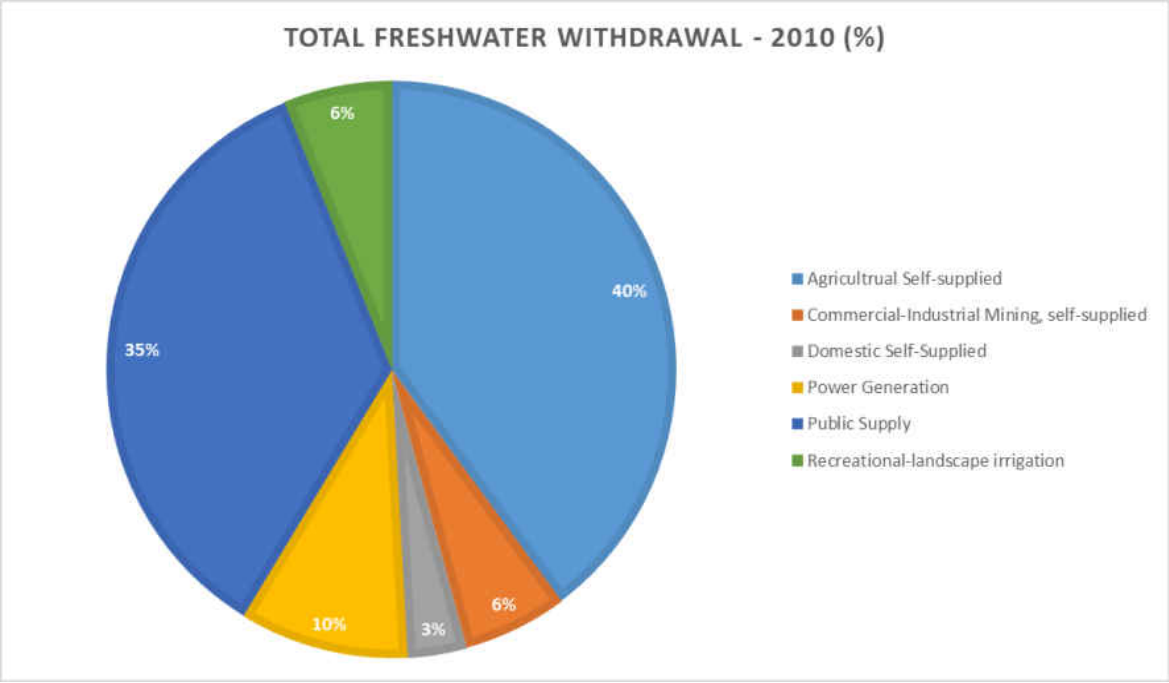

Figure 10: Statewide Freshwater Consumer Withdrawal (Marella, 2014).

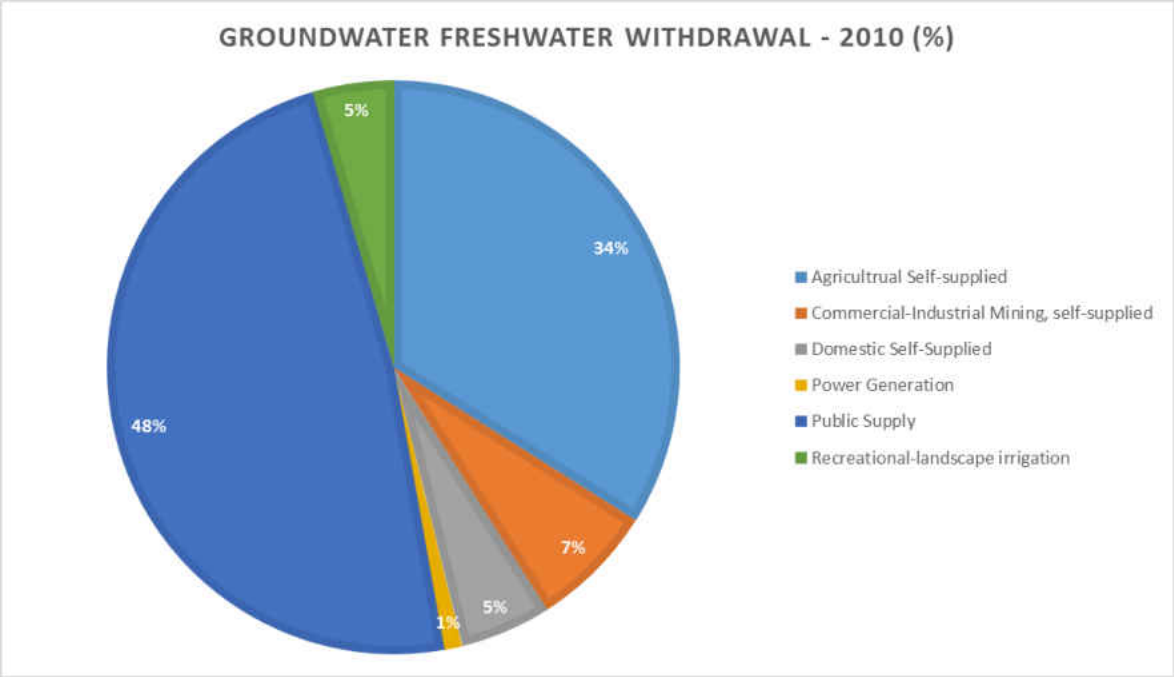

Figure 11: Statewide Groundwater Consumer Withdrawal (Marella, 2014).

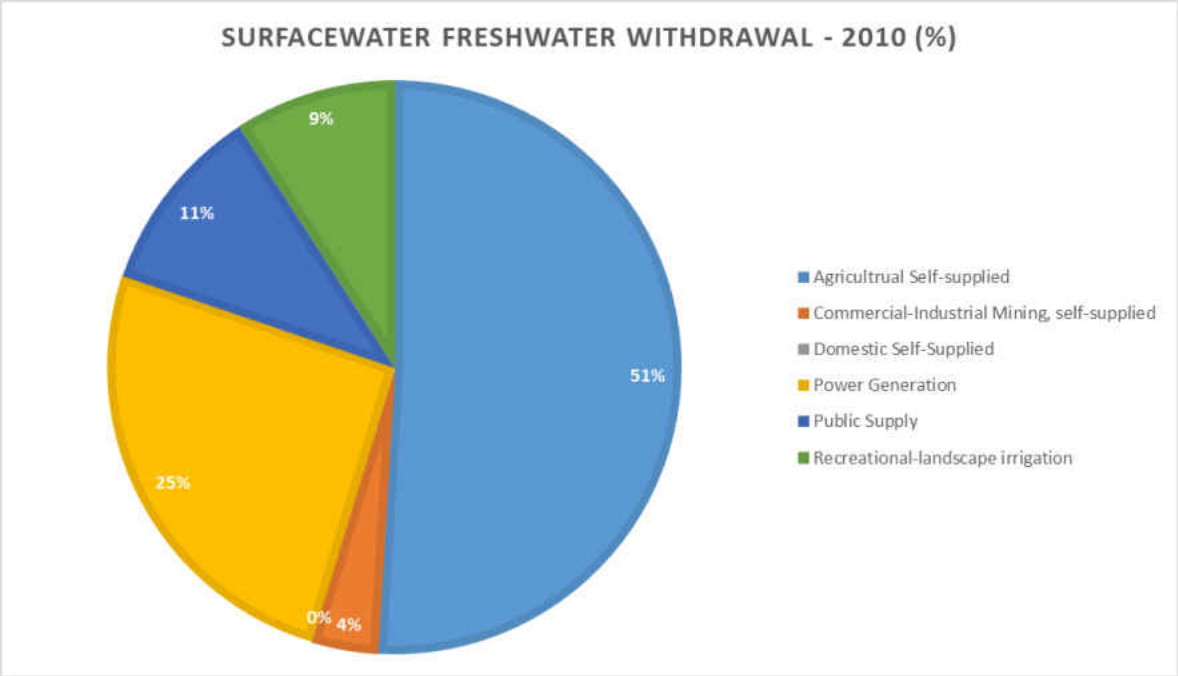

Figure 12: Statewide Surface Water Consumer Withdrawal (Marella, 2014).

2.3.2 Columbia and Suwanee County Usage

Despite Statewide consumption of water has decreased, water usage within Columbia and Suwannee County has increased. As of 2012, Columbia County's total water usage was 16.89 MGD (up 2.8 MGD since 2000) and Suwanee County withdrew 178.77 MGD (up 50.95 MGD). In comparing groundwater consumption, we see that both counties have increased since 2000: Columbia (16.71 MGD, up 2.83 MGD) and Suwannee (40.22 MGD, up 13.81 MGD) (Marella, 2014). The primary source of groundwater for both counties is the Floridan Aquifer.

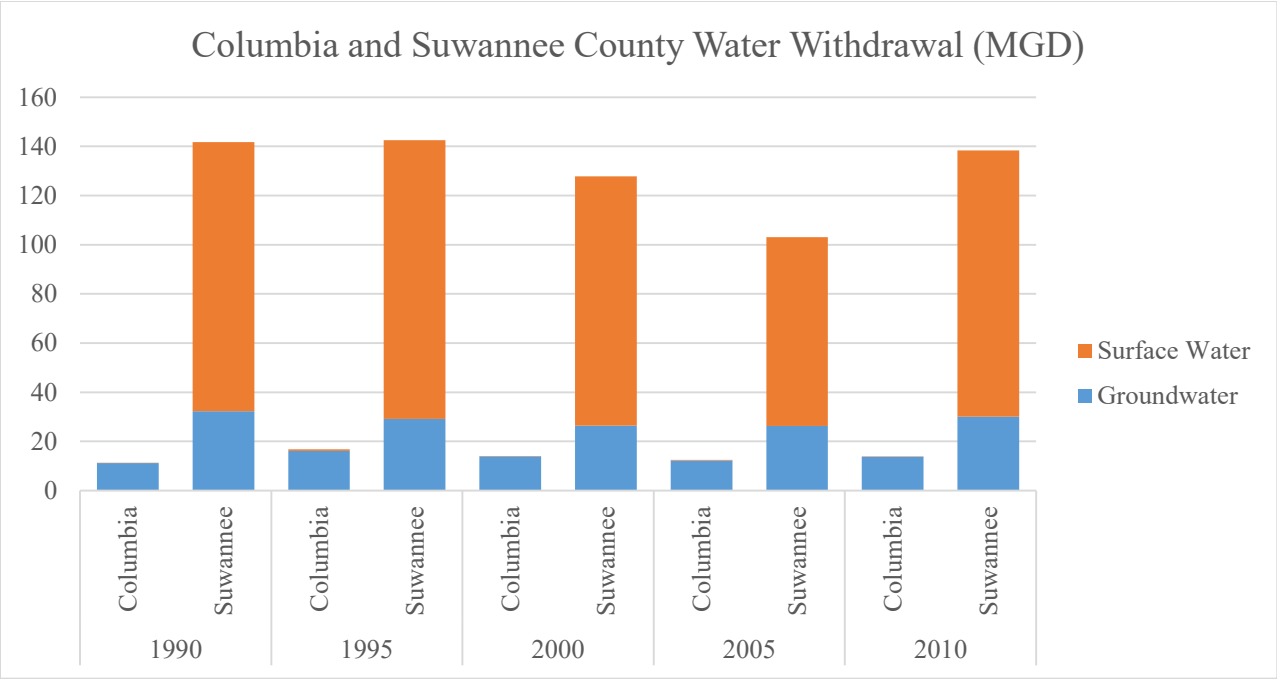

Figure 13: Columbia and Suwannee County Water Withdrawal (Marella, 2014).

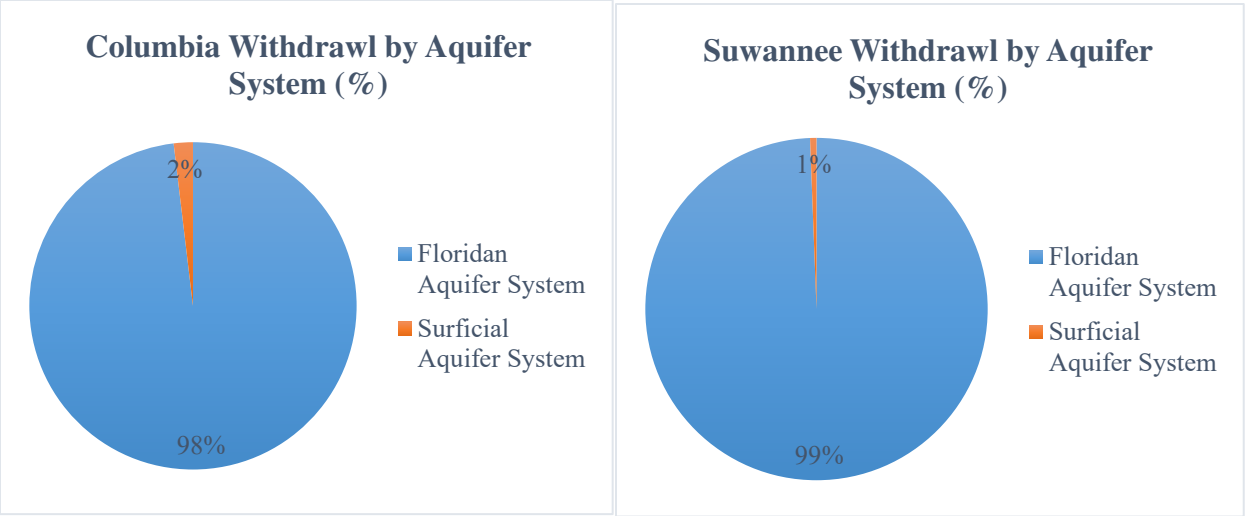

Figure 14: Columbia and Suwannee Aquifer Withdrawal (Marella, 2014).

We see that Suwannee County consumes a larger percentage of Surface Water (78%) in comparison to Columbia County (2%) (Marella, 2014). This is due to power plant in Suwanee County, located on the Suwanee River and operated by Duke Energy.

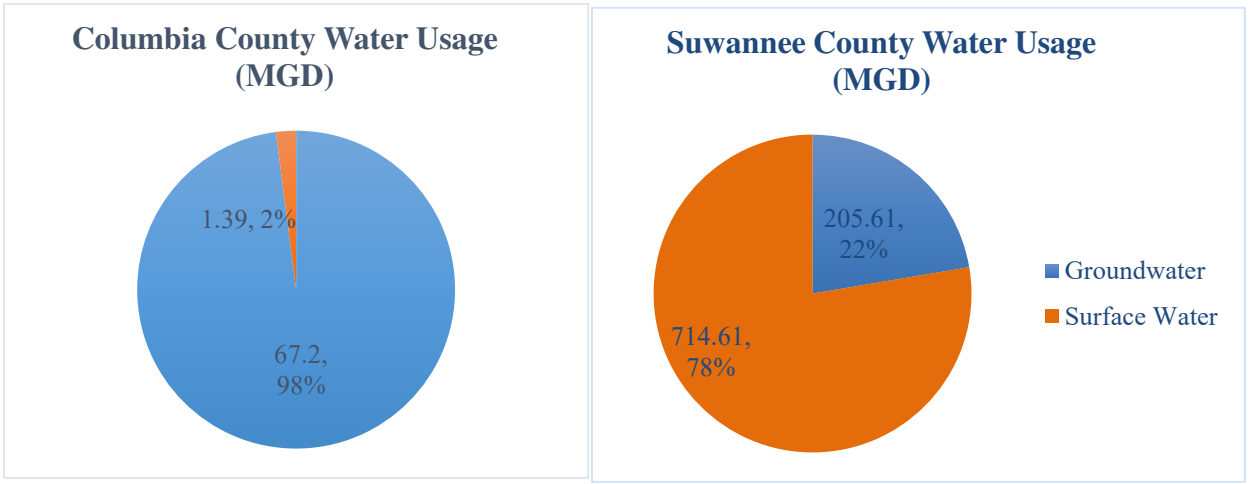

Figure 15: Columbia and Suwannee Water Usage (Marella, 2014)

Surface water withdrawal by Suwanee County has increased since 2000, due to urbanization and growth in population within the area. Groundwater withdrawal for power generation has also increased, but as of 2010 remains below 1 MGD (Marella, 2014).

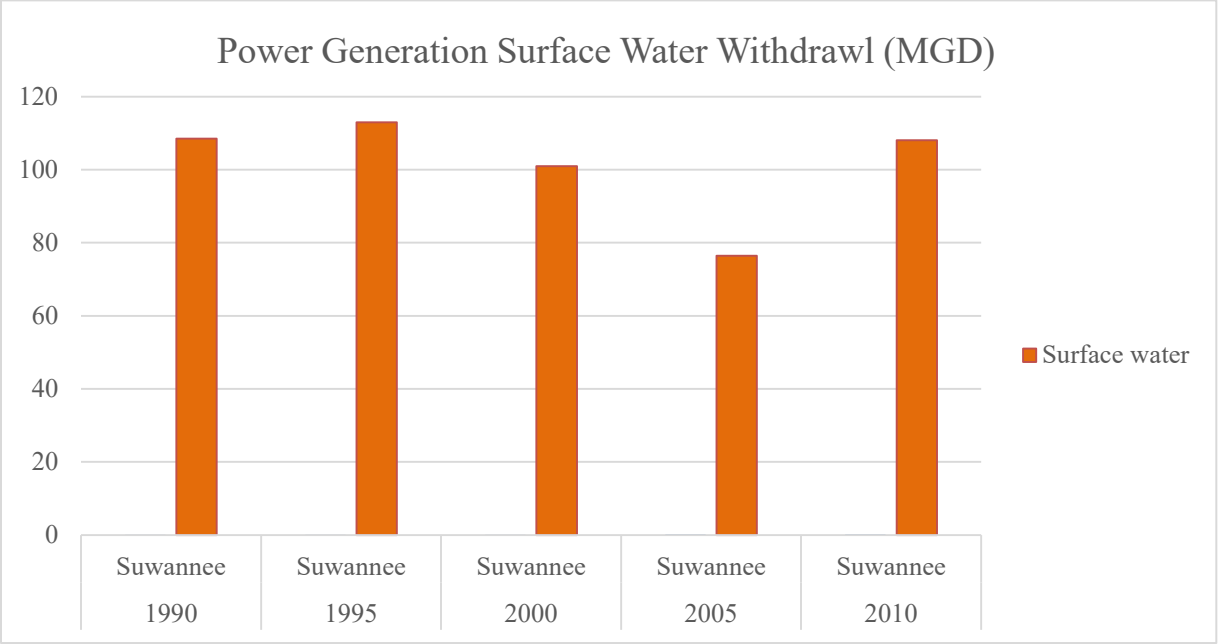

Figure 16: Suwannee County Power Generation Water Withdrawal (Marella, 2014)

Agriculture within Columbia and Suwannee County is sustained through groundwater withdrawal. There has been an increase in groundwater withdrawal since 2000, increasing by 2% for Columbia County and 15% for Suwannee County (Marella, 2014).

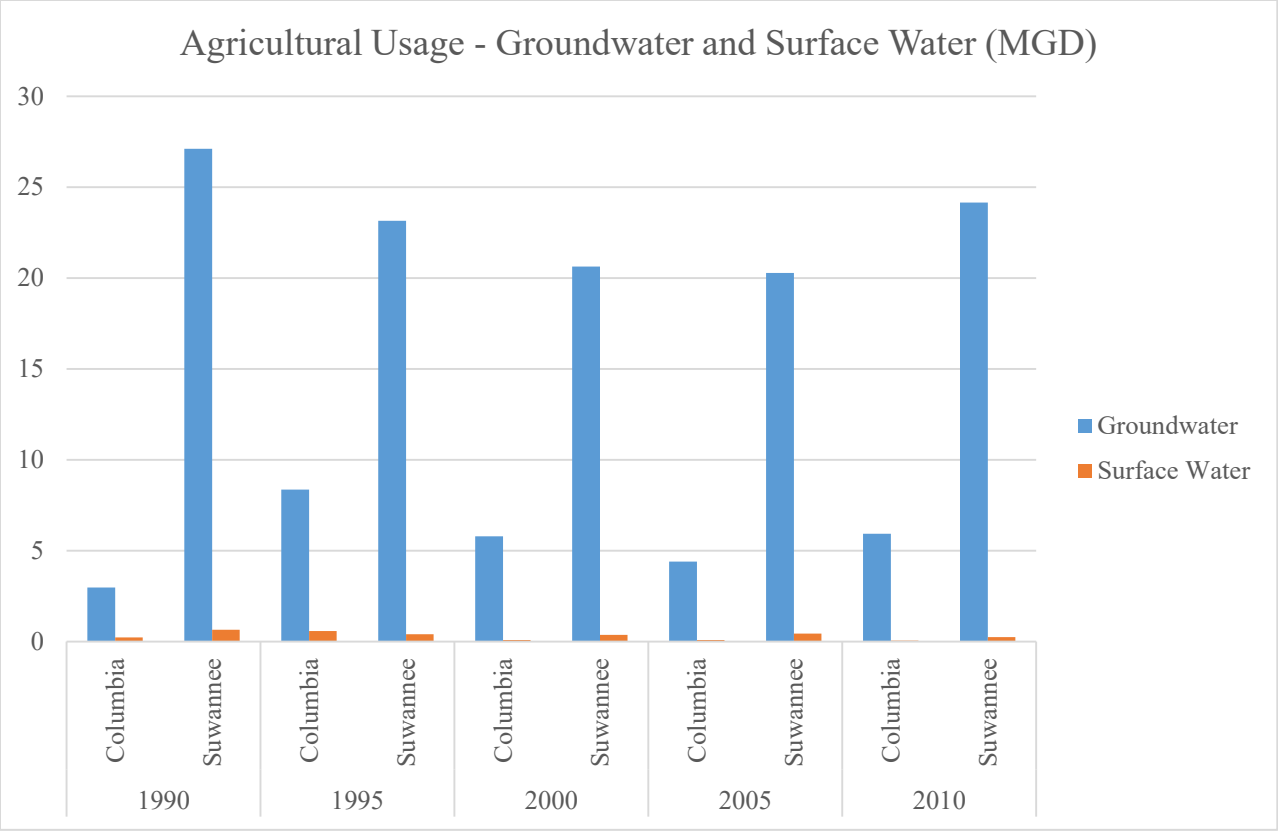

Figure 17: Suwannee and Columbia County Agricultural Usage (Marella, 2014)

As of 2010, Suwannee County's total water withdrawal was 30 MGD. More than 75% of Suwannee County residents use self-supplied water sources. Agricultural self-supplied water withdrawal use accounted for 24.16 MGD (80.5%) (Marella, 2014). In 1995 Agricultural self-supplied water withdrawal use accounted for 80% of Suwannee County's water withdrawals (Marella, 1995).

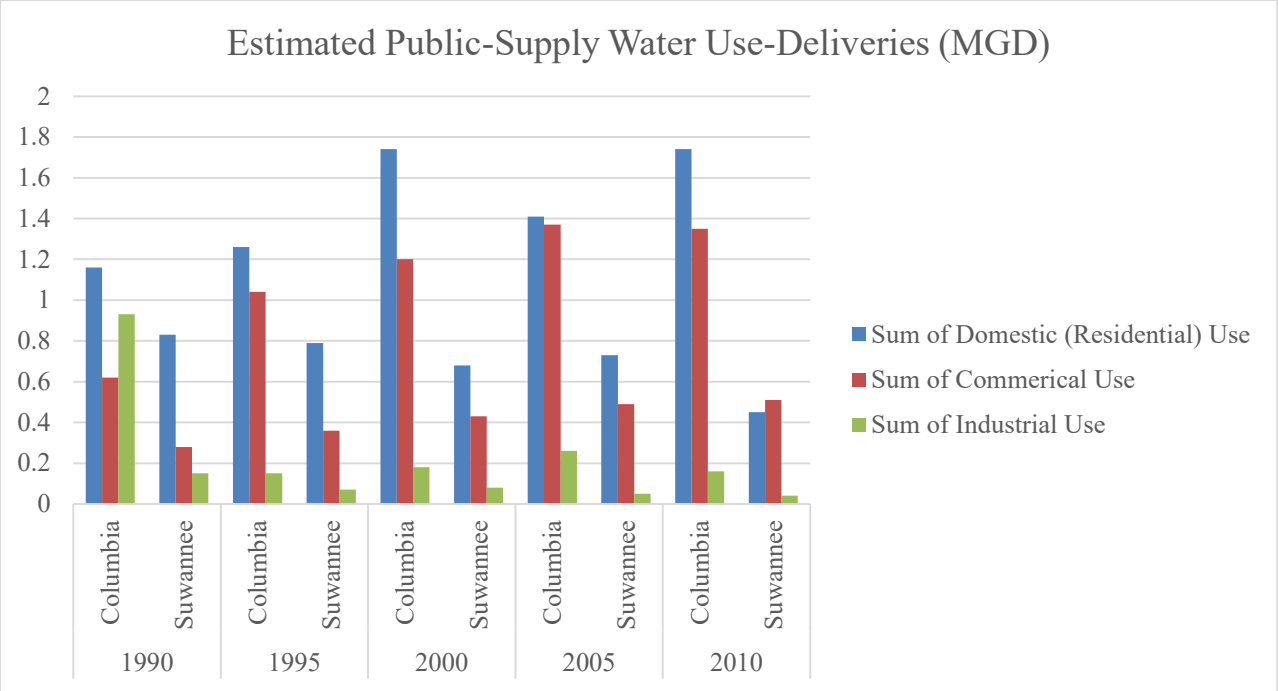

Figure 18: Suwannee and Columbia County Public-Supply Delivery (Marella, 2014).

Domestic Use in Columbia County has increased with the increase in population, but commercial and industrial use has dropped. Domestic use in Suwannee County has decreased, despite population growth, but commercial use has increased since 2005 (Marella, 2014).

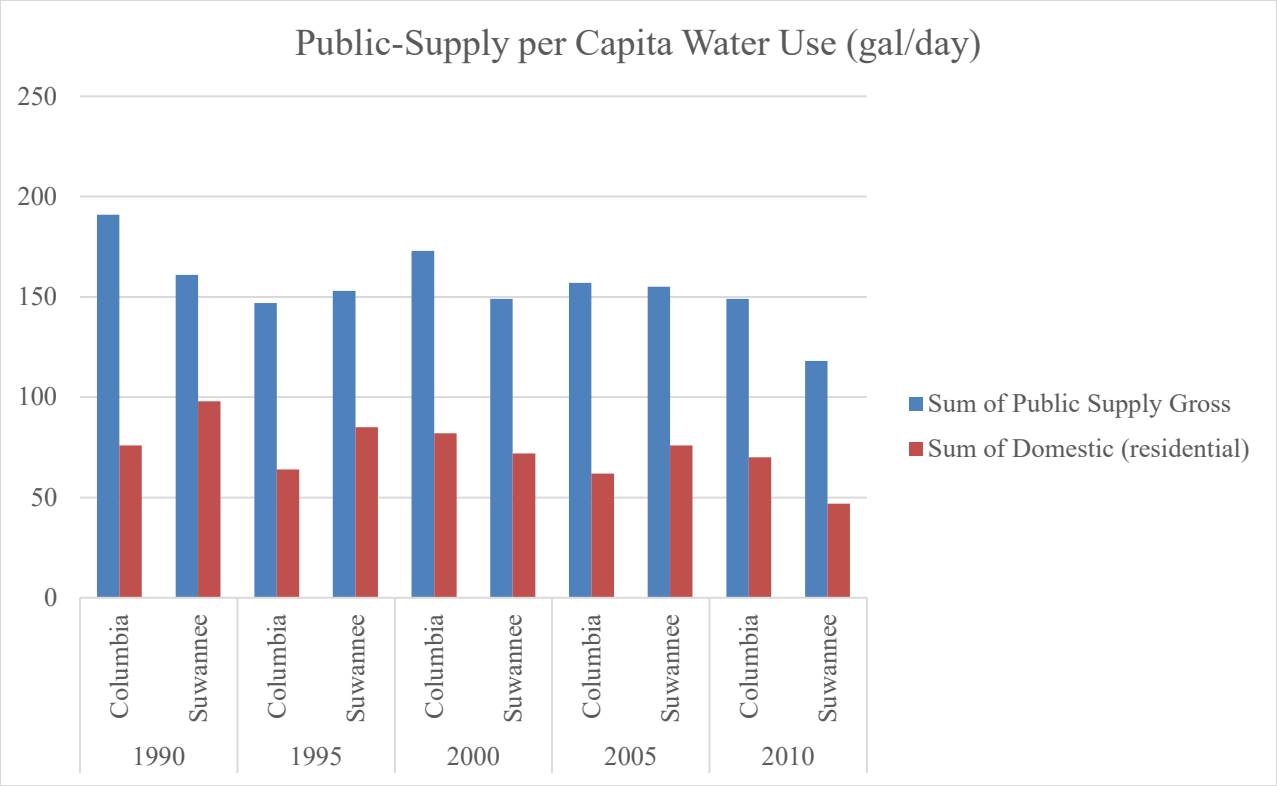

Figure 19: Suwannee and Columbia County Public-Supply Usage per Day (Marella, 2014)

Despite population growth since 2005, public-supply water use per capita has decreased since 2000. This could be due to more people relying on private wells and better water use practices (Marella, 2014).

2.4 Topography

The topography of the Ichetucknee Springshed varies considerably. Land-surface elevations range from less than 20 feet above mean sea level (MSL) along the southern boundary near the Santa Fe River to heights more than 160 feet above MSL in upland areas to the east of Lake City (Figure 20) (SRWMD, GIS 2014).

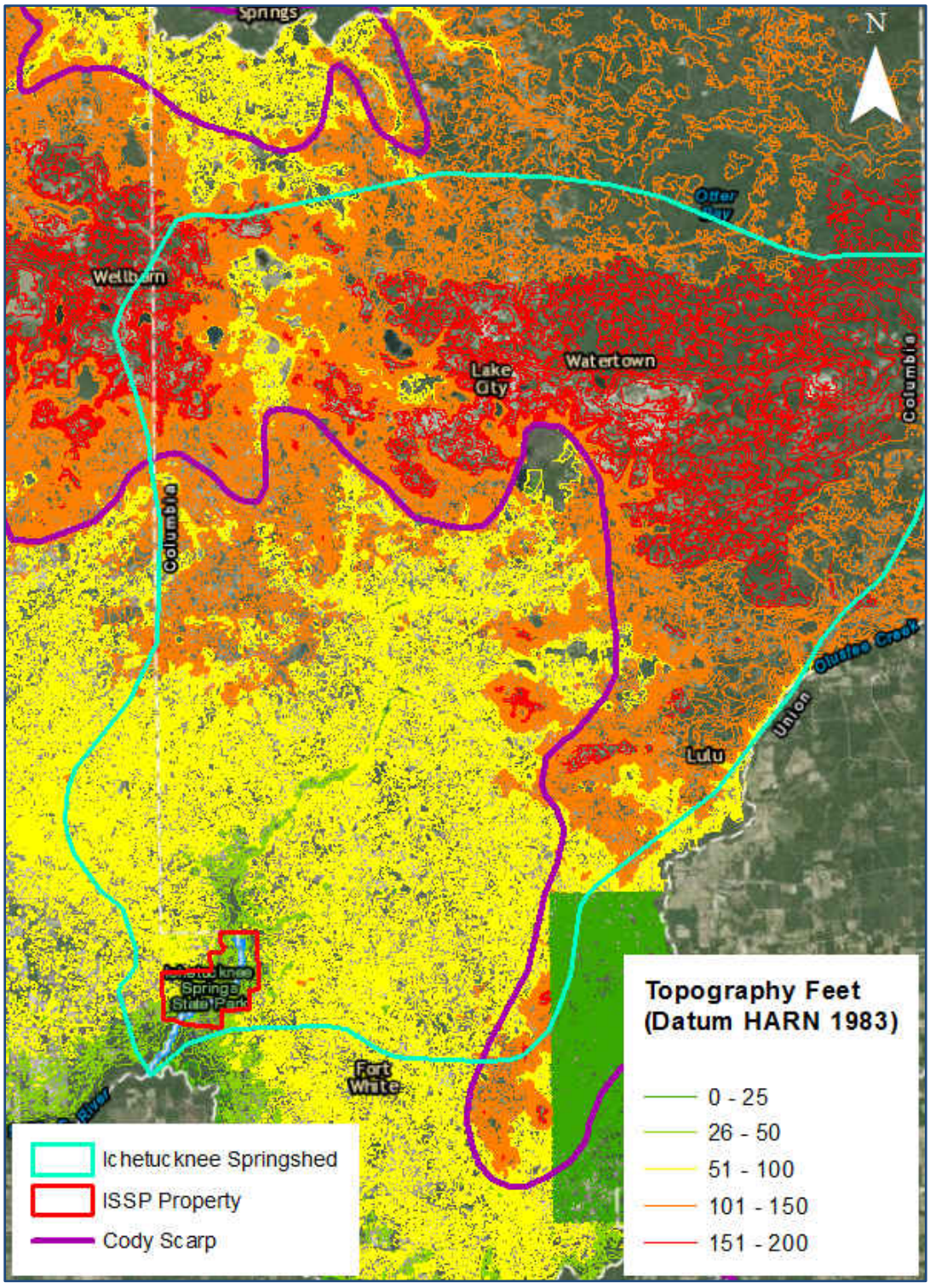

Figure 20: Ichetucknee Springshed Topography (Feet MSL)

In the immediate vicinity of the springs, however, elevations typically range between 25 and 50 MSL (SRWMD, GIS 2014). The springs drain an estimated 245,414 acres Springshed (SRWMD, GIS 2014) that includes both confined and unconfined areas of the Floridan Aquifer. The gradient along the entire river is less than 2m/km and, although there is little evidence for physical erosion, bedrock is increasingly exposed downstream in and along the channel.

2.5 Geology

The watershed is entirely underlain by the upper Floridan aquifer, which is composed of Suwannee (Oligocene) and Ocala (Upper Eocene) limestone. The boundary between confined and unconfined regions of the upper Floridan aquifer occurs at the Cody Escarpment (or Cody Scarp), an erosional edge of the Miocene Hawthorn Group (Upchurch, 2007). The Cody Scarp separates the watershed into the Northern Highlands in the upper reach and the Gulf Coastal Lowlands in the lower reach (Figure 20). In the northeastern portion of the groundwater basin, the Northern Highlands, sands and clays of the Hawthorn Group lie above the limestone and provide a partial confining layer to the aquifer by absorbing some nutrients and pollutants before reaching the groundwater (Upchurch, 2007). The Gulf Coastal Lowlands, in the southwestern portion, is an area of Florida where the Hawthorn sediments were eroded, washed away by Pleistocene seas, and karst features such as sinkholes, limestone outcrops, and springs are exposed near the surface (Upchurch, 2007).

2.6 Surface Water Hydrology

The crystal clear water emerging from a depth of about 30 feet at Ichetucknee Head Spring joins other springs to form the 5.5 mile-long Ichetucknee River (Figure 21).

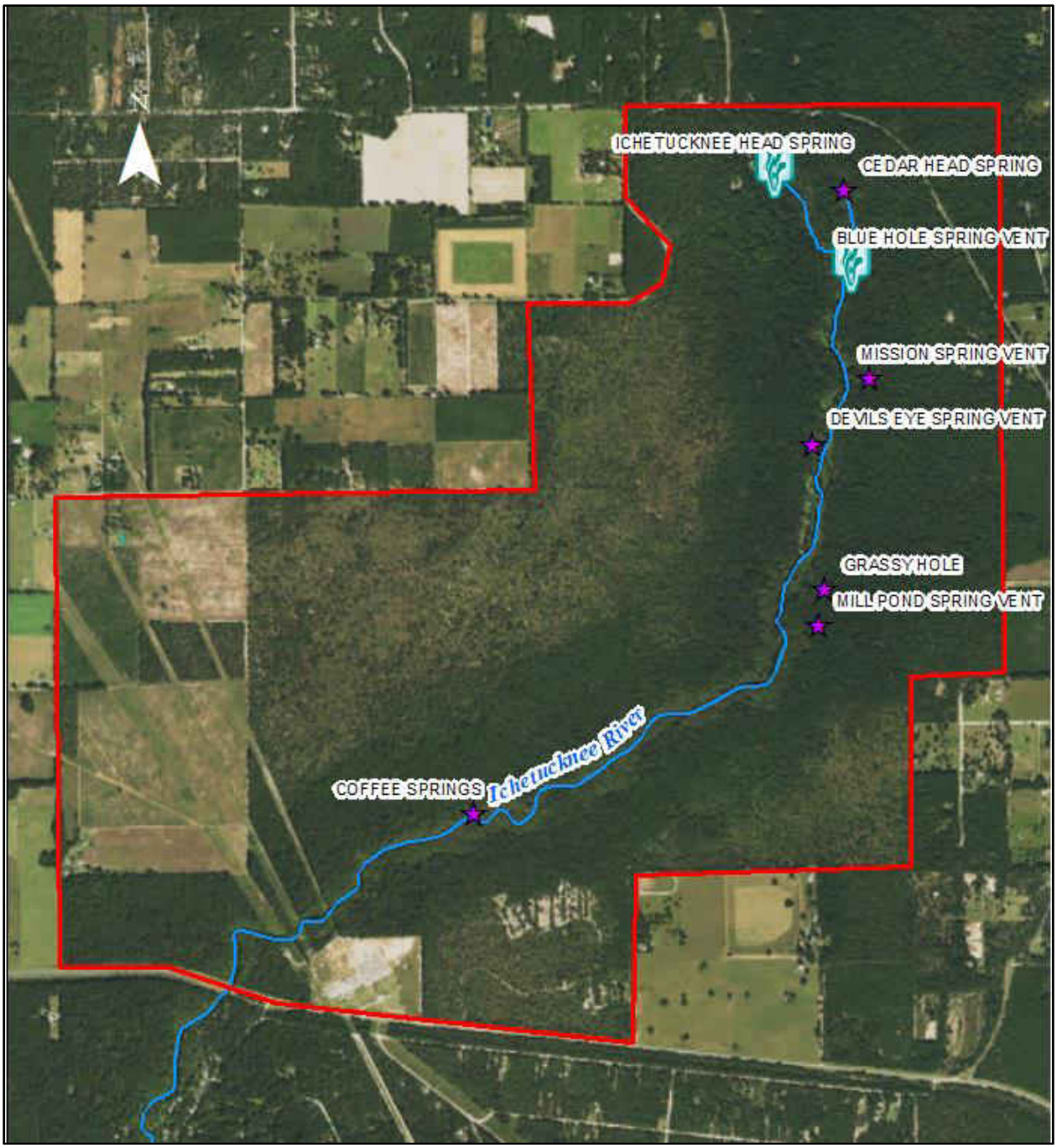

Figure 21: Springs along the Ichetucknee River

In 2016, this clear flowing river contributed close to 274.5 cfs (147.7 mgd) (USGS 02322700 Ichetucknee R @ HWY 27 NR Hildreth) of spring water each day to the Santa Fe

River, which ultimately flows to the mighty Suwannee River (USGS, 2017a). Other springs in the Ichetucknee Springs Group include: Blue Hole (the largest spring in the group); Cedar Head; Roaring Spring and Singing Spring (collectively referred to as Mission Springs); Devil's Eye; Grassy Hole; Mill Pond; and Coffee Spring (Figure 21) (Floridasprings.org, 2014).

The average river width is 6 to 10 m and average depth is approximately 1 m in the upper reaches of the river. At approximately 550 m downstream, the river meets the southward flow of Cedar Head Spring and Blue Hole Spring. The river then flows about 4800 m south, then 6400 m southwest and discharges into the Santa Fe River. Depth increases in the middle and lower reaches of the river to approximately 2 to 4 m. (PBSJ 2003).

2.7 Groundwater Hydrology

The Ichetucknee River once flowed overland from Lake City to the Santa Fe River. The dry river valley is now known as the Ichetucknee Trace (Champion and Upchurch, 2004). Cannon Creek, Clay Hole Creek and Rose Creek were once surface tributaries to the pre-historic Ichetucknee River, but now discharge directly into sinkholes (sinking streams). Outlines of this ancient river lie within the Springshed typography and the Trace is bound to the North/North-East by the Cody Scarp (Figure 20) (Upchurch and Champion, 2004).

Karst Environmental Services, Inc. (KES) conducted qualitative dye trace studies of sinkholes located within Clay Hole Creek Trace from May through September 2003 (Butt and Murphy 2003). Dye tracers were released into Dyal and Black Sinks on the first day of the study, and waters in local wells, the down-gradient subterranean Rose Creek Cave System, and in the Ichetucknee System were sampled for the next four months. The dye tracers from both release sites were eventually recovered in the Rose Creek Cave System within 26 to 34 days of initial

release and by day 65 at three of the Ichetucknee Springs: Mission Spring, Blue Hole Spring, and Devil's Eye Spring. No dye was detected at the Ichetucknee Head Spring, Cedar Head Spring, Mill Pond Spring, or Grassy Hole Spring. This study concluded that there is a direct hydraulic connection between sinkholes southwest of Lake City and a portion of the Ichetucknee System. However, there is no observed connection between the Lake City sinkholes and the Ichetucknee Head Spring, indicating there are differing areas of the overall Ichetucknee Springshed and layers of the underground aquifer responsible for providing water to the various springs in the Ichetucknee System (FSI, 2012).

2.8 Recharge

Upchurch and Champion (2002) defined the Ichetucknee Springs groundwater basin to be about 370 square miles, encompassing 2/3 of Columbia County and small portions of Suwannee, Baker, and Union counties. The Ichetucknee River Springshed is smaller and bound by the Cody Scarp in the North/North-East, about 200 square miles (Figure 20). Rainfall and subsequent groundwater recharge in the Ichetucknee Springshed is the primary source of water that feeds Ichetucknee Springs. The long-term average rainfall in the Springshed is about 51 inches per year (FAWN 2015). Average evapotranspiration (ET) rates in the Ichetucknee Springshed are estimated to be about 35 inches per year or about 69% of the average annual rainfall total (FAWN 2015). Rainfall in the Ichetucknee Springshed that does not return to the atmosphere by ET (an average of about 16 inches per year) recharges the Floridan Aquifer or drains to creeks and ditches. The U.S. Geological Survey has estimated the recharge rate to the Floridan Aquifer in northeast Florida as about 1.3 inches per year where the Floridan Aquifer is confined. The

average net recharge rate in the Northeastern region to the unconfined areas of the Upper Floridan Aquifer was about 13.6 in/yr. (FSI, 2014).

2.9 Submerged Aquatic Vegetation

Submerged Aquatic Vegetation (SAV) is a crucial component of the mosaic of instream habitats and serves several diverse purposes. It provides forage to manatees and other aquatic species, shelter for fish and benthos, assimilates nutrients and other chemicals, and stabilizes the river channel to reduce erosion and turbidity. During low water levels, SAV is vulnerable to damage resulting from recreational activities such as boating, and especially tubing on the Ichetucknee River. Monitoring the condition of SAV can also help identify trends in water quality and flows. Maintaining water levels at sufficient depths to protect the SAV provides many benefits to the riverine ecosystem.

Wild-rice (*Zizania aquatica*) is dominant species in the Ichetucknee Head Spring and approximately 200 m of the spring run (Kurz, et al., 2004). Downstream, and for the duration of the river channel, strap-leaf sagittaria (*Sagittaria kurziana*), is the most abundant species of SAV. Tape grass (*Vallisneria americana*) and muskgrass (*Chara sp*.) are also abundant throughout the Ichetucknee River (Kurz, et al., 2004). Approximately 600 m downstream of the Ichetucknee Head Spring, the river channel widens into the rice marsh reach of the river (Kurz, et al., 2004). This reach of the river has little to no SAV cover. The channel then narrows once more approximately 1500 m further downstream where the canopy typically covers the entire river channel. While the river bottom is predominantly populated by SAV (~78%), 3.3% of the channel is bare with substrata that include coarse sand and gravel (Kurz, et al., 2004).

Ichetucknee Springs State Park staff has the most challenging set of tasks. Staff must facilitate the daily traffic of hundreds of visitors tubing on the river, while safeguarding the fragile and valuable SAV within the spring run. The park's management plan describes the impact of overuse on a spring-run stream as the bare sand and rock that remain after aquatic vegetation is trampled and dislodged by recreation. The park was purchased by the state in 1970, and a daily maximum limit of 3,000 tubing participants was set in 1979 for North Entrance access. That number was soon lowered to 1,500 per day and in 1989 and further lowered to its current standard of 750 per day (FDEP, 2000). Even with this significant reduction in tubing traffic, SAV monitoring by park personnel indicates that SAV coverage is reduced each season and regenerates mainly over the winter offseason. Additionally, when water levels are low, the existing exit platform for tubing participants is rendered unusable, as the water level may be too low for people to safely access the stairs and dock.

2.10 Ichetucknee Springs State Park

Ichetucknee Springs State Park (the Park) was purchased by the State of Florida in 1970 from the Loncala Corporation. In 1972, the U.S. Department of the Interior declared the Ichetucknee Spring a National Natural Landmark. From Memorial Day (end of May) until Labor Day (early September), visitors can tube/canoe/kayak down the river starting at the Head Spring, which is a three-hour float. During the off season (September to May), visitors can tube starting at the Midpoint Dock which is a 1.5-hour float. From October through March SCUBA diving is available in the Blue Hole, only if you are cave certified (Figure 21).

In 1979, Charles DuToit completed a field study (1977-1978) to measure the types and amounts of recreational activity that could be sustained by the Ichetucknee River without causing

permanent damage. He recommended no more than 3000 people a day should tube down the river during summer weekends and approximately 1000 people during the weekdays. In 1989, a carrying capacity of 750 per day was set at the north entrance while the Midpoint capacity was increased to 2250 per day (Figure 22). Dampier's Landing remains unrestricted (FDEP, 2000). The Park receives over one hundred thousand visitors a year. From 2013 to 2014 visitor numbers have nearly doubled and in 2015 over 400,000 thousand visitors have visited the Park (Table 2). During the summer, it is not uncommon to see more that 4000 people visit the park in one day, which exceeds DuToit's recommendations (ISSP, 2017).

Table 2: Annual Visitors to Ichetucknee Springs State Park

Year	Total visitors to the Park	Tubing from North Launch
2004	163,043	124,059
2005	151,749	124,140
2006	194,688	148,204
2007	196,798	149,334
2008	163,547	121,892
2009	169,695	140,021
2010	218,247	181,925
2011	181,058	150,279
2012	134,917	108,938
2013	141,857	115,577
2014	224,051	157,851
2015	481,603	171,419
2016	439,664	139,992

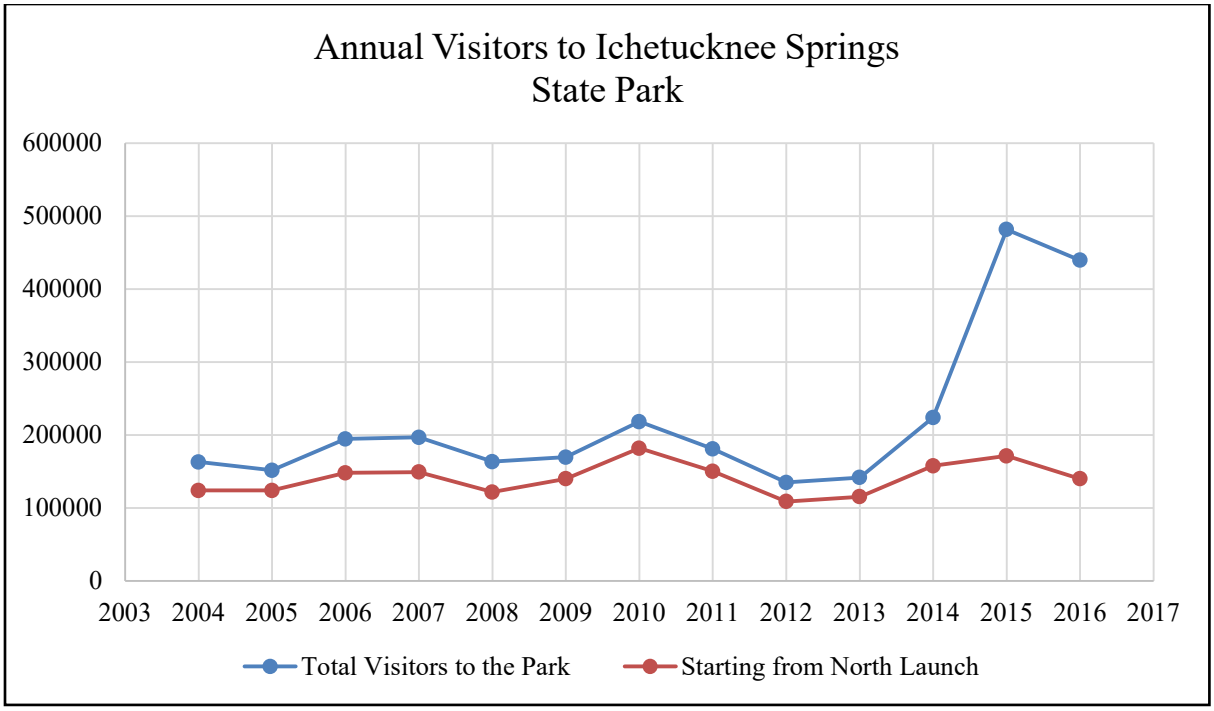

Figure 22: Ichetucknee Springs State Park Visitor Totals

Since 2012, the number of people allowed to float from the Head Spring (from May to September) was capped at 750 visitors a day. The park scientists were worried about how the overwhelming number of people could affect the aquatic plant life around the head springs and northern portion of the river (Figure 22). During holidays (Memorial Day, 4th of July, Labor Day), the 750-person threshold can be met within a couple of hours of the park opening. The limit enforced in 2012 has kept the number of visitors to the North Launch relatively steady, while the total number of visitors to the park has quadrupled. The Park scientists are continuously monitoring the health of the springs and surrounding habitats; by finding ways to improve the water quality and striving to educate the community about the importance of water conservation and environmentalism. Our project is to assist Park staff in investigating how the

number of visitors to the Park affect the water quality and sediment transport in Ichetucknee Springs.

CHAPTER 3: LITERATURE REVIEW

3.1 Sediment Discharge and Water Quality

Barbara Mahler, research hydrologist for the USGS, has been researching sediment transport through karst springs since the late 1990s. In 1998, B.J. Mahler and F.L. Lynch focused on: "temporal changes in geochemical characteristics of particulates discharging from a major karst spring in response to precipitation, and relate them to sediment source and potential for contaminant transport" (p. 166). They looked at Barton Springs in central Texas, which has had elevated levels of metals which associated with sediments in local wells. Barton Springs is composed of Edwards and Georgetown Limestones and has an average discharge of 1.42 m^3/s (22.82 MGD). Hourly samples for sediment and water analyses were collected from the Head Spring following two high-intensity storms and one drawdown (non-storm) event. Suspended sediment samples were analyzed for: pH, specific conductance (SC), turbidity, total suspended substance (TSS), and cation and anion concentrations (Mahler and Lynch 1998).

Mahler and Lynch found that TSS began to increase about 8 to 9 hours after rainfall and peaked about 15 to 16 hours after rainfall. Baseline concentrations were reached more than 30 hours after rainfall. Peak concentrations of TSS discharging form Barton Springs coincided with flushing of surface water through the aquifer. Arrival of surface water at Barton Springs in response to the storms was indicated by decreases in specific conductivity, CA2+, and MG 2+. In the Barton Springs aquifer, approximately a metric ton of sediment was discharged from Barton Springs in the 24 hours following each of the two major storm events. The large quantity of sediment flushing through the aquifer indicates that mobile sediments have the potential to play an important role in the concentration and transport of contaminants. During the drawdown event, turbidity remained low and constant, and the amount of sediment discharging was

insufficient for mineralogical analysis (Mahler and Lynch 1998).

Similar research has been conducted in the Wild River Basin of Northwest Minnesota. This primary tributary of the Red River has been listed as an impaired stream turbidity since 2006, by the Minnesota Pollution Control Agency. The turbidity standard for aquatic life is currently set at 25 nephelometric turbidity units (NTU). The river has had a history of water issues including flooding, erosion, sediment deposition, and habitat degradation. The study's objectives were: "to define the relation between turbidity and SSC for use in developing criteria for total maximum daily loads and to improve estimation techniques for suspended-sediment concentrations (SSC) and suspended-sediment loads (SSL)" (p. 1). To achieve their objective, they assessed spatial and seasonal variations and evaluated relations between streamflow, SSC, and turbidity (Ellison, et al. 2011).

Water quality data was collected at five monitoring sites in the Wild Rice River Basin from February 2007 to June 2009. Water quality parameters collected for this study included streamflow, turbidity nephelometric turbidity units (NTU), suspended-sediment concentration (SSC), transparency (Ttube), specific conductivity (SpC), percentage of suspended sediment sieve diameter (SSSD) less than 0.062 millimeter, and water temperature. Samples were collected at six-week intervals with up to two additional samples obtained during amplified streamflow events (Ellison et al., 2010).

Ellison, et al., utilized S-Plus software to calculate descriptive statistics. They found large spatial and temporal variations in the SSC-streamflow relation that may have been attributed to backwater effects from the northern portion of the Red River. Pearson's correlation tests were used to normalize data and test transformed variables. Kendall's tau correlation test was used for censored data and to test transparency. The inverse of transparency was used for the Kendall's

tau correlation test. The Pearson's correlation test indicated strong positive relations between turbidity and SSC (r=0.96) and between streamflow and turbidity (r=0.71). These relations indicate that SSC and turbidity increased as streamflow increased, due to runoff, erosion, scouring, and resuspension. When streamflow increased, specific conductivity decreased, possibly due to dilution. Linear regression analysis showed that turbidity was the strongest predictor of SSC. They proposed turbidity can be used in time-series calculations of SSC and SSL. Using turbidity, a single regression equation may be suitable for calculating SSC at sites along the Red River (Ellison et al., 2010).

In 2015, Byrne and Guillen studied the studied Texas Wild Rice (TWR) and recreational use of the upper San Marcos River. Increased turbidity and total suspended solids were studied due to their impeding effect on photosynthesis. They measured recreation and its resultant turbidity at different stations along the river during high and low recreation. They saw a strong correlation between high visitor numbers and turbidity at the three sampling points (a>0.5). However, they did not see any significant correlations between turbidity and reaction during low recreational periods. Byrne and Guillen recommended further analysis on how recreation influences spatial and temporal patterns in other factors such as nutrients, sedimentation, and periphyton growth (Byrne and Guillen 2015).

3.2 Ichetucknee Springs State Park: Environmental and Economic Impact

In 1979 Charles Dutoit studied the carrying capacity of Ichetucknee Springs and River as part of his master's thesis for the University of Florida. He reviewed the water quality, flora and fauna population of the river, and recommended carrying capacities based on present activity. From 1977 to 1978 he found that tubing was the most popular form of recreation at the Springs;

3000 people per day (the historical limit) regularly floated down the River during the summer weekends, and over 1000 people would float down the river during the week days. The section between the Head Spring and Blue Hole Spring sustained the greatest impact, both in terms of channel and bank erosion and in percent loss of vegetation. Trampled plant beds supported less aquatic life and could not protect against sediment erosion as well as healthy beds. He recommended limiting the number of tubers from the North Launch to 100 tubers per hour. Swimming was primarily confined to Blue Hole and the Head Spring, which resulted in little to no plant or fish life in the pool areas, but mitigated damage further downstream. Canoeing had little impact on submerged aquatic vegetation (SAV). Scuba diving had the greatest impact on Blue Hole, especially in winter. The damage caused by divers eroding sediments and uprooting vegetation exceeded the growth rates of new plants. A limit of 12 divers per hour was recommended to minimize the damage (Dutoit, 1979).

After years of monitoring SAV cover before and after the visitor season, in 1989 daily limits on the number of tubers at the North Launch were lowered to 750 people during the summer tubing season. Overall visitors to the Midpoint tube launch was increased to 2250 per day, and an unlimited number of tubers may enter the river at Dampier's Landing tube launch. This general rule varies from year to year based on water levels. As water levels drop, vegetation damage increases due to increased foot traffic on the river bottom (FDEP, 2000).

In 2000, Ichetucknee Springs State Park updated and improved their Unit Management Plan. This plan identifies the objectives, criteria and standards that guide each aspect of Ichetucknee Springs State Park administration, and sets forth the specific measures and policy that are implemented to meet management objectives by providing detailed inventory and assessment of the natural and cultural resources of the park, identifying resource management

problems and needs, and establishing specific management objectives for each resource type. The plan recommends that systematic water quality monitory continue as well as monitoring land use within and outside of the park, particularly in the Ichetucknee Trace. There are also recommendations for prescribed burning, erosion control, polluted runoff prevention, dye trace studies, and monitoring aquatic vegetation for seasonal trends. For cultural resource management, it was recommended that approval from the Department of State, Division of Historical Resources (DHR) be obtained before taking actions, such as development or site improvements. Projects would include, increase park staff training on cultural resources, record and photograph cultural and recreational resources, and regularly visitation to cultural resources to foster knowledge and understanding for staff, visitors, and locals (FDEP, 2000).

Land use planning incorporates both natural and cultural resource management. At least 23 cultural sites have been recorded within the park boundaries due to the activities of avocational and professional archaeologists. The land use responsibilities include preserving: "representative examples of original natural Florida and its cultural resources, and to provide outdoor recreation opportunities for Florida's citizen and visitors" (p. 43). In order to accomplish this, the Division of Recreation and Parks must keep in mind external and internal conditions: evaluating adjacent lands for future resources and effectively utilizing existing property to its environmental, recreational, and cultural potential. This includes protected areas, hiking and shared-use trails, visitor and park facilities, parking and picnicking areas, and water access points. In 2002, approximately 8,500 acres was identified as desirable land to be added to Ichetucknee Springs State Park. The majority of this land is to the northwest and contains significant portions of longleaf pine and xeric oak sandhill communities (FDEP, 2000).

In 2015, the Food and Resource Economics Department of the University of Florida IFAS Extension studied the economic contributions, consumer surplus, and ecosystem services provided by recreational use of fifteen major spring sites in north central Florida, including Ichetucknee Springs State Park. Visitor information was gathered for the period of 2000-2012. Spending by visitors was estimated based on entry fees and average visitor spending for transportation, food, and lodging. IMPLAN software and associated databases were used to analyze the economic contributions of springs-related recreational spending. Across the nine-county study, nearly 70 percent of visitors to the springs were from outside the county. From 2008-2013, Ichetucknee Springs had over 100,000 visitors per year (Borisova et al. 2015). Estimated annual economic contributions for the 15 springs included (Borisova et al. 2015):

- $84.2 million in total visitor spending for springs recreation
- $45.3 million in spending by non-local visitors
- 1,160 full-time and part-time jobs generated
- $30.42 million in labor income
- $94.00 million in industry output (gross sales revenues)
- $52.58 million in value added, equivalent to Gross Domestic Product (GDP)
- $6.56 million in local/state government tax revenues, including property taxes of $4.13 million and sales taxes of $1.58 million
- $6.57 million in federal government tax revenues

For 2012 to 2013 Ichetucknee Springs saw (Borisova et al. 2015):

- Average annual visitor days – 177,543
- Total Spending - $13.10 million dollars

- Spending from nonlocal visitors - $9.17 million dollars
- Employment – 169 jobs maintained
- Labor Income- $4.86 million dollars
- Value Added to Local Economy - $8.29 million dollars
- Industry Output - $15.02 million dollars
- Consumer Surplus - $1.31 million dollars

3.3 Ichetucknee Springs: Ecosystem Evaluation

In 2006, Wetland Solutions, Inc. (WSI) evaluated the environmental effect of nutrient load increases in the Ichetucknee springs. The water quality from 2004 – 2006 indicated elevated levels of nitrogen in the Ichetucknee System in comparison to historic conditions and similar spring runs in the area. It was observed that plant communities within the Ichetucknee System may be altered compared to natural conditions and that elevated nutrients levels may have caused growth of filamentous algae. This research is done in support of developing a nutrient total maximum daily load (TMDL) if necessary to protect the Class III water system (WSI, 2006).

From 2002 to 2004, Water quality was recorded from different spring vents and locations in the Ichetucknee system: Blue Hole, Cedar head, Devil's Eye, Head Spring, Mill pond, Mission, and the Ichetucknee River at US HWY 27 (WSI, 2006). While most water quality measures were relatively constant amongst the different spring vents, there were significant and consistent differences in dissolved oxygen, specific conductance, and nitrate-nitrite nitrogen concentrations between spring vents. The Ichetucknee Head Spring had the highest dissolved oxygen, specific conductance, and nitrate+nitrite nitrogen concentrations on average, followed by Blue Hole Springs, Mission Springs, and Devil's Eye Spring. At the Head Spring,

nitrate+nitrite nitrogen concentrations average 0.77 mg/L, and increase since Ronsenau et al. (1977) report: 1946 – 0.23 mg/L and 1975 – 0.43 mg/L (WSI, 2006).

The Ichetucknee System Work Plan (Work Plan) is a living document that is intended to provide a "roadmap" for future environmental studies as additional information becomes available to assess the relationship between nutrients and existing ecological conditions in the Ichetucknee System (WSI, 2006). This Work Plan is intended to go beyond the bioassessment measures of the Florida Stream Condition Index (SCI) and attempts to incorporate historic and current, important ecosystem linkages that tie-in environment factors, ecosystem metabolism, and internal/external energy balances. A part of this Work Plan, sampling plans, methods, data analysis, and impairment determination strategies were recommended to assess for: external forcing function, physical/chemical conditions, biological conditions, human uses, and ecosystem-level metrics (WSI, 2006).

WSI continued their work in 2010 on an ecosystem-level study of Florida's springs on behalf of the Florida Fish and Wildlife Conservation Commission. They completed six project quarterly periods of ecological data collection and analysis for twelve key artesian springs located in Florida (WSI, 2010). Seasonal variations in sunlight, temperature, and precipitation are buffered in spring-fed aquatic ecosystems due to the buffering effect of the groundwater reservoir and quality of the dependent surface water flora and fauna. Sunlight is the only major environmental factor that varies from spring to spring. WSI had to normalize primary productivity based on measured incidental light energy: "this photosynthetic or 'ecological' efficiency provides a comparable measure of overall spring function regardless of season and latitude" (WSI, 2010). In order to account for seasonal variability, WSI followed a series of

protocols that accounted for spring pool and vent size, plant productivity, and sampling location (WSI, 2010).

WSI focused on Ichetucknee Springs in July 2009. They divided the system into sections: the upper run (head spring to midpoint launch) and lower run (midpoint to US-27). The Ichetucknee head spring was not individually studied, due to so many other contributing springs (WSI, 2010). Also, human-use densities could not be accurately estimated at Ichetucknee. It did have the highest level of tubing activity and one of the busiest spring pool areas, noted by the visual patterns of SAV absence (WSI, 2010). In 2008, Ichetucknee had just over 150,000 visitors. Nitrate nitrogen decreased from about 1 mg/L at the Head Spring to 0.36 mg/L at US 27. Chlorophyll-a concentrations increased from 1.3 ug/L at the Head Spring to 2.1 ug/L at US 27 (WSI, 2010). Turbidity increased with distance downstream, from 0.22 NTU at the Head Spring to 0.84 NTU at US 27. Metabolism parameters were used to estimate the overall function of the aquatic ecosystem: "spring ecosystems utilize oxygen for aerobic metabolism and exhale carbon dioxide throughout the day. At night, they consume oxygen to meet the needs of their metabolism and during the day the plants in the ecosystem "exhale" more oxygen into the water column than they consume in their respiration" (WSI, 2010). The gross primary productivity (oxygen produced) averaged 8.3 g O2/m2/d and community respiration (oxygen consumed) averaged 15.7 g O2/m2/d in the spring run. The overall net primary productivity was positive in the pool area, but negative for the Ichetucknee Spring Run, where respiration was much higher in the downstream segment (WSI, 2010).

3.4 Ichetucknee Springs: Submerged Aquatic Vegetation Studies

The 2003, PBS&J focused on establishing the shoreline boundary and vegetative coverage extent. Where conditions allowed, GPS mapping was used to delineate the shoreline and record SAV coverage. Where GPS couldn't be used, due to dense tree canopy, the shoreline and SAV were recorded by field reconnaissance: going out in a canoe to take photos, taking photos, and interpreting aerial photography. Transect mapping was performed as an alternative to GPS mapping in three general sections of the Ichetucknee River: 1) the confluence of the Mill Pond Spring to Dampier's Landing Dock, 2) Dampier's Landing to the power lines, and 3) the U.S. 27 bridge to the take-out point (PBS&J, 2003).

The total area of submerged habitat surveyed and classified during the 2003 study was approximately 150,658.22 m^2 or 37.23 acres. A total of 305 separate SAV beds were mapped with a total coverage of 118,035 m^2 or 29.2 acres (PBS&J, 2003). Using the collected SAV data, hydrologic data, and visitor logs collected by the Park Staff, PBS&J looked into the relationships between water levels, visitor numbers, and changes in SAV coverage after periods of heavy reactional use to see if damage was greater during time of drought and/or low water levels. The Park Service collected transect data from 1989- 2003 at 17 transects in the park to evaluate recreational impacts (PBS&J, 2003). These data are typically collected in April/May, prior to the start of the high use summer period, and in late fall following the peak use period.

They found that the heaviest park use occurred between June and August, but there was an overall trend of less people visiting the north end since the late 1980s. However, more people visit the southern portion, up to 100,000 people in 1999 (PBS&J, 2003). The heaviest park usage occurred during the declining limbs of seasonal, peak water levels at the head spring. Declines in vegetation cover at the head spring suffer the greatest declines during drought conditions

(PBS&J, 2003). However, park usage was not scientifically related to vegetation changes at any of the transects. Despite high number of park visitors during the 2000's, there was insufficient data for transects to make adequate statistical inferences: "it appears that the greatest percent change in vegetation cover occurs when headspring water levels drop below 25 ft. NGVD, regardless of park usage" (PBS&J, 2003). Future analysis is warranted with SAV and depth contour maps, in conjunction with transect sampling and looking at water quality and park usage trends.

Physical and chemical conditions in the Ichetucknee System were also monitored as part of this SAV study. Average water depth in the river channel transects was 1.47 m with a range of 0.3 to 3.0 m (PBS&J, 2003). Average flow velocity in the system was 0.20 m/s (measured range from -0.01 to 0.56 m/s). Average water temperature was 23.1 oC (range 21.8 to 23.8 oC) with a gradual increase with travel distance downstream. Specific conductance averaged 327 μS/cm (range 309 to 348 μS/cm) with a general increase with distance downstream. Average dissolved oxygen was 6.4 mg/L (range 3.6 to 8.1 mg/L) with a general increase downstream until saturation with atmospheric oxygen concentrations were reached. Average pH was 7.7, with a range from 7.2 to 7.9 standard units. A gentle downstream increase in pH was also noted (PBS&J, 2003).

In 2004, PBS&J continued their 2003 research on SAV coverage of Ichetucknee Springs. They compared their SAV coverage analysis between 2003 and 2004. Two years of data was collected including the mapping and monitoring of submerged aquatic vegetation (SAV) and collection and analysis of water quality data (PBS&J and Woithe, 2004). SAV coverage declined by approximately 454 m^2 or 0.1 acres between 2003 and 2004. This represents an approximate 2% loss within the remapped areas. The observed loss was a result of changes in SAV to either

bare bottom or emergent vegetation coverage. The greatest losses of SAV occurred at the downstream take out area at US 27 (PBS&J and Woithe, 2004). This loss in SAV may have been caused by disturbances from reconstruction of the floating dock structures and changes in flow velocities caused by the installation of a new floating barrier across the river at this location.

Analyses between nutrients and SAV cover, SAV biomass and periphyton were made among samples collected from the main river. No significant relationships were observed ($p > 0.05$), between nutrients and these parameters, suggesting that nutrient concentrations are not limiting for SAV or periphyton in the main river (PBS&J and Woithe, 2004). Specific analyses were also conducted to characterize relationships between SAV coverage and depth, flow and terrestrial canopy cover. SAV coverage and depth were positively correlated ($r2 = 0.03$), suggesting that depth was not limiting SAV growth in this river. There was no observed significant correlation between stream flow and SAV coverage (PBS&J and Woithe, 2004). When comparing SAV coverage to terrestrial canopy cover (%), a weak negative correlation was observed ($r2 = 0.02$), suggesting that terrestrial canopy, in some cases, may reduce potential SAV coverage (PBS&J and Woithe, 2004). There was a significant positive correlation between periphyton abundance and soluble reactive phosphorus concentrations, as well as total phosphorous. Overall PBS&J recommended that SAV coverage and a complete remapping should be performed at least once every five years, more analysis and comparison should be done from the 1979 Dutoit study, and water quality should be further assessed to study the relationships between groundwater and surface water, SAV coverage, biomass, and periphyton abundance (PBS&J and Woithe, 2004).

3.5 Ichetucknee Springs: State Response and Action

In 2008, the FDEP adopted the Total Maximum Daily Loads (TMDL) Program to provide numerical water quality restoration targets for the Lower Santa Fe River. The TMDL requires reductions in nutrient concentrations of 35 percent. FDEP believes that a monthly average nitrate [NO3] concentration of 0.35 mg/L should sufficiently protect the aquatic flora or fauna in the Suwannee and Santa Fe River Basins (FDEP, 2008). In 2012, the FDEP adopted the Santa Fe River Basin Management Action Plan (BMAP); the purpose of the BMAP is to identify actions and strategies to reduce nutrients in the Santa Fe River. The District is a partner with the FDEP in implementing the BMAP through state cost share funds to agriculture, to implement nutrient reduction and water conservation strategies (FDEP, 2012). The goal of the BMAP is the reduce nutrient loading in the Santa Fe River and associated springs, decrease algal mass in the springs basins, adopt applicable fertilizer and irrigation ordinances, implement agricultural best management practices (BMPs), and developed and implement applicable nonagricultural BMPs (FDEP, 2012).

In support of the TMDL, Florida Springs Institute prepared a Restoration Plan for Ichetucknee Springs (FSI, 2012). The Ichetucknee Springs Restoration Plan is an overall assessment of the Ichetucknee System and the steps necessary to improve the water quality of the springs. They found that the average flows in the Ichetucknee River have declined significantly since the 1970s (estimated as 18 to 25%). This decline is due to increases in human groundwater use and a multi-year drought. Groundwater feeding into the Ichetucknee Springs has elevated levels of nitrate nitrogen derived from human activities. Dominant sources of nitrate include synthetic fertilizers, human/animal waste, and agriculture/commercial land use. Nitrogen loading needs to be reduced by 50% for the Ichetucknee Springshed reach the nitrate water quality

criterion of 0.35 mg/L, established by the TMDL. The primary recommendations of the Restoration Plan are to engage stakeholders, create education initiatives in the local community, and organizing regulatory assistance across different agencies (FSI, 2012).

Minimum flows and levels (MFL) are established for water bodies to prevent significant harm as a result of withdrawals. The water management districts are required, by Florida Statute 373.042, F.S., to develop a priority list of water bodies for which they will establish minimum flow and levels. In 2013, the Suwannee River Water Management District (SRWMD) established an MFL for the Lower Santa Fe and Ichetucknee Rivers and Priority Springs. Following the 2010 Water Supply assessment (SRWMD, 2010), SRWMD recommended designating the Lower Santa Fe River Basin as a Water Supply Planning Region because modeling analysis concluded that existing sources of water would not meet increases in water use over the 20-year planning period while providing sustainable flow to the river. "Given the characteristics of the rivers and the available flow data, MFLs have been developed at two gages; the predominant Water Resource Value metrics used include: Santa Fe River near Fort White – fish passage, floodplain vegetation inundation, hydric soils, bankfull flows, in-stream habitat; Ichetucknee River at US 27 – fish passage, recreation, bankfull flows, hydric soils, in-stream habitat" (p. 3-6) (SRWMD, 2013).

To determine the current condition of the Lower Santa Fe and Ichetucknee rivers with respect to recommended MFLs an estimate of the available water was calculated. The available water was determined from the difference in the 10-year annual low flow for the Baseline and MFL from 1933-1990. To facilitate this analysis, the Baseline and MFL flow regimes were each aggregated into annual means. This analysis resulted in 118 cfs of available water at Fort White and 18 cfs of available water on the Ichetucknee River. It is important to note that although these

values also represent the maximum water availability under the MFL regime, they do not necessarily represent the current water availability as they do not account for impacts from existing uses. After accounting for the existing uses, the Lower Santa Fe River is estimated to be in recovery with a deficit of 17 cfs (11 mgd) in 2010. The Ichetucknee River is estimated to be in recovery with a deficit 3 cfs (2 mgd) in 2010. Therefore, the District has determined that both rivers are in recovery. Consistent with Section 373.0421, F.S., these circumstances necessitate the development of a Recovery Strategy for these rivers and their associated springs (SRWMD, 2013).

3.6 Ichetucknee Springs: Human Use on Turbidity

From May to December 2010, Wetland Solutions, Inc. (WSI) measured turbidity at multiple stations within the Ichetucknee System between the Head Spring and US 27 during periods of high, medium, and low human use activities. The purpose of this project was to document the direct relationship between human use and turbidity, and subsequent indirect effects of turbidity on water clarity, light transmission, and ecosystem productivity (WSI, 2011). Three times during the summer study period, human counts were conducted at Dampier's Landing and one at the North Launch of the Head Spring. Counts were divided based on in-water and out-of-water actives including: tubing, snorkeling, picnicking, etc. Total counts were made for entries, exits, and passersby's. Counts were completed in 15 minute intervals and counts were multiplied by 0.24 hours to estimate the average persons-per-hour throughout the observation periods. Human use densities during the medium and low-use periods were only characterized by park entry data (WSI, 2011).

At four stations along the Ichetucknee System, a YSI 6920 recording data sonde was deployed to collect continuous measurements of temperature, dissolved oxygen, pH, specific conductance, and turbidity (Figure 23). These data were automatically collected at preprogrammed intervals of 10-30 minutes. Length of deployment varied based on sampling frequency, but generally 7-14 days per deployment (WSI, 2011).

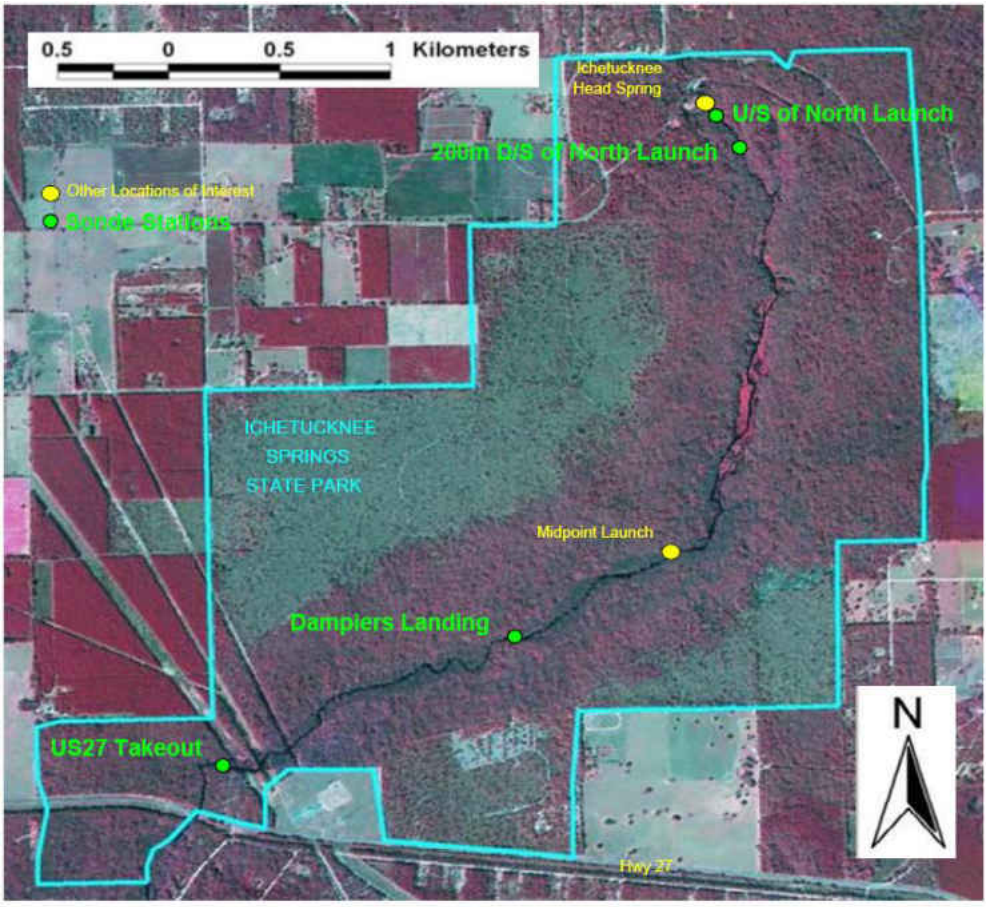

EXHIBIT 4-1
Sonde Deployment Locations in Ichetucknee Springs State Park

Figure 23: Sonde Location by Three Rivers in their 2010 Study (WSI, 2011).

The first sonde station was in the spring run upstream of the North Tube Launch and below the Head Spring. The second station was located approximately 200 meters downstream

of the North Launch and upstream of the confluence with the outlets from Cedar Head Springs and Blue Hole. The third station was installed at Dampier's Landing. The last station was put at the takeout dock at US 27. Light attenuation data were collected using a Licor (LI-1000 or LI-1400) data logger, a surface photosynthetically active radiation (PAR) sensor (LI-200SA), and an underwater PAR sensor (LI-192) (WSI, 2011).

Attenuation measurements showed a decrease in maximum transmittance when moving downstream in the river. The effects of turbulence and high flows were observed at serval of the stations, caused by ripples and shadows. Secchi distances recorded at the US 27 take out were shallower (12.3 m) than distances measured near the North Launch (13.9 m). Increasing turbidity decreases light transmittance in the spring water which effects the light available to plants and reduces overall rates of photosynthesis and primary and secondary productivity (WSI, 2011).

Turbidity and water quality measurements were taken continuously for one to two week periods at each of the four stations. The data showed a diurnal pattern in turbidity at all stations south of the North Launch. There were, on average, higher levels of turbidity during the weekends than during the week (WSI, 2011). Turbidity generally increased downstream, regardless of human activity, due to primary productivity and the surrounding forest. Turbidity was also higher in the afternoon than in the mornings, related to human use and primary productivity. During the tubing season, the station upstream of the North Launch had approximately 2 NTU of additional turbidity during weekends and 0.2 NTU during weekdays. Three Rivers found that the turbidity increase at the north station is related to human use in the Head Spring during weekend days (WSI, 2011).

Off-season turbidity measurements were made after the close of tram services following Labor Day. During the off-season minimal differences were observed between the weekday and

weekend use. However, extreme values of turbidity (both day and night) were recorded during deployment; which leads to concerns that the data does not represent water conditions (WSI, 2011).

At the locations where human use counts were completed, turbidity was compared to visitor density (Figure 24). At Dampier's Landing a positive correlation existed between number of people and turbidity values. For the count at the Head Spring a correlation was found between people in the main boil and the sonde located above the North Launch (WSI, 2011).

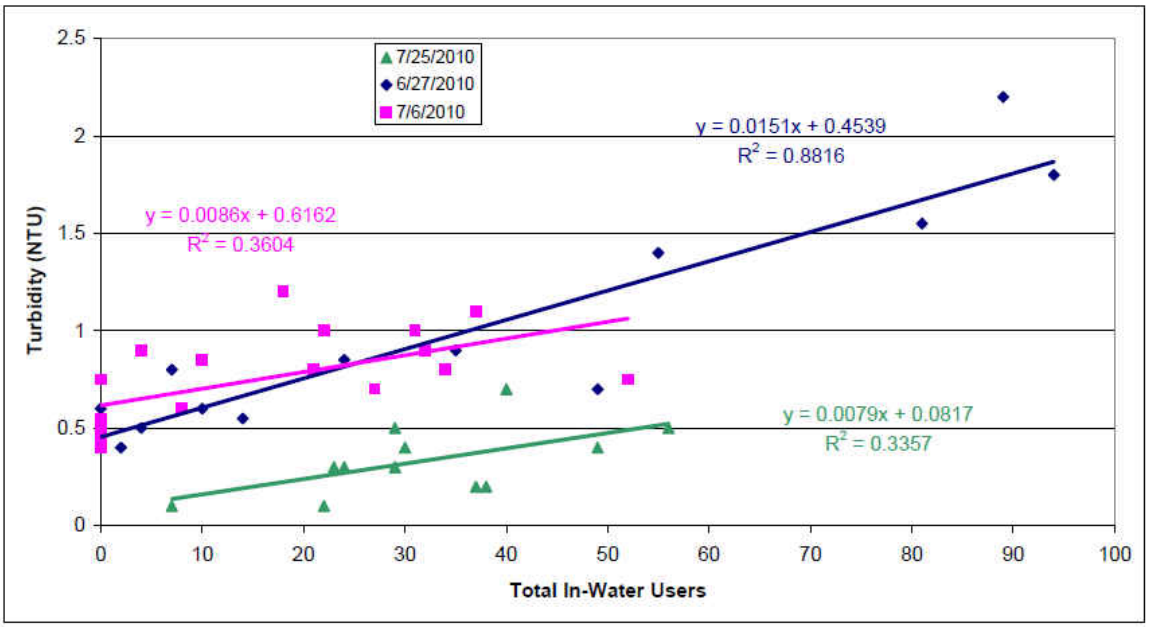

EXHIBIT 5-19
Ichetucknee River Detailed Human Use Density (in-water users at the time of observation) and Turbidity – Dampier's Landing 6/27/2010 and 7/6/2010, and North Tube Launch on 7/25/2010

Figure 24: Turbidity and Visitor Density Linear Regression (Three Rivers, 2010)

Human use does influence the turbidity in the river, but the effect is confounded by the daily changes in productivity and export from the system. To evaluate the human aspect and eliminate the effect of primary productivity on turbidity, the lowest human use days were

examined to approximate background turbidity for each station (WSI, 2011). Above the North Launch, turbidity is not expected to be due to productivity because of a lack of vegetation in this very short distance from the Head Spring. It was difficult however to measure baseline turbidity at the southern stations due to the constant flow of visitors during the on and off season. Even if visitor attendance was low, it was probably due to weather, which added another factor to effect productivity and turbidity. It was noted that turbidity caused by humans settled rapidly and/or diluted before being visibly transported downstream a significant distance (WSI, 2011).

CHAPTER 4: WATER QUALITY PARAMETERS

4.1 Temperature

Aquatic flora and fauna all have a preferred ecosystem and temperature range they thrive in. If the temperature increases or decreases above the ideal range, the species population may decrease or over produce. Chemical reactions generally increase at high temperature; such as dissolving minerals or volatizing gases. Warm water also holds less dissolved oxygen than cool water If the water does not contain enough dissolved oxygen to sustain all the different species of aquatic life, it can lead to an anaerobic shift and fish kills (USGS, 2017b).

4.2 Turbidity

Turbidity is the measure of light traveling through water. It is measured by a turbidimeter, which shines light through a vial of water. The higher the lower amount of light that passes through, the higher the turbidity. Materials that contribute to water turbidity include clay, silt, fine inorganic and organic material, algae, plankton and other microscopic organisms. High concentrations of particulate matter affect light penetration, plant productivity, recreational values, and habitat quality. In streams where increased sedimentation and siltation occur, can harm habitat areas for fish and other aquatic life. Particles also provide transport for other pollutants, notably metals and bacteria (USGS, 2017b).

4.3 Specific Conductance

Specific Conductance (SC) is a measure of how well water can conduct an electrical current. Conductivity rises with increasing concentration of ions (salts), such as: chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron. These measurements can be correlated to total dissolved solids (TDS) and are indicators of water pollution. Specific

conductance is temperature dependent and measurements are usually corrected to 25ºC. Background levels of freshwater specific conductance may rise by weathering of rocks and minerals, atmospheric deposition of materials, and flow from contaminated groundwater. In karst typography, specific conductance tends to be higher than in surface freshwater. Specific Conductance will rise after a large storm event indicating a surface water influence, before dropping due to increased recharge (flushing the system) (USGS, 2017b).

4.4 pH

pH stands for "potential Hydrogen" and is the measure of the relative amount of free hydrogen ions (H+) and free hydroxyl ions (OH-) available in water. The pH of water determines the solubility and bioavailability of nutrients, minerals, and metals. For example, it affects how much and what form of phosphorus is most abundant in the water. In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble. In Florida, the limestone aquifer is made of calcium carbonate (CaCO3) and acidic water will react and dissolved the limestone, neutralizing the water. The buffering capacity of water is influenced by the concentrations of carbon dioxide (CO2), bicarbonate (HCO3-), and carbonate (CO32-) dissolved in the water. The buffering capacity of groundwater coming out of the spring provides a relatively stable pH environment for organisms (USGS, 2017b).

4.5 Dissolved Oxygen

Dissolved oxygen in surface water is used by all forms of aquatic life. Oxygen enters a stream from the atmosphere and from groundwater discharge. The contribution of oxygen from groundwater discharge is significant, however, only in areas where ground water is a large

component of streamflow, such as karst typography. Photosynthesis is the primary process affecting the dissolved-oxygen/temperature relation; water clarity and strength and duration of sunlight, in turn, affect the rate of photosynthesis. Oxygen in water is measured as either mg/L of oxygen or percent saturation. Percent saturation corrects for temperature by accounting for the maximum amount of oxygen that could be dissolved in water at any temperature. Due to naturally occurring seasonal changes in temperature and daily changes in photosynthetic production, dissolved oxygen typically shows both daily and seasonal fluctuations (USGS, 2017b).

4.6 Nitrate

Elevated concentrations of nutrients in water discharged from a spring vent can cause ecological imbalances in the spring system. Nitrogen is found in several forms and is pervasive in the environment. Nitrate (NO3) is the form of nitrogen that occurs in the highest concentrations in ground water and springs. Nitrite-nitrogen (NO2) is an intermediate form of nitrogen that is almost entirely converted to nitrate in the nitrogen cycle. Nitrite is typically present as a very small fraction of NOx, and is also bioavailable and contributes to pollution issues. Historically nitrogen was only a minor constituent of spring water and typical nitrate concentrations in Florida were less than 0.2 mg/L until the early 1970s. Since then, nitrate concentrations of greater than 1 mg/L can be found in many springs (FSI, 2012). With sufficient phosphorus in the water column, seemingly low nitrogen concentrations can cause a significant shift in the balance of spring ecological communities, leading to the degradation of biological systems due to overgrowth of algae and aquatic plants. High nitrate levels can also create human health concerns. The Federal drinking water standard for nitrate is 10 mg NOx-N/L.

Concentrations above this can cause methemoglobinemia, or "blue baby" syndrome (USGS, 2017b).

CHAPTER 5: METHODOLOGY AND STATISTICAL SOFTWARE

5.1 Introduction

Data were collected in the Ichetucknee System to allow for characterization of human utilization and water quality parameters. Visitor numbers were provided by the ISSP staff. Total visitors to the park are recorded daily and the total numbers of visitors to the North Launch are recorded during the tubing season. Real-time water quality data is provided by the SRWMD in correspondence with their Springs Dashboards (http://www.mysuwanneeriver.org/dashboards/). Nitrate-nitrogen concentrations are recorded by a Submersible Ultraviolet Nitrate Analyzer (SUNA V2) and six different water quality parameters are recorded by the EXO2: temperature, conductivity, dissolved oxygen, pH, dissolved organic matter, and turbidity. Discharge and water levels are provided by the USGS and rainfall data is provided by the UF IFAS Florida Automated Weather Network.

5.2 Human Utilization

Human use is an important component of this study and accurate estimates of usage are necessary for understanding the effects of recreation on the Ichetucknee System. The park monitors daily attendance, 356 days a year (except when the park is closed due to extreme weather). No camping is allowed at the park so nighttime usage is zero. The park also has a separate count of the number of visitors entering the river from the North Launch. This number is maxed at 750 people a day during the tubing season and no one is allowed to launch from the North End during the off season. However, there is no way to distinguish the number of visitors to the North End versus the South End. Therefore, the total daily visitor number is evaluated.

5.3 Water Quality Monitoring

The SRWMD installed the continuous water quality monitoring station (SUNA V2 + EXO2) on April 2015 on the north side of the Head Spring. In 2015, during the 4th of July weekend, visitors damaged the station and it was disconnected until mid-August 2015. The monitoring station was then moved 200 ft. south of the Head Spring, hidden under oak canopy in an inaccessible area to park visitors (Figure 25). It is north of the North Launch and does not account for visitors entering the river for tubing or canoeing. It has been continuously monitoring every hour since April 2, 2015, except for times when it was under maintenance and calibration. Data is provided directly by the SRWMD after an initial QAQC. Days when the monitoring station was disconnected and under maintenance are removed from the data set.

Figure 25: SRWMD Monitoring Station and North Launch Locations

5.4 SUNA V2

The SUNA V2 (Submersible Ultraviolet Nitrate Analyzer) is a chemical-free UV nitrate sensor based on the ISUS (In Situ Ultraviolet Spectroscopy) UV nitrate measurement technology developed at Sea Bird Atlantic has adapted the technology to develop the SUNA V2 to measure nitrate in increasingly more challenging environments including extremely turbid and high CDOM conditions. With improved optics and built-in logic intelligence, the SUNA V2 measures nitrate with industry leading accuracy and stability over a wide range of environmental conditions, from blue-ocean nitraclines to storm runoff in rivers and streams. It has an accuracy of 2 uM (0.028 mg N/L) with a precision (at 3 std. dev) of 0.3 uM and a detection limit of 0.3 uM (Figure 26) (Sea Bird Scientific, June 2017).

Performance

	10 mm Pathlength	5 mm Pathlength
Accuracy	2 µM (0.028 mgN/L)	4 µM (0.056 mgN/L)
Turbidity Operating Range	0 - 625 NTU	0 - 1250 NTU
	Fresh water or Seawater with T-S Correction	**Seawater withour T-S Correction**
Precision (at 3σ)	0.3 µM	2.4 µM
Limit of Detection	0.3 µM	2.4 µM
Drift (per hour of lamp time)	<0.3 µM	<1.0 µM

Figure 26: SUNA 2 Product Specification by Manufacturer (Sea Bird Scientific, 2017)

5.5 EXO2

The EXO2 is developed by YSI, a xylem brand. Its advanced water quality monitoring platform includes the versatile multiparameter EXO2 sonde for oceanographic, estuarine, or surface water applications. It has high-accuracy sensors with on-board memory, wireless communication, and a built-in antifouling system to protect data integrity. The EXO2 contains 6 universal sensors ports a central port for an anti-fouling wiper. The anti-fouling wiper keeps sensor clear of biofouling and lengthens deployment times by 25%. See sensor specification in Figure 27.

Sensor Specifications*

Sensor	Range	Accuracy*	Response	Resolution
Ammonium [11] (ammonia with pH sensor)	0 to 200 mg/L [1]	±10% of reading or 2 mg/L-N, w.i.g.	-	0.01 mg/L
Barometer	375 to 825 mmHg	±1.5 mmHg from 0 to 50°C	-	0.1 mmHg
Blue-green Algae Phycocyanin (PC) (part of Total Algae sensor)	0 to 100 RFU; 0 to 100 µg/L PC	Linearity: R^2 > 0.999 for serial dilution of Rhodamine WT solution from 0 to 100 µg/mL PC equivalents	T63<2 sec	0.01 RFU; 0.01 µg/L PC
Blue-green Algae Phycoerythrin (PE) (part of Total Algae sensor)	0 to 100 RFU; 0 to 280 µg/L PE	Linearity: R^2 > 0.999 for serial dilution of Rhodamine WT solution from 0 to 280 µg/mL PE equivalents	T63<2 sec	0.01 RFU; 0.01 µg/L PE
Chloride [11]	0 to 18000 mg/L-Cl [2]	±15% of reading or 5 mg/L-Cl, w.i.g.	-	0.01 mg/L
Chlorophyll (part of Total Algae sensor)	0 to 400 µg/L Chl; 0 to 100 RFU	Linearity: R^2 > 0.999 for serial dilution of Rhodamine WT solution from 0 to 400 µg/L Chl equivalents	T63<2 sec	0.01 µg/L Chl; 0.01 RFU
Conductivity [3]	0 to 200 mS/cm	0 to 100: ±0.5% of reading or 0.001 mS/cm, w.i.g.; 100 to 200: ±1% of reading	T63<2 sec	0.0001 to 0.01 mS/cm (range dependent)
Depth [4] (non-vented)	0 to 10 m (0 to 33 ft)	±0.04% FS (±0.004 m or ±0.013 ft)	T63<2 sec	0.001 m (0.001 ft) (auto-ranging)
	0 to 100 m (0 to 328 ft)	±0.04% FS (±0.04 m or ±0.13 ft)		
	0 to 250 m (0 to 820 ft)	±0.04% FS (±0.10 m or ±0.33 ft)		
Vented Level	0 to 10 m (0 to 33 ft)	±0.03% FS (±0.003 m or ±0.010 ft)		
Dissolved Oxygen Optical	0 to 500% air saturation	0 to 200%: ±1% of reading or 1% saturation, w.i.g.; 200 to 500%: ±5% of reading [5]	T63<5 sec [6]	0.1% air saturation
	0 to 50 mg/L	0 to 20 mg/L: ±0.1 mg/L or 1% of reading, w.i.g.; 20 to 50 mg/L: ±5% of reading [5]		0.01 mg/L
fDOM	0 to 300 ppb Quinine Sulfate equivalents (QSE)	Linearity: R^2 > 0.999 for serial dilution of 300 ppb QS solution Detection Limit: 0.07 ppb QSE	T63<2 sec	0.01 ppb QSE
Nitrate [11]	0 to 200 mg/L-N [1]	±10% of reading or 2 mg/L-N, w.i.g.	-	0.01 mg/L
ORP	-999 to 999 mV	±20 mV in Redox standard solutions	T63<5 sec [7]	0.1 mV
pH	0 to 14 units	±0.1 pH units within ±10°C of calibration temp; ±0.2 pH units for entire temp range [8]	T63<3 sec [9]	0.01 units
Salinity (Calculated from Conductivity and Temperature)	0 to 70 ppt	±1.0% of reading or 0.1 ppt, w.i.g.	T63<2 sec	0.01 ppt
Specific Conductance (Calculated from Cond. and Temp.)	0 to 200 mS/cm	±0.5% of reading or .001 mS/cm, w.i.g.	-	0.001, 0.01, 0.1 mS/cm (auto-scaling)
Temperature	-5 to 50°C	-5 to 35°C: ±0.01°C [10] 35 to 50°C: ±0.05°C [10]	T63<1 sec	0.001 °C
Total Dissolved Solids (TDS) (Calculated from Conductivity and Temperature)	0 to 100,000 mg/L Cal constant range 0.30 to 1.00 (0.64 default)	Not Specified	-	variable
Total Suspended Solids (TSS) (Calculated from Turbidity and user reference samples)	0 to 1500 mg/L	Not Specified	T63<2 sec	variable
Turbidity [11]	0 to 4000 FNU	0 to 999 FNU: 0.3 FNU or ±2% of reading, w.i.g.; 1000 to 4000 FNU: ±5% of reading [12]	T63<2 sec	0 to 999 FNU: 0.01 FNU; 1000 to 4000 FNU: 0.1 FNU

Figure 27: EXO2 Product Specification by Manufacturer (YSI, 2017)

5.6 USGS Monitoring Station

The USGS monitoring station located at Ichetucknee Head Spring has been discontinued since 2010 (USGS 02322685). Therefore, the discharge measurements are limited to 2010 data. Discharge in 2009 averaged 44.1 cfs (23.7 mgd) and water levels averaged 1.087 reference gage height.

5.7 UF IFAS FAWN Network

Rainfall Data is collected from the University of Florida IFAS Extension's Florida Automated Weather Network (FAWN). The Alachua Station is used to collect daily precipitation and weather data from April 2015 to July 2017. The rainfall data (total inches/day) is compared to the water quality data from the Head Spring to see if it is a contributing factor. Qualifying rainfall events were limited to events equal to or larger than 0.2 inches. For runoff analysis, the minimum initial abstraction value recommended by TR-55 (USDA, 1986) is 0.2 inches. Also utilized is Solar Radiation (w/m^2) to account for light penetration into the spring as it may contribute to turbidity readings. However, the station is located under an oak canopy and is well shaded during most of the day.

5.8 Data Processing and Compilation

Hourly water quality data provided by the SRWMD was processed and compiled prior to analysis. All data points that were negative or below zero were removed. All turbidity samples prior to March 1, 2016 were removed due to the erratic readings that indicated a lack of calibration. All turbidity reading greater than 5 NTUs were removed based on boxplots showing values greater than 3 NTUs were outliers, but not wanting to exclude values that maybe due to visitors based on visual analysis of the scatterplot. If turbidity was greater than 5 NTUs, it was

likely due to direct human influence on the meter during calibration or unwanted interference. After initial removal of the zero and negative values, a visual review of the data was done to remove any excessive outliers. However, data outside of three standard deviations were not necessarily removed because the objective of this study is to see if there were fluctuations in water quality parameters due to high numbers of visitors. After the visual review, the data was compiled into daily maximum values and compared to daily visitor totals. Maximum daily water quality parameters were also compared to daily environmental parameters, such as atmospheric temperature, rainfall, and solar radiation.

5.9 Minitab Statistical Software

Minitab 17 Statistical Software was used to create all the water quality graphs and to perform the statistical tests. Data were split based on season: Season 1 (off season) – day after Labor Day to day before Memorial Day, and Season 2 (tubing season) – Memorial Day to Labor Day. Time series were created for maximum daily water quality readings. Kruskal-Wallis tests were completed for each water quality parameter in congruence with grouped boxplots to determine if there were significant differences in water quality between the two seasons. Spearman (Rho) Correlation tests were completed comparing each water quality parameter to visitor counts and rainfall events to signify possible relationships. Autocorrelation and cross correlation were done for each water quality parameter and in comparison to daily visitors counts, rainfall, and solar radiation.

CHAPTER 6: RESULTS AND DISCUSSION

6.1 Daily Maximum Water Quality Parameter Patterns

From April 2, 2015 to September 5, 2017, maximum daily values for each water quality parameter were evaluated. Because the research focuses on using daily max values, diurnal patterns due to metabolism, that are typically seen within a 24hr period, are not represented in the analyzed dataset. Seasonal and annual patterns were seen in water temperature (Temp C^{o}), which followed the changes in atmospheric temperature (T Max), solar radiation (SolRad), and evapotranspiration (ET) (Figure 28 and Figure 29). Nitrate (SUNA Nitrate) and pH values were primarily influenced by calibration drift and do not reflect environmental changes. In general, Nitrate did not see an increase or decrease greater than 0.1 units (Figure 28). Specific Conductivity (Spec. Cond.) shows a slight seasonal pattern, but there were breaks in the data where the calibration drifted off (Figure 28). Turbidity data were reviewed from March 1, 2016 to September 5, 2017. Across the period of record, turbidity showed an apparent increase in values (Figure 28). However, given the low values of turbidity, this amount of increase (<5.0 NTUs) would be difficult to see with the naked eye. Visitor numbers were highest during the summer months, which corresponded to the peaks in temperature, SolRad, and ET cycles (Figure 29). Rainfall values of 0.1 inches and greater were reviewed for this analysis. Rainfall was highest during the summer months, which is typical of the Florida rainy season (Figure 29)

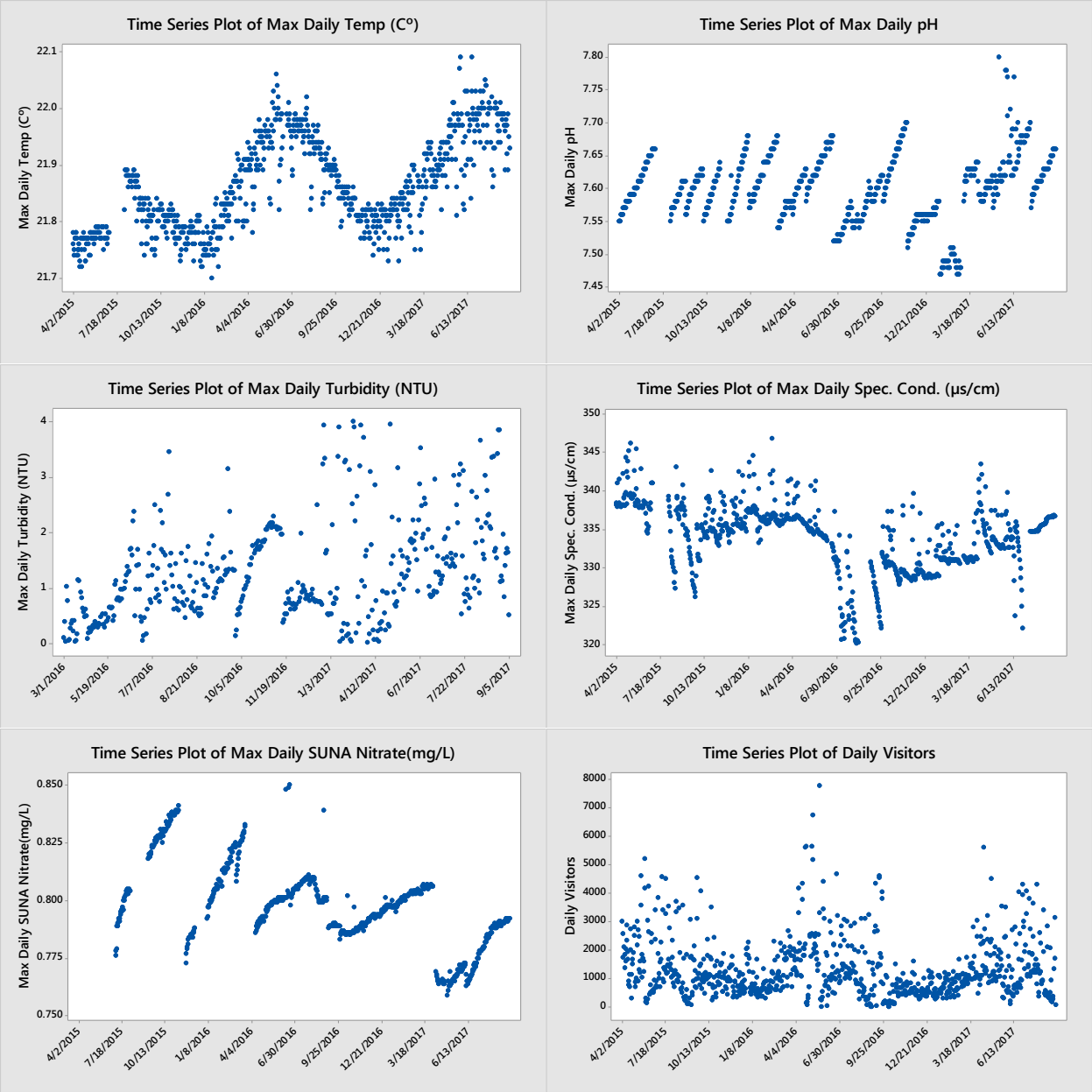

Figure 28: Maximum Daily Quality Parameters and Daily Visitor Totals Time Series

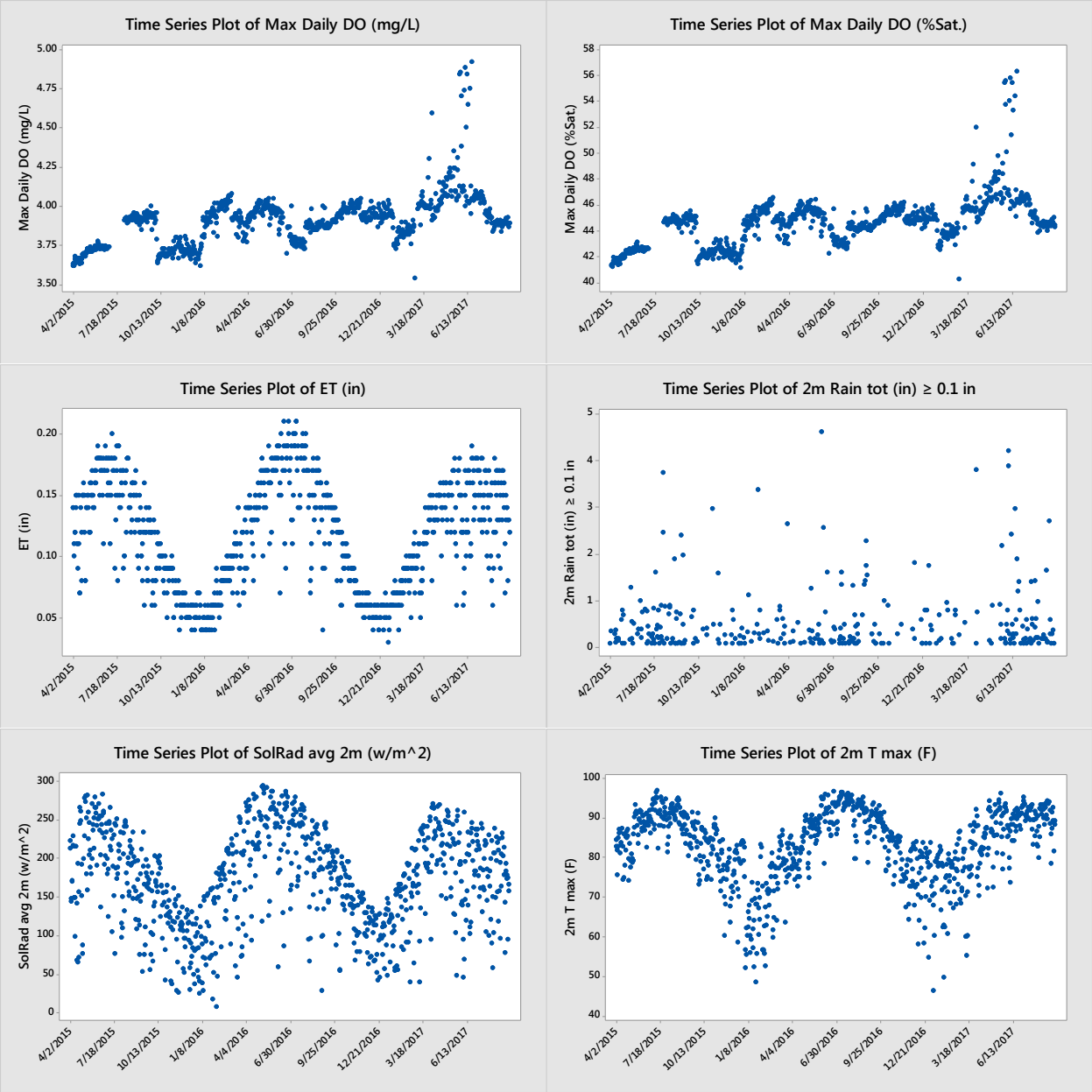

Figure 29: Water Quality and Environmental Parameters Time Series

6.2 Daily Maximum Water Quality Seasonal Comparison

Water quality data were divided by season for the Kruskal-Wallis Test. Seasons were based on the tubing season, when visitors were restricted from tubing from the North Launch (Season 1 – Labor Day to Memorial Day), and when visitors had access to the North Launch

(Season 2 – Memorial Day to Labor Day). There were significant differences in all water quality parameters between both seasons (Table 3) except for Dissolved Oxygen (mg/L and %Sat). This would be expected due to tubing season being restricted to summer months (i.e. rainy season) while Season 1 is between fall and spring (Figures 30 and 31). Dissolved Oxygen follows a diurnal (24 hours) pattern that is influenced by the time of day and other more complex environmental and chemical properties; which outweigh any direct human interference.

Table 3: Kruskal-Wallis Seasonal Results

Parameter	Count	Min	Max	Unit Factor (Max/Min)	Season 1 Median	Season 2 Median	H-Value	P-Value
Temperature	823	21.7	22.09	1.02	21.82	21.95	228.34	<0.001
Turbidity (<5 NTU)	435	0.02	4.71	235.50	0.83	1.39	39.11	<0.001
Spec. Cond.	823	288.5	346.8	1.20	334.9	334	26.62	<0.001
pH	816	7.47	7.84	1.05	7.6	7.61	16.78	<0.001
Nitrate	686	0.759	0.881	1.16	0.798	0.795	13.03	<0.001
DO (mg/L)	823	3.54	4.92	1.39	3.93	3.9	0.02	0.901
DO (%Sat)	823	40.29	56.29	1.40	44.8	44.59	0.054	0.461
Visitors	864	0	7749	--	978	1173	9.54	0.002
Rainfall (≥0.2 in)	302	0.2	4.19	20.95	0.52	0.775	1.22	0.269
Solar Radiation	866	7.86	293.64	37.36	158	203.4	64.65	<0.001
Evapo-transpiration	862	0.03	0.21	7.00	0.09	0.16	266.23	<0.001

There was also a significant increase in turbidity in Season 2 in comparison to Season 1 ($p<0.001$) (Figure 30). There was not a significant difference in the median size (i.e. inches) of rainfall in qualify events (≥0.2 in) between seasons, even though there were more rain events during Season 2 (Figure 31). Though the median values of rainfall magnitudes were not significant, further analysis Spearman (Rho) Correlation tests were completed to see if these seasonal differences in water quality were due to visitors or rainfall events.

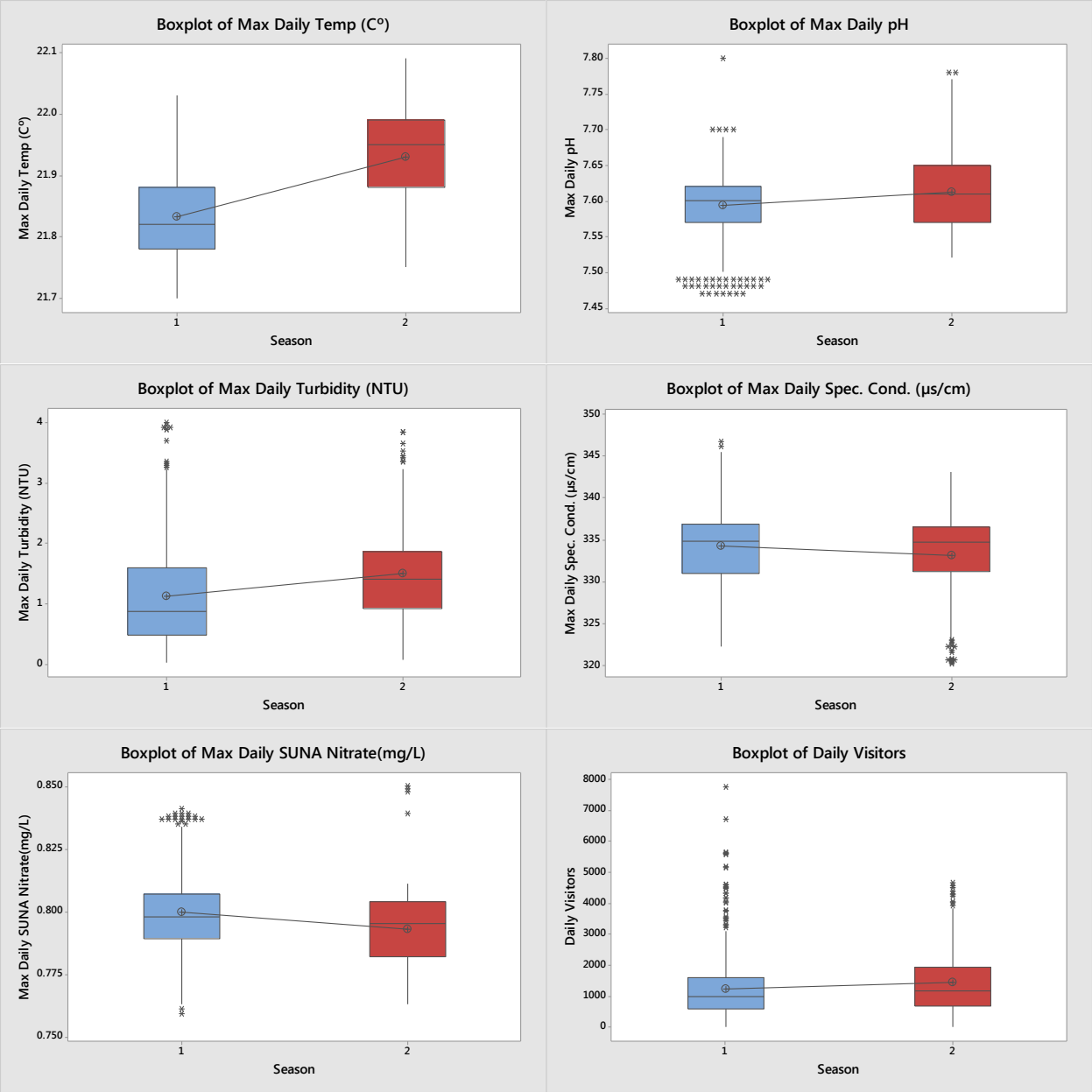

Figure 30: Box Plot of Max Daily Water Quality Parameters

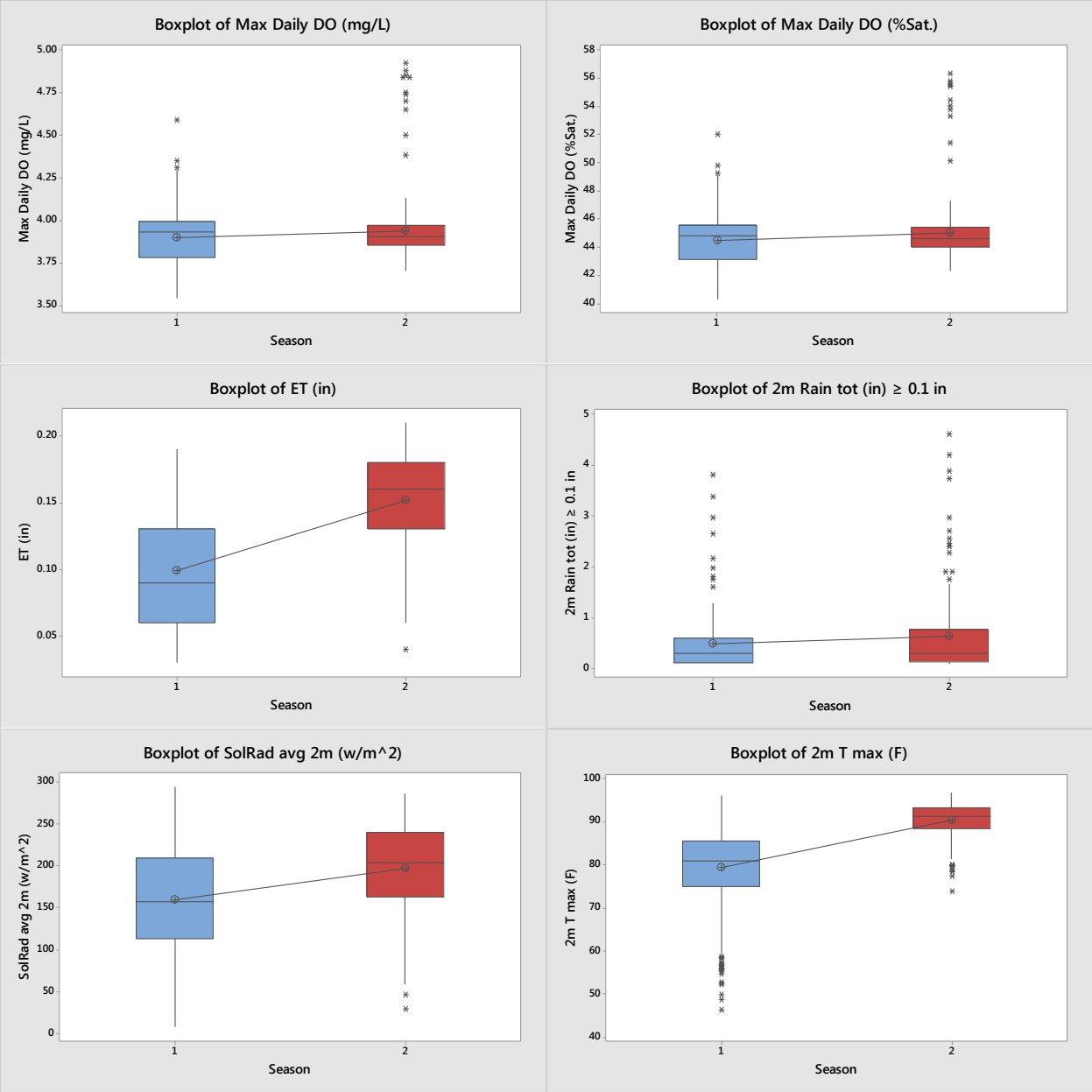

Figure 31: Boxplots of Daily Max DO and Environmental Parameters

6.3 Daily Maximum Water Quality and Visitor Relationships

Spearman (Rho) Correlation analysis between all water quality parameters and daily visitor counts were completed to see if there were significant correlations between visitor counts and water quality parameters (Table 4). Scatterplots with linear regressions were plotted in order

to see any visual signs of linear correlations that needed to be further investigated (Figure 31 and Figure 32).

Table 4: Spearman (Rho) Correlations Results

Spearman Rho	Max Daily Temperature (C°)	Max Daily Turbidity (NTU)	Max Daily Spec. Cond. (µs/cm)	Max Daily pH	Max Daily DO (mg/L)	Max Daily DO (%Sat.)
Visitors (Rho)	0.259	-0.023	0.107	-0.003	-0.027	-0.012
P-Value	P<0.001	0.631	0.002	0.926	0.445	0.73
2m Rain tot (in) (Rho)	0.053	0.351	-0.169	0.051	-0.05	-0.049
P-Value	0.129	0.007	0.086	0.142	0.148	0.158
Spearman Rho	**Max Daily Nitrate (mg/L)**	**Visitors**	**2m T max (F)**	**2m Rain tot (in)**	**SolRad avg 2m (w/m^2)**	**ET (in)**
Visitors (Rho)	0.03	1	0.285	-0.151	0.4	0.126
P-Value	0.434	P<0.001	P<0.001	0.099	P<0.001	P<0.001
2m Rain tot (in) (Rho)	-0.049	-0.151	0.134	1	-0.265	-0.008
P-Value	0.203	0.099	P<0.001	P<0.001	P<0.001	0.808

From the Spearman (Rho) Correlation analysis, we see a significant correlation between total rainfall and turbidity values (Rho = 0.351, P = 0.007). A linear relationship was also visual seen between rainfall and turbidity when plotted in a scatterplot (Figure 33). Rainfall causes surface water runoff and after large events, washing fine sediments from the immediate surrounding typography into the water column. There was a significant correlation between

visitor counts and specific conductivity (Rho = 0.107, P = 0.002) and there was not a detected correlation between specific conductivity and rainfall, which indicates human usage as a signaling factor. This could be caused by the amount of people in the springs urinating and/or the sun-screens and bug sprays washing off people as they bathe in the Head Spring. Further investigation is needed coupled with in the field water sampling.

There was a significant correlation between visitors and water temperature (Rho = 0.259, P = <0.001) and a linear relationship can be seen between water temperature (Temp C^{o}) and visitors; however, that would be expected because people would seek the refreshing coolness of the spring-fed river during hot summer days (Figure 32). There were no other linear relationships detected between maximum daily water quality parameters and visitor totals (Figures 32 and 33). There was no observable relationship between daily max turbidity values and visitor counts (Figure 32). This may be due to the location of the monitoring station, which is upstream of the North Launch and does not measure the tubers' influence. Water Temperature did increase as atmospheric temperature (T max F) increased, which would occur since the water leaving the head spring would be heated by the sun as it traveled by the monitoring station (Figure 33).

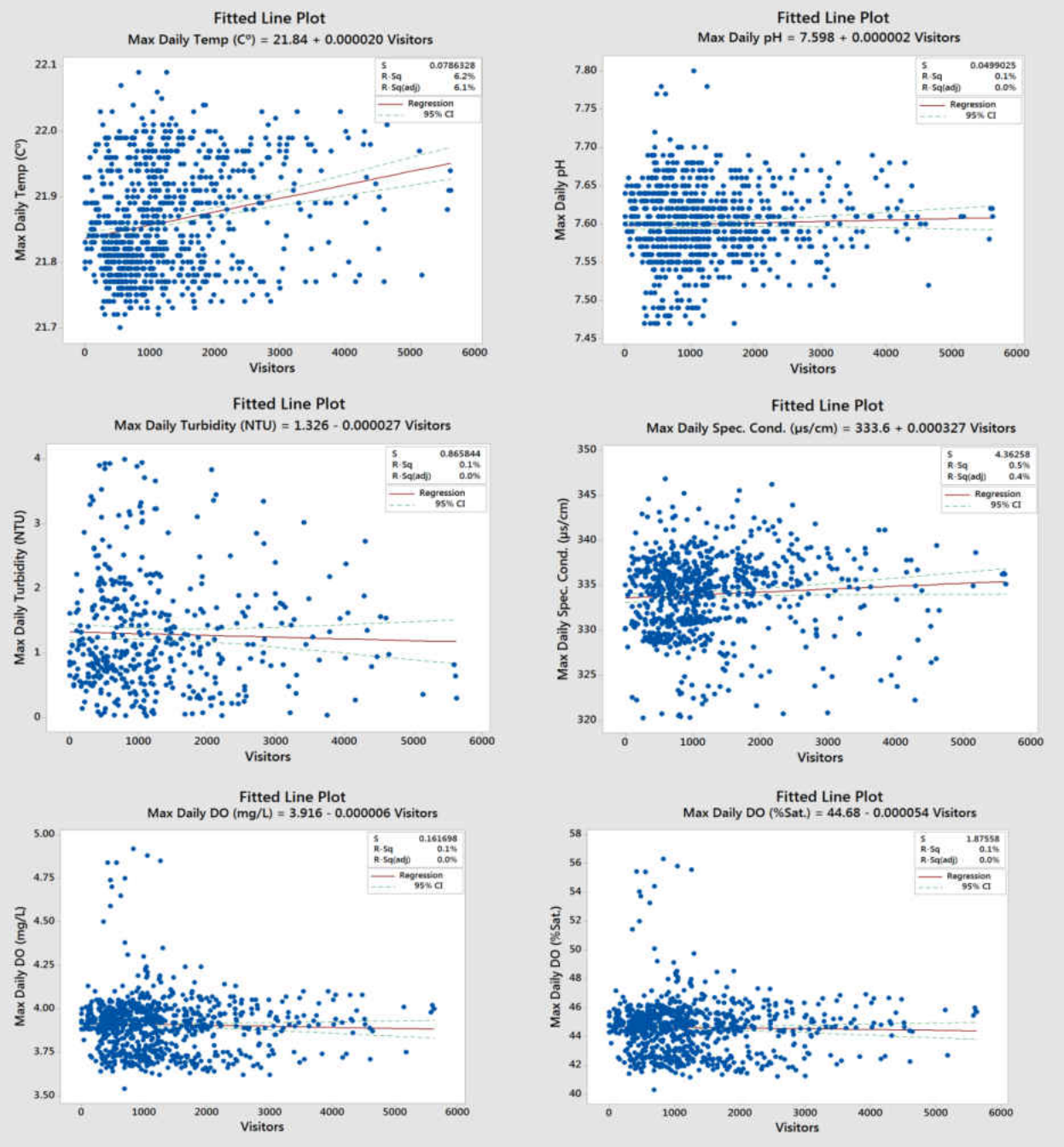

Figure 32: Scatter Plot of Daily Max Water Quality Parameters and Visitor Counts

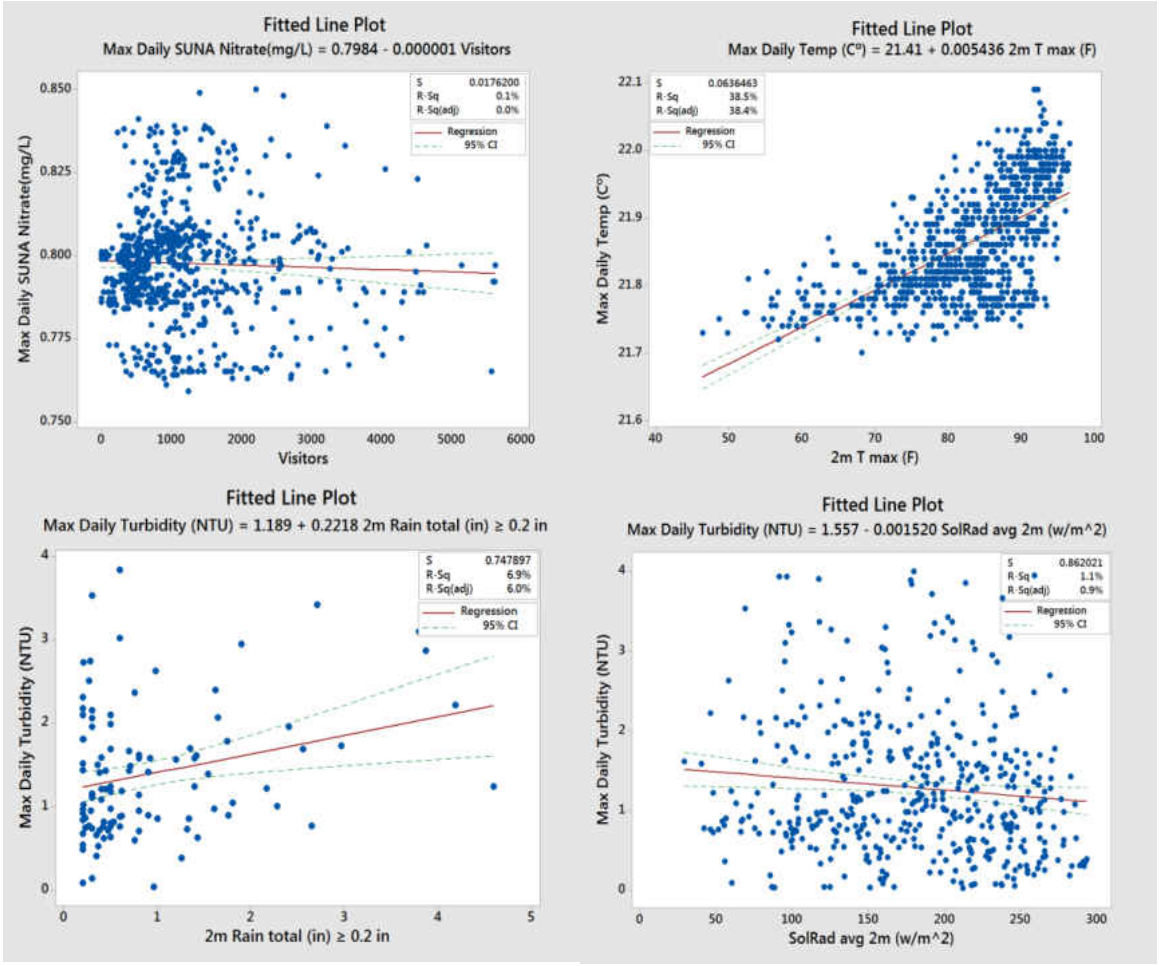

Figure 33: Scatterplot of Daily Max Water Quality Parameters and Environmental Parameters

6.4 Daily Maximum Turbidity and Visitor Counts Correlations

As turbidity is the most likely indicator of visitors' influence on the springs and spring-run, further correlation analysis was completed comparing turbidity and visitor counts. On a daily scale, visitors and turbidity were significantly auto-correlated, which was expected. Based on autocorrelation function analysis, it was found that visitors showed a seven-day pattern in visiting habits, which lines up with weekend visits (Figure 34). Turbidity was significantly auto-correlated for one day (correlation >0.5), but quickly dropped as time progressed. This shows that turbidity is more easily influenced by external factors than the other water quality

parameters. When comparing turbidity to rainfall, turbidity showed a weak positive correlation (correlation<0.2) with rainfall; with a lag increasing two days after a rainfall event. Based on the Spearman (Rho) Correlation and cross correlation analysis, rainfall is a contributing factor to changes in turbidity (Figure 34). Across the entire dataset, on a daily timescale, turbidity did not cross-correlate with visitor counts (Figure 34). When dividing the dataset by seasons, a serial correlation (correlation<0.5) between turbidity and visitors is detected during the tubing season (Figure 35) which aligns with the seven-day pattern seen in visitor counts. This shows that during the weekends of the tubing season (summer months) turbidity is high enough in the Head Spring to signal a change in water quality as it enters the Spring Run. This serial correlation, based on the Spearman (Rho) analysis, is not strong enough to warrant limiting visitors' access to the Head Spring. The weak correlation signals between turbidity, rainfall, and visitor counts are most likely due to the location of the monitoring station. The station is not close enough to the Head Spring's boil to measure immediate discharge from the spring after a rainfall event and the station is not south of the North Launch to measure the effects of tubers on water quality.

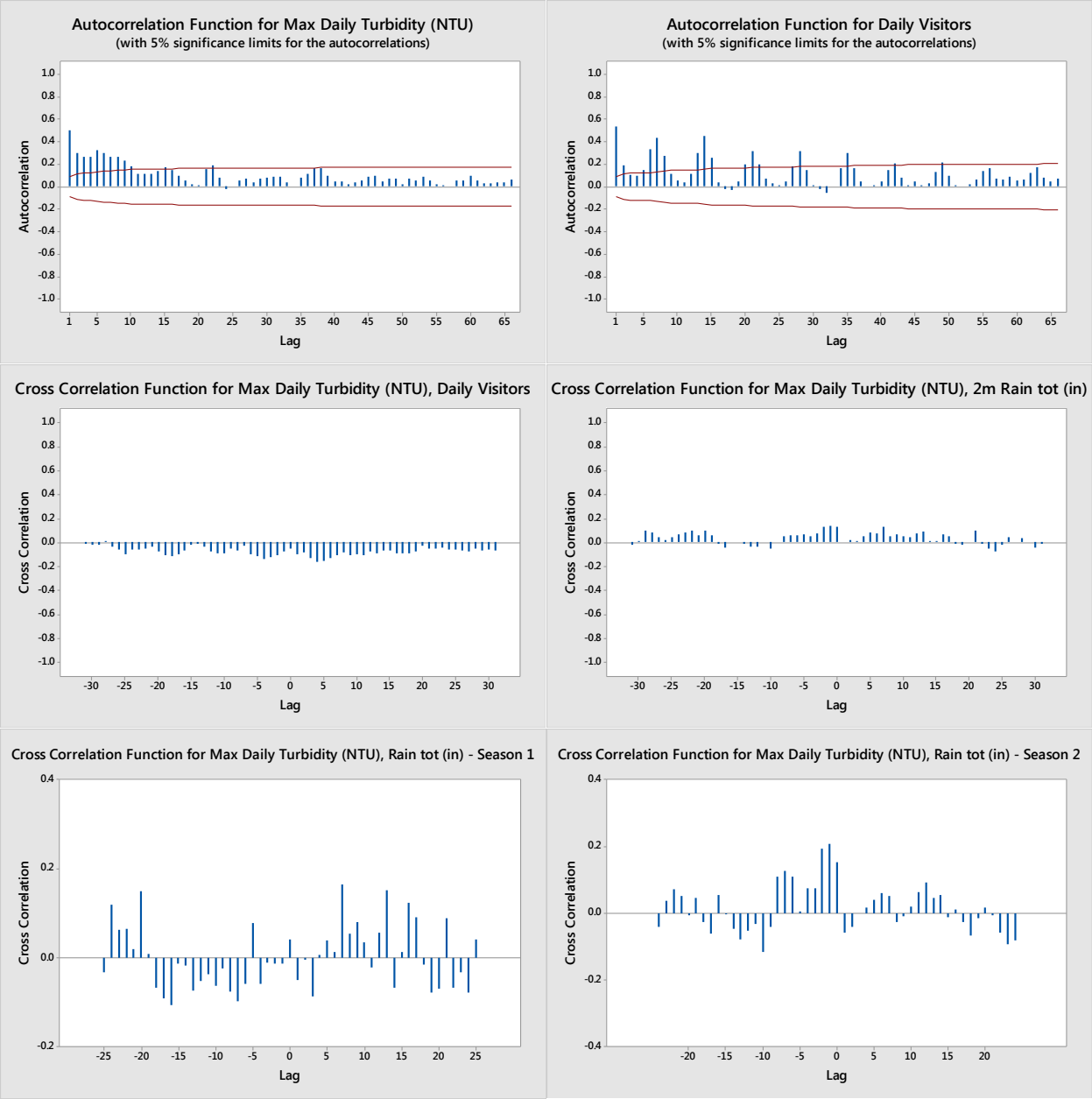

Figure 34: Auto and Cross- correlation of Max Daily Turbidity with Visitor Counts and Rainfall

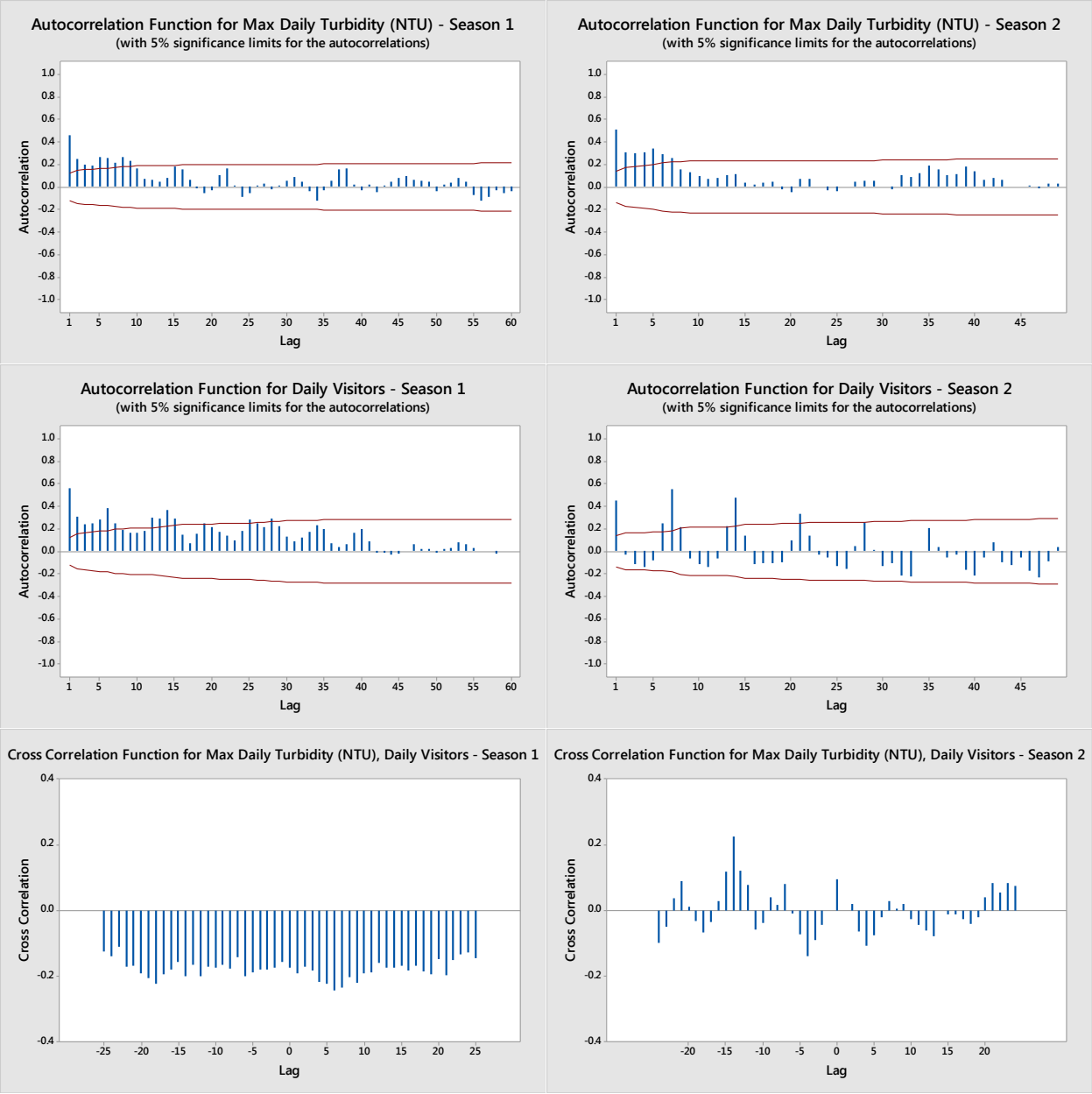

Figure 35: Seasonal Auto and Cross-Correlation of Max Daily Turbidity with Visitor Counts and Rainfall

CHAPTER 7: CONCLUSION AND FUTURE RESEARCH

From April 2, 2015 to September 5, 2017, maximum daily values for each water quality parameter were evaluated to see if there were seasonal patterns in water quality changes due to visitors during the tubing season at Ichetucknee Springs State Park. The results of processing led to 24% of the data being removed due to zero or negative values. Visual study of the time series showed that turbidity readings prior to March 1, 2016 were inaccurate and possibly due to calibration error. In the future, maintenance and calibration logs should be utilized in processing the data to clean the dataset of dates that correspond with maintenance issues.

After processing the continuous monitoring data, correlation analysis and statistical tests were performed comparing the distinct water quality parameters to visitor daily totals. It was found that median water quality varied significantly between the on and off tubing season. Rainfall events did not show a significant difference in strength between on and off season, but did show a significant positive relationship with turbidity. This is due to the frequency of rainfall events during the summer as well as runoff and recharge potential to influence turbidity in the groundwater. Specific conductivity was significantly correlated to visitor counts and not related to rainfall, though during the tubing season the median decreased by less than 1 us/cm. Further investigation and possible chemical analysis of water quality are warranted. Turbidity significantly increased during the tubing season, though a direct correlation between daily maximums and visitor totals could not be distinguished. By conducting a seasonal cross correlation analysis during the tubing season, a serial correlation pattern in turbidity increases as visitor counts increase every seven days (on the weekends). Though a correlation is present, the signal is not strong enough to warrant limiting the number of visitors to the Head Spring.

Overall, seasonal patterns in water quality changes were expected to correspond to environmental changes such as atmospheric temperature, solar radiation, and rainfall. The correlation between rainfall and turbidity is due to surface water runoff and flushing of the surrounding Springshed after large rain events. Though statistically significant, median turbidity during the tubing season increased less than 1 NTUs, which is not a visible difference. The location of the SRWMD monitoring station does not measure water quality after visitors entered the North Launch, which is the primary area of concern for SWRMD and ISSP staff. Being located between the Head Spring discharge and the North Launch, the station can only monitor water as it enters the Spring Run. Given the amount of research and funding focused on the SAV and aquatic life of the Ichetucknee River, a second monitoring station is recommended to be installed south of the North Launch in an area with monitored SAV habitats. This station would allow for water quality comparisons between water leaving the Head Spring and Blue Hole Spring to water quality changes after visitors enter the North Launch.

Another recommendation regarding measuring the impacts of visitors on the Ichetucknee River is that visitors entering the Park from the North Entrance should be counted separately from visitors entering the Park at the South entrance. Currently ISSP staff only has a total count of visitors to the park. They do not record how many people enter the North Entrance, only how many people who enter the River from the North Launch. This would give Park Staff a better idea of how many people utilize the Head Spring and Blue Hole spring, which can be later analyzed in comparison to water quality records at their individual SRWMD stations.

Further investigation is warranted into understanding the effects of visitors on water quality at Ichetucknee Springs State Park. The SRWMD station at the Head Spring allows researchers to remotely diagnose the health of the Spring and paint a holistic picture of how

seasonal changes may affect water quality. Recording visitor usage of the North Park and continuous water quality monitoring, coupled with frequent equipment calibration and maintenance, will more accurately assist SRWMD scientists and ISSP Staff in their Ichetucknee Springs' ecosystem resource management.

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