Protecting Water Quality of the Ichetucknee Springs in Florida

By

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1. Introduction

The Ichetucknee River and Springs system is 6.5 miles long and contains 10 named springs in North Central Florida. Ichetucknee Springs was designated as an Outstanding Florida Spring and National Natural Landmark in 1972 and an Outstanding Florida Water in 1979. The source of the system is groundwater, originating in the roughly 300 square mile springshed encompassing three counties, of which Columbia is the majority (Figure 1). Water flows from the Ichetucknee River into the Santa Fe River which then joins the Suwannee River and eventually the Gulf of Mexico. Average daily flow of the Ichetucknee River near the Hildreth gage (near the confluence of the Santa Fe River) between October 2019 and October 2020 is 201 million gallons per day (USGS, 2020).

Land adjacent to the northern section of Ichetucknee River is owned and managed by Ichetucknee Springs State Park (ISSP). Approximately 26 acres of the park is directly focused on conservation and recreation efforts, with roughly 1230 acres of undeveloped xeric scrub and mesic forest habitat, 127 acres of wetlands, and 900 acres of mixed uplands (WSI, 2010). Peak visitation at ISSP is May through August and is centered on outdoor and water recreation (Bonn and Bell, 2003). Over 400,000 people visited the park in 2016 (Faraji, 2017). The springs have an important financial component, bringing $4.5 million to the local economy (Florida Springs Task Force, 2000).

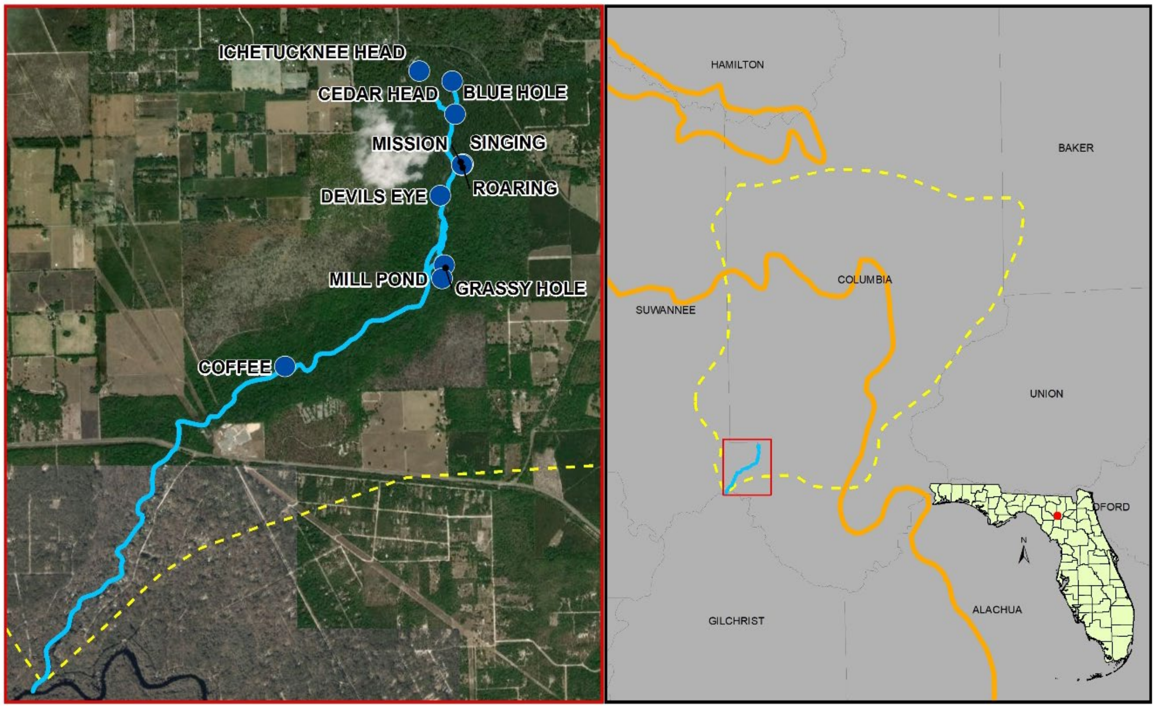


Figure 1: Left- The Ichetucknee River and Springs. Right- Ichetucknee Springshed boundary (yellow) and Cody Escarpment (orange) in the northern portion of the springshed. (Credit: Suwannee River Water Management District, National Hydrography Dataset.)

Water quality management is critical for maintaining a superior recreational experience to the public for years to come. This quality is heavily influenced by unique karstic geology that aids pollutant transport, including nitrogen, into Ichetucknee Springs. The Cody Scarp, which has its boundaries within the springshed, contains clays above the Floridan Aquifer that partially protects from groundwater pollution (Figure 1). Areas outside of the scarp are more susceptible to infiltration and pollution due to a more immediate connection to the aquifer via sandy substrate and underlying karst geology. Karst pathways are created by CO_2 forming carbonic acid, which dissolves limestone and creates voids within the bedrock. Links between groundwater and surface water are complex in the Ichetucknee Springshed. Obvious interactions in the springshed include sinks and spring boils, while less obvious exchanges include seepage, bank storage space and hyporheic exchange (Brown et al., 2016).

The Ichetucknee Trace is a historic topographic connection between Alligator Lake in Lake City and Ichetucknee Headspring and contains several of these exchanges between the surface and groundwater (Figure 2). Ichetucknee Trace is approximately 11 km long (Katz, 2009) and includes 664 acres of land (FDEP, 2018). Entry points include Black Sink and Rose Creek Sink. These exchanges make Ichetucknee Trace a vulnerable pathway for pollutant transport to Ichetucknee Springs and is a focus for water quality management.

The extent of aquatic vegetation at Ichetucknee Springs has varied with time and can be used as an indicator of water health. Before ISSP was established the river was popular for tubing and other recreation, leading to widespread submerged aquatic degradation without proper management. Between 1973 and 2003, aquatic vegetation has increased by 350% (Katz, 2009). Plant surveys are regularly conducted as a part of the monitoring plan at ISSP to better understand conditions. Algae is a growing issue at the springs as nutrient loads, originating from numerous sources in the springshed, are rising. Algal growth has potential to throw off ecological balances in the springs, cause human health concerns, inhibit recreation, and decrease spring aesthetics (FEDP, 2018).

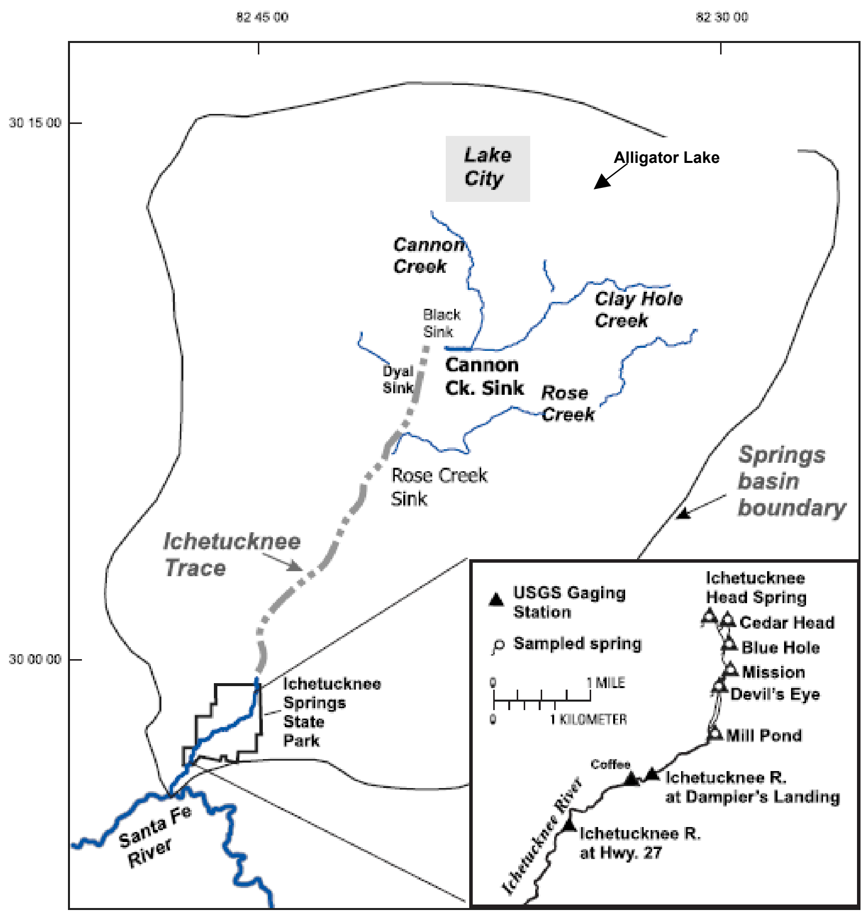


Figure 2: Ichetucknee Trace connects Alligator Lake, Rose Creek, Clay Hole Creek, Cannon Creek to Ichetucknee Springs. (Source- Katz, 2009).

2. Ichetucknee Water Quality

The health of the Ichetucknee River is jeopardized by negative shifts to water quality parameters. Rivers and springs in general are subject to many water quality woes, including imbalances in the physical (temperature, sediment, light, color, etc.), biological (bacteria and viruses), and chemical (toxins, dissolved oxygen, conductivity, pH, biological oxygen demand, nutrients, etc.) characteristics. Contaminants, especially nitrates, are of particular concern due to the karstic nature of the Upper Florida Aquifer and its ability to transport them through groundwater more rapidly than other groundwater systems. Stream impairment limits at

Ichetucknee, a class III water, are set by Florida law and are detailed in 62-302 Florida Administrative Code, a subset of which is shown herein (Table 1).

Table 1: Water quality parameters from 62-302 Florida Statutes.

Parameter	**Criteria**
Turbidity	Less than or equal to 29 NTU above background conditions
Specific Conductivity	1275 micromhos/cm
Fecal Coliform	400 col/100 mL
pH	6.0 – 8.5

Parameter	**Criteria**
Phosphorus (elemental)	0.1 microgram/L (drinking water, none for class III)
Nitrate + Nitrite	0.35 mg/L in spring vents
Dissolved Oxygen	5 mg/L

2.1 Physical Water Quality Parameters

High stream temperature is identified as an issue in many urban streams (Somers et al., 2013), but has generally not been identified as an issue at Ichetucknee because groundwater-driven flow keeps water temperature from experiencing large temperature fluctuations (USGS, 2020). One study found other factors, such as the number of park guests swimming in Ichetucknee Springs, did not have a direct correlation with changes in spring temperature. Ambient air temperature was deduced to play a significant role in water temperature increases during the hottest periods of the day and year (Faraji, 2017). Data shows fluctuations in temperature on a daily and seasonal basis (Figure 3), but this variation in temperature has not caused Ichetucknee to be classified by the State of Florida as impaired for temperature (USGS, 2020). Additionally, many studies have collected temperature data at Ichetucknee Springs as beneficial information secondary to their study. A sampling of this data is included in Table 2.

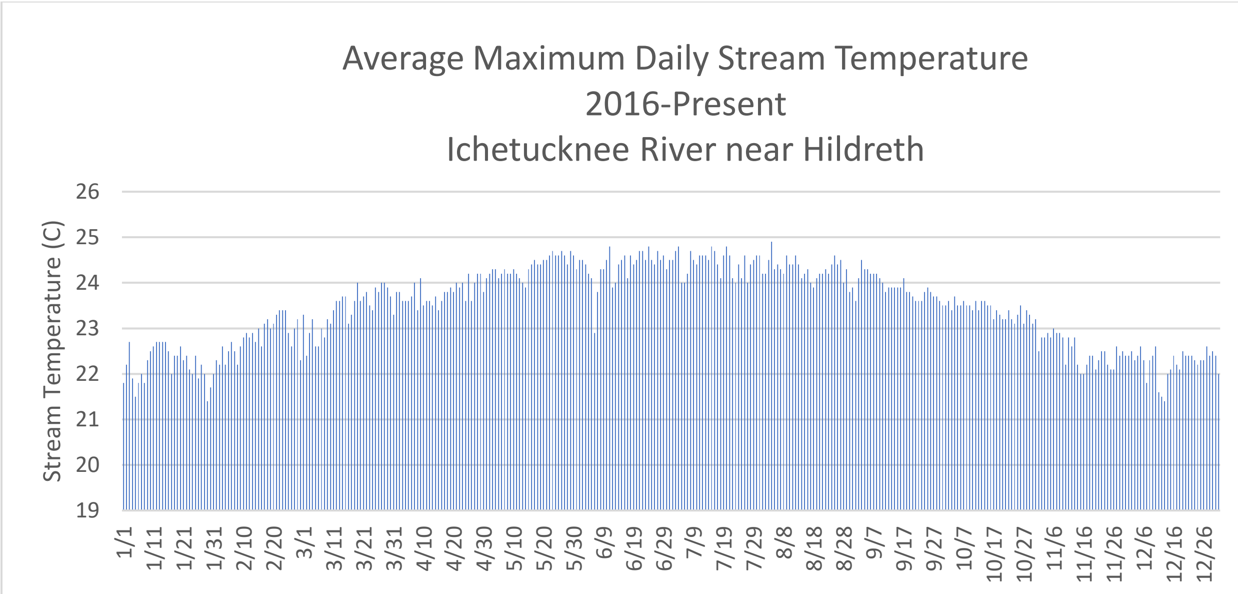


Figure 3: Average maximum daily stream temperatures in Ichetucknee River between 2016 and 2020 (USGS gage 02322700). Temperatures range from 21.3 to 24.9 C and change seasonally (Source- USGS, 2020).

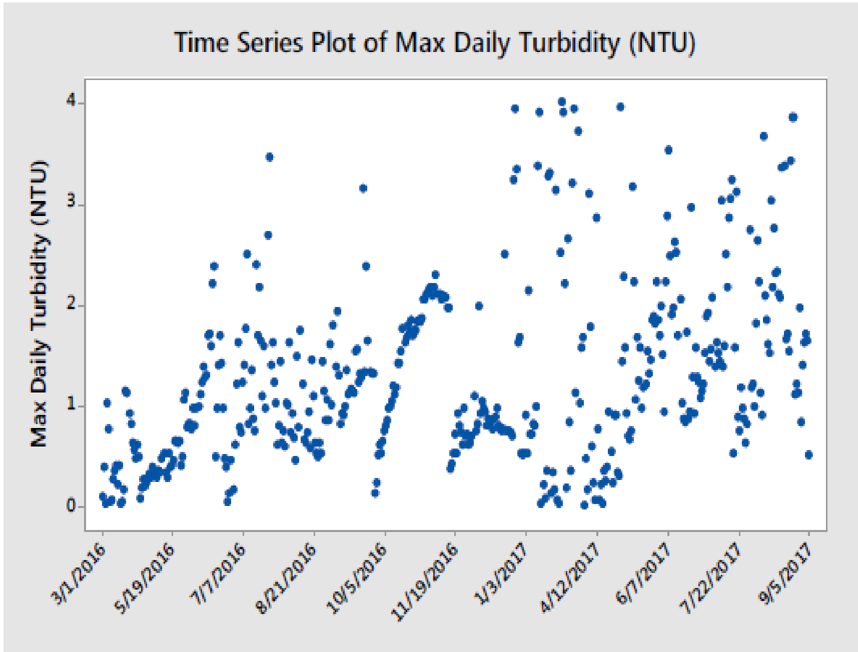
Stream turbidity has been studied at Ichetucknee, driven by a desire to understand connections between recreationists, particularly tubers, and the channel bottom. Two studies showed turbidity values below the regulatory limit of 29 Nephelometric Turbidity Units (NTUs) (Faraji, 2017 and WSI, 2011). Research conclusions are mixed regarding a correlation between recreation and increased turbidity.

In their thesis, Faraji found their data did not support a direct correlation between visitor activity and maximum daily turbidity but assigned potential rises and falls in turbidity to rainfall (Faraji, 2017). A positive correlation was identified between turbidity and rainfall events greater than 0.2 inches, including measurements during two tubing seasons between March 2016 and September 2017 (Figure 4). Although turbidity generally increased with rainfall, the observed range of turbidity for this study were less than 4.7 NTU's and well below the impaired limit of 29 NTUs above background concentrations (Surface Water Quality Standards, 2016).

Contributions to turbidity were also ascribed to primary productivity in the river and the contributing basin.

*Table 2: Physical water quality measurements for multiple studies in Ichetucknee Springs. * = average, ^ = median.*

Temperature (C)	21.7 – 22.09	Apr 2015 – Sept 2017	Faraji, 2017
	22.4*	Spring 2004	Steigerwalt, 2005
	21.8 - 23.8, 23.1*	2003	Notestein et al, 2004
	21.8 - 22.9	2004	Notestein et al, 2004
	21.7	Aug 14, 1997	Katz et al, 1999
Turbidity (NTU)	0.02 – 4.71	Apr 2015 – Sept 2017	Faraji, 2017
	0.1 – 0.35, 0.175^	2006	Harrington et al, 2010
	0-20	2010	WSI, 2011



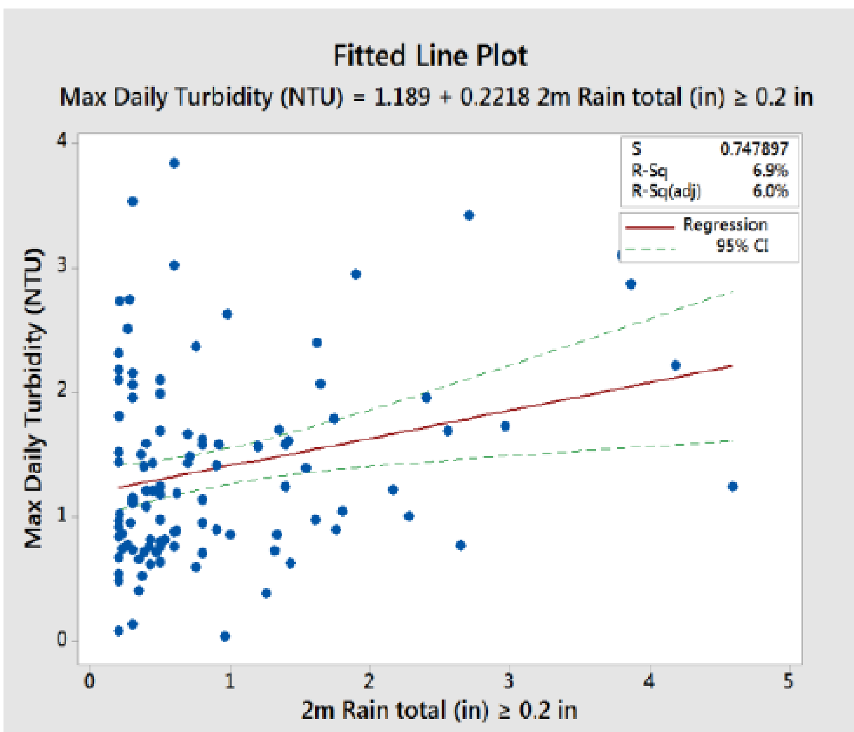


Figure 4: Time series of maximum daily turbidity and a fitted line plot showing positive relationship between precipitation events greater than 0.2 inches and maximum daily turbidity (Faraji, 2017).

Conversely, Wetland Solutions Inc ascribed measured increases in turbidity to recreational sources (WSI, 2011). Data was collected at three locations throughout the river which were targeted at popular entrance points to capture changes in turbidity due to human activity. The study time was in two-week segments taken in the summer and winter for contrast. Their study found that peak weekend turbidity values were higher (4.5, 3.5 and 3.8 NTU upstream to downstream) than weekday values (2.3, 2.5, and 2.7 NTU upstream to downstream). Increases in turbidity downstream during the weekday were attributed to accumulation of particles associated with aquatic plant primary productivity.

2.2 Biological Water Quality Parameters

Bacteria and viruses are present in Florida Springs. A recent study has documented the abundance and diversity of prokaryotic and viral communities in five North Florida springs, including Ichetucknee, and serves as a baseline for future changes (Malki et al., 2020). The overall abundance of prokaryotic and viral particles was found to be relatively less than other groundwater systems. Of the ten most observed families in Ichetucknee Springs, Phormidiaceae was the most common at 26% (Figure 5) and was only abundant at this spring. Phormidiaceae is a family with cyanobacteria genera, which can sometimes create cyanotoxins, block sunlight via blooms and use oxygen in the water column. The authors discussed algal mats existing near their collection site, which may have influenced these results. An association between land use and nutrient load with prokaryotic and viral abundance was discussed in this study. Volusia Spring, which has more phosphate than the other springs (Table 3) had the highest amounts of bacteria and viruses. Volusia Spring also had more urbanized land in the watershed compared to the other contributing areas and is explained to be the cause of the higher phosphate concentration.

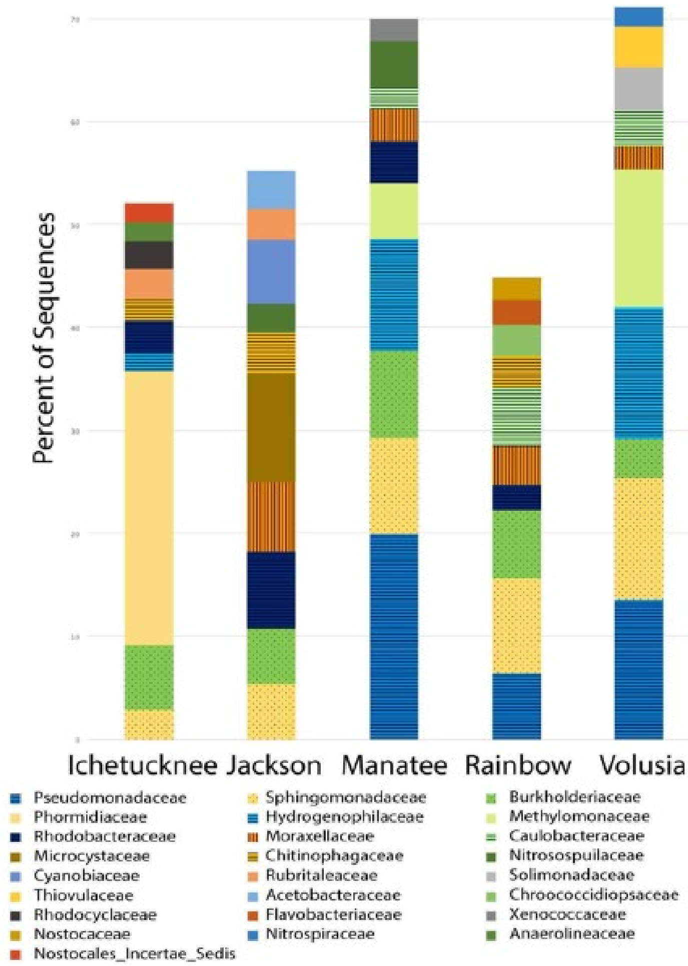


Figure 5: Water quality Ichetucknee was unique in having a dominance of Phormidiaceae. Volusia Spring had the highest percent of sequences than the other springs (Source: Malki et al, 2020).

Table 3: Water quality parameters from the prokaryotic and viral community study. The research suggests springs with higher phosphorus (Volusia) show greater amounts of viruses and bacteria, creating a greater importance for positive nutrient management in Ichetucknee Springshed (Source: Malki, et al., 2020).

Spring Site	Collection Date	Temp (C)	pH	Turbidity (NTU)	% DO	Conductivity (µS/cm)	Nitrate (µM)	Nitrite (µM)	Ammonium (µM)	Phosphates (µM)
Ichetucknee	30 May, 2017	25.4	7.67	3.8	43.6	327.9	28.5	0.06	1.10	0.12
Jackson	1 June, 2017	21.2	7.70	3.1	35.7	270.5	230.9	0.13	8.75	0.30
Manatee	5 May, 2017	22.4	7.33	3.5	14.0	504.0	153.1	0.04	0.12	0.56
Rainbow	26 May, 2017	23.0	8.33	3.5	83.3	146.8	85.4	0.07	0.33	0.38
Volusia	22 May, 2017	22.3	7.43	3.4	39.3	183.6	23.1	0.10	2.68	1.30

2.3 Chemical Water Quality Parameters

Chemical parameters at Ichetucknee River and Springs have been collected for many studies and can be used as background understanding for other water quality parameters. A portion of these secondary parameters include dissolved oxygen, pH, and specific conductivity. Table 4 summarizes findings for a few studies at Ichetucknee Springs.

The Santa Fe River Basin, which Ichetucknee is part of, is designated in the State's Basin Management Action Plan (BMAP) as impaired for nitrates by exceeding the target level of 0.35 mg/L (FDEP, 2018). The target nitrate limit was set by the State of Florida based on four considerations: laboratory bioassay analysis, a comparison of metabolic rates of aquatic communities, an examination of algae and nutrient conditions in the Florida Springs Report, and an investigation of the relationship between biomass and nitrate concentrations in the Santa Fe River Basin (Hallas & Magley, 2008). Nitrate concentrations more than 0.35 mg/l have been scientifically determined to contribute to algal and macrophytic growth in Ichetucknee, increasing the likelihood of harmful toxins, decreased aesthetics, and recreational access (FDEP, 2018).

Historic nitrate levels in the Santa Fe River system have been approximated at 0.05 mg/L (Maddox, et al., 1992). Nitrate levels increased between 1959 and 2007 from 0.1 mg/L to 0.5 mg/L (Figure 6). According to this data, nitrate levels began to exceed 0.35 mg/L in 1985 and surpassed this limit many times to 2007. Nitrate concentrations in Ichetucknee continue to exceed this threshold at levels around between 0.7 and 0.8 mg/L in the Ichetucknee Headspring and between 0.5 and 0.6 mg/L downstream near the confluence with the Santa Fe River, shown in data collected by USGS between 2016 and Fall 2019 (Figure 7)

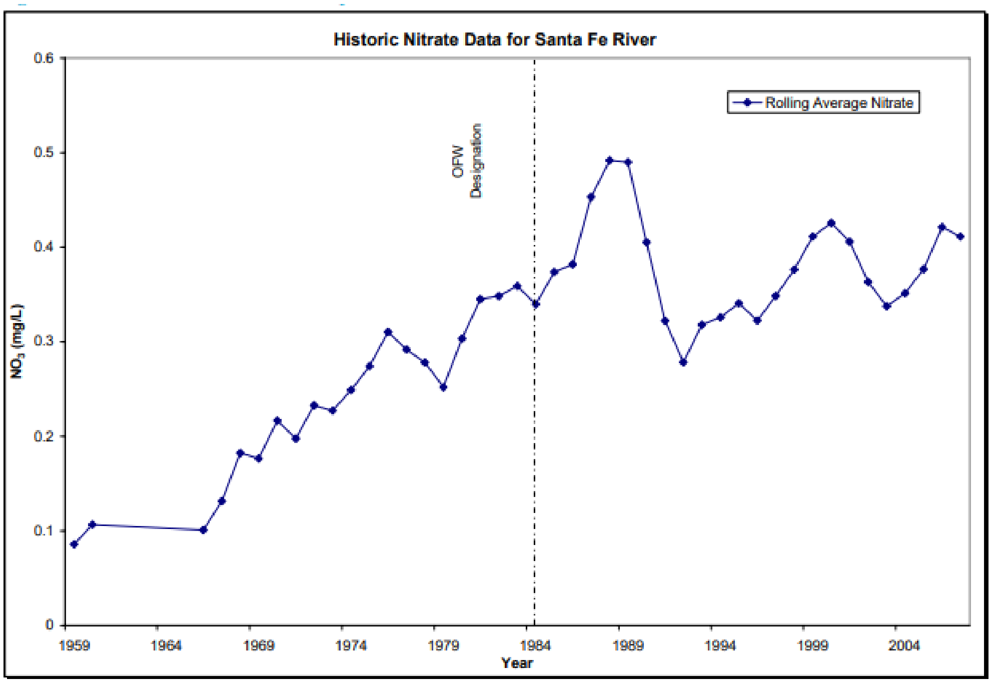


Figure 6: Nitrate levels at the Santa Fe River (of which Ichetucknee is a tributary) have been rising since the 1950's, which even then were above historic levels of 0.05 mg/l. Source- Maddox et al., 1992).

Table 4: Selected water quality parameters of Ichetucknee Springs and River. "Measurements" column represents a single, range of, average (denoted with an asterisk), or median measurement (denoted by a ^) for certain time periods.

Parameter	**Measurements**	**Timeframe**	**References**
Dissolved Oxygen (mg/L)	3.54 - 4.92	Apr 2015 – Sept 2017	Faraji, 2017
	5.36*	Spring 2004	Steigerwalt, 2005
	3.6*	2008 – 2009	WSI, 2010
	3.6- 8.1, 6.4*	2003	Notestein et al, 2004
	3.7-7.4, 5.6*	2004	Notestein et al, 2004
	3.37 – 3.81, 3.445^	2006	Harrington et al, 2010
	2.42	Aug 14, 1997	Katz et al, 1999
pH	7.67	May 2017	Malki et al., 2020
	7.47 – 7.84	Apr 2015 – Sept 2017	Faraji, 2017
	7.48*	2008 - 2009	WSI, 2010
	7.2 - 7.9, 7.65*	2003	Notestein et al, 2004
	7.53 – 7.92, 7.73*	2004	Notestein et al, 2004
	7.3 – 7.6, 7.35^	2006	Harrington et al, 2010
	7.39	Aug 14, 1997	Katz et al, 1999
Spec. Conductivity (mS/cm)	288.5 - 346.8	Apr 2015 – Sept 2017	Faraji, 2017
	0.32*	Spring 2004	Steigerwalt, 2005
	312*	2008 – 2009	WSI, 2010
	309 – 348, 327*	2003	Notestein et al, 2004
	299 – 310, 305*	2004	Notestein et al, 2004
	327 – 340, 334^	2006	Harrington et al, 2010
	262	Aug 14, 1997	Katz et al, 1999
Fecal Coliform (col/mL)	0 - 5, 0^	2006	Harrington et al, 2010

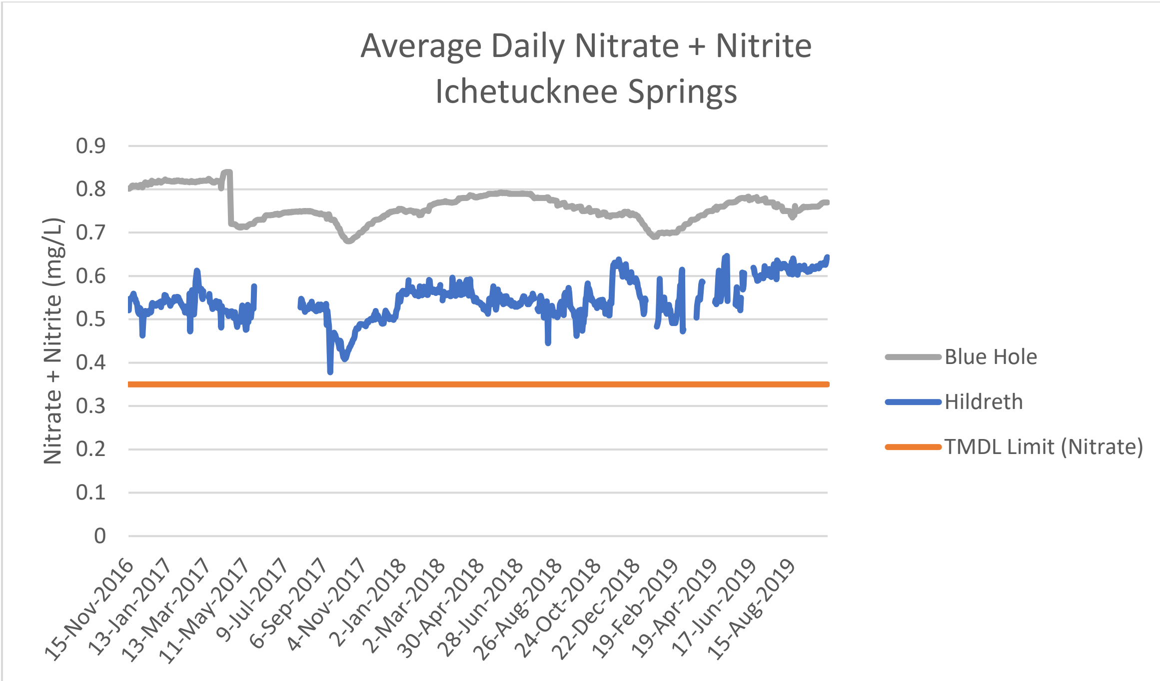


Figure 7: Current USGS data for nitrate + nitrite at Ichetucknee Springs. Average nitrate levels continue to rise and fluctuate. Data source- USGS, 2020.

Many Florida springs are impaired for nitrate, approximately 80% of the state's recorded 1090 springs, or about 870 (FSI, 2018). These springs vary in their level of degradation. Nitrate levels in 130 springs were compared in 2008, including 6 of Ichetucknee's main springs (Figure 8). Ichetucknee Head Spring, Blue Hole, Cedar Hole, Devil's Eye, Mill Pond and Mission measured between 0.4-0.91 mg/L nitrate in 2008, compared to an average of 0.8 mg/L and range 0.004-5.10 mg/L nitrate for the dataset (FSI, 2012). Additionally, Wetland Solutions, Inc. compared the nitrogen composition and abundance of twelve springs in 2010 (WSI, 2010). Nitrate levels in springs across Florida at the time of the study varied from near 0 mg/L nitrate in Silver Glen Springs to well over 3 mg/L in Jackson Blue Springs. Ichetucknee measured at near 0.6 mg/L in this study, again exceeding target health levels (Figure 9). Although excessive nitrates at Ichetucknee Springs have been identified, the variation in nitrate levels observed across the state suggests reductions and increases are possible, highlighting the need for successful nutrient management.

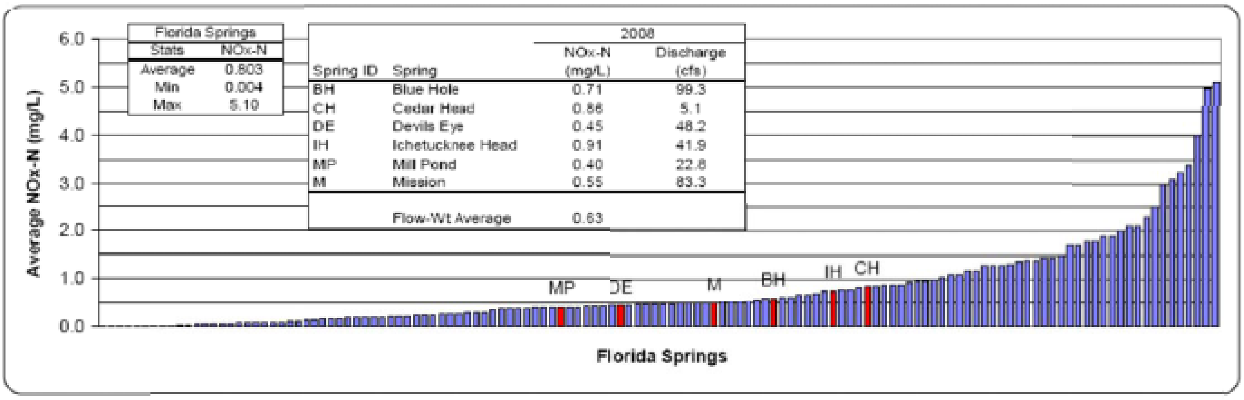


Figure 8: A comparison of average nitrate level of several Florida Springs. (Source- FSI, 2012).

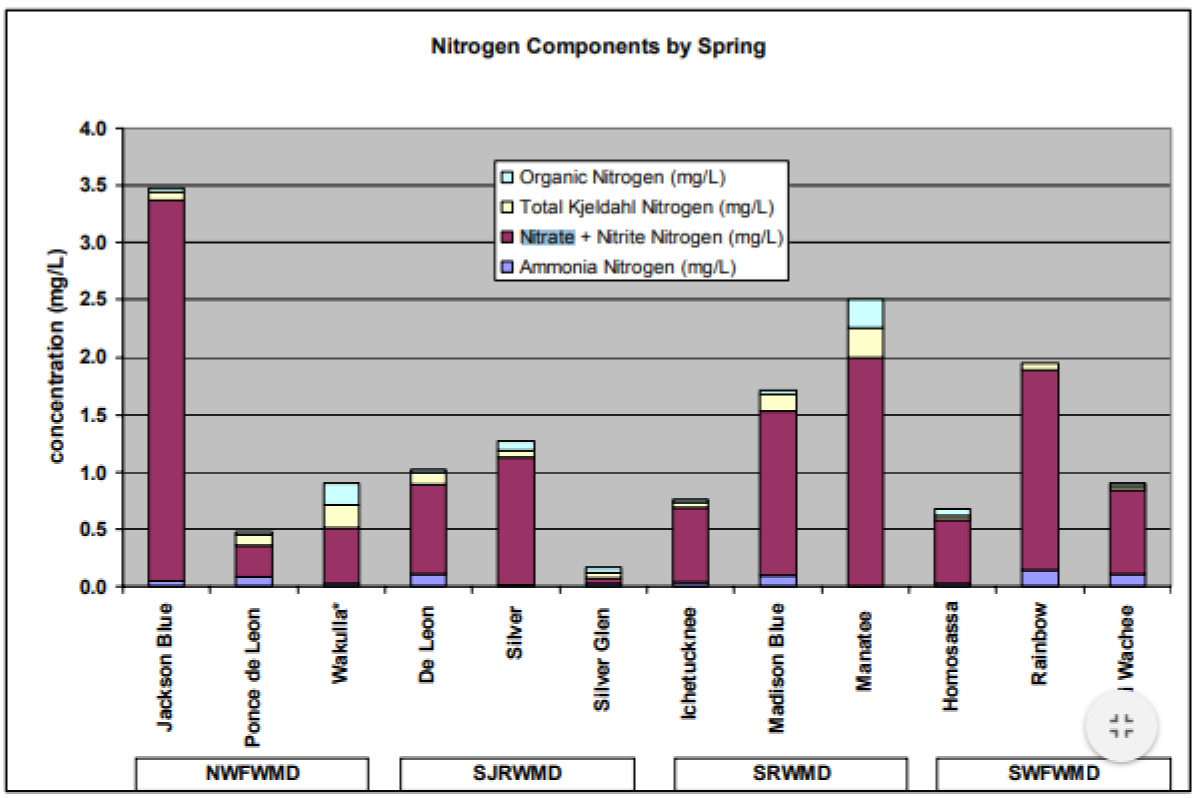


Figure 9: A nitrogen composition and concentration comparison of 12 springs throughout Florida. (Source- WSI, 2010)

Natural and anthropogenic nitrogen sources within Ichetucknee Springshed are diverse and difficult to estimate accurately. These sources include the atmosphere, fertilizers, livestock and animals, secondary effluent treatment (primarily Ichetucknee Sprayfield), and septic systems. Nutrient loads and percentages of each contributing source for the Ichetucknee Springshed and springs have been estimated in literature (Foster, 2008, Katz, 2009, and FSI, 2018) and is summarized in Table 5. Percentages of nitrate sources varied between studies, with the greatest variability found in fertilizers and atmospheric deposition estimations, which range from 19-51% and 8-32%, respectively. All studies agreed that wastewater treatment and septic systems were among the lowest contributions of nitrate.

Methods of creating the nitrogen budgets varied. Foster performed a simple budget, multiplying acreages of landcover type with studied concentrations. Katz combined direct measurements and estimates of nitrogen loading with an N-isotope analysis. Lastly, FSI used FDEP's Nitrogen Source Inventory Loading Tool (NSILT) which incorporates spatial and quantitative data in GIS and excel to estimate loading rates. This model also accounts for variability in transport pathways.

Table 5: A contrast of three nitrogen sourcing studies for Ichetucknee Springs.

<table>
<tr><td></td><td></td><td>Foster</td><td>Katz</td><td>BMAP</td></tr>
<tr><td colspan="2">Year</td><td>2008</td><td>2009</td><td>2018</td></tr>
<tr><td colspan="2">Method</td><td>Simple Budget calculation</td><td>Budget and N-Isotope Analysis</td><td>NSILT Model</td></tr>
<tr><td colspan="2">Springshed Load (lb-N/yr)</td><td>622,998</td><td>267,554 - 1,343,626</td><td>820,549</td></tr>
<tr><td colspan="2">River Load (lb-N/yr)</td><td>184,235</td><td>266,000 +/- 40,000</td><td>308,107</td></tr>
<tr><td colspan="2">% N Reaching Springs</td><td>30%</td><td>10-20%</td><td>38%</td></tr>
<tr><td rowspan="7">N Sources %</td><td>Farm Fertilizer or Crops</td><td>9</td><td rowspan="3">51</td><td>36</td></tr>
<tr><td>Urban Fertilizer</td><td rowspan="2">10</td><td>11</td></tr>
<tr><td>Sports turfgrass Fertilizer</td><td>2</td></tr>
<tr><td>Livestock, Animal Waste and/or Pasture</td><td>35</td><td>27</td><td>20</td></tr>
<tr><td>Atmospheric Deposition</td><td>32</td><td>8</td><td>15</td></tr>
<tr><td>Wastewater treatment</td><td>6</td><td>2</td><td>2</td></tr>
<tr><td>Septic Systems</td><td>8</td><td>12</td><td>14</td></tr>
</table>

3 Water Quality Remediation

Because nitrate is the only water quality parameter identified in the Basin Management Action Plan, water quality improvement at Ichetucknee Springs is focused on nitrate removal and prevention in the springshed. Other physical, biological, and chemical water quality parameters greatly influence spring health but do not currently pose a great threat to water quality. To meet

0.35 mg/L N-NO_3 in Ichetucknee within the imposed goal of 15 years, approximately 200,000 lbs of nitrate will need to be removed annually from source waters (FDEP, 2018).

Nitrate removal already occurs naturally in groundwater via denitrification, where relatively long residence times and low oxygen levels support an ideal environment. Furthermore, once groundwater emerges into spring boils the Ichetucknee River and floodplain further process nitrate via additional denitrification and plant assimilation (Brown et al, 2016). One study showed denitrification rates in Ichetucknee River at 522 mg N/m^2/day and assimilation rates of 83 mg N/m^2/day (FSI, 2012). Figure 7 shows evidence of these processes by the difference in nitrate concentrations between the headspring and downstream near US Highway 27, approximately a 3.2-mile distance. Although spring water is treated via denitrification and assimilation within the channel, nutrient issues still exist in springs where algal mats are more likely present.

Initiatives to reduce Ichetucknee nitrate levels are multi-faceted and originate from several agencies and entities. Efforts are focused on reducing and preventing anthropogenic nitrate sources from entering the system via a variety approaches, a few of which are summarized herein.

3.1 Ichetucknee Springshed Water Quality Improvement Project

The Ichetucknee Springshed Water Quality Improvement Project was completed in 2016 and is designed to provide improved treatment of secondary effluent from the city of Lake City in Columbia County. Secondary effluent was previously treated in spray fields south of Lake City and are now processed through a series of cells in a treatment wetland in the same location (Figure 10). Nitrogen that used to leach into groundwater and into the Ichetucknee system is now treated more completely with microbes and vegetation in the constructed wetlands. The project was initiated as part of the Basin Management Action Plan for Ichetucknee Springs with goals to reduce outgoing total nitrogen (TN) by 84%, decrease total volume of TN to the Ichetucknee system by up to an estimated 20%, and increase groundwater recharge by one million gallons per day (Knight and Keller, 2019).

A monitoring campaign was completed between January 2017 and February 2018 to determine project success. Nitrates and TN were considerably reduced by the treatment wetland. Inflows to the wetland were measured to contain approximately 41,600 pounds of nitrogen for the monitoring period and a concentration of 12.2 mg/L TN. An estimated 30,600 pounds of nitrate was removed, and outgoing TN concentrations reduced to 2.3 mg/L. Final outflow nitrate concentrations were reduced from 1.8 mg/L to 0.02 mg/L, a 90% reduction (Knight and Keller, 2019).

3.2 Septic Tanks

Septic tanks are a source of nitrate in the Ichetucknee Springshed and are considered relatively easily identifiable sources of nitrate pollution. The local community was surveyed in 2008 to determine willingness to spend an additional utility fee to provide a fund for septic upgrades (Foster, 2008). Based on the survey results, 84% of participants stated they supported protecting water quality in Ichetucknee Springs. The average dollar amount each household was willing to pay per month to fund this improvement program was $16.90, providing an estimated $42.4 million over 10 years. With the estimated program cost of $25 million, the proposed increase in funds more than covers the expense.

Figure 10: The Ichetucknee Sprayfield Treatment Wetlands. Secondary effluent flows through the nine cells, treating nitrogen and phosphorus-laden waters, which is ultimately ends in groundwater recharging cells. Source- Knight and Keller, 2019.'

A project called the Ichetucknee Trace Water Quality Improvement Project is being proposed to remove septic tanks in Cannon Creek Sink, a 422-acre area near Lake City (FDEP, 2020). The budget for this project is greater than $2.6 million from state and local sources. This project will expand sewage access to other septic-based subdivisions in Ichetucknee Springshed and result in an immediate reduction in nitrate leaching.

Lastly, the BMAP for Ichetucknee Springshed lists multiple outreach and regulatory efforts to inform the public and septic contractors and increase septic restrictions in certain situations. The BMAP also summarizes plans to remove septic tanks from wetlands near Dampier's Landing at ISSP, reducing the direct impact of effluent to the river and springs (FDEP, 2018).

3.3 Land Acquisition

Land has historically been purchased by local and state agencies to reduce potential impacts to environmentally sensitive areas in Ichetucknee Springshed. A few examples of these purchases include ISSP, Alligator Lake in 1994, which was historically one of the headwaters of the Ichetucknee River, nearly 700 acres of mined land in the springshed, almost 100 acres of land near sinks and swallets, 176 acres in Ichetucknee trace, and a 3000 acre conservation easement (Ichetucknee Alliance). The Department of Environmental Protection, Suwannee River Water Management District, and other state and local agencies also own additional properties within the springshed. Land purchases prevent septic tanks from being installed, fertilizers from being applied on the property, and animal wastes and the nitrates associated with these activities.

3.4 Other Basin initiatives

Other initiatives include numerous trash cleanup events, for example a cleanup organized by the Ichetucknee Alliance in 2000 in Rose Sink. Volunteer groups, like the Springs Watch (2013) and Aquifer Watch (2019), have been organized to monitor and educate the public about water quality awareness in the basin. Additional and future initiatives are identified in the Ichetucknee Springs BMAP.

4 Summary

Ichetucknee Springs is an important resource for the North Florida economy, culture, and environment. Protecting water quality in Ichetucknee Springs is vital to maintaining this valuable resource. Knowledge of contaminant sources, parameter variability, and regulatory thresholds are critical to managing the physical, biological, and chemical water quality. Algae blooms are of special concern as nitrate levels continue to rise in the spring. Nitrate levels have been formally identified as an impairing water quality factor through the TMDL process and are the focus of many water quality efforts.

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