Technical Publication SJ2016-3

DETERMINATION OF MINIMUM FLOWS FOR DE LEON SPRINGS, VOLUSIA COUNTY, FLORIDA

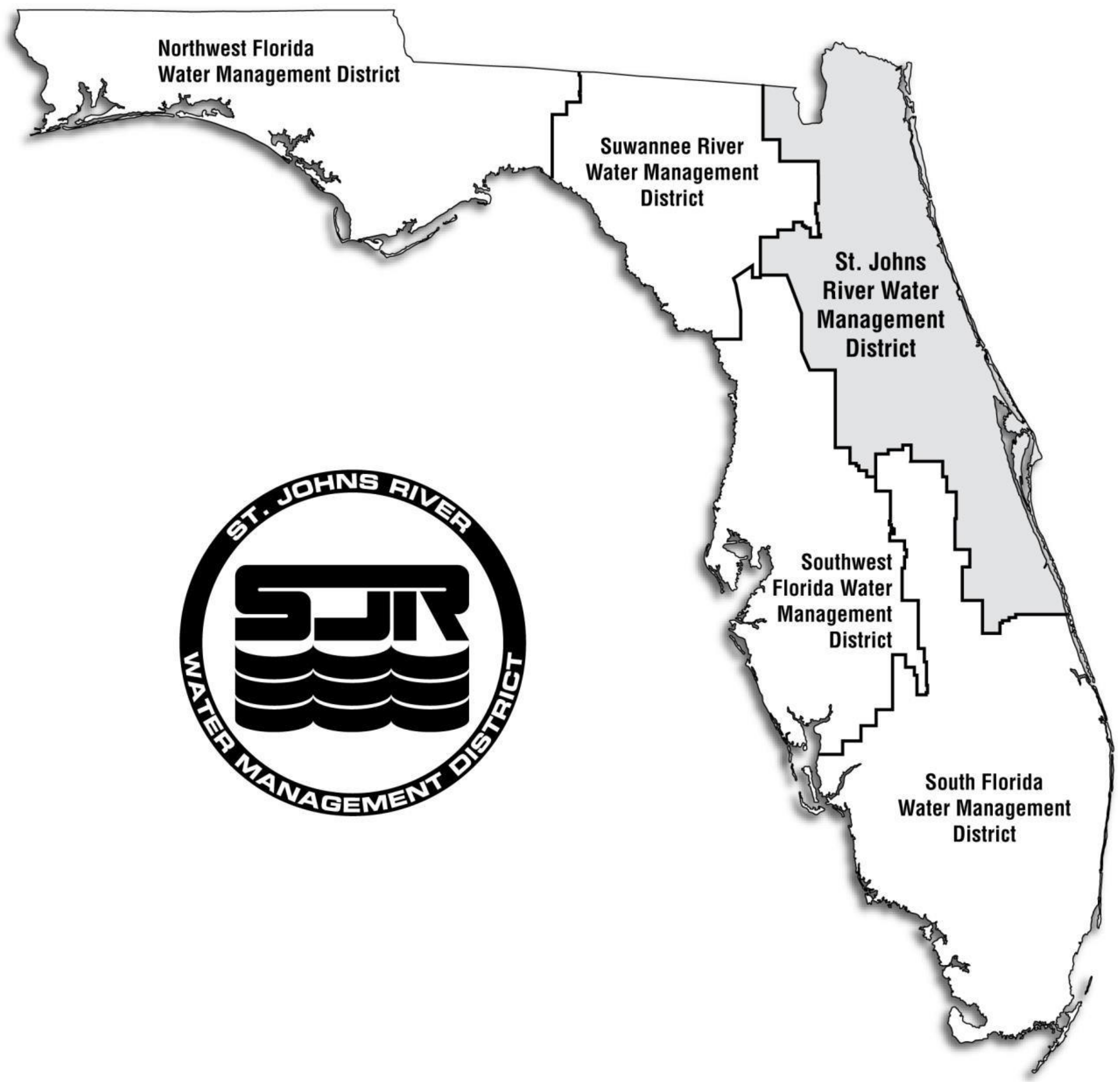
Photo by Robert Sitler, 2016

by

Casey Harris
Fatih Gordu, P.E.
Jian Di
Andrew Sutherland, Ph.D.

St. Johns River Water Management District
Palatka, Florida

2016


Northwest Florida
Water Management District
Suwannee River
Water Management
District
St. Johns
River Water
Management
District
Southwest
Florida Water
Management
District
South Florida
Water Management
District

EXECUTIVE SUMMARY

The St. Johns River Water Management District (SJRWMD) establishes minimum flows and levels for priority waterbodies within its boundaries. Minimum flows and levels provide a standard for decision-making regarding planning and permitting of surface water or groundwater withdrawals, by defining the limits at which further withdrawals would be significantly harmful to the water resources or ecology of the area. Section 373.042, Florida Statutes, requires the adoption of minimum flows and levels for Outstanding Florida Springs including De Leon Springs by July 1, 2017.

De Leon Springs is a second-magnitude spring located in De Leon Springs State Park, north of the city of DeLand, Florida. The spring discharges into a large half-acre pool, which has attracted visitors for swimming for more than 100 years. The pool is highly altered, with concrete sides and walkways. Water from the spring pool mainly flows over a constructed waterfall into Spring Garden Run. Spring Garden Run discharges into Spring Garden Creek and Spring Garden Lake, Lake Woodruff, and Lake Dexter before reaching the St. Johns River. The area has a long history of human use dating back 6,000 years.

De Leon Springs is identified as an important spring used by manatees in winter by both the U.S. Fish and Wildlife Service (USFWS) and Florida Fish and Wildlife Conservation Commission (FWC), and is federally designated as critical habitat for manatees. Manatees are susceptible to cold stress in water below 20°C (68°F), and cold stress is a significant cause of manatee mortality, especially during particularly cold winters. During winter, manatees seek shelter from the cold at a limited number of locations providing warm-water habitat, such as Spring Garden Run at De Leon Springs.

USFWS has proposed downlisting manatees from endangered to threatened under the Endangered Species Act. Part of the basis for this action includes a determination that ongoing concerns such as the loss of warm-water habitat are being addressed. The adoption of minimum flows to support manatees at important springs including De Leon Springs is listed in the USFWS Florida Manatee Recovery Plan as a criterion for downlisting. According to USFWS, FWC, and other researchers, the potential loss of warm-water habitat in Florida over the next several decades is one of the most serious concerns for the continued recovery of manatee populations.

Winter warm-water habitat for Florida manatees is the most sensitive ecological resource evaluated for the determination of a minimum flow regime at De Leon Springs. Water temperature modeling indicates that any reduction in spring flow leads to a decrease in water temperatures in Spring Garden Run where manatees seek refuge in winter. Given the need for the protection of warm-water habitat for manatees, the minimum flow regime recommended by SJRWMD for De Leon Springs is intended to allow no further decrease in warm-water habitat due to water withdrawals.

The recommended minimum flow regime for De Leon Springs is a mean flow of 25.6 cfs. This is the mean flow of the period of record from 1965 - 2015, adjusted by the reduction in spring flow due to 2010 water use, as though 2010 water use occurred throughout that time period. The year 2010 was selected due to the availability of a comprehensive groundwater model for that year, and is considered the best available estimate of current water use. To maintain the recommended flow regime and the warm-water habitat available for manatees under this flow regime, reductions in spring flow due to water use should remain at or below 2010 levels.

Additional reductions in spring flow are not expected within the 20-year planning horizon, as water use is projected to decline from 2010 levels. Therefore, the recommended minimum flow is expected to be achieved over the 20-year planning horizon. The status of the spring and the recommended minimum flow will be monitored and updated over time.

TABLE OF CONTENTS

Executive summary 3
Introduction 6
  Legislative overview 6
  SJRWMD's approach to determining minimum flow regimes 7
Description of De Leon Springs 8
  Land use and groundwater use 11
  Habitat for Florida manatees 14
Technical approach for determining a minimum flow regime for De Leon Springs 16
  Overview 16
  Observations of manatees at De Leon Springs 16
  Manatee habitat reduction due to spring flow reductions 19
  Hydrologic data analysis 27
  Groundwater pumping impact assessment 28
  Calculation and comparison of the minimum flow regime 29
    Comparison with other adopted minimum flows in Florida 29
  Consideration of water resource values 30
  Minimum flows status assessment 32
    Determine the baseline flow 32
    Determine the minimum flow 32
    Determine the current status 32
    Determine the status at the 20-year planning horizon 32
Conclusions 34
Literature cited 35
Appendix A: Water resource values at De Leon Springs 38
Appendix B: Hydrologic data analysis 54
Appendix C: Intra-annual variation in flow at De Leon Springs 72
Appendix D: Rainfall data 77
Appendix E: De Leon Springs cavern 81

INTRODUCTION

LEGISLATIVE OVERVIEW

The St. Johns River Water Management District (SJRWMD) is directed to establish minimum flows and levels for priority waterbodies within its boundaries based on the best available information (section 373.042(1), Florida Statutes [F.S.]). Minimum flows and levels for a given waterbody are the limits "at which further withdrawals would be significantly harmful to the water resources or ecology of the area" (section 373.042, F.S.).

SJRWMD uses minimum flows and levels as a standard for decision-making regarding planning and permitting of surface water or groundwater withdrawals. If a requested withdrawal would cause significant harm to a waterbody, a permit cannot be issued. If a waterbody is not in compliance, or expected not to be in compliance during the next 20 years due to withdrawals, a recovery or prevention plan must be developed and implemented.

When establishing minimum flows and levels, consideration is also given to "changes and structural alterations to watersheds, surface waters, and aquifers and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of the affected watershed, surface water, or aquifer...," provided that none of those changes or alterations shall allow significant harm caused by withdrawals (section 373.0421(1)(a), F.S.).

The minimum flows and levels section of the State Water Resources Implementation Rule (rule 62-40.473, Florida Administrative Code [F.A.C.]) also requires that "consideration shall be given to natural seasonal fluctuations in water flows or levels, nonconsumptive uses, and environmental values associated with coastal, estuarine, riverine, spring, aquatic, and wetlands ecology." The environmental values described by the rule include:

1. Recreation in and on the water
2. Fish and wildlife habitats and the passage of fish
3. Estuarine resources
4. Transfer of detrital material
5. Maintenance of freshwater storage and supply
6. Aesthetic and scenic attributes
7. Filtration and absorption of nutrients and other pollutants
8. Sediment loads
9. Water quality
10. Navigation

Rule 62-40.473, F.A.C., states that minimum flows and levels "should be expressed as multiple flows or levels defining a minimum hydrologic regime, to the extent practical and necessary, to establish the limit beyond which further withdrawals would be significantly harmful." Waterbodies experience variations in flows and levels that often contribute to significant functions of the system, such as the environmental values listed above.

SJRWMD'S APPROACH TO DETERMINING MINIMUM FLOW REGIMES

Minimum flows and levels are typically established as a "minimum flow regime" or "minimum hydrologic regime", rather than a single value representing an absolute minimum. A minimum flow regime represents the range and timing of flows and/or levels needed to maintain the characteristics and functions of a waterbody or system (Basso et al. 2011). Much work is still needed before all the characteristics and functions of waterbodies or systems are understood, and even more work is needed before the hydrologic requirements of each are understood.

When establishing a minimum flow regime, a recommended approach is to consider what alterations of the natural flow regime are allowable while still protecting ecosystem biodiversity and other beneficial uses (B. Richter et al. 1996; Bunn and Arthington 2002; Postel and Richter 2003). In establishing a minimum flow regime, the water management district must consider any "environmental values" associated with a system (the ten values described in rule 62-40.473, F.A.C.).

A report from the National Research Council of the National Academies (2005) summarized several general principles to follow when determining flow regimes:

1. Preserve whole functioning ecosystems rather than single species
2. Mimic, to the extent possible, the natural flow regime, including seasonal and interannual variability
3. Include floodplain and riparian zones in flow considerations
4. Take an interdisciplinary approach
5. Use a variety of tools and approaches for technical evaluations of particular lake/river/spring systems
6. Practice adaptive management
7. Involve stakeholders

Whenever possible, SJRWMD follows the principles listed above, as well as the technical details described by Neubauer et al. (2008). When applicable, SJRWMD takes into account the ability of upland, wetland, and aquatic communities to adjust to hydrologic changes. Significant harm occurs when changes in hydrology cause impairment or loss of characteristics and functions of an ecosystem (e.g., loss of manatee habitat due to inadequate water temperatures caused by a decrease in flow due to water withdrawals).

DESCRIPTION OF DE LEON SPRINGS

De Leon Springs (29°08'03.4"N, 81°21'45.8"W) in Volusia County, Florida, is a secondmagnitude spring located in De Leon Springs State Park, northwest of the city of DeLand, Florida. The State of Florida purchased De Leon Springs in 1982 and established De Leon Springs State Park. The park now comprises 625 acres, including uplands, wetlands, and Spring Garden Run.

At De Leon Springs, water from the upper and lower Floridan aquifers vents through a cavern and chimney into a large half-acre constructed spring pool (Figure 1) surrounded by concrete sides and walkways. Water from the spring pool flows over a constructed waterfall and other outlet structures to enter Spring Garden Run, which flows to Spring Garden Lake and Spring Garden Creek, then to Lake Woodruff, Lake Dexter, and the St. Johns River (Figure 2). Spring flow is a reflection of the potentiometric surface (the level to which groundwater rises in a well) of the Floridan aquifer at the spring, and is currently estimated using well V-1030 in De Leon Springs State Park (Figure 3). The water levels in the spring pool are controlled by the elevation of the constructed waterfall. However, water levels in Spring Garden Run are dominated by downstream water levels (Stewart 2016). Very little difference in water surface elevation occurs between Spring Garden Run and the St. Johns River.

The spring pool, popular for swimming, is the focal point of De Leon Springs State Park (Figure 4). The walkway over the constructed waterfall from the spring pool allows visitors to view Spring Garden Run (Figure 5). Other recreational activities at the park include boating, fishing, picnicking, hiking, wildlife viewing, and dining at a pancake restaurant (DEP 2006). According to the Florida Department of Environmental Protection, park attendance in fiscal year 2013-2014 exceeded 220,000 and visitor expenditures resulted in a direct economic impact of approximately $17 million (approximately $1 million in state sales tax revenue) (Scruggs 2014).

De Leon Springs has a long history of human use. Some of the oldest canoes found in North America, dating back 5,000 and 6,000 years, were found in De Leon Springs' pool buried in peat next to the spring vent (Sitler 2016). Burial mounds, shell mounds, and middens from Native Americans sit to the east and northeast of the spring pool including underneath the ranger's residence and the visitor center (Sitler 2016). The spring pool was dammed for a water-powered mill, the first of its kind in Florida, in the 1830s and became a tourist resort (later featuring water skiing elephants) in the 1880s (De Leon Springs State Park visitor center, pers. comm., 2016). In the 1930s, the area on the southwest side of the spring was filled in and at least two large artesian wells were drilled to create another attraction very similar to the neighboring resort, with swimming pools and playgrounds, which operated until the 1950s (Williamson 2008).

Figure 1: Map showing De Leon Springs pool and the upper part of Spring Garden Run.

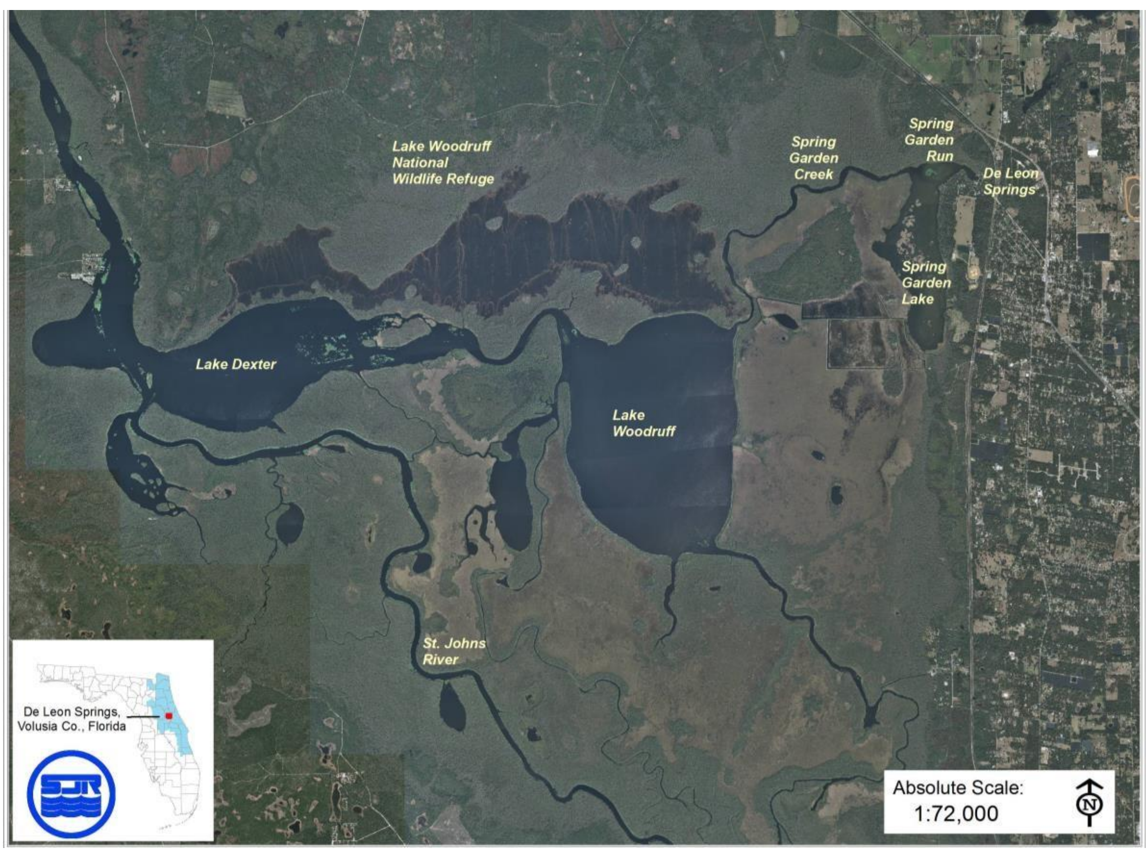


Figure 2: Map showing the area from the St. Johns River to De Leon Springs in Volusia County, Florida.

Figure 3: Map showing the proximity of De Leon Springs to Spring Garden Lake, Spring Garden Creek, and well V-1030. SJRWMD uses well V-1030 to estimate flows at De Leon Springs.

Figure 4: View of De Leon Springs pool (2016).

Figure 5: View of the upper part of Spring Garden Run showing De Leon Springs spillway and mill in 2016 (left) and 1915 (right, source: State Archives of Florida.)

LAND USE AND GROUNDWATER USE

Land use near De Leon Springs has changed since the 1970s with increases in both agricultural and urban land cover relative to forested or other natural land cover (Figure 6). Groundwater use in an area of about 40 square miles near the spring increased sharply in the late 1970s, reached a maximum in the mid to late 1980s, and has remained relatively stable since 1990 with perhaps a slight downward trend over the past five years (Figure 7) (see Appendix B).

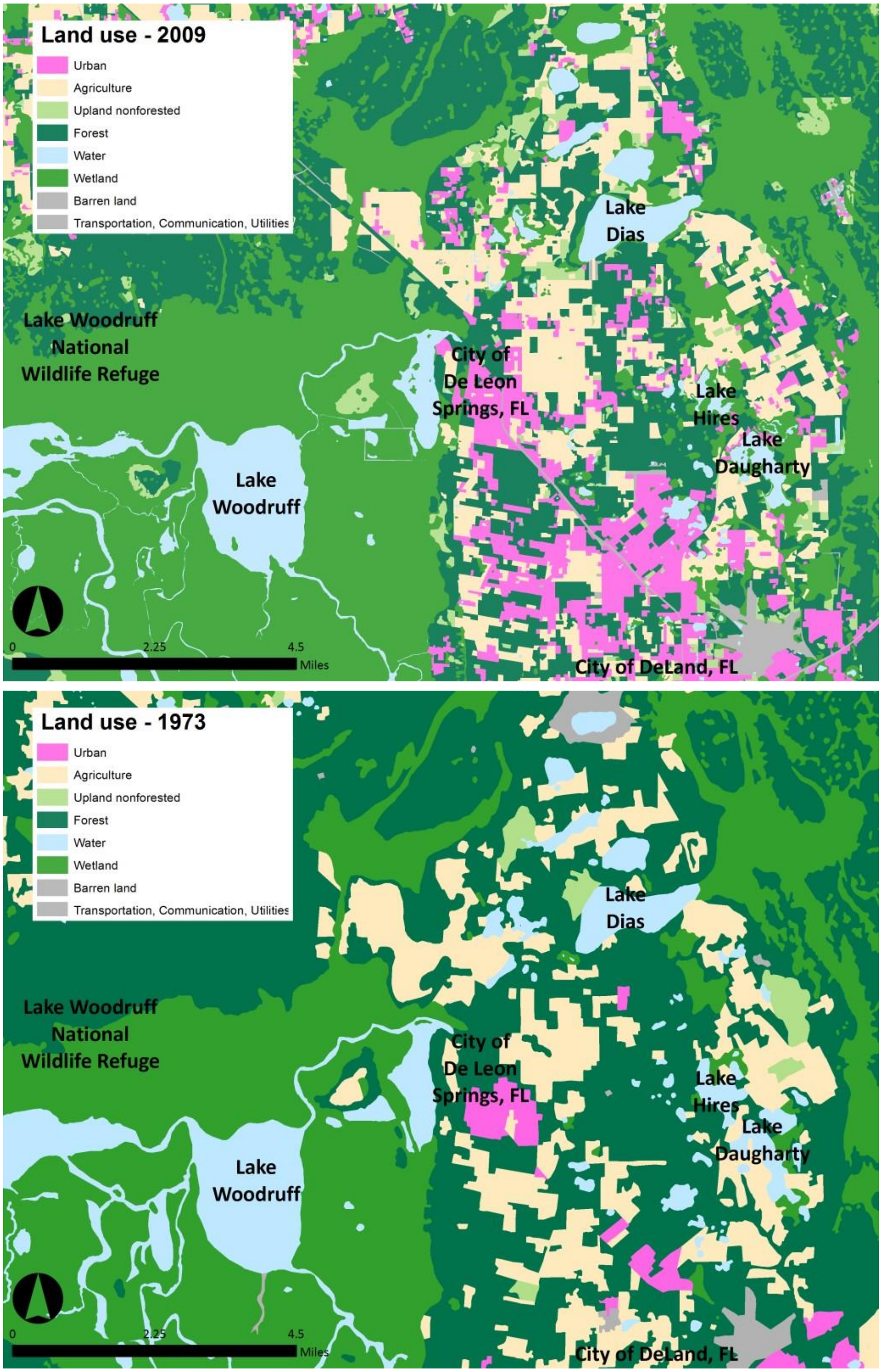


Figure 6: Land use near De Leon Springs as of 2009 (top) and 1973 (bottom). Note that the land use classification methods used in 1973 were different from the methods used in 2009, and an attempt has been made to reconcile those differences for this figure.

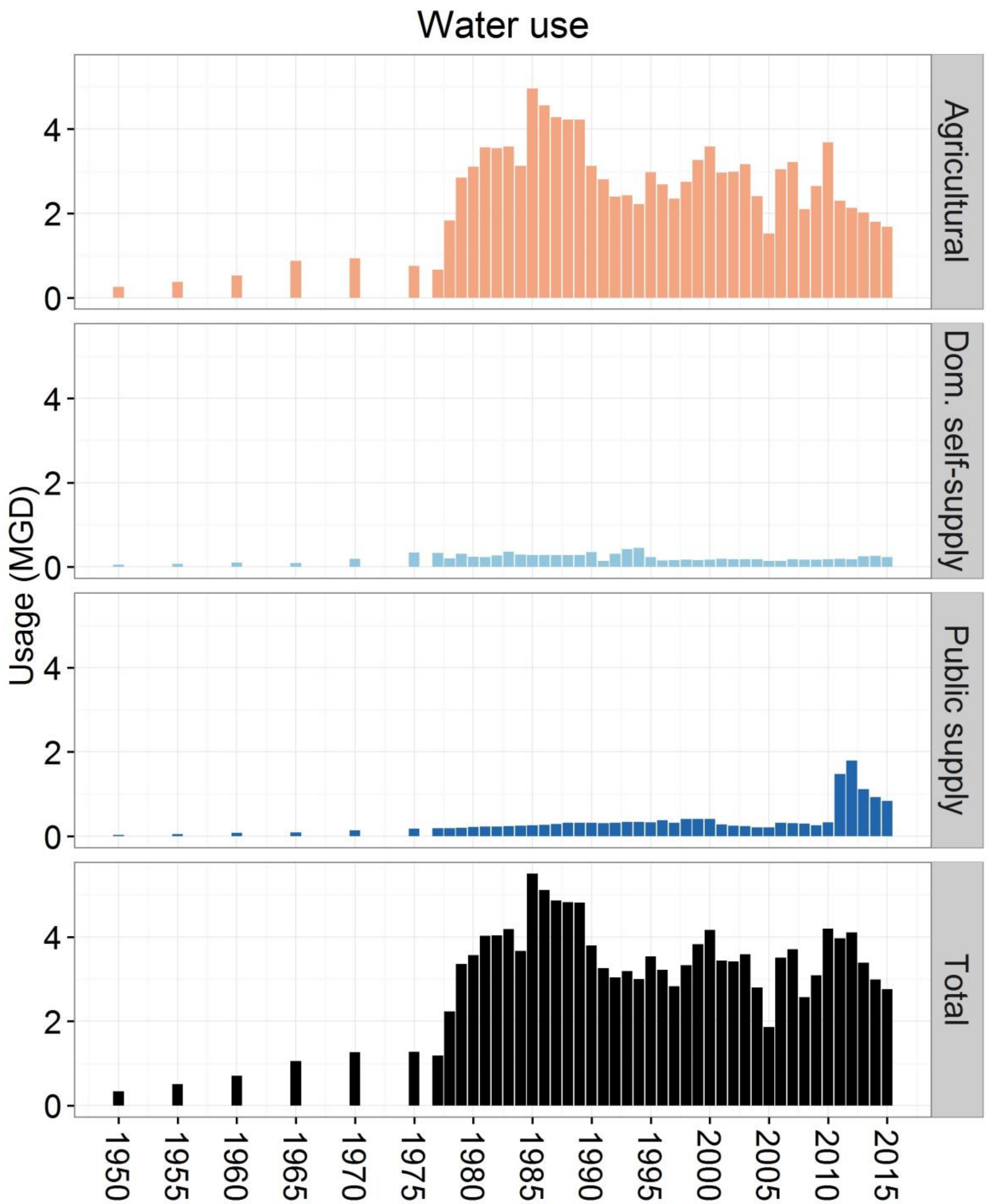


Figure 7: Groundwater use in an area of about 40 square miles near De Leon Springs, 1950 - 2015. See Appendix B for a map of the area used.

HABITAT FOR FLORIDA MANATEES

Winter warm-water habitat for Florida manatees is the most sensitive ecological resource evaluated for the determination of a minimum flow regime at De Leon Springs. Exposure to water temperatures below 20°C (68°F) often results in "cold stress syndrome" in Florida manatees (*Trichechus manatus latirostris*), including emaciation and fat depletion, skin lesions and abscesses, dehydration, digestion problems, and heart disease (Irvine 1983; Worthy 2000; Bossart et al. 2002). Cold stress syndrome also leaves manatees more susceptible to infections, diseases, and death; between 1995 - 2005, 9.4% of manatee deaths in Florida with known causes were due to cold stress (FWC 2007). To avoid cold stress syndrome, manatees rely on warm-water refuges like Spring Garden Run, where warm water is provided by spring flow.

The only warm-water refuge with consistent use by more than 50 manatees in the St. Johns River system is Blue Spring Run (USFWS 2007). Other warm-water refuges in the St. Johns River system include Spring Garden Run, Silver Glen Springs Run, and Salt Springs Run (Figure 8) (USFWS 2007). As part of the St. Johns River system, all of these refuges are federally designated as critical habitat for manatees (75 Federal Register at 1577, 2010). Besides providing necessary warmth for manatees, the network of warm-water refuges created by these springs in the St. Johns River system allows manatees to access more foraging opportunities in winter (Provancha et al. 2012). Near De Leon Springs, manatees are able to forage in Lake Woodruff and the surrounding waterways (Provancha et al. 2012).

The U.S. Fish and Wildlife Service (USFWS) has proposed reclassifying manatees from endangered to threatened under the Endangered Species Act of 1973. Part of the basis for this proposed action includes a determination that ongoing concerns such as the loss of warmwater habitat are being addressed. According to their proposal, "it is unlikely (< 2.5 percent chance) that the Florida population of manatees will fall below 4,000 total individuals over the next 100 years, assuming current threats remain constant indefinitely" (81 Federal Register at 1024, 2016, emphasis added). The loss of warm-water habitat is a large threat to Florida manatees, second only to watercraft collisions (81 Federal Register at 1014, 2016). The USFWS proposal asserts that warm-water habitat loss is being addressed in part by establishing minimum flows at important springs used by manatees - including De Leon Springs (81 Federal Register at 1012, 2016).

Objective #3 in the USFWS Florida Manatee Recovery Plan includes the protection of existing natural warm-water refuges, the management of regional networks such as the network of springs providing warm-water habitat in the St. Johns River system, and the establishment of minimum flows and levels to protect resources of importance to manatees (USFWS 2001). Minimum flows are established at many other Florida springs used by manatees, including Blue Spring, Fanning Spring, Manatee Spring, the Weeki Wachee River system and Weeki Wachee Springs, Homosassa Springs, and Chassahowitzka Spring (81 Federal Register at 1012, 2016).

The Florida Fish and Wildlife Commission (FWC) has also emphasized the importance of maintaining warm-water habitat for manatees. According to the FWC's 2007 Manatee

Management Plan, "changes in the network of warm-water refuges over the next several decades present one of the most serious long-term threats to manatees in Florida" (FWC 2007), especially as some aging power plants that currently provide some warm-water refuge for manatees are replaced by newer and more efficient power plants without warm-water discharges (FWC 2007). To address warm-water habitat loss, one of the FWC's primary objectives stated in the 2007 Manatee Management Plan is to cooperate with water management districts to establish minimum flows that protect the warm-water habitat requirements of manatees at Florida springs (FWC 2007).

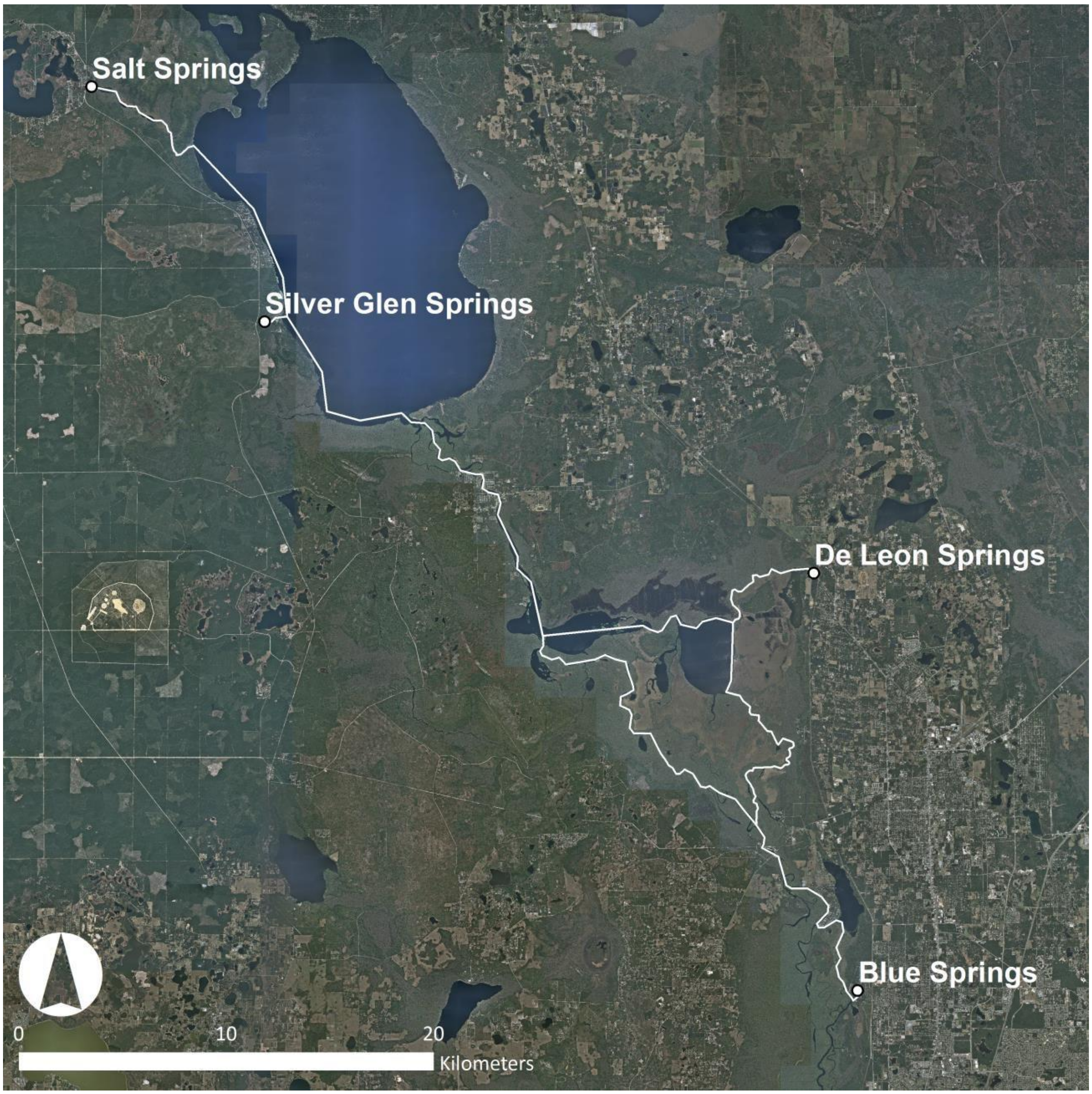


Figure 8: Network of warm-water refuges in the St. Johns River system.

TECHNICAL APPROACH FOR DETERMINING A MINIMUM FLOW REGIME FOR DE LEON SPRINGS

OVERVIEW

The minimum flow regime at De Leon Springs is intended to prevent further warm-water habitat loss for manatees due to water use, while also protecting any less-sensitive ecological resources and beneficial uses at De Leon Springs. The following are described in this section:

- Manatee observations at De Leon Springs
- Manatee habitat reduction due to spring flow reduction
- Hydrologic data analysis
- Groundwater pumping impact assessment
- Calculation and comparison of the minimum flow regime
- Consideration of water resource values
- Minimum flow status assessment

OBSERVATIONS OF MANATEES AT DE LEON SPRINGS

A 2009 - 2010 study documented the use of Spring Garden Run by manatees during winter (Ross 2011). Manatees were observed feeding, resting, and traveling in Spring Garden Run, most often near the boat ramp/boat dock and an area on the southwest side of the run near an additional very small spring ("Gumbo Spring", Mitch Wainwright, pers. comm., 2016) (Figure 9). More manatees were observed around the initial onset of cold weather, and none were observed when water temperatures fell below 18°C and eventually reached a minimum of 16°C (Ross 2011). The study noted that both water temperatures and manatee use were less consistent in Spring Garden Run than at Silver Glen Springs or Salt Springs, two other springs considered warm-water refuges for manatees near the Ocala National Forest in the St. Johns River basin.

Observations in winter 2015 - 2016 by Frank Wiltse and Kimberly Schmidt of Fountain of Youth Eco/History Tours (Frank Wiltse, pers. comm., 2016), a twice-daily pontoon boat tour at De Leon Springs, noted manatees in Spring Garden Run primarily when water temperatures measured in the middle of the run were above 20°C. On five days between January 18 and February 3, several manatees including two juveniles were observed when water temperatures ranged between 19 - 21°C. On those same days, water temperatures in the St. Johns River at Astor ranged from 14 - 17°C, and De Leon Springs may have provided critical warmth for the manatees (Figure 10). It should be noted that these observations include manatees that the tour captains happened to see during boat tours. When no manatees were observed, it does not necessarily mean that no manatees were present -- manatees can easily remain out of sight in the often dark waters of Spring Garden Run. The advantage of these observations is that the "effort" expended to survey manatees was comparable from one day to the next, so the observations can be compared across the time period. On days when no tours occurred, no data is available. De Leon Springs State Park is considering installing boardwalks for better manatee viewing on the southwest side of the spring run (DEP 2006) (Figure 11).

The observations by both Ross (2011) and the tour boat captains suggest a relationship between manatee use and winter water temperatures in Spring Garden Run. Manatees do use the run as a winter warm-water refuge on some days when water temperatures in the St. Johns River would be unsuitable. Water temperatures in Spring Garden Run may be unsuitable for manatees on some of the coldest days of the year, as no manatees were observed when water temperatures were particularly low.

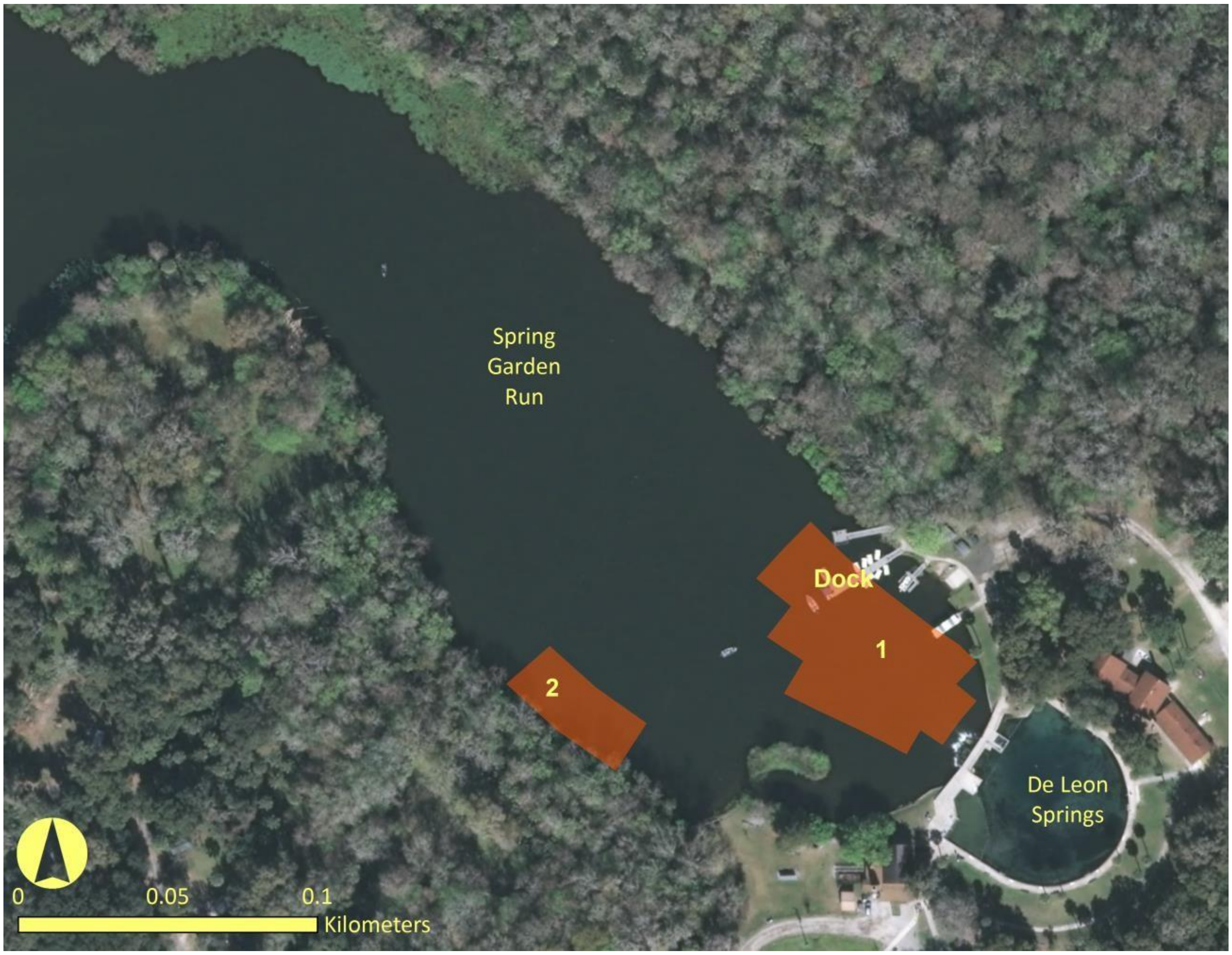


Figure 9: Areas of the spring run where manatees are frequently observed in winter, according to Ross (2011). Area 1 is near the boat ramp/boat dock and area 2 is near an additional very small spring ("Gumbo Spring", Mitch Wainwright, pers. comm., 2016).

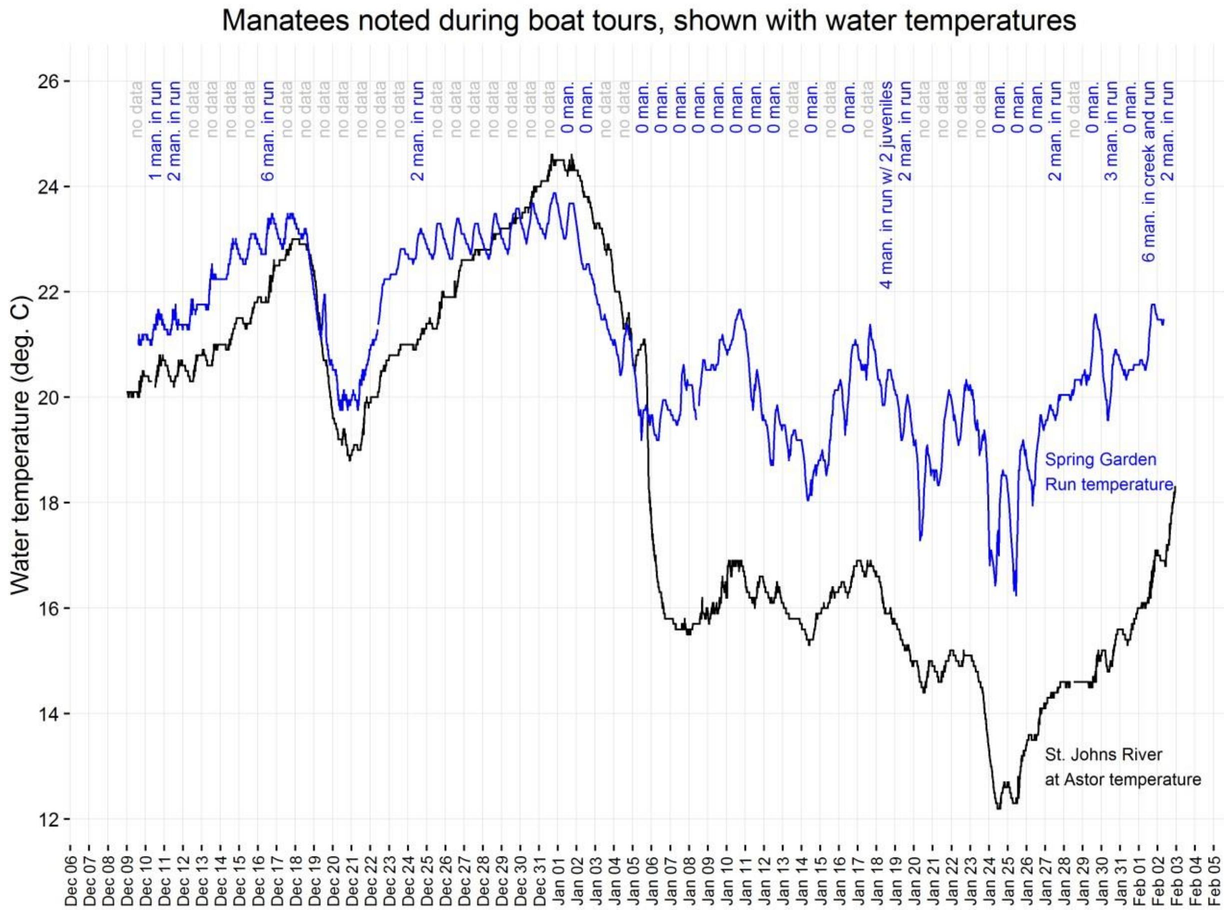


Figure 10: Manatees noted during boat tours at De Leon Springs, winter 2015 - 2016. Manatee observations were provided by Frank Wiltse and Kimberly Schmidt of Fountain of Youth Eco/History Tours. Spring Garden Run temperatures were obtained from a temperature recorder placed by SJRWMD below the surface of the water column near the middle of the run. St. Johns River temperatures at Astor were obtained from USGS.

Figure 11: Manatee at Spring Garden Run on February 9, 2016; a manatee calf is also just barely visible below the larger manatee.

MANATEE HABITAT REDUCTION DUE TO SPRING FLOW REDUCTIONS

Based on a model developed for Spring Garden Run using the environmental fluid dynamics code (EFDC), reductions in spring flow result in lower winter water temperatures in the spring run (see report by Stewart (2016) for model details). Four flow scenarios over the time period from November 2014 - March 2015 were modeled to examine changes in water temperatures with increases or reductions from observed flow.

- actual flow recorded during that time period (observed flow) (see Appendix C)
- 10.3% flow increase
- 5% flow reduction
- 25% flow reduction

Within the model, the water column at Spring Garden run was divided into six layers of equal depth. Results are discussed for two of those layers, the near-surface (second layer from top) and near-bottom (second layer from bottom).

The scenario with a 10.3% increase from observed flow represents a hypothetical "no pumping" condition, or what could occur in the absence of groundwater pumping. This scenario was evaluated to estimate the decrease in warm water habitat that is already occurring due to current water use. Based on groundwater modeling, current water use reduces spring flow by an estimated 2.6 cubic feet per second (cfs), which is 10.3% of the recommended mean flow of 25.6 cfs (2.62 / 25.55 cfs).

Model results presented in Figures 12 and 13 show estimated temperatures near the surface and near the bottom for the four scenarios on one of the coldest days of the model period, February 21, 2015. Near the surface of the spring run, 94% of grid cells (182/194) had water temperatures above 20°C in the scenario with a 10.3% increase from observed flow, compared to 77%, 64%, and 24% in the observed, 5% reduction, and 25% reduction in flow scenarios, respectively (Figure 12). Near the bottom of the spring run, fewer grid cells had water temperatures above 20°C in all scenarios. Even in the scenario with a 10.3% increase from observed flow, only 10% of grid cells (19/194) had water temperatures above 20°C (Figure 13).

The estimated volume of warm-water habitat for manatees in the spring run was calculated as the sum of the volumes of the grid cell layers with mean temperatures above 20°C on each day in winter 2014 - 2015. The volume of warm-water habitat ranged from about 19,000 to 72,000 m^3 for the scenario with observed flow, and from about 26,000 to 72,000 m^3 for the scenario with a 10.3% increase from observed flow (Figure 14). The volume of warm-water habitat lost due to groundwater pumping on any given day ranged from about 0 to 6,800 m^3 (Figure 15) or 0 to 26% (Figure 16).

On some days, the volume of warm-water habitat lost due to groundwater pumping may be greater than the 0 to 26% shown in Figures 15 and 16. The model tended to overestimate water temperatures, especially on the coldest days of 2014 - 2015 (Figure 17) and other years (Stewart, 2016, p. 39). In the scenario with a 10.3% increase from observed flow, it should be noted that while 10.3% is the difference between mean spring flow under current and "no pumping" conditions, the difference may be smaller or larger on individual days depending on water use.

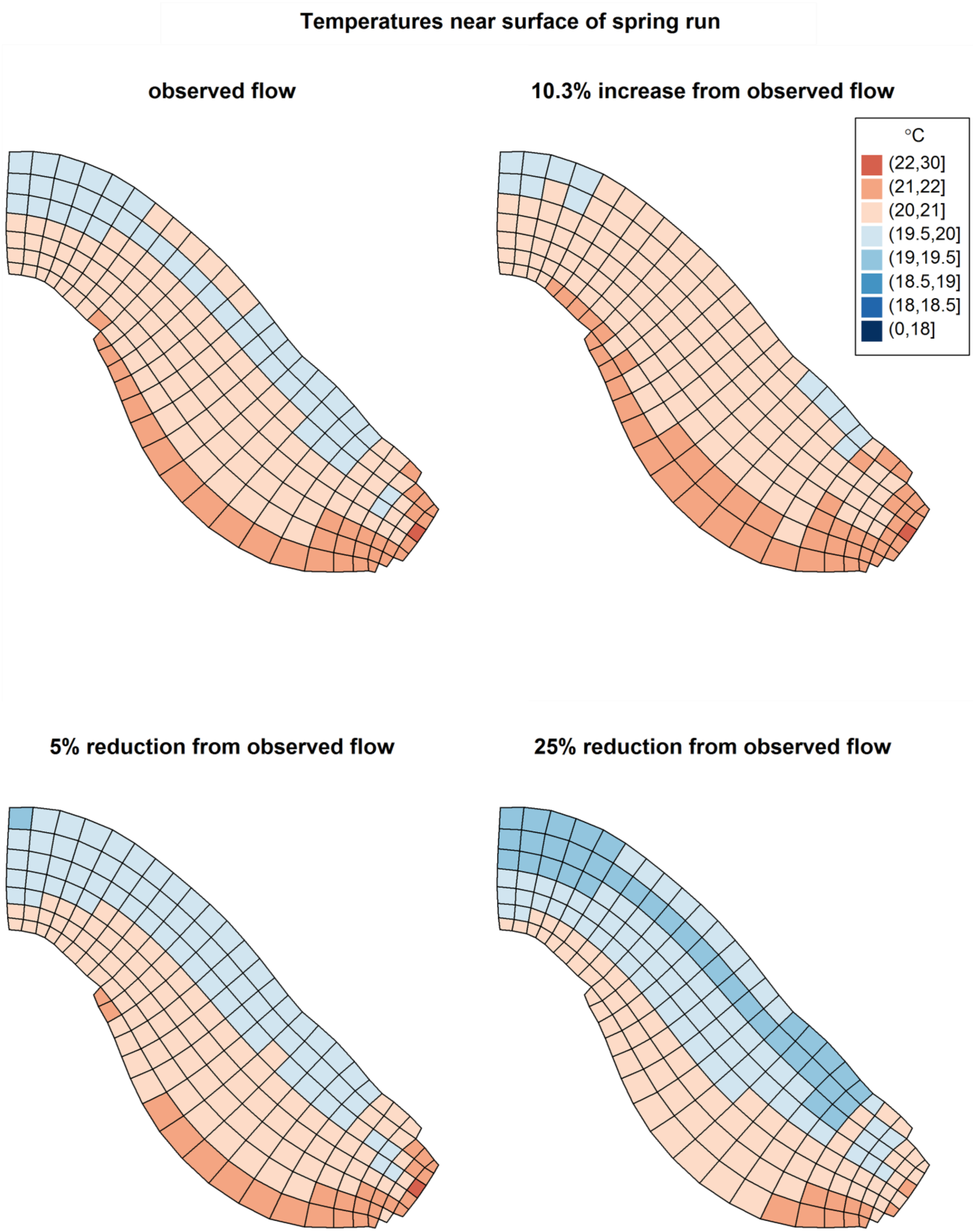


Figure 12: Average temperatures near the surface of the water column in the spring run on Feb. 21, 2015, for each flow scenario.

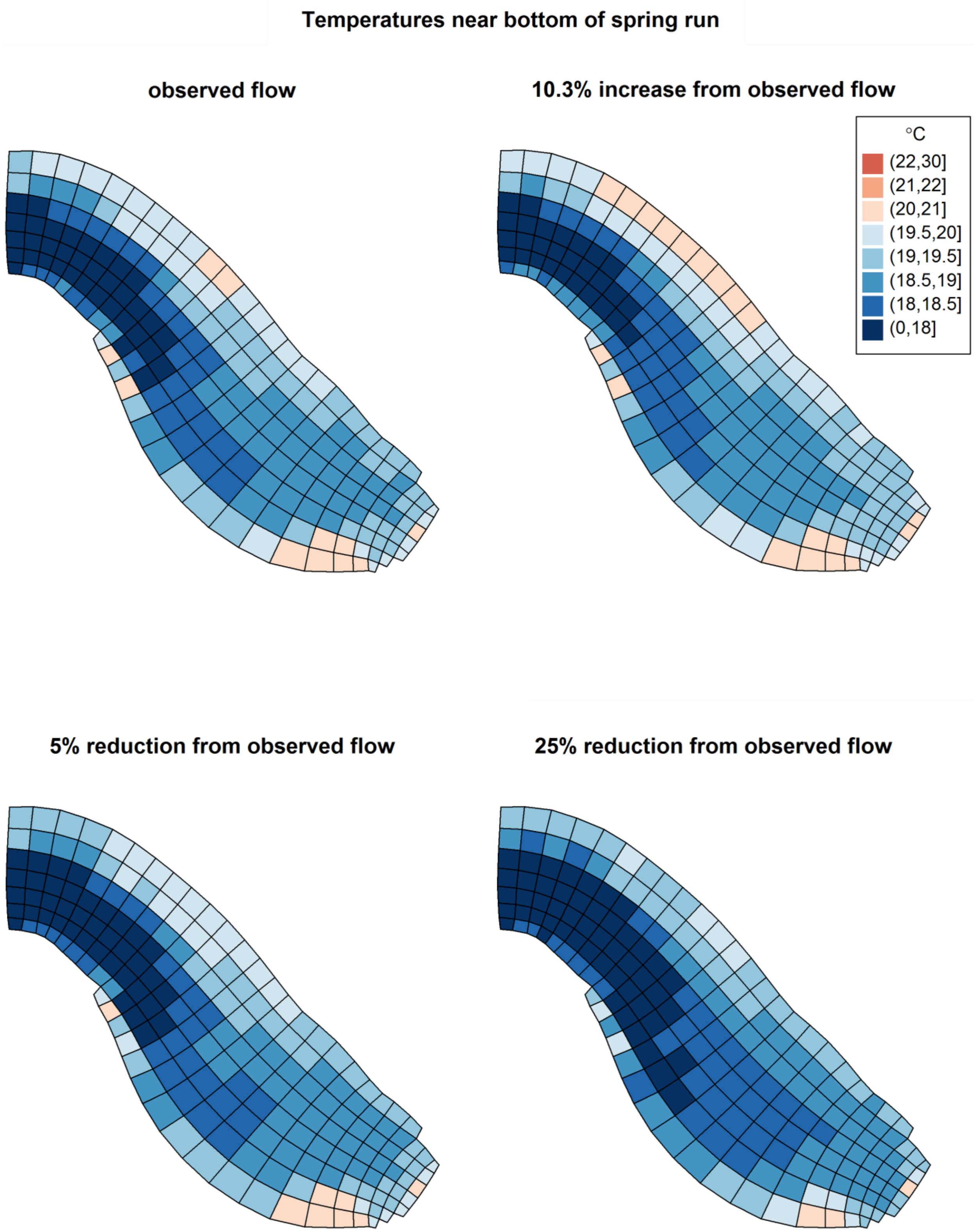


Figure 13: Average temperatures near the bottom of the water column in the spring run on Feb. 21, 2015, for each flow scenario.

Technical approach for determining a minimum flow regime for De Leon Springs

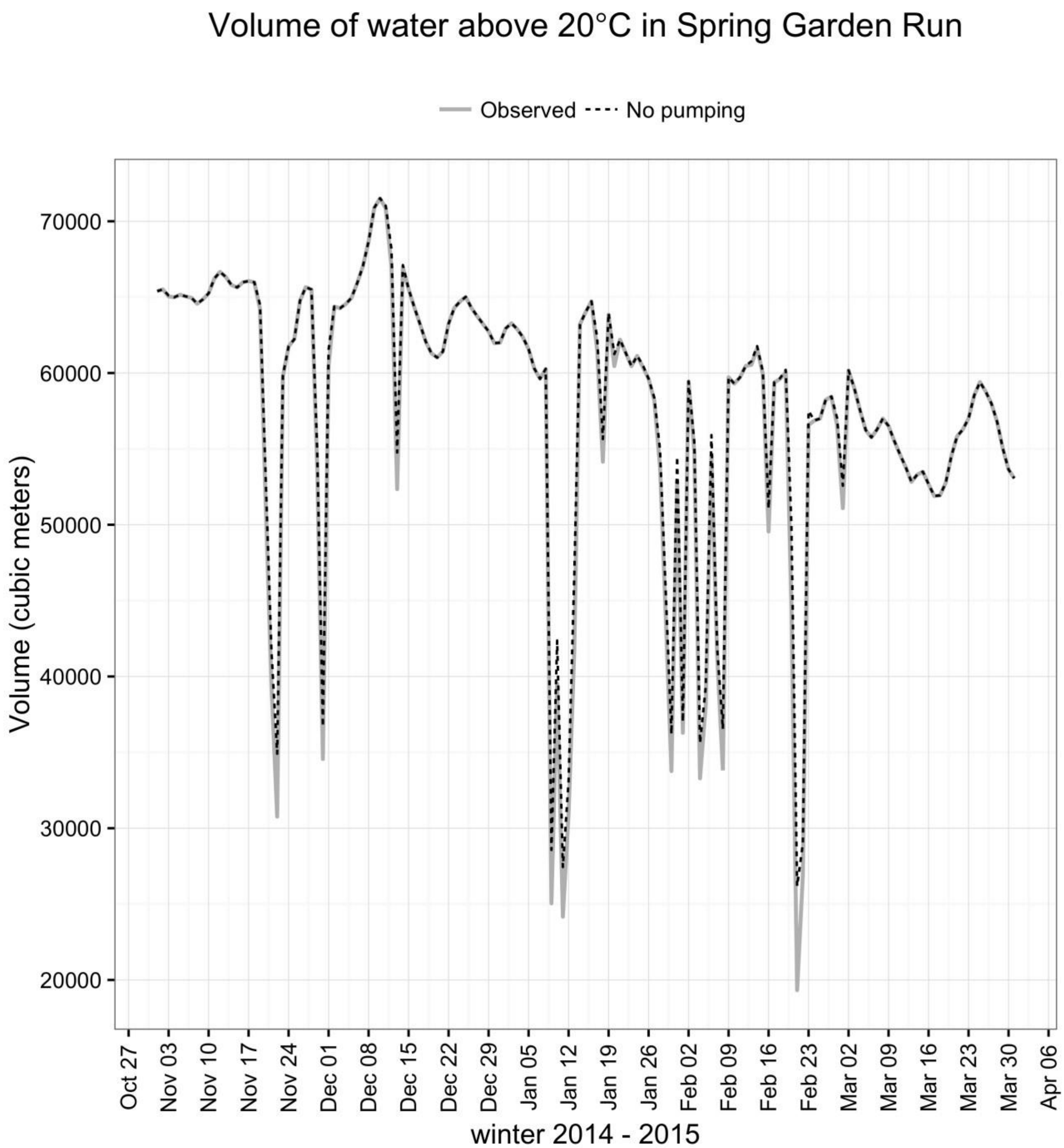


Figure 14: Volume of water above 20°C in Spring Garden Run in winter 2014 - 2015, for the scenario with observed flow (gray) and the "no pumping" scenario with a 10.3% increase from observed flow (black).

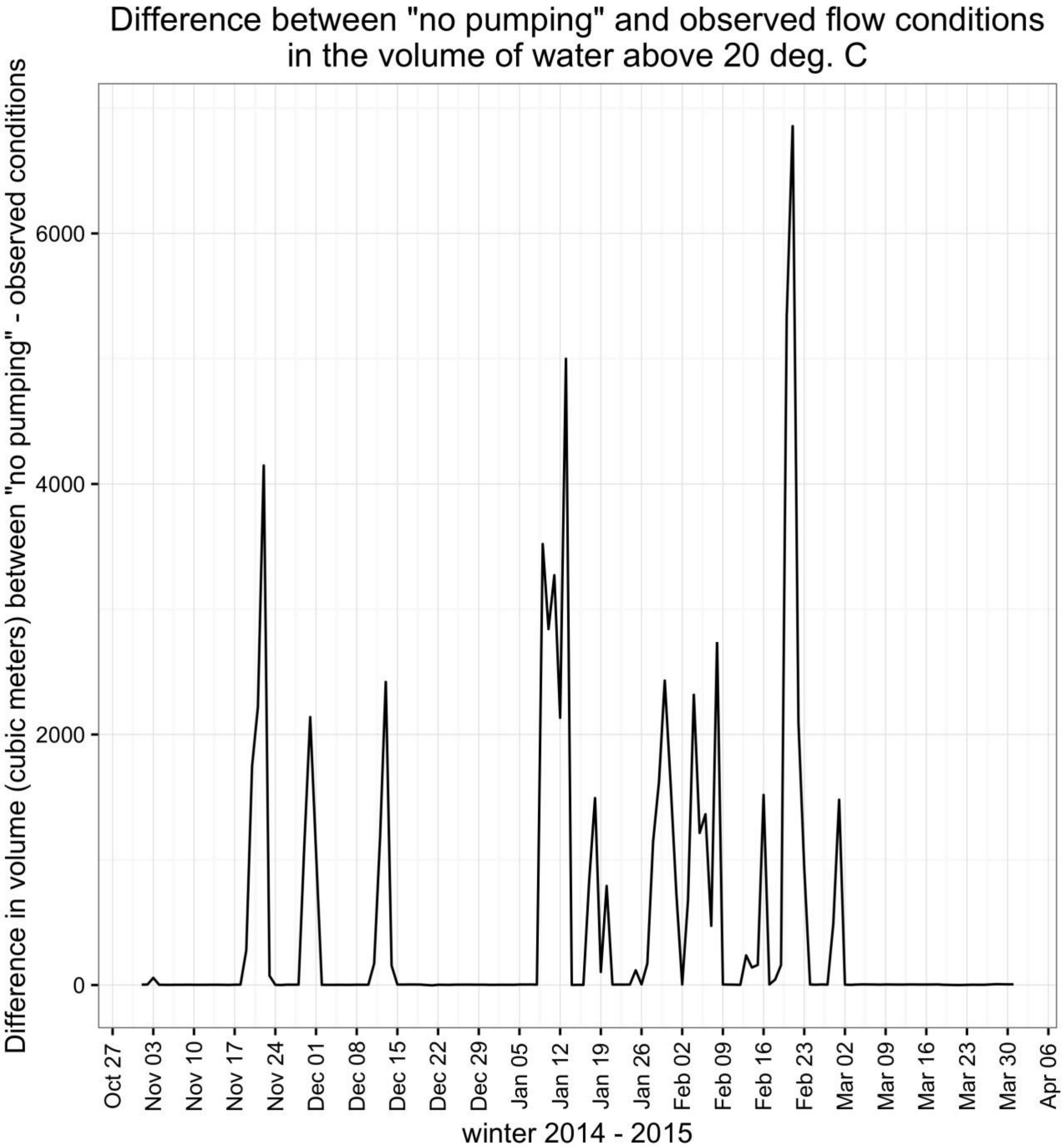


Figure 15: Difference in the volume of water above 20°C between the scenario with a 10.3% increase from observed flow and the scenario with observed flow in winter 2014 - 2015.

Technical approach for determining a minimum flow regime for De Leon Springs

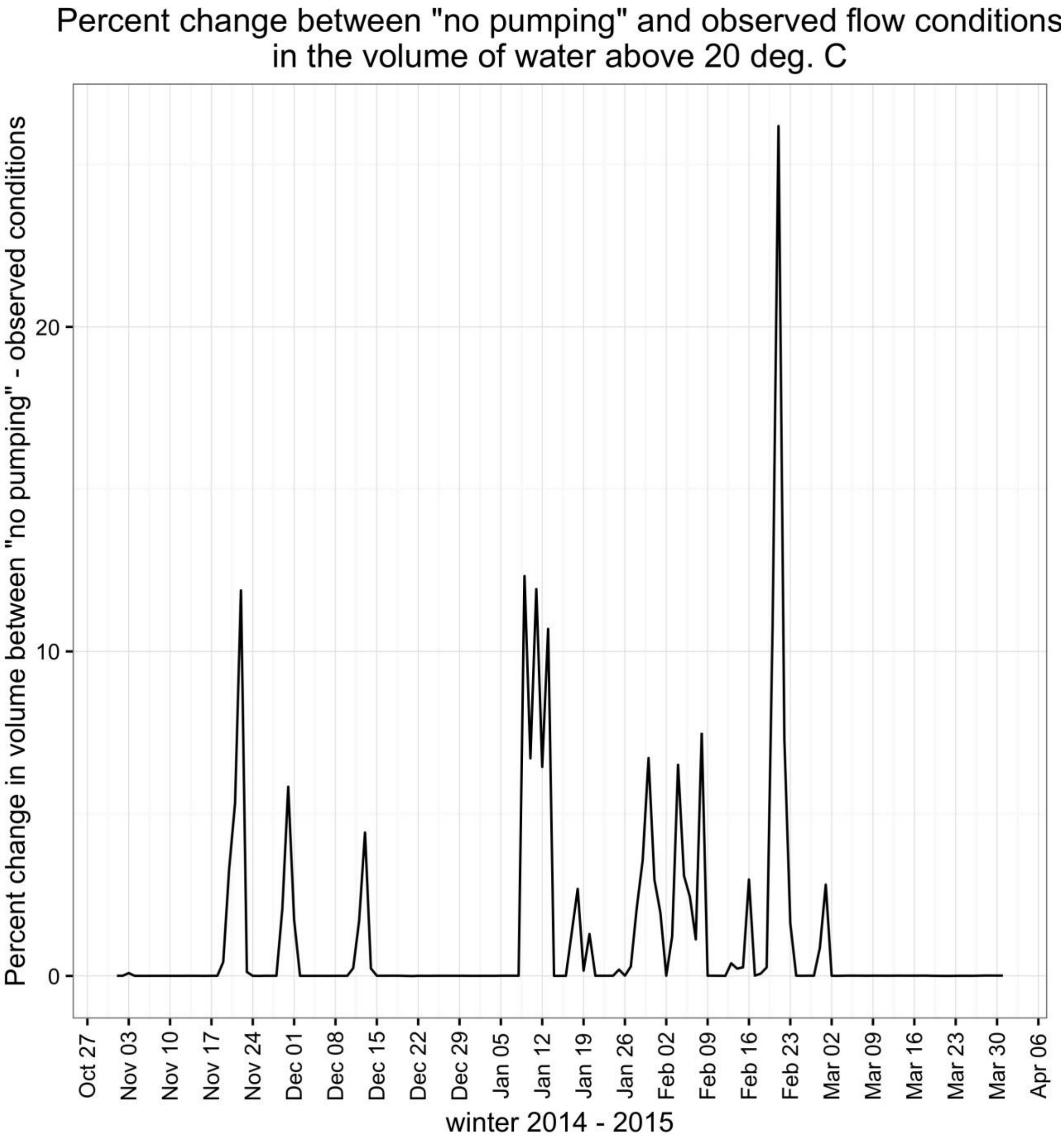


Figure 16: Percent difference in the volume of water above 20°C between the scenario with a 10.3% increase from observed flow and the scenario with observed flow in winter 2014 - 2015 (calculated as the percent difference from the "no pumping" condition).

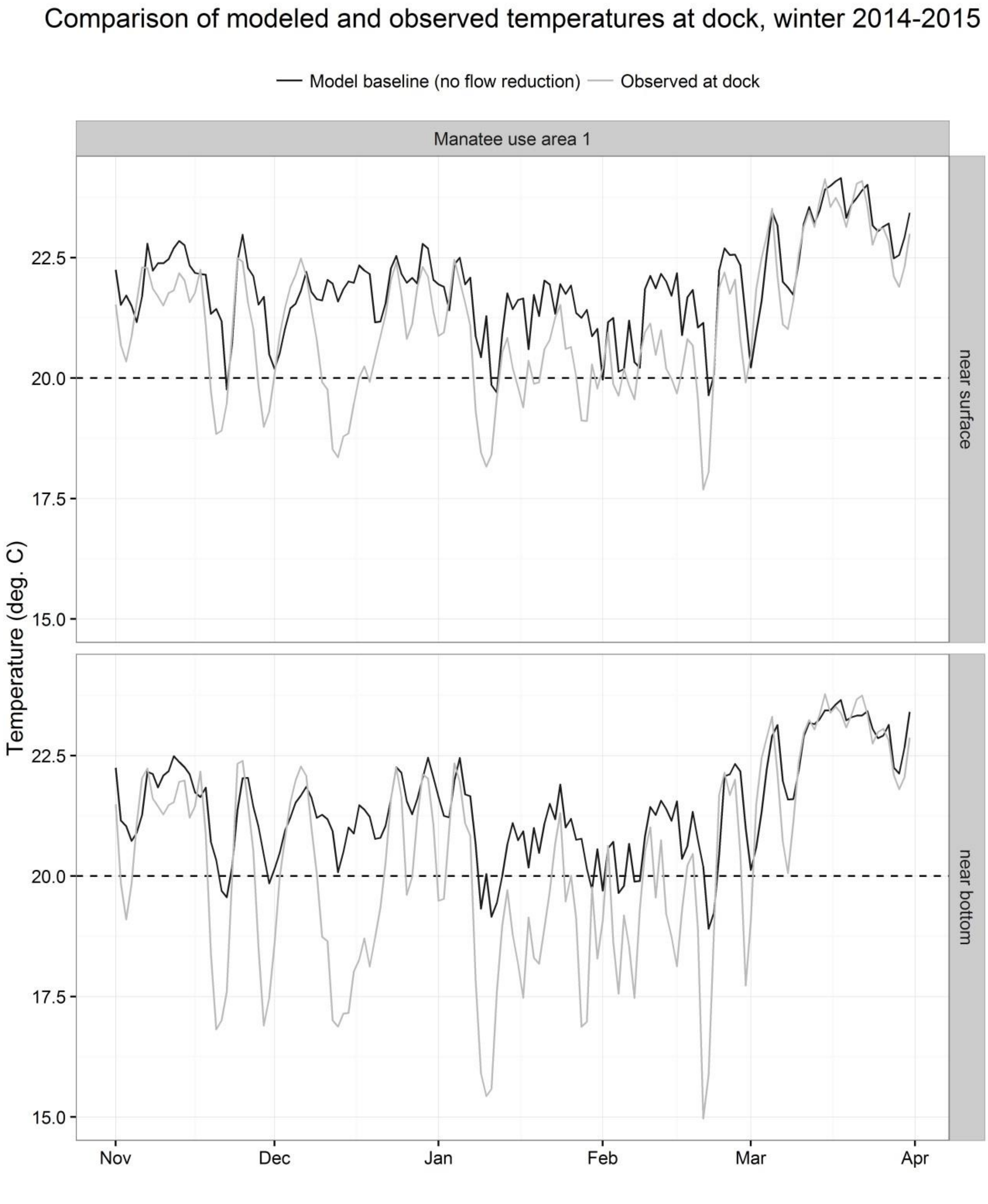


Figure 17: Comparison of observed temperatures at the dock (from temperature recording devices placed near the dock) and model-estimated temperatures at the dock in winter 2014 - 2015. Note that the model tended to overestimate temperatures, especially on the coldest days.

HYDROLOGIC DATA ANALYSIS

Spring flow data were obtained from USGS and SJRWMD. USGS manual measurements were available from 1964 - 2010, and SJRWMD manual and continuous measurements (continuous measurements were calculated from a rating curve) were available from 1983 - 2016. There was a gap in the data from 1997 - 2006, which was filled using data from well V-1030 in De Leon Springs State Park (see Appendix B) (Figure 18). Daily and monthly variations in spring flow were examined in Appendix C. Monthly mean spring flow was calculated by averaging all available daily values for each month (Figure 19). Annual mean spring flow was calculated by averaging the monthly means.

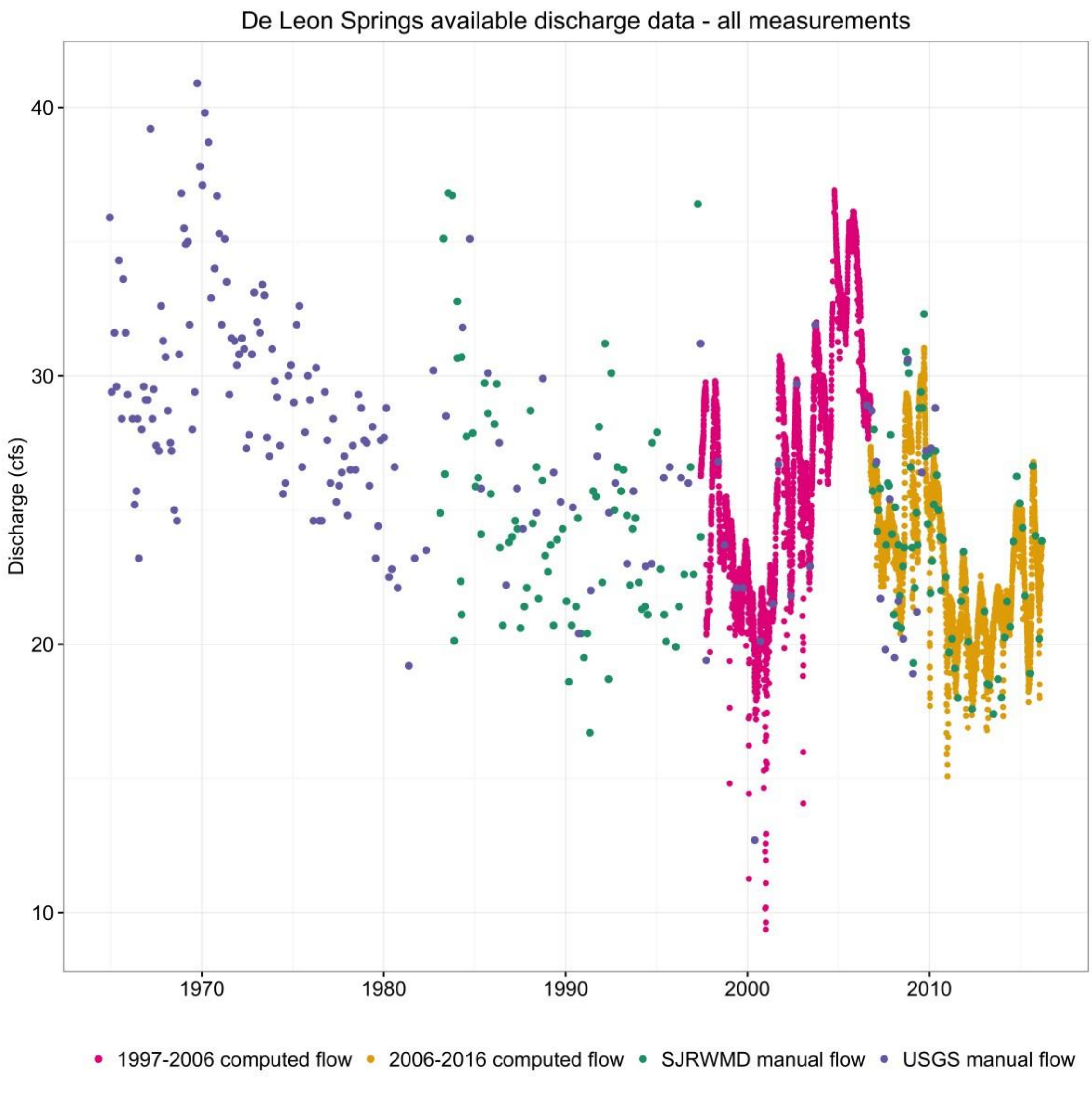


Figure 18: Discharge measurements at De Leon Springs, including measurements from USGS and SJRWMD and measurements estimated from a rating curve with well V-1030.

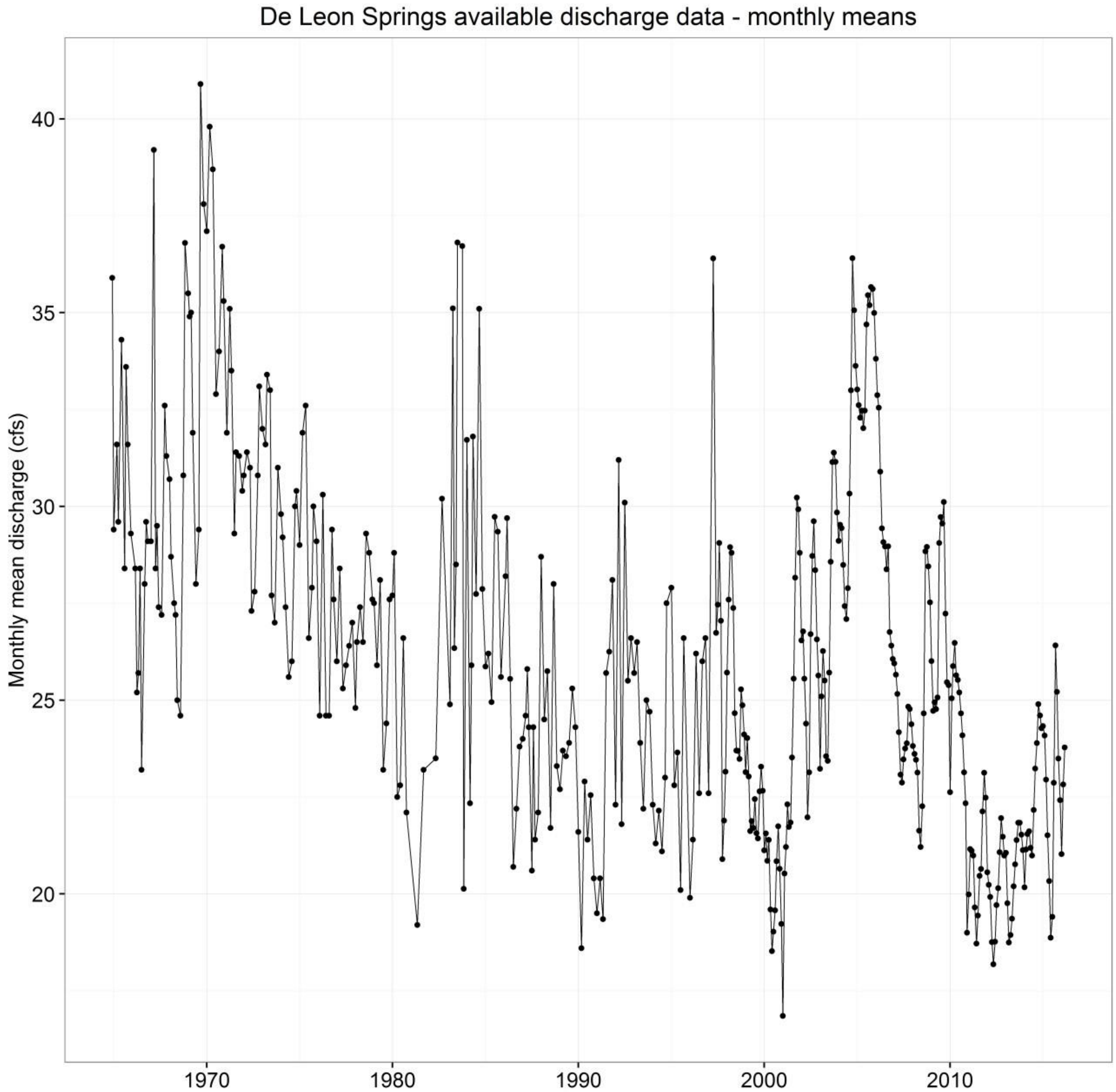


Figure 19: Monthly mean spring flow at De Leon Springs.

GROUNDWATER PUMPING IMPACT ASSESSMENT

The latest version of the SJRWMD Volusia County steady-state groundwater model (SJRWMD 2016) was used to assess the impact of groundwater pumping on spring flows. This assessment involved the development of two hypothetical or synthetic datasets. A "no pumping" flow timeseries was generated to represent annual mean spring flows that might have occurred from 1965 - 2015 in the absence of groundwater pumping. A "baseline pumping" flow timeseries was generated to represent annual mean spring flows that might have occurred from 1965 - 2015 if 2010 groundwater pumping occurred throughout the same time period. Groundwater pumping in 2010 was considered current because the latest version of the Volusia model was developed for 2010. The modeling results estimate that baseline (2010) groundwater pumping reduces spring flow by an average of 2.6 cfs (1.7 million gallons per day) or 9.3% compared to the no pumping condition (see Appendix B).

A previous assessment at De Leon Springs used statistical modeling to estimate the impact of water use on spring flows, and the results were similar to the results estimated by the steadystate groundwater model (see Appendix B). The Volusia County steady-state groundwater model allows the estimation of the impacts of groundwater pumping alone on spring flows, while the statistical model may include the influence of other anthropogenic effects besides groundwater pumping. An important part of the minimum flows program is having the ability to assess how water use, rather than other factors, impacts spring flows. For these reasons, the results estimated from the Volusia County steady-state groundwater model, rather than the statistical model, were used for determining the recommended minimum flow for De Leon Springs.

CALCULATION AND COMPARISON OF THE MINIMUM FLOW REGIME

The recommended minimum flow regime for De Leon Springs is a mean flow of 25.6 cfs, which is the mean of the baseline flow timeseries. The mean of the no pumping dataset was 28.2 cfs. The difference between these two means, 2.6 cfs or 9.3% of the no pumping mean, is the estimated amount that annual mean spring flow at De Leon Springs is reduced due to current water use.

Spring flow at De Leon Springs is calculated on an hourly basis using well V-1030 in De Leon Springs State Park, so the relationship between spring flow and well V-1030 must be noted. Based on the current rating curve between spring flow and the well (see Appendix B), the groundwater level in well V-1030 corresponding to the recommended mean flow of 25.6 cfs is 17.65 ft NAVD88. If any human alteration of the spring vent or the weir at De Leon Springs occurs, altering the relationship between spring flow and groundwater levels in the well, the recommended minimum flow regime for De Leon Springs may need to be reevaluated.

Comparison with other adopted minimum flows in Florida

Minimum flow regimes have been defined by Florida's water management districts in various ways for different springs, depending on the environmental resources of interest at each spring and the measures needed to adequately protect them.

Within SJRWMD, minimum flow regimes have previously been adopted for two spring systems -- Blue Spring in Volusia County, where the adopted minimum flow is a mean flow that increases over time, and the Wekiva River system springs (Wekiwa, Rock, Seminole, Sanlando, Starbuck, Messant, Palm, and Miami Springs), where a mean flow and mean groundwater level were adopted for each spring (rule 40C-8.031, F.A.C.).

Rather than adopting mean flows, the Suwannee River Water Management District

(SRWMD) has adopted percent flows of the historic flow regime or specific flow durations (chapter 40B-8, F.A.C). At Manatee, Fanning, and Little Fanning Springs, 90% of the historic flow regime will be maintained, and an additional specific flow duration will be maintained during winter months as well. At Blue Spring in Levy County and the Wacissa River system springs, 90% and 93.5% of the historic flow regime will be maintained, respectively. At the Upper Santa Fe River which includes flow contributions from Santa Fe Spring, the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles of river flow on a flow duration curve will be maintained.

The Southwest Florida Water Management District (SWFWMD) has adopted percent flows of the natural flow regime, mean or median flows, and minimum flow thresholds for various springs (chapter 40D-8, F.A.C.). At the Chassahowitzka, Homosassa, and Weeki Wachee River systems and springs, 97%, 97%, and 90% of the natural flow regime will be maintained, respectively. At Gum Slough Spring Run, 94% of the natural flow regime will be maintained and 100% of flows will be above a minimum threshold. At Zolfo Springs, 95% of flows will be above a minimum threshold. At Sulphur Springs, various minimum thresholds dependent on downstream conditions were adopted. At the Weeki Wachee River system and springs, Lower Alafia River system and springs, and Crystal Springs (on the Hillsborough River), 5-year and 10-year moving averages of annual mean and median flows were adopted.

The Florida Department of Environmental Protection has adopted minimum flow regimes for two spring systems -- the Lower Santa Fe River springs, where the median baseline flow will not be reduced by more than 8%, and the Ichetucknee River springs, where the median baseline flow will not be reduced by more than 3% (chapter 62-42, F.A.C.).

Some of the adopted minimum flow regimes listed above have been based at least in part on protecting winter warm-water habitat for manatees, including Blue Spring in Volusia County, Manatee/Fanning Springs, the Chassahowitzka River system and springs, the Homosassa River system and springs, the Weeki Wachee River system and springs, Sulphur Springs, and the Ichetucknee River.

At De Leon Springs, the adoption of mean flow is recommended, similar to the definitions used by SJRWMD at both Blue Spring in Volusia County and the Wekiva River system springs. For comparison with other water management districts, the mean flow under the minimum flow regime at De Leon Springs will not be reduced by more than 9.3% due to water use. Approximately 90.7% of the "no pumping" flow regime will be maintained at De Leon Springs.

CONSIDERATION OF WATER RESOURCE VALUES

A literature review, field visits, and additional analyses were conducted to determine which of the ten water resource values (WRVs) listed in rule 62-40.473, F.A.C., are applicable to De Leon Springs and whether they would be protected under the recommended minimum flow (Table 1). Appendix A is the WRV report for De Leon Springs.

Table 1: Summary of water resource values for De Leon Springs.

Water resource value	Relevance to De Leon Springs	Relevance to the minimum flow regime	Protected by minimum flow regime?
Recreation in and on the water	Swimming, snorkeling, and instructional diving in the spring pool and fishing, boating, and wildlife viewing in the spring run	Reductions in discharge could negatively affect recreation, especially due to increased water residence times	Yes
Fish and wildlife habitats and the passage of fish	The spring pool and spring run serve as habitat for many species of fish, macroinvertebrates, and other wildlife including manatees	Manatees in particular would be negatively impacted by any further reductions in spring discharge	Yes
Estuarine resources	Discharge eventually reaches estuaries far downstream	The overall contribution to estuaries is very small	Yes
Transfer of detrital material	Discharge transports detrital material downstream	Reductions in discharge would likely lead to a reduction in the transfer of detrital material downstream, due to increased water residence times	Yes
Maintenance of freshwater storage and supply	Spring discharge is an indicator of the condition of the aquifer potentiometric surface	Efforts to maintain a long-term mean spring discharge may similarly maintain the potentiometric surface over some area	Yes
Aesthetic and scenic attributes	Appearance of the manmade waterfall, and clarity of the spring pool and spring run	Reductions in discharge could negatively affect water clarity in the spring pool and spring run, especially due to increased water residence times	Yes
Filtration and absorption of nutrients and other pollutants	Mats of bacteria in the cavern may uptake and process some nutrients and pollutants before the water enters the pool	Discharge required to maintain the diversity of the microbial community is probably minimal, but the biomass of the microbial community may fluctuate with discharge	Yes

Sediment loads	Discharge transports some sediment out of the pool, and assists with keeping unsettled sediments moving downstream	Reductions in discharge could reduce sediment transport	Yes
Water quality	Water quality degradation is prohibited in De Leon Springs	Reductions in discharge could alter water quality	Yes
Navigation	The spring run is navigable for boaters using canoes, kayaks, paddle boats, and motor boats	Reductions in discharge would not affect water levels in the spring run	N/A

MINIMUM FLOWS STATUS ASSESSMENT

This section reviews the determination and status of the minimum flow regime at De Leon Springs.

Determine the baseline flow

Baseline flow is a long-term dataset that incorporates the natural variability of spring flow and the best estimate of current water use conditions. For De Leon Springs, observed and estimated flow for the period of record from 1965 - 2015, adjusted by the reduction in flow due to 2010 water use, was used to calculate a mean baseline flow.

Determine the minimum flow

The minimum flow at De leon Springs is intended to prevent further warm-water habitat loss due to water use, while also protecting any less-sensitive ecological resources and beneficial uses. Winter warm-water habitat for manatees was the most sensitive ecological resource evaluated for the determination of the minimum flow at De Leon Springs, in accordance with rule 62-40.473, F.A.C. The minimum flow for De Leon Springs was equal to the baseline flow.

Determine the current status

The status of De Leon Springs at the time when the minimum flow was determined was assessed by subtracting the minimum flow from the baseline flow to calculate the amount of potentially available flow. If the available flow is less than zero, the minimum flow is not being achieved and the spring is in "recovery". Since the minimum flow at De Leon Springs was equal to the baseline flow, the available flow was zero, and the spring was not in recovery.

Determine the status at the 20-year planning horizon

The expected status of De Leon Springs at the 20-year planning horizon was assessed by subtracting the minimum flow from the estimated flow at the 20-year planning horizon based on the best available groundwater model, to calculate the amount of potentially available flow. If the available flow is less than zero, the minimum flow is not being achieved at the 20-year planning horizon and the spring is in "prevention". Since water use near De Leon Springs is projected to decline from 2010 levels, the available flow was greater than zero, and the spring was not in prevention.

CONCLUSIONS

According to USFWS, FWC, and other researchers, the potential loss of warm-water habitat in Florida over the next several decades is one of the most serious concerns for the continued recovery of manatee populations. Water temperature modeling for De Leon Springs indicates that any reduction in spring flow leads to a decrease in water temperatures in Spring Garden Run, and current water use as estimated by groundwater modeling already leads to substantial decreases in warm-water habitat volume for manatees in Spring Garden Run.

The minimum flow regime recommended by SJRWMD for De Leon Springs, a mean flow of 25.6 cfs, is intended to allow no further decrease in warm-water habitat for manatees due to water withdrawals beyond the mean baseline flow. The mean baseline flow is the best available estimate of long-term mean flow for the period of record 1965 - 2015, adjusted by the reduction in flow due to 2010 water use. To maintain the recommended flow regime and the warm-water habitat available for manatees under this flow regime, reductions in spring flow due to water use should remain at or below 2.6 cfs or 9.3% of the no pumping flow regime.

Additional reductions in spring flow are not expected within the 20-year planning horizon, as water use is projected to decline from 2010 levels. Therefore, the recommended minimum flow is expected to be achieved over the 20-year planning horizon and will continue to be monitored.

Literature cited

LITERATURE CITED

Basso, Ron, Jason Hood, Marty Kelly, Jonathan Morales, and Tammy Hinkle. 2011. *Proposed minimum flows and levels for the Gum Slough Spring Run Final Report*. Brooksville, Florida: Southwest Florida Water Management District.

Bossart, Gregory D., Rene A. Meisner, S. A. Rommel, Shin-je Ghim, and A. Bennett Jenson. 2002. Pathological features of the Florida manatee cold stress syndrome. *Aquatic Mammals* 29: 9–17.

Bunn, S.E., and A.H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* 30: 492–507.

Davis, Aubrey, and Brenda Herring. 2006. *Inventory of rare and endemic plant and animal species of Ponce DeLeon, Gemini, and Green Springs*. Tallahassee, Florida: St. Johns River Water Management District, Special Publication SJ2006-SP8.

[DEP] Florida Department of Environmental Protection. 2006. *De Leon Springs State Park unit management plan*. State of Florida Department of Environmental Protection, Division of Recreation and Parks.

Environmental Consulting and Technology Inc. 2008. *Environmental evaluations for the development of minimum flows and levels for the St. Johns River near DeLand at State Road 44, Volusia county*. St. Johns River Water Management District, Special Publication SJ2004-SP30.

[FWC] Florida Fish and Wildlife Conservation Commission. 2007. *Florida manatee management plan*. Tallahassee, Florida: Florida Fish and Wildlife Conservation Commision, Florida.

Griffith, Glenn, Daniel Jr. Canfield, Christine Horsburgh, James Omernik, and Sandra Azevedo. 2016. Lake regions of Florida. https://www.flrules.org/gateway/readRefFile.asp?refId=1254{\&}filename=Florida Lake Regions Map 2.pdf. Accessed June 1.

Herman, J. S., F. B. Franklin, A. L. Mills, A. L. Giannotti, and T. N. Tysall. 2008. Bacterial activity and geochemical reactions in submerged cave development - impact on karst aquifers in Florida. *American Geophysical Union, Spring Meeting, abstract #H33D-04*.

Irvine, A. Blair. 1983. Manatee metabolism and its influence on distribution in Florida. *Biological Conservation* 25: 315–334. doi:10.1016/0006-3207(83)90068-X.

Lowe, Edgar F., and Lawrence E. Battoe. 2009. *Alternative water supply cumulative impact assessment interim report*. St. Johns River Water Management District.

Morris, Lori, and Dean Dobberfuhl. 2009. *Appendix 9A: Submerged Aquatic Vegetation Patterns in the Lower St . Johns River Basin*. St. Johns River Water Management District.

National Research Council of the National Academies. 2005. *The science of instream flows: A review of the Texas instream flow program*. Edited by Committee on Review of Methods for Establishing Instream Flows for Texas Rivers. Washington, D.C.: The National Academies Press.

Neubauer, Clifford P., Greeneville B. Hall, Edgar F. Lowe, C. Price Robison, Richard B. Hupalo, and Lawrence W. Keenan. 2008. Minimum flows and levels method of the St.

Johns River Water Management District, Florida, USA. *Environmental Management* 42: 1101–1114. doi:10.1007/s00267-008-9199-y.

Phelps, G.G., Stephen J. Walsh, Robert M. Gerwig, William B. Tate, and By G G Phelps. 2006. *Characterization of the hydrology, water chemistry, and aquatic communities of selected springs in the St . Johns River Water Management District, Florida, 2004*. U.S. Geological Survey, Open-File Report 2006-1107.

Postel, Sandra, and Brian Richter. 2003. *Rivers for life: Managing water for people and nature*. Washington, D.C.: Island Press.

Provancha, Jane, Cynthia Taylor, Manny Gimond, Michael Wild, and Shahrokh Rouhani. 2012. *K-assessment of manatee forage and warm-water associated with eleven Florida sites*. Merritt Island, Florida: Innovative Health Applications, LLC.

Richter, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. *Conservation Biology* 10: 1163–1174.

Ross, Monica. 2011. *Manatee use of secondary springs in central Florida*. Sea to Shore Alliance.

Scruggs, Lewis. 2014. *Economic impact assessment - Florida State Park System*. Tallahassee, Florida: Florida Department of Environmental Protection, Office of Park Planning.

Shelton, Douglas N. 2005. The rare and endemic snails of selected springs within the St. Johns River Water Management District: 1–24.

Sitler, Robert. 2016. Immersed in millennial history at DeLeon Springs. DeLand, Florida.

[SJRWMD] St. Johns River Water Management District. 2016. *Updated Volusia regional groundwater flow model (electronic files)*.

Spechler, R. M. 1995. *Estimated discharge and chemical- constituent loading from the Upper Floridan Aquifer to the Lower St . Johns River, northeastern Florida, 1990-91*. U.S. Geological Survey, Water Resources Investigations Report 94-4132.

Stewart, Joseph B. 2016. *Spring Garden Run temperature model: Hydrodynamic analysis and model summary*. Palatka, Florida: St. Johns River Water Management District.

Teegavarapu, Ramesh S V, Aneesh Goly, and Jayantha Obeysekera. 2013. Influences of Atlantic multidecadal oscillation phases on spatial and temporal variability of regional precipitation extremes. *Journal of Hydrology* 495. Elsevier B.V.: 74–93. doi:10.1016/j.jhydrol.2013.05.003.

[USFWS] U.S. Fish and Wildlife Service. 2001. *Florida manatee recovery plan, Third revision*. Atlanta, Georgia: U.S. Fish and Wildlife Service, Southeast Region.

[USFWS] U.S. Fish and Wildlife Service. 2007. *West Indian manatee 5-year review: Summary and evaluation*. U.S. Fish and Wildlife Service, Southeast Region, Jacksonville Ecological Services Office, Caribbean Field Office.

Wetland Solutions, Inc. 2010. *An ecosystem-level study of Florida's springs*.

Williamson, Ronald W. 2008. *Volusia county's west side: Steamboats and sandhills*. Florida: The History Press.

Worthy, Graham. 2000. Florida manatees and warm water: Proceedings of the warm-water workshop, Jupiter, Florida, August 24-25, 1999. Jacksonville, Florida: U.S. Fish and Wildlife Service.

APPENDIX A: WATER RESOURCE VALUES AT DE LEON SPRINGS

OVERVIEW

All relevant water resource values at De Leon Springs were considered, and are anticipated to be protected under the recommended minimum flow regime. Over the 20-year planning horizon, the recommended minimum flow regime will maintain the estimated mean spring flow that would have occurred from 1965 - 2015 if 2010 levels of water use had occurred throughout that time period. This spring flow will be referred to throughout this appendix as baseline flow.

RECREATION IN AND ON THE WATER

Recreation at De Leon Springs includes swimming, snorkeling, and instructional diving in the spring pool and fishing, boating, and wildlife viewing in the spring run. A tour boat also runs from the top of the spring run and down part of Spring Garden Creek twice daily. The recommended flow regime is unlikely to negatively affect any of these activities, since baseline flow will be maintained. Any additional reduction in flow, however, could negatively affect recreation, especially due to increased water residence times in the spring pool and spring run.

Water residence times

Based on a model developed for Spring Garden Run using the environmental fluid dynamics code (EFDC), any reduction in spring discharge would likely lead to longer residence time of water in the spring pool and spring run (Stewart 2016). Spring discharge keeps water and suspended solids moving out of the spring pool and down Spring Garden Run. With longer water residence time, more solids may settle out of the water column and add to the muck layer on the bed of Spring Garden Run. In some cases, longer water residence times have been associated with higher phytoplankton biomass and percent dominance by cyanobacteria, as well as longer durations of algal blooms in waterways of the St. Johns River basin (Lowe and Battoe 2009).

To estimate how much residence time would change with reductions in spring discharge, the model was used to estimate water "age" (expressed as days since exiting the spring pool) in Spring Garden Run during the time period from November 2014 - March 2015 with the actual discharge recorded during that time period (model baseline), 5% less discharge (model scenario with 5% reduction), and 25% less discharge (model scenario with 25% reduction) (Stewart 2016). The model divided the water column into six layers of equal depth. Results are shown for two of those layers, the near-surface (second layer from top) and near-bottom (second layer from bottom), at manatee use areas 1 and 2. (Note: Ideally, we would have been able to estimate water age during April - October months as well, but the EFDC model was built only for the winter months with the intent of using it to estimate water temperature for manatee habitat.)

Appendix A: Water resource values at De Leon Springs

The near-surface and near-bottom of manatee use areas 1 and 2 all showed similar patterns in water age. For example, water age at the near-surface of the water column at manatee use area 1 increased by 57% on average (2.3 days) between the model baseline and model scenario with a 25% reduction in observed discharge. In the model baseline, water was estimated to have exited the spring pool an average of 4.0 days prior. In the model scenario with a 25% reduction in discharge, water was estimated to have exited the spring pool an average of 6.3 days prior (Table 1, Table 2, Figure 1, Figure 2).

The largest differences between the model baseline and model scenario occurred at times when water age was already very high; for example, on March 14, 2015, water near the surface of the water column at manatee use area 2 was estimated to have exited the spring pool an average of 15.7 days prior and in the model scenario with a 25% reduction in discharge this increased to 23.7 days, a difference of more than a week (Figure 3, Figure 4).

With the recommended flow regime, baseline flow will be maintained, and similar water residence times should be be maintained as well.

Table 1: Comparison of water age for the model baseline and model scenario with a 5% reduction in observed discharge, winter 2014-2015.

Manatee use area / layer	Baseline (days)	5% (days)	Diff. (days)	Diff.
Area 1 near surface	4	4.6	0.6	14%
Area 1 near bottom	8	8.8	0.8	9%
Area 2 near surface	4	4.5	0.6	14%
Area 2 near bottom	8.4	9.2	0.8	9%

Table 2: Comparison of water age for the model baseline and model scenario with a 25% reduction in observed discharge, winter 2014-2015.

Manatee use area / layer	Baseline (days)	25% (days)	Diff. (days)	Diff.
Area 1 near surface	4	6.3	2.3	57%
Area 1 near bottom	8	11	3	37%
Area 2 near surface	4	6.2	2.2	56%
Area 2 near bottom	8.4	11.5	3.1	36%

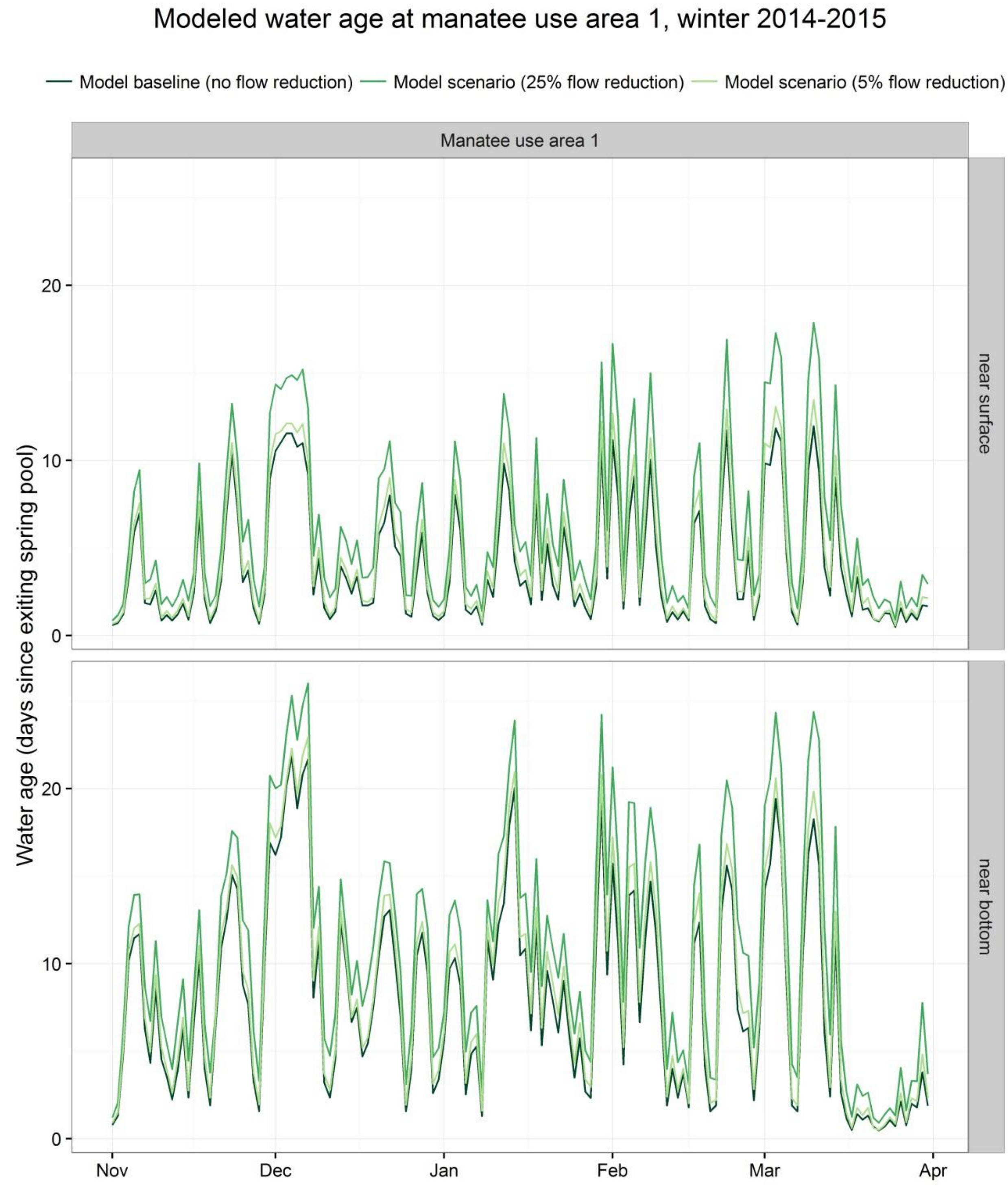


Figure 1: Water age (days since exiting the spring pool) near the surface and bottom of the water column at manatee use area 1 at De Leon Springs, winter 2014-2015.

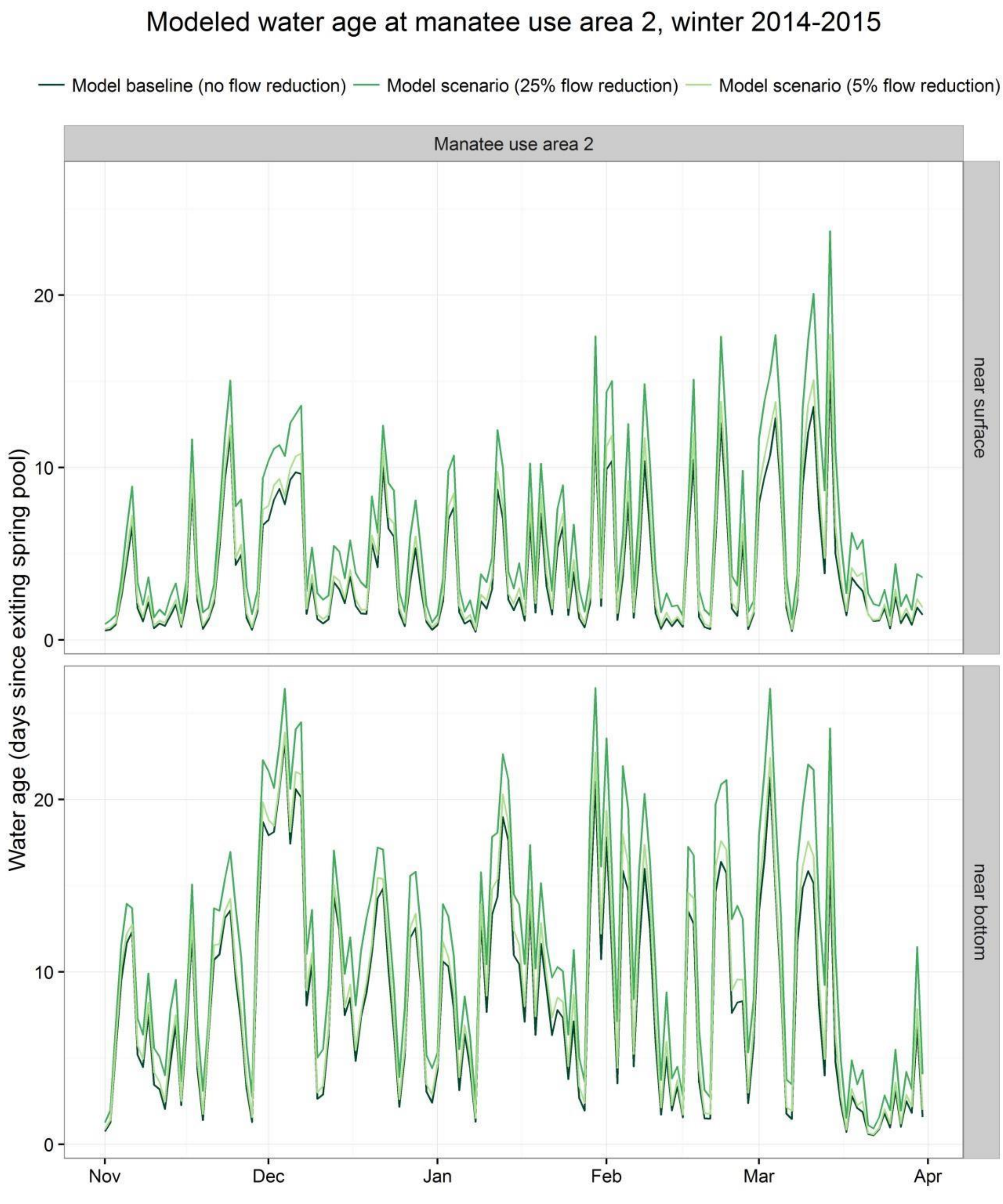


Figure 2: Water age (days since exiting the spring pool) near the surface and bottom of the water column at manatee use area 2 at De Leon Springs, winter 2014-2015.

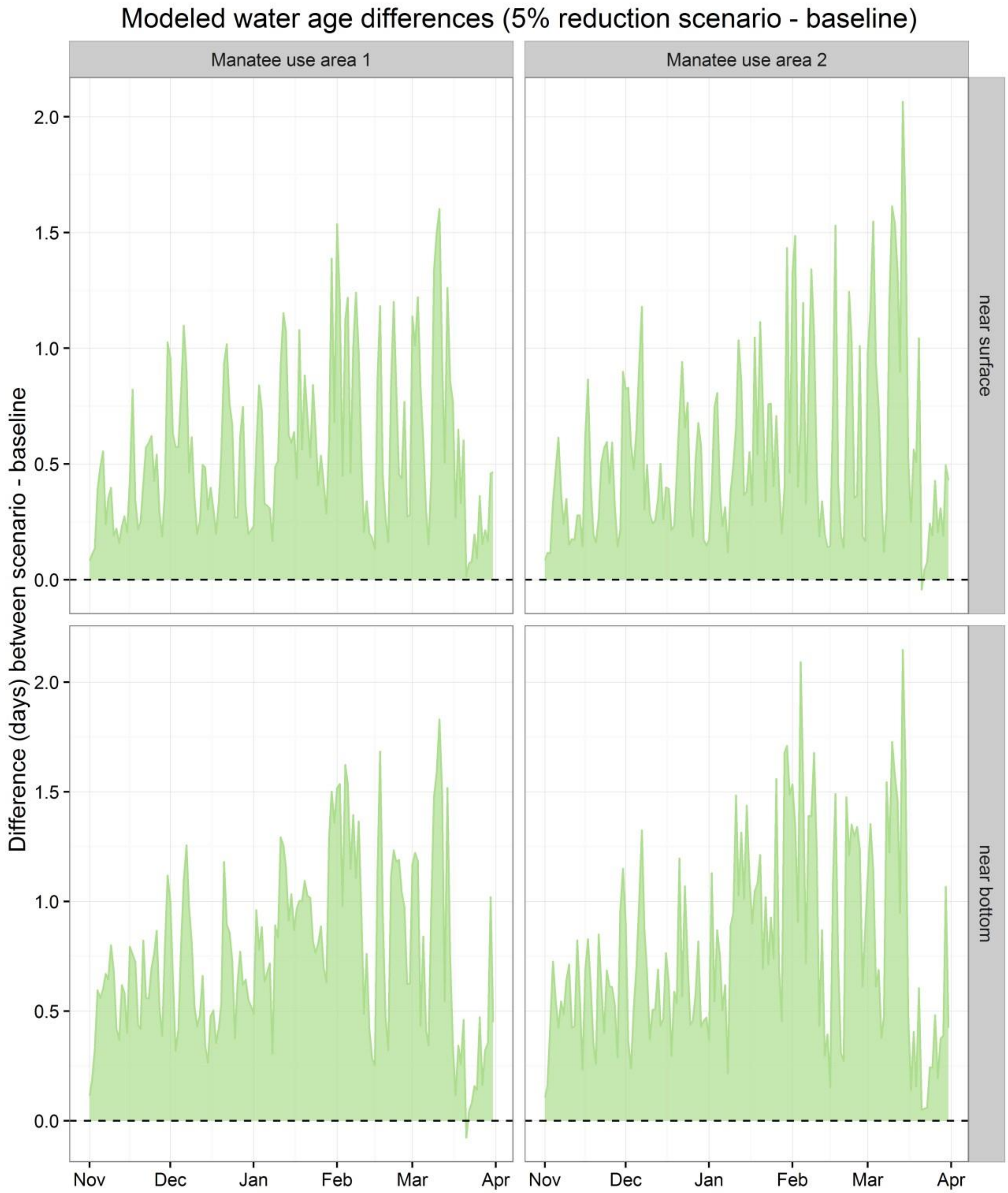


Figure 3: Difference in water age (days since exiting the spring pool) between the model baseline (actual observed discharge) and model scenario with a 5% reduction in observed discharge at De Leon Springs, winter 2014-2015.

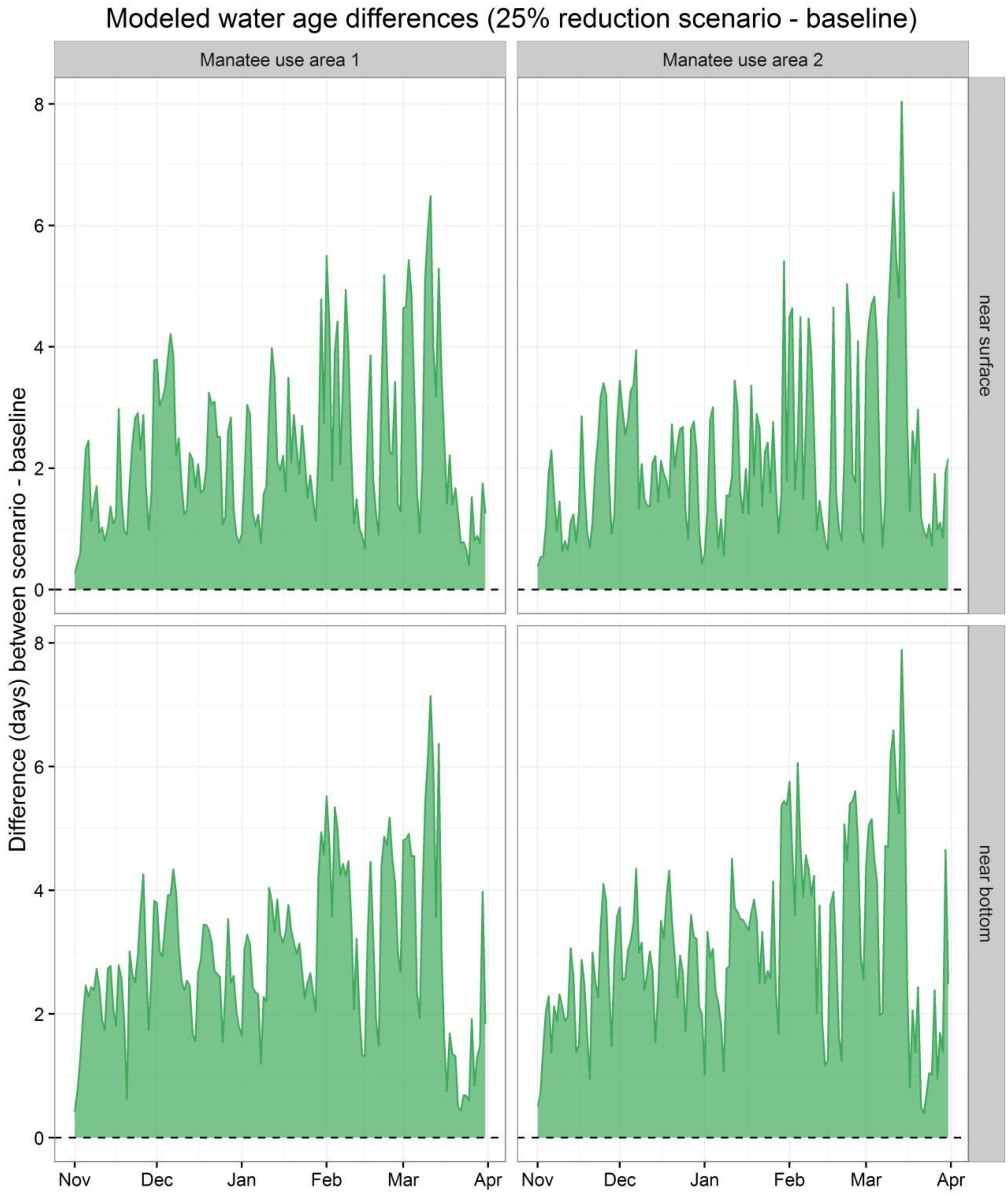


Figure 4: Difference in water age (days since exiting the spring pool) between the model baseline (actual observed discharge) and model scenario with a 25% reduction in observed discharge at De Leon Springs, winter 2014-2015.

FISH AND WILDLIFE HABITAT AND THE PASSAGE OF FISH

The spring pool and spring run serve as habitat for many species of fish (at least 39 species recorded), macroinvertebrates (at least 61 taxa recorded), and other wildlife including manatees (G. Phelps et al. 2006; Wetland Solutions 2010). The recommended flow regime is unlikely to negatively affect wildlife at De Leon Springs, since baseline flow will be maintained. Any additional reductions in flow, however, could negatively affect some wildlife, especially due to changes in temperature, salinity, and other changes in water quality in the spring run.

Salinity

Any reduction in spring discharge would likely lead to slight increases in salinity in the spring run. De Leon Springs discharge salinity is usually lower than downstream salinity, so a reduction in discharge would lead to higher salinity in the spring run. De Leon Springs is also a source of freshwater for the St. Johns River, accounting for about 1% of the flow of the St. Johns River at Astor. To show how salinity in the spring run would likely increase with reduced spring discharge, the same EFDC model as mentioned in the previous sections was used to estimate salinity in Spring Garden Run during the time period from winter 2014-2015 with the actual discharge recorded during that time period (model baseline), 5% less discharge (model scenario with 5% reduction), and 25% less discharge (model scenario with 25% reduction) (Stewart 2016). The same locations, the near-surface and near-bottom of the water column at manatee use areas 1 and 2, were considered.

Of the locations considered, salinity at the near-bottom of the water column at manatee use area 2 was the most proportionally affected by reduced spring discharge. Salinity at this location increased by 0.014 psu on average between the model baseline and model scenario with a 25% reduction in discharge. Salinity was an average of 0.454 psu in the model baseline, and salinity was an average of 0.468 psu in the model scenario with a 25% reduction in discharge (Table 3, Table 4, Figure 5, Figure 6).

Salinity in any of the model cells in manatee use areas 1 and 2 on any day ranged from 0.379-0.591 psu in the model baseline, and from 0.379-0.620 psu in the model scenario with a 25% reduction in discharge. The largest difference between the model baseline and model scenario was on March 14, 2015, when salinity near the surface of the water column at manatee use area 2 was an estimated 0.496 psu and increased to 0.542 psu in the model scenario with a 25% reduction in discharge (Figure 7, Figure 8).

Most of the fish species found at De Leon Springs can tolerate much wider ranges of salinity (Table 5) and would not likely be affected by any changes in salinity due to changes in discharge at De Leon Springs. For example, largemouth bass have a salinity range of at least 0-17.5 ppt (units of ppt are nearly equivalent to psu). Taillight shiners and black crappies have narrower salinity ranges (0.09-1.0 and 0-2.4 ppt, respectively) (G. Phelps et al. 2006; Environmental Consulting and Technology Inc. 2008; Wetland Solutions 2010).

Submerged aquatic plants at De Leon Springs also tolerate fairly wide ranges of salinity and would not likely be affected by any changes in salinity due to changes in discharge at De Leon Springs. The dominant species in Spring Garden Run are eel grass (*Vallisneria americana*) and coontail (*Ceratophyllum demersum*), both eaten by manatees and other wildlife (Davis and Herring 2006). A study of submerged aquatic plants in the St. Johns River basin concluded that plant diversity and coverage increased upstream in the St. Johns River basin where salinity was lower and less variable (Morris and Dobberfuhl 2009). Eel grass was generally found in areas with salinity of 0 - 7 psu with temporary increases in salinity up to 12 psu. Coontail was more sensitive, and was generally found in areas with salinity below 2 psu (Morris and Dobberfuhl 2009).

With the recommended flow regime, baseline flow will be maintained, and similar salinity should be maintained as well.

Table 3: Comparison of average salinity for the model baseline and model scenario with a 5% reduction in observed discharge, winter 2014-2015.

Manatee use area / layer	Baseline (psu)	5% (psu)	Diff. (psu)
Area 1 near surface	0.432	0.435	0.003
Area 1 near bottom	0.453	0.456	0.003
Area 2 near surface	0.43	0.433	0.003
Area 2 near bottom	0.454	0.457	0.004

Table 4: Comparison of average salinity for the model baseline and model scenario with a 25% reduction in observed discharge.

Manatee use area / layer	Baseline (psu)	25% (psu)	Diff. (psu)
Area 1 near surface	0.432	0.443	0.011
Area 1 near bottom	0.453	0.466	0.013
Area 2 near surface	0.43	0.44	0.01
Area 2 near bottom	0.454	0.468	0.014

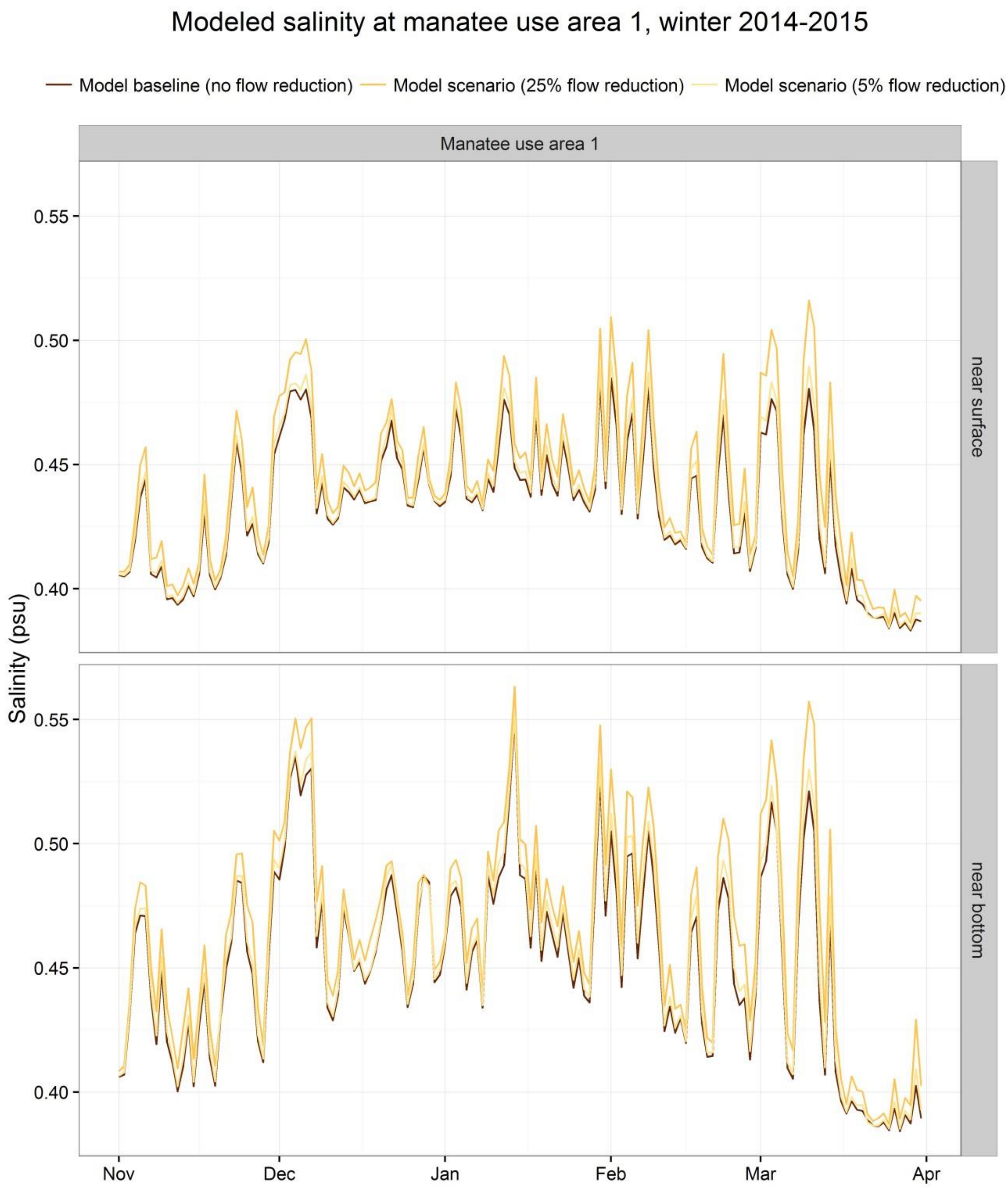


Figure 5: Salinity near the surface and bottom of the water column at manatee use area 1, winter 20142015.

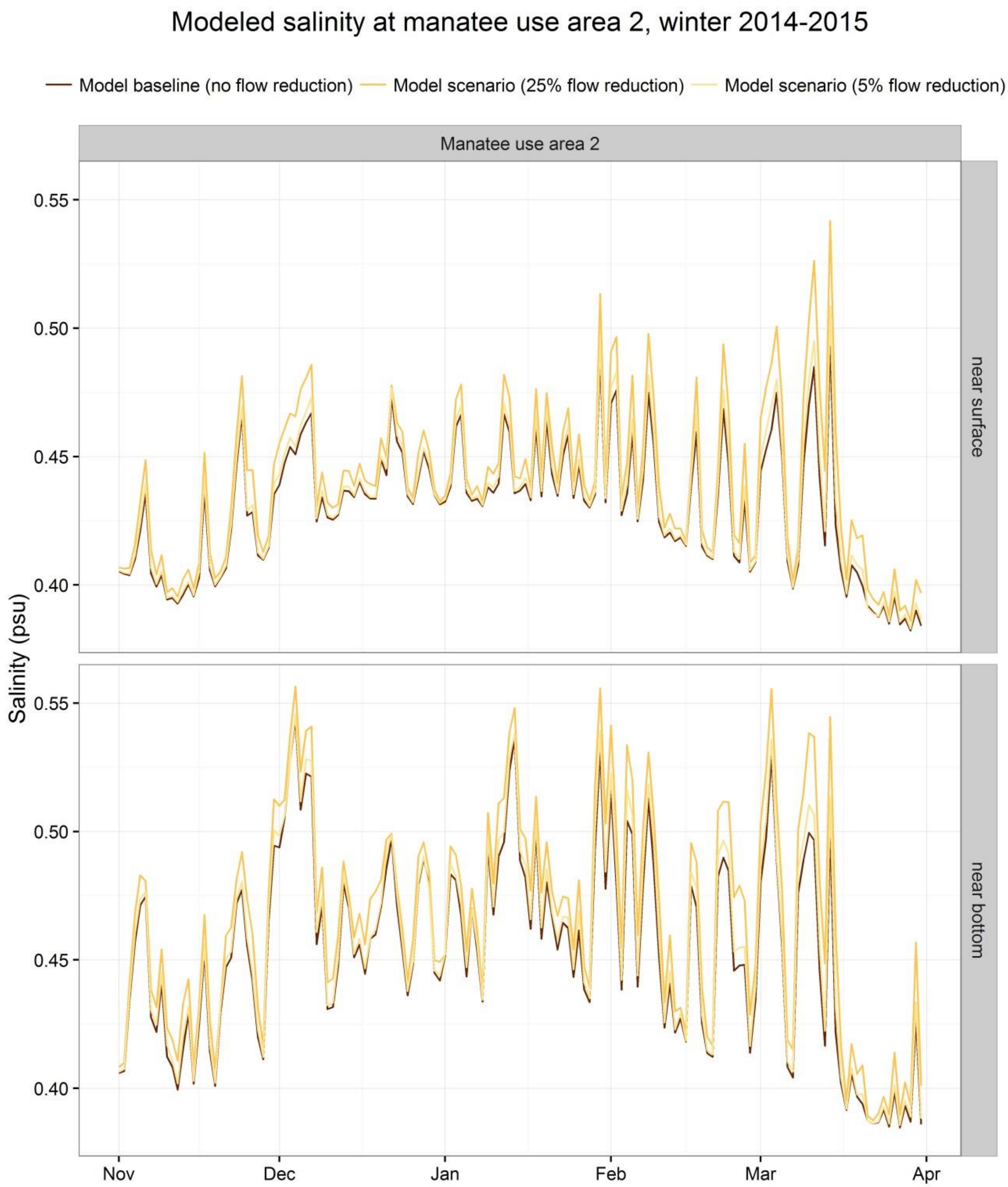


Figure 6: Salinity near the surface and bottom of the water column at manatee use area 2.

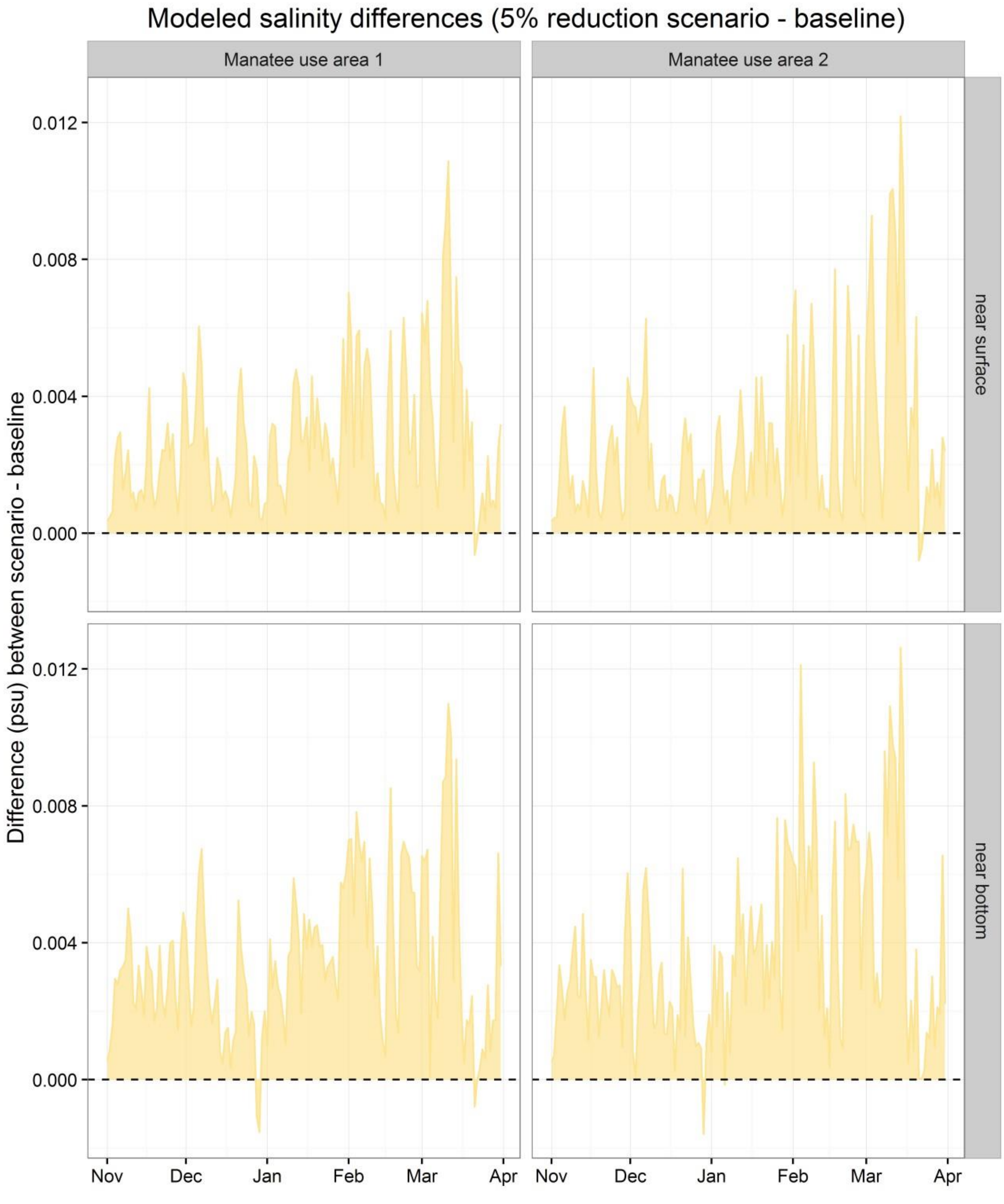


Figure 7: Difference in salinity between the model baseline (no discharge reduction) and scenario with a 5% reduction in observed discharge at De Leon Springs, winter 2014-2015.

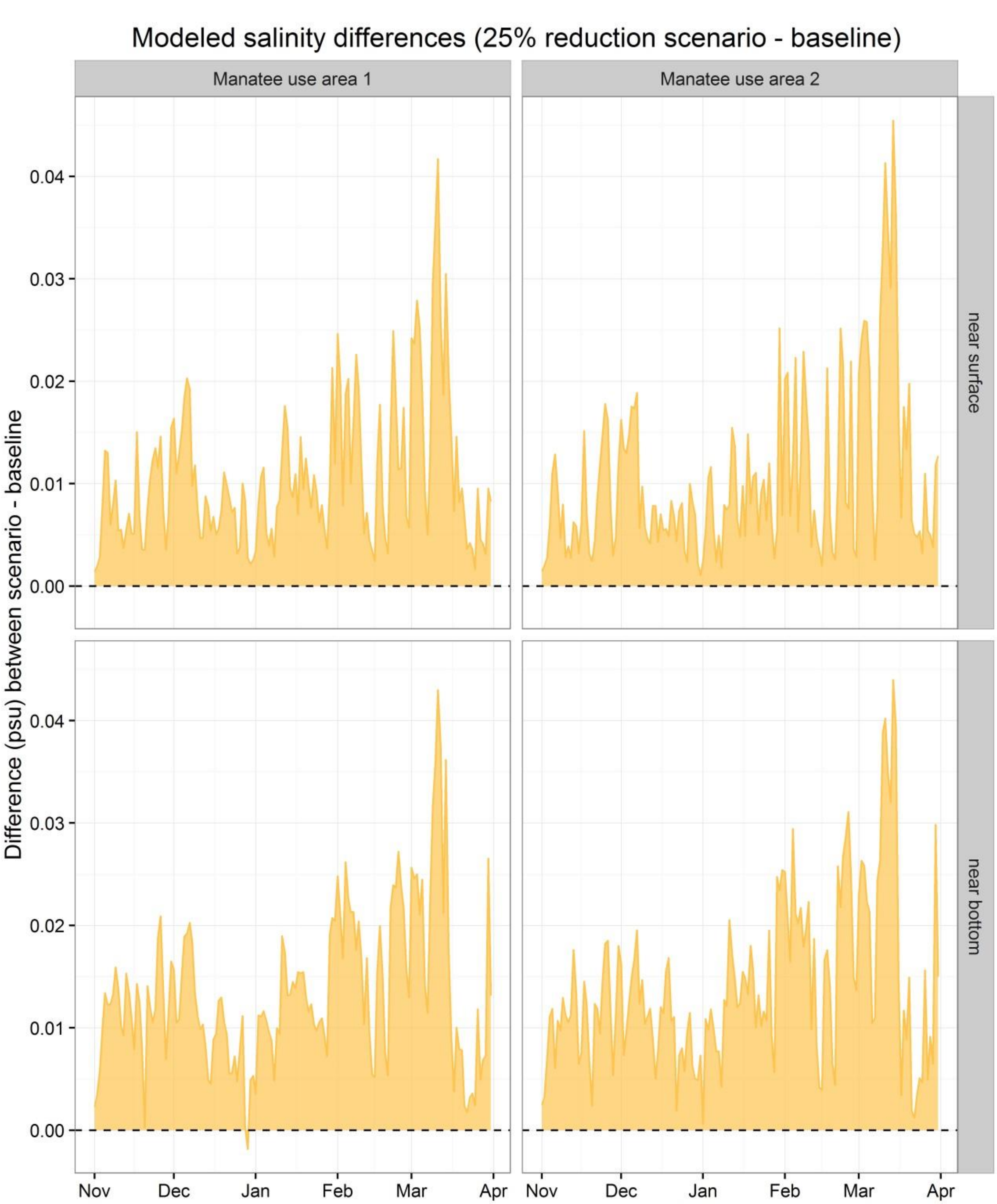


Figure 8: Difference in salinity between the model baseline (no discharge reduction) and scenario with a 25% reduction in observed discharge at De Leon Springs, winter 2014-2015.

Table 5: List of fish species found in De Leon Springs or Spring Garden Run and known salinity ranges.

Compiled from Phelps, 2006; Wetland Solutions, 2010; and SJRWMD, 2008.

Species	Common_name	Salinity_range_ppt
Ameiurus natalis	Yellow bullhead	0 - 12
Amia calva	Bowfin	
Anguilla rostrata	American eel	0.3 - 29.9
Astronotus ocellaus	Oscar	
Dasyatis sabina	Atlantic stingray	.09 - 41
Dorosoma cepedianum	Gizzard shad	0.0 - 24.7
Elops saurus	Ladyfish	0 - 35
Enneacanthus gloriosus	Bluespotted sunfish	0 - 3.8
Erimyzon sucetta	Lake chubsucker	0.6 - 14.4
Esox niger	Chain pickerel	0 - 7.5
Etheostoma fusiforme	Swamp darter	
Fundulus chrysotus	Golden topminnow	0 - 5
Fundulus rubrifrons	Redface topminnow	
Fundulus seminolis	Seminole killifish	0 - 7.3
Gambusia holbrooki	Mosquitofish	0 - 30
Heterandria formosa	Least killifish	0 - 30.2
Hoplosternum littorale	Brown hoplo	
Lepisosteus osseus	Longnose gar	1.2 - 26.9
Lepisosteus platyrhincus	Florida gar	0 - 26.0
Lepomis auritus	Redbreast sunfish	0
Lepomis gulosus	Warmouth	0.5 - 14.4
Lepomis macrochirus	Bluegill	0 - 13.8
Lepomis marginatus	Dollar sunfish	5
Lepomis megalotis	Longear sunfish	
Lepomis microlophus	Redear sunfish	0 - 14.4
Lepomis punctatus	Spotted sunfish	0 - 17.5
Lucania goodei	Bluefin killifish	0 - 12
Lucania parva	Rainwater killifish	0 - 28
Micropterus salmoides	Largemouth bass	0 - 17.5
Mugil cephalus	Striped mullet	0 - 39.0
Notemigonus crysoleucas	Golden shiner	1.3 - 10.7
Notropis maculatus	Taillight shiner	0.09 - 1.0
Noturus leptachanthus	Speckled madtom	0.22
Oreochromis aureus	Blue tilapia	
Poecilia laptipinna	Sailfin molly	0 - 33
Pomoxis nigromaculatus	Black crappie	0 - 2.4
Pterygoplichthys disjunctivus	Vermiculated sailfin catfish	
Strongylura marina	Atlantic needlefish	0 - 23.0
Trinectes maculatus	Hogchoker	0 - 35

Importance of other water quality parameters

In 2005, researchers noted snails from the genera Aphaostracon in the spring, but could not identify them to species (Shelton 2005). Not much information is available about the genera Aphaostracon - they live in freshwater or brackish water and consume algae, bacterial films, and detritus. Several Aphaostracon species appear to be endemic to individual springs in the St. Johns River basin. The researchers recommended evaluating baseline chemical composition and flow regime data for any spring with rare snails, since any alteration of chemical composition or flow regime could potentially affect snails' ability to "feed, reproduce, or endure" (Shelton 2005). This evaluation has not yet occurred.

ESTUARINE RESOURCES

De Leon Springs discharge eventually reaches estuaries far downstream and may help to maintain the salinity gradient from freshwater to saltwater in the St. Johns River. However, its overall contribution by the time it nears estuaries is small. Assuming a typical salinity of 0.4 psu and a mean discharge of 26.06 cfs for De Leon Springs, and a typical salinity of 11 psu and a mean flow of 5700 cfs for the lower St. Johns River at Jacksonville (Spechler 1995), salinity in the lower St. Johns River at Jacksonville would increase by no more than 0.05 psu even if De Leon Springs discharge ceased completely. A change of 0.05 psu is very small, as discussed in the "Fish and wildlife habitat and fish passage" section. With the recommended flow regime, baseline flow will be maintained, and there should be no additional negative impacts on estuarine resources.

TRANSFER OF DETRITAL MATERIAL

Spring flow transports detrital material downstream. Any reduction in spring discharge would likely lead to a reduction in the transfer of detrital material downstream, due to longer residence times of water in the spring pool and spring run. Water residence times were discussed in the "Recreation in and on the water" section.

MAINTENANCE OF FRESHWATER STORAGE AND SUPPLY

Spring discharge depends on the level of the potentiometric surface, which changes over the short-term and possibly over the long-term due to trends in rainfall and groundwater pumping. If long-term mean spring discharge is maintained at the recommended minimum flow and the pool water level also remains steady, the potentiometric surface at the spring will also be maintained, on average, over the long-term, along with the associated freshwater storage and supply in the Floridan aquifer for existing and future permitted users within the groundwater contributing area of De Leon Springs.

AESTHETIC AND SCENIC ATTRIBUTES

The aesthetic and scenic attributes of De Leon Springs are important for recreation, and were part of the reason for the establishment of De Leon Springs State Park and its designation as an Outstanding Florida Water. The clarity of the water in the spring pool and spring run may be the most prominent aesthetic and scenic attributes of De Leon Springs. Any reduction in spring discharge could potentially affect these attributes of De Leon Springs, especially due to longer water residence times in the spring pool and spring run as discussed in the "Recreation in and on the water" section of this report. Since the recommended minimum flow is expected to maintain baseline flow, aesthetic and scenic attributes should remain similar as well.

The man-made waterfall where spring discharge exits the spring pool at De Leon Springs State Park is also a unique and attractive feature of De Leon Springs. The appearance of the waterfall is the result of spring discharge, and less water would flow over the waterfall if any reduction in discharge occurred. However, according to De Leon Springs State Park staff, the appearance of the waterfall does not noticeably change with typical fluctuations in discharge (Brian Polk, pers. comm., 2015). Since the recommended minimum flow is expected to maintain spring flow under 2010 water use, similar fluctuations in discharge due to rainfall and groundwater pumping should continue to occur, and the appearance of the waterfall should be maintained (Figure 9).

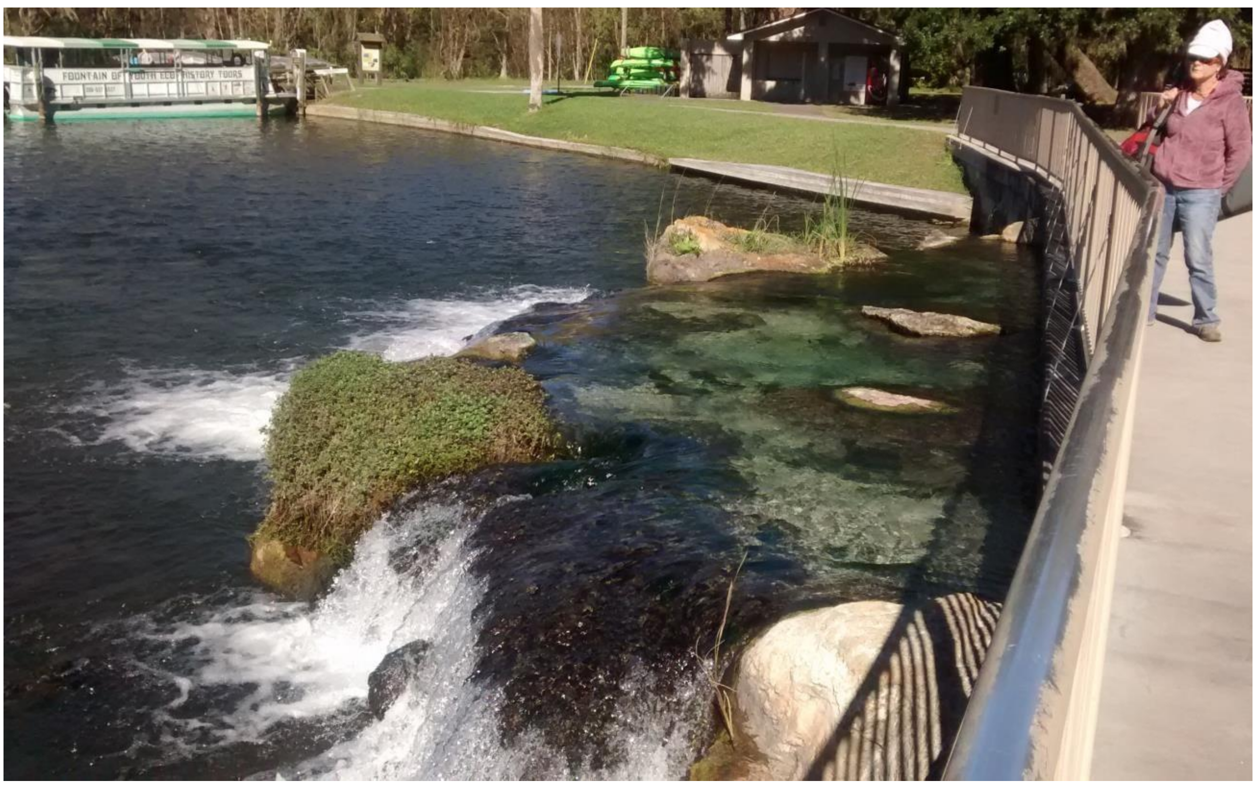


Figure 9: Constructed waterfall at De Leon Springs State Park.

FILTRATION AND ABSORPTION OF NUTRIENTS AND OTHER POLLUTANTS

A large, dark cavern and narrow passageway are the last areas that water from the Floridan aquifer passes through before being vented into the spring pool. The ceiling and walls of the cavern include microbial communities, in dense mats up to 10 cm thick, largely comprised of sulfur-oxidizing bacteria (Herman et al. 2008) (see Appendix E for a diagram and photos of the underground portion of De Leon Springs). The microbial communities form long streamers often extending 1-2 feet and waving in the strong current. The dense mats of bacteria may uptake and process some nutrients and pollutants from spring discharge before the water enters the pool or run.

Researchers who have studied the bacterial mats in De Leon Springs cave hypothesize that the discharge required to maintain the diversity of the microbial community is probably minimal, requiring only continuously non-zero discharge (Aaron Mills, pers. comm., 2015). However, the biomass of the microbial community may fluctuate with discharge. If discharge were to decrease significantly for a period of time, the microbial population might decline as well, and may take time to bounce back and resume its full productivity and filtration/absorption functions after discharge increases again. The recommended minimum flow is not expected to negatively impact the filtration and absorption of nutrients and other pollutants, although information on this subject is currently very limited.

SEDIMENT LOADS

Sediment is likely introduced into the spring run by runoff, wind, and by reverse flows when wind pushes water upstream into Spring Garden Run. Spring discharge also transports some sediment out of the pool and into the spring run, and assists with keeping water and and unsettled sediments moving downstream. The recommended minimum flow regime is expected to maintain baseline flow, and impacts on sediment loads should be maintained as well.

WATER QUALITY

De Leon Springs and Spring Garden Run are designated as Outstanding Florida Waters (OFWs). Water quality degradation due to proposed activities or discharges is generally prohibited in OFWs under rule 62-302.700, F.A.C. De Leon Springs was designated as an OFW on May 14, 1986. Since the recommended minimum flow is expected to maintain baseline flow, and water use in 1986 was similar to or greater than water use in 2010, water quality should not be negatively affected.

NAVIGATION

The spring run is navigable for boaters using canoes, kayaks, paddle boats, and motor boats. However, navigation is not relevant to an MFL for discharge at De Leon Springs, since it depends on water levels rather than discharge. Water levels in the spring run are determined by the stage of the St. Johns River rather than De Leon Springs discharge, and water levels in the spring pool are determined by the openings in the concrete wall of the spring pool.

APPENDIX B: HYDROLOGIC DATA ANALYSIS

INTRODUCTION

In addition to extensive work conducted to understand the ecological structure and function of priority water bodies, determining minimum flows and levels (MFLs) and evaluating the current status of water bodies require substantial hydrologic analysis of available data. Several steps were involved in performing the hydrologic data analysis for the De Leon springs MFLs determination:

1. Review of available data
2. Determination of period-of record (POR) for data analysis
3. Groundwater pumping impact assessment
4. Development of flow time series representing no-pumping and current-pumping conditions
5. MFL determination

This document describes each of the above steps and associated results.

DATA REVIEW

Discharge data for De Leon Springs was available from several sources, including USGS and SJRWMD (Table 1):

- Manual discharge measurements for De Leon Springs, USGS site ID 02236110, were downloaded from http://waterdata.usgs.gov/nwis/inventory/?site_no=02236110 (accessed February 2016).
- Manual and computed discharge measurements for De Leon Springs, SJRWMD site ID 00301897, were obtained from SJRWMD in March 2016 and were also available from http://webapub.sjrwmd.com/agws10/hdsnew/map.html.
- Water level measurements for well V-1030 in De Leon Springs State Park, SJRWMD site ID 02381300, were obtained from SJRWMD in March 2016 and were also available from http://webapub.sjrwmd.com/agws10/hdsnew/map.html.

Manual measurements collected by USGS were similar to manual and computed discharge measurements collected by SJRWMD on the same days. Measurements collected by both agencies were available on 19 days between 1984 - 2010. SJRWMD measurements were higher than USGS measurements on 9 of the 19 days and equal to USGS measurements on 1 day (Figure 1).

Table 1: Data sources for the De Leon Springs discharge period of record

Agency_ID	Meas_type	N	Qual_desc	Date	Freq
USGS 02236110	manual discharge	181	134 good 43 fair 4 unsp.	1929 - 2010	Less than yearly to serveral per year
SJRWMD 00301897	manual discharge	219	148 good 7 unver. 64 bad	1983 - 2016	Several per year
SJRWMD 00301897	computed discharge	3417	3315 good 102 est.	2006 - 2016	Daily mean of hourly data
SJRWMD 02381300	well V-1030 water level	7713	7604 good 109 unver.	1994 - 2016	Hourly

[1] The 6 measurements made prior to December 1964 were not included in our analyses - the measurements were too sparse to be considered part of a continuous period of record. [2] 64 measurements were unusable due to data quality concerns. Instead, well water level measurements were used as described below.

[3] Only well data back to 1997 was included in our analyses for the purpose of filling in the gap in the period of record.

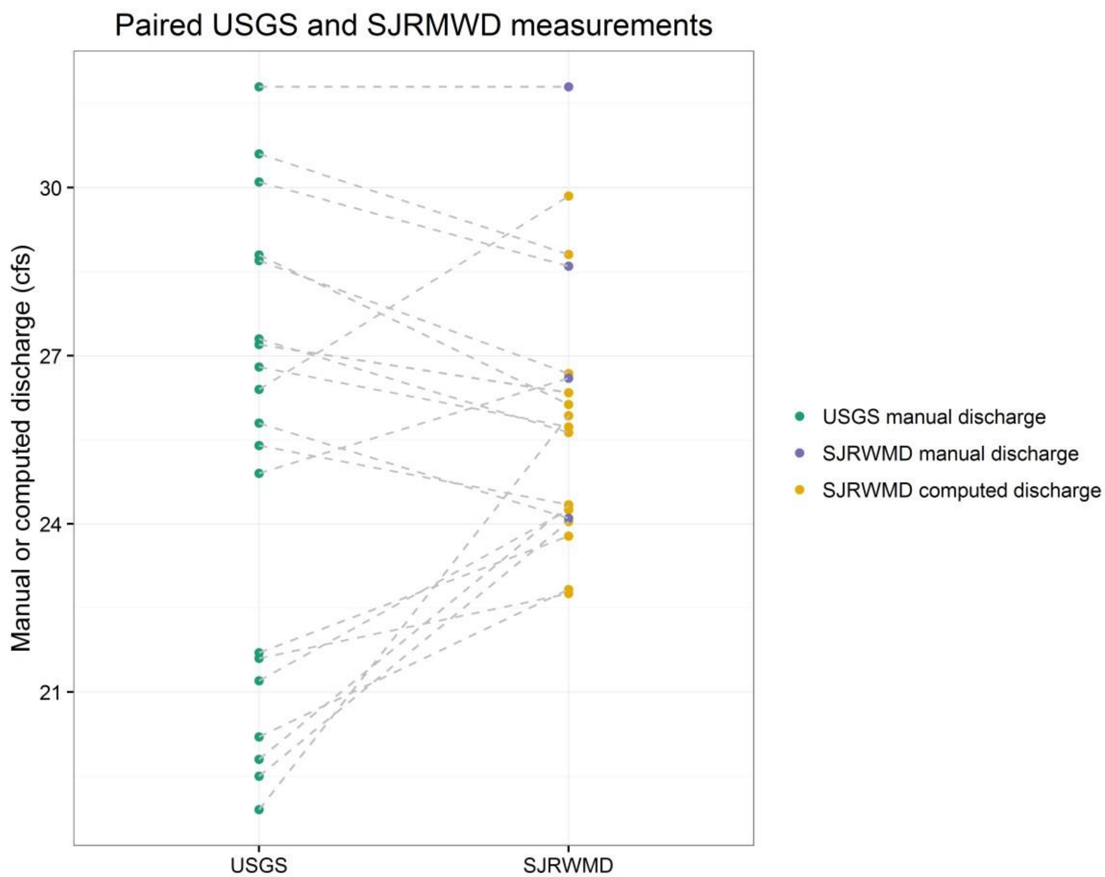


Figure 1: The dashed lines connect measurements collected on the same day by both USGS and SJRWMD. Measurements collected by different agencies on the same days were generally similar.

Rating curves

Rating curves can be used to compute discharge at springs based on measurements of water levels in a nearby well. However, the relationship between spring discharge and well water levels may change over time, gradually or abruptly. To address this, rating curves are updated occasionally (M. Wainwright, SJRWMD, pers. comm., 2016).

Rating curves for De Leon Springs have been used to compute discharge based on groundwater levels in well V-1030 located in De Leon Springs State Park. From October 2006 - September 2009, the rating curve used to compute discharge was

$Q = 1.792 * x - 2.867$ (Rating curve 1) where

Q is discharge in cubic feet per second and x

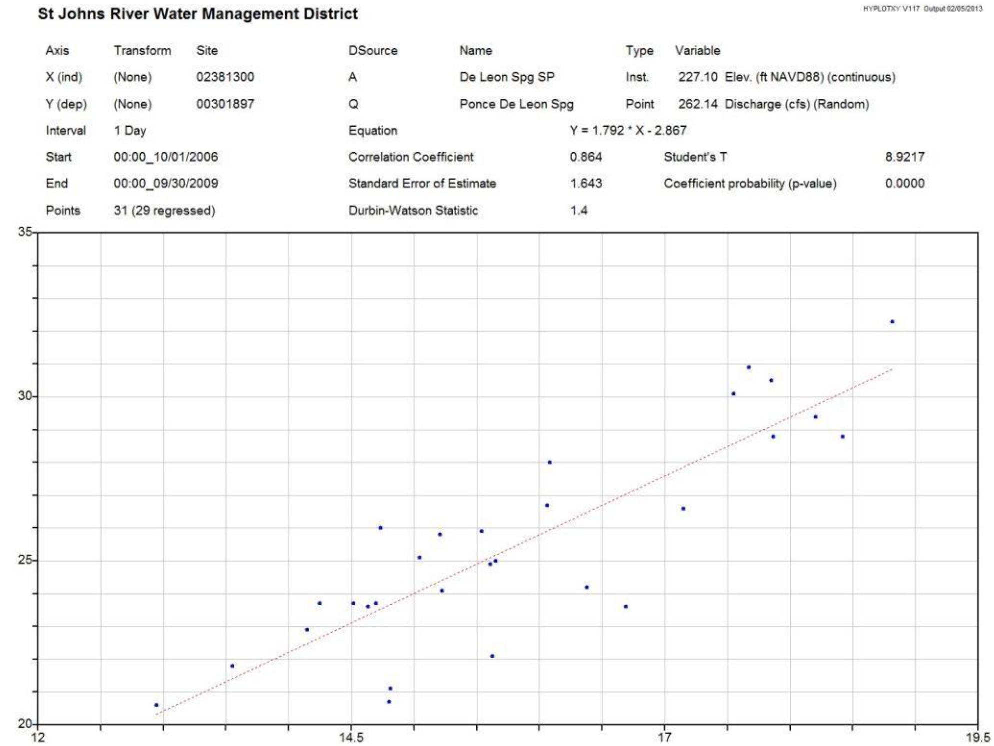
is water level in feet NAVD88

Rating curve 1 was developed from a linear regression of available manual discharge measurements and groundwater level observations from well V-1030 from October 2006 - September 2009 (Figure 2) (M. Wainwright, SJRWMD, pers. comm., 2016).

From October 2009 - present, the rating curve used to compute discharge has been

$Q = 1.785 * x - 5.96$ (Rating curve 2)

Rating curve 2 was developed from a linear regression of available manual discharge measurements and groundwater level observations from well V-1030 from October 2009 - September 2012 (Figure 3) (M. Wainwright, SJRWMD, pers. comm., 2016). Additionally, shift tables have been used to shift computed discharge to any available manual discharge measurements. The rating curve has not been changed since October 2009, since no consistent deviation of manual measurements from computed discharge has been noted at De Leon Springs (M. Wainwright, SJRWMD, pers. comm., 2016).



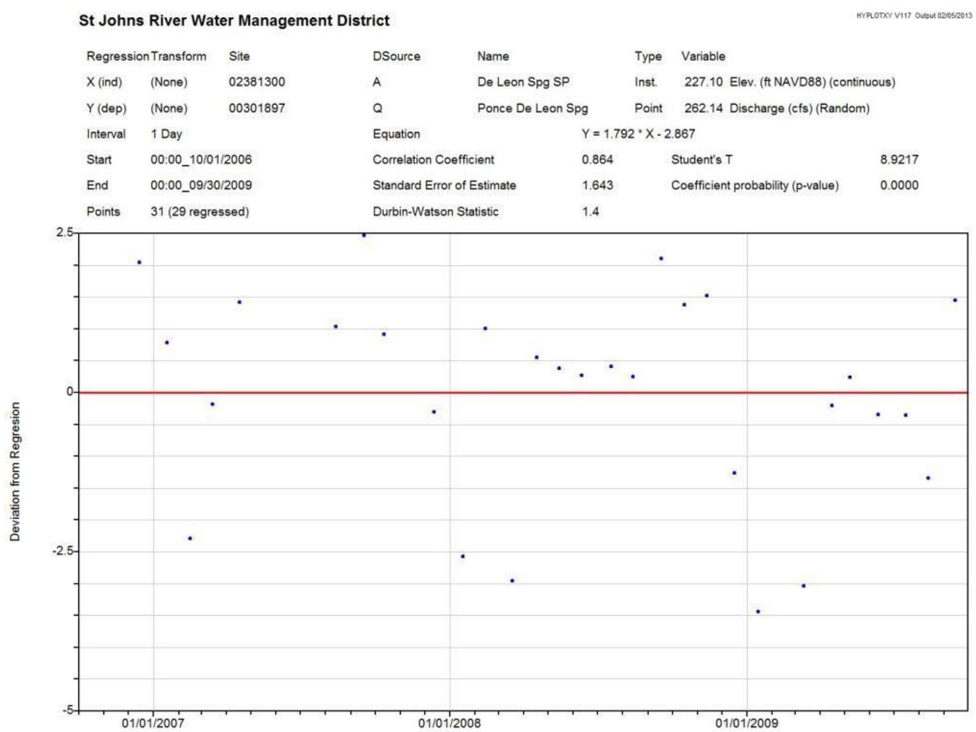


Figure 2: Rating 1, based on 2006 - 2009 data (top). Standard deviation of manual discharge measurements from Rating 1 (bottom). When the deviations of new measurements are consistently above or below zero, rather than sufficiently randomly distributed like this, a new rating curve is typically computed for a site.

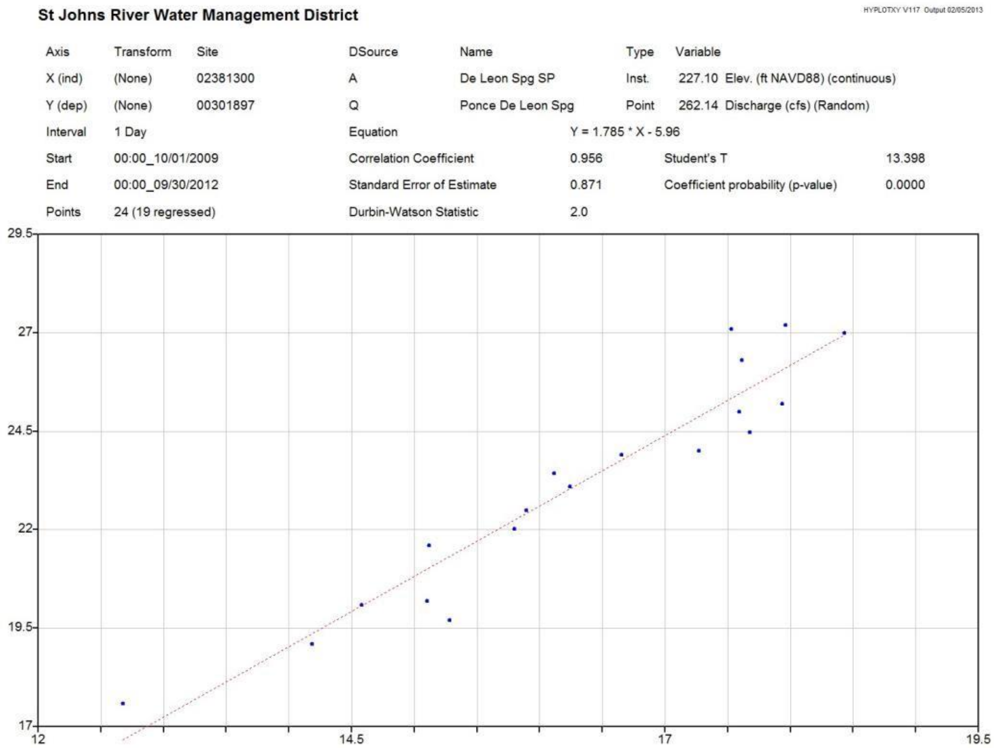


Figure 3: Rating 2, based on 2009 - 2012 data (top). Standard deviation of manual discharge measurements from Rating 2 (bottom). When the deviations of new measurements are consistently above or below zero, rather than sufficiently randomly distributed like this, a new rating curve is typically computed for a site.

Filling a gap in the discharge dataset

The weir structure at De Leon Springs was rebuilt in late 1997 (B. Polk, De Leon Springs State Park, pers. comm., 2016). After the weir was rebuilt, manual discharge measurements made by SJRWMD from November 1997 - October 2006 incorrectly accounted for part of the flow by an unknown amount and cannot be considered reliable (M. Wainwright, SJRWMD, pers. comm., 2016). However, thirteen manual discharge measurements made by USGS are available for that time period, along with hourly automated measurements of water levels in well V-1030. The same rating curve used from October 2006 - September 2009 was used to compute discharge for the November 1997 - October 2006 period, and a shift table was used to shift the computed discharge to the USGS manual discharge measurements.

All available discharge measurements for De Leon Springs, including the 1997 - 2006 gap filled using well data, are shown in Figure 4.

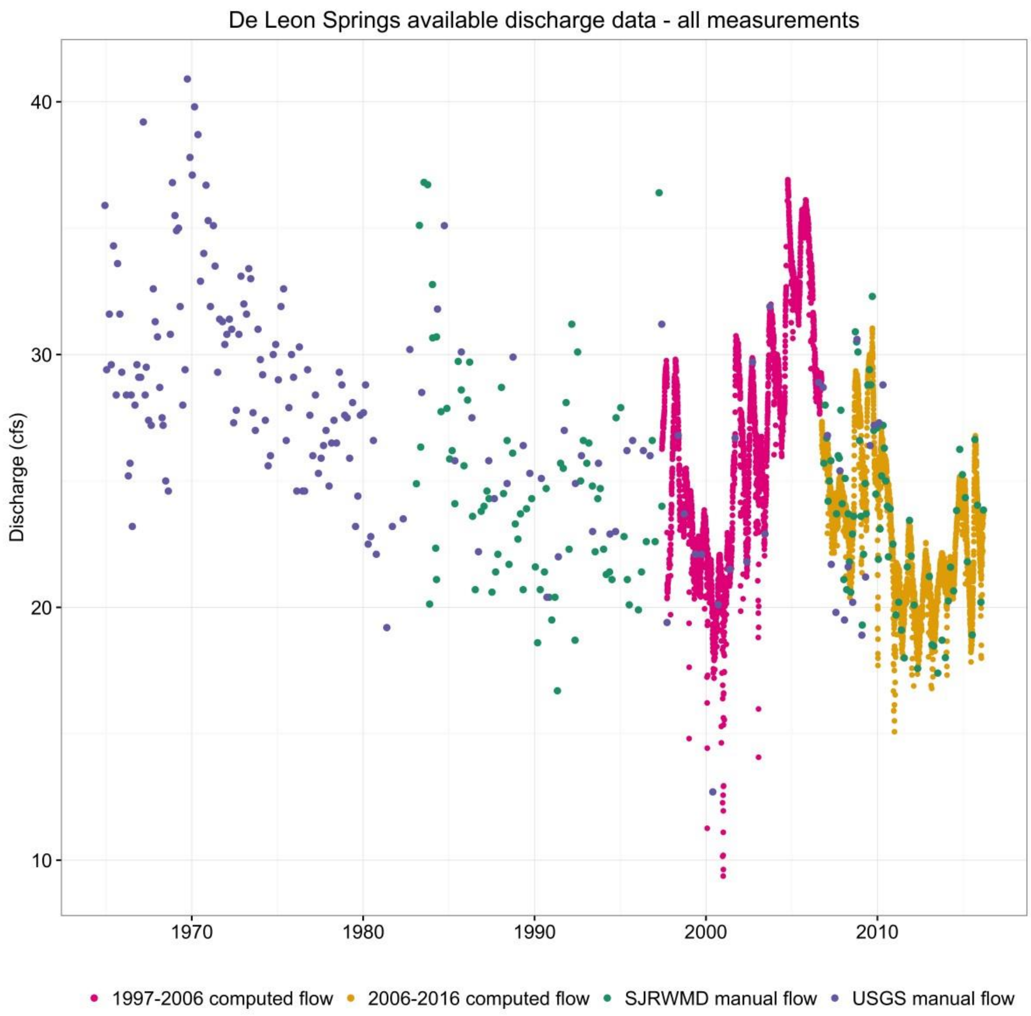


Figure 4: Discharge measurements available for De Leon Springs, including all useable measurements from USGS and SJRWMD and measurements estimated from a rating curve with well V-1030.

Monthly mean discharge period of record

Monthly mean discharge from December 1964 to February 2016 was calculated by averaging the available discharge measurements for each month (Figure 5) and used for data analysis. No monthly mean discharge was calculated for months without any available measurements.

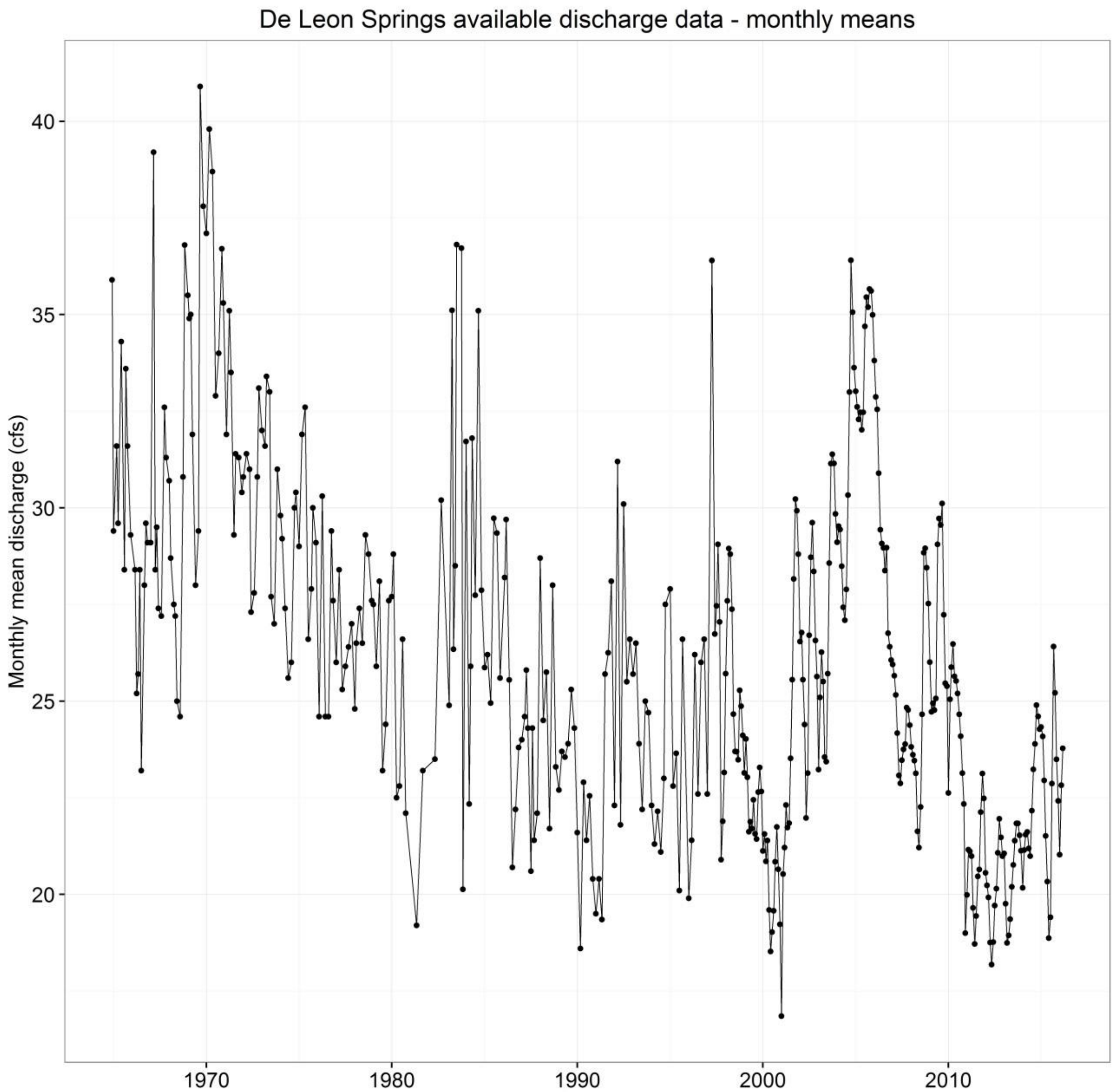


Figure 5: Discharge measurements available for De Leon Springs averaged by month.

GROUNDWATER PUMPING ASSESSMENT

Groundwater use

To estimate the impact on spring flows from pumping, annual groundwater use from 1950 to present was estimated within the groundwater contributing area of De Leon Springs. The groundwater contributing area of De Leon Springs (Figure 6) was estimated to be about 39 square miles. The shape and extent of this area were determined by referencing maps of the Upper Floridan aquifer potentiometric surface. It should be noted that the area shown is approximate, and was determined for the purpose of considering water use within a defined area near De Leon Springs. The groundwater contributing area does not define the limit of impact to spring flow; water use outside the area shown could impact spring flow as well.

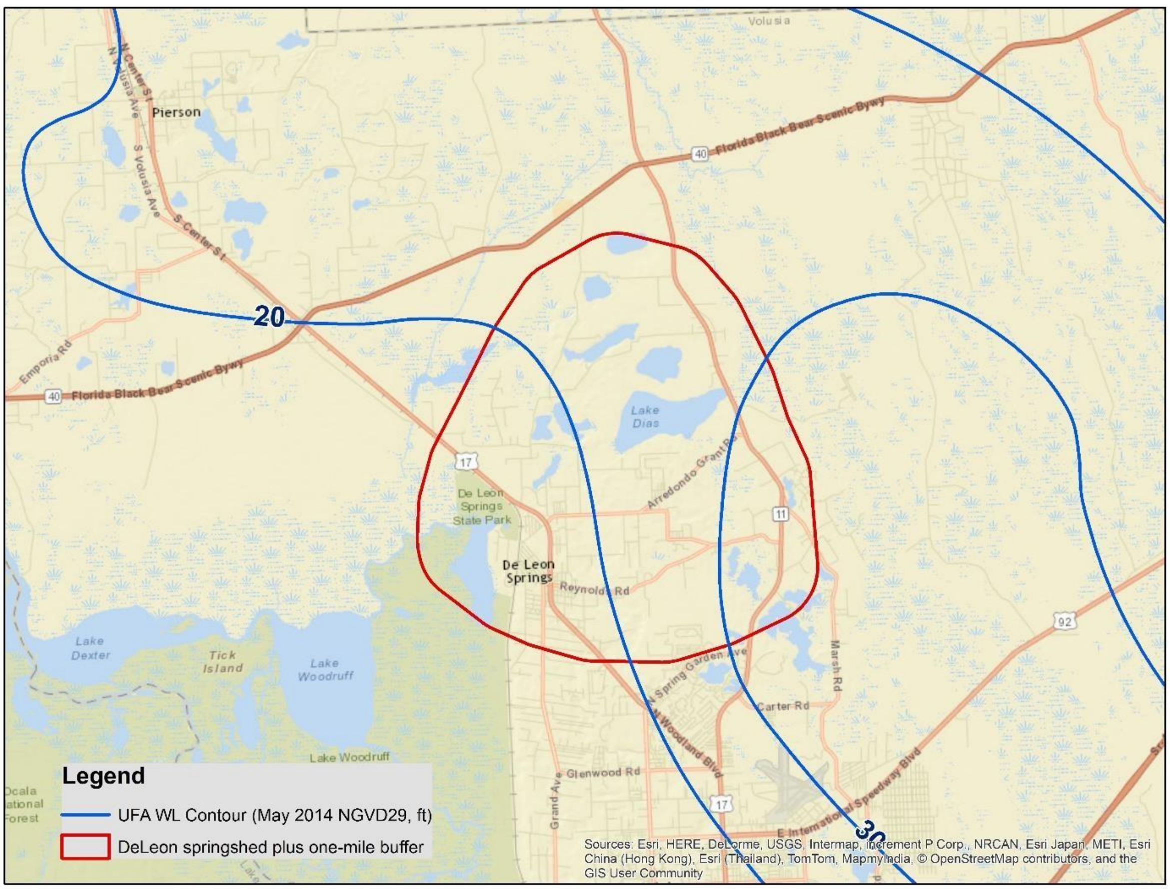


Figure 6: De Leon Springs' approximate groundwater contributing area. (Water use outside the area shown could also impact spring flow.)

Groundwater pumping from 1950 - 2015 was estimated using annual groundwater use data from two sources. Data within the adjusted groundwater contributing area was available from SJRWMD from 1995 to 2015. Data within Volusia County was available from USGS from

1950 to 1994. To estimate groundwater use from the county data, groundwater use for each available year was multiplied by the average proportion of groundwater use within the adjusted groundwater contributing area. The average proportion from 1995 to 2015 was used to estimate domestic self-supply and agricultural groundwater use from 1950 to 1994, and the average proportion from 1995 to 1999 was used to estimate public supply groundwater use from 1950 to 1994. Figure Figure 7 shows the estimated groundwater use within the groundwater contributing area.

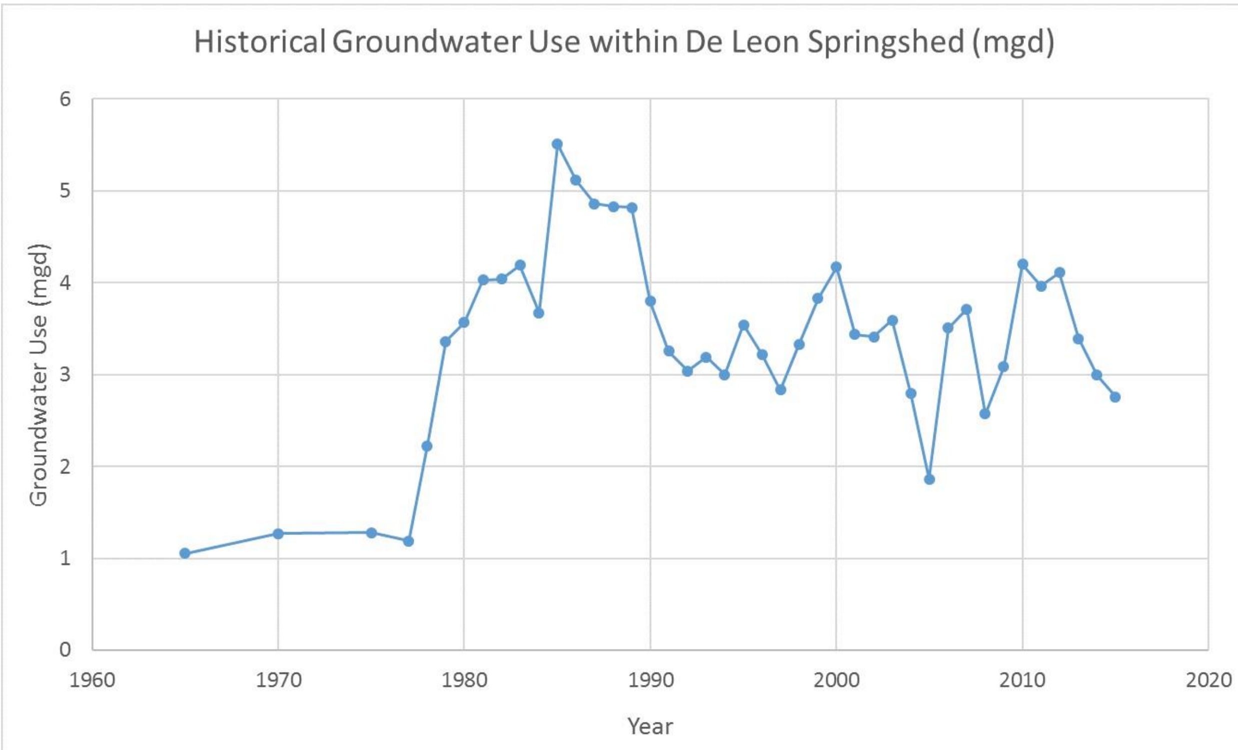


Figure 7: Groundwater use in De Leon Springs' approximate groundwater contributing area, 1950 - 2015.

Estimated impact on spring flows

The latest version of the SJRWMD Volusia County steady-state groundwater model (SJRWMD 2016) was used in the assessment of the impacts of groundwater pumping on spring flows. Because the latest version of the Volusia model was developed for 2010, the assessment was estimated under the 2010 groundwater pumping condition and resulted in an estimated impact of 2.6 cfs.

In addition to the steady-state groundwater model, a statistical model was developed to further evaluate the impact of groundwater pumping on spring flows (described in detail in the attachment below). The statistical model indicates that the average impact on spring flows under 1997 - 2016 groundwater pumping conditions is 3.0 cfs. Because the groundwater pumping within the springshed after 1990 was relatively stable (see Figure 9), the estimated average impact under 1997-2016 pumping condition can be assumed to reflect the current pumping condition. The estimated impact of 3.0 cfs is consistent with what was estimated by the steady-state groundwater model. Thus, the statistical model supports the conclusion that the groundwater pumping impact of 2.6 cfs estimated using the Volusia groundwater model is reasonable. However, the results of the statistical model should be reviewed cautiously. On one hand, the statistical model may have underestimated the impact of current groundwater pumping, since it compares the 1997 - 2015 period with the 1964 - 1977 period, and the groundwater use in the 1964 - 1977 period was not zero. On the other hand, the statistical model does not remove the impacts of other anthropogenic influences such as land use changes and change in outlet structure, which may have resulted in the overestimation of groundwater pumping impact. Because the groundwater model estimates only groundwater pumping impacts on spring flows, the results from the Volusia groundwater model were used in MFL determinations.

Next, the relationship between the groundwater pumping and the reduction in spring flow due to pumping was developed using the Volusia groundwater flow model. Figure 8 shows the relationship between the pumping and the reduction in flow.

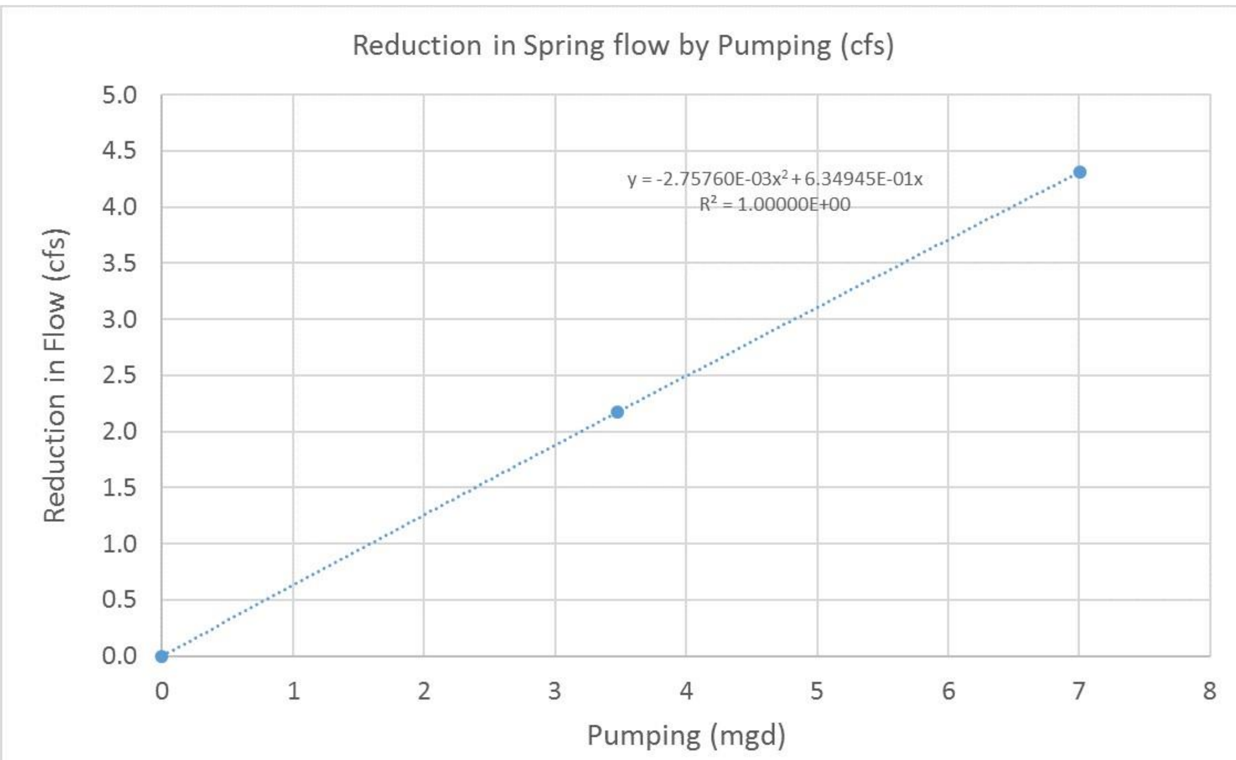


Figure 8: Relationship between pumping and change in spring flow.

Using the estimated groundwater pumping from 1965 to present and the relationship between pumping and the reduction in spring flow (polynomial function shown in Figure 8), annual impact to the spring flow from historical pumping was estimated (Figure 9).

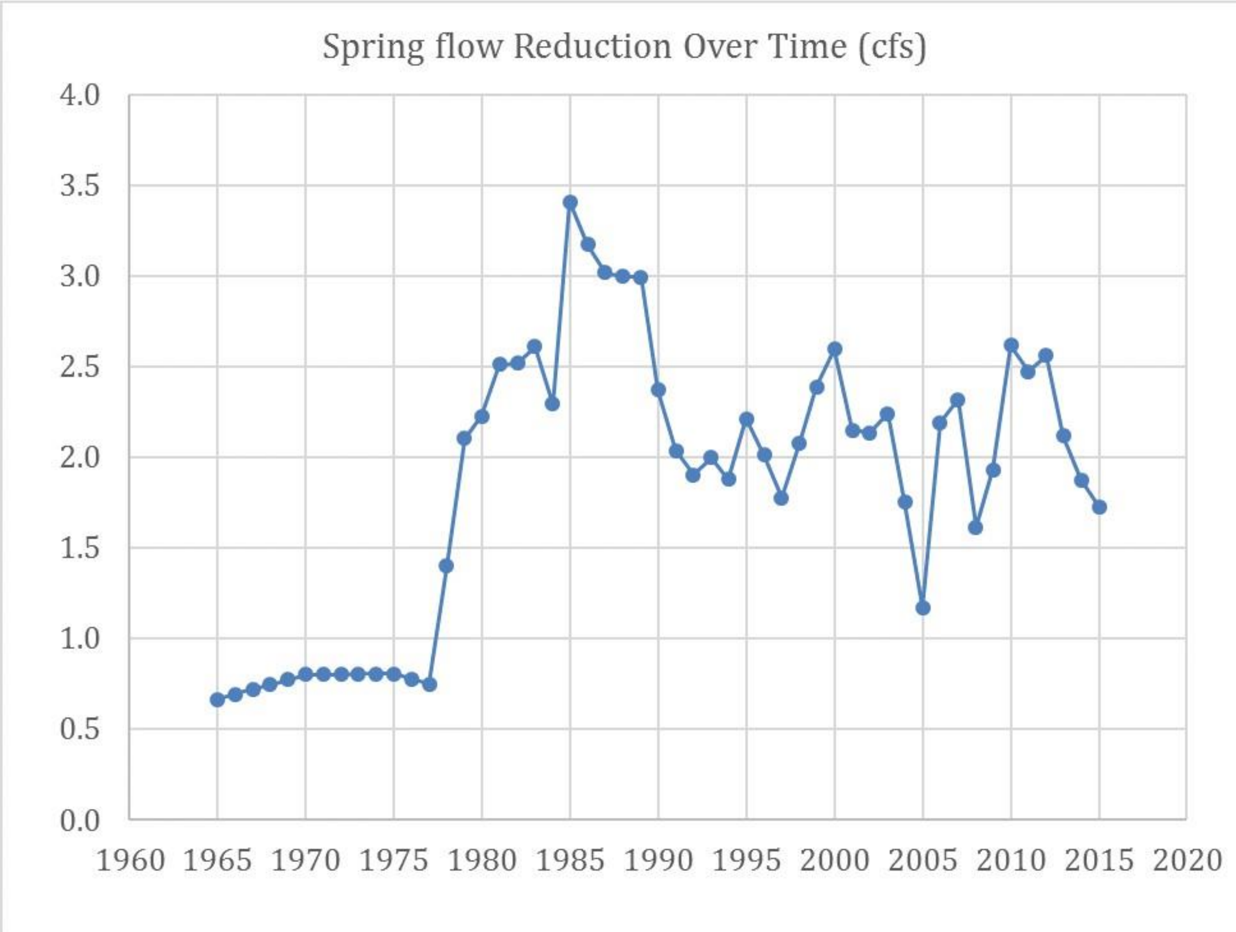


Figure 9: Impact of pumping on spring flow over time.

DEVELOPMENT OF SYNTHETIC FLOW TIME SERIES

Since the recommended minimum flow regime is to allow no further warm-water habitat loss for manatees, the current flow regime must be maintained. The first step in creating the current-pumping condition flow time series, which in this case is the "2010-pumping condition" flow time series, is to create a "no-pumping condition" flow time series. The "nopumping condition" flow time series was created by adding an estimate of impact due to historical pumping (i.e., change in spring flows due to pumping) to each year in the observed record.

"No-pumping condition" flow time series

The impacts of pumping as shown in Figure 9 were added to the annual means of the monthly means of observed spring flow data to create a "no pumping condition" flow time series. This synthetic flow time series constitutes a reference state of the spring in which the impact from groundwater pumping is assumed to be minimal.

"2010-pumping condition" flow time series

The Volusia groundwater model estimated a reduction of spring flow of 2.6 cfs in 2010 due to pumping. This amount was subtracted from monthly synthetic no-pumping condition flow time series dataset to estimate a 2010-pumping condition flow time series dataset for De Leon Spring. The synthetic 2010-pumping flow time series dataset represents a reference state of spring in which the impact from groundwater pumping on spring flows is constant over time at a rate of 2.6 cfs. Assuming climatic, rainfall, and other conditions present from 1965 - 2015 are repeated over the next 50 years, the 2010-pumping condition flow time series would reflect the future condition of the spring flows if the groundwater pumping does not change from 2010. Therefore, this flow dataset was used to evaluate the MFLs at De Leon Springs. Figure 10 shows the observed, no-pumping and 2010-pumping condition flows.

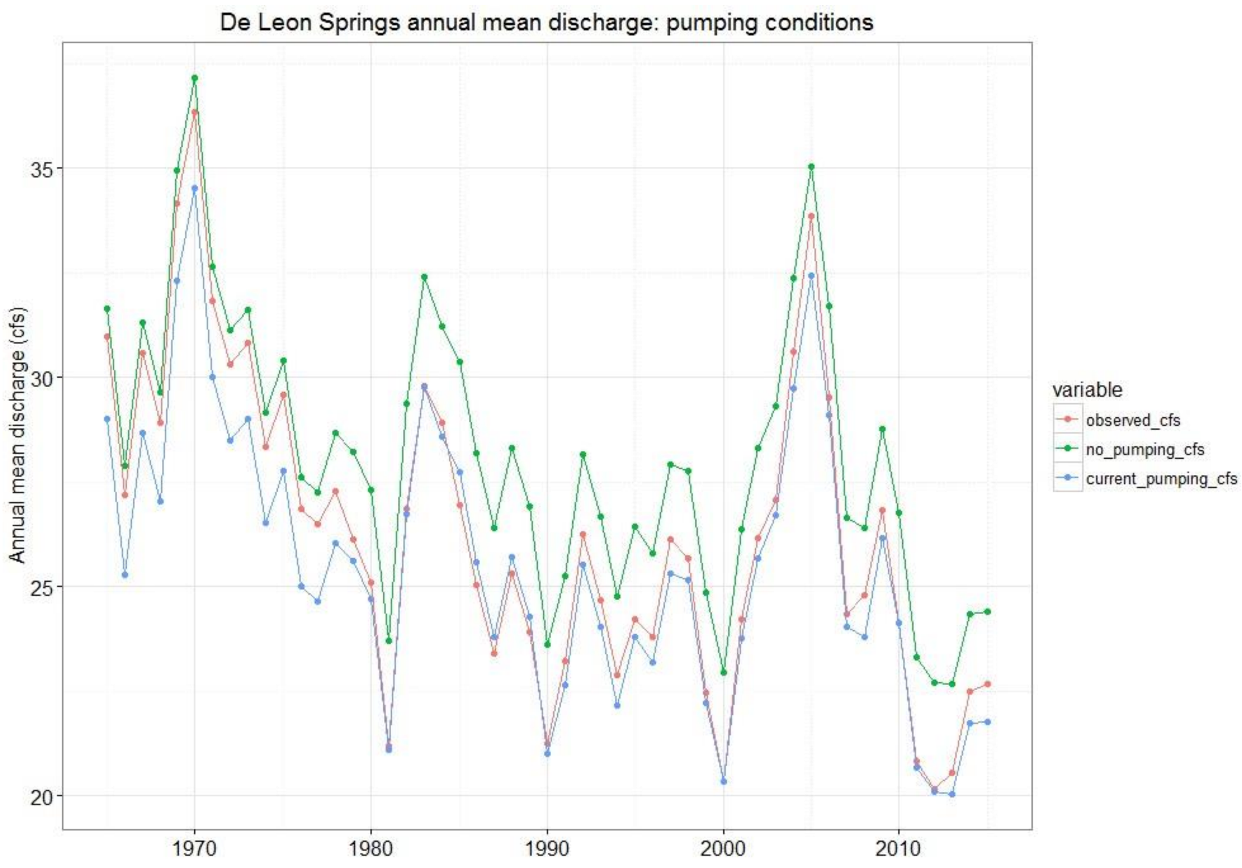


Figure 10: Observed and synthetic spring flow datasets.

DETERMINATION OF MINIMUM FLOWS

The synthetic flow time series representative of the 2010-pumping condition was used to calculate the recommended minimum flows at De Leon Springs. The recommended mean discharge is 25.6 cfs, which was calculated from the 1965 - 2016 simulated monthly mean discharge under the 2010-pumping condition. The average annual rainfall (Crescent City station) for the same time period is 49.8 inches whereas the long-term (1908 - 2015) average annual rainfall is 51.9 inches. Therefore, the time period used to determine the minimum flow represents a slightly lower than average rainfall condition.

REFERENCES

SJRWMD, 2016. Updated Volusia regional groundwater flow model (electronic files)

ATTACHMENT: DE LEON SPRINGS STATISTICAL MODEL

Introduction

A rainfall and discharge regression model was built to evaluate effects of groundwater pumping on discharge in recent years and hindcast discharge in De Leon Springs.

When time series data are used in regression analysis, often the error term is not independent through time. Instead, the errors are serially correlated (autocorrelated).

Ordinary regression analysis is based on several statistical assumptions. One key assumption is that the errors are independent of each other. However, with time series data, the ordinary regression residuals usually are correlated over time. It is not desirable to use ordinary regression analysis for time series data since the assumptions on which the classical linear regression model is based will usually be violated.

Violation of the independent errors assumption has three important consequences for ordinary regression. First, statistical tests of the significance of the parameters and the confidence limits for the predicted values are not correct. Second, the estimates of the regression coefficients are not as efficient as they would be if the autocorrelation were taken into account. Third, since the ordinary regression residuals are not independent, they contain information that can be used to improve the prediction of future values.

To build a regression model with serially correlated data, it should incorporate a serial correlation factor into the statistical model for improving the model prediction power. The AUTOREG procedure in SAS can address the serially correlated data in the regression analysis appropriately (SAS 2013). Therefore, we used this method.

Data

- Monthly rainfall data from Crescent Lake station (see next Appendix D)
  - November 1908 - February 2016
- Monthly average discharge data from Deleon Spring
  - Dec. 1964 - April 1997 monthly data with missing values
  - June 1997 - February 2016 continuous monthly data
- Groundwater usage data within the springshed
  - 1950 - 1965 average usage is about 0.5 MGD (0.78 cfs)

- 1965 - 1977 average usage is about 1 MGD (1.55 cfs)
- 1980 - 2014 average usage is about 3.5 MGD (5.43 cfs)

Methods

First, a multiple linear regression model was developed. The monthly average discharge was assumed to be the dependent variable, and current month and previous 24 months' monthly total rainfall were used as the independent variables. Because rainfall is the only explanatory variable that was used to build the statistical model, a period, in which change in anthropogenic influences, especially change in impact from pumping, is believed to be minimal, needed to be selected to build the statistical model. By doing so, the rest of the POR data can be used to evaluate the impact from pumping.

After reviewing historical regional pumping and the spring flow data, the period from 1997 to 2016 was selected to be the model calibration period. Groundwater use in the De Leon Springs groundwater contributing area increased sharply in the late 1970s, reached a maximum in the mid to late 1980s, and has remained relatively stable since 1990 (Figure 9 in the technical memorandum). Therefore, assuming the period from 1997 to 2016 represents a period that the impact from pumping on the spring flows is relatively constant is reasonable. In addition, the period from 1997 to 2016 is also representative of the current configuration of the weir structure.

In addition, the other important reason for choosing 1997 - 2016 as the calibration period is that monthly data were available without any missing values throughout that period.

The final selected model gave the highest total r-squared during the model calibration period, and the smallest average residuals for the calibration period.

Model selection process

After determining that an autocorrelation correction was needed, the order of the autoregressive error model to be used was selected. In SAS, one way to select the order of the autoregressive error model is stepwise autoregression. The stepwise autoregression method initially fits a high-order model with many autoregressive lags and then sequentially removes autoregressive parameters until all remaining autoregressive parameters have significant t-tests. In this exercise, we started with a fifth-order (AR5) effect with 30 lagged variables using stepwise autoregression with the BACKSTEP elimination option. Table 1 shows the eliminated autoregressive terms by the BACKSTEP elimination process. The autoregressive parameters at lags 3, 4, and 5 were insignificant and eliminated, resulting in a second-order model.

Lag	Estimate	t Value	Pr > |t|
3	-0.069276	-0.66	0.5072
4	0.097875	1.16	0.2455
5	-0.0662	-1.59	0.1144

Table 1: Backward elimination of autoregressive terms (AR5 with 30 lag terms).

The coefficients for the lag (explanatory variable) terms after correcting for serial correlation showed that after 25 months, all were negative. This result suggests that an AR2 structured model might be appropriate. However, the results of the AR2 model with 25 lagged terms indicated that the AR1 model was the most appropriate autoregressive structural model for this data set.

Durbin-Watson statistics indicated that the autocorrelation was insignificant at 0.1 level after the serially correlated errors were corrected using the AR1 autoregressive error model (Table 2). It should be noted that Pr < DW is the p-value for testing positive autocorrelation and Pr > DW is the p-value for testing negative autocorrelation. In contrast, the autocorrelation was significant when the AR1 error model was not used (Table 3). The original data had a significant positive autocorrelation between the current month's deviation from the mean and the previous months' deviation.

Order	DW	Pr < DW	Pr > DW
1	1.7867	0.0751	0.9249

Table 2: Durbin-Watson statistics after the autoregressive error model (AR1 with 23 lags model).

Order	DW	Pr < DW	Pr > DW
1	0.0806	<.0001	1.0000

Table 3: Durbin-Watson statistics on the original groundwater elevation data without autocorrelation correction.

We ran the AR1 model with 25 lagged terms to 21 lagged terms and compared coefficients of determination (r^2) during the model calibration period, and minimum average residuals for the calibration period. The AR1 model with 23 lagged terms had the highest r^2 and yielded the smallest average residuals during the calibration period, therefore we used that as our final model to estimate long-term monthly mean discharge under the current impacted condition.

Results

The predicted long term (1910 - 2016) average discharge under the current impacted condition is 26.06 cfs. For the same period the median is 25.93 cfs, P10 is 22.18, and P90 is 30.16 cfs. Figure 1 shows the model predicted and observed discharges. The black line is the model predicted discharge from 1910 - 2016 and red line with the dot is observed discharge from 1964 - 2016. The grey band is model estimated upper and lower 95% confidence limits.

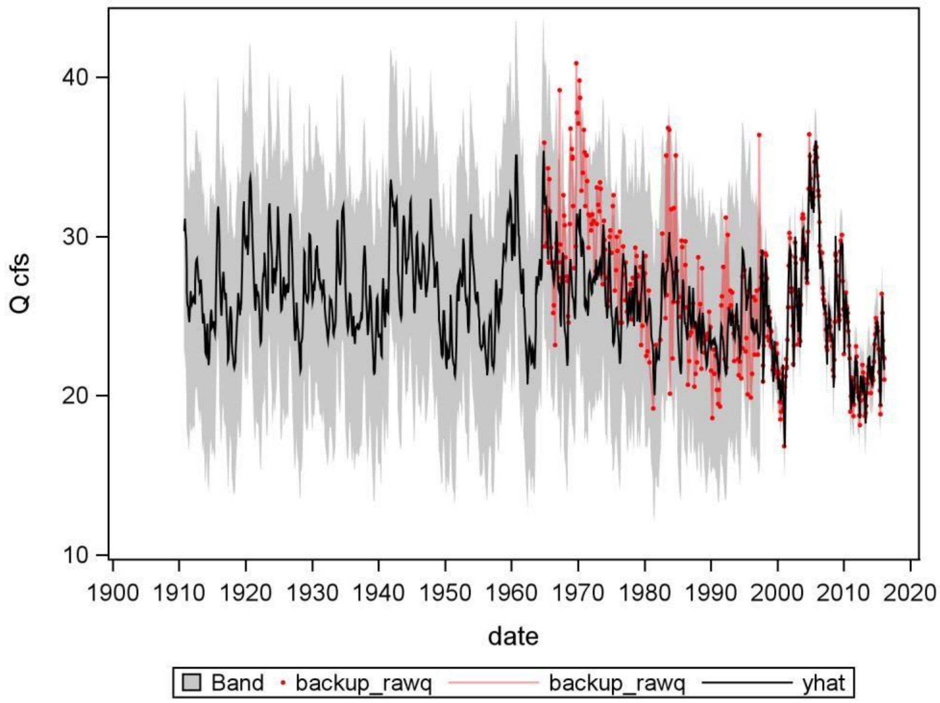


Figure 1: Predicted and observed discharge of Deleon spring.

The observed discharge during the 1964 - 1977 period was used to represent the discharge under the non-impacted condition and compared that with the model-simulated discharge under the current impacted condition to estimate the amount the discharge reduction would be if the current condition (water usage or pumping) were applied to the 1964 - 1977 period (Figure 2). The model estimated that on average there would have been 3.02 cfs less discharge at De Leon Springs during the 1964 - 1977 period if the current water usage was applied back then. This also can be interpreted as that the current water usage has caused an average 3.02 cfs flow reduction (11.6% of the 26.06 cfs mean flow) at De Leon Springs.

Figure 3 and Figure 4 were used to verify that the model met the basic regression model assumptions and that the serial correlation had been addressed appropriately. Figure 4 is the residual vs. predicted value plot which shows that the residuals randomly fluctuate from zero across the entire range of predicted discharge. The ACF plot indicates that AR1 is the appropriate autoregressive structure and the PACF plot indicates that after the AR1 term was included in the regression model, the serial correlation in the original data was factored in the estimation of the model coefficients.

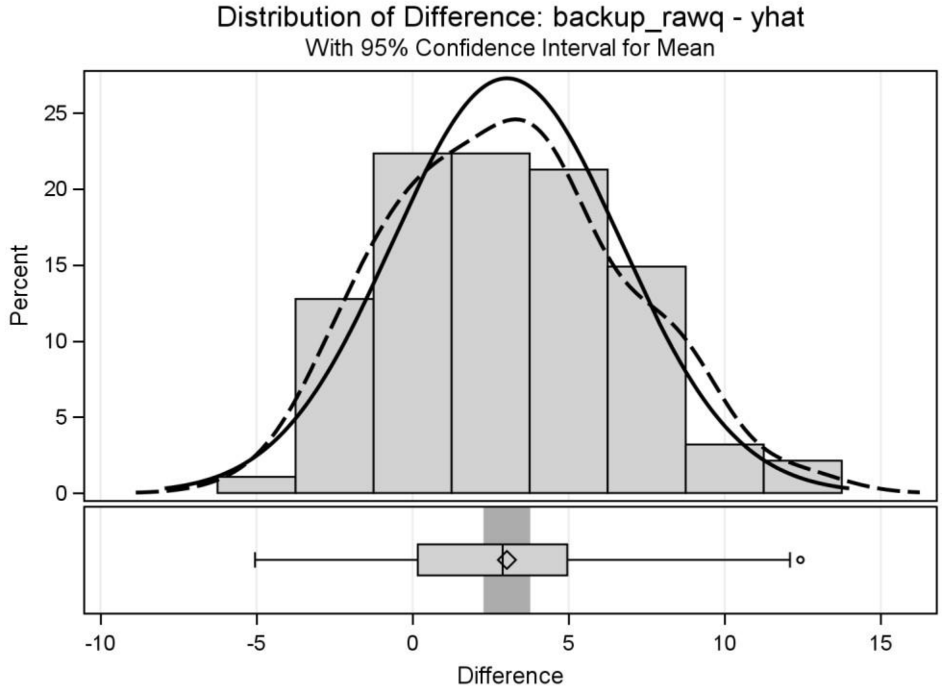


Figure 2: Distribution of the differences between the observed discharge and model predicted discharges during the 1964 - 1977 period.

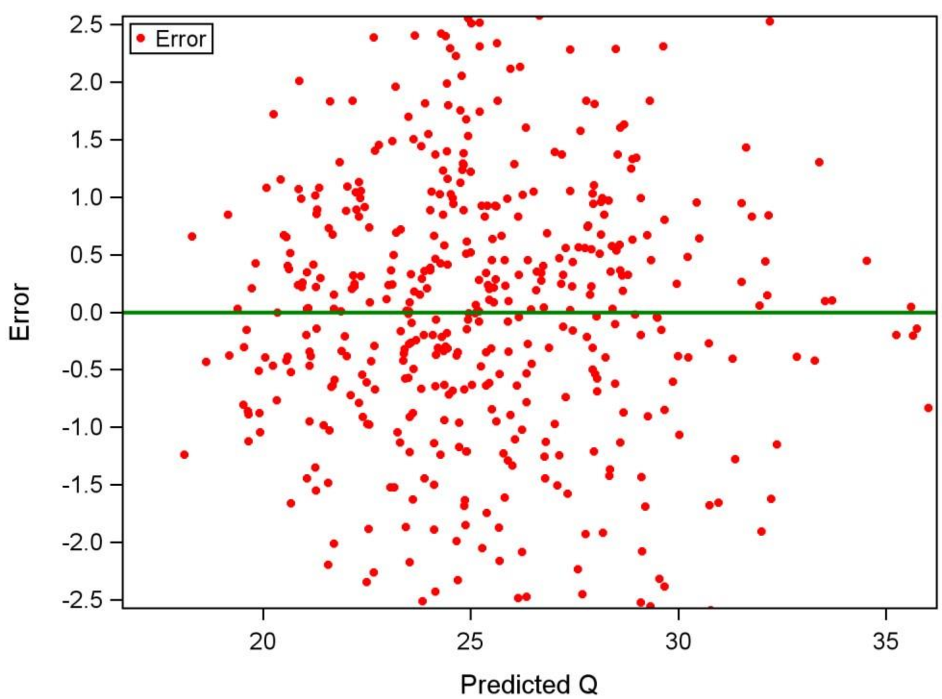


Figure 3: Predicted discharge vs. model residual of the calibration period 1997 through 2016.

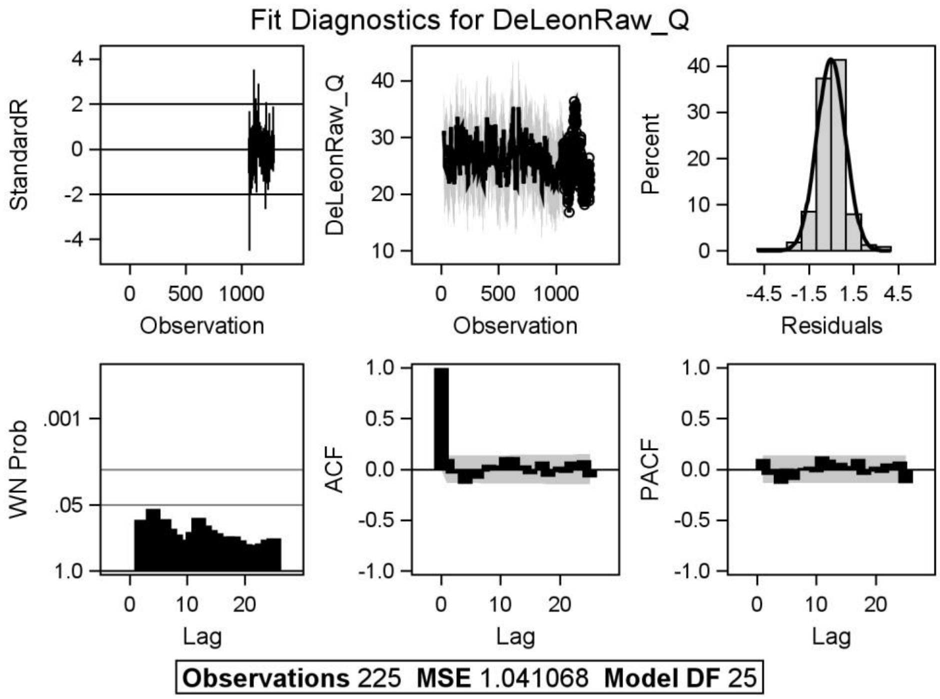


Figure 4: AR1 with 23 lagged terms autoregressive model diagnostic plots.

APPENDIX C: INTRA-ANNUAL VARIATION IN FLOW AT DE LEON SPRINGS

Starting in 1997, flow at De Leon Springs was estimated hourly using well V-1030 in De Leon Springs State Park, and these hourly estimates were used to compute daily mean flows. Daily mean flows for the past several years are shown in Figure 1. Days with the highest mean flow in any individual year most often occurred in September, October, or November (Figure 2). Days with the lowest mean flow in any individual year most often occurred in January (Figure 3), even though May, June, and July tended to have lower monthly mean flows. The timing of these 1-day low flows in January may be due to agricultural pumping for freeze protection.

Variation between monthly mean flows was examined for 1965-2014. Prior to 1997, flow was measured about once every other month. For years with at least six months of data available for comparison (46 of 50 years), the difference between the month with the highest mean flow and the month with the lowest mean flow in any individual year ranged from 3 to 16 cfs, with an average difference of 7 cfs. The lowest monthly mean flow usually occurred in May, June, or July (Figure 4), and the highest monthly mean flow usually occurred in September or October (Figure 5). Also notable is that the lowest monthly mean flows have become lower over this time period, and the highest monthly mean flows have become lower as well (Figure 6).

Spring flow data at De Leon Springs showed little variation between seasonal flows. Variation between seasonal mean flows was examined for 1965-2014, with years defined as November 1 - October 31 to avoid splitting seasons between years. For the purposes of this analysis, we considered November 1 - April 30 as winter and May 1 - October 31 as summer. For years with both winter and summer data available for comparison (48 of 50 years), flows at De Leon Springs showed very little variation between seasons. Winter mean flows were very similar to summer mean flows, and were only higher by an average of 0.5 cfs. Summer mean flows ranged from 20 to 35 cfs with a mean of 26.2 cfs, and winter mean flows ranged from 20 to 38 cfs with a mean of 26.7 cfs.

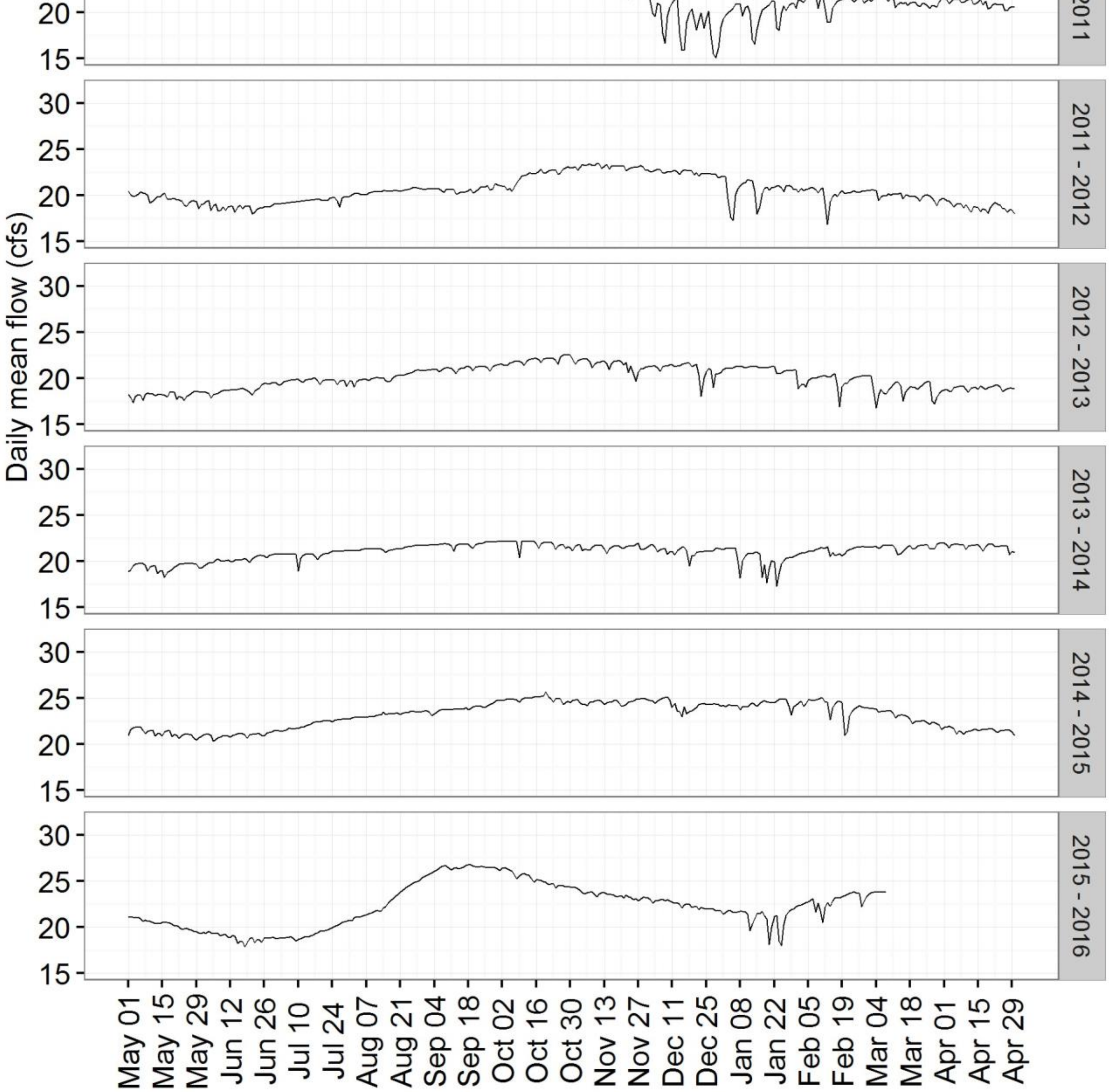

Observed daily flow
Daily mean flow (cfs)
30
25
20
15
2009 - 2010
2010 - 2011
2011 - 2012
2012 - 2013
2013 - 2014
2014 - 2015
2015 - 2016
May 01
May 15
May 29
Jun 12
Jun 26
Jul 10
Jul 24
Aug 07
Aug 21
Sep 04
Sep 18
Oct 02
Oct 16
Oct 30
Nov 13
Nov 27
Dec 11
Dec 25
Jan 08
Jan 22
Feb 05
Feb 19
Mar 04
Mar 18
Apr 01
Apr 15
Apr 29

Figure 1: Observed daily mean flows at De Leon Springs.

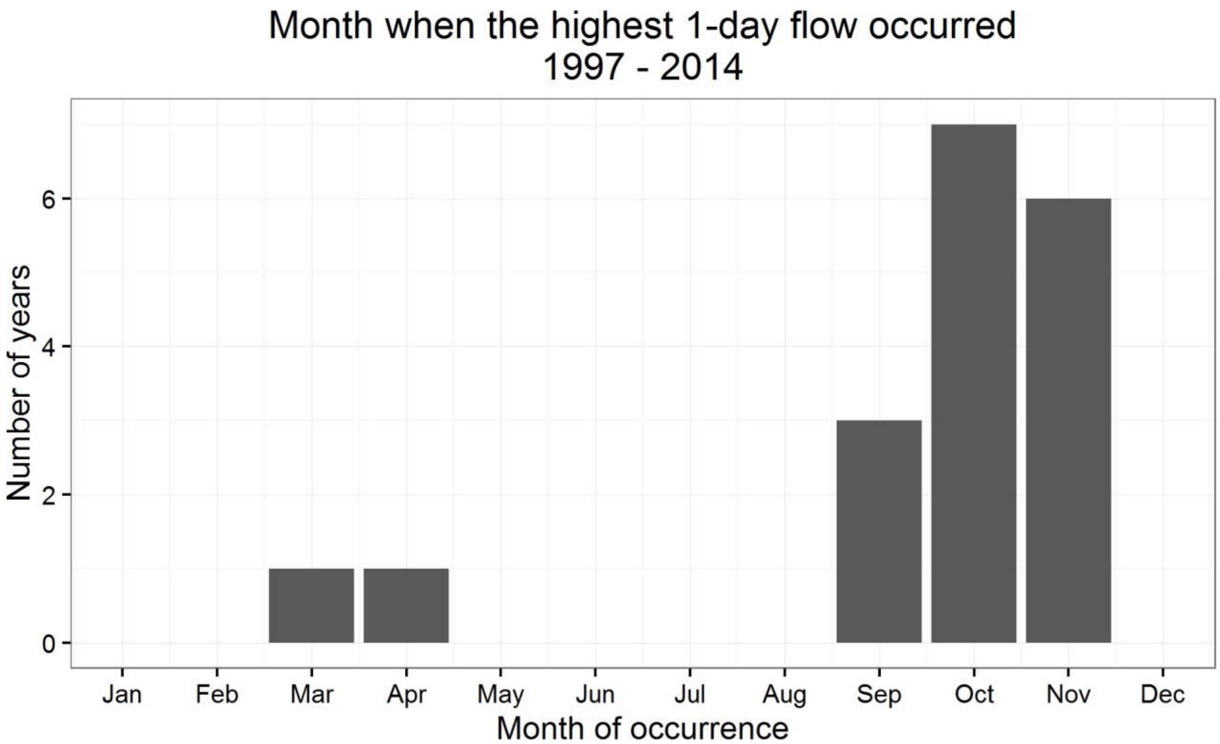


Figure 2: Bars show the number of years that the highest 1-day flow occurred in a given month.

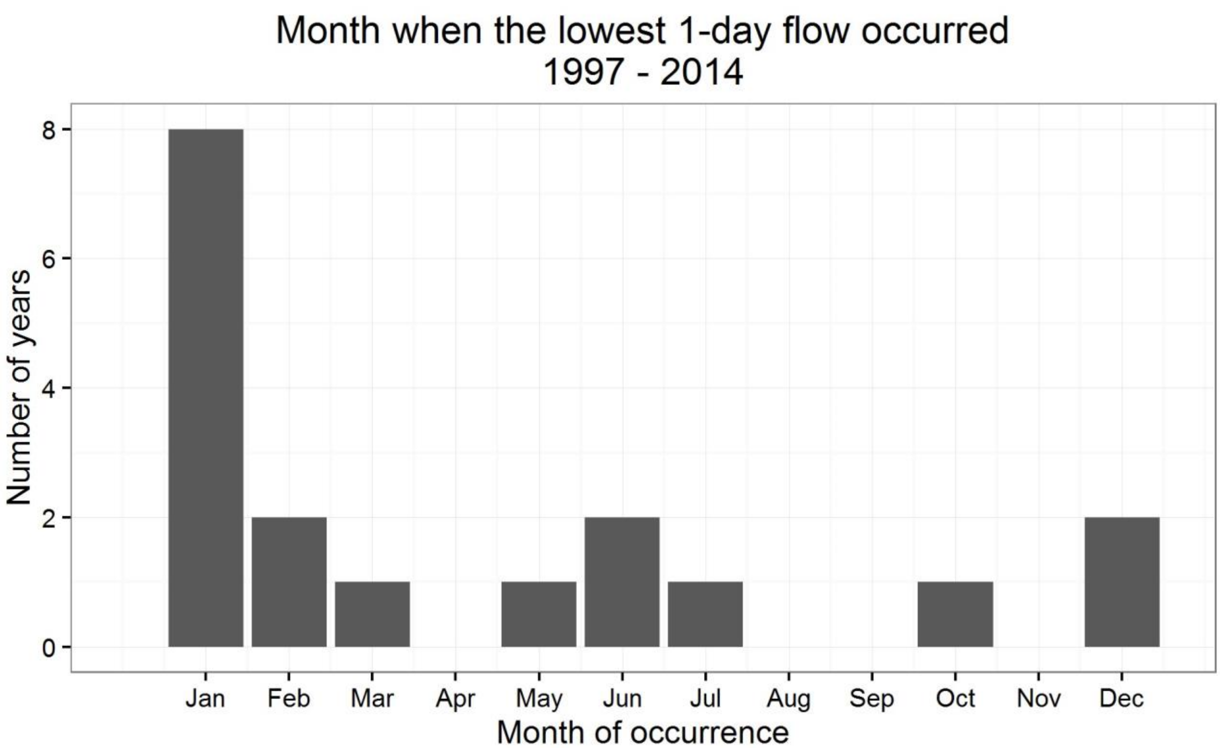


Figure 3: Bars show the number of years that the lowest 1-day flow occurred in a given month.

Appendix C: Intra-annual variation in flow at De Leon Springs

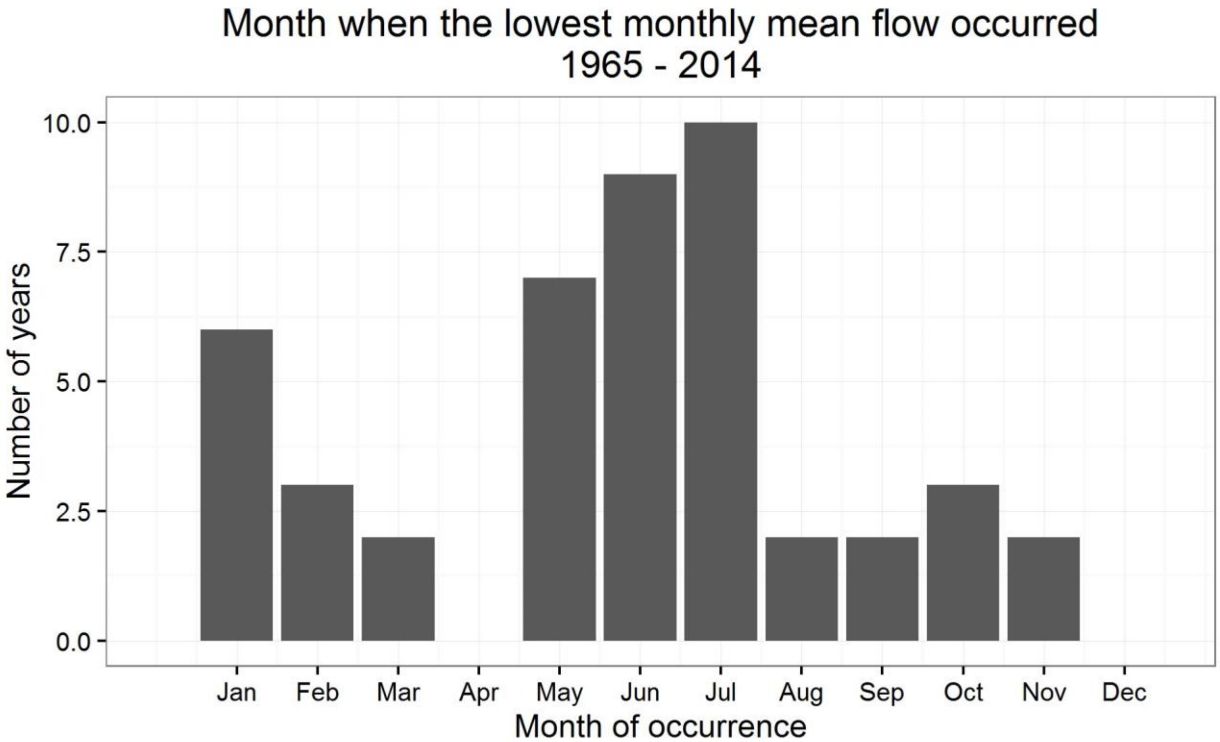


Figure 4: Bars show the number of years that the lowest monthly mean flow occurred in a given month.

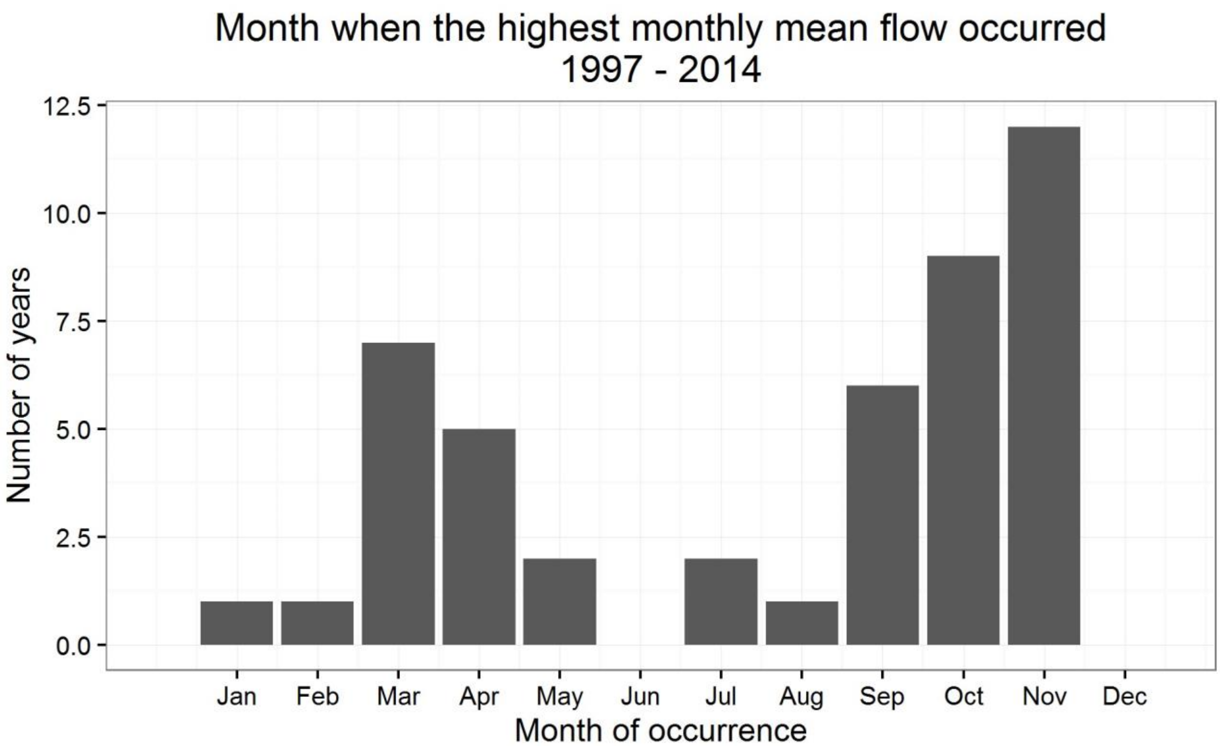


Figure 5: Bars show the number of years that the highest monthly mean flow occurred in a given month.

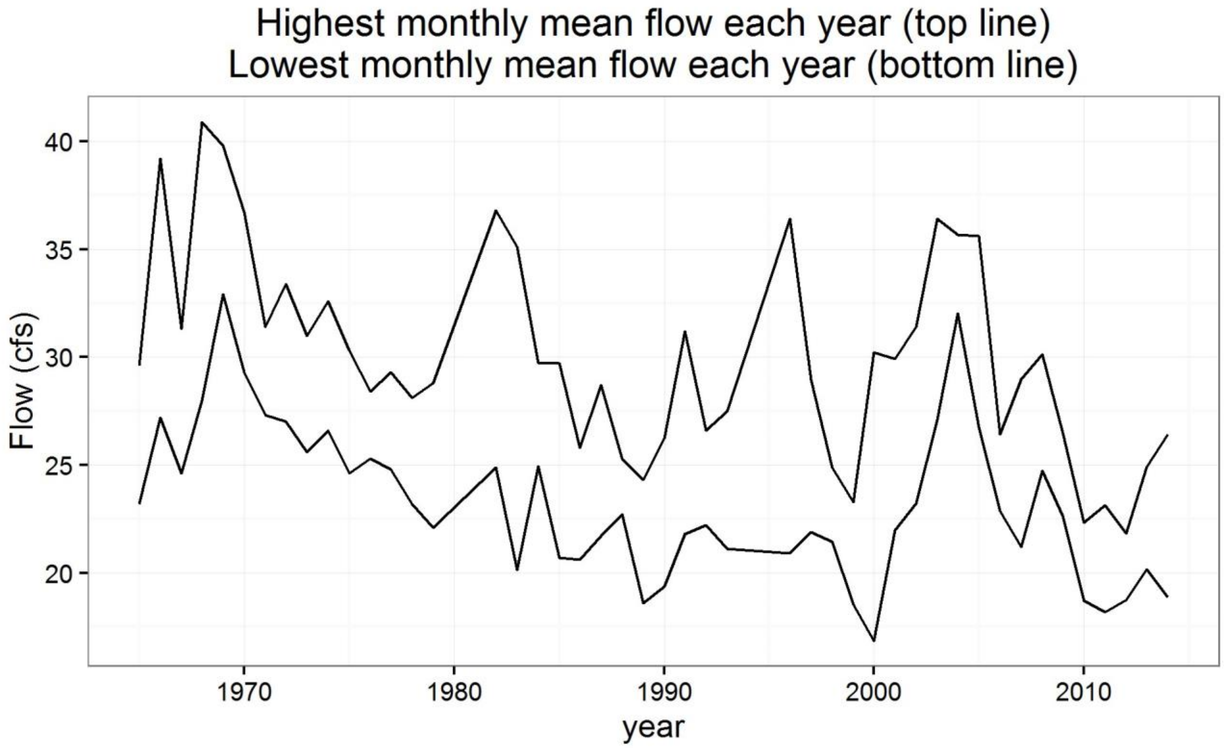


Figure 6: Comparison of the highest and lowest monthly mean flows at De Leon Springs each year.

APPENDIX D: RAINFALL DATA

Monthly rainfall records were downloaded from NOAA https://www.ncdc.noaa.gov/cdoweb/ (accessed February 2016) (Table 1). Rainfall back to 1908 was available for DeLand (NOAA ID USC00082229), located about 8 miles southeast of De Leon Springs. Rainfall back to 1912 was available for Crescent City (USC00081978), located about 22 miles northwest of De Leon Springs. Both DeLand and Crescent City are located 20-25 miles from the Atlantic coast in the Crescent City/DeLand Ridges lake region. This region includes typically rain-fed lakes, sandy upland ridges, and thick sandy soils (Griffith et al. 2016).

Some months were missing from the DeLand rainfall record (24 of 1288 months between 1908 - 2016). Rainfall for these months was estimated using the average of three nearby stations when available: Alexander Springs (available for 14 of the missing months, USC00080070), Sanford (available for 23 of the missing months, USC00087982), and Crescent City (available for all 24 of the missing months, USC00081978).

Some months were also missing from the Crescent City rainfall record (46 of 1248 months between 1912 - 2016). Rainfall for these months was estimated using the average of Federal Point (available for 41 of the missing months, USC00082915) and DeLand (available for all 46 of the missing months, USC00082229).

Table 1: Summary of rainfall records downloaded from NOAA

station	mean_inches	months	start	end
DELAND1SSEFLUS	45.7	1264	Nov. 1908	Feb. 2016
ALEXANDERSPRINGS3FLUS	45.7	234	Jun. 1956	Aug. 1979
CRESCENTCITYFLUS	42.5	1202	Mar. 1912	Feb. 2016
FEDERALPOINTFLUS	42.0	1125	Feb. 1915	Feb. 2010
SANFORDFLUS	40.3	717	Jun. 1956	Feb. 2016

To visualize the rainfall records, monthly rainfall was summed seasonally (May-October and Nov.-April) and annually (May-April) and plotted with local regression curves (loess curves) (Figures 1 and 2).

Climate oscillations, in particular the Atlantic multidecadal oscillation (AMO), may affect rainfall in Florida. Research has suggested that the effects of the AMO on rainfall vary spatially and seasonally across Florida (Teegavarapu et al. 2013). Warm and cool phases of the AMO last 20-40 years each ("warm" and "cool" refer to sea surface temperatures as measured in the North Atlantic Ocean). Since De Leon Springs discharge is likely affected by rainfall as well as human impacts, it is relevant to consider cycles of the AMO in the discharge record. The available discharge record for De Leon Springs includes over 50 years (1964-2016), with 20-30 years of a cool AMO phase (mid-1960s to mid-1990s) and at least 20 years of a warm AMO phase (mid-1990s to present). Additional cycles of the AMO (Figure 3) were included in the discharge record by modeling De Leon Springs discharge back to 1910 based on rainfall records (see Appendix B).

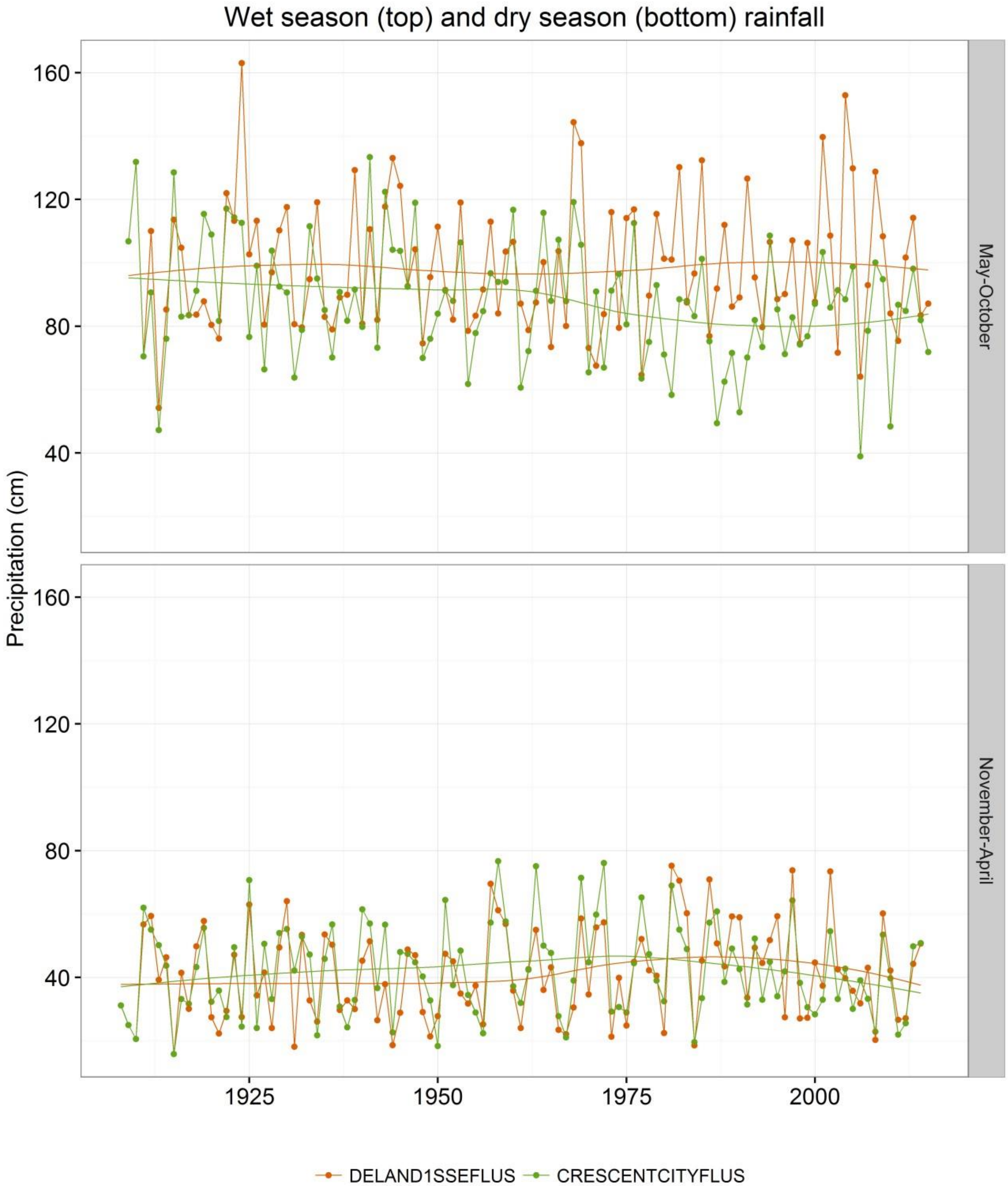


Figure 1: May-October and November-April total rainfall at DeLand and Crescent City.

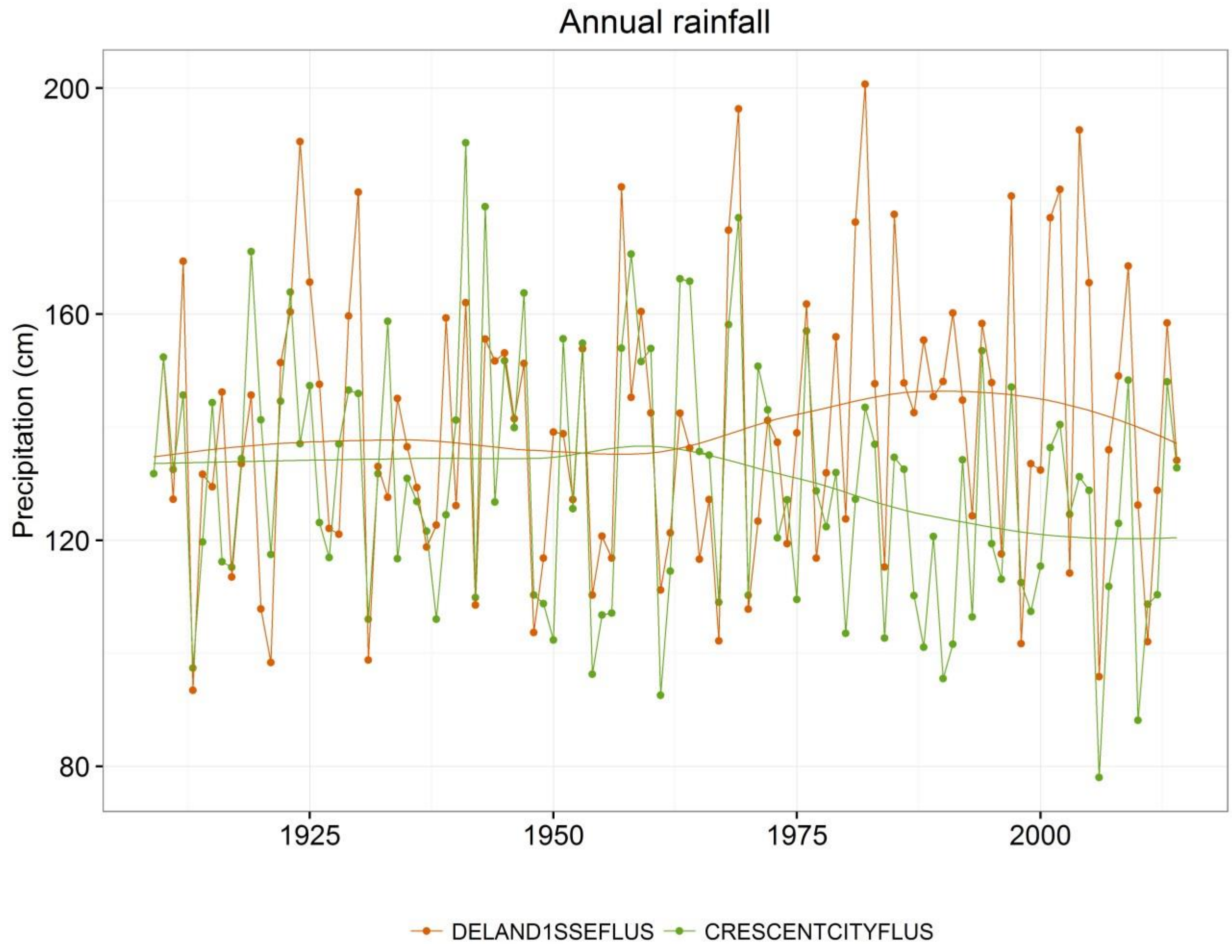


Figure 2: Annual total rainfall at DeLand and Crescent City.

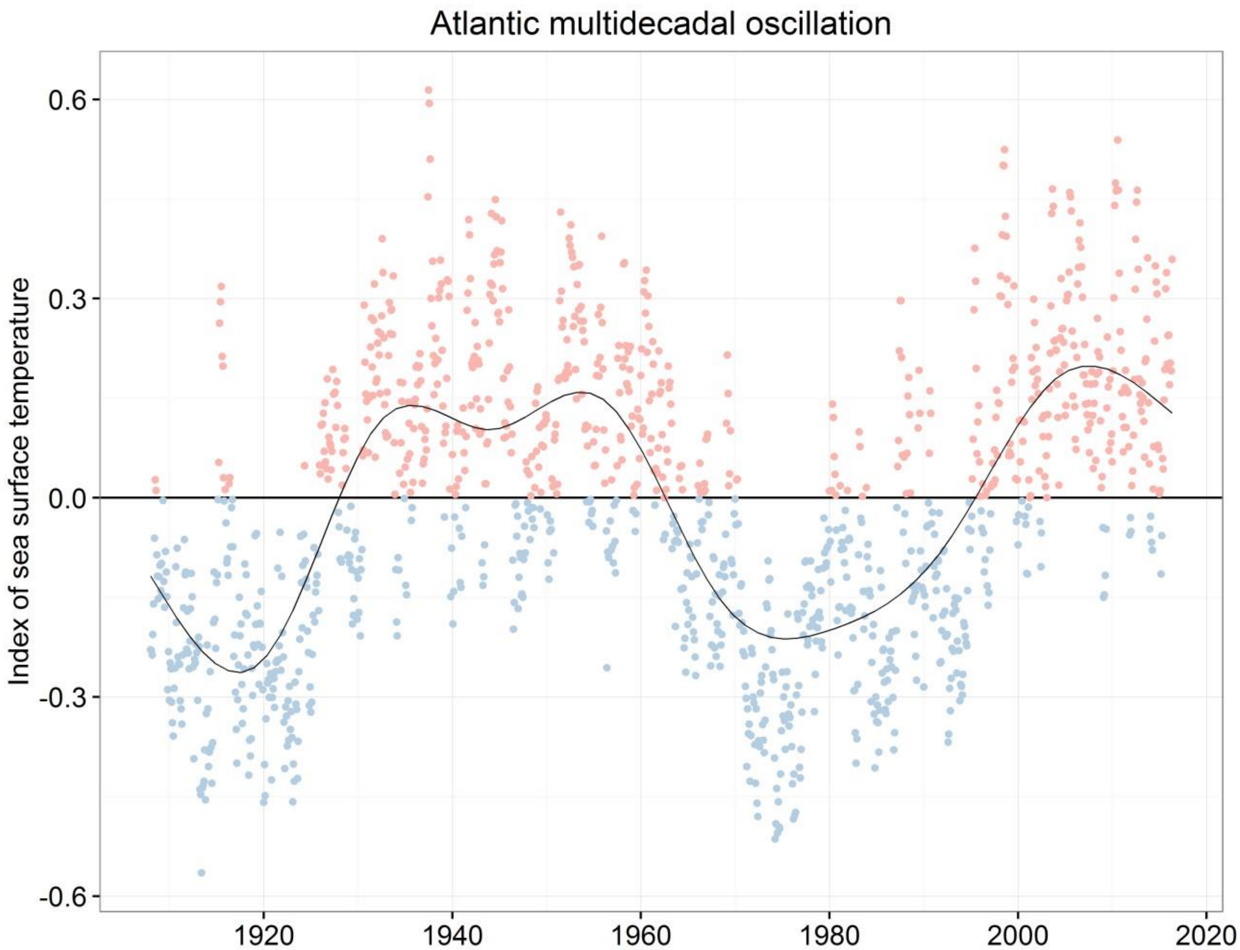


Figure 3: The AMO index from 1908-2016; predominantly red periods indicate warm phases and predominantly blue periods indicate cool phases.

APPENDIX E: DE LEON SPRINGS CAVERN

The water that flows from De Leon Springs comes from the Floridan aquifer and flows through underground crevices and caverns and before reaching up to the surface at the spring pool (Figure 1). At the surface of De Leon Springs pool, a "boil" is visible where water flows out of a vent thirty feet below (Figure 1A-C). Below the vent, a strong current flows through a large submerged limestone cavern (Figure 1D-E). The floor of the cavern includes shells and wood debris while the ceiling and walls include long whitish streamers of bacteria (Figure 1F). The cavern extends toward the west under the sidewalk dam and Spring Garden Creek and narrows after about 130 feet (Figure 1G) (Pete Butt of Karst Environmental Services, pers. comm., 2015).

The cavern is part of the Ocala limestone formation in the Floridan aquifer.

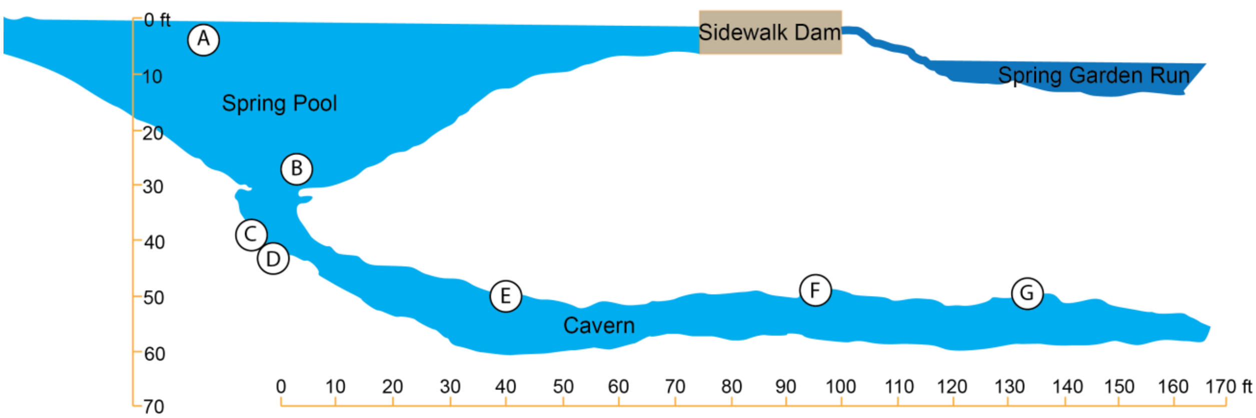


Figure 1: Diagram of De Leon Springs, adapted from a poster on display at De Leon Springs State Park based on drawings by Mike Stallings.

Figure 1A. The spring boil visible at the surface of De Leon Springs where water flows out of a vent thirty feet below (photo by Robert Sitler).

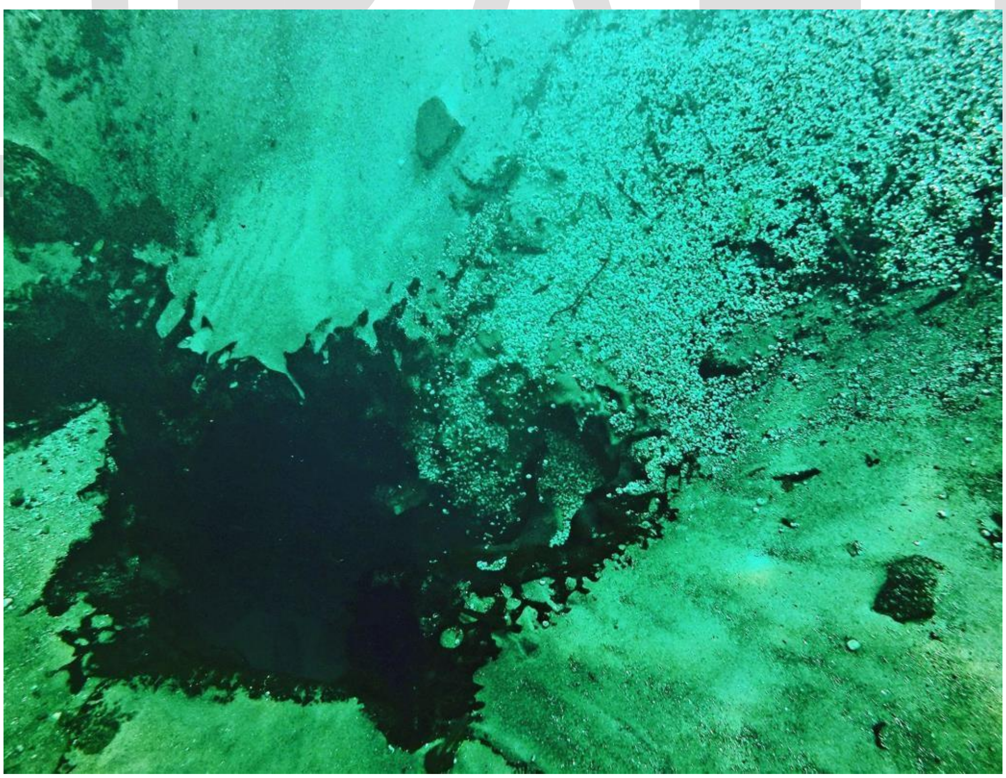


Figure 1B. The bottom of De Leon Springs pool, thrity feet below the surface, looking down into the spring vent (photo by Robert Sitler).

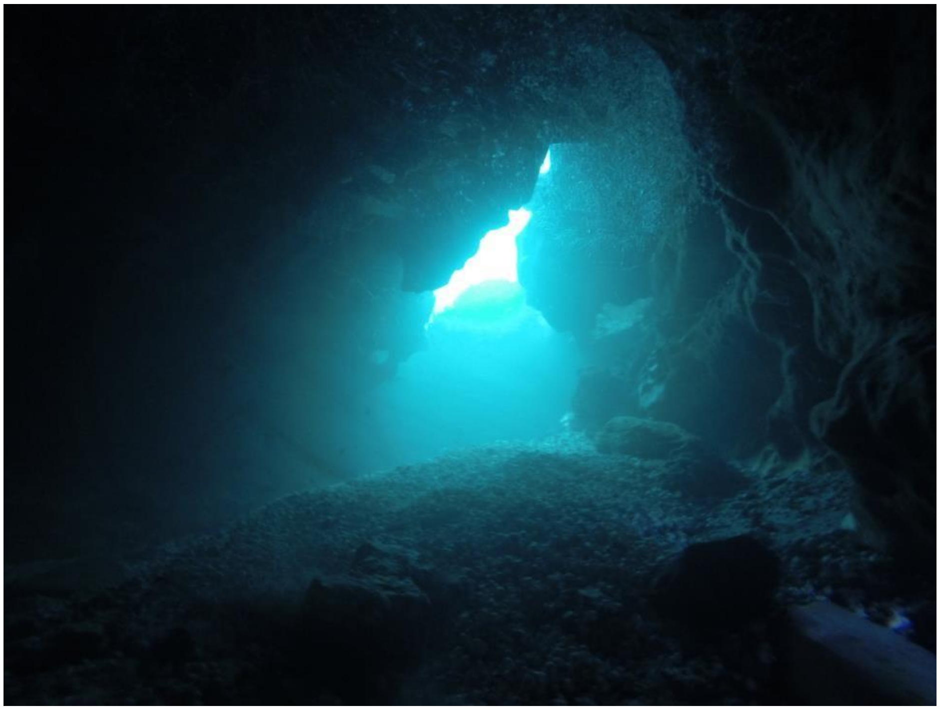


Figure 1C. Looking upward toward the spring pool from inside the spring vent at De Leon Springs (photo by Pete Butt of Karst Environmental Services).

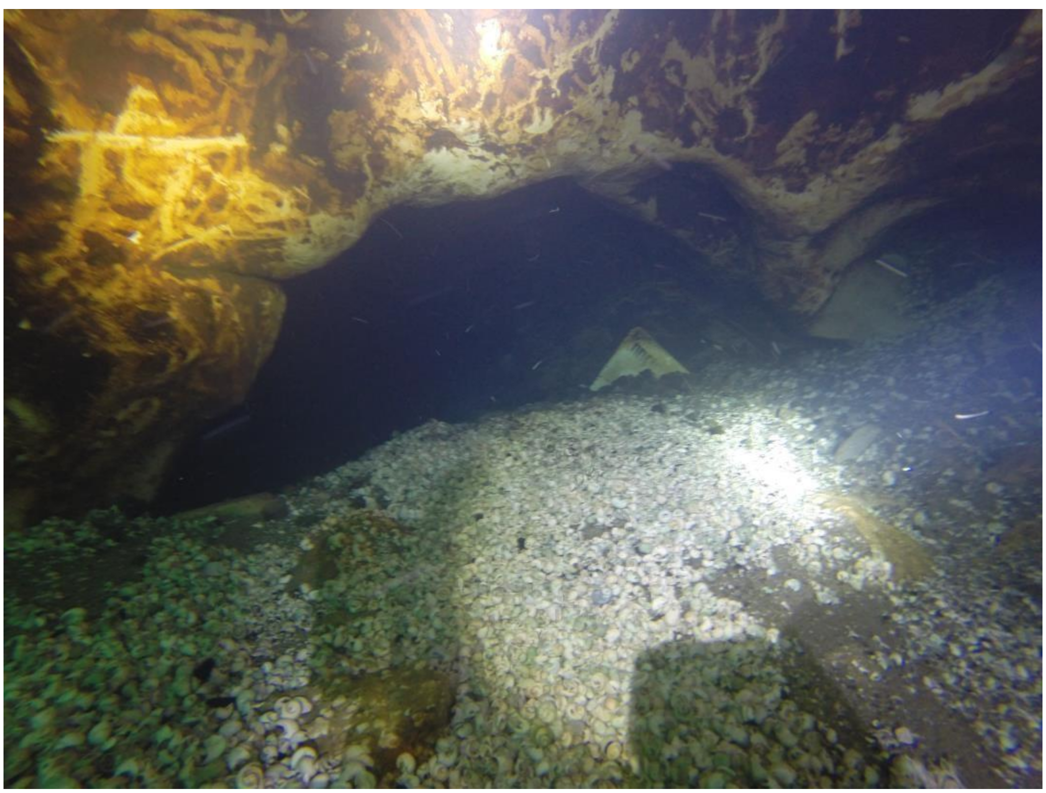


Figure 1D. Looking downward toward the entrance to the cavern at De Leon Springs (photo by Pete Butt of Karst Environmental Services).

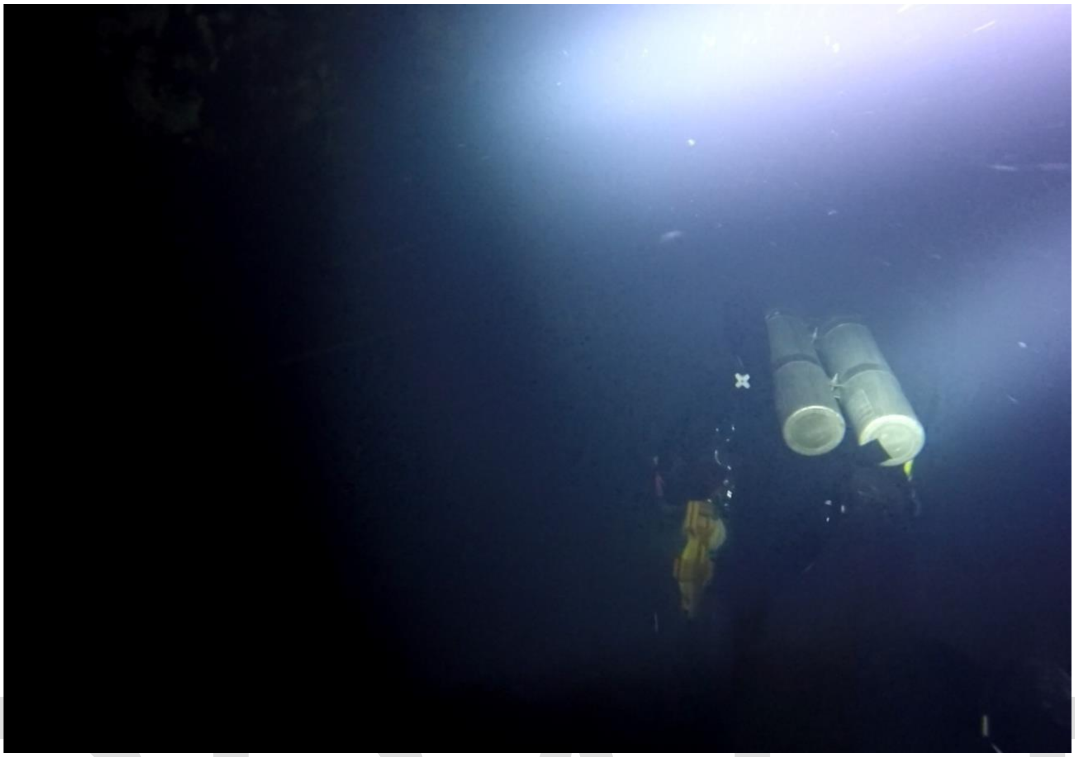


Figure 1E. A diver swims through the cavern at De Leon Springs. The cavern is completely dark and the water is essentially devoid of oxygen (photo by Pete Butt of Karst Environmental Services).

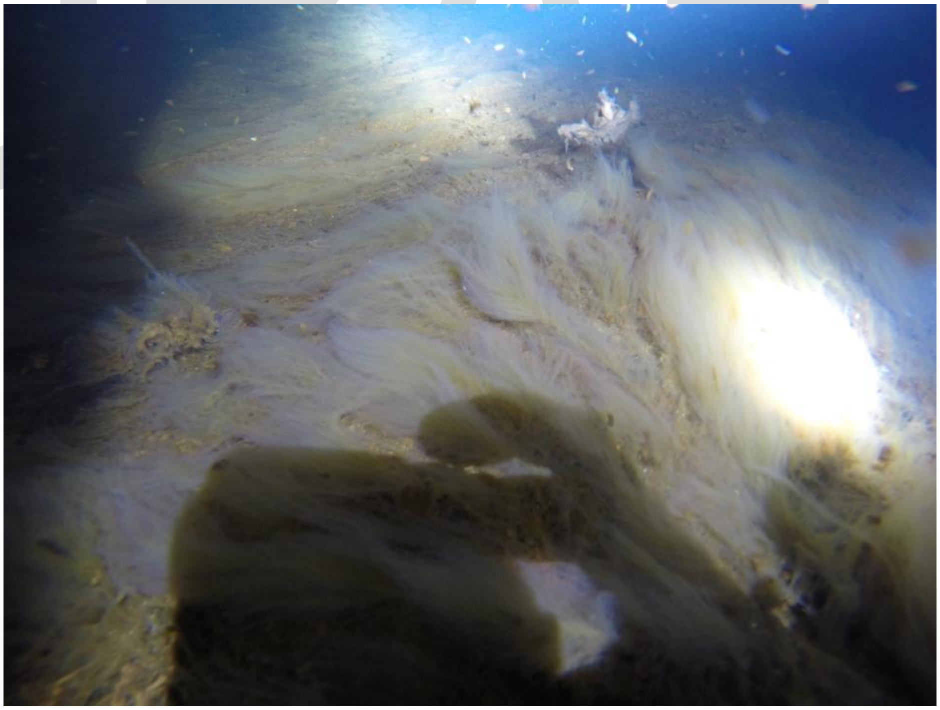


Figure 1F. Dense mats of microbes cover the walls and ceiling of De Leon Springs cavern. Some mats are 10 cm thick with whitish filaments often 1-2 ft. long (photo by Pete Butt of Karst Environmental Services).

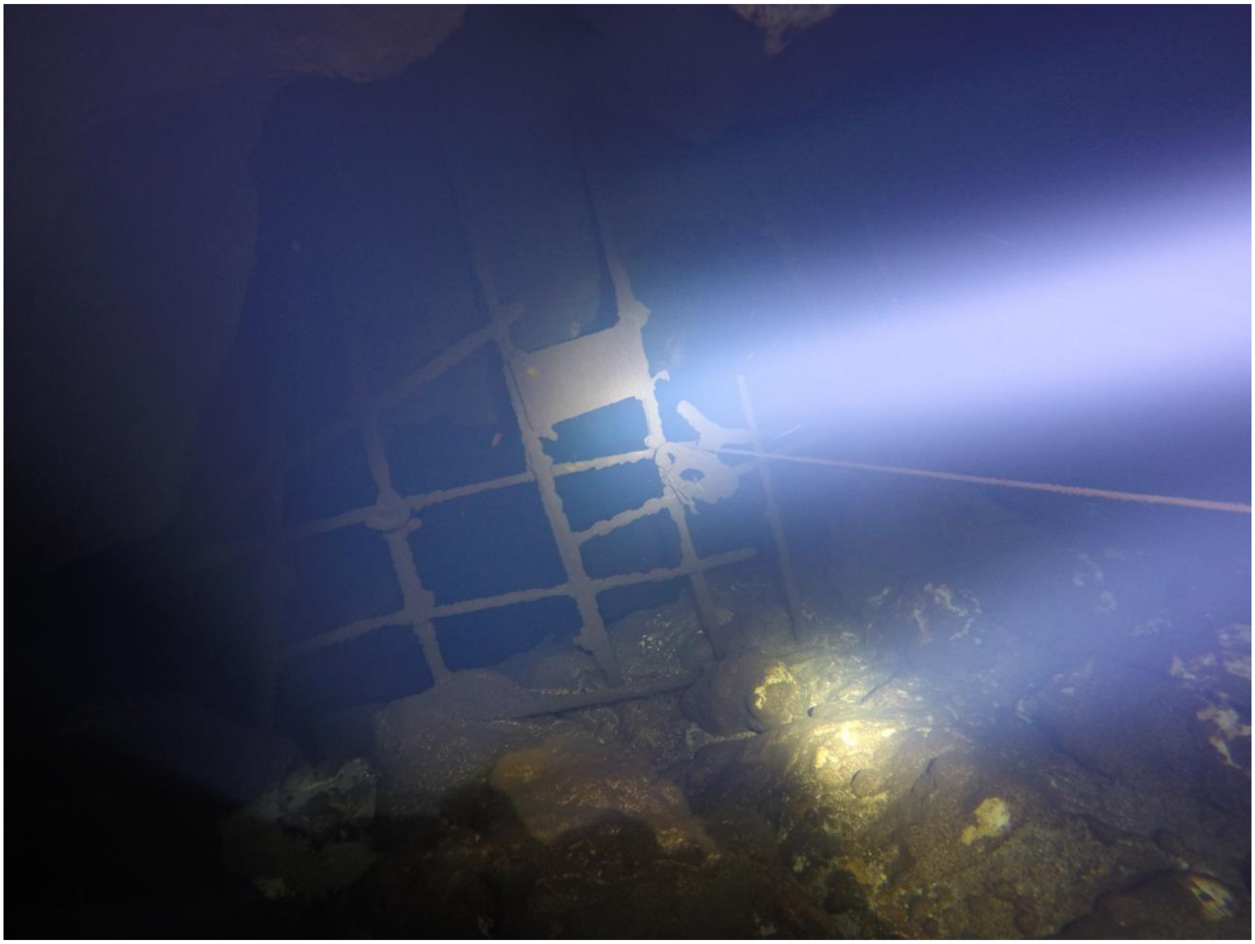


Figure 1G. A steel grate blocks the end of the cavern passage for divers at De Leon Springs (photo by Pete Butt of Karst Environmental Services).