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WATER RESOURCE VALUE MONITORING FOR BLUE SPRING AND BLUE SPRING RUN, VOLUSIA COUNTY, FLORIDA

FINAL REPORT 2009-2020

by

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EXECUTIVE SUMMARY

In 2006 the St. Johns River Water Management District (SJRWMD) adopted a minimum flow for Blue Spring in Volusia County, pursuant to Chapter 373.042, *Florida Statutes*. This was adopted as a "minimum flow regime" (MFR) that required progressive increases in the long-term mean annual flow of the spring over a 25-year period. The MFR is expected to accommodate an increasing population size of Florida manatee that use the spring as a winter warm-water refuge and to restore and maintain the discharge of the spring at a long-term mean of 157 cubic feet/second (cfs).

To determine if relevant Water Resource Values (WRVs) are being protected by the MFR (e.g., protection of fish and wildlife other than manatees, recreation, water quality, etc.), SJRWMD developed and implemented a monitoring program. The monitoring program was developed in partnership with the other agencies that assisted SJRWMD in the development and adoption of the MFR. The monitoring program was structured on a five-year rotating schedule, with one year of intensive monitoring (collecting hydrological, water quality, ecological, and human use data), followed by four years of less intensive data collection (mainly hydrological and water quality).

The first round of intensive monitoring was conducted in 2007–2008 and involved staff with SJRWMD, the Florida Department of Environmental Protection, the Florida Park Service, the Florida Fish and Wildlife Conservation Commission, U.S. Geological Survey, Stetson University, and private consultants. The second round of intensive monitoring was conducted in 2014–2016 and involved some of the same entities. A third round of intensive monitoring was conducted in 2019–2020, but this effort was truncated due to COVID restrictions. This report presents the data collected during the three years of less-intensive monitoring in 2009–2012 and during the intensive monitoring conducted in 2014–2016 and 2019–2020. These more recent results are compared and combined with the results of the first intensive monitoring in 2007–2008.

Discharge (flow) in Blue Spring was higher in 2009–2010, declined in 2011, remained reduced 2012–2016 and flow increased 2016–2020. These changes in spring flow generally mirrored rainfall patterns. Statistical analysis of the flow record for the period 1932–2013 indicated a significant decline in spring discharge over this period.

Blue Spring is characterized by very low dissolved oxygen (DO) concentrations and high concentrations of total dissolved solids (TDS; dissolved salts and minerals). DO concentrations in the spring run were moderately associated with spring discharge. DO was reduced and conductivity was higher during the period of lower spring discharge 2011–2016. Dissolved nitrogen as NOx-N was also reduced during the low-flow period.

The size of the manatee population using Blue Spring and its run during the winter has been increasing exponentially over the past 3–4 decades. Over 700 uniquely identified manatees have been observed using the spring and run as a warm-water refuge between November and March.

Over the past 16 years, the maximum daily count of manatees using the spring run has exceeded original use projections (based on data from 1978–2005). Putative signs of cold exposure have been observed on a substantial proportion of manatees using Blue Spring, but these have nearly all been minor. Cold stress syndrome has rarely been observed on manatees using Blue Spring, in one case involving a rescue (severe cold stress signs developed on this animal prior to its arrival at Blue Spring). To date the flow has been below the adopted MFR but appears to be providing adequate warm-water refuge for the existing and growing manatee population using Blue Spring.

The submerged aquatic vegetation (SAV) community of Blue Spring is dominated by benthic, filamentous algal mats. Blue Spring does not support the dense, extensive beds of submerged macrophytes (rooted, flowering plants) that are frequently seen in other spring-run streams in the St. Johns River basin. This appears to be related to historical impacts not connected with spring discharge or the changes which have occurred in discharge. Current velocity in the spring run itself may help reduce algal abundance by physically sloughing and removing algae. No correlation between algal cover and discharge was seen in the 2014–2019 data. To the extent that the higher mean annual flow target in the adopted MFR will generally be associated with higher current velocities in the spring run, the MFR should not promote proliferation of algal mats.

The benthic macroinvertebrate community of the spring and run has long been known to be depauperate due to the very low DO and elevated TDS concentrations. A moderately diverse community of freshwater snails (most belonging to the family Hydrobiidae) is present in the spring run, mostly consisting of native species (including two endemic snail species found only in Blue Spring), and three introduced exotic species. A significantly more diverse snail community was present in 2014–2015 and 2019–2020 than in 2007–2008. This was mainly due to more detailed taxonomic identifications (sampling effort) in the latter two sampling efforts. Snail abundance was similar between all three time periods, except for a large peak in abundance of immature hydrobiid snails in June 2008. The two most abundant snail taxa were the hydrobiids *Floridobia parva* (one of the endemics) and *Pyrgophorys platyrachis*. Comparison of total snail abundance with mean monthly discharge in the month snail samples were collected yielded a weak but non-significant positive relationship between snail abundance and current velocity.

The overall macroinvertebrate community was assessed using the DEP Stream Condition Index (SCI) methodology. The habitat assessment component of the SCI indicated “optimal” habitat conditions in 2007–2008 and “suboptimal” habitat in 2015–2016 and 2019–2020. SCI scores in all three sampling efforts indicated “impaired” conditions, which has been seen previously in Blue Spring Run and is typical in springs due to low DO. SCI scores in 2015–2016 and 2019–2020 were generally lower than measured in 2007–2008 in the upper and middle reaches of the spring run and were higher than measured in 2007–2008 in the lower reach of the run. There was a significant positive relationship between SCI score and quarterly spring discharge, with a higher SCI score at higher flows, indicating a better-quality macroinvertebrate community. Overall, the adopted MFR should not adversely affect and will be protective of benthic macroinvertebrate communities in the spring run.

The fish community of Blue Spring is characteristic of and similar to the fish community of the adjacent St. Johns River, consisting mostly of centrarchids (sunfish and largemouth bass), cyprinids (minnows and shiners), fundulids (killifish), and poecilids (live bearers). Numerically, poecilids (particularly the Mosquitofish, *Gambusia holbrooki*) were the most abundant group of fish in the spring. This group of fish has morphological and behavioral adaptations that enable them to tolerate low DO. Fish density ($\#/m^2$) was significantly lower in 2019–2020 compared to prior sampling efforts. Fish diversity (Shannon-Weiner Index) was higher during the more recent time period, but this difference was not statistically significant. Overall, total fish density and diversity were significantly higher at higher spring flows (>130 cfs), indicating that the adopted MFR should be protective of the fish community of the spring and run.

Ecosystem metabolism and nutrient assimilation data generally indicate that spring discharge is not a major factor influencing either of these attributes. Primary production in the spring appears to be lower than other spring-run stream ecosystems in the middle St. Johns River mainly due to lack of submerged macrophytes and the exceptionally low DO of the spring. Based on limited data, higher spring discharge appears to be associated with higher nitrate uptake but increased export of phosphorus compounds. The adopted MFR will not impair functional ecosystem characteristics such as primary productivity and nutrient uptake.

There were weak but positive relationships between spring discharge and DO concentrations, statistically significant negative relationships between discharge and basic dissolved constituents such as TDS and calcium, and statistically positive relationships between discharge and NOx-N concentrations. The adopted MFR will not adversely affect DO concentrations in the spring and run (which are naturally low) and will maintain basic dissolved constituent concentrations at historic levels. Management of NOx-N concentrations in the spring discharge are a function of decreasing landscape nitrogen loading in the springshed and cannot be managed by adjusting spring discharge via the MFL process.

Daily visitor attendance at Blue Spring State Park continues to be high and has not changed substantially in recent years. Surveys of visitor perceptions conducted in 2008 and again in 2013 indicated that the public values spring flow and is supportive of efforts to protect/maintain historical mean annual flows in Blue Spring.

The data collected in the Blue Spring MFR monitoring to date (2007–2020) indicate that the adopted MFR is protective of all relevant Water Resource Values, in addition to providing adequate winter warm-water refuge for the population of Florida manatee using the spring and run.

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INTRODUCTION

BACKGROUND

The St. Johns River Water Management District (SJRWMD), pursuant to its statutory responsibilities, in 2006 approved a minimum flow regime for Blue Spring and Blue Spring Run, Volusia County, Florida (Figures 1 and 2) that increases minimum flows incrementally over time. The first increment allowed a minimum long-term mean annual spring flow of 133 cubic feet per second (cfs), which is less than the current long-term mean flow of 157 cfs, until March 31, 2009. This minimum long-term mean flow would be raised during each of four subsequent five-year intervals to the following:

- 133 cfs (from Dec. 3, 2006, through March 31, 2009)
- 137 cfs (from April 1, 2009, through March 31, 2014)
- 142 cfs (from April 1, 2014, through March 31, 2019)
- 148 cfs (from April 1, 2019, through March 31, 2024)
- 157 cfs (after March 31, 2024)

Under the approved rule, after March 31, 2024, the minimum long-term mean annual flow of the spring run is required to be 157 cfs.

The Blue Spring minimum flow regime (Blue Spring MFR) is based on protection of the existing and projected future population of Florida manatees (*Trichechus manatus latirostris*) that use Blue Spring as a winter warm-water refuge. The Blue Spring MFR is also expected to protect other relevant water resource values (WRVs) listed in Section 62-40.473, Florida Administrative Code (F.A.C.). These WRVs include: recreation in and on the water; fish and wildlife habitats and passage of fish; estuarine resources; transfer of detrital material; maintenance of freshwater storage and supply; aesthetic and scenic attributes; filtration and absorption of nutrients and pollutants; sediment loads; water quality; and navigation.

To develop the minimum flow regime, SJRWMD formed the Blue Spring Minimum Flow Interagency Working Group (Blue Spring MFIWG). Consisting of experts from various participating organizations, including the Florida Department of Environmental Protection (DEP) and the Florida Fish and Wildlife Conservation Commission (FWC), the Blue Spring MFIWG assisted SJRWMD in the formulation of the Blue Spring MFR. The U.S. Fish and Wildlife Service (USFWS) and Save the Manatee Club, Inc. (SMC), also participated in the Blue Spring MFIWG, primarily in reviewing and commenting on draft recommendations.

SJRWMD received numerous comments from individuals and other agencies regarding implementation of the Blue Spring MFR. A recurring comment was, given the phased structure of the rule, that SJRWMD may not be able to ensure that the required flows will actually be achieved by the dates established. Stakeholders were also concerned that relevant WRVs not

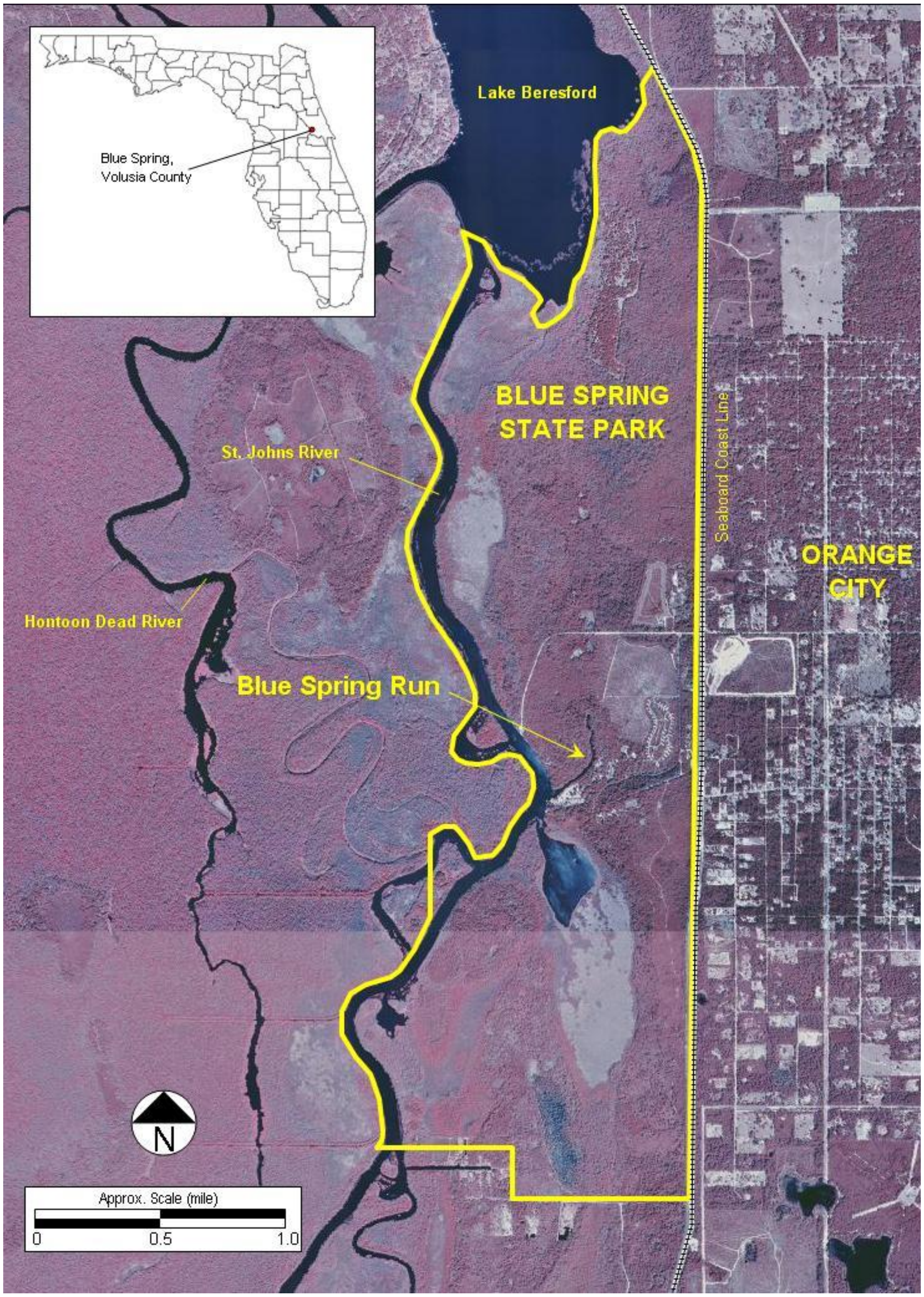


Figure 1. Location map of Blue Spring State Park and Blue Spring Run, Volusia County, Florida (USGS aerial photo).

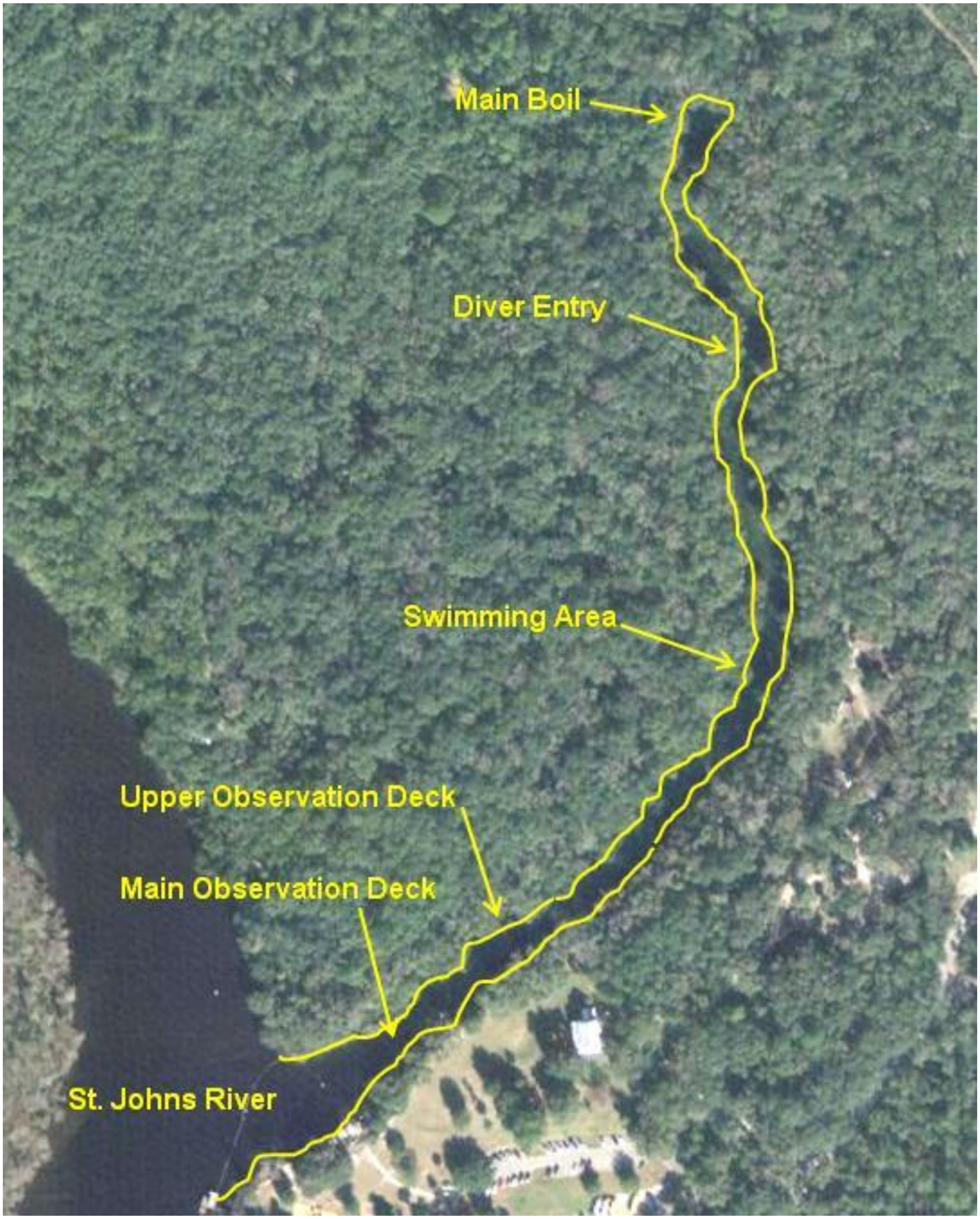


Figure 2. Aerial photo map of Blue Spring Run illustrating the principal geographic/public use features. This is an older map, and the diver entry has been moved up to near the headspring.

related to manatee protection may not be protected. To address these concerns, the SJRWMD Governing Board authorized SJRWMD staff to develop the comprehensive Volusia Blue Spring Minimum Flow Regime Action Plan (“Action Plan”) in September 2006. The Action Plan directs the implementation of a multifaceted approach by SJRWMD staff to ensure, to the extent possible, that the increasing minimum flows required by the Blue Spring MFR will be met in the future and that relevant WRVs in addition to manatee protection are being addressed.

The Action Plan was designed to adaptively manage implementation of the Blue Spring MFR. Monitoring is an integral part of the implementation process, providing an array of data needed to reduce uncertainties and to allow for modification of the Action Plan as needed to ensure that the Blue Spring MFR protects the natural resources and ecology of the spring. The Action Plan directed that a detailed Monitoring Plan be developed that includes the physical, chemical, and ecological monitoring and data analysis required for the periodic evaluation of the WRVs pertinent to the Blue Spring MFR. The Monitoring Plan was developed in partnership with DEP and FWC to cooperatively develop, fund, and implement the Monitoring Plan work elements. Continuing oversight was provided by representatives of the Blue Spring MFIWG, the U.S. Geological Survey (USGS), and the USFWS. The basic structure of the monitoring plan is a 5-year rotating schedule that includes one year of intensive monitoring (including hydrology, water quality, aquatic ecology, and human use/perception), followed by four years of less-intensive monitoring focusing on hydrology/water quality characteristics.

The first intensive monitoring effort was conducted in 2007–2008 and the data from that effort were summarized in Wetland Solutions, Inc. (2009). Relevant findings from that effort were:

- Water quality was linked to spring discharge, with higher concentrations of dissolved salts and minerals occurring at lower flows, possibly reflecting a greater relative fraction of “older” deeper groundwater contribution to spring flow. Nitrate concentrations were significantly lower at lower spring flows and higher at higher flows.
- The submerged plant community was dominated by benthic and filamentous algae. Algal abundance, measured as mat thickness, was higher in the upper and middle portions of the spring run.
- The benthic macroinvertebrate community was overall depauperate, mainly due to very low DO levels in the spring discharge and high dissolved solids content. As indicated by the Stream Condition Index (SCI), a higher-quality invertebrate community was present at higher spring flows.
- A moderately diverse community of gastropods (snails) is present in the spring and run.
- The spring run supported a moderately diverse fish and turtle community.
- Spring ecosystem primary productivity is strongly related to solar input and appears to be lower than in other spring systems in the region and state, probably due to the exceptionally low DO in the spring discharge and lack of submerged macrophyte beds.
- Manatee use of the spring run as a winter warm-water refuge continues to increase.

PROJECT OBJECTIVES AND MONITORING PLAN

The overall objective of the Blue Spring WRVs monitoring is to measure and evaluate the hydrological, water quality, and ecological characteristics of the spring and its run relative to the specific, relevant environmental values identified in the Florida Water Resources Implementation Rule (Chapter 62-40.473 (1), F.A.C.), applicable to Blue Spring, including:

- Recreation in and on the water
- Fish and wildlife habitats and the passage of fish
- Transfer of detrital material
- Aesthetic and scenic attributes
- Filtration and absorption of nutrients and other pollutants
- Sediment transport
- Water quality

The WRVs estuarine resources, freshwater storage and supply, and navigation were considered not relevant to the Blue Spring MFR. Components of the WRV monitoring effort are summarized in Table 1. Members of the Blue Spring MFIWG and consultants cooperatively developed the Monitoring Plan components.

Table 1. Monitoring plan components and developmental and implementing team members.

Monitoring Category	Team Members
Physical and chemical conditions monitoring • Hydrological and meteorological • Water quality	SJRWMD, USGS
Manatee population and behavior monitoring	FWC, DEP/Blue Spring State Park
Water resource value monitoring • General biological structure • Ecological functions • Human uses	SJRWMD, Stetson University, Wetland Solutions, Inc., DEP/Blue Spring State Park

This report summarizes the results of the Blue Spring MFR monitoring conducted 2009–2020. It includes data collected during years of less-intensive monitoring (2009–2013 and 2017–2018), data from the second round of intensive monitoring, collected 2014–2016, and data from the third round of intensive monitoring in 2019–2020. These data are compared to the first intensive monitoring effort in 2007–2008.

METHODS

STUDY SITE DESCRIPTION

Blue Spring is located in Volusia County, west of the town of Orange City, at Latitude 29^0 56' 51.0" N; Longitude 81^0 20' 22.5" W, in Section 8/Township 18 S/Range 30 E. The head spring is a circular pool about 32 m (105 feet) in diameter east-to-west (Scott et al. 2002; Figure 3). Depth over the main vent is about 6 m (20 feet). The spring feeds Blue Spring Run, which runs 670 m (2,198 ft) in a south/southwest direction into the St. Johns River upstream of Lake Beresford (Figure 1). The spring and run are entirely encompassed by Blue Spring State Park, operated and managed by the Florida Park Service, DEP.

Carbonate outcrops of the Hawthorn group are exposed at the headspring and main spring vent. Carbonate outcrops are also found along the length of the upper spring run, which also has extensive areas of sandy or sandy mud bottom (Scott et al. 2002). The bottom profile of the spring run was surveyed in 2007 by SJRWMD survey personnel; from these data, the approximate wetted surface area of the spring and its run is 4.1 acres (1.7 ha).

Figure 3. Volusia Blue Spring headspring pool in February 2008.

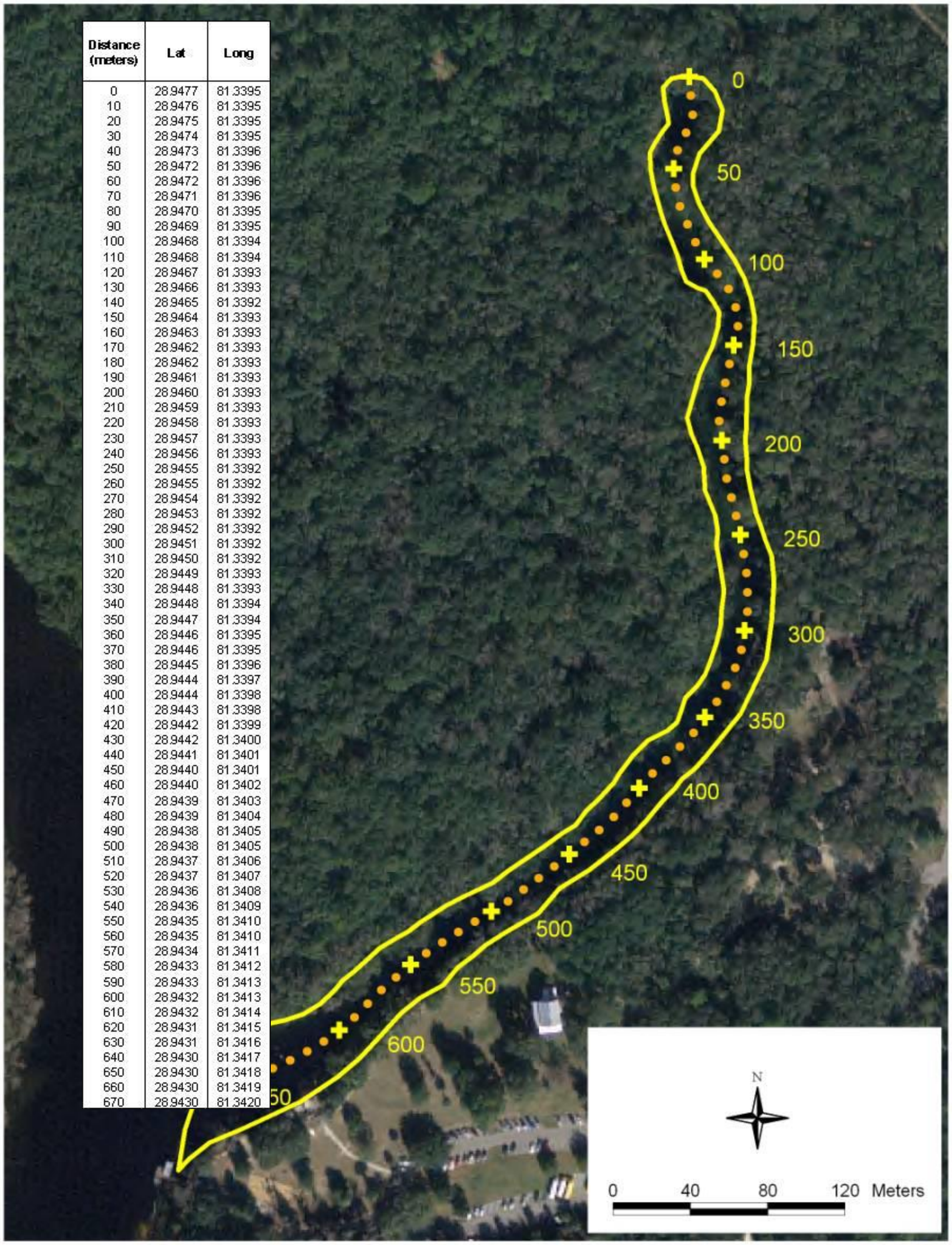
Blue Spring is one of four first magnitude springs or spring groups found in the St. Johns River basin. These are defined as springs exhibiting a mean annual discharge or flow of >100 cfs according to the system proposed by Meinzer in the 1920s. Mean annual flow of Blue Spring is 157 cfs based on the period-of-record of flow data collected by the USGS from 1932–2006 (Osburn 2011; NewFields 2007).

Water quality in Blue Spring is characterized by very low levels of DO and high concentrations of total dissolved solids (TDS). Odum (1957) described Blue Spring as an “anaerobic spring” because of the very low DO he measured (0.25 mg/L). In the more distant past, the spring had high levels of hydrogen sulfide based on the noticeable odor; the English naturalist William Bartram visited the spring in 1774 and described it as “smelling like bilge-water”, as did his father John Bartram when he visited the spring in 1766. Current median DO in the spring, based on data collected 2009–2013, is 0.36 mg/L (Di and Mattson, unpublished report). Woodruff (1993) classified Blue Spring as a “salt spring” based on the high TDS concentrations, and Slack and Rosenau (1979) similarly described the spring as a “sodium chloride” water quality type. Based on recent data (2009–2013), the spring has a median conductivity of 1,680 µmhos/cm and median TDS of 945 mg/L (Di and Mattson, unpublished report).

Sampling Locations

A standardized spring run sampling location system was established (Figure 4) to facilitate the locating of sampling stations and the organization and collection of data as part of the Blue Spring WRV monitoring effort.

Each of the monitoring components is briefly described in the following sections and summarized in Table 2. The descriptions of each monitoring component include sampling methods, sampling stations, sampling frequency, responsible parties, and database management. All monitoring methods conformed to the following standard operating procedures (SOP) to the extent possible: the USGS streamflow-gaging protocols, *Surface Water Quality-Assurance Plan for the Altamonte Springs Office of the Florida Integrated Science Center of the U.S. Geological Survey* (Shelton 2005); *USGS National Field Manual for the Collection of Water-Quality Data* (http://water.usgs.gov/owq/FieldManual/index.html#Citation); *Quality-Assurance Plan for Water-Quality Activities in the USGS Florida Integrated Science Center, Orlando, Florida Office* (Kroening 2003); and *DEP’s Standard Operating Procedures Manual* (http://www.dep.state.fl.us/labs/qa/sops.htm). USGS follows US Department of Commerce, National Oceanic and Atmospheric Administration SOP for meteorological data collection (http://www.ofcm.gov/siting/text/a-cover.htm). New or innovative methods that are not included in the USGS or DEP’s SOP manuals are included in Table 2 as “Provisional” and were described in the 2013 Blue Spring Monitoring Work Plan (SJRWMD 2012).



Distance (meters)	Lat	Long
0	28.9477	81.3395
10	28.9476	81.3395
20	28.9475	81.3395
30	28.9474	81.3395
40	28.9473	81.3396
50	28.9472	81.3396
60	28.9472	81.3396
70	28.9471	81.3396
80	28.9470	81.3395
90	28.9469	81.3395
100	28.9468	81.3394
110	28.9468	81.3394
120	28.9467	81.3393
130	28.9466	81.3393
140	28.9465	81.3392
150	28.9464	81.3393
160	28.9463	81.3393
170	28.9462	81.3393
180	28.9462	81.3393
190	28.9461	81.3393
200	28.9460	81.3393
210	28.9459	81.3393
220	28.9458	81.3393
230	28.9457	81.3393
240	28.9456	81.3393
250	28.9455	81.3392
260	28.9455	81.3392
270	28.9454	81.3392
280	28.9453	81.3392
290	28.9452	81.3392
300	28.9451	81.3392
310	28.9450	81.3392
320	28.9449	81.3393
330	28.9448	81.3393
340	28.9448	81.3394
350	28.9447	81.3394
360	28.9446	81.3395
370	28.9446	81.3395
380	28.9445	81.3396
390	28.9444	81.3397
400	28.9444	81.3398
410	28.9443	81.3398
420	28.9442	81.3399
430	28.9442	81.3400
440	28.9441	81.3401
450	28.9440	81.3401
460	28.9440	81.3402
470	28.9439	81.3403
480	28.9439	81.3404
490	28.9438	81.3405
500	28.9438	81.3405
510	28.9437	81.3406
520	28.9437	81.3407
530	28.9436	81.3408
540	28.9436	81.3409
550	28.9435	81.3410
560	28.9435	81.3410
570	28.9434	81.3411
580	28.9433	81.3412
590	28.9433	81.3413
600	28.9432	81.3413
610	28.9432	81.3414
620	28.9431	81.3415
630	28.9431	81.3416
640	28.9430	81.3417
650	28.9430	81.3418
660	28.9430	81.3419
670	28.9430	81.3420

Figure 4. Blue Spring Run standardized sampling station location map. Stations with corresponding latitude and longitude coordinates are marked at 10-m intervals. Sampling stations are designated by the following example abbreviation – VBS220 (i.e., Volusia Blue Spring – 220 m Station).

Table 2. Summary of Volusia Blue Spring monitoring plan components for 2009–2020.

Parameter Group	Subcategory	SOP	Sampling Locations	Frequency	Description
Physical and Chemical Conditions Monitoring					
Hydrological and Meteorological	Spring discharge	USGS	VBS 520-330	Hourly and Monthly	Monthly and daily spring discharges and daily spring stage
	Weather data		Near spring location	Hourly	From closest NWS site; supplemented by SJRWMD data (e.g., Doppler rainfall)
Water Quality	Field Meters	DEP FT1000, 1100, 1200, 1400, 1500, 1700; USGS (Kroenig 2003); SJRWMD SOP	VBS 35, 330, 570	SJRWMD-Monthly at 330 (swim area) USGS-quarterly at 10 (headspring), 330 (swim area) and 570 (upper observation deck) during intensive years (1 year in 5)	SJRWMD/USGS: Water temperature, pH, specific conductance, conductivity, dissolved oxygen, light penetration
	Analytical parameters (lab)	DEP FT1000, 1100, 1200, 1400, 1500, 1700; USGS (Kroenig 2003); SJRWMD SOP	VBS 35,330, 570	SJRWMD-Monthly at 330 (swim area) USGS-quarterly at 10 (headspring), 330 (swim area) and 570 (upper observation deck) during intensive years (1 year in 5)	Basic: SJRWMD (color, turbidity, alkalinity, Cl, SO4, Si-T, SiO2-D, TDS, TSS); USGS (alkalinity, SO4, Si) N species: SJRWMD (TKN-T, TKN-D, NOx-D, NH4-D); USGS (NOx, NH4, TKN) P species: SJRWMD (TP-T, TP-D, PO4-D); USGS (TP-D, TP-T, PO4) Organic: SJRWMD (TOC, DOC, Chlorophyll a) Metals (all-T): SJRWMD (Ag, Al, As, Ba, Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Se, Sr, Zn) Major ions: SJRWMD (Ca, K, Mg, Na); USGS (Ca, Mg, Na)
Manatee Population and Behavior Monitoring					
Manatee population	Manatee biology	Provisional	Entire spring run	Daily, November-March	Monitor individual manatee occurrence and provide maximum one-day count
Manatee condition	Manatee biology	FWC protocols	Entire spring run	Daily, November-March	Assess and record body condition and overt cold stress ischemic skin lesions to document level of cold stress being experienced by the animals

Table 2. Continued. Summary of Volusia Blue Spring monitoring plan components for 2009–2020.

Parameter Group	Subcategory	SOP	Sampling Locations	Frequency	Description
Ecological Monitoring					
General Biological Structure	Periphyton/algae	Provisional	5 transect locations	Quarterly 1 year in 5	Total algal percent cover and field identification of dominant taxa in algal mats
	Aquatic plants	Provisional	5 transect locations	Quarterly 1 year in 5	Percent cover by species
	Macroinvertebrates-entire community	DEP (FT3000)	Three 100 m reaches	Quarterly 1 year in 5	Stream Condition Index assessment
	Macroinvertebrates-gastropods	Provisional	Three 100 m reaches	Quarterly 1 year in 5	Quantitative sampling for density (by species or LPTL) and diversity
	Fish	Provisional	5 reach locations	Monthly 1 year in 5	Species population counts and diversity
Ecosystem Function	Ecosystem metabolism	Provisional	2 reach locations	Bimonthly 2009-2012	Gross and net primary productivity, community respiration, P/R ration, ecological efficiency
	Nutrient assimilation	Provisional	2 reach locations	Monthly	Net changes of mass loads of N and P
Human Use	Total human use	Provisional	Park Entrance	Daily	Human-use days in park and spring run

PHYSICAL AND CHEMICAL CONDITIONS MONITORING

The Blue Spring ecosystem is an expression of the physical and chemical environment it occupies. That physical environment includes air and water temperatures, precipitation rates, sunlight inputs, spring run channel morphology and substratum, and groundwater and surface water inflow quantity and quality.

The monitoring of selective environmental variables also provides SJRWMD with data required for the development/refinement, calibration, and verification of predictive mechanistic and statistical models, such as the Blue Spring Environmental Fluid Dynamic Code (EFDC) hydrodynamic model, steady state regional groundwater flow models, transient groundwater flow models, and predictive relationships between flows and various WRVs.

Meteorological and Hydrological Monitoring

Monitoring of weather conditions (daily rainfall and minimum air temperature) was conducted using data downloaded from the National Weather Service DeLand station.

Spring discharge is measured at the long-term USGS gauge “Blue Spring near Orange City” (USGS# 0223550). The gauge is located about 300 m downstream of the headspring, near the swimming area at Station 330 (Figure 4). Supplemental discharge measurements are periodically made by USGS personnel at locations downstream of the gauge. Monthly manual discharge measurements have been collected by the USGS since 1932. Continuous flow measurements have been made by the USGS since 1998 with acoustic velocity meters. USGS monitoring followed standard operating procedures (SOP) to ensure data quality assurance (Shelton 2005). Trends in long-term discharge of Blue Spring were evaluated by Di and Mattson (unpublished report) using the non-parametric Spearman’s correlation to compare discharge with time.

Water Quality Monitoring

SJRWMD currently samples water quality monthly at one permanent station in Blue Spring Run (approximately at VBS 30), at the diver entrance dock, which is now located just downstream of the headspring pool, Station Name BLSP-dock. Previously there was a long-term monitoring site (BLSPR) at VBS330 near the swimming area. This was discontinued in 2016. District water quality measures included field (water temperature, conductivity, pH, and DO), basic (color, alkalinity, turbidity, total silica, dissolved silicon, sulfate, chloride, total dissolved solids, total suspended solids), nitrogen and phosphorus species (NO_x-D, TKN-T, TKN-D, NH_4-D, TP-D, TP-T, PO_4-D), major ions (calcium, magnesium, potassium, sodium), and metals (silver, aluminum, arsenic, barium, cadmium, chromium, copper, iron, manganese, molybdenum, nickel, lead, selenium, strontium and zinc). All field measurements are made with field instruments calibrated using SJRWMD and DEP SOPs. Laboratory analyses are conducted in the SJRWMD laboratory using methods approved by the DEP and/or USEPA.

The USGS operated a continuous monitoring station for field parameters (specific conductance, DO, and water temperature) at the location of its flow gauging station between 2007-2013. In 2014 this USGS station was discontinued and SJRWMD installed its own continuous water quality monitoring equipment, consisting of a YSI EXO multi-parameter probe measuring specific conductance, DO, water temperature, turbidity and pH, a SUNA optical sensor monitoring nitrate, and a Cycle PO_4 monitoring orthophosphate. Water quality measurements at the continuous stations were taken at hourly or 15-minute intervals and supplemented with monthly grab sampling at the site CM-BLSPR adjacent to the sensor probes. This site was discontinued in 2018.

The ongoing SJRWMD water quality monitoring was supplemented in 2007–2013 by adding two additional quarterly stations near the spring vent (VBS 35) and downstream at the upper observation deck (VBS 570). Samples were collected by the USGS and analyzed in their laboratory using USGS-approved methods. These grab samples were analyzed for the following parameters: Field (water temperature, pH, specific conductance, conductivity, dissolved oxygen, light penetration), basic (alkalinity, sulfate, silica, and chloride), nitrogen and phosphorus species (TKN, NO_x, NH_4, TP-D, PO_4), and major ions (calcium, magnesium, sodium). Analyses were conducted according to USGS and DEP SOPs (Kroening 2003; and http://www.dep.state.fl.us/labs/qa/sops.htm).

Water quality data were statistically analyzed for temporal trends using the non-parametric Seasonal Kendall test (Di and Mattson unpublished report). Water quality concentrations were compared to discharge using multiple regression (J. Di, SJRWMD, unpublished data).

Manatee Monitoring

The Blue Spring MFR was established to accommodate the projected increase in the number of manatees using Blue Spring and Blue Spring Run as a winter warm-water refuge, based on data collected between 1978-2005. The data analysis used to establish the MFR centered on estimates of (1) projected growth in manatee usage of Blue Spring and its run, and (2) the maximum manatee carrying capacity of the spring and spring run to provide manatees with thermal refuge during the winter to avoid death and debilitating effects due to cold stress. Upon implementation of the Blue Spring MFR, assessments of the status and trajectory of the manatee population and management of spring flows rely on the same metrics used to establish the MFR (i.e., maximum daily manatee counts and manatee packing densities). Manatee population monitoring is required to provide SJRWMD with data to determine if actual manatee use or manatee carrying capacity have deviated from the original projections, and to identify any signs of negative ecological impacts to manatees.

Manatee Population Monitoring

Since 1978, rangers at Blue Spring State Park have conducted daily counts of manatees using the spring run during the winter cold season (typically November-March each year). Over the years, the methodology has been adjusted as needed, but the monitoring protocols have always been peer-reviewed and approved by manatee biologists with the FWC, the USFWS, and the Save the Manatee Club. For most of this time, counts have largely been conducted by Wayne Hartley, a long-serving ranger at Blue Springs Park. He is now retired but continues to help the park staff conduct the daily counts, often still conducting the counts himself, as an employee of the Save the Manatee Club.

Manatee counts are currently conducted 3-5 days per week between November-March, usually in the morning after sunrise, between 8-10 a.m. Afternoon counts have been made in the past and continue to occasionally be made. Counts begin at the mouth of the spring run and proceed upstream to the headspring using a canoe. Formerly, water temperature was measured in the river, but more recently river temperature was obtained from the USGS continuous water quality sensor at the gauge St. Johns River near Sanford (USGS# 02234500), which matched measurements taken about the same time each day. During the counts, individual manatees are identified by distinctive marks (e.g., boat scars, fluke mutilations, etc.). Count data include location of the animals in the run. Two types of manatee counts are reported here. The “total count” is the total number of uniquely identified individual manatees sighted during the entire November-March season. The “maximum daily count” is the highest single-day count during the entire November-March season.

Manatee Condition Monitoring

The Blue Spring MFR defines “significant harm” (per Chapter 373.042, F.S.) as “the death of one manatee attributable to the reduction of flow of Blue Spring as a result of human activity.” Death due to cold stress is the mortality factor of concern here, so implementation of a program to monitor sub-lethal cold stress in the manatees using Blue Spring in the winter was determined to be necessary. Since 2009, biologists with the FWC Fish and Wildlife Research Institute (FWRI), Blue Spring State Park, and volunteers have assessed the condition of manatees using the spring run to evaluate cold stress, disease, and other health factors. Manatees were scored for the presence and severity of putative cold-related skin bleaching, lesions, sloughing, or abscesses on their head, trunk and tail.

The stages, criteria, and descriptions of apparent cold exposure signs are described in detail in a document developed by an interagency team of manatee biologists in 2009 (de Wit et al. 2009). The head, trunk, and fluke were scored separately on a four-point scale to rank the severity of putative cold exposure signs on the skin, as follows:

- 0 = None. No cold-induced signs observed
- 1 = Slight. May include whitening or bleaching of skin on extremities (head, flippers, or fluke margin); or scattered, small lesions anywhere on the body
- 2 = Moderate. Widespread small blisters/ulcers (cold-induced lesions); or fewer large lesions; or abscesses (bulges filled with pus)
- 3 = Severe. Extensive areas of open, cold-induced lesions; extensive sloughing of epidermis; or open (blown-out) abscesses
- U = Unknown. Body part not seen or insufficient observation

Two different approaches to monitoring manatee cold stress signs at Blue Spring have been implemented during the period covered by this report. During the first five winters (2009–2010 through 2013–2014) manatees were mostly surveyed by canoe, approximately monthly from December to February (and one March survey) during cold weather (when large numbers of animals were aggregated in the spring run) to assess the presence, type, and severity of cold exposure signs on manatee skin. A volunteer with Americorps (trained by Monica Ross, Sea to Shore Alliance) conducted surveys from 2009–2010 to 2010–2011. FWC staff conducted the surveys from 2010–2011 to 2013–14. For consistency in assessments, all FWC data were collected by a single observer, Rachel Cimino (trained by Chip Deutsch, FWC). A detailed monitoring protocol is provided in Cimino and Deutsch (2014). Analyses included FWC data, except those from winter 2010–2011 because they were not collected with comparable methods (i.e., shore-based instead of from canoe).

After evaluation of the above results and considering staff resources and challenges involved in consistent data collection and interpretation of findings, FWRI staff concluded that an alternative monitoring protocol should be instituted. Starting in winter 2014–2015, FWC evaluated dead and rescued animals instead of assessing all of the animals using Blue Spring Run (de Wit and Deutsch 2015). As part of FWC's existing carcass salvage, necropsy, and rescue programs, all dead and rescued manatees found between 1 December and 30 April near Volusia Blue Spring were examined for signs of cold exposure or stress. The geographic area subject to this analysis encompasses the St. Johns River main stem, lakes, and tributaries between the Lake George entrance on the north and Lake Monroe on the south (including Lake Monroe itself). This reach of the St. Johns River is regarded as the area most likely to be used by manatees making foraging trips outside of Blue Spring Run. In addition to basic biological information (sex, length, potential cause of death or rescue, etc.), an examination of the carcass or rescued animal is made for external signs of exposure to cold and, for carcasses, internal findings of cold stress disease.

WATER RESOURCE VALUES MONITORING

This component of the MFR monitoring involves collection of data related to non-manatee WRVs in Blue Spring and run. Three types of data were collected: general biological structure (algae and aquatic macrophyte cover, snail populations, macroinvertebrate community condition, and fish populations), ecosystem function (gross and net primary productivity, community respiration, and nutrient assimilation), and human use monitoring and perceptions (daily counts of use types, visitor perceptions, etc.). Methods described here are adapted from Work and Gibbs (2015; 2020) and Wetland Solutions, Inc. (2009; 2010; 2011; and 2012).

General Biological Structure

Algae and Aquatic Plants. Abundance of filamentous algae and aquatic plants (collectively, submerged aquatic vegetation, SAV) was measured as percent cover, using the Braun-Blanquet scale. This is an ordinal scale which categorizes plant cover into five classes:

1 – Less than 5% cover

2 – 5-25% cover
3 – 25-50% cover
4 – 50-75% cover
5 – 75-100% cover

A score of "0" was recorded for bare bottom (no plant cover at all). Cover was measured using a 0.25 m^2 quadrat (0.5 m x 0.5 m). Algal cover was measured collectively (all algae) and the dominant algal species present in the mat was field-determined, along with a visual estimate of the relative amount of live and senescent algae. Aquatic macrophyte cover was determined by species.

SAV cover was assessed at five transects, each one located within the five reaches where fish populations were monitored (see below). Five replicate quadrats, evenly spaced across the transect from bank-to-bank were measured at each vegetation transect. Algae and aquatic macrophyte cover were measured by Stetson University researchers on an approximately quarterly schedule from September 2014 to August 2015. In 2017, Blue Spring was added to the list of spring runs monitored annually for SAV by SJRWMD; monitoring was conducted in May 2017, 2018, and 2019. The park was closed due to the COVID outbreak in 2020, so no monitoring was conducted that year. Additional monitoring was conducted by Stetson University in June and October 2019 as part of the third round of intensive monitoring, but again, had to be curtailed in 2020 due to COVID closure. It should be noted that the park closes the spring run to human use (including by investigators) between November and March while manatees are using the run as a warm-water refuge, so no data were collected from December-February.

Algal cover data collected by Stetson University were statistically evaluated among sampling sites and dates using ANOVA on untransformed data. Algae cover was compared to water quality data using Pearson correlation on untransformed data. Aquatic macrophytes were only present in trace amounts, so those data were not analyzed.

Snail Populations. Aquatic snail populations were sampled in 2014–2015 and 2019–2020 by Stetson University using the same methods and at the same locations used by the DEP in 2007–2008 (Wetland Solutions Inc. 2009). Three 100 m reaches were sampled: upper (VBS 50-150), middle (VBS 250-350) and lower (VBS 450-550). Within each of these 100 m reaches 11 transects were established at 10 m intervals. Nine points were established on each transect; one point located 0.1 m from the left and right banks of the spring run (total of 2 points), one in the middle of the transect, and the remaining six points located equally between these three. One point was randomly selected on each transect and sampled with a 15 x 15 cm quadrat and a small dip net to collect snails. Samples collected from all 11 transects in a reach were composited into a single sample for that reach, so a sample represented the upper, middle, or lower reaches where and when it was collected. Samples were preserved in 95% alcohol and returned to the laboratory for processing. All snails collected were sorted from the samples, identified to lowest practical taxonomic level (species whenever possible), and enumerated. Snail collections were made in September and November 2014 and March, May, and August 2015, although the lower reach was not sampled in September 2014 and August 2015 due to high river stage. Snail collections were again made in June and October 2019 and May 2020; again, collections were truncated due to closure of the park due to COVID. Collections were made at the upper and middle reaches in 2019-2020 due to high water and inability to adequately sample the lower reach.

Snail population taxa richness, density (#/m^2) and diversity (Shannon-Wiener Diversity Index, H') were evaluated. Percent hydrobiid snails and percent exotic taxa were also calculated and evaluated. Snail population data among sampling sites and dates were compared with a two-factor ANOVA; data were tested for normality first with a Kolmogorov-Smirnov test and natural log (ln) transformed as needed before statistical analysis. Snail population data were compared with water quality and discharge using Pearson correlation on transformed data.

Stream Condition Index

Macroinvertebrate Community Condition. The overall condition of the spring run macroinvertebrate community was assessed using the SCI methodology developed by the DEP and its contractors. This technique involves sampling a 100 m stream reach with a US 30 mesh, D-frame dip net, focusing on "most productive habitat" as assessed by the investigator. Samples collected from a reach are composited into a single sample for that reach and processed in the laboratory. DEP conducted SCI sampling at three 100 m reaches in Blue Spring Run in 2007–2008; these were the same reaches as those used for snail population monitoring.

SCI sampling was conducted by SJRWMD staff in the same three 100 m reaches DEP used in 2007–2008 (also the same reaches as those used for the snail monitoring). Sampling was conducted November 2015 to September 2016 and March 2019 to January 2020. A habitat assessment was conducted within each 100 m reach first, using DEP methods FT 3000 and SCI 1000. Dip net sampling was then conducted using the same SOPs, focusing on most productive habitat. Per SCI protocol, 20 dip net sweeps (each of about 0.5 m) were taken in each sampling reach. Dip net samples were composited for a reach and preserved in 10% formalin and shipped to the DEP Biology Laboratory in Tallahassee for processing according to DEP Biology Lab internal SOPs and protocol, including IZ-01, IZ-02, IZ-06 and any related. Invertebrates collected were identified to lowest practical taxonomic level.

SCI data were evaluated graphically and using the scoring criteria developed by the DEP.

Fish Populations. Fish were sampled monthly at five reaches (designated as "Stations") along the length of the spring run (Figure 5) between August 2014 and September 2015 and again between May 2019 and June 2020. Sampling was temporarily discontinued in December 2014 and January 2015 when manatees were in the spring run and was not conducted between December 2019 to April 2020 due to manatee presence (December 2019 to February 2020) and park closure due to COVID (March-April 2020). Each fish sampling trip began at the headspring (Station 1) and continued downstream to Station 5. This sampling scheme was developed based on previous fish surveys (Work et al. 2010; Work and Gibbs 2015), allowing comparisons to be made between stations and time periods. At each of the 5 stations, the entire reach was snorkeled and larger fish (6-8 cm total length) were visually identified to the lowest practical taxonomic level (species when possible) and counted. Upon completion of the visual snorkel

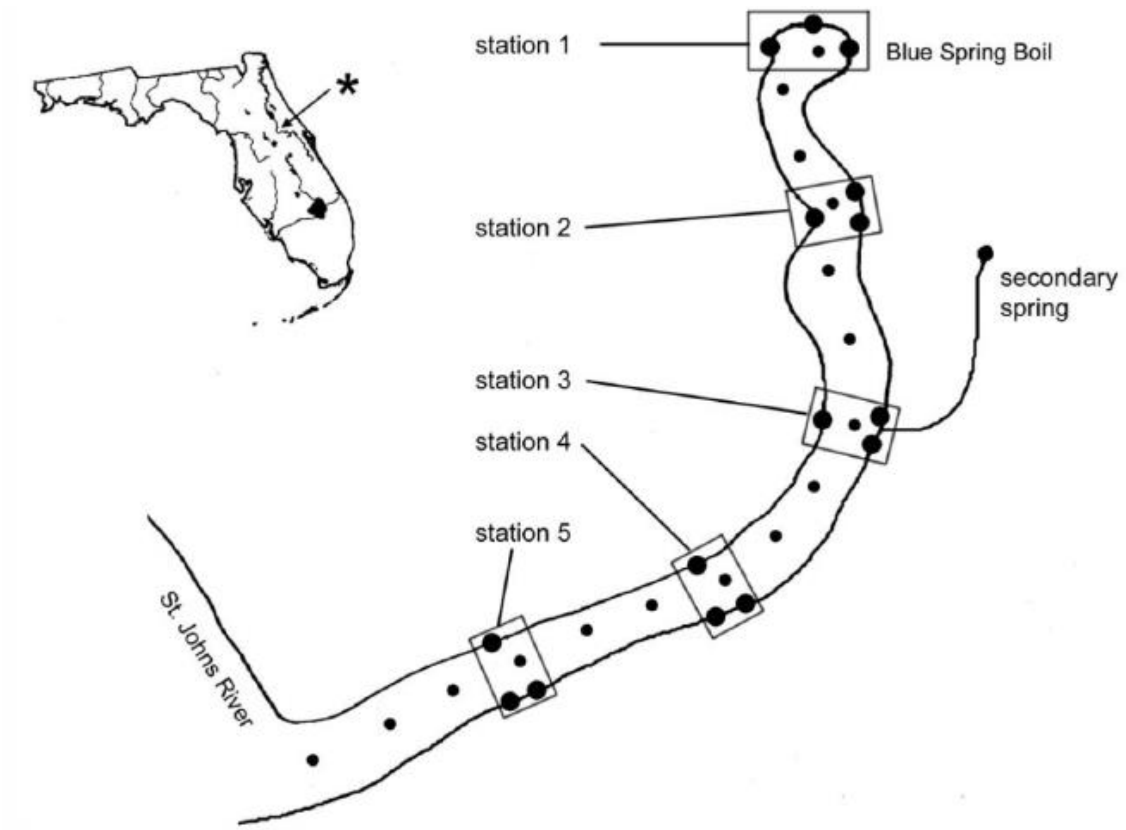


Figure 5. Locations of the five reaches used for fish population and aquatic plant assessments. Large dots within each station represent seine sampling locations. Small dots are locations where *in-situ* water quality field measurements were taken. From Work and Gibbs 2015.

surveys, seine samples were collected from three sub-sampling sites within each Station. The purpose of the seine samples was to collect smaller taxa (e.g., poecilids, small cyprinids, etc.) not adequately sampled by the visual surveys. The locations of the seine sites were along the banks on both sides of the spring run, and each sub-sampling site was approximately 6 m long x 3 m wide and 30 cm to 1 m deep. Criteria for initial selection of sub-sampling sites were presence of fish, nearby cover (bushes, submerged limbs, algal beds), and relative freedom from obstacles to the seine within the site. Most sites typically possessed sandy substrate covered with varying densities of algae, with the exception of two sub-sampling sites at Station 1, which were rockier and had the least available fish cover. Fish captured in the seine were identified (to species if possible), enumerated, and released in the field. DO was measured concurrently with a YSI 85 meter at all sites within stations during sampling events. Fish density was calculated for each fish species on each sampling date by dividing the number of individuals counted in each sample by the area sampled. Fish assemblage diversity was calculated from the densities of individual species at each station using the Shannon-Wiener diversity index. In addition, the proportion of the fish assemblage that was exotic species and the proportion that can be described by each functional/ taxonomic group (poecilids, fundulids, cyprinids, sunfish, and piscivores) was calculated for each station and sampling date.

Spring stage and discharge data were obtained from the USGS Real Time Water Data website (http://waterdata.usgs.gov/nwis/rt) and water quality data were provided from SJRWMD. Data were selected from the same day of fish sampling from these larger data sets for the discharge, stage, and water quality data. Data for fish abundances and for water quantity and quality parameters were natural log-transformed if they did not pass Kolmogorov-Smirnov normality tests. Measures of water quantity (discharge and stage), water quality, and fish density and diversity were compared among years (2019–2020, 2014–2015, 2007–2008, and 2001–2003) and between stations using two-factor ANOVA on monthly means for each year. When ANOVA detected a significant difference, differences among years and stations were assessed with Tukey multiple comparisons. Principle Components Analysis was used to evaluate whether a) composite measures of water quantity and quality, and b) composite measures of fish assemblage structure could differentiate years.

Relationships between water quantity, water quality, and fish abundance and diversity were evaluated with Pearson correlation. Like the temporal analyses, the data used for these correlations were monthly means with the exception of DO, for which we had data for each sample. Finally, stepwise multiple regression was used to find the best predictors of fish density, diversity, and abundance of functional groups from the water quantity/quality and appropriate fish abundance data (e.g. potential prey abundance was used in the multiple regression of piscivorous fish abundance).

Ecosystem Function

Ecosystem Metabolism. Ecosystem metabolism (gross and net primary productivity and community respiration) was evaluated by Wetland Solutions, Inc. under contract with SJRWMD in 2009–2010, 2010–2011, and 2011–2012 using the upstream/downstream DO method developed by Odum (1957). DO inputs to a spring run include spring discharges, diffusion from the atmosphere, inflow from other tributaries (if applicable), and production of DO by primary producer photosynthesis. Loss of DO includes metabolic respiration of plants and animals and sediment oxygen demand. By measuring DO continuously at an upstream and a downstream location, gross primary production (GPP), community respiration (CR) and net primary production (NPP) can be calculated. The methods developed for the spring were defined in Wetland Solutions Inc. (2009). GPP in Blue Spring Run is largely due to the submerged aquatic plants and algae in the spring and run. Primary production of emergent and floating plants is not included in these estimates, but these are a very small fraction of the plant community in Blue Spring Run. CR was estimated using nighttime DO rate-of-change measurements, corrected for diffusion and inflow. Daytime rate-of-change estimates were added to CR to get GPP. NPP was calculated as the difference between GPP and CR. These measurements took into account area, volume, current velocities and diffusion in the reaches being measured. Oxygen diffusion rates were assessed using the floating dome method as described in Wetland Solutions, Inc. (2009) and SJRWMD (2012).

Ecosystem metabolism parameters were estimated using the single-station method adapted from the methods used by Odum (1957). In this case, continuous DO data from the USGS and SJRWMD DO sondes located at the discharge gauge at VBS 330 were used to estimate GPP, NPP, and CR for the reach between the headspring and VBS 330. Because DO concentrations at the headspring are low and relatively constant, this method was considered reasonable and appropriate (R. Knight, personal communication)

Nutrient Assimilation. Nutrient assimilation was calculated for ammonium nitrogen, nitrate-nitrite nitrogen (NOx), total Kjeldahl nitrogen (TKN), total nitrogen (calculated as the sum of TKN and NOx), orthophosphate, and total phosphorus using water quality data at upstream and downstream stations when these were concurrently collected, and data were thus available. For the period 2008–2012, average nutrient mass inputs and outputs were estimated based on average water concentrations and discharge over a particular study period and nutrient assimilation was estimated as the percent change in mass for a reach (the stretch of spring run between two water quality stations). For the period 2012–2016, nutrient assimilation as percent reduction/increase was estimated for the reach from the headspring to VBS 330 using the change in concentration between the headspring and BLSPR, as the earlier analyses by Wetland Solutions, Inc. (2009; 2011; 2012) showed that the percent change in concentration is identical to the percent change in mass for a given reach.

Human Use Monitoring

Park Visitor Attendance. Visitor counts are conducted and maintained at the park entrance station. Total visitor counts from 2009–2020 were obtained from the park manager. These counts included both day use and overnight visitors (camping in the park campground). Overall, prior data show that the vast majority of park visitors are day use.

Park staff conducted park visitor perception surveys in 2013. These surveys were patterned after similar surveys conducted in 2003 and 2008 by Bonn Marketing Research (Wetland Solutions, Inc. 2009). These involved staff administering a survey consisting of 25 questions which included basic demographic data (state/country of residence, gender, income, etc.), reason for visit, perceptions regarding historical versus current condition of the spring (if they had visited the spring previously), and perceptions regarding reductions in spring flow, importance of State Park springs, and willingness to pay for alternative water supplies to reduce impacts to spring flow.

RESULTS AND DISCUSSION

METEOROLOGICAL AND HYDROLOGICAL MONITORING

Daily rainfall and air temperature data were obtained from the National Weather Service DeLand station. Minimum daily air temperature for the period January 2009–December 2020 is shown in Figure 6. The winters of 2010, 2011 and 2012 experienced multiple continuous days of sub-freezing minimum temperatures (Figure 6). Winters of 2014–2020 were less severe, with only periodic days of freezing or sub-freezing minimum air temperature.

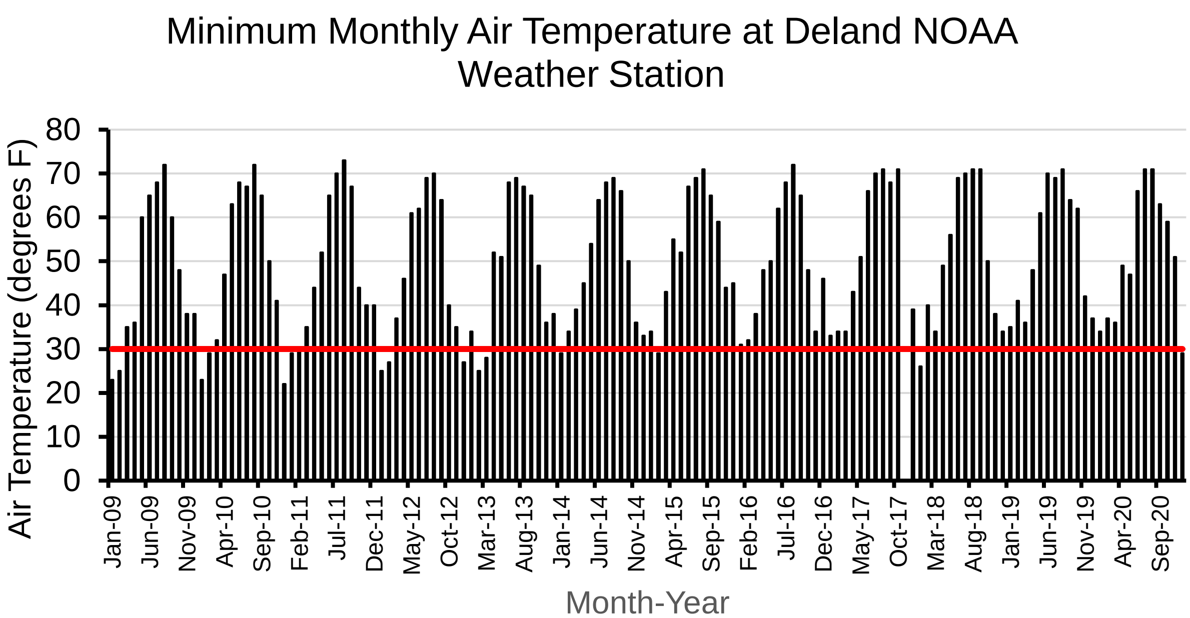


Figure 6. Minimum monthly air temperature at the DeLand NOAA weather station. "Gaps" in the record in 2017–2018 are periods when no data were recorded. Red line is at 30^0 F, indicating sub-freezing temperatures below this.

Total monthly rainfall at the DeLand weather station for the period January 2009 to December 2020 (Figure 7) and total annual rainfall at this station for the same period (Figure 8) are shown. Hurricanes Matthew (2016) and Irma (2017) affected the region. Highest monthly rainfall during the period was in May 2009 and June 2017 (Figure 7). The period 2010–2016 (particularly 2011–2012) was generally drier, with less rainfall. Higher amounts of rainfall occurred in 2017–2019, while it looked like a drier period was entered in late 2015–2016 (Figure 7). No overall trend in rainfall 2009–2020 was seen by visual inspection of Figure 7. The drier period in 2011–2012 can be seen a bit more clearly when plotting annual total rainfall (Figure 8). Lowest total annual amounts were received at the DeLand station for the period 2011–2012 (Figure 8).

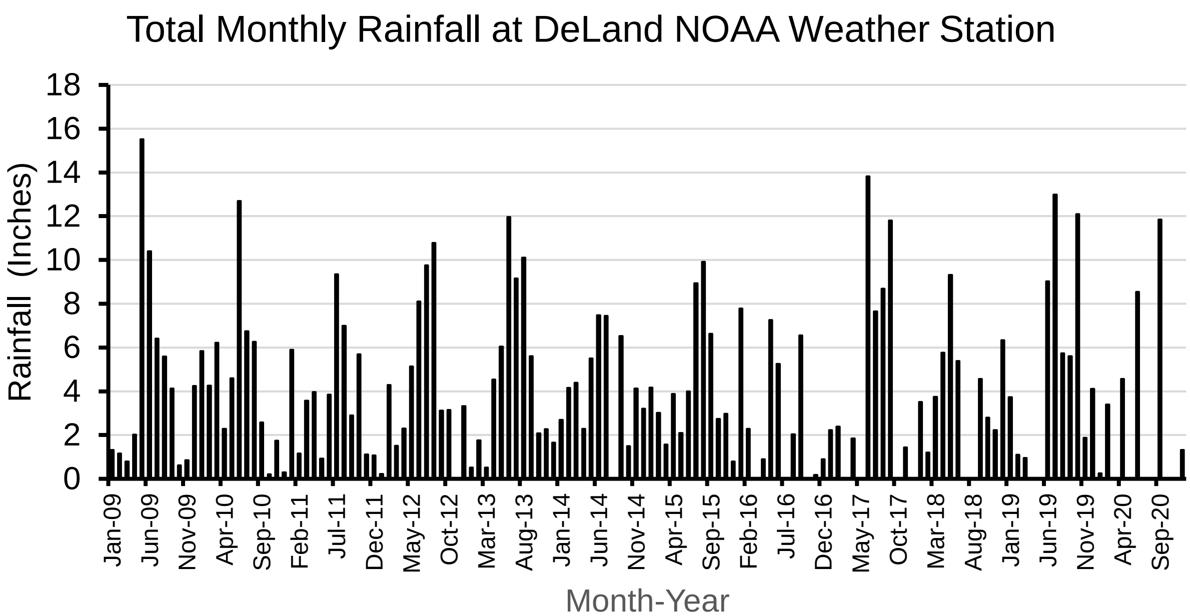


Figure 7. Monthly total rainfall (inches) at the DeLand NOAA Weather Station for 2009-2020.

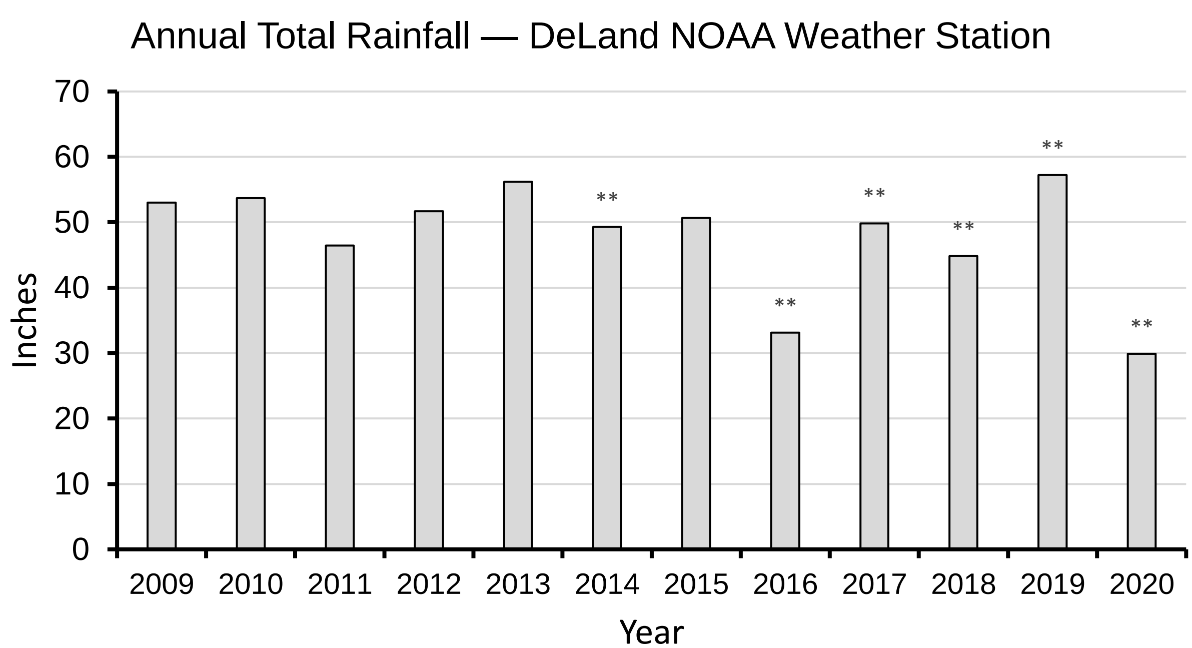


Figure 8. Annual total rainfall (inches) at the DeLand NOAA Weather Station for 2009–2020.
** - one or more months in the year were missing, so record is incomplete.

Wetland Solutions Inc. (2009; 2011; 2012) presented data on total insolation and total PAR (photosynthetically active radiation) from two nearby Florida Automated Weather Network (FAWN) stations (Apopka and Pierson) for the period 2010–2012 and from data collected at a temporary weather station maintained in Blue Springs State Park in 2007–2008. Peak levels of both measures occurred in the mid- to late spring/early summer, probably in association with less cloud cover during this time and higher sun angles.

Mean daily spring discharge for the period 2009–2020 is shown in Figure 9. Both Wetland Solutions, Inc. (2009) and Work and Gibbs (2015) found no statistical relationship between stage (water level elevation) in the spring run and spring discharge. Stage in the entire spring run is a function of the stage in the adjacent St. Johns River (NewFields 2007), not spring discharge. The relationship between spring discharge and stage is complex, depending upon both the potentiometric surface in the Floridan Aquifer and river stage; high river stages generally suppress spring discharge (Wetland Solutions Inc. 2009; NewFields 2007). Stage is not reported in this report.

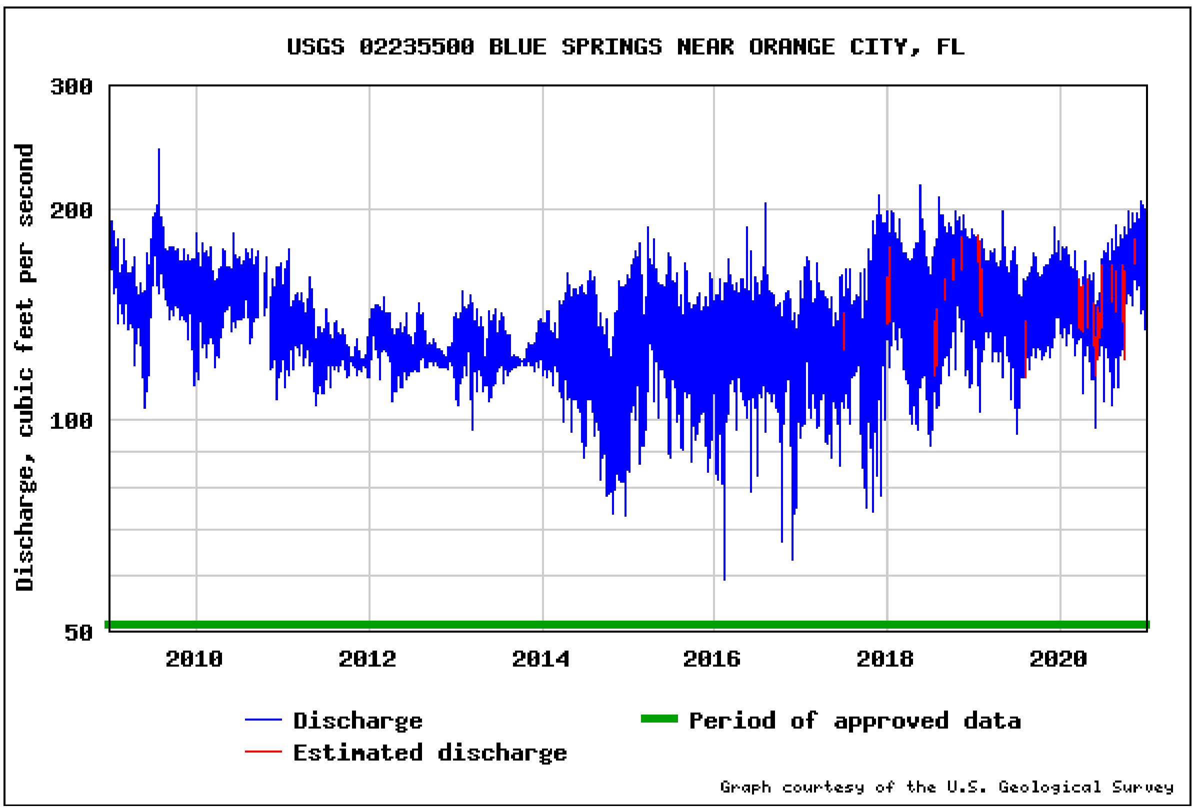


Figure 9. Mean daily discharge at USGS site “Blue Spring near Orange City” (USGS # 0223550) for the period January 2009–December 2020. Source: https://nwis.waterdata.usgs.gov/fl/nwis/

Highest overall spring flow for this period occurred 2009–2010 and 2018–2020. Flows declined in 2011 and remained relatively low through 2012–2014. Very low flow events (< 100 cfs) occurred more frequently 2014–2018 (Figure 9), and a low monthly flow occurred in November 2014 (Figure 10), possibly in conjunction with very high river stages causing a “suppression” effect in the spring run and reducing discharge out of the spring vent. Flows generally increased after 2016 to magnitudes as high as 2009.

Mean monthly flow at the USGS gauge is shown in Figure 10. Temporal patterns in flow were similar to those seen in the daily discharge record, with highest monthly flows in 2010 and 2019–2020, lowest monthly flows in 2011-2016, and increasing monthly spring flow in 2016–2020. From 2006 when the MFR was adopted through 2020, there are fluctuation in spring flows with an overall increasing trend. Long-term mean flow from April 1, 2014, to March 31, 2019, was 136 cfs which is below the MFR (142 cfs) for that time period. However, mean flow for April 1, 2019, to December 31, 2020, was 149 cfs which is slightly above the MFR (148 cfs) for that time period.

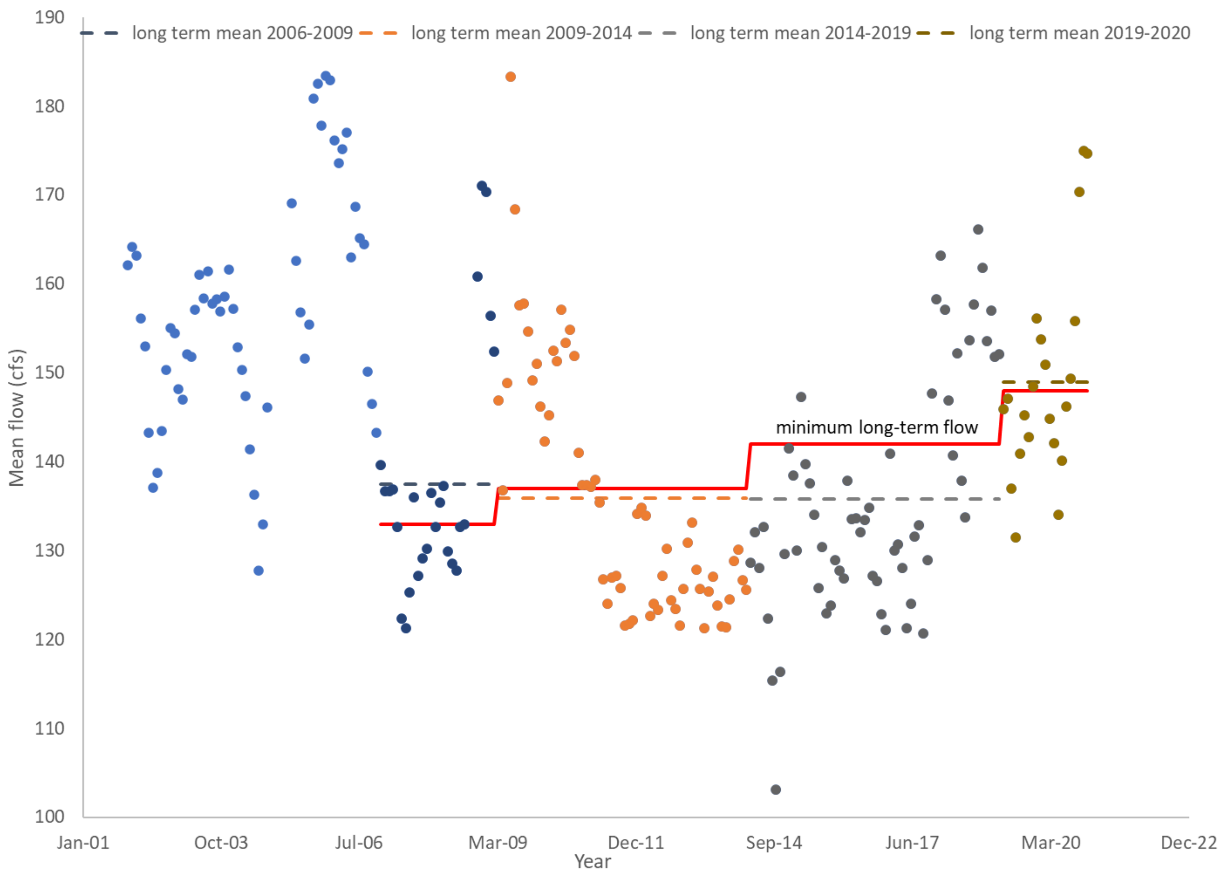


Figure 10. Mean monthly discharge at USGS site “Blue Spring near Orange City” (USGS # 0223550) for the period December 2001–December 2020. Solid red line indicates minimum long-term flow as set by Blue Spring minimum flow regime and dashed lines represent long-term mean flow rates for December 2006–March 2009, April 2009–March 2014, April 2014–March 2019, and March 2019–December 2020, respectively.

Blue Spring exhibited a statistically significant declining trend in flow (Spearman's Rho = -0.23; p <0.0001; Di and Mattson unpublished report; Figure 11) for the period 1932–2013 of discharge monitoring at the USGS gauge "Blue Spring near Orange City." Prior work (Wetland Solutions, Inc. 2009; NewFields 2007) indicated that this was likely associated with trends in long-term rainfall, as this period concluded during the period of lower rainfall and reduced spring flows.

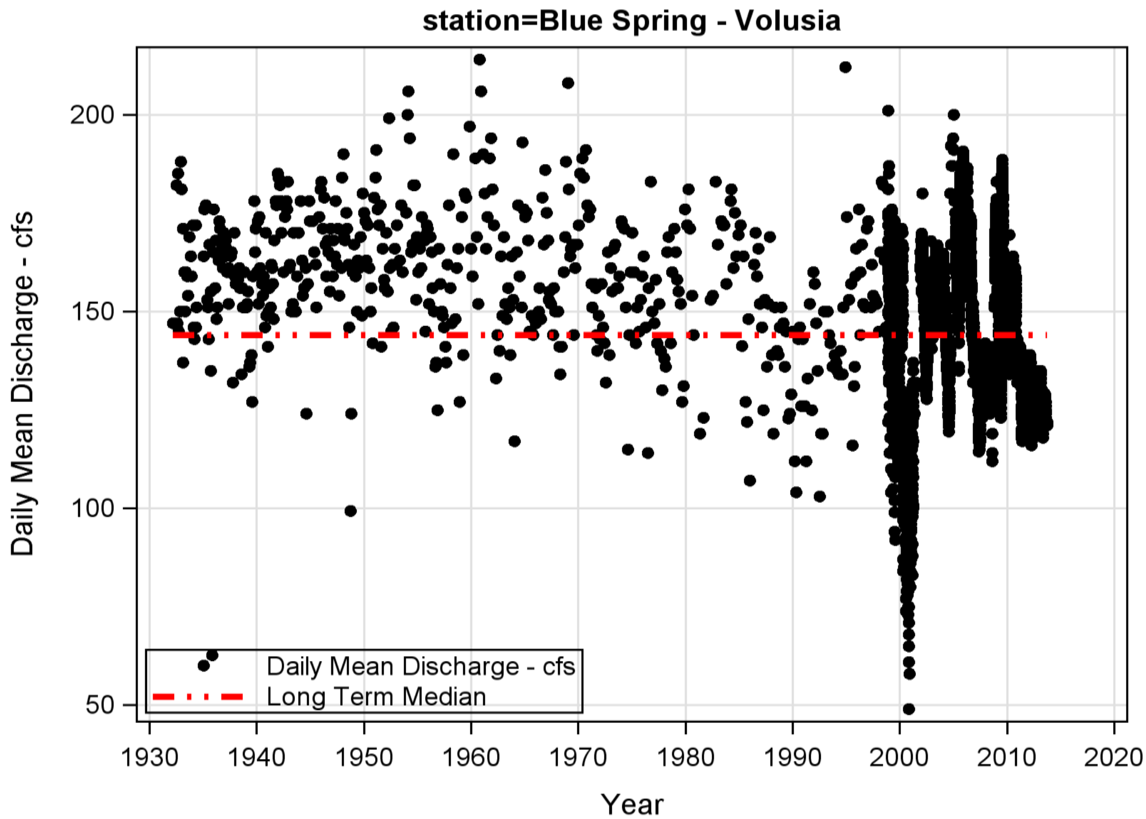


Figure 11. Blue Spring discharge, 1932–2013. Source: Di and Mattson (unpublished report).

WATER QUALITY MONITORING

Spatial changes in water quality in Blue Spring Run were evaluated when multiple stations were concurrently sampled in the spring run 2007–2012. Stetson University (Work and Gibbs 2015) also conducted longitudinal sampling of selected water quality measures down the spring run using *in-situ* instruments in 2014-2015 during fish population sampling events. Spatial changes along the length of the run for selected water quality variables (USGS and SJRWMD grab samples) are shown in Table 3. Data collected at the headspring by the Florida Geological Survey (at VBS 10) are also included in these results.

Table 3. Spatial changes in selected water quality measures (mean value shown; n varied) down the length of Blue Springs Run. VBS 10 is at the headspring and VBS 570 is near the confluence with the St. Johns River.

Water Quality Measure	Spring Run Station			
Dissolved Oxygen (mg/L)	**VBS 10**	**VBS 35**	**VBS 330/355**	**VBS 570**
2007-2008	0.02	0.19	0.79	1.16
2009-2010	0.22	0.33	0.88	1.23
2010-2011	0.36	0.24	0.68	1.33
2011-2012		0.25	0.80	1.10
Specific Conductance (µmhos/cm)	**VBS 10**	**VBS 35**	**VBS 330/355**	**VBS 570**
2007-2008	2114	2081	2059	1970
2009-2010	1658	1515	1507	1518
2010-2011	1725	1855	1855	1813
2011-2012		2145	2145	2150
Color (PCU)	**VBS 10**	**VBS 35**	**VBS 330/355**	**VBS 570**
2007-2008		8.67	7	25.6
2009-2010	2.5	2	3	2
2010-2011	6.3	1.5	1.5	13
2011-2012		1	1.5	2
Total Nitrogen (mg/L N)	**VBS 10**	**VBS 35**	**VBS 330/355**	**VBS 570**
2007-2008		0.58	0.60	0.67
2009-2010		0.77	0.74	0.76
2010-2011	0.67	0.58	0.56	0.63
2011-2012		0.55	0.55	0.53
Nitrate-Nitrite Nitrogen (mg/L N)	**VBS 10**	**VBS 35**	**VBS 330/355**	**VBS 570**
2007-2008		0.40	0.40	0.35
2009-2010	0.61	0.67	0.65	0.64
2010-2011	0.55	0.45	0.44	0.42
2011-2012		0.37	0.37	0.36
Total Phosphorus (mg/L P)	**VBS 10**	**VBS 35**	**VBS 330/355**	**VBS 570**
2007-2008		0.08	0.08	0.09
2009-2010	0.07	0.07	0.07	0.07
2010-2011	0.07	0.07	0.07	0.09
2011-2012		0.08	0.07	0.07
Orthophosphate (mg/L P)	**VBS 10**	**VBS 35**	**VBS 330/355**	**VBS 570**
2007-2008		0.07	0.07	0.07
2009-2010	0.07	0.07	0.07	0.07
2010-2011	0.07	0.08	0.07	0.07
2011-2012		0.08	0.08	0.08

DO was generally lowest at the headspring (VBS 10) and highest near the confluence with the St. Johns River (VBS 570), although overall the increase in DO down the spring run was relatively minimal (Table 3). Work and Gibbs (2015) found that DO concentrations were substantially higher at the channel margins of the spring run than in mid-channel (probably due to better oxygenation and mixing at the margins), and that DO concentrations progressively increased downstream in the run, but they also found that the DO increase downstream was relatively minimal.

Color was uniformly very low throughout the run, with highest color seen at VBS 570, near the St. Johns River confluence. Most other water quality measures displayed little spatial trend down the run from the headspring. Specific conductance and phosphorus measures (Total Phosphorus and Orthophosphate) exhibited little spatial trends. Nitrogen measures (Total Nitrogen and Nitrate-Nitrite Nitrogen) exhibited slight decreasing downstream concentration trends.

A component of the water quality monitoring conducted during the first intensive sampling episode in 2007–2008 and subsequently in 2010–2012 was monthly measurement of bottom water temperature along the lower part of the spring run from VBS 370 to VBS 680. This monitoring was discontinued after 2012 based on the judgement of the members of the MFIWG; the data were no longer needed for calibration of the hydrodynamic model and manatee experts believed that the other surface water sampling data were providing the data they needed. The average bottom water temperature exceeded the critical manatee threshold temperature of 20^0 C (68^0 F) all of the time in 2010–2011 and 2011–2012 from about VBS 610-600 and locations upstream to VBS 370 (Wetland Solutions, Inc. 2011; 2012). Minimum bottom water temperatures below this threshold (17.0^0 C – typically seen in January) were measured up to VBS 530, while minimum bottom water temperature at VBS 370 never went below the threshold (no data were collected between VBS 530 and 370).

Temporal changes in water quality over the period 2010–2020 were evaluated using the grab sample monitoring data collected by SJRWMD at the stations BLSPR, CM-BLSPR, and BLSP-dock (at the current diver entry). Relevant results from the monitoring at this location include:

- Water temperature exhibited less than 1^0 C of fluctuation during the period 2010–2020 (Figure 12). Lowest water temperatures were measured in the winters of 2010 and 2012–2013 in association with sustained hard freezes (Figure 6). A period of generally higher water temperature was measured during the latter part of this monitoring period (2014–2020).
- DO concentrations were generally below 2 mg/L, and often below 1.5 mg/L (Figure 13). DO was generally lower during the latter half of the monitoring period (2014–2020), due to the data coming from BLSP-dock near the headspring, which generally exhibited lower DO concentrations than the two downstream stations (Figure 13).
- Alkalinity did not change appreciably over the period of monitoring, generally falling between 150–160 mg/L as $CaCO_3$ (Figure 14). Field-measured conductivity (a measure of the dissolved solids concentration) was generally higher during the period 2011–2016 (Figure 15).

- Nitrate-nitrite Nitrogen (NO_x-N) was measured as "dissolved" (the water sample was filtered prior to lab analysis) through all of the monitoring period (Figure 16). NO_x-N concentrations were highest in early 2010, at the beginning of the monitoring period, then dropped to below 0.5 mg/L NO_x-N, and then increased during the latter portion of the monitoring period (2016–2020).

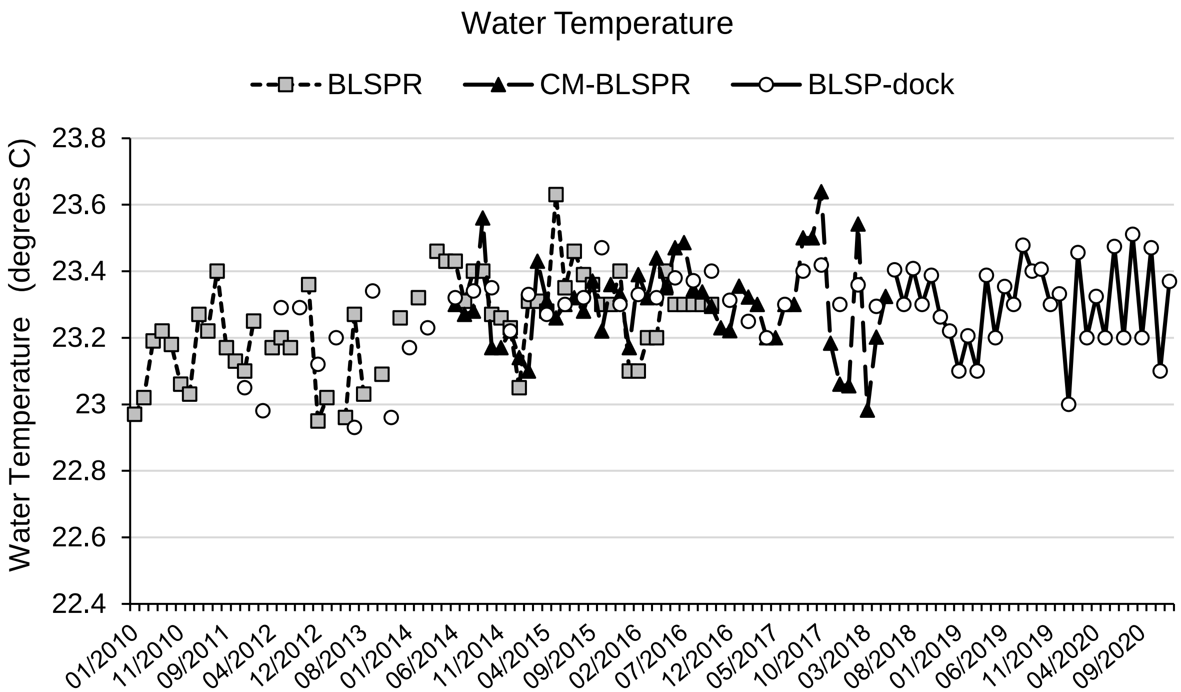


Figure 12. Temporal changes in water temperature (measured near water surface) at SJRWMD monitoring sites in Blue Spring and Run.

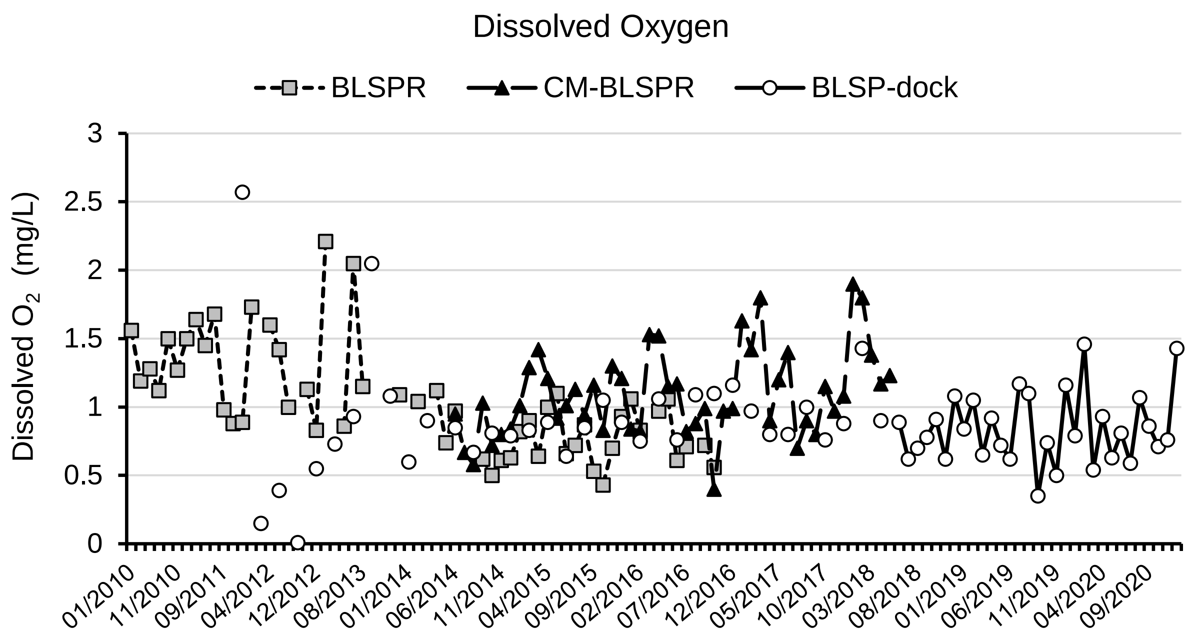


Figure 13. Temporal changes in DO concentration at SJRWMD monitoring sites in Blue Spring and Run.

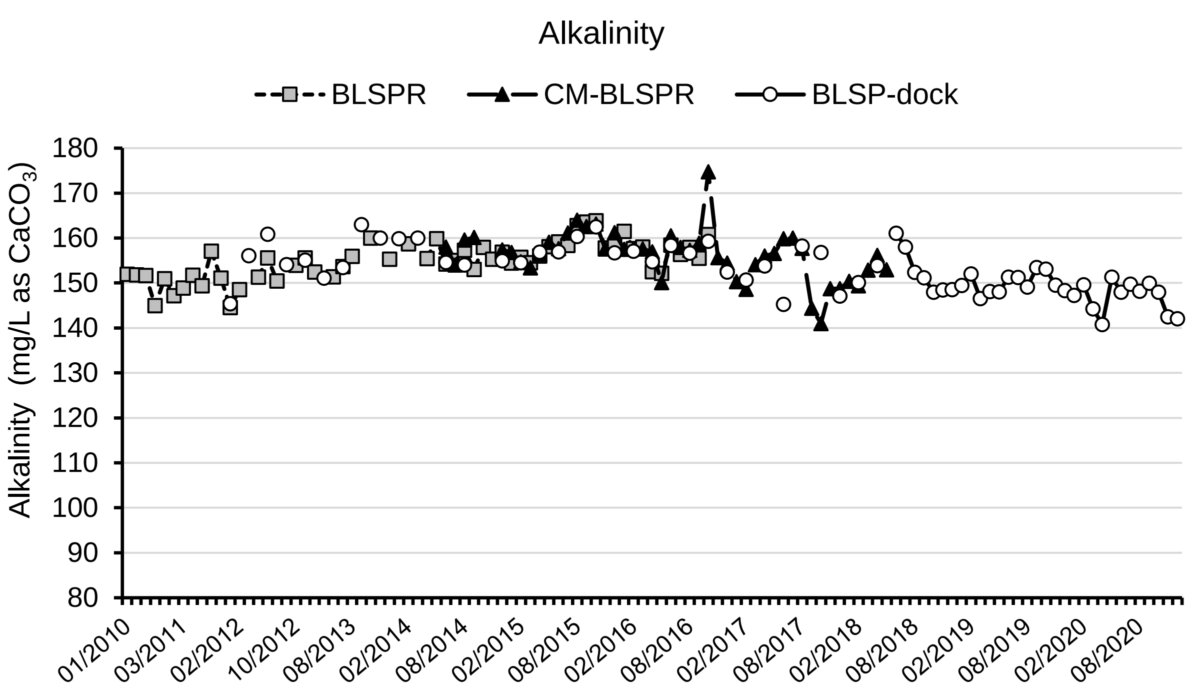


Figure 14. Temporal changes in alkalinity at SJRWMD monitoring sites in Blue Spring and Run.

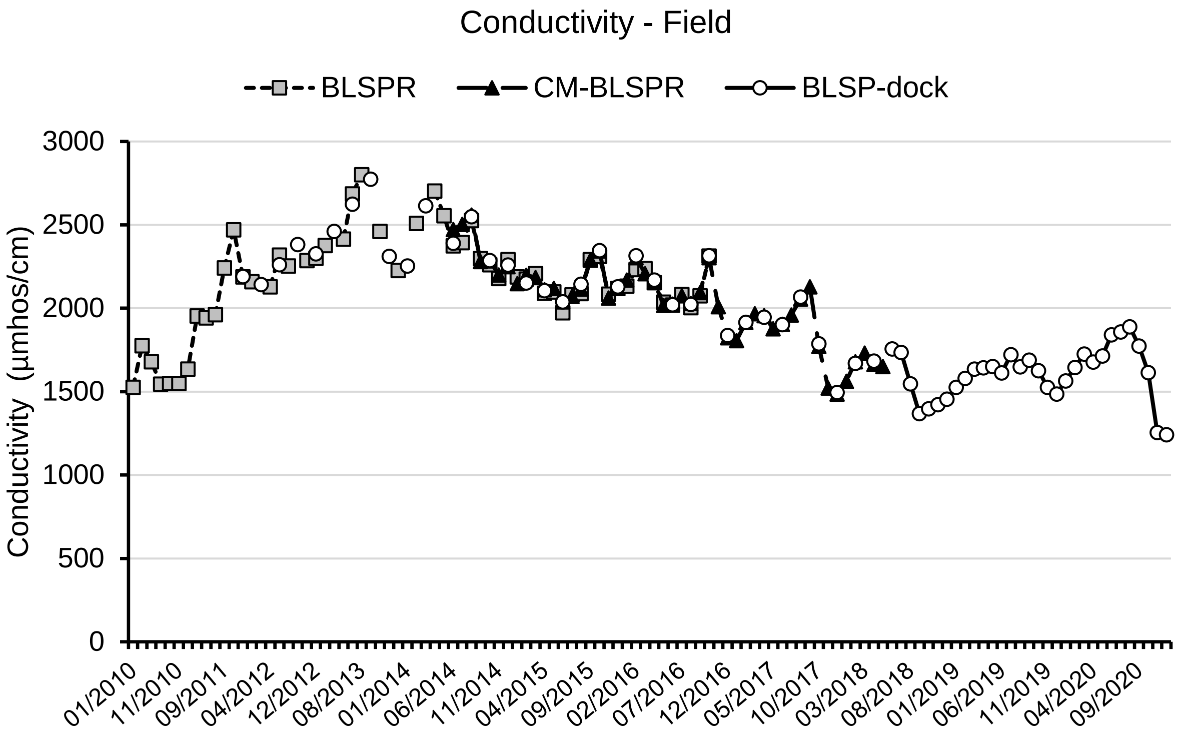


Figure 15. Temporal changes in conductivity at SJRWMD monitoring sites in Blue Spring and Run.

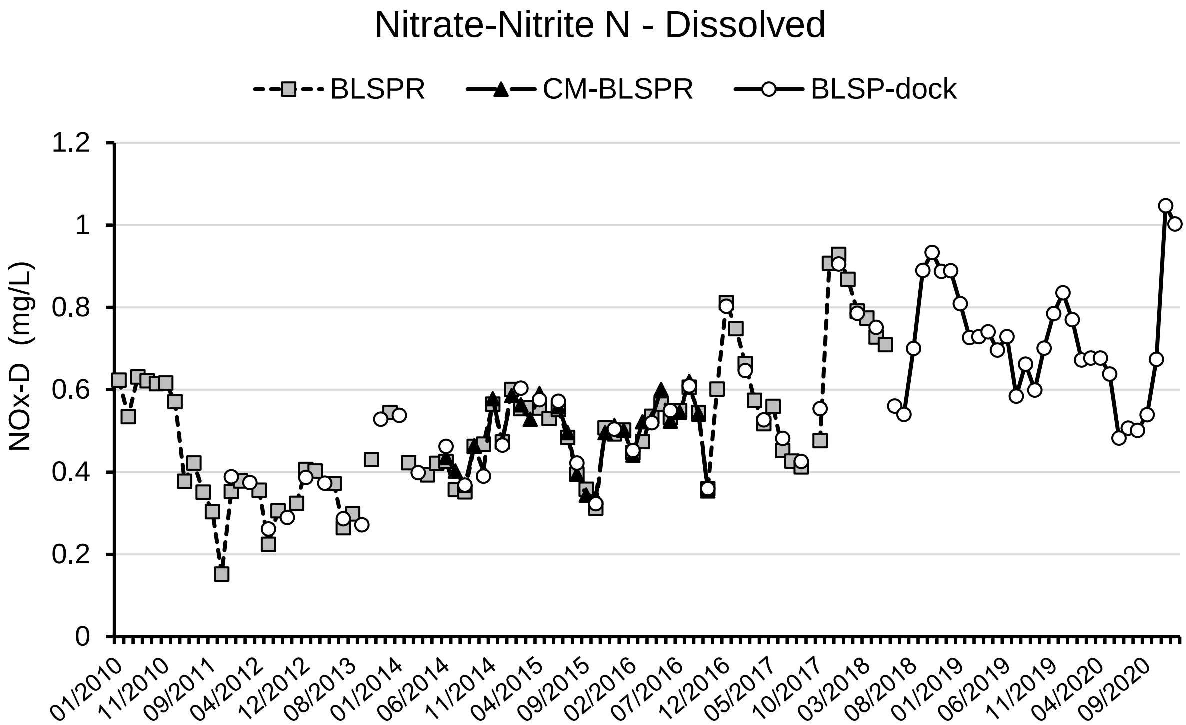


Figure 16. Nitrate-Nitrite Nitrogen (NO_x-N) measured as "dissolved" (filtered sample) at the SJRWMD monitoring stations in Blue Spring and Run.

Di and Mattson (unpublished report) evaluated trends in water quality in Blue Spring for the period 1932–2013. Alkalinity, NO_x, TDS, conductivity, potassium, and sulfate all exhibited statistically significant increasing trends over this time period as indicated by the Seasonal Kendall test. Significant declining trends were exhibited by pH and fluoride. DO, orthophosphate, chloride and iron exhibited no trend. The 2021 SJRWMD Status and Trends Assessment, which examines water quality trends from 2002–2016 at the long-term SJRWMD spring run site (Station ID "BLSPR"), also identified significant upward trends in all dissolved ions, specific conductance, and water temperature. The Status and Trends assessment also documented increasing trends in water temperature and phosphorus forms. The assessment only identified only one downward trend, for pH.

Earlier work by Wetland Solutions, Inc. (2009) and more recent work by Di (unpublished data) and Work and Gibbs (2015) showed that some water quality measures in Blue Spring were strongly associated with spring discharge. In particular, measures generally indicating the "age" or depth of the water (how long it has been in the limestone of the aquifer or deeper in the aquifer), such as alkalinity and conductivity, showed statistically significant negative correlations with discharge (higher concentrations at lower spring discharge). Nitrogen concentrations as indicated by NO_x showed significant positive correlations with discharge (higher concentration at higher discharges). These relationships will be discussed again later in this report.

MANATEE MONITORING

Manatee Population Monitoring

Manatee count data from Blue Spring State Park and the Save the Manatee Club are shown in Figure 17. Total count is the total number of manatees seen/counted during the entire November–March season. This includes all animals which could be uniquely identified, even if a particular individual was only seen for one day. Maximum daily count is the highest single-day count in the spring/spring run during the entire November–March season. Since about 2000, the manatee population size using Blue Spring has been increasing at a near-exponential rate (Figure 17). With few exceptions, a new record has been set for manatee total numbers and maximum daily count each year for the past 16 years.

As part of the establishment of the Blue Spring MFR, the existing manatee population maximum daily count data through the 2005 season were used to construct a predictive regression model of population growth rate to forecast future size of the manatee population using the spring (NewFields 2007). The model that was developed best fit an exponential curve:

$$y = 23.520e^{0.066(t-1977)}$$

$$R^2 = 0.957$$

Where t = year and y = predicted max. daily manatee population count

The last 16 years of actual maximum daily count data have exceeded the predicted rate of increase generated by the regression model (Figure 18).

Manatee Condition Monitoring

Data collected by the Americorps volunteer during the severely cold winter of 2009-2010 showed that 79.2% of 490 manatees observed during nine weekly surveys in February and March showed putative signs of cold exposure (over all three body regions). Earlier observations (by FWC and/or park staff) for the 2006–2007 and 2007–2008 winter seasons reported a total of 15 individual manatees exhibiting cold stress signs (based on earlier assessment protocols). Most of these were characterized as “minor” stress, with four animals exhibiting signs of “moderate” stress. The observers at that time reported that these animals arrived at Blue Spring already exhibiting cold stress signs, leading to the conclusion that the stress was not due to the animals being excluded from warm-water refuge habitat at Blue Spring (Wetland Solutions, Inc. 2009).

For the three winters from 2011–2012 through 2013–14, 45.9% of 760 manatees observed during nine FWC surveys were assessed as showing evidence of cold exposure signs on one or more body regions. This measure of overall prevalence varied among winters from 18% (winter 2012–2013) to 54% (2011–2012). The severity of these signs was scored as slight (score=1) in all except three cases, where it was moderate (score=2). The body region most often reported to show signs of cold exposure was the head. Whitening of the skin was the most common type of cold exposure sign (94.8% of those with score=1+); other types of cold exposure signs were

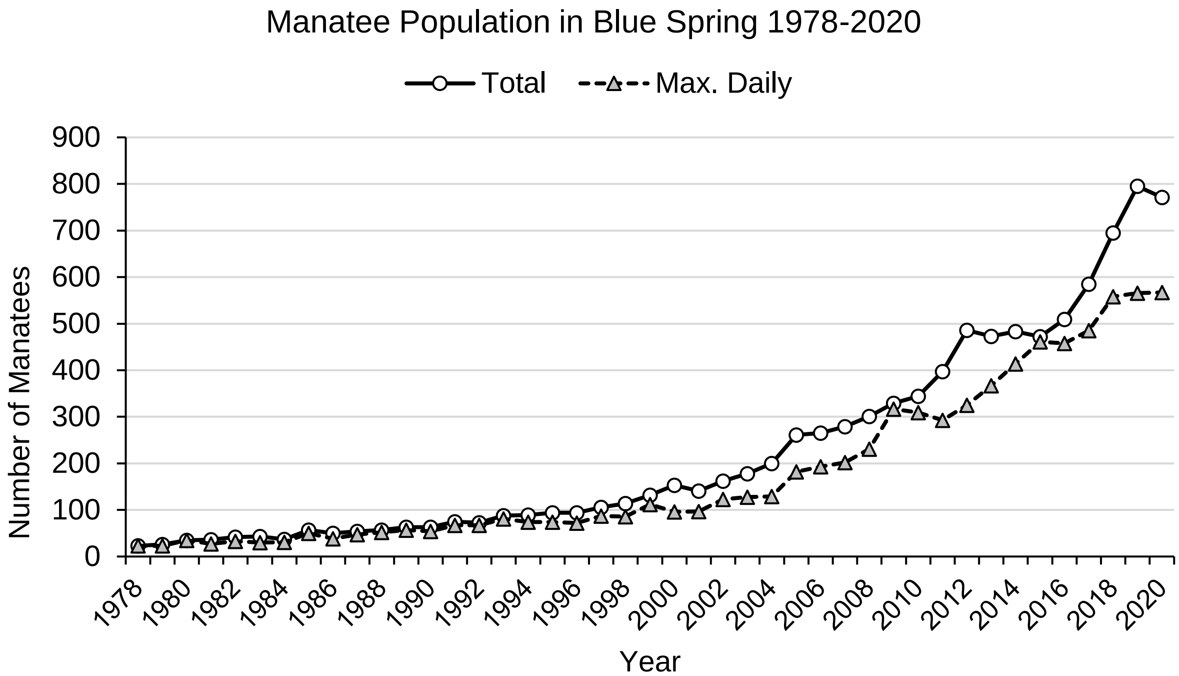


Figure 17. Total and maximum daily counts of manatee numbers in Blue Spring and Blue Spring Run during the period November-March from 1978-2020.

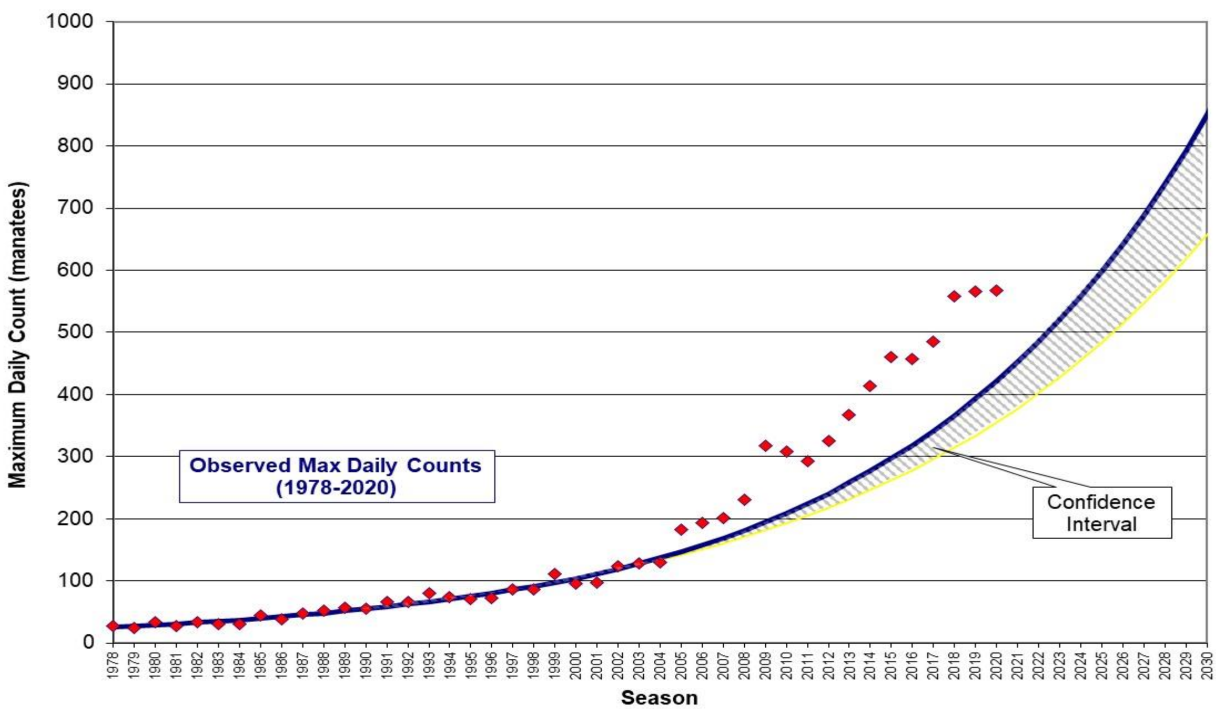


Figure 18. Predicted (solid blue line) vs. observed (red symbols) maximum daily manatee count in Blue Spring up to the most current monitoring period (2020–2021).

much less common, including abscesses (4.9%), lesions (4.2%), and skin sloughing (2.9%). Prevalence of cold exposure signs increased slightly from December to January in all three winters; from January to February, it increased in winter 2011–2012 and decreased in winter 2013–2014.

During the winter of 2014–2015, six manatees (three rescues and three carcasses) were recovered in the vicinity of Blue Spring (de Wit 2015). One of these rescued manatees had cold exposure scores of 1–2 on various regions of its body (head, trunk, and fluke), with an overall assessed score of 2 (moderate cold exposure signs). This individual was first seen on 10 December in Welaka Spring (about 50 km downstream of Blue Spring) showing signs of cold stress but could not be captured at that time. When it arrived at Blue Spring on 19 December, it was identified and monitored for nine days, then rescued on 28 December for treatment of chronic cold stress syndrome at a rehabilitation facility. Upon capture, it was noted that the manatee also had sloughing skin on its flippers and poor body condition with a flat, folded ventrum. It appeared that cold exposure impacts in this animal began before it arrived at Blue Spring (based on the sighting at Welaka Spring). The animal was treated at SeaWorld Orlando and released back to the wild in March 2015. None of the other animals assessed in 2014–2015 exhibited signs of cold stress, although one was badly decomposed and could not be assessed. In the winter season of 2014–2015, there was no evidence from the carcass salvage and necropsy program of manatee cold stress issues associated with exposure during their time at Blue Spring (de Wit 2015).

During the winter of 2015–2016 six manatees (two rescues and four carcasses) were recovered in the Blue Spring region (de Wit 2016). None of these exhibited cold exposure signs, although assessment of one carcass was “undetermined” due to the degree of decomposition. For the 2015–2016 winter season, there was no evidence from the carcass salvage and necropsy program of cold stress or exposure acquired during the manatee populations’ time at Blue Spring (de Wit 2016). Cold stress monitoring was not conducted after 2016.

WATER RESOURCE VALUES MONITORING

General Biological Structure

Algae and Aquatic Plants. Mean macroalgal cover (Braun-Blanquet score) for the 2014–2020 period at the five transects down the spring run are shown in Figure 19. Overall, algal cover was similar at all transects, with no clear spatial or temporal trends. Higher algal cover was generally seen at Transect 1 during the early period 2014–2015, but cover was generally lowest at this site 2017–2019 (Figure 19). Algal cover generally declined over the 2014–2015 period, with lowest cover seen in the last sampling episode in August 2015. Temporally, lower algal cover was generally seen in the spring/summer, but some of the highest algal cover values were measured at Transects 3 and 4 in May 2018 (Figure 19).

Work and Gibbs (2015) reported that the major taxa observed in the algal mats were the cyanobacterium *Oscillatoria* spp., the xanthophyte *Vaucheria* spp., and the filamentous diatom

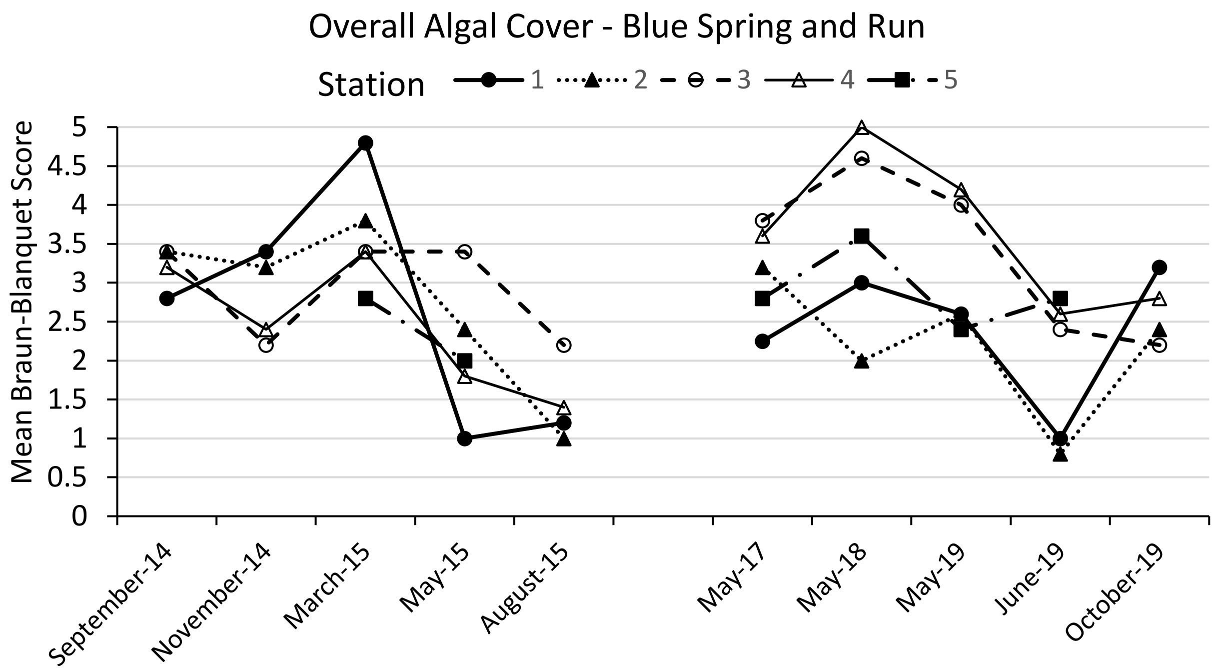


Figure 19. Mean algal cover (n = 5 at each transect each sampling episode) at the five monitoring stations for the periods 2014–2015 and 2017–2019.

Melosira sp. The diatom was observed commonly throughout the spring run. Qualitatively, it appeared *Oscillatoria* was more common in the upper half of the spring run, while *Vaucheria* was more common in the lower half of the run. *Melosira* tended to be found more toward the channel margins while the other two algal taxa occurred more frequently in mid-channel (Work and Gibbs 2015). DEP found that diatoms generally dominated the abundance in algal mats in the spring run in 2007–2008 (Wetland Solutions, Inc. 2009), with filamentous cyanobacteria generally comprising much of the remainder of the algal abundance. Green algae (Chlorophyta) comprised the remainder of most of the algal mats. Dominant diatoms collected by DEP were species in the Fragilariaceae and the filamentous diatom *Staurosira elliptica* (Wetland Solutions, Inc. 2009). *Vaucheria* was not collected by DEP in 2007–2008.

Work and Gibbs (2015) observed that some portion of the algal mats always consisted of dead or senescent algal filaments. There were no significant spatial differences among the five transects when algae were statistically compared (all sampling dates pooled), whether or not senescence was taken into consideration (Work and Gibbs 2015; 2020). For the period 2014–2015, there were significant differences among sample dates when senescence was excluded and only live algae coverage was tested (all transects pooled), with higher cover measured in spring (March) 2015. Overall, both Work and Gibbs (2015; 2020) and the SJRWMD annual surveys (2017–2019) indicated considerable spatial and temporal variation in macroalgal abundance as cover.

DEP employed Rapid Periphyton Survey (RPS) techniques to sample the algal community in Blue Spring Run in 2007–2008 (Wetland Solutions, Inc. 2009). Sampling was conducted in the three reaches used for SCI and quantitative snail monitoring (designated upper, middle and lower reach). Algal abundance was estimated using the thickness of the algal mat, scored using an ordinal scale from 0 (no algae) to 5 (algae >20 mm in thickness). Generally, half or more of the measured points in the upper and middle reaches had algal thickness scores of 4–5 (6–20 mm thickness or >20 mm thickness). Most of the measured points in the lower reach had algal thickness scores of 3 or less (>1 to <6 mm algal thickness). SJRWMD repeated the field component of the RPS in 2015–2016 and 2019–2020 and found similar results. Wetland Solutions, Inc. (2009) interpreted this to mean algal abundance was generally reduced in the lower part of the spring run, a finding that is similar to the algal cover measurements made in 2014–2015, however the data from 2019–2020 indicated the opposite (higher cover downstream).

Filamentous macroalgae were the dominant plants in the submerged aquatic vegetation (SAV) community in Blue Spring Run. Occurrence and abundance of submerged macrophytes was very sparse. Scattered individuals of red ludwigia (*Lugwigia repens*) and freshwater eelgrass (*Vallisneria americana*) were rarely observed during monitoring in 2014–2015. Earlier work in 2007–2008 by the DEP only found *L. repens* and small patches of southern naiad (*Najas guadalupensis*) in the SAV community in Blue Spring Run (Wetland Solutions, Inc. 2009). The complete lack of dense beds of submerged macrophytes in Blue Spring Run has not been explained, given the common occurrence of these SAV beds in many other spring-run streams in Florida and in the St. Johns River basin (Mattson and Lehmensiek 2010). Hypotheses proposed for the lack of SAV in Blue Spring Run have included grazing by manatees, destruction by unmanaged recreational use prior to the spring becoming a State Park, and even herbicide applications by the prior owner before the spring became a State Park. Anecdotally, Blue Spring Run did appear to historically support extensive macrophyte beds, as might be expected. When he first sampled the headspring and run for hydrobiid snails in the early to mid-1960s, Thompson (1968) noted that:

> "*The spring boil is nearly devoid of rooted vegetation, but the spring run has thick growths of aquatic plants throughout its course*." (Pg. 91), and
>
> "*The water in the spring pool and the run is very clear, and supports a thick luxurious growth of aquatic vegetation*." (Pg. 144)

Work and Gibbs (2015; 2020) found no statistically significant relationships between water flow or water quality and algal cover. Wetland Solutions, Inc. (2009) found a weak positive correlation between sediment Total Kjeldahl Nitrogen (TKN) and algal thickness score and a weak negative correlation between tree canopy cover over the spring run and algal thickness score. Both of these relationships were not statistically significant. The dominant algal taxa found in Blue Spring Run generally appear to have a wide nutrient tolerance and may be found in spring-run stream ecosystems ranging from oligotrophic to moderately eutrophic (Stevenson et al. 2007).

Grazing is also a factor in determining algal abundance, occurrence, and species composition (Steinman 1996). This was not evaluated in this study effort, but observations by the staff at the State Park have indicated that periodic mass incursions of the algae-feeding Vermiculated sailfin catfish (*Pterygoplichthys* sp.) into the run (particularly in winter) generally denudes the benthic algae. However, when the catfish leave the spring run to return to the St. Johns River, the algae quickly re-grow to cover large areas of the run. Part of this appears to be facilitated by the persistence of the catfish "frass" (fecal casts) in the spring run after they leave, which may provide a nutrient source to promote algal regrowth (M. Gibbs, Stetson University, pers. comm.).

A "target" or "desirable" level of macroalgae cover (or other measure of algal abundance) has not been determined for Florida springs. All of the algal species present in Blue Spring have always been a component of the SAV community in Florida springs (Whitford 1956); the main change over the past 50 years has been an increase in the overall and/or relative abundance of macroalgae (Stevenson et al. 2007; Mattson and Lehmensiek 2010). Welch et al. (1988) identified a "nuisance" level of macroalgae as >100-150 mg/m^2 chlorophyll *a*, or a cover of >20%, in northwestern US and European streams. This was largely based on aesthetics and the ability of anglers to wade without slipping. Quantitative algal data collected in Blue Spring Run in 2015 (SJRWMD unpublished data) found algae cover ranging from 40–90% (Braun-Blanquet scores of 3-5) and uncorrected chlorophyll *a* concentrations of 282–1,449 mg/m^2 (which includes living and dead algae), roughly 2 to 10 times greater than the thresholds suggested by Welch et al. (1988). Comparison of benthic macroinvertebrate and algae data collected in Florida springs found that the EPT Score (the number of taxa of mayflies, stoneflies, and caddisflies) declined when >15-20% of the algal community was composed of Cyanobacteria and Chlorophyta (Mattson 2009). These two groups of algae contain most of the filamentous species regarded as "nuisance" taxa. The proliferation of benthic filamentous algae in freshwater ecosystems, particularly the cyanobacterium *Lyngbya wollei* (a common nuisance taxon in Florida springs), appears to be a growing and widespread phenomenon (Hudon et al. 2014).

<u>Snail Populations</u>. Snails fulfill a number of ecological roles in spring-run streams; they are important algal grazers/herbivores and are food items for many species of fish and turtles. The snail community in Blue Spring Run exhibits relatively high total taxa richness and is dominated by snails in the Family Hydrobiidae ("silt snails"). The snail community of Blue Spring Run is of particular interest/significance because in the 1960s, Thompson (1968) collected and described two endemic species of hydrobiid snails found only in Blue Spring: the Blue Spring hydrobe (*Aphaostracon asthenes*) and the Pygmy siltsnail (*Floridobia* [formerly *Cincinnatia*] *parva*). Two other snail taxa of interest found in Blue Spring are the Hyacinth siltsnail (*Floridobia floridana*), which is endemic to Florida, and the Goblin elimia (*Elimia vanhyningiana*), which is endemic to the St. Johns River basin. The latter snail was collected for the first time in Blue Spring in this study. Hydrobiid snails dominated the overall taxa richness and relative abundance in the snail community in 2007–2008, 2014–2015, and 2019–2020 (Wetland Solutions, Inc. 2009; Work and Gibbs 2015; 2020). The endemics *F. parva* and *A. asthenes* were present in the snail collections in 2014-2015 and 2019–2020 when they were identified (Work and Gibbs 2015; 2020). After hydrobiids, the two other common snail groups collected (by abundance and/or

number of taxa) were native planorbid snails (*Planorbella* spp.) and two exotic snails in the Family Thiaridae; *Melanoides* sp. and *Tarebia granifera*.

Snail taxa richness (number of distinct species or genera identified) was generally higher in 2014–2015 and 2019–2020 than measured in the earlier period 2007–2008 (Figure 20). Snail taxa richness range was 3-9 taxa in 2007–2008, 8-16 taxa in 2014–2015, and 10-16 taxa in 2019-2020. This is due to the more detailed taxonomic identification conducted in the two latter periods, rather than an actual increase in snail taxa richness. Work and Gibbs (2020) found that snail diversity (Shannon-Weiner Index) at the genus level differed significantly among the three sampling periods; this is probably due to a combination of higher snail taxa richness in the latter periods and the extreme dominance of small, immature hydrobiids in the collections in 2007–2008. Peak snail taxa richness appeared to occur in the spring/early summer (May/June) in all three reaches in the spring run. Highest taxa richness was generally seen in the middle reach in all time periods. Work and Gibbs (2020) found that diversity did not differ significantly among the three sampling reaches.

Snail total abundance (#/m^2) was highly variable and generally similar in 2007–2008 and 2014–2015 (Figure 21) except for a huge spike in abundance in June 2008 due to collection of thousands of small, juvenile hydrobiids (that could not be identified to genus or species). Abundance appeared to be slightly higher in 2019–2020 (Figure 21). Overall, Work and Gibbs (2020) found no statistically significant difference in snail abundance between the three time periods. Peak snail abundance generally appears to occur in the late spring/summer (May-August). Highest snail abundance was seen in the middle reach in June 2008 (30,000/m^2) and August 2015 (10,864/m^2) and in the upper reach in May 2020 (18,360/m^2). In most other sample periods snail total abundance was below 5,000/m^2. The lower reach in the spring run could not be sampled in February 2008 due to spring run closure and was not sampled in September 2014 and August 2015 due to high water levels. It was not sampled in 2019–2020 due to the frequent difficulty in sampling due to water depth.

Overall, hydrobiids were the most abundant group of snails in the snail community (Figure 22; Work and Gibbs 2020), often comprising over 90% of the total density. The percent hydrobiids differed significantly among years (Work and Gibbs 2020), primarily due to the high abundance of juveniles in the 2007–2008 samples. Percent hydrobiids did not differ significantly among the three sample reaches (Work and Gibbs 2020). The two most commonly collected native snail species (by density) were two hydrobiids; the endemic Pygmy siltsnail, *Floridobia parva*, and the Serrated crownsnail, *Pyrgophorus platyrachis*. These were collected in almost every sampling episode in all three reaches. *P. platyrachis* was sometimes the dominant macroinvertebrate species in the SCI samples collected by SJRWMD in 2015–2016 (described in next subsection). The other endemic snail reported from Blue Spring, *Aphaostracon asthenes*, was also collected and identified in 2014–2015 and 2019–2020, but was present in low abundance.

Wetland Solutions, Inc. (2009) and Work and Gibbs (2015) reported two species of exotic snails (both from Southeast Asia) in Blue Spring and Run; a species of *Melanoides* and *Tarebia*

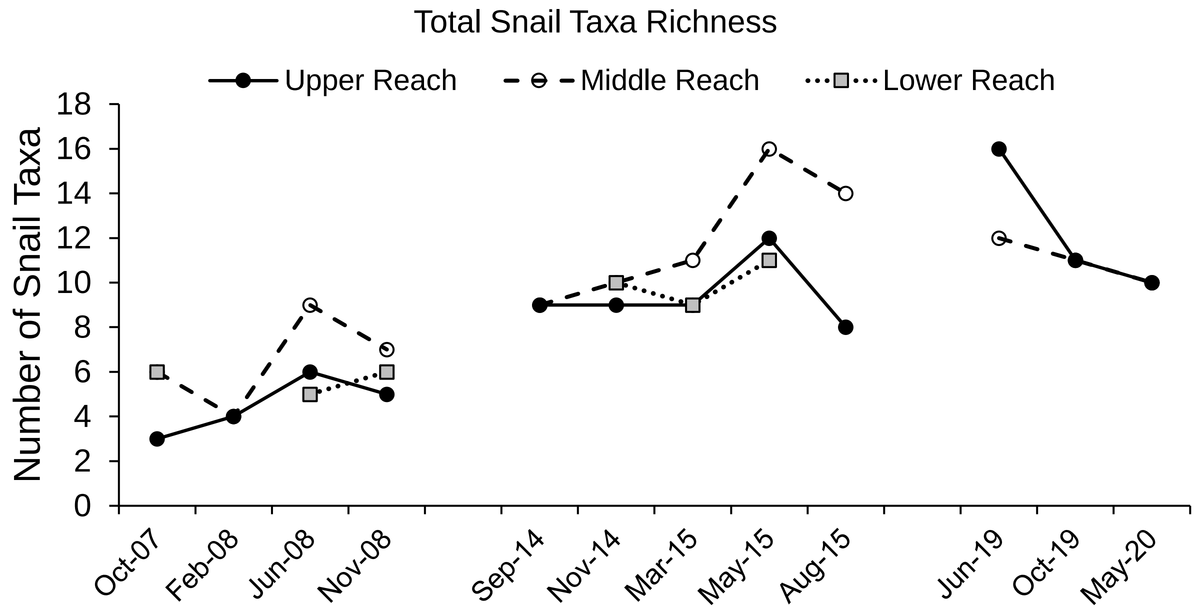


Figure 20. Total taxa richness of snails in Blue Spring and Run in 2007–2008 (DEP) and 2014–2015 and 2019–2020 (this study, Stetson data).

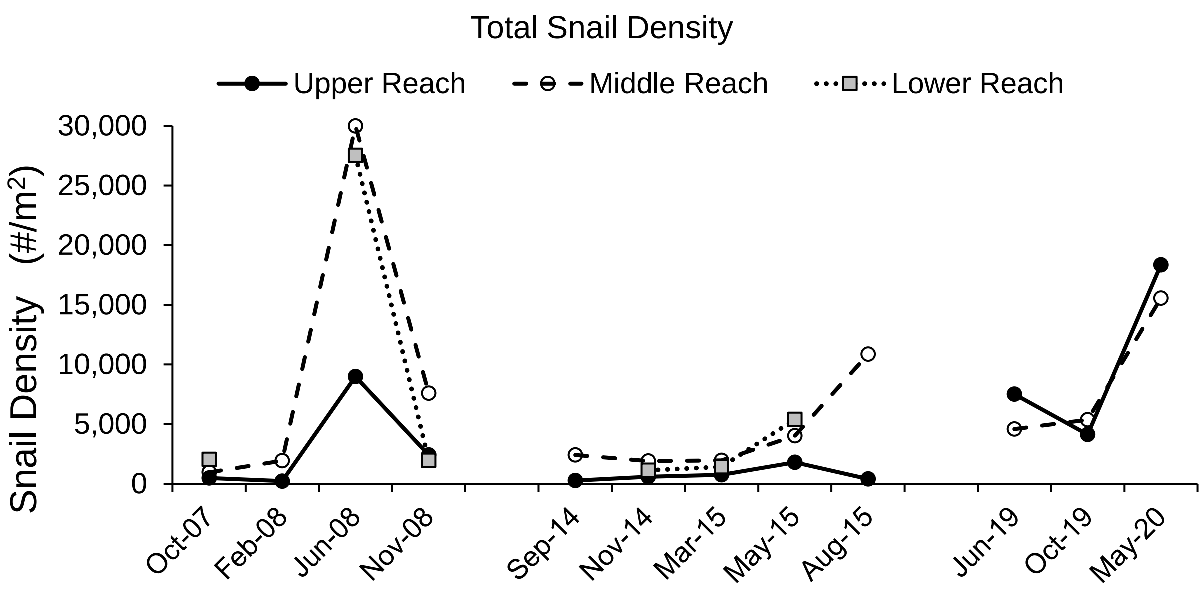


Figure 21. Snail abundance (#/m^2) in Blue Spring and Run in 2007–2008 (DEP) and 2014–2015 and 2019–2020 (this study, Stetson data).

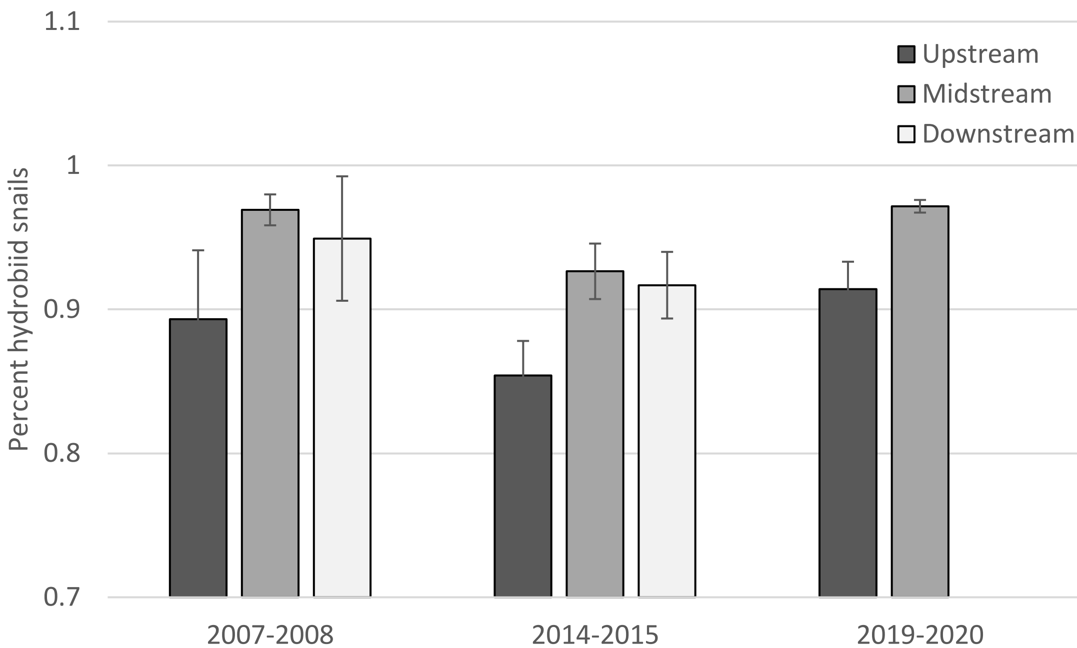


Figure 22. Relative abundance (as % of total density) of hydrobiid snails in the snail community in Blue Spring and Run. From Work and Gibbs (2020)

granifera. Work and Gibbs (2015) found that both constituted a relatively small fraction of the overall snail abundance (generally about 5% on average combined), but that the fraction of the overall snail community composed of these exotics was significantly higher in 2014–2015 than in 2007–2008. In 2019–2020, a third exotic species was observed/collected, a species of *Pomacea* (Apple snail), probably *P. maculata*. With the new round of data collected in 2019–2020, the percent of exotics in the snail community did not differ among the three sampling periods (Work and Gibbs 2020). Exotic snail abundance was significantly higher in the Upper Reach (near the headspring) than downstream in the run (Work and Gibbs 2020). The limited amount of data restricted comparison of exotic snail abundance with water flow or water quality.

<u>Macroinvertebrate Community Condition</u>. The overall status or "health" of the macroinvertebrate community in Blue Spring and Run was evaluated using the SCI. This is a multi-metric index determined by evaluating macroinvertebrate community measures that reflect richness and diversity, presence/absence of pollution-sensitive taxa (e.g., EPT taxa), presence of long-lived larval invertebrates and filter-feeding invertebrates (in part evaluating productivity characteristics), and relative abundance measures. The basic concept is to provide a numeric score rating the condition of the invertebrate community based on multiple ecological measures evaluating invertebrate community structure and function (Barbour et al. 1996).

The SCI methodology also includes a habitat assessment (HA) component, as it is known that various forms of disturbance of stream ecosystems can include physical disruption as well as chemical contamination by water pollution (Barbour et al. 1996). The HA is determined in the 100 m reach using a semi-quantitative scoring system to evaluate bank stability, current, bottom habitat, occurrence of productive habitats such as SAV and large wood debris, and related factors. HA scores for the three reaches assessed in Blue Spring Run are shown in Figure 23. In general, the HA scores indicated the availability of excellent (= “optimal”) habitat for macroinvertebrates in 2007–2008 and good (= “suboptimal”) habitat conditions in 2015–2016 and 2019–2020. Part of this difference could be due to differences in the field investigators performing the assessments and part could be due to a decline in habitat quality in in the latter two sampling periods. Despite the lack of SAV habitat in the spring run, the existence of various sizes of submerged large wood debris (“snags”) and rocky habitat through much of the spring run provides good habitat for benthic invertebrates. Bottom sediments are mostly sand or muddy sand, which is also generally good benthic habitat. The only major habitat impediments are periodic smothering by algal mats or turbidity due to suspended sediments kicked up by swimmers downstream of the swimming and diving areas.

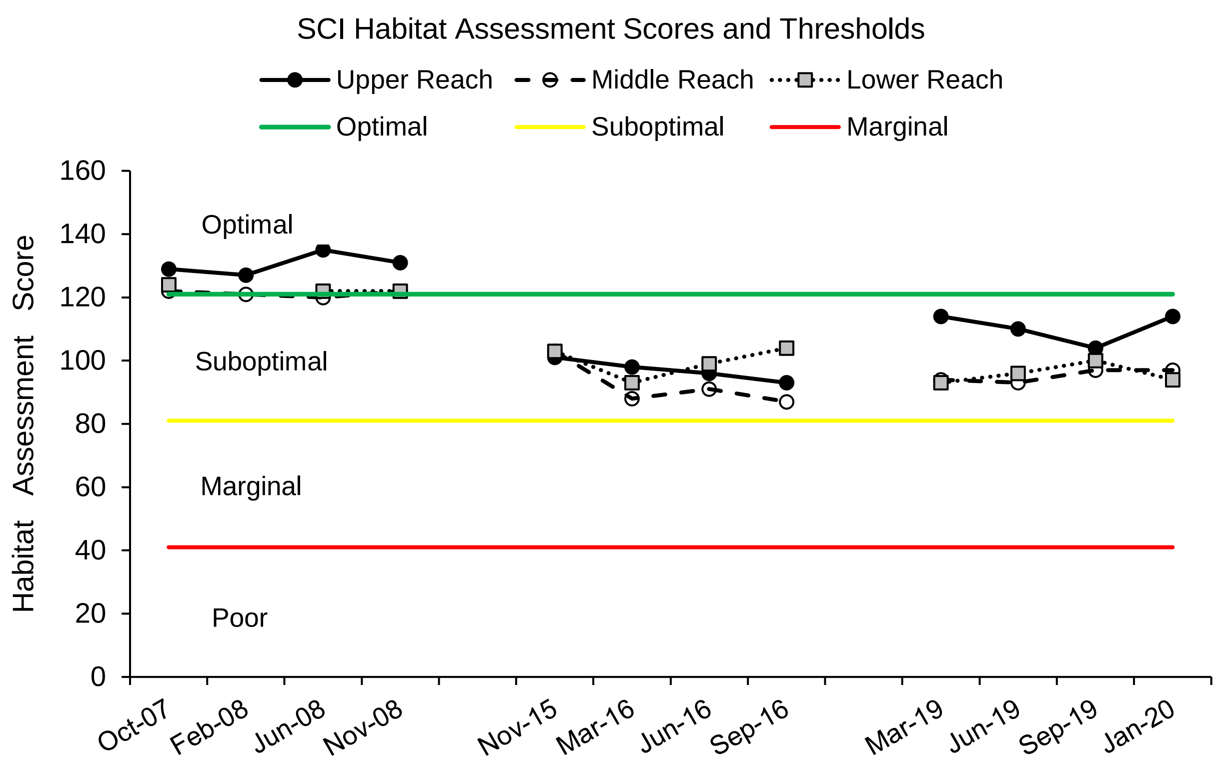


Figure 23. SCI habitat assessment scores and thresholds for Blue Spring and Run in 2007-2008 (DEP data) and 2015–2016 and 2019–2020 (SJRWMD data).

The SCI scores from the 2007–2008, 2015–2016, and 2019–2020 indicate an “impaired” condition (Figure 24). Blue Spring and Run are located within the Peninsular Bioregion, and an

SCI score <40 indicates impairment based on the condition of the macroinvertebrate community. This has been seen in prior work with macroinvertebrate communities in Blue Spring and Run (Wetland Solutions, Inc. 2009; DEP 2008). As noted previously, this is primarily a natural condition due to the very hypoxic conditions in the spring run, along with high TDS concentrations. In 2007–2008, the upper and lower reaches displayed higher SCI scores during the one year of quarterly sampling. Scores ranged from 4 to 15 among all three reaches. In 2015–2016 and 2019–2020, the lower reach consistently displayed the highest SCI scores during the year of sampling, and scores ranged from 0 to 25 among all three reaches. SCI scores were similar or higher in the upper and middle reaches in 2007–2008 versus 2015–2016 and 2019–2020 (Figure 24).

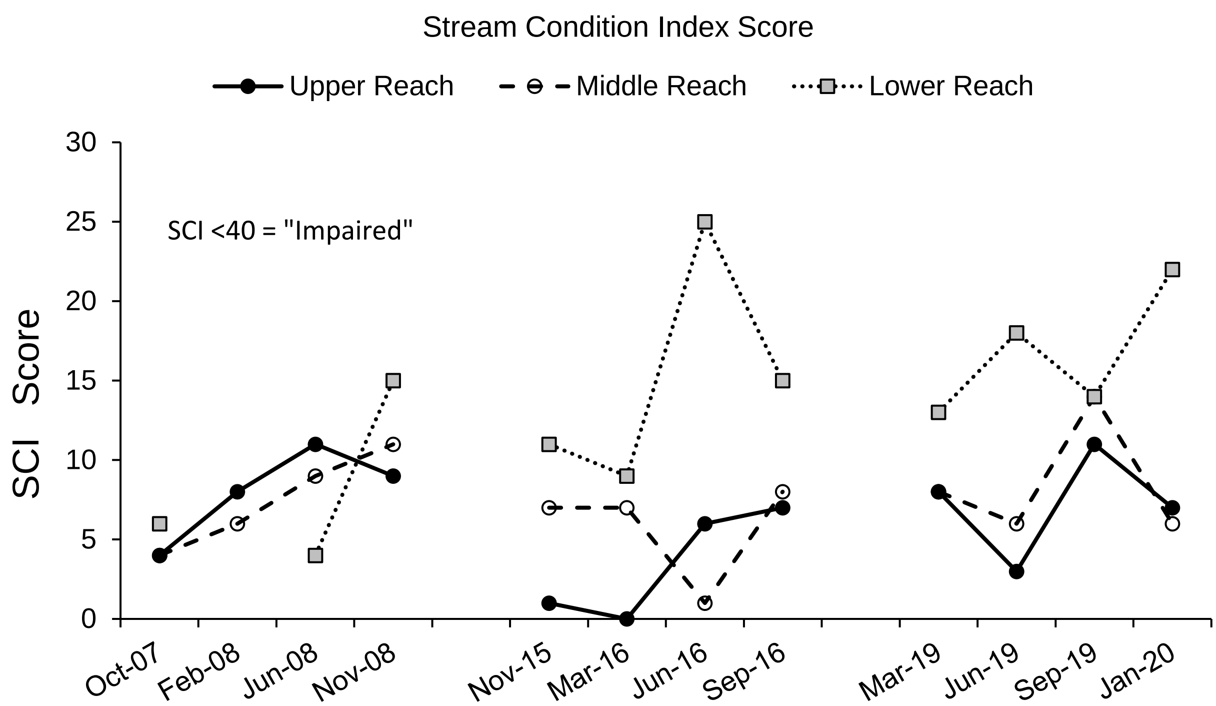


Figure 24. Stream Condition Index (SCI) scores in Blue Spring and Run in 2007–2008 (DEP data) and 2015–2016 and 2019–2020 (SJRWMD data).

Total taxa richness (the number of species, genera, and/or families of invertebrates collected) displayed almost the same patterns as the SCI scores (Figure 25), indicating that it was a major contributor to the overall SCI score. The other component metric which occasionally influenced the SCI score was the “Percent dominant taxon” — the relative abundance (as % of the total individuals collected in the sample) of the most abundant single invertebrate taxon. In both

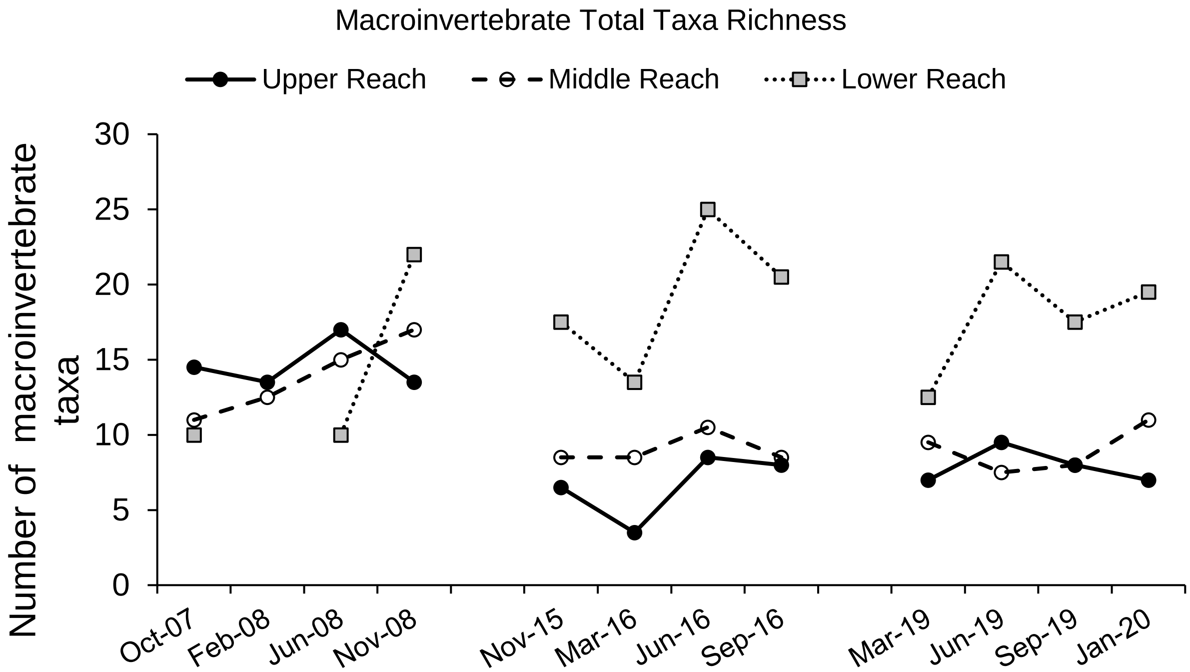


Figure 25. Total taxa richness of macroinvertebrates in Blue Spring and Run collected during SCI sampling.

sampling periods, these tended to be the hydrobiid snail *Pyrgophorus platyrachis*, amphipods in the *Hyalella azteca* group, the oligochaete *Limnodrilus hoffmeisteri*, other hydrobiid snails, or chironomid midges. Very few or no invertebrate taxa in other SCI components (EPT taxa, sensitive taxa, long-lived taxa) were collected in Blue Spring and Run. Rarely, an individual baetid mayfly nymph or hydroptilid caddisfly larva would be collected in the SCI sampling.

Fish Populations. Overall lowest fish taxa richness was usually observed at the most upstream sampling reach, Station 1 (Figure 26) during the monitoring periods of 2014–2015 and 2019–2020. Generally, highest fish taxa richness was seen at a downstream transect, typically Stations 2, 3 or 4. Station 5 was frequently difficult to sample due to water conditions (water depth, color, etc. which limited observation ability), but when it could be sampled, taxa richness was usually similar to Stations 2-4 (Figure 26). Generally higher fish taxa richness was seen in 2019-2020 (Figure 26)

Highest fish population density (#/m^2) was typically seen at one or more of the three upstream reaches (Stations 1-3; Figure 27). Lower fish population density was seen at the two lower reaches during both monitoring periods in 2014–2015 and 2019–2020. Fish population density appeared reduced in 2019–2020. Work and Gibbs (2020) pooled the data from all sampling dates that they sampled fish in Blue Spring (2001–2003, 2007–2008, 2014–2015, and 2019–2020) and found that the upstream reach, Station 1, exhibited significantly higher fish population densities than the downstream reaches (Figure 28), largely due to the high abundance of poecilid fishes

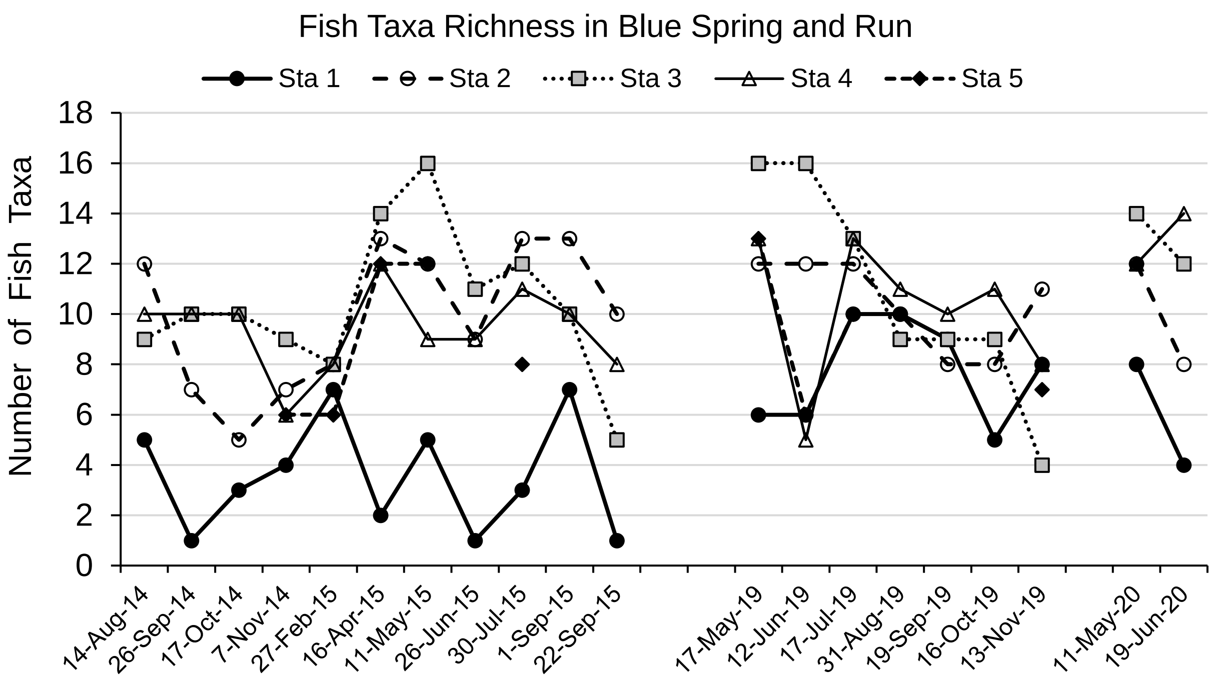


Figure 26. Total fish taxa richness at the five fish monitoring reaches in 2014–2015 and 2019–2020.

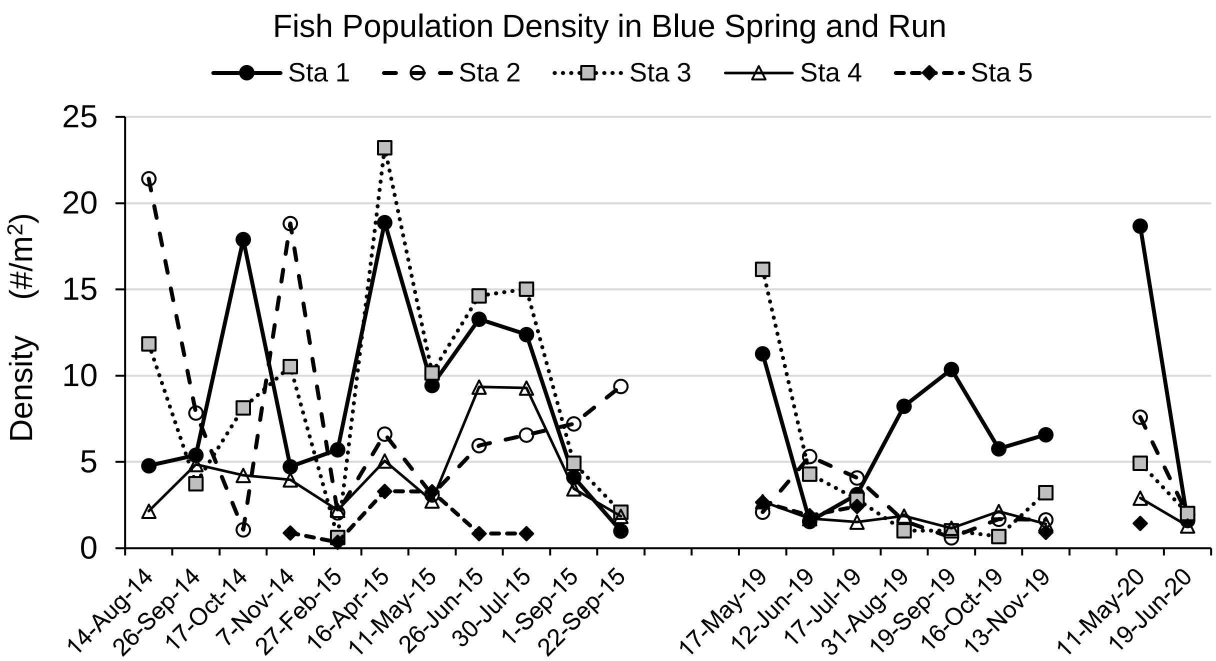


Figure 27. Fish abundance (as density, #/m^2) at the five fish monitoring reaches in 2014-2015 and 2019-2020.

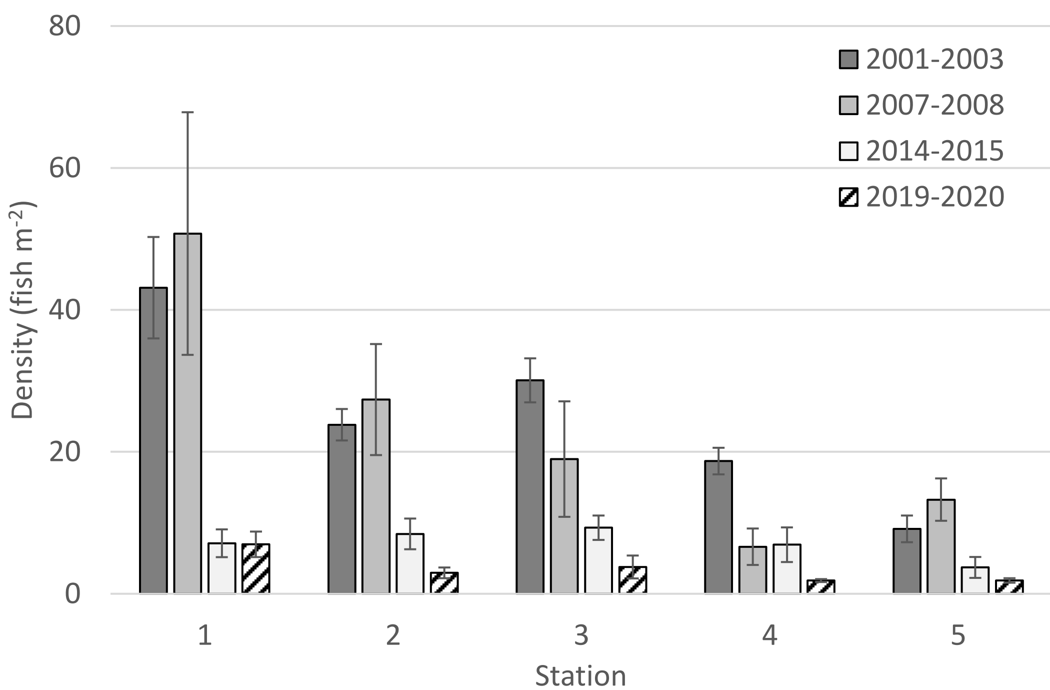


Figure 28. Overall changes in fish abundance (density) at the five sampling stations pooled for the four sampling periods. Source: Work and Gibbs 2020.

(Mosquitofish, *Gambusia holbrooki*; Sailfin molly, *Poecilia latipinna*; and Least killifish, *Heterandria formosa*), which were often the only fish observed at Station 1 (this study and Work et al. 2010).

Similar to fish taxa richness, diversity as measured by H' (Shannon-Weiner Index) was lowest at the most upstream sampling reach (Station 1; Figure 29) generally throughout both monitoring periods. Diversity was similar or higher at the four downstream reaches (Figure 29). Work and Gibbs (2015) pooled fish diversity from four sampling periods (2001–2003; 2007–2008; 2014–2015; and 2019–2020) and found significantly lower diversity at Station 1 compared with the four downstream stations (Figure 30). Overall, fish diversity in Blue Spring and Run was low and never exceeded an H' value of 1.00. This appears largely due to high relative abundance of a few fish taxa (mostly poecilids), thus contributing to low evenness (= relative abundance) in the H' index, although taxa richness was also low (1-3 fish taxa) and a contributor to low fish diversity.

Fish abundance was significantly lower in the 2019–2020 monitoring period than in prior monitoring efforts (Work and Gibbs 2020), including the first MFR monitoring effort in 2007–2008 (Figure 31). Work et al. (2010) noted the high level of variation in abundance of fishes in Blue Spring, which they attributed to a combination of migration of species from the adjacent St. Johns River and the periodic incursion of higher numbers of predatory fish into Blue Spring Run. High variation in abundance can be seen in Figures 27 and 28, both spatially and temporally

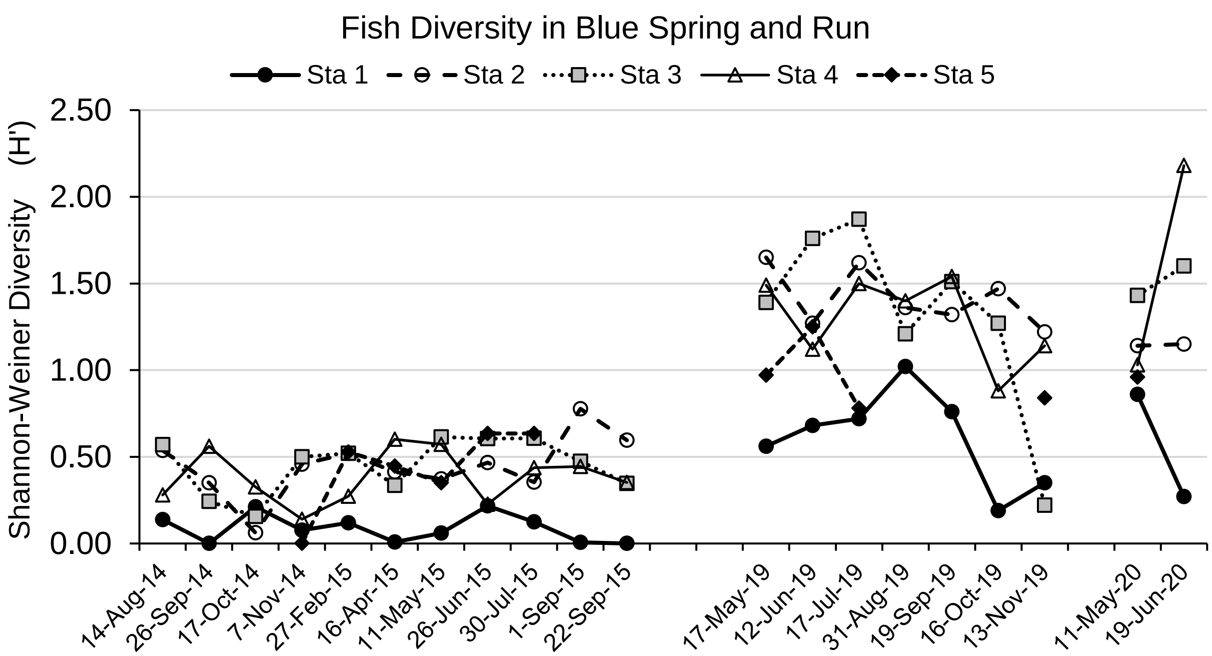


Figure 29. Fish diversity (H' – Shannon-Weiner Index) at the five fish monitoring reaches in 2014–2015 and 2019–2020.

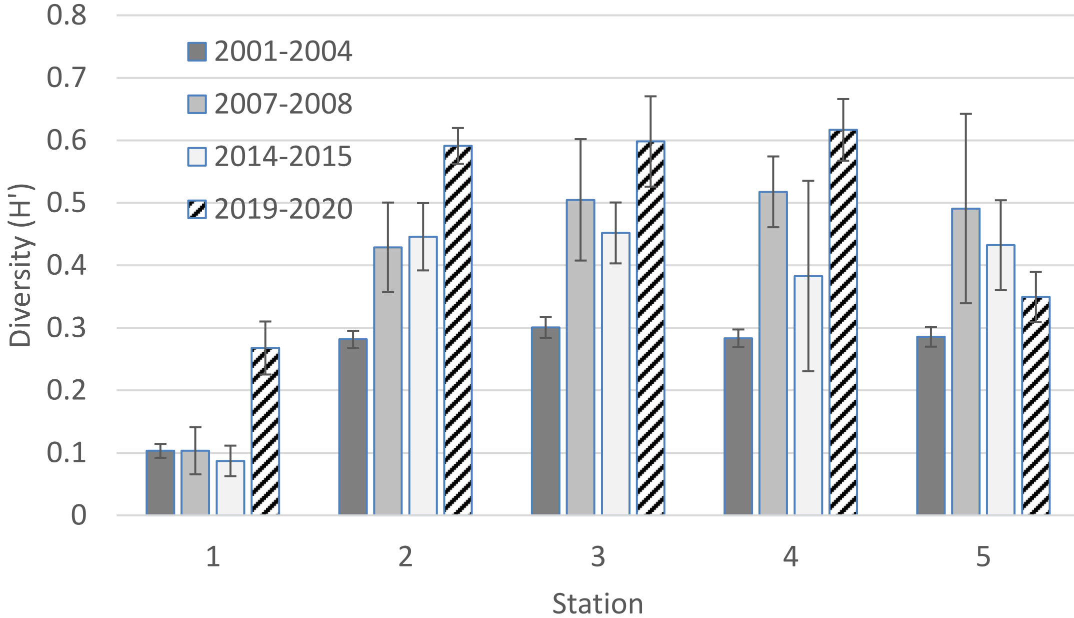


Figure 30. Overall changes in fish diversity (H’) at the five sampling stations for the four sampling periods. Source: Work and Gibbs 2020.

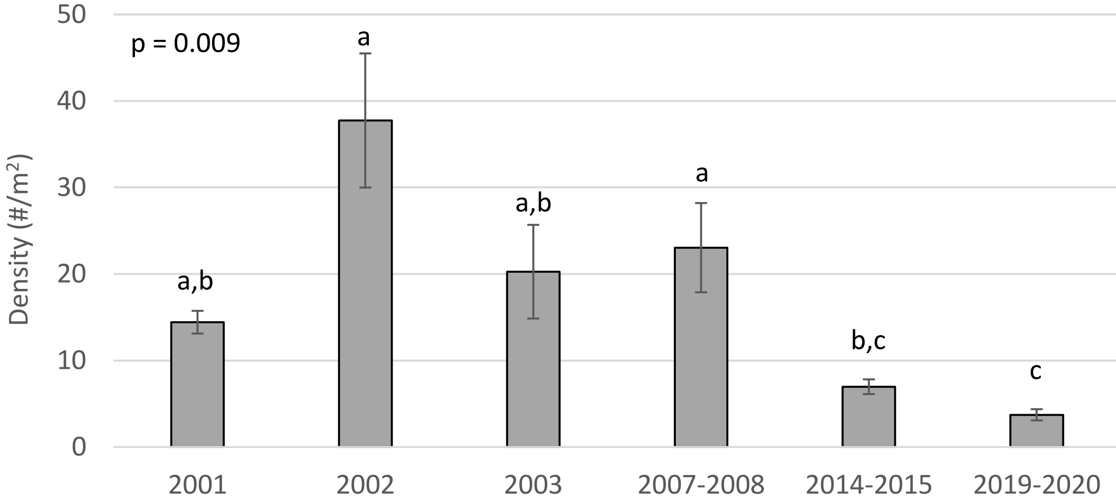


Figure 31. Changes in overall fish abundance (density, as $\#/m^2$) over time, all five sampling stations pooled for each year shown. Years with same letter are not significantly different. Source: Work and Gibbs 2020.

Fish diversity was similar to or somewhat higher in 2019–2020 compared to previous years’ fish population assessments in Blue Spring and Run (see Figure 16 in Work and Gibbs 2020 and

Figure 29 this report), particularly for the three sampling episodes conducted under the WRV monitoring.

Ecosystem Function

Ecosystem Metabolism. The measurement of functional attributes such as gross and net primary production (GPP and NPP, respectively) and community respiration (CR) provides a broader view of how an ecosystem is "working," in addition to measurement of structural attributes such as taxa richness, abundance, and diversity of plants and/or animals. In 2007–2008, community metabolism was measured with multiple DO sondes using the "two-station" method of Odum (1957). This enabled estimation of metabolism in the upper half and the lower half of Blue Spring Run. In subsequent years, the "single-station" method was employed using continuous DO collected at the location of the USGS flow gauge at VBS 330; this enabled estimation of metabolism only in the upper half of the run.

Highest GPP was measured in 2011–2012 (Figure 32). When multiple stations were used, slightly higher GPP was seen in the lower half of the run, and overall GPP was highest for the spring run as a whole (Figure 32). NPP was negative in all portions of the spring run in 2007–2008 and in the upper reach in 2008–2009 but was positive in subsequent years (Figure 33). Highest NPP across years was seen in 2009–2010. Peak GPP and NPP generally were seen in the late spring or summer months in both segments and in the spring run as a whole (Wetland Solutions, Inc. 2010; 2011; 2012). Community respiration (CR) was also generally highest

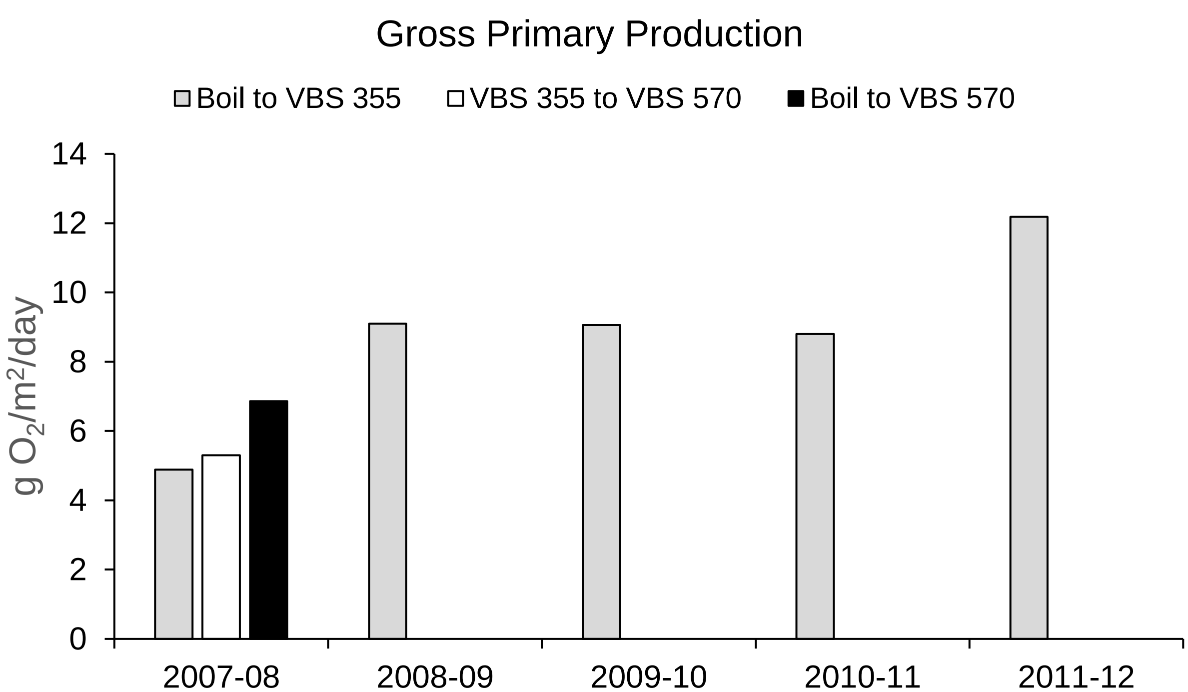


Figure 32. Gross primary production (g O_2/m^2/day) in Blue Spring and Run.

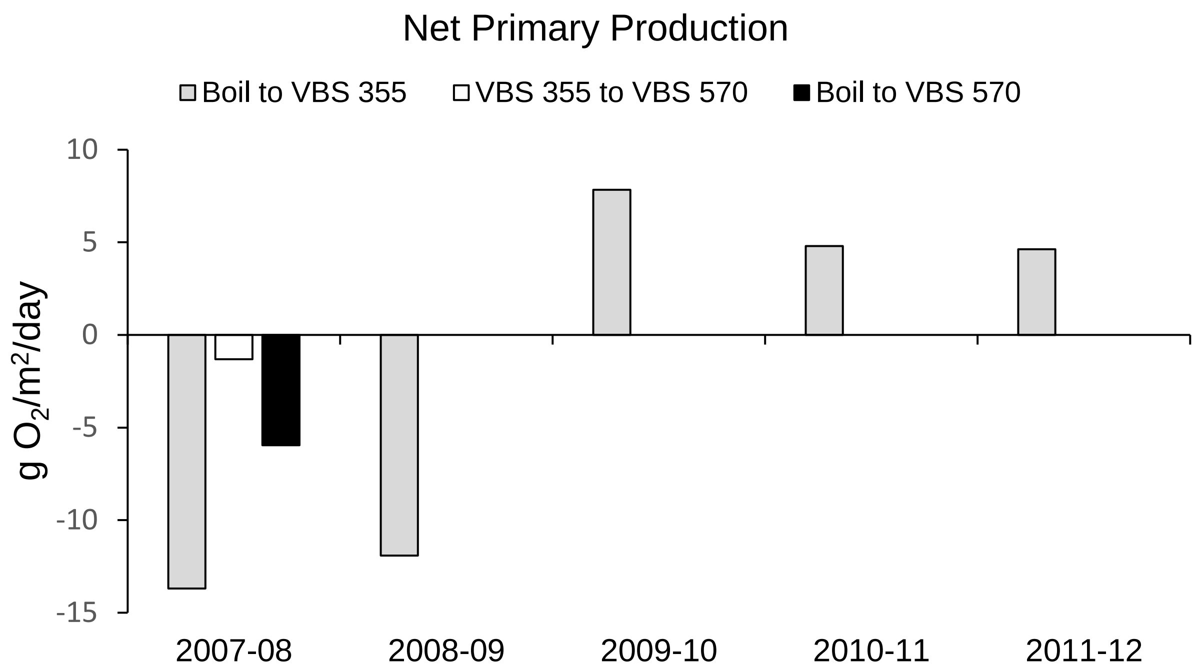


Figure 33. Net primary production (g O_2/m^2/day) in Blue Spring and Run.

during the summer (Wetland Solutions, Inc. 2010; 2011; 2012). The Production/Respiration (P/R) ratio is the ratio of GPP to CR. It indicates whether or not an ecosystem is net autotrophic (P/R > 1) or heterotrophic (P/R < 1). Both segments and the spring run as a whole were net heterotrophic in 2007–2008 and 2008–2009, but the upper segment was autotrophic 2009–2012 (Figure 34). Highest P/R ratio was seen in 2009–2010.

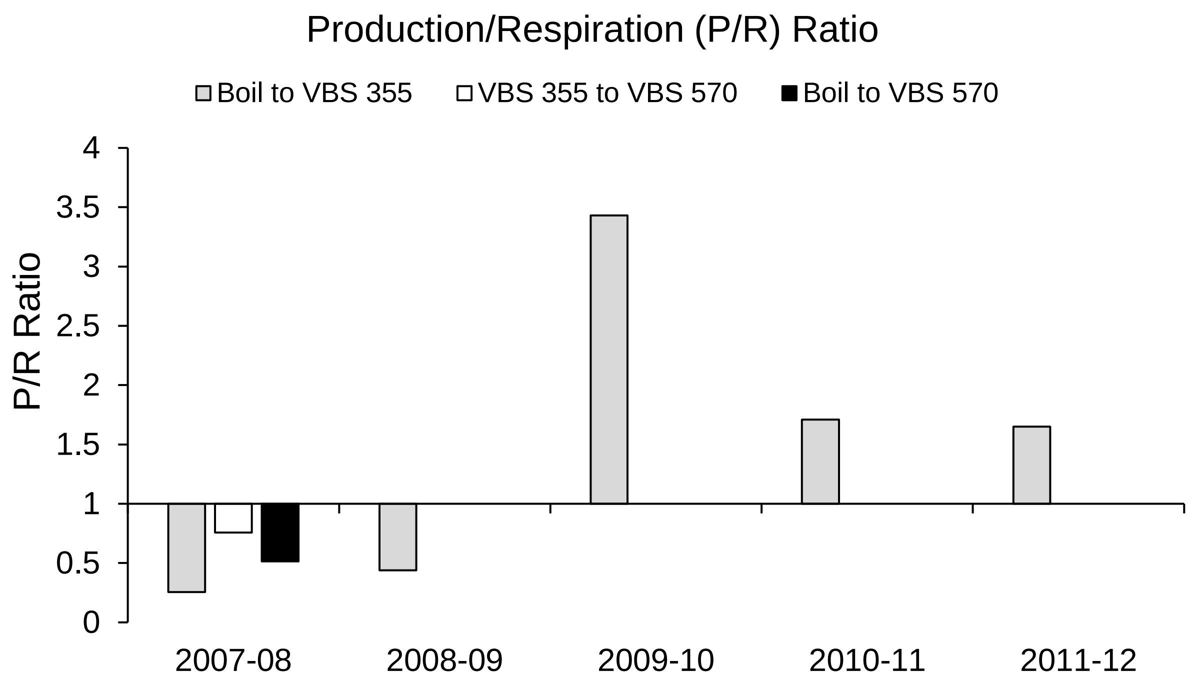


Figure 34. The Production/Respiration ratio for Blue Spring and Run.

Nutrient Assimilation. Nutrient assimilation was assessed throughout Blue Spring Run in 2007–2012 when multiple water quality stations were sampled in the run (Wetland Solutions, Inc. 2009; 2010; 2011; 2012). After 2012, water quality data were available at the long-term water quality site BLSPR and data were collected less frequently near the headspring at the diver entrance stair. Nutrient assimilation was calculated for this upper/headspring reach (Headspring/main boil to VBS330/355) when upstream/downstream data for this reach were concurrently collected (typically within a two-week window).

Nitrogen assimilation in the headspring reach of Blue Spring Run is shown in Figure 35. Both ammonium and TKN varied over time as to whether the compound was added/increased within the reach (negative assimilation) or whether it was reduced/assimilated within the reach (positive assimilation). Nitrate-nitrite N (NOx) and Total N were both consistently reduced (via uptake,

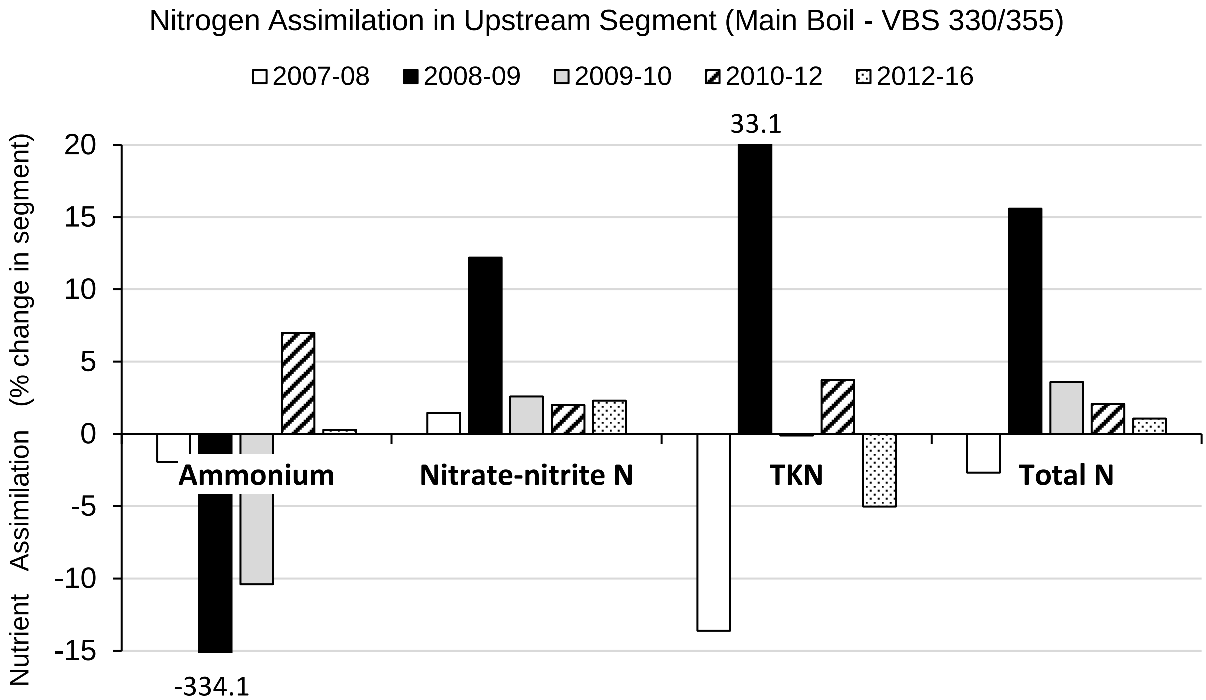


Figure 35. Nitrogen assimilation (as % change from upstream to downstream) in the headspring reach of Blue Spring Run. Note negative values indicate addition of the constituent in the reach.

denitrification, etc.) in the reach. NOx assimilation did not vary much from 2009 to 2016. Total N assimilation was negative in 2007–2008 and was lower in 2012–2016 than in 2009–2010 (Figure 35).

Phosphorus assimilation is shown in Figure 36. Both orthophosphate and Total P were consistently taken up in the headstream reach in most years, but both were exported from the reach in 2008–2009 (Figure 36). Highest orthophosphate assimilation was in 2012–2016 and highest Total P assimilation was in 2009-2010.

Human Use Monitoring

Total attendance data collected at the Blue Spring State Park entrance station indicate no trends in attendance for the period 2009–2020 (Figure 37), except when the park was closed during the COVID lock-down. This includes day use visitors and overnight visitors at the park campground. The overwhelming majority of attendance is day use (Wetland Solutions, Inc. 2009). As noted in prior WRV monitoring reports (Wetland Solutions, Inc. 2012), there are two annual peaks in visitor attendance at the park; a summer peak associated with swimmers, divers, etc., and a winter peak associated with manatee viewing. Monthly attendance for the period 2009–2020

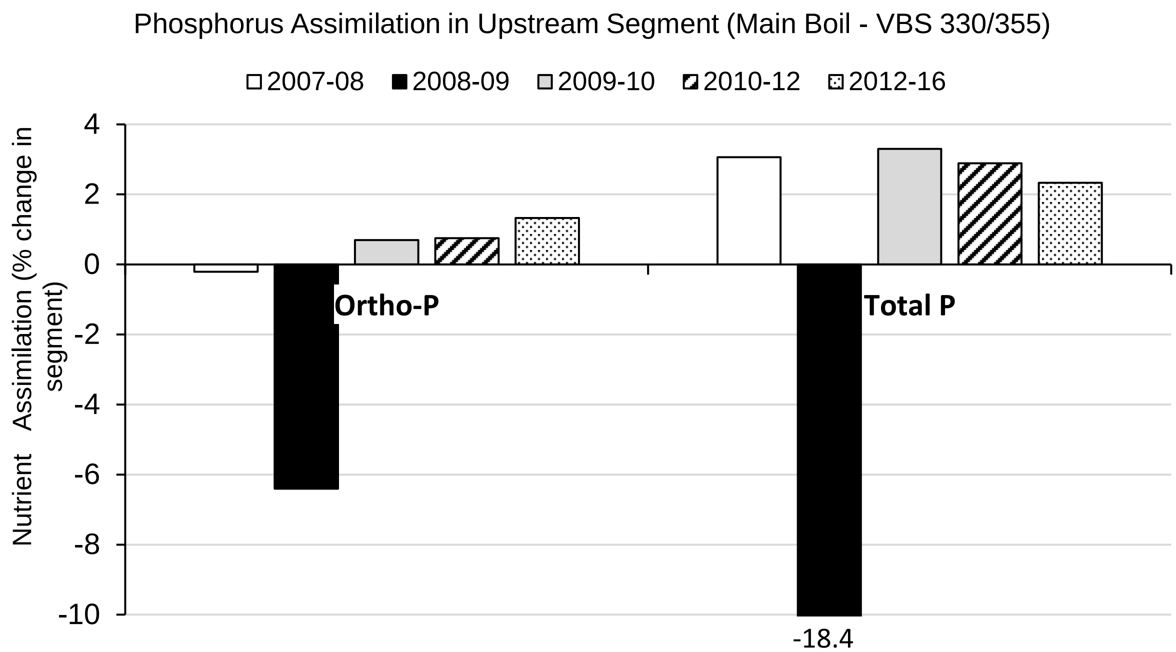


Figure 36. Phosphorus assimilation (as % change from upstream to downstream) in the headspring reach of Blue Spring Run. Note negative values indicate addition of the constituent in the reach.

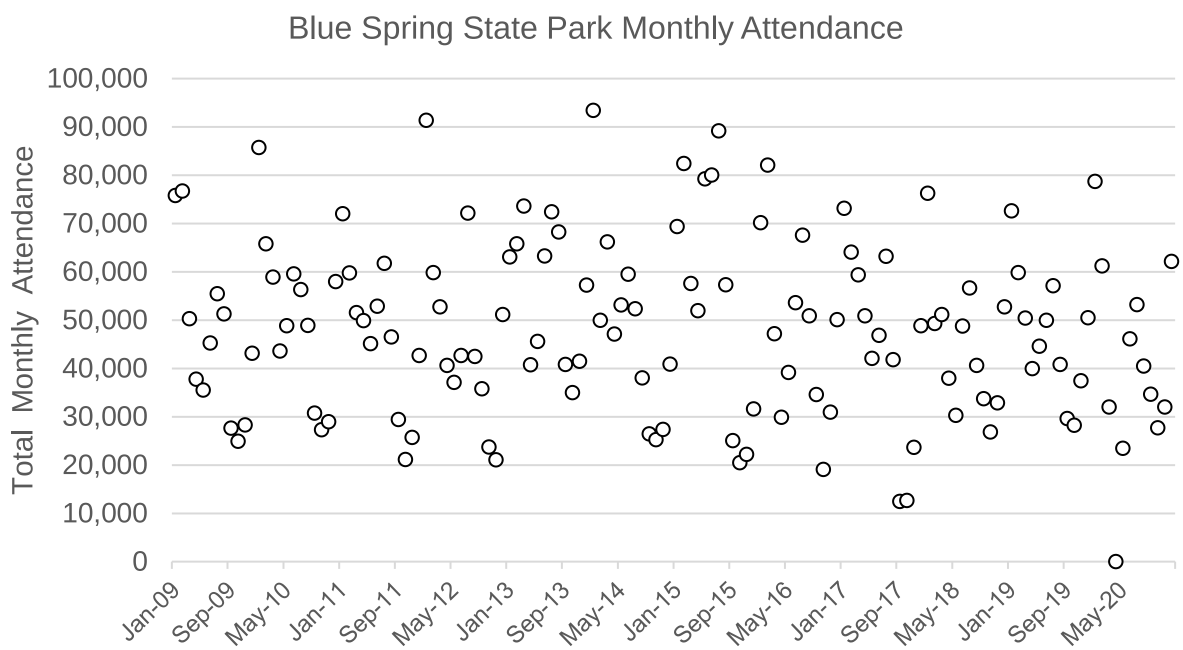


Figure 37. Total monthly attendance data for Blue Spring State Park 2009–2020. Source: Blue Springs State Park.

(when the park was open) ranged from 20,000 to over 90,000 visitors (Figure 37). In most years, highest monthly attendance was in January for the purposes of manatee viewing, with the summer peak being lower, except in 2015. Total annual attendance was over a half-million visitors to the park every year from 2009–2020.

A total of 418 visitor perception surveys were completed by park staff in 2013. 200 of these were completed in January and February 2013 (100 each month), and 218 were completed in June and July of 2013 (114 and 104, respectively). The total number of surveys completed were nearly the same as the number conducted in 2008 by Bonn Marketing Research (100 surveys in each of January, February, June and July of 2008 for a total of 400 surveys).

The surveys were not compiled, and copies of the raw survey forms were provided to SJRWMD. A random subsample of 60 surveys (15 each from January, February, June and July) were selected from the 418 and the responses to selected questions were tabulated for this subsample. The majority of respondents (60%) were from Florida and resided in the greater Orlando area. Visitors from other states included North and South Carolina, Pennsylvania, Virginia, Maryland, Michigan, Minnesota and New York. Visitors from other countries included England, Germany, and Norway.

Of the responses to the question, “Do you believe it is in the public interest to reduce spring flow in state parks to meet public water supply needs?”, 41 out of the subsample of 60 surveys listed a response; 83% of the responses were “No” (Figure 38), indicating that park users believed that

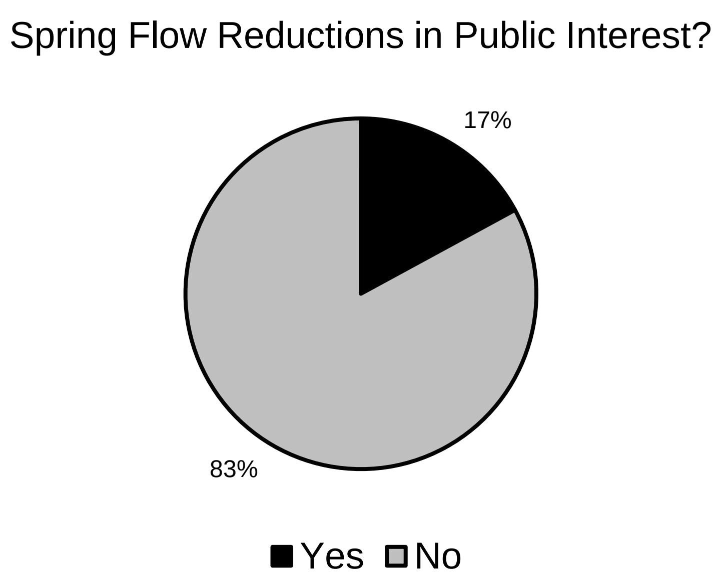


Figure 38. Responses to the question, “Do you believe it is in the public interest to reduce spring flow in state parks to meet public water supply needs?”.

spring flow reductions were not in the public interest, even if the purpose was to meet public water supply needs. For the question "What percentage of flow could be lost before you considered it to constitute significant harm to aesthetics, swimming or diving experience, or positive visitor experience?" only 23 out of the subsample of 60 responded to this question. The majority of those who responded to this question (74%) believed that a reduction of greater than 10% would constitute significant harm to one of the listed experiences. At least some of these answered "zero" to this question, suggesting that they did not want to see spring flows reduced. At the same time, a few responses were on the order of "50–70%" and "75–100%", which, along with the low response rate, might suggest that visitors may not have entirely understood the question.

Visitors were asked, "Please rate the importance of Florida State Park springs, lakes, and rivers to your quality of life." The scale ran from 1 (Very Unimportant) to 7 (Very Important). All 60 surveys in the subsample had a response to this rating, and the average of the responses was 6.4, indicating that park visitors regarded State Park springs and other aquatic resources as important to very important for their quality of life.

In response to the question, "If you knew the alternative water supply source (other than groundwater) could be developed so as to not reduce spring flows in state parks, would you be willing to pay more for them on your monthly water bill?", 85% of the respondents (52 out of 60) answered "Yes", they would be willing to pay more on their bill (Figure 39).

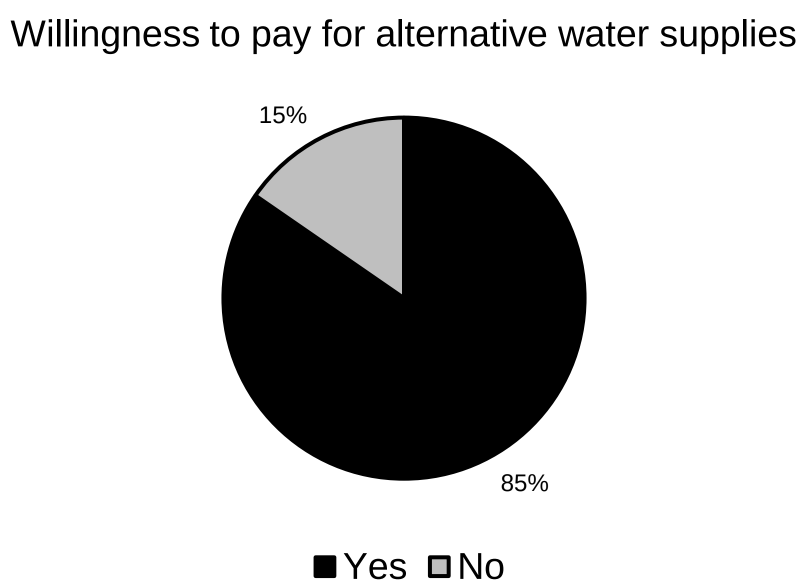


Figure 39. Responses to the question, "If you knew the alternative water supply source (other than groundwater) could be developed so as to not reduce spring flows in state parks, would you be willing to pay more for them on your monthly water bill?".

PROTECTION OF WATER RESOURCE VALUES

As noted earlier in this report, the MFR adopted for Blue Spring and Run is required to consider the protection of the water resource values (WRVs) specified in Chapter 62-40.473 F.A.C. Of the ten WRVs listed in that rule, the following seven are considered relevant to Blue Spring:

- Recreation in and on the water
- Fish and wildlife habitats and the passage of fish
- Transfer of detrital material
- Aesthetic and scenic attributes
- Filtration and absorption of nutrients and pollutants
- Sediment loads
- Water quality

As indicated in the earlier section presenting results of hydrological (spring discharge) monitoring 2010–2016, discharge from Blue Spring was lower for the period 2011–2015. Overall, discharge in Blue Spring has been exhibiting a declining trend over the past 20–30 years. Identifying and implementing alternative water supply and water conservation projects that reduce groundwater withdrawals in the Blue Spring springshed will aid in recovering spring discharge to meet the adopted long-term mean of 157 cfs.

Recreation in and on the water/Aesthetic and scenic attributes

Wetland Solutions, Inc. (2009) noted that the two main human recreational uses of Blue Spring and Run are:

1) Swimming, snorkeling, and SCUBA diving in the spring during the period April-October, when the run is open to human use and during hot weather;
2) Manatee viewing on the boardwalks running along the spring run in November-March when the spring run is closed to human use and manatees are using the spring as a warm-water refuge during the winter.

Comparison of spring flows with total visitor usage indicated no relationship between discharge and visitor number (Wetland Solutions, Inc. 2009). Visitor perception surveys conducted in 2003 and again in 2008 (results reported in Wetland Solutions, Inc. 2009) indicated that a large majority of the public using the spring (75–82%) believed that reductions in spring discharge in State Park springs such as Blue Spring due to adjacent groundwater withdrawal was not in the public interest. Survey questions asked of spring visitors in 2008 addressed what magnitude of spring discharge reduction would be considered “significant”, and the average of the responses was on the order of 10–12% reduction in flow. To the extent that the adopted MFR for Blue Spring has a long-term target of restoring and maintaining the historical annual mean flow of Blue Spring, the WRV pertaining to recreation in and on the water and aesthetics should be protected, as this reflects historical conditions in the spring which have always supported recreation and contributed to aesthetic value.

The subsample of visitor survey results obtained by the park staff in 2013 reflects many of the same perceptions as the earlier surveys. The majority of the people who visit and use Blue Spring continue to believe that reductions in spring flow, even if due to public supply, are not in the public interest, and an apparent majority regard a reduction in spring flow of 10% or greater to be significantly harmful. The paucity of answers to this latter question (what reduction in spring flow would be significant harm) suggests that it was a difficult question for park visitors to grasp. Park visitors also indicated that they are willing to pay more on their monthly water bill to fund alternative water supplies to prevent or reduce impacts to spring flows in state parks. Many of these indicated that they would be supportive of a “minimal” or “moderate” increase in their bill, but a few visitors indicated that they would be willing to pay a “substantial” increase.

Fish and wildlife habitats and the passage of fish

Manatee Monitoring. The manatee population using Blue Spring is part of the “Upper St. Johns River” manatee subpopulation, one of four regional manatee subpopulations, or management units, recognized by the USFWS (U.S. Fish and Wildlife Service 2001). Each of these groups is a relatively distinct, interacting population, with little interaction with other subpopulations (U.S. Fish and Wildlife Service 2001). The MFR adopted for Blue Spring and Run was largely based on provision of an adequate “usable warm-water habitat” to accommodate the growing manatee population (NewFields 2007). Wetland Solutions, Inc. (2009) compared manatee abundance with spring discharge for the period 1983-2008 and saw a slight positive (but not statistically significant) correlation of manatee abundance with spring discharge. The actual numbers of manatees currently using Blue Spring exceeds the projections made in 2006 (Figure 18), and overall, no incident of cold stress in manatees due to exclusion from the Blue Spring warm-water refuge has been documented to date. Regardless of the size or quality of a warm-water refuge, during prolonged cold spells manatees will often make short trips to foraging areas, which exposes them to cold waters for variable periods of time (Deutsch and Barlas 2016). This exposure can result in the development of small lesions, bleaching of skin, and other dermatological issues. The occurrence of slight cold exposure signs on a substantial proportion of manatees at Blue Spring may be due to this process or it may reflect cold exposure prior to arrival at the spring. Thus far, the adopted MFR appears to be protecting manatees on the St. Johns River by providing an adequate volume of warm-water refuge habitat in winter for the growing St. Johns River manatee population.

General Biological Structure Monitoring. The data from the monitoring of algae and aquatic plants, snails, macroinvertebrates, and fish were compared with discharge to evaluate relationships and assess whether other ecological characteristics (beyond manatees) were being protected as part of this WRV.

Prior work has found significant negative relationships between current velocity and algal abundance as cover (King 2014; Reaver et al. 2019). A current of approximately 0.2-0.25

m/second has been identified as a threshold, above which more significant algal sloughing and loss occurs, generally reducing overall algal abundance as cover. The earlier algal data collected in 2007–2008 by DEP could not be compared or combined with the cover data collected in 2014–2015 and 2017–2019 due to differing methodology of collection. Current velocity data at the time of cover measurement were also not collected in 2014–2015 for comparison with algal cover. As a surrogate, the mean monthly spring discharge in the month algal cover data were collected was compared with the 2014–2019 algal cover to investigate possible relationships between algal abundance and spring discharge/current velocity in the run. There was no relationship between spring discharge and algal cover (Pearson r = 0.089; P=0.807). Additional algal monitoring is now being conducted as part of the ongoing SJRWMD spring run SAV monitoring program to collect additional algal cover data, and this includes measurement of current velocity at the time of collection of algal data. To the extent that increased spring discharge over the long term should generally be associated with higher current velocities in the spring run, the adopted MFR for Blue Spring should not promote or allow for proliferation of macroalgal mats.

The abundance of snails (2007–2008, 2014–2015, and 2019–2020 data sets combined) was compared with mean monthly spring discharge for the month snail samples were collected (Figure 40). A weak positive relationship was seen between discharge and snail density, but it was not statistically significant (Pearson r = 0.29; p=0.17). Generally higher snail abundance values were seen at a discharge ≥130 cfs (Figure 40). Lowest snail abundance was also seen above this apparent threshold, but it may be a useful statistic to use in the future, as all of the higher snail densities were above this flow. Based on this, the adopted MFR for Blue Spring and Run should be protective of snail populations in Blue Spring, including the endemic species.

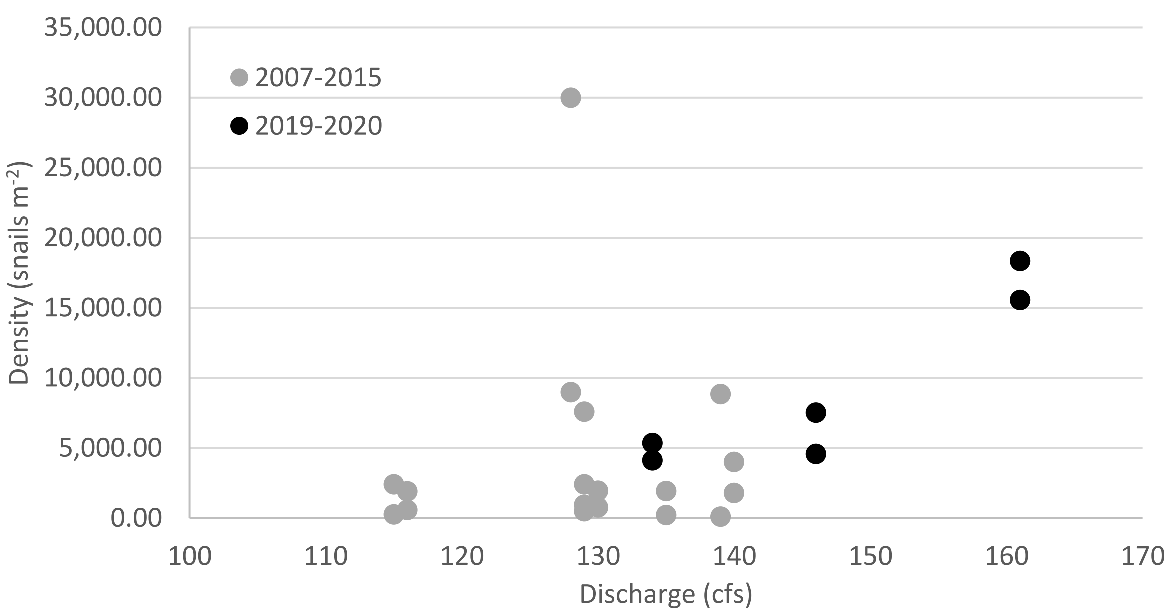


Figure 40. Plot of total snail abundance versus mean monthly discharge the month snail samples were collected in Blue Spring and Run. Source: Work and Gibbs 2020

The SCI work done in 2007–2008 and earlier showed a significant positive correlation between quarterly spring discharge and the magnitude of the SCI score, with higher scores at higher spring flows (Figure 5-3 in Wetland Solutions, Inc. 2009). To conduct a comparable analysis, quarterly spring discharge values were calculated using the mean monthly discharge for the month SCI data were collected averaged with the mean discharge for the prior two months. These spring flow data were compared with the overall mean SCI Score for the month by averaging together the scores from the three reaches in 2007–2008, 2015–2016, and 2019–2020. Earlier SCI scores collected by DEP (single values, not average of three reaches) from May 2007 and 2006 and April 2005 were added to this data set (with a comparable quarterly spring discharge value). Results are in Figure 41.

There was a significant positive relationship (Pearson r = 0.771; P=0.002) between quarterly spring discharge and SCI score (compare with Figure 5-3 in Wetland Solutions, Inc. 2009). SCI scores collected from Blue Spring Run earlier than 2005 were not used because the index has been recalibrated from these earlier data, so they are not entirely comparable. Based on the earlier results of Wetland Solutions, Inc. (2009) and Figure 41, the adopted MFR should be protective of the overall macroinvertebrate community and will generally result in a more diverse, productive community as measured by the SCI Score.

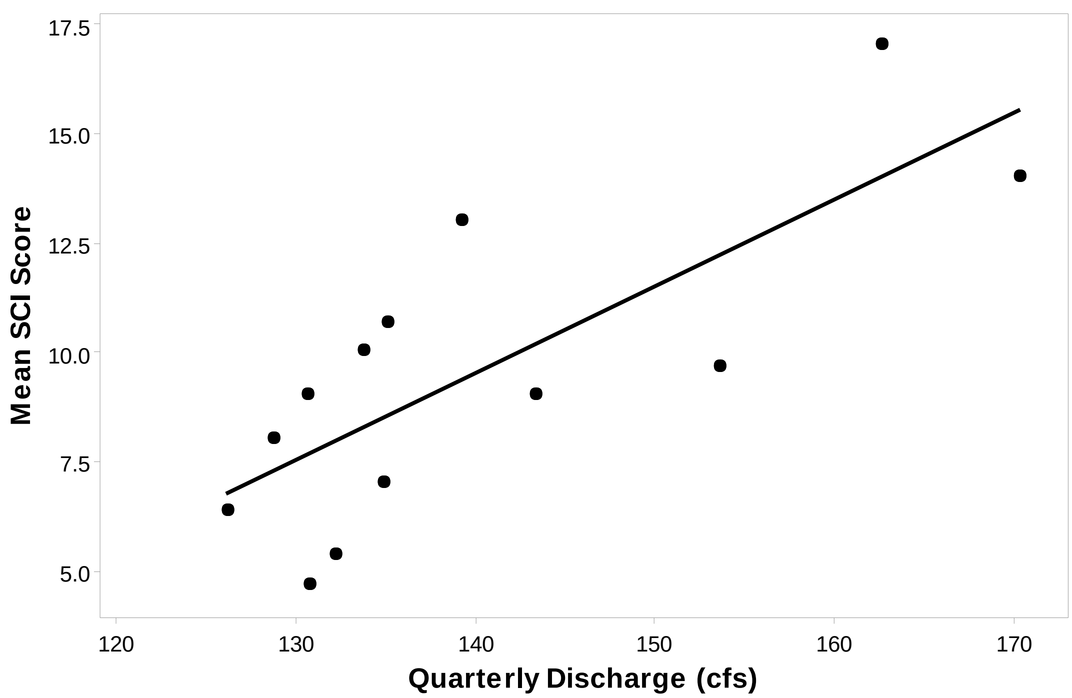


Figure 41. Comparison of quarterly spring flow (cfs) and mean SCI score for data from April 2005 to September 2019. See text for description of how the values plotted were calculated.

Work and Gibbs (2020) found somewhat weak but statistically significant positive relationships between spring flow and fish abundance and diversity (Figure 42). For the natural log of abundance versus spring discharge, Pearson r = 0.398 (p=0.006) and for diversity versus flow, Pearson r = 0.327 (p=0.025). In general, highest fish abundance and diversity were seen at spring discharges of about 130 cfs or greater, similar to the snail density data, again suggesting this might be a useful threshold to guide any revisions of the MFL. Overall, this suggests that the currently adopted MFR of a long-term mean spring flow of 157 cfs should be adequately protective of the fish community in Blue Spring Run.

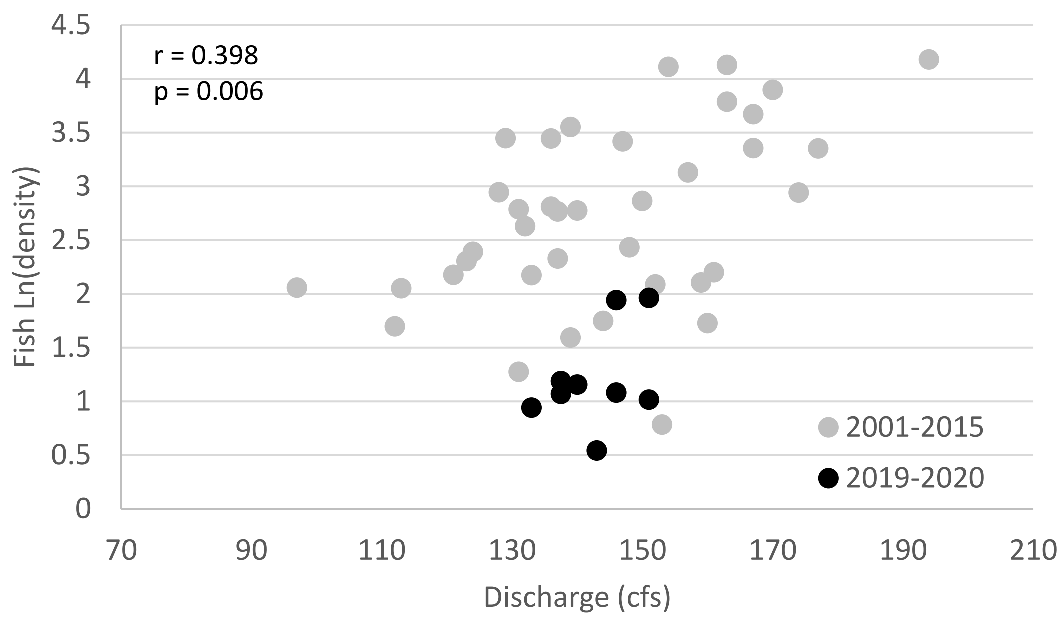
DO is one of the other main factors influencing fish populations in Blue Spring and Run, particularly because it is so low. Work and Gibbs (2020) found significant positive relationships between DO and fish populations (Figure 21 in Work and Gibbs 2020). Lowest fish community diversity values (near or equal to zero) were mostly seen at DO concentrations <1 mg/L. Both Wetland Solutions, Inc. (2009) and Work and Gibbs (2015; 2020) found that these low concentrations could occur across a range of spring flows, from 100 cfs to over 150 cfs. Based on this, the adopted MFR will have little to no effect on DO concentrations, as other factors appear to be more influential (volume of low-DO spring water discharged from the vent vs. spring run volume, photosynthetic activity, etc.).

Work et al. (2010) also stated that predation pressure on small fishes (poecilids and cyprinids) could be a factor influencing their abundance and occurrence in the spring run. Schlosser (1987) found that small-bodied fishes (darters and cyprinids) occurred at highest densities in shallow riffle and raceway habitat in a small warmwater stream in Illinois. This enabled them to escape predation from larger piscivore predators. Work et al. (2010) noted that smaller-bodied species in Blue Spring Run tended to be confined to or more abundant in shallow-water areas, primarily in middle reaches of the run. These areas also appear to have higher DO concentrations than the deeper, mid-channel portions of the spring run, as noted earlier (Work and Gibbs 2015).

Transfer of detrital material/Sediment loads

In the initial monitoring effort conducted in 2007–2008, plankton nets were left suspended in the water column at various locations in Blue Spring Run to measure particulate export (Wetland Solutions, Inc. 2009). This component of the monitoring was not continued in the period 2009–2020. Results from the first intensive monitoring effort in 2007-2008 (Wetland Solutions, Inc. 2009) indicated that particulate export rates were higher in the upstream segment of the spring run (Headspring to VBS 355) than the lower reach (VBS 355-VBS 570). Overall, of the total amount of dry matter collected in the plankton nets (as g dry matter/day), the majority was inorganic in nature (mineral material such as particles of sand, silt, etc.); organic material export was mostly a combination of algal cells and fragments, organic detritus, and bacteria (Wetland Solutions, Inc. 2009).

No statistically significant relationships were found to exist between downstream export of particulate material and spring discharge (Wetland Solutions, Inc. 2009). It was observed that particulate export rates were noticeably higher during periods when the spring and run are open



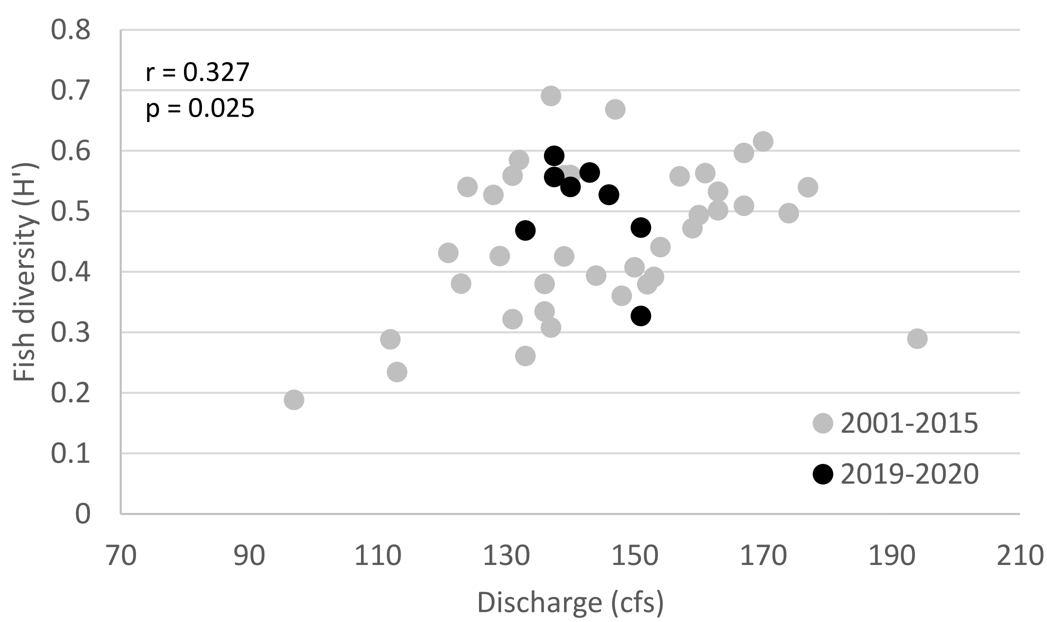


Figure 42. Comparison of fish abundance (as density) and diversity (H') with discharge for fish data collected in Blue Spring and Run 2001–2020. Source: Work and Gibbs 2020.

to human use, indicating that human activity is suspending material in the water column, which is then being transported down the run (Wetland Solutions, Inc. 2009). Based on this, the adopted MFR should not adversely affect the transfer of detrital material or sediment loads in Blue Spring Run. Wetland Solutions, Inc. (2009) noted that (pg. 5-9), ". . . downstream export of any materials in the water column would be enhanced by spring discharge.", and to the extent that the adopted MFR mandates meeting the historical long-term mean flow, these water resource values would not be adversely affected.

There was a weak, but statistically significant (ANOVA; $p < 0.001$) positive relationship between spring discharge and mean daily turbidity at the SJRWMD continuous monitoring site at VBS 330 (Figure 43). Examination of the time series, however, indicated that elevated turbidity in Blue Spring Run at this location is very seasonal, with peak levels during the summer, when swimmer/diver activity is high, and a lesser peak in the winter, possibly due to manatee or fish activity (Figure 44). From these results and the observations of Wetland Solutions, Inc. (2009), the amount of suspended material in the water column of Blue Spring Run is heavily influenced by human and perhaps biological activity and is not solely a function of spring discharge. Overall, these data don't indicate a strong relationship between flow and particulate or sediment transport measured as turbidity, suggesting that the adopted MFR will not adversely affect detrital transport or sediment load.

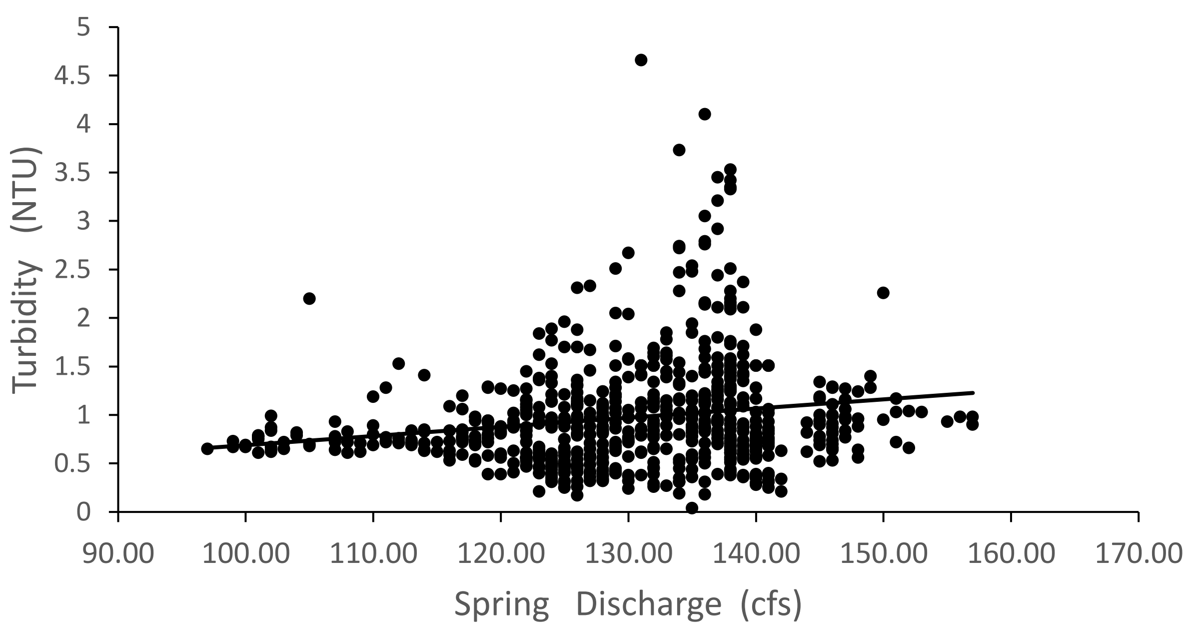


Figure 43. Relationship between spring discharge and daily measurement of turbidity at the SJRWMD continuous monitoring sensor at VBS 330 for the period 2014–2018 (after which continuous monitoring was discontinued).

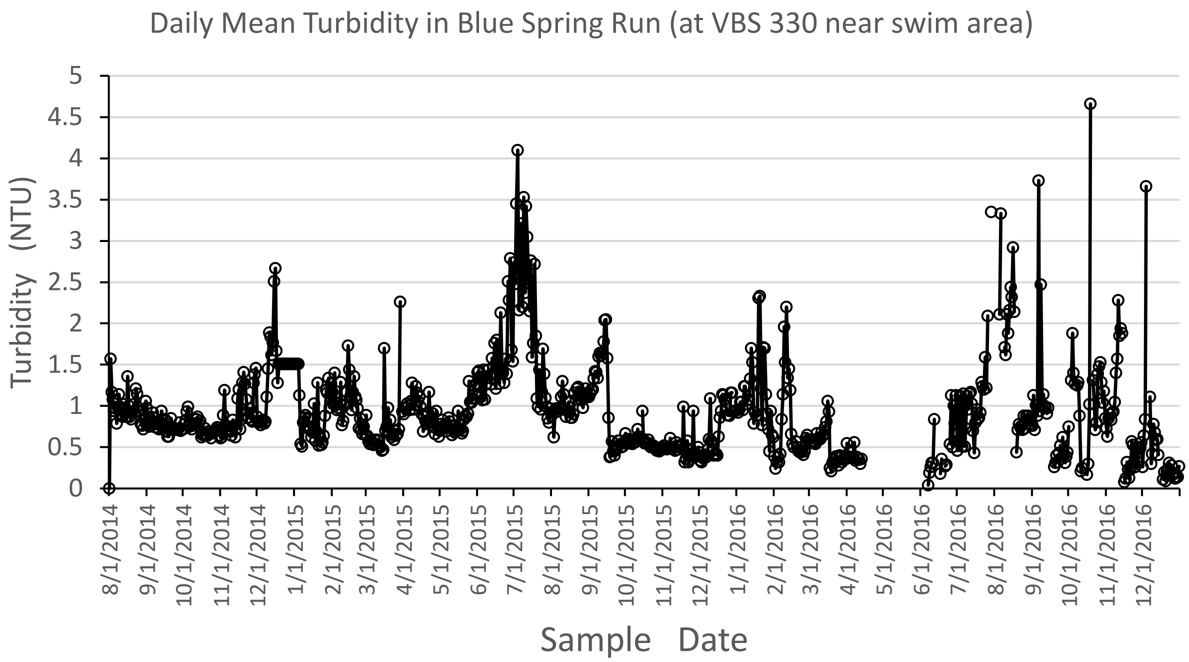


Figure 44. Time series of mean daily turbidity (August 2014–December 2016) at the SJRWMD continuous monitoring sensor at VBS 330.

Filtration and absorption of nutrients and pollutants/Water quality

The upper segment of Blue Spring Run (Headspring to VBS 330) exhibits reduced concentrations of Total N, Total P, NOx, and orthophosphate over its length (Figures 35 and 36), although not substantially. This is probably due to a combination of uptake/assimilation (both N and P), denitrification (for NOx and TN), and possibly dilution (under some conditions). The net positive GPP and NPP in this segment of the spring run (Figures 32 and 33) in 2009–2012 suggests that algal uptake of nutrients is related to these results.

Wetland Solutions, Inc. (2009) found a weak positive relationship between spring discharge and ammonium assimilation but no relationship between discharge and NOx assimilation. Similarly, they found weak, non-significant relationships between discharge and ecosystem metabolism measures; generally negative relationships in the lower segment and the entire spring run (e.g., lower GPP, NPP, and ecological efficiency at higher spring flows) and a weak positive relationship in the upper segment (higher GPP, etc. at higher spring flows). Generally, when NPP and the P/R ratio in the upper segment are indicative of heterotrophic conditions (Figures 32 and 33), then assimilation in that segment is generally more negative and it exports nitrogen and/or phosphorus (Figures 35 and 36).

Based on the current results, a moderately strong, but not statistically significant (ANOVA; p=0.107) positive relationship was exhibited between spring discharge and NOx uptake/ assimilation (Figure 45) in the upper segment (headspring to VBS 330/355). The opposite (negative) relationship was seen for Orthophosphate and discharge and TP and discharge (Figure 46), and these were also not statistically significant (ANOVA; p=0.139 for PO_4; p=0.150 for TP). Addition of phosphorus may be due to physical weathering by current from the exposed Hawthorn formation at the spring vent. At the long-term mean flow of 157 cfs, these relationships suggest that the upper reach of the run will be retentive of nitrate nitrogen but will export phosphorus. The MFR target mean annual discharge reflects historical conditions, and presumably the relationship in Figure 46 of export of phosphorus at higher flows may be a reflection of these historical conditions, and thus no adverse impact on Blue Spring Run or the downstream St. Johns River is anticipated. Until additional data and analysis can be conducted, the adopted MFR appears to satisfy the WRV pertaining to filtration and absorption of nutrients and other pollutants or would have no adverse effect on this WRV.

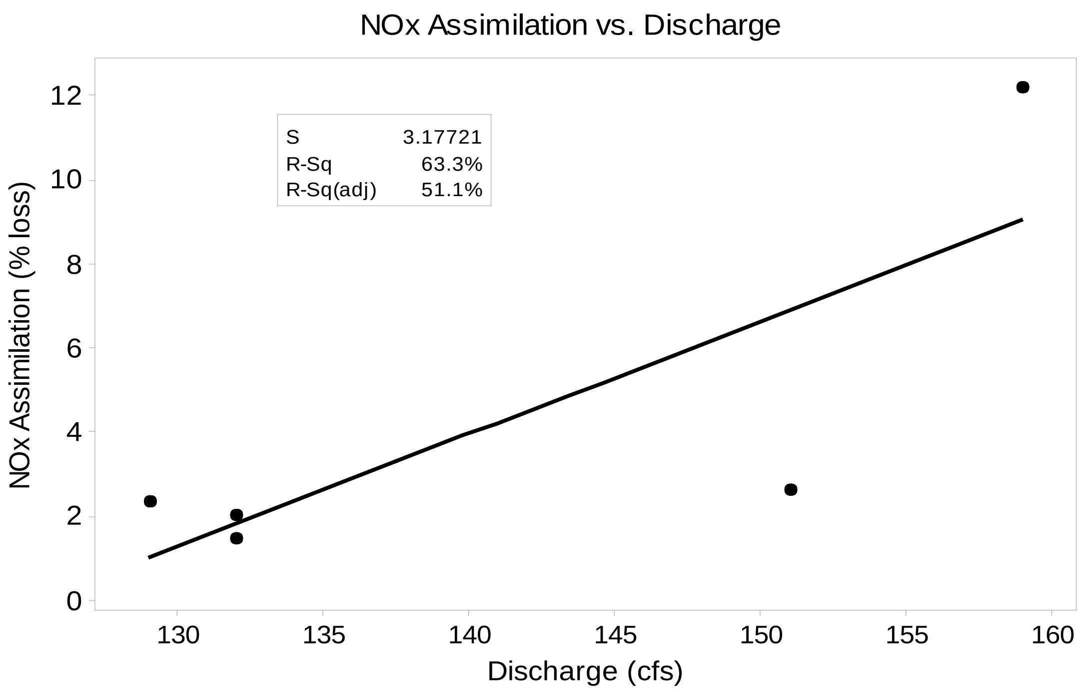


Figure 45. Spring discharge versus Nitrate-nitrite assimilation (%) in the upper segment of Blue Spring Run.

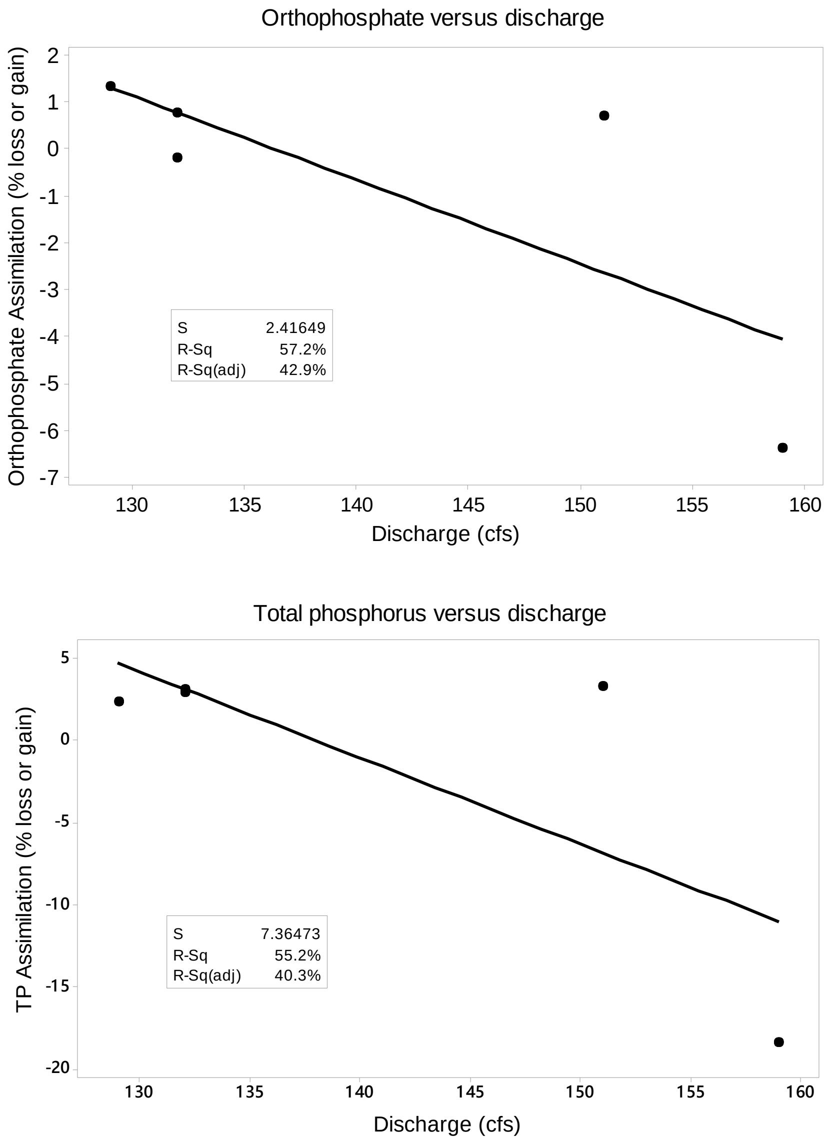
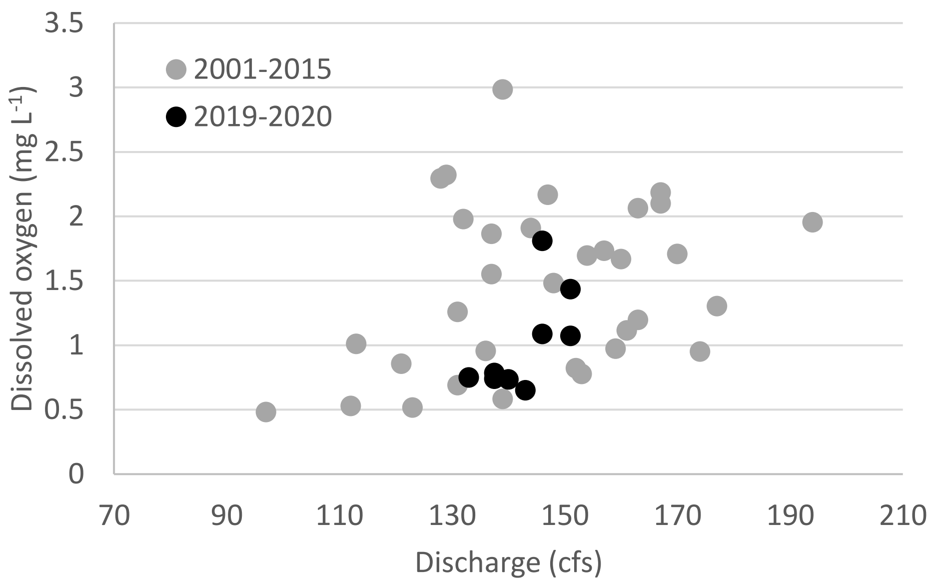


Figure 46. Relationships between orthophosphate assimilation vs. discharge and Total phosphorus assimilation and discharge in the upper segment of Blue Spring Run. Negative values indicate addition (gain) in the segment

Regression analyses by Wetland Solutions, Inc. (2009) and Work and Gibbs (2020) showed various relationships between spring discharge and water quality. As noted earlier in this report, there were weak positive relationships between discharge and DO concentration (Figure 47), and generally the minimal increase in DO down the spring run suggests that higher spring flows will not be reliably associated with higher DO, therefore the adopted MFR will have no or minimal effect on DO concentrations in the spring run.

A)



B)

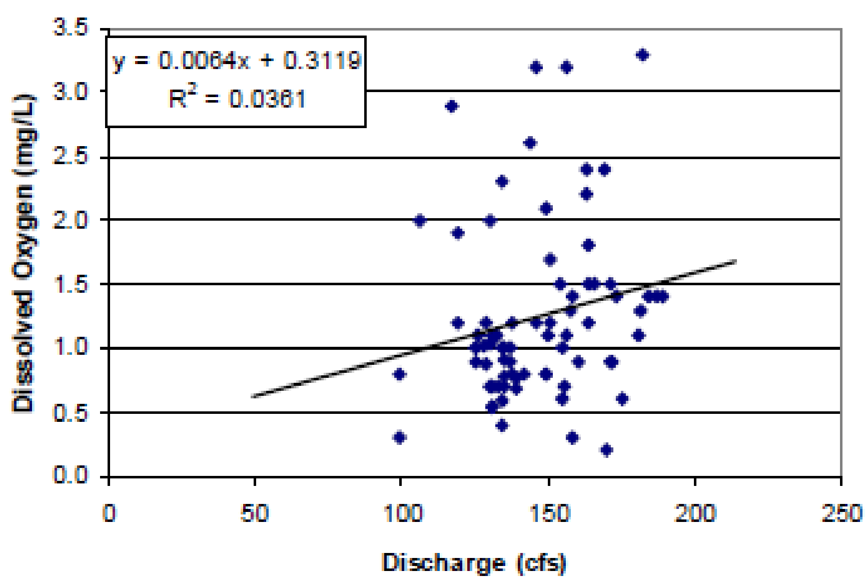
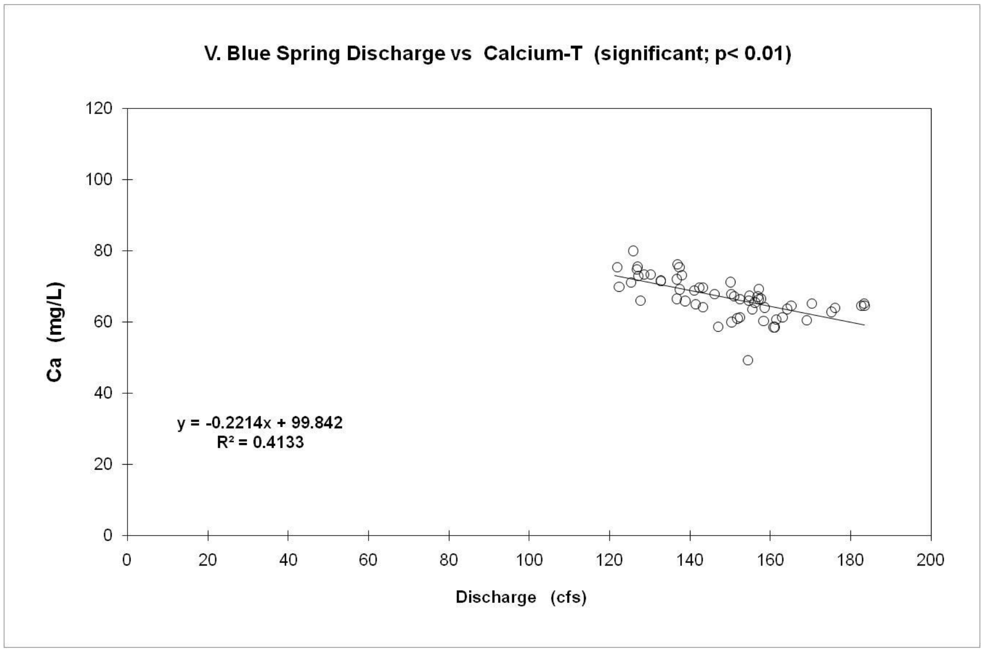


Figure 47. Relationships between Blue Spring discharge and dissolved O_2 concentrations in the spring run. A) from Work and Gibbs (2020); B) from Wetland Solutions, Inc. (2009).

Other water quality measures exhibit fairly strong negative relationships with discharge. At lower flows, water quality measures indicating water “age” (how long the water has been in the limestone matrix of the Floridan Aquifer System), such as calcium concentration, are significantly higher (Figure 48). Saline indicator measures, such as TDS (reflecting water from deeper within the Floridan Aquifer), are also higher at lower flows (Figure 48). Work and Gibbs (2015), Wetland Solutions, Inc. (2009), and Di (unpublished data) have also seen these water quality/discharge relationships in Blue Spring. This appears to indicate that at lower discharge, a greater fraction of the water discharged from the spring vent is “older” water that has been resident in the aquifer longer or is water from deeper within the aquifer as indicated by the saline indicator measures. Chronically reduced spring flows will result in “saltier” water in Blue Spring and Run, with effects on biotic communities (e.g., a more depauperate macroinvertebrate community as reflected by the SCI Score; Figure 41). Higher spring discharge mandated as part of the MFR will likely keep the ionic composition of Blue Spring and Run more reflective of historical water quality conditions. This is important because Copeland et al. (2009) and Di and Mattson (unpublished report) have shown that a number of springs, statewide and in the St. Johns River basin, respectively, are displaying increasing trends for these water age and saline measures, indicating a progressive “salinization” of the Floridan Aquifer System due to upconing of deeper, more saline water and resultant effects on spring water quality. Copeland et al. (2009) attributed these trends to a combination of changing rainfall patterns and groundwater withdrawal. The adopted Blue Spring MFR should help mitigate these changes, at least for Blue Spring.

Prior work has also shown a strong positive relationship between spring discharge and nitrate concentrations (as NOx; Figure 49). Nitrate concentrations are higher at higher spring flows. This relationship was shown by Work and Gibbs (2015), Wetland Solutions, Inc. (2009) and Marzolf and Mattson (2012). Elevated nitrate levels in Florida springs is a statewide issue (Stevenson et al. 2007; Copeland et al. 2009) and the impacts of this may include increased growth and proliferation of macroalgae (Stevenson et al. 2007; Mattson et al. 2006) and increased potential for nitrate toxicity (Mattson et al. 2007).

The higher flows mandated by the adopted Blue Spring MFR would result in higher nitrate loading to the spring run and the downstream St. Johns River, but this cannot be ameliorated by managing spring flows. Increased nitrate concentrations in the spring are a result of increased landscape loading of nitrogen in the Blue Spring springshed (Holland and Bridger 2014), which is being transported into the Floridan Aquifer System and then to Blue Spring. Addressing this issue will involve addressing landscape nitrogen loading, which is being dealt with through the Basin Management Action Plan process to implement the TMDL for nitrate that has been adopted for Blue Spring (Holland and Bridger 2014). Upchurch et al. (2008) demonstrated that spring discharge management/MFLs cannot be used as a tool to ameliorate or manage nitrate loading in springs of the Suwannee River basin, and the MFR adopted for Blue Spring is not the appropriate tool to use to reduce nitrate concentrations in the spring discharge.



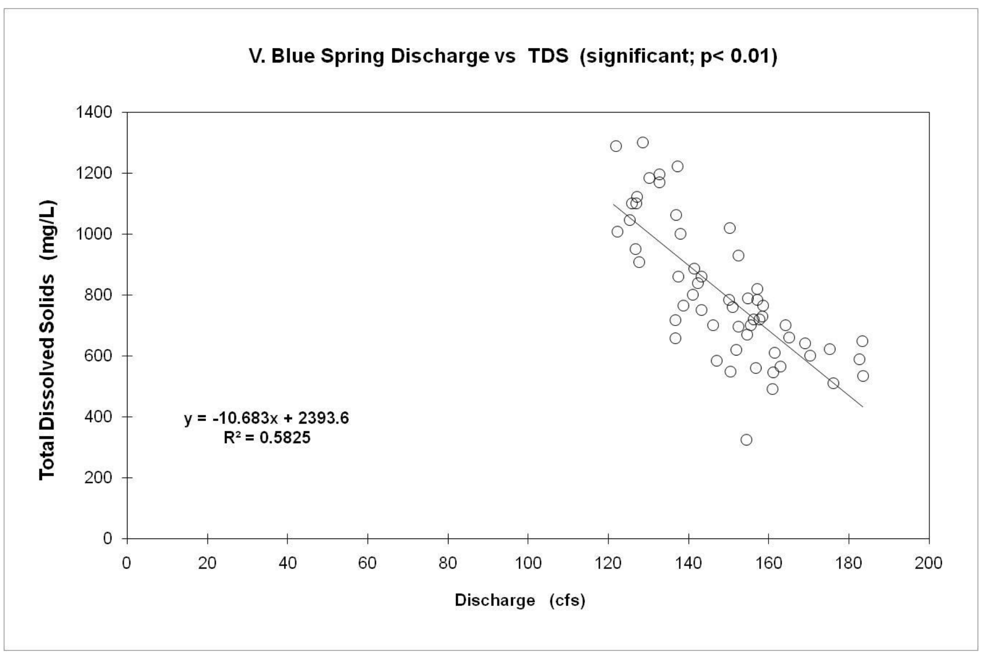


Figure 48. Relationships between calcium concentration and Blue Spring discharge (top) and total Dissolved Solids concentration and spring discharge (bottom). Source: Marzolf and Mattson 2012.

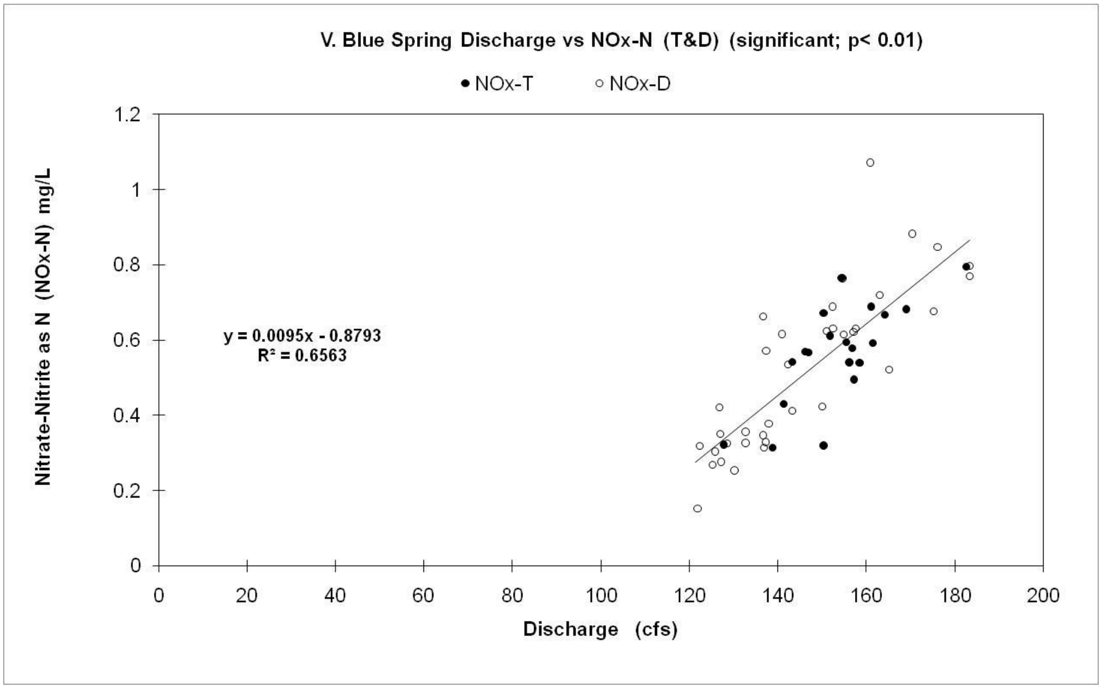


Figure 49. Relationship between nitrate concentrations in Blue Spring versus spring discharge. Source: Marzolf and Mattson 2012.

CONCLUSIONS AND RECOMMENDATIONS

The results reported here and in the earlier comprehensive WRV monitoring report (Wetland Solutions, Inc. 2009) indicate the following:

- The discharge of Blue Spring is a function of both rainfall and groundwater withdrawals in the springshed. Long-term declining trends in the flow of Blue Spring are mainly related to long-term changes (reduced periods) in rainfall.

- Water quality in Blue Spring is characterized by naturally low DO concentrations and high concentrations of dissolved solids (salts and minerals). Lower flows are associated with low DO and/or higher TDS concentrations, most likely due to a larger fraction of the spring discharge being composed of "older," deeper water from the Floridan Aquifer System. Achieving the adopted MFR should keep TDS concentrations more reflective of natural background conditions. DO concentrations are a function of multiple factors in addition to spring discharge, and the MFR should not adversely affect DO concentrations in the spring run.

- Elevated nitrate concentrations in the spring discharge is a function of landscape loading of nitrogen in the springshed and cannot be managed using the MFR or spring flow in general as a strategy.

- Manatee use of Blue Spring in the winter continues to increase at a rate that exceeds modeled population. To date the amount of usable warm-water habitat in the spring run appears able to accommodate this increasing use, and no incidents of cold stress in manatees due to exclusion from the Blue Spring winter refuge have been documented to date. The observed flows from Blue Spring and the stage of the St. Johns River between (2016–2020) continue to provide warm-water habitat for manatees.

- Higher spring flows are associated with an improved SCI score for the macroinvertebrate community and higher fish density and diversity. Overall, the adopted MFR should be beneficial for benthic macroinvertebrate and fish communities in Blue Spring Run and should not promote the additional proliferation of macroalgal mats.

- Higher spring flows may be associated with increased assimilation of nitrate and may be associated with export of phosphorus from the upper portion of the spring run (headspring to the swimming area reach). More data on these relationships is needed, but in general the adopted MFR will satisfy the WRV concerning "filtration and absorption of nutrients and other pollutants" or will not adversely affect this WRV.

- Based on the data presented in this and the prior WRV monitoring report (Wetland Solutions, Inc. 2009), overall, the MFR adopted in 2006 has not yet been achieved but incremental increases in flow have been occurring since 2017 and are anticipated to continue increasing to meet the MFR in 2024. The Water Resource Values identified as relevant to the Blue Spring MFR should continue to be monitored until MFR is achieved and into the future to assess if MFR is protective of the WRVs.

RECOMMENDATIONS

The collection of a long-term record of physical, chemical, and concurrent ecological data in Florida spring-run streams has been identified as an important management need for springs (Florida Springs Task Force 2000), and the data from a consistently implemented monitoring effort for Blue Spring will enable better understanding of the relationships between spring flow and the relevant WRVs (Wetland Solutions, Inc. 2009). Recommendations from this current monitoring effort include:

- Periodically deploy continuous water quality monitoring instrumentation at the USGS flow gauge (temperature, DO, conductivity, pH and turbidity) in order to evaluate short-term changes in water quality.

- Continue to repeat the monthly fish sampling for at least a one-year period in 2024–2025; also repeat the quarterly quantitative snail monitoring and the quarterly SCI surveys during this same time period.

- Continue the annual surveys for SAV and macroalgae at the 5 transects surveyed by Work and Gibbs (2015) begun in 2017 by SJRWMD. Consider making more detailed measurements of current velocity in association with algal cover measurements.

- Continue to work with local utilities, agriculture, and the public to implement projects to conserve water and reduce nitrogen loading to the landscape in the Blue Spring springshed as described in the Prevention/Recovery Strategy for the Implementation of Minimum Flows and Levels for Volusia Blue Spring and Big, Daugharty, Helen, Hires, Indian, and Three Island Lake (SJRWMD 2013).

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